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Improving Stability of Ghana's Power System Using Power System Stabiliser (PSS)

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Master of Science in Electric Power Engineering
Submission date: June 2009
Supervisor: Olav B Fosso, ELKRAFT

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Problem Description

Volta River Authority operates and maintains the power system in Ghana consisting of 1180MW hydropower capacity and about 600MW thermal capacity. The Transmission system consist of about 75km of 225KV line , 3650Km of 161KV line, 132.9km of 69KV line and about 43 substations This system is presently saddled with instability problems resulting in power swings and oscillations which sometimes lead to a total collapse of the system. System improvement study was done and it was suggested that the activation of PSS on the generator can dampen the oscillations.

TASK
 Modelling of Ghana power system with PSSE
 Where in the power system should it be activated?
 Investigate to what extend can the PSS reduces system oscillation and improve stability
 Suggest system improvement to optimise the activation of PSS.

Assignment given: 15. January 2009
Supervisor: Olav B Fosso, ELKRAFT

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MASTERS THESIS

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PREFACE

This thesis is the result of my final year project in the Masters of Electrical Power Engineering at Norwegian University of Science and Technology (NTNU). This thesis has a weight of 30 credits out of 120 credits for the entire program and was carried out from February to June 2009 for my company in Ghana, Volta River Authority (VRA) under the supervision of Prof Olav Fosso of SINTEF Energy Research and NTNU, Norway.

This thesis is entitled, 'Improving stability of Ghana's power system with power system stabiliser**.** The aim of the project is to improve small signal and transient stability of Ghana's power system by activating power system stabilisers on some of the generating units in Ghana. Since small signal and transient stability depend on the steady state stability margin, improvement in steady state stability of the VRA system is vital. Therefore, ways of improving steady state stability, particularly during the peak were also included in the scope of the study.

This study is expected to complement measures that are being taken to improve VRA's system stability. These include long term measures of increasing VRA's generation capacity by building new power plants as well as building new transmission facilities with higher operating voltage which will make VRA's system part of the a bigger West Africa Power Pool Network. The short to medium term measures include, reinforcing and upgrading some existing transmission lines and provision of local reactive power compensation devices.

Even though the master program lasted for two years, it was only the last five months of the program that were devoted to this study. Because of time constraint, the effect or interaction of some protection and control devices such as automatic frequency load shedding (AFLS), line protection relays on the performance of power system stabilizer was not considered in the scope of this study. Further studies are therefore needed and these have been highlighted in chapter five under further scope of work.

Trondheim, June 2009 Kwaku Sarpong Mensah

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My program at NTNU would not have materialized without the support of my company in Ghana, Volta River Authority (VRA). I do really appreciate this opportunity the company gave me and I am indeed very grateful to all those who played a role in making my study in Norway possible. To Mr Kirk Koffi, Deputy Chief Executive of VRA, I really appreciate the role you played and therefore want to thank you for the personal effort you put in, to make my study possible. I also want to acknowledge Mr Charles des Bordes, Plant Manager –Kpong Generating Station (VRA) for his support and Akim Tijani of VRA for his assistance during data collection.

I would also like to acknowledge the contribution made by the Norwegian Government by providing me with a scholarship under the Quota scheme, which helps develop capacity in developing country like Ghana. This will go a long way in addressing some of the energy challenges we have been facing as a country.

Finally, I thank my wife Dr(Mrs) Akosua Agyeiwaa Sarpong and my children, Awurama, Kwadwo and Adwoa, who sacrifice their lives without my presence for two years. Akosua, I do appreciate the difficult job you did in raising our children alone for two years and I am so much indebted to you. God bless you for your love, sacrifice and support.

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SUMMARY

Stability of a power system is vital for its reliable operation and maintaining system stability has been a big challenge for engineers over the years. One way of improving system stability is the use of power system stabiliser (PSS). Its main function is to add damping to the generator rotor oscillation by modulating the generator excitation so as to develop a component of electrical torque in phase with the rotor speed deviation. In Ghana, two power stations have their generators equipped with PSS but none of the PSS are activated. The main objective of this study is to assess how the stability of the power system of Ghana can be improved by activating the power system stabilizers (PSS) on the excitation system of some of the generating units. To effectively perform the study the following questions had to be answered.

- To what extent will the activation of the PSS on some generating units affect the overall system dynamic performance?
- Where in the power system should the PSS be activated?
- To what extend can the PSS reduces system oscillation?
- What improvement can be made to the power system to optimise the performance of the PSS?

Data of Ghana and the interconnected systems were first collected, reviewed and all the systems were modelled using PSSE program. Steady state stability studies were then performed to identify the inadequacy in the system during steady state operations. Five base cases including peak and average load condition with and without contingency were used for this study. Dynamic stability studies were also carried out by selecting appropriate dynamic models for generators, exciters and governors that best fit the dynamic behaviour of the generating units in the PSSE program. Appropriate PSS models were selected for units equipped with PSS based on manufacturers' recommendation. Series of dynamic simulations were carried out to identify the best location and parameter settings for the PSS. Small signal stability studies were also carried out to complement the results obtained from the transient studies using NEVA. There was however a defect in the NEVA program and full results could not be obtained.

In conclusion, Ghana's system is likely to experience voltage collapse during a transmission outage on some critical lines at peak period unless some loads are shed. This risk can be reduced by improving the power factor to 0.95 using more reactive power compensating devices (capacitor bank) at the local substation. Transient stability results also show that the best location for the PSS to effectively damped oscillation is Akosombo GS. Inter-area oscillations of 0.5Hz between Ghana and Ivory Coast systems, local-area oscillation of 0.8Hz between the Akosombo units and Aboadze units in Ghana, were effectively damped within 7sec with PSS at Akosombo GS.

It is highly recommended that PSS at Akosombo generation station be activated since their application has a positive impact on the dynamic performance of Ghana's system. Steady state stability be improved by correcting the power factor at the local stations and line relay settings reviewed to accommodate the present operating condition. It is also recommended that the PSS be coordinated effectively with the protection and control devices for optimal performanc

CHAPTER ONE

1.0 INTRODUCTION

This chapter describes the background of my thesis as well as my motivation for undertaking this study. It describes the existing power system and the structure of the electricity sector in Ghana. Load forecast, generation and transmission plans for the next ten years have also been highlighted. The chapter also discusses the objectives of this study together with the methodology used. All the assumptions made in this thesis have been highlighted as well.

1.1 BACKGROUND

Ghana is a developing country in West Africa with a GDP of 6.3% and a population of about 23millon (27). As a developing country, the need for reliable electricity for development cannot be overemphasis. At present Ghana has a total power generation capacity of 2030MW with a peak load of about 1600MW (28). These consist of about 60% hydro and 40% thermal energy. Power is transmitted to about 65% of the population through a solid transmission network which covers the entire country. The transmission system is made up of 45 substations and approximately 4,000 circuit kilometres of transmission lines consisting of about 75km of 225KV, 3800Km of 161KV, 132.9km of 69KV lines. Ghana's power system is interconnected with three neighbouring countries Togo, Benin and La Côte d'Ivoir. A 330KV line is being constructed along the coast of these three countries to strengthen the interconnection as part of a bigger project to interconnect all the countries in West Africa (West Africa Power Pool Project, WAPP) (29).

In Ghana, Volta River Authority (VRA) is mandated by law(established on 26th April 1961, under the Volta River Development Act, Act 46 of the Republic of Ghana) to generate and supply electrical energy for industrial, commercial and domestic use. VRA had been responsible for operating and maintaining the transmission system until, the formation of a new company called Ghana Grid Company in 2006 as part of measures to deregulate the power sector of Ghana.

As demand grew, the power system was made to operate close to its stability limit because system expansion has not proceeded as planned as a result of financial constraint. This has introduced a lot of instability problems, resulting in total system collapse, and reduced damping of the system during disturbances and voltage instability. As part of the measures to improve system stability, automatic frequency load shedding was installed on some of the lines so as to shed load when the system frequency falls. The over frequency tripping device settings on the generators at the main hydro generation station, Akosombo GS (1070MW) was modified to trip the units sequentially at different frequency levels during over-frequency resulting from large disturbance. These are some measures that were introduced to improve system stability.

Power system stabilisers (PSS) have been used by utilities since 1960, to improve system stability, especially small signal stability by damping system oscillations. In Ghana some of the stations are equipped with PSS (Akosombo GS and Aboadze GS). However, this facility has not been activated because studies have to be done to know its impact on the dynamic performance of the system upon its activation. Also studies on tuning the PSS for optimal performance need to be carried out. This is because, if the PSS is not properly tuned it can introduce serious system instability.

This thesis therefore will attempt to model Ghana Power System with PSSE and try to answer the following questions:

- To what extent will the activation of the PSS on some generating units affect the overall system dynamic performance?
- Where in the power system should the PSS be activated?
- To what extend can the PSS reduces system oscillation?
- What improvement can be made to the power system to optimise the performance of the PSS?

1.2 DESCRIPTION OF GHANA'S POWER SECTOR (29)

1.2.1 Electricity Sector Structure

The key players in the power sector in Ghana are Volta River Authority (VRA) responsible for power generation; Ghana Grid Company (Gridco) responsible for power transmission to entire country; Electricity Company of Ghana (ECG) responsible for power distribution in southern Ghana, where most of the electricity is consumed; and Northern Electricity Department (NED), which is VRA subsidiary responsible for power distribution in Northern Ghana. All of these agencies are owned by the Government of Ghana and regulated by the Energy Commission and Public Utility and Regulating Commission (PURC).

Government policy encourages Independent Power Producers (IPPs) in the generation sector, and there are already some IPP operating power stations at Tema in southern Ghana and Takoradi in western Ghana.

1.2.2 Existing Power System

1.2.2.1 Existing Generation

In 2008, the peak power supplied by the VRA network was 1500MW and the total energy consumed in Ghana for the year was 7300GWh. VRA sells power to about nine major bulk custormers, the largest of which is Electricity Company of Ghana (ECG), which distributes power in the heavily populated south. The second largest customer is Valco aluminium smelter at Tema. However the smelter is operating at 30% of its capacity due to insufficient generation. Bulks sales are also made to a number of smaller industries, mines and to CEB in Togo and Benin

VRA's generation mix is dominated by the 1070MW Akosombo Hydroelectric Plant, which was commissioned in 1965 and the 160MW Kpong Hydroelectric Plant, which was commissioned in 1982. The Akosombo Plant completed a refurbishment in 2003 which increased its power from 912 to 1070MW.Both plants are on the Volta River about 100Km northeast of Accra. Kpong is downstream of Akosombo.

Ghana current demand for electricity has outstripped the supply from the two hydro generation stations. The shortfall in demand is therefore being met through the development of thermal power systems. A 330MW Combined Cycle thermal plant was commissioned at Aboadze near Takoradi in western Ghana in 1999.This was followed by the addition of a further 220MW simple cycle thermal plant at the same site, developed through a joint-venture partnership between VRA and CMS Energy in 2000. A heat Recovery Steam Generator and 110MW steam turbine are to be added in the future to convert the plant to combined cycle. This will bring the total installed thermal generation capacity to 660MW. The plant is run on imported light crude oil(LCO), but has been converted to a dual fired plant in anticipation of gas from the West Africa Gas Pipeline which will bring natural gas from Nigeria. The pipeline is expected to be commission in 2010.

At present, the total generation capacity of VRA is 1180MW from the two hydro stations and 740MW from the thermal plants in Tema and Takoradi. The firm energy supply is made up of 4800GWh hydro and 2500GWh thermal(66 percent hydro and 34 percent thermal).However depending on the water inflows into the Volta lake, the hydro output can reach up to 6100GWh.

Aside these major plants, VRA operates 110MW emergency diesel generating plants at Tema. These plants were brought in to supplement generation during 2006 national power crises caused by very low Akosombo reservoir level, but they are presently not in use due to their high operating cost. The station at Effasu in the western region of Ghana is a barge mounted power plant(2X62.5MW) acquired by the Ghana National Petroleum Company and handed over to VRA for operation and maintenance. This plant is not in operation yet and currently has no source of fuel. Its location at Effasu was intended to take advantage of the gas discoveries offshore, however the gas /oil fields are not being developed at present.

Photo 1.1: Front view of Akosombo Hydro Power Generating Station in Ghana with a capacity of 1070MW

Photo 1.2: New stainless steel turbine used to replace the old turbine during retrofitting of Akosombo GS. The capacity of the plant was increased from 912MW to 1070MW

Photo 1.3: Rewinding of generators for increased capacity during retrofit of Akosombo GS

Table 1.1 shows a summary of VRA exiting and committed generation.

Station	Type	Year	Installed capacity (MW)	2009 Avaliable capacity (MW)
Akosombo	Hydro	1965	1070	1020
Kpong	Hydro	1982	160	148
Takoradi-1	Thermal	1997-1998	330	330
Takoradi-2(IPP)	Thermal	2000	220	220
Tema (Siemens)	Thermal	2007	50	50
Tema (VRA)	Thermal	2006	100	100
Tema(Mines)	Thermal	2006	40	40
Effasu(Osagyefo)	Thermal	2011	125	

1.2.2.2 Transmission Network

Fig 1.1 shows a map of VRA's transmission network, which is made up of about 45 substations and approximately 4000Km of transmission lines in a loop covering most part of the country. The Northern region beyond Kumasi was linked up in 1997 when VRA established the Northern Electricity Department. The standard transmission voltages are 161KV and 69KV.

VRA's 161kV transmission networks consist of the following main circuit:

- ❖ 161kV circuit connecting the electric generation station at Akosombo (1070MW) and Kpong(160MW) and the major load centres of Tema, Accra and Kumasi. These circuits include:
  - ✓ Three double-circuits Akosombo-Volta(80Km).
  - ✓ One single-circuit Kpong-Volta(55Km).
  - ✓ Three lines from Akosombo to Tafo and Kumasi.
- ❖ 161kV circuit connecting generation from the 550MW Takoradi Power Station at Aboadze, imported power from CIE at Prestea and the planned 125MW barge power plant at Effasu to the major load centres in Kumasi and Accra. These circuits includes:
  - ✓ One double circuit coast line Aboadze Achimota(196Km).
  - ✓ Two single circuit south-to-north lines Aboadze-Prestea-Obuasi.
- ❖ 161KV loop connecting the other principal urban centres and mining communities in southern Ghana.

- ❖ Single circuit 161kV radial lines from Kumasi supplying power to communities of Northern Ghana.

Fig 1.1 VRA Transmission Network

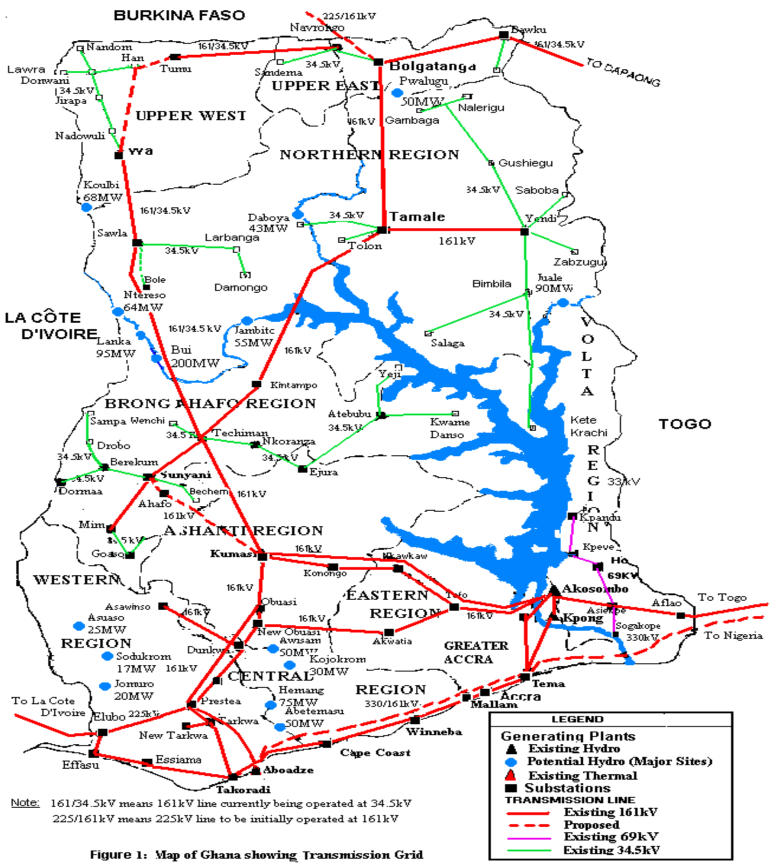


Figure 1: Map of Ghana showing Transmission Grid

Ghana's transmission system is interconnected with the national electricity grids of Cote d'Ivoire, Togo and Burkina Faso(MV connection).The major interconnection facilities are

- ❖ Ghana(Akosombo)-Togo(Lome): The VRA-CEB interconnection consists of a 161KV double circuit line 129km in length, which has been in operation since 1972
- ❖ Ghana (Prestea)-Cote d'Ivoire(Abobo): The VRA-CIE interconnection consists of 225KV single circuit line 220Km in length, which has been in operation since 1983.

Details of the transmission network is shown in Fig 1.2

1.2.3 System Operations

VRA operates a modern control centre at the Volta Substation in Tema. Presently the transmissions system operation is being carried out by a new company called Ghana Grid Company(Gridco). A generation pre-schedule is prepared daily and shared with CEB in Togo and CIE in Cote d'Ivoire to ensure co-ordinated operation. The pre-schedules covers all of the generating plants of VRA and CEB and the schedule for the tie line with CIE. Communications with the VRA generating plants and the neighbouring utilities are by telephones and fax. An energy management system is not in use yet and there is no automatic generation control system at any plant.

The SCADA (Supervisory Control and Data Acquisition) system was upgraded in 1996 with RTUs installed at all generating units and stations so they can be monitored from the control centre. All the communication schemes for SCADA were predominately based on the Power Line Carrier (PLC) system. But now most of the stations in the southern part of Ghana have been upgraded to OPGW (Optical fibre ground wire). All transmission substations are fully automated and can be operated from dispatch centre at Tema (System Control Centre, SCC). The VRA system occasionally experience major blackouts. There are well-developed procedures for load shedding in the event of emergencies. Under-frequency and over-frequency relays operating on the rate of change are deployed at all major points.

1.2.4 Electricity Supply Plan(30)

The following summary of VRA's network expansion is based mainly on a review of the report VRA of Generation and Transmission Master Plan: 2000-2020(Acres International Limited, 2001).

1.2.4.1 Demand Forecast

Table 1.2 and Table 1.3 show the energy demand forecasts up to 2020 for each VRA consumer category. In summary, total consumption is expected to grow at an annual rate of 6.3 percent from now to 2020.The forecast was based on the following key assumption:

- ❖ The economy of Ghana will continue to grow at five percent until 2020 based on the growth rate of the past decade.
- ❖ Ghana will move towards a sustainable electricity pricing policy representing long-run marginal cost (LRMC) to ensure that VRA meets its financial obligations.
- ❖ A key uncertainty in the demand forecast is the supply of VALCO. According to VRA-VALCO Power Agreement, Supply to VALCO is set at 315MW and 2760GWh depending on availability of supply. However VALCO is sometimes forced to shut down when the Akosombo reservoir level becomes very low.

Table 1.2 Peak Demand forecast in MW for Ghana

Category	**2007**	**2011**	**2015**	**2020**
ECG	1072	1392	1792	2393
NED	98	126	164	222
Mines	136	140	142	145
Others	12	14	15	17
VALCO	315	375	375	375
Subtotal Ghana	**1693**	**2047**	**2488**	**3152**
Export to CEB	45	45	45	45
Export to SONABEL	10	10	10	10
Total	**1748**	**2102**	**2543**	**3207**
Coincident Peak[1]	1615	1944	2354	2971

1. *Load coincidence factors for each category are used in derive the coincident peak demand.*
2. *The actual peak load recorded was less than what Acres report estimated in 2007.*

Table 1.3 Energy Demand forecast in GWh for Ghana

Category	**2007**	**2011**	**2015**	**2020**
ECG	6772	8791	11315	15113
NED	470	606	789	1064
Mines	910	933	944	957
Others	72	80	89	101
VALCO	3285	3285	3285	3285
Subtotal Ghana	**11509**	**13695**	**16422**	**20520**
Export to CEB	300	300	300	300
Export to SONABEL	60	60	60	60
Total	**11869**	**14055**	**16782**	**20880**
3.1% losses	365	432	516	642
Generation required	**12235**	**14502**	**17301**	**21552**

1.2.4.2 Generation Plan

The VRA Master Plan identifies the following main candidates generating resources addition:

- Simple cycle and combined cycle combustion turbine-based power plant. Initially, the plants will use imported light crude oil(LCO) and later they can be converted to burn natural gas from the West Africa Gas Pipeline(WAGP) that is being built to transport gas from Nigerian to Ghana
- Bui Hydroelectric Plant. The Bui Hydroelectric Project (400MW, 963GWh per $US484 million) consists of a new dam and powerhouse upstream of Lake Volta on the Black Volta River.

The Acres study strongly recommends the thermal alternative. Bui (and several other hydro options) are considered less attractive, especially in view of the potential for WAGP natural gas fired generation. There is little interest among private developers for hydro project because electricity pricing is not economic in Ghana and therefore cost recovery could be very difficult for investors.

However the Government of Ghana decided to develop the Bui Hydroelectric Power Project in 2006 with assistance from the Chinese Government. This project has started and it is expected to be completed in 2013.

Table 1.4 summary of the total thermal generating capacity additions recommended in the VRA Master Plan for 2007 to 2020.

Period	Added Capacity(MW)
2007-2011	330
2011-2015	440
2015-2020	770

Tema is identified as an ideal location for future generation owning to the fact that it is close to the load centres in Accra and Tema and relatively close to the border for exports to Togo and Benin with minimal transmission losses. Generation for Takoradi and energy imports from Cote d'Ivoire can take care of the load in the western and northern areas in Ghana.

1.2.4.3 Transmission Plan

With new generation additions at Takoradi Power Station, and Effasu in southwest of Ghana, and Tema in southern Ghana there are two immediate objectives for expansion of VRA transmission network:

- To reinforce line south-to-north that evacuate power from Takoradi to Kumasi;
- To reinforce the coast lines west-to-east that evacuate power from Takoradi to Accra

VRA has decided to step up to the 330KV voltage instead of continued development at 161kV. A 330 system can handle more load with lower power losses, and is better suited to the long distance traversed .VRA is planning the following priority transmission lines:

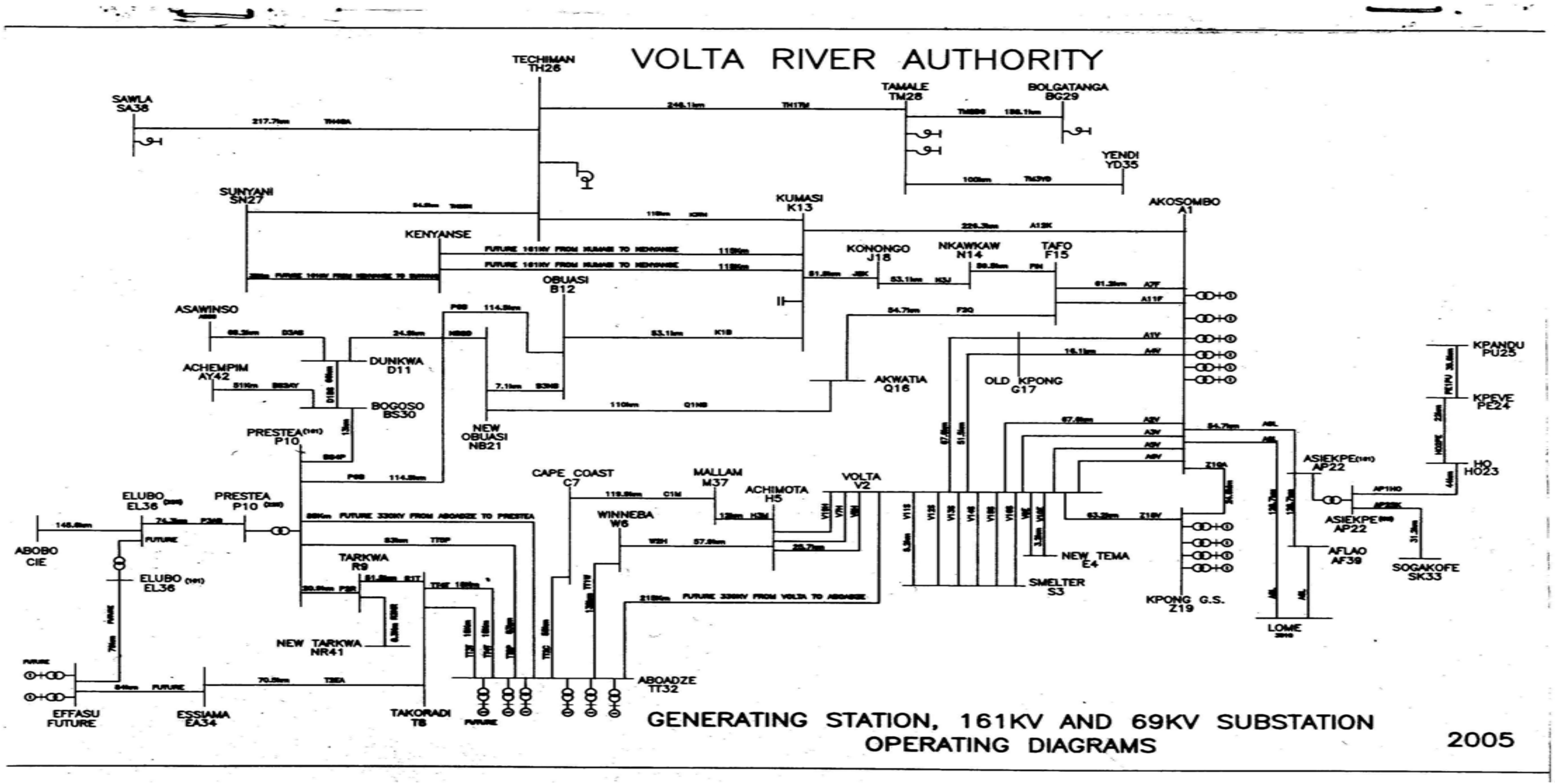
- 330kV Volta-Mome Hagou(Togo)(222Km)-Second line to Togo, strengthens the VRA-CEB-NEPA interconnection.
- 330kV Aboadze-Volta (216km)-Third coastal line to evacuate power from Takoradi to Accra/Tema load centre.
- 330kV Aboadze –Prestea (75Km)- Third line to evacuate power from Takoradi towards Kumasi.
- 161KV Kumasi-Sunyani(115km)-Required for power supply to the North.

Photo 1.4:160MW Kpong Generating Station in Ghana downstream Akosombo GS on the Volta Lake

Photo1.5: Refurbishment of a 40MW unit at Kpong Hydro Generating Station. Removal of salient pole rotor

Photo 1.6: A 550MW Takoradi Thermal Power Station(TTPP) at Aboadze, Ghana

Fig 1.2 Generating Station, 161KV and 69KV substation operating diagram.



1.3 STUDY OBJECTIVE

The general objective of this study is to assess how the stability of the power system of Ghana can be improved by activating the power system stabilizers (PSS) on the excitation system of some of the generating units. However for the general objective to be met the following specific objectives should be achieved:

- Determine appropriate power system and control stimulation tool to model the power system of Ghana and the interconnected system.
- Carry out load flow studies to know the weakness in Ghana's power system during peak and off peak periods.
- Assess the effect of activating PSS on the performance of dynamic stability of Ghana's Power system.
- Determine the most approtrate location for the PSS so as to improve the overall system stability.
- Assess the effectiveness of PSS application on small signal and transient stability.
- Determine the appropriate settings for the PSS necessary to avoid system oscillatory instability and improve the overall system stability performance.
- Identify improvements that can be made to the power system in order to optimise the performance of the PSS.

1.4 ASSUMPTIONS

- An extensive effect was made to collect, process and review the data for the interconnected power system of Ghana. However not all the information was available. Some were retrieved from design and commission report. The data obtained could not be checked on the field as to whether some modification or adjustment has been made in the cause of operations. It was therefore assumed that data obtained tally the field equipment settings.
- Load data use for load flow simulations were based on load forecast for 2009. VALCO is expected to operate two pot lines (140MW). All existing transmissions line were assumed to be operational and new transmission line project were not considered, because existing transmission line project might be completed after 2009.

- VALCO and the mines were modelled as 100% of their peak load since they run a 24hr operations. The rest of the loads were modelled as 80% of the peaks loadings. These assumptions were made when modelling the Average Day Load(ADL) for simulations.

- Actions of protection and control devices like protection relays, under frequency relay and others in the system were not considered in the study. These devices are trigged during large disturbances and can affect the performance of PSS. In practice, PSS should be coordinated properly with these protection and control devices for optimal performance.

1.5 METHODOLOGY

Load flow and dynamic data of Ghana's power system as well as the interconnected systems were first collected from engineering department of Volta River Authority (VRA) and reviewed. Appropriate power system and control stimulation tool was then selected to model VRA power system and its interconnections. PSSE was selected as the appropriate power system simulation tool because it has been the traditional tool for planning engineers in Ghana. It will therefore be easier to pass the knowledge, experience and the findings of this thesis to the planning engineers in Ghana. PSSE is power system tool from Siemens, used worldwide for carrying out power system studies especially for big network.

Load flow simulations were done under steady state conditions for peak and off-peak loads condition to determine the inadequacies in the system. Particular attention was given to system voltage profile and line losses and how it could be improved throughout the system using reactive power compensators. Five different steady state base cases were simulated and used in the steady state stability studies. These included a normal and a stressed peak load condition and normal and stressed average load condition. The stressed conditions were created by some transmission contingency resulting in poor system voltage profile.

Appropriate PSS models were selected for Akosombo and Abaodze generating units since they are the only generating units equipped with PSS. Preliminary simulation was carried out to identify the best location for the PSS between Akosombo and Aboadze Generating Station. However it was only Akosombo PSS that was activated for detail studies. This is because Akosombo supplies more than 50% of the power requirements in Ghana and in normal industrial practise, a plant of this magnitude is a very good candidate for PSS (6). Small signal stability studies were also performed to determine to what extent the VRA power system is able to maintain synchronism when subjected to small disturbance. Such disturbances occur all the time in the system because of continuous variation in the system load. If the system does not have sufficient damping torque any small disturbance will make the system unstable. Small signal stability studies enables inherent mode of oscillations to be determined together with their participation factors. The different modes of oscillation that exist in the VRA interconnected network were determined by eigen value method using PSSE NEVA software for linear analysis.

PSS tuning was carried out by selecting appropriate time and stabiliser gain constants based on standard industrial practices and recommendation by equipment manufacturers. Series of simulations were therefore carried out to obtain optimal stabilizer setting for optimal performance of the PSS. Effect of activating PSS at Akosombo on transient stability was performed using the five base cases used in the steady state stability studies. The oscillatory behaviour of some system parameters, trigged by system faults were monitored with and without PSS at Akosombo GS. The performance and the effectiveness of the PSS at Akosombo GS were based on the extent to which the PSS was able to effectively damp the system oscillation. Fig 1.3 gives a summary of the methodology.

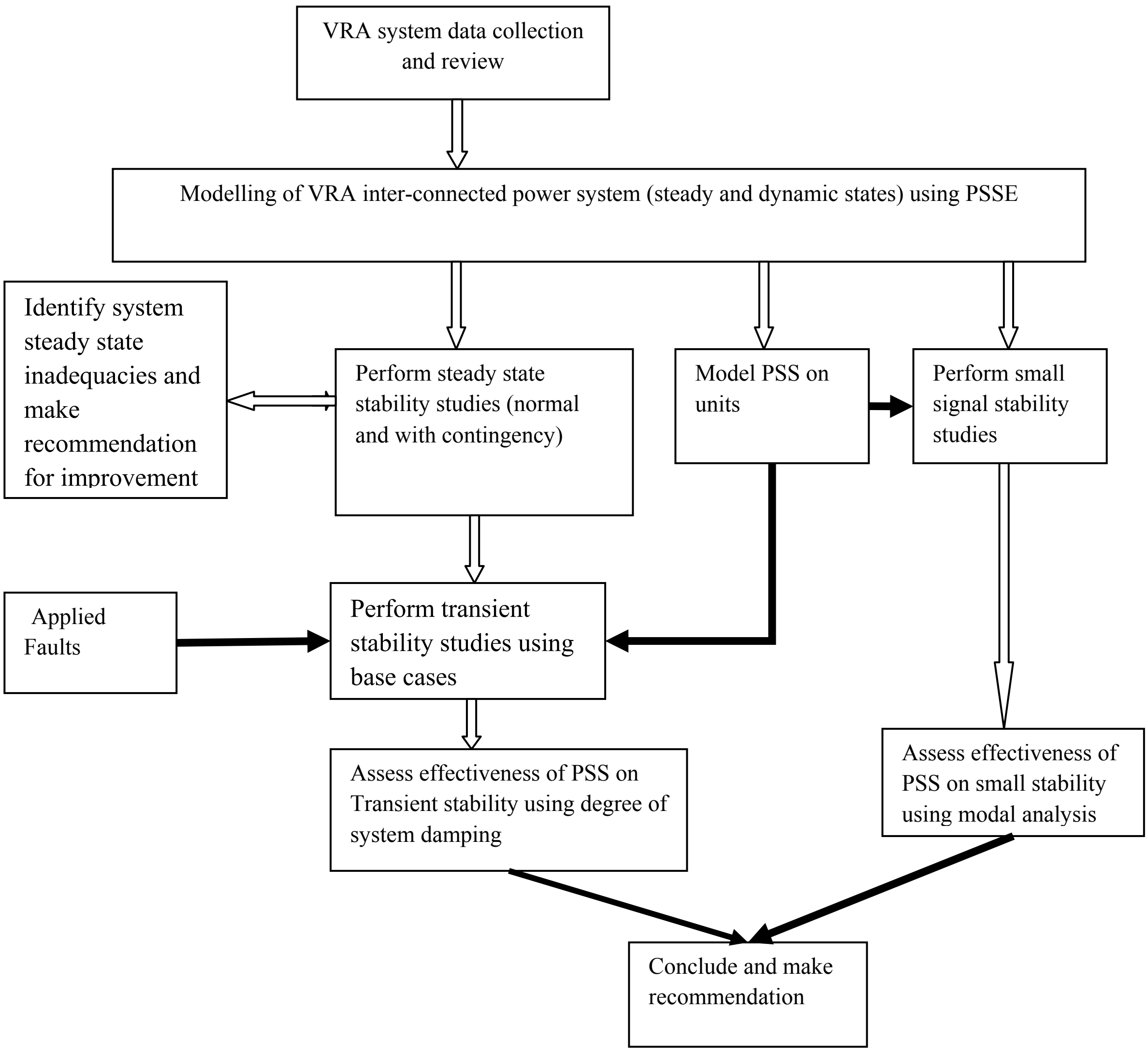


Fig: 1.3 Methodology for the project.

CHAPTER TWO

2.0 POWER SYSTEM STABILITY

2.1 INTRODUCTION

An electrical power system consist of many individual elements connected together with transmissions lines to form a large, complex system capable of generating, transmitting and distributing electrical energy over a large geographical area(1). Due to interconnection of elements, a large variety of dynamic interactions are possible, some of which will only affect some of the elements, others will affect fragments of the system, whilst others may affect the system as a whole. The challenge associated with a system like this is making the individual elements to remain working together irrespective of the type of disturbances it is subjected to. The system is said to be stable if it is able to remain in a state of operating equilibrium under normal operating conditions as well as regain acceptable state of equilibrium after it has been subjected to a disturbance. The study of power system stability is classified into three areas, rotor angle stability, frequency stability and voltage stability as shown in fig 2.1(2). This chapter defines power system stability and looks at the different types of stability in the power system. Various ways of improving stability have also been discussed.

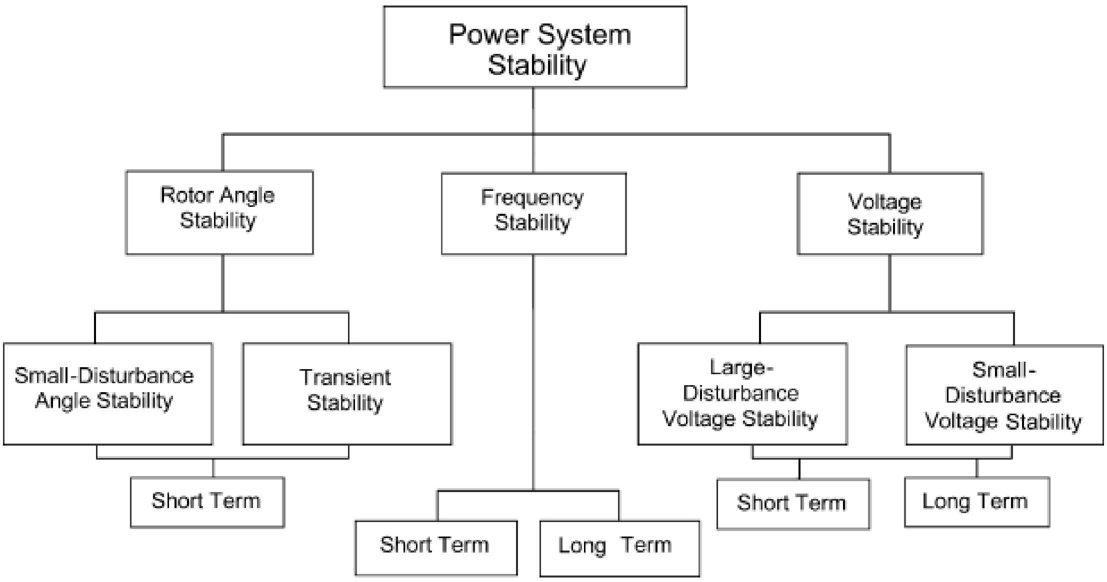


Fig 2.1 Classification of power system stability.

2.2 CLASSIFICATION OF POWER SYSTEM STABILITY (1, 2)

Power system stability can broadly be defined as the ability of an electric power system, for a given initial operating condition, to regain a state of equilibrium after being subjected to physical disturbance, with most of the system bounded so that practically the entire system remains intact.

For further explanation of this, let us consider a generator G1 which is part of a power system and it is connected to other generators represented by an equivalent generator G2 through a transmission line with reactance X_T as shown in fig 2.2. G2 can be assumed to have the same characteristics as an infinite bus bar.

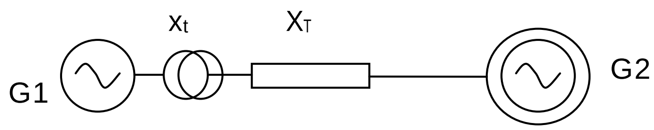


Fig2.2 A generator G1 connected to generator G2 through a transmission line with reactance X_T

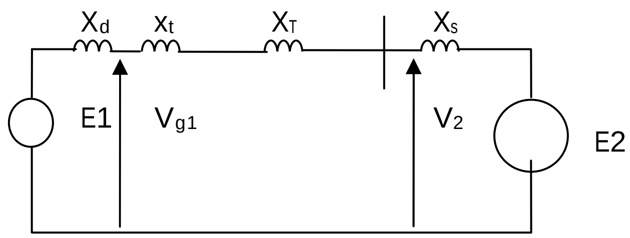


Fig2.3 :An equivalent circuit of fig 2.2

The electrical power P_{ag} transferred from generator G1 to the power system is governed by the equation 2.1

$$P_{ag} = \frac{E_1 V_2}{X} \sin\theta \qquad 2.1$$

Where E_1 is the emf of G1(Voltage behind synchronous reactance), X_d reactance of G1 , Xt is the reactance of the step up transformer , X_T is the reactance of the transmission line connecting G1 to the power system and Xs reactance of G2. X in equation 2.1 is the reactance between G1 and the bus where G2 is connected i.e $X = X_d + x_t + X_T$ and θ is the angle between E_1 and V_2 also called rotor angle.

All generators are designed to convert mechanical power produced by the turbine to electrical power. When a generator is connected to a very big system (infinite bus) an increase or decrease in the turbine power will not result in an increase or decrease in generator speed, but rather an associated increase or decrease in the rotor angle. From equation 2.1, it can be deduced that an increase or decrease of electrical power (Pag) is achieved by an increase or decrease in the rotor angle while E1,V2 and X remain constant. The speed of the generator G1 is synchronised to, and determined by the frequency of the big system(G2).

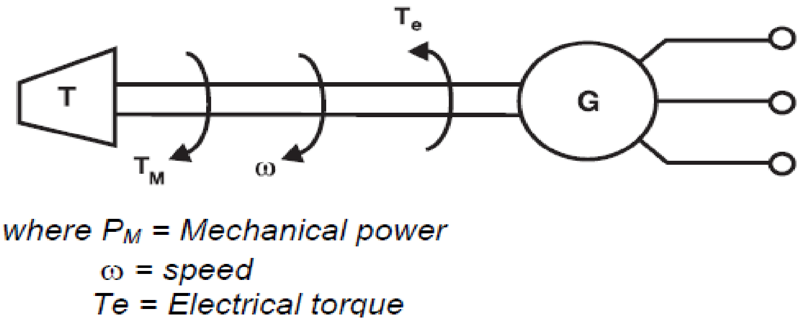


Fig2.4: A balance between mechanical power by the turbine and electrical power by generator

For G1 to achieve stability at all times, there should be a power balance between the turbine power and the opposing electrical Power (air gap power) generated by the current flow from the generator. This power balance is affected by a lot of factors which will be discussed later. Any phenomenon that affects this power balance is called a disturbance. Changes in electrical power are very fast and are felt almost instantly by the generator whiles that of mechanical power are relatively slow. The difference in the responses between the electrical and mechanical power results in power imbalance that disturbs the generator. This results in a system disturbance.

Stability can be classified into different forms depending on the type of disturbance. The disturbance can either be large or small. Small disturbances can be in the form of load changes occurring continuously .With this, the system should be able to adjust to changing condition and operate in a satisfactory manner. For large disturbance like short circuit on the transmission line or loss of a large generation, a robust system should be able to survive the disturbance.

A power system can also be considered as a dynamic system and like all dynamic systems, differential equations can be used to describe and modelled the system. Equation 2.2, mathematically models and describes the dynamic behaviour of a power system (1).

$$M_m \frac{\partial^2 \theta_m}{\partial t^2} = P_m - P_e - D_m \frac{\partial \theta_m}{\partial t} \qquad 2.2$$

This equation is called the swing equation and is the fundamental equation governing rotor dynamic of a generator in a power system. Equation 2.2 was derived from Newton's law of Motion. M_m is inertial coefficient, *θ_m is the rotor angle,* P_m is mechanical power from the turbine, P_e is air gap power (Electrical Power) and D_m is damping coefficient.

2.2.1 Steady State operation

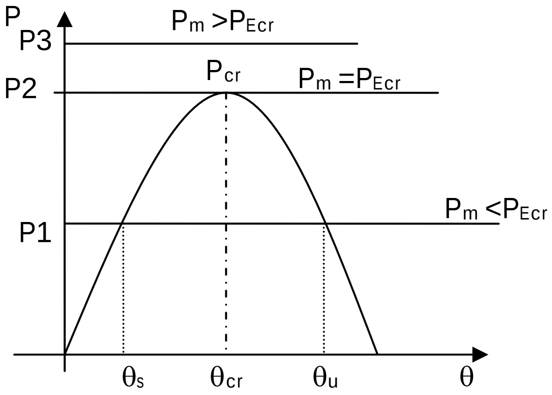


Fig 2.5 Equilibrium point for various values of mechanical power

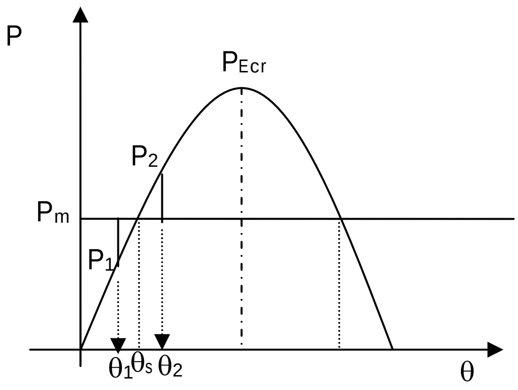


Fig 2.6 Steady state operation

Fig 2.5 shows how electrical power varies with rotor power angle and this is a graphical representation of equation 2.1. The mechanical power can be assumed to be constant and is represented by a straight line Pm. When the power system is in a state of equilibrium there is a balance between mechanical power and the electrical power. This is called steady state operation. In the case under consideration the generator G1 is operating at rotor power angle of θ_s. The maximum electrical power that can be delivered into system is P_{Ecr} ($\frac{E_1 V_2}{X}$). This is referred to as the critical power P_{Ecr} and it occurs at a rotor angle θ_{cr}.(90 deg electrical). From fig 2.5 three situations are possible (1):

- $P_m > P_{Ecr}$. Clearly no equilibrium point exists and the generator cannot operate at such a condition.
- $P_m = P_{Ecr}$. There is only one equilibrium point at θ_{cr}
- $P_m < P_{Ecr}$. There are two equilibrium points at θ_s and θ_u. This condition corresponds to the normal operations. However the generator can only be steady state stable at θ_s. This will be discussed later.

2.2.2 Small Signal Stability

A system is said to be steady state stable for a particular operating condition if, following any small disturbance, it reaches a steady-state operating point which is identical, or close to, the pre-disturbance condition(1). This is known as small disturbance, or small signal stability. A small disturbance is the disturbance for which the equations that describe the dynamics of the generator may be linearised for analysis purposes. This means that we can consider the portion of the power-angle characteristics curve in fig 2.6 between θ_1 and θ_2 to be a straight line.

Using fig 2.7 as an example, the generator G1 is operating at steady state or in equilibrium state at a rotor angle of θ_s . Following a small disturbance its electrical power changes to P_2 with a rotor angle of θ_2. Assuming there is no automatic regulation from the governor (constant mechanical power, Pm) and excitation system (constant E) , the new opposing electrical power P_2 will be greater than the mechanical power Pm. This will cause the rotor to decelerate and the extent of deceleration is proportional to P2-Pm. As the machine slows down, the rotor angle decreases, decreasing the electrical power as well as the deceleration power. However by the time the electrical power becomes the same as the mechanical power at θ_s , the rotor inertia will make it move down further to P_1. At this point Pm >P1 and this will make the rotor accelerate again to P2 if there is no damping power to reduce the acceleration. If however there is enough positive damping, the rotor will oscillate and finally settle down at a rotor angle θ_s as shown in fig 2.9. We can therefore conclude that the operating area of G1 makes it steady state stable since it is able to settle at steady operating point after a small disturbance. If there is no damping, the rotor can oscillate continuously about the steady state point as shown in fig 2.10. On the other hand if there is negative damping the oscillation can grow as shown in fig 2.11 and the generator will eventually lose synchronism.

2.2.2.1 Conditions for small signal stability

For a generator to have small signal stability it should operate at a rotor angle $0 < \theta < \theta_{cr}$ as shown in fig 2.7. In this region any deviation in electrical or mechanical torque that disturbs the torque or power balance, the system has the ability to generate a counter opposing torque to ensure the power balance is regained. On the other hand assuming the generator is operating at a rotor angle of θ_3($\theta_{cr} < \theta < \theta_5$) in figure 2.7 and a disturbance changes the operating point to θ_4, because the electrical power at that point is greater than the mechanical power , rotor will decelerate, reducing the rotor angle and this will further increase the electrical power. The power balance cannot be regained. A disturbance in this region will make the rotor either accelerate or decelerate continuously till it loses synchronism.

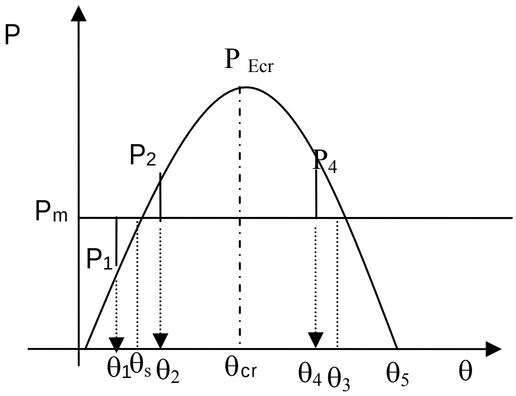


Fig 2.7 small disturbance about steady state

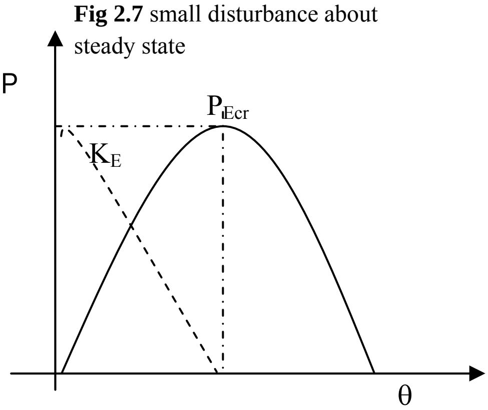


Fig 2. 8 Generator steady state power and synchronising power coefficient

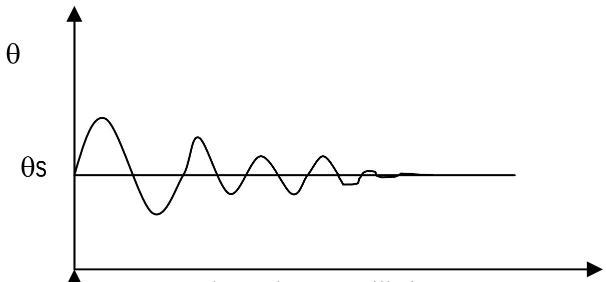


Fig 2.9 damped rotor oscillation about steady state

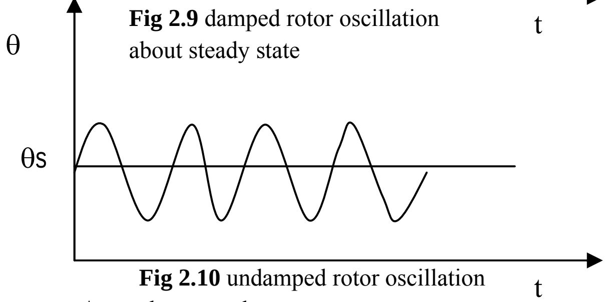


Fig 2.10 undamped rotor oscillation about steady state

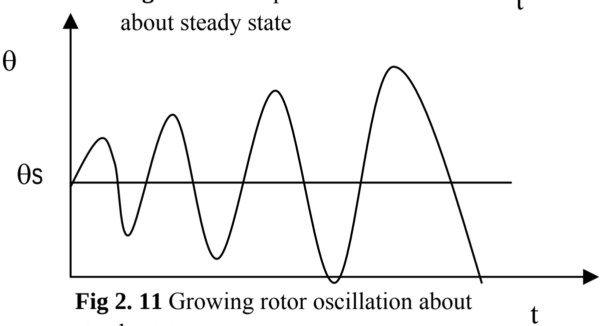


Fig 2. 11 Growing rotor oscillation about steady state

Also in the stable region $0 < \theta < \theta_{cr}$ an increase (decrease) in mechanical power causes a corresponding increase (decrease) in electrical power while converse is true in the unstable region$\theta_{cr} < \theta < \theta_4$

It can be observed that the generator will only be steady state stable on the left side of the power curve (Fig 2.8) where the slope K_E positive.

$$K_E = \frac{dP_E}{d\theta} > 0 \qquad 2.3$$

K_E is referred to as steady-state synchronising power coefficient whiles the critical power P_{Ecr} is often referred to as the pull out power to emphasise the fact that a larger mechanical power will result in the unregulated generator losing synchronism with the rest of the system. Fig 2.8 shows the plot of $K_E(\theta)$ and $P_{Ecr.}$ ***The value of P_{Ecr} is also referred to as the steady state stability limit*** and can be used to determine steady state stability margin as

$$CE = \frac{P_{Ecr} - P_m}{P_{Ecr}} \qquad 2.4$$

where Pm is the actual loading of the generator. The stability margin varies between CE=1(where the generator is unload) and CE=0.

Again following a disturbance, the change in electrical torque can further be resolved into two components:

$$\Delta T_e = K_s \Delta\delta + K_D \Delta\omega \qquad 2.5$$

Where:

Ks Δδ = the component of torque that is in phase with the rotor angle change. This is known as the Synchronizing torque. Ks is synchronising torque coefficient.

K_D Δω = the component of torque that is in phase with the speed change. This is known as the damping torque. K_D is damping torque coefficient. Here torque and power can be used interchangeable because they have the same per unit value.

A generator will remain stable as long as there are sufficient positive synchronizing and damping torques acting on its rotor for all operating conditions as shown in fig 2.13. While sufficient synchronising power or torque ensures that the rotor angle does not drift and increase in magnitude with time, positive damping torque ensures that oscillations do not grow but become damped.

A number of factors can influence the damping coefficient of a synchronous generator. These include the generators design, the strength of the machines interconnection to the grid, and the setting of the excitation system. While many units have adequate damping coefficients for normal operating conditions, they may experience a significant reduction in the value of K_D following transmission outages, leading to unacceptably low damping ratios. In extreme situations, the damping coefficient may become negative, causing the electromechanical oscillations to grow, and eventually causing lose of synchronism (6). This form of instability is normally referred to as dynamic, small-signal or oscillatory instability to differentiate it from the steady-state stability and transient stability as shown in fig 2.13.

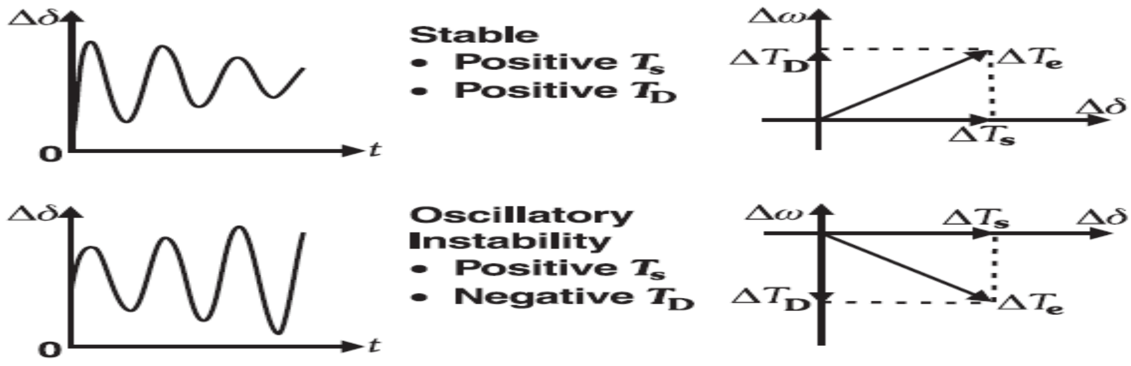


Fig 2.13 Behaviour of rotor oscillations due different damping torque

Other factors that affect small signal stability are

- Initial operating point of the generator.
- The type of excitation control.
- The strength of the transmission network connecting the generator to the rest of the system.

2.2.2.2 Analysis of small signal disturbance

For a small signal disturbance analysis, suitable for steady state stability purposes, the equations describing the generator behaviour (rotor angle behaviour) equation 2.2 can be linearised in the vicinity of the pre-disturbance operating point. Assuming a constant flux generator model with constant E, the swing equation 2.2 becomes

$$M\frac{d^2\Delta\theta}{dt^2} + D\frac{d\Delta\theta}{dt} + K_E\Delta\theta = 0 \qquad 2.6$$

With initial disturbed conditions being

$$\Delta\theta(t = 0^+) = \Delta\theta_0 \neq 0 \text{ very small change}$$

Assuming no change in speed i.e $\Delta\omega = 0$

Equation 2.6 is a second order linear differential equation whose solution is determined by the root of the characteristic equation

$$\lambda^2 + \frac{D}{M}\lambda + \frac{K_E}{M} = 0 \qquad 2.7$$

Where the two roots λ_1 and λ_2 are

$$\lambda_{1,2} = -\frac{D}{2M} \pm \sqrt{\left(\frac{D}{2M}\right)^2 - \frac{K_E}{M}} \qquad 2.8$$

The roots of the equation are called eigenvalues. Small signal stability can be determined by the nature of the eigenvalues. This also gives the different dynamic modes of the system.

The above equation has three possible roots

1. Real and distinct roots and the solution is in the form $\Delta\theta(t) = A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t}$.

2. The roots are real and equal, $\lambda_1 = \lambda_2 = \lambda$ and the solution is of the form

$\Delta\theta(t) = e^{\lambda}(A_1 + A_2 t)$.

3. The roots forms a complex conjugate pair $\lambda_{1,2} = \sigma \pm j\omega$.

The stability of the system is determined by the eigenvalues as follows:

- The real eigenvalue corresponds to a non-oscillatory mode. A negative real eigenvalue represents a decaying mode. The larger its magnitude, the faster the decay. A positive real eigenvalue represents aperiodic instability.

- Complex eigenvalues occur in conjugate pairs and each pair corresponds to an oscillatory mode. The real component of the eigenvalue gives the damping and the imaginary component gives the frequency of oscillation. A negative real part represents a damped oscillation where as a positive real part represents oscillation of increasing amplitude. Thus for a complex pair of eigenvalues

$$\lambda_{1,2} = \sigma \pm j\omega \qquad 2.9$$

The frequency of oscillation in Hz is give by

$$f = \frac{\omega}{2\pi} \qquad 2.10$$

This represents the actual or damped frequency. The damping ratio is given by

$$\zeta = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}} \qquad 2.11$$

The damping ratio ζ determines the rate of decay of the amplitude of the oscillation. The time constant of the amplitude decay is 1/|σ|. In other words, the amplitude decays to 37% of the initial amplitude in1/|σ| seconds or in 1/(2πζ).

The frequency of oscillation or rotor swing frequency can also be calculated from the following equation (34).

$$f = \frac{1}{2\Pi}\sqrt{\frac{\omega_N E'V\cos\delta_o}{T_A X}}\left[Hz\right] \qquad 2.9b$$

where

ω_N	is nominal angular frequency (=2pfN) in 1/second
E'	is pu voltage behind the generator's transient reactance
V	is pu voltage at the infinite bus
δ_o	is steady state rotor angle between E' and V;
TA	is generator inertia time constant (=2H) in seconds
X	is the total reactance between E' and Vs

From equation 2.9b it can be concluded that:

- The longer the transmission lines (with a large X), the lower the frequency
- The heavier the power transfer (with a large δ_o), the lower the frequency
- The larger the generation system (with a great inertia time constant TA), the lower the frequency.

2.2.2.3 Different Mode of Oscillation (4,6)

The various oscillation modes that exist in the power system can be recognised and analysed with system eigenvalues. An interconnected power system, depending on its size, has hundreds to thousands of modes of oscillation. In the analysis and control of system stability, two distinct types of system oscillations are usually recognized. These are Local modes or machine-system mode and inter-area mode oscillation. Other modes are Control, Inter-units and Torsional modes.

Inter-unit Oscillations - These oscillations involve typically two or more synchronous machines at a power plant or nearby power plants. The machines swing against each other, with the frequency of the power oscillation ranging between 1.5 to 3 Hertz.

Local Mode Oscillations - These oscillations generally involve one or more synchronous machines at a power station swinging together against a comparatively large power system or load centre. The frequency of oscillation is in the range of 0.7 Hertz to 2 Hertz. These oscillations become troublesome when the plant is at high load with a high reactance transmission system.

Inter-area Oscillations - These oscillations usually involve combinations of many machines on one part of a power system swinging against machines on another part of the power system. Inter-area oscillations are normally in the frequency range of less than 0.5 Hertz.

Control modes Oscillation - These are associated with generating units and other controls. Poorly tuned exciters, speed governors, HVDC converters and static var compensators are the usual causes of instability in this mode.

Torsional modes oscillation -Theses are associated with turbine –generator shaft system rotational components. Instability of the torsional mode may be caused by interaction with excitation controls speed governors, HVDC control and series-capacitor-compensated line.

2.2.2.4 Damping of Electromechanical Oscillations

If these modes of oscillation are not well managed, small signal instability can result, leading to some generators losing synchronism. In today's practical system, small-signal instability is largely a problem of insufficient damping of oscillation. Damping can be improved by using ammotiser winding and strengthening the transmission network. Also Power System stabilizer (PSS) installed on generator excitation system can improve small signal stability. The basic function of the PSS is to add damping to these types of system oscillations.

2.2.3 Transient Stability (1)

In power system large disturbance like short circuit, loss of generation due to fault are inevitable. However, when they occur, a robust system can maintain synchronism irrespective of the nature of the disturbance. Large-disturbance rotor angle stability or transient stability as it is commonly referred to, is concerned with the ability of the power system to maintain synchronism when subjected to severe disturbance, such as short circuit on the transmission line (3).

For an explanation of this phenomenon, consider a generator G1 represented by a classical model with a constant transient emf E' behind a transient reactance X'_d connected to a system represented by a constant voltage V_2 behind a equivalent reactance Xs by two transmission lines L1 and L2 as shown in fig 2.14.

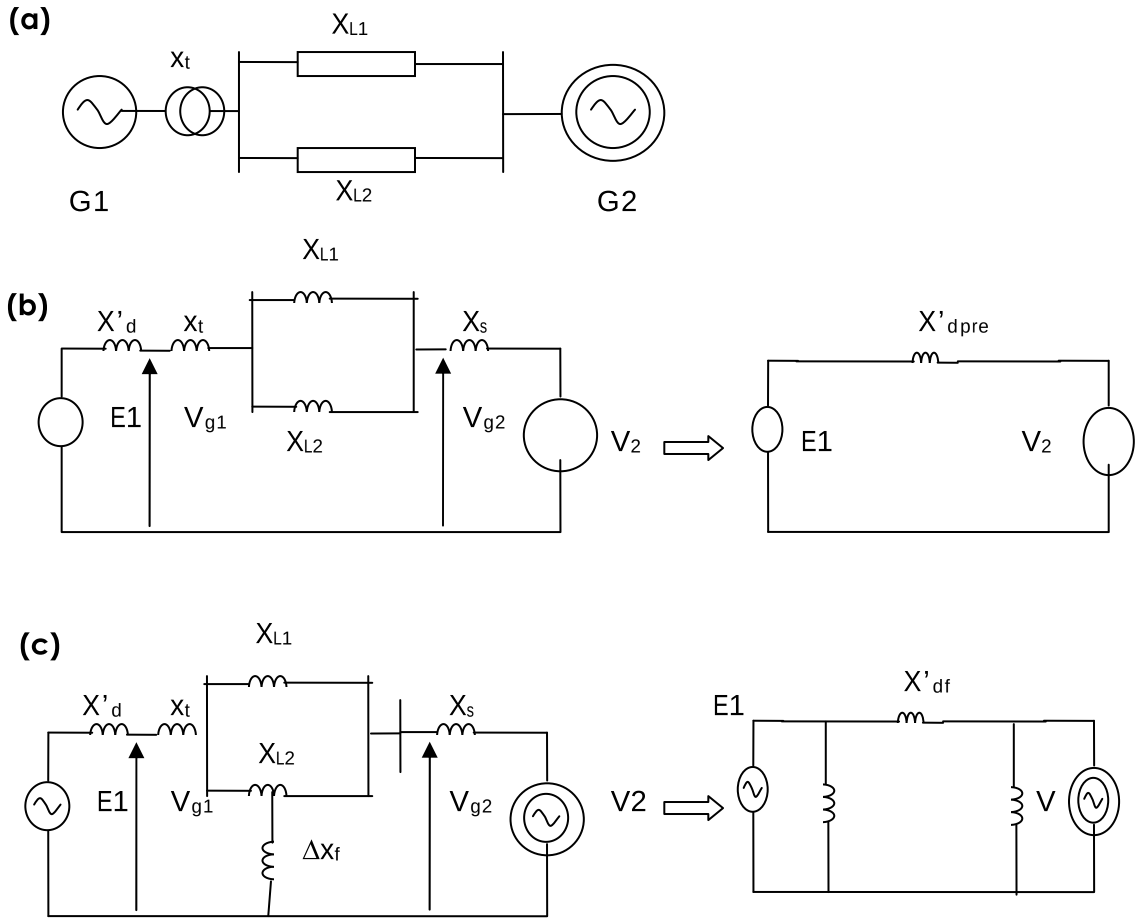


Fig 2.14 (a) G1 connected to a system through two transmission line L1 and L2 **(b)** equivalent circuit during pre-fault condition. **(c)** Equivalent circuit during post-fault condition.

2.2.3.1Fault Impedance

There are usually three states associated with the disturbance with generally different equivalent reactance X'_{eq} between G1 and the system. From fig 2.14 the equivalent impedance can be calculated as follows:

1. The steady state condition of G1 before the fault,(pre fault condition), $X'_{eq} = X'_{dpre}$

$$X'_{dpre} = X'_d + X_T + X_L + X_s \qquad 2.12$$

2. During the fault when $X'_{eq} = X'_{dft}$

$$X'_{dft} = X'_d + X_T + X_L + X_s + \frac{(X'_d + X_T)(X_L + X_s)}{\Delta X_f} \qquad 2.13$$

The value of the fault shunt ΔX_f depends on the type of fault as shown in table 2.1

Table 2.1Shunt reactances representing different types of fault

Fault type	Three –phase (3ph)	Double phase-to-ground (2ph-g)	Phase-to-phase (2ph)	Single phase (1ph)
ΔX_f	0	$\frac{X_2 X_0}{X_2 + X_0}$	X_2	$X_1 + X_2$

Where X_1, X_2 and X_0 are the positive, negative and zero sequence Thevenin equivalent reactance as seen from the fault terminal.

3. After the fault state (post fault condition).i.e after the fault has been isolated, with equivalent reactance $X'_{eq} = X'_{dpost}$.. The value of X'_{dpost} depends on the configuration of the network after the fault. If there is no change in the network after the fault is cleared then $X'_{dpre} = X'_{dpost}$.

2.2.3.2 Equal Area Criteria

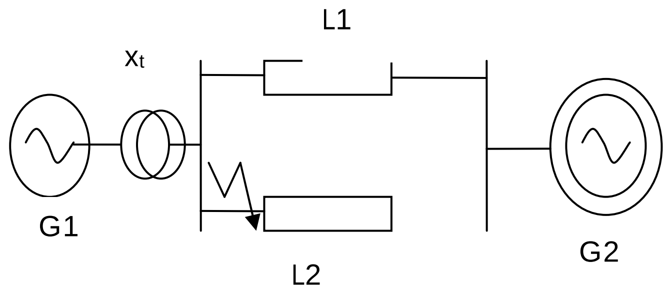


Fig 2.15: Three phase ground fault on L2 which is opened at G2 end of the line

Consider fig 2.15 with L2 opened at G2 end and a three phase fault occurred on line 2 close to G1 bus. For a three-phase fault ΔX_f =0 and from equation 2.13 $X'_{df} = \infty$. This means that electrical power transfer from the generator to the system is completely blocked by the fault with the fault current being purely inductive. Prior to the fault the generator was operating at a steady state at a rotor angle of θ_s and transferring electrical power of $P(\theta_s)$ equal to the mechanical power Pm, into the system as shown in fig 2.16 .

During the fault the electrical power drops from its pre-fault value to zero (from point 1 to 2) and continue to produce no active electrical power until the fault is cleared. From equation 2.2, assuming there is no damping and Pe=0, acceleration $\varepsilon = \frac{d^2\theta}{dt^2} = \frac{P_m}{M}$. 2.14

Integrating equation 2.14 twice with initial conditions $\theta(0) = \theta_o$.

$$\Delta\theta = \theta - \theta_0 = \frac{\varepsilon t^2}{2} \qquad 2.15$$

From equation 2.15 the rotor angle deviation is proportional to the square of the fault duration and acceleration. This means that the longer the fault clearing time the larger the rotor angle deviation from its steady state value. The acceleration of the rotor is also proportional to the mechanical power. Therefore a heavily loaded generator of the same inertia will have a higher acceleration than a lightly loaded generator during fault.

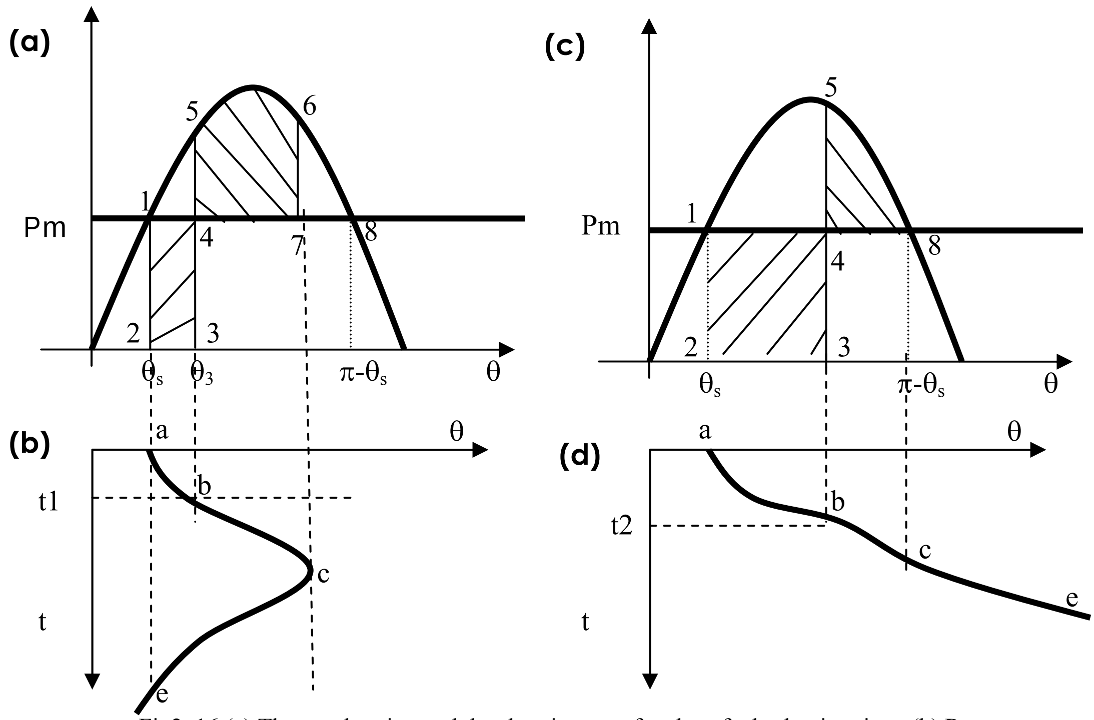


Fig2. 16 (a) The acceleration and deceleration area for short fault-clearing time. (b) Rotor angle trajectory for short fault-clearing time. (c) The acceleration and deceleration area for long fault-clearing time. (d) Rotor angle trajectory for long fault-clearing time.

With no opposing electrical power, turbine power (mechanical power) then accelerate the rotor of G1, changing its angle from point 2 to point 3 in fig2.16a, following trajectory a,b in fig2.16b. The acceleration power is proportional to line 1-2 in fig2. 16a. The rotor also acquires kinetic energy proportional to the shaded area 1-2-3-4.

After the fault is cleared at t1 by opening the circuit breaker, the rotor immediately follows the power angle characteristic P(θ) corresponding to a rotor angle θ_3. The generator operating point therefore jumps from point 3 to point 5 in fig 16a. Because at this point the opposing electrical power is greater than the mechanical power, the rotor now experiences a deceleration torque, with magnitude proportional to the length of the line 4-5,. However due to the rotor momentum , the rotor angle continues to increase until the work done during deceleration, area 4-5-6-7, equals the kinetic energy acquired during acceleration , area 1-2-3-4. For the rotor to regain stability

$$\text{Area}(4\text{-}5\text{-}6\text{-}7)=\text{Area}(1\text{-}2\text{-}3\text{-}4)$$

In other words, for G1 to have transient stability, during a large disturbance, its acceleration area should be equal to the deceleration area. This criteria is called equal area criteria.

If the fault is not cleared on time, the kinetic energy acquired during acceleration, proportional to area 1-2-3-4 become much larger than the available deceleration area 4-5-8 in fig 2.16c. As a result the work performed during deceleration, proportional to the area 4-5-8, cannot absorb the kinetic energy acquired during acceleration and the speed deviation does not become equal to zero before the rotor reaches point 8 in fig 2.16c.b After passing point 8 where the mechanical power Pm is also greater than the electrical power P(θ), the rotor experiences a net acceleration torque which further increases it angle. The rotor makes an asynchronous rotation and loses synchronism with the system.

For transient stability two important conditions must be satisfied:

- The generator during the first swing should not go beyond point 8 corresponding to rotor angle of $\pi-\theta_s$.
- The area 4-5-8 is the available deceleration area with which to stop the swinging generator rotor. This area must be larger than acceleration area forced by the fault.
  i.e Area(1-2-3-4)<area(4-5-8).

In fig 2.16a, because the generator did not use the whole available deceleration area the remaining area 6-7-8 divided by the available deceleration area, can be used to define the ***transient stability margin***

$$K_{area} = \frac{area(6-7-8)}{area(4-5-8)}$$

The fault clearing time directly affect the acceleration area. The longer the fault clearing time the bigger the acceleration area and the smaller the available deceleration area from equation 2.15. The longest clearing time for which the generator will remain in synchronism is referred to ***critical clearing time.***

Transient stability margin can also be defined by the fault clearing times as below

$$K_{time} = \frac{t_{cr} - t_f}{t_{cr}}$$

Where t_{cr} and t_f are the critical and actual clearing times.

2.2.3.3 Effect of fault type on stability

Transient stability is also affected by the type of fault

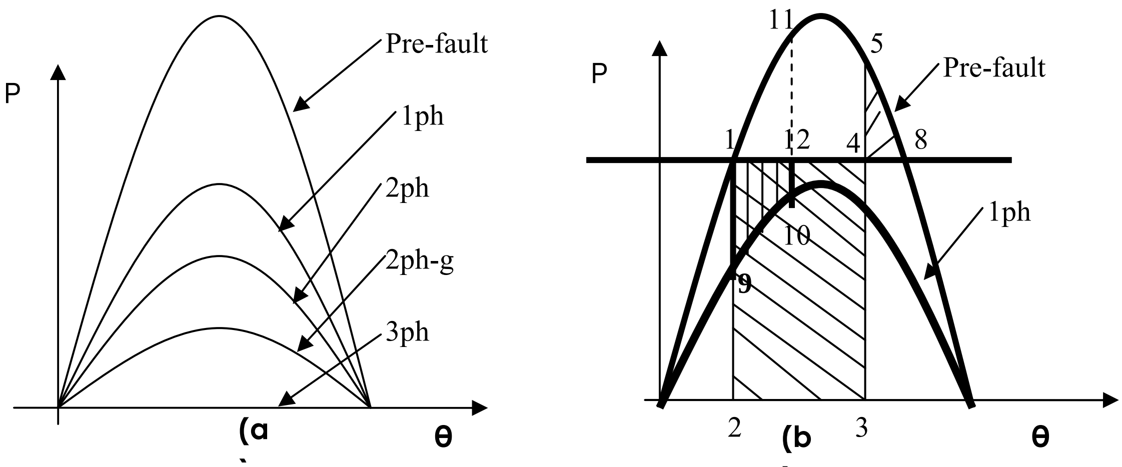


Fig 2.17 Effect of unbalanced fault (a) Comparison of power-angle characteristics (b)acceleration and deceleration area during a three-phase fault and a single-phase fault

A single phase fault has the highest fault shunt reactance as shown in table 2.1. However from equation 2.13, single phase fault gives the smallest equivalent reactance between generator G1 and the rest of the system. This make a single phase fault less severe since the generator is capable of transferring some power to the system .The severity of the fault in decreasing order is listed below

- A three-phase fault(3ph)
- A phase to phase to ground fault(2ph-g)
- A phase-to-phase fault(2ph)
- A single phase fault(1ph)

The effect of an unbalance fault on system stability is examined by comparing a three phase fault to single phase fault in fig2.17b. During a three phase fault the electrical power drops from point 1 to 2. Acceleration power corresponding to line1-2 accelerates the rotor angle rapidly from point 2 to 3 thus covering a bigger acceleration area 1-2-3-4. The acceleration area1-2-3-4 is bigger than the available deceleration area 4-5-8 and this makes the generator unstable. However during a single phase to ground fault the electrical power drops from point 1 to 9 with a smaller acceleration power corresponding to line1-9. This slowly accelerate the rotor from point 9 to10 corresponding to a smaller acceleration area 1-9-10-12 and a smaller rotor angle deviation. The acceleration area 1-9-10-12 is much smaller than the available deceleration area 11-8-12 and the system is stable with large stability margin. A longer fault clearing time would result in generator losing stability but the critical clearing time for the single phase fault is significantly longer than that for the three-phase fault.

2.2.3.4 Effect of pre-fault load on stability

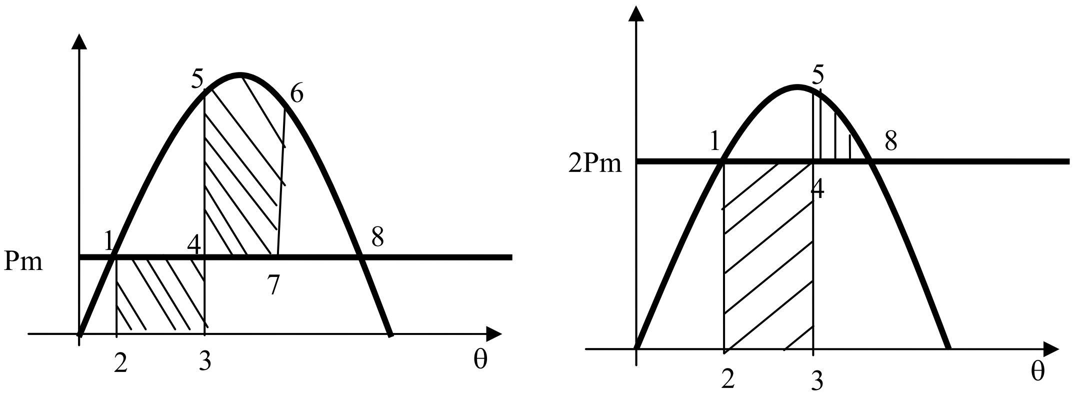


fig2 .18 . Acceleration and deceleration areas for two different pre-fault loads Pm and 2Pm.The fault clearing time is the same for both cases.

Fig 2.18 shows how the pre-fault load affects transient stability. A generator that is lightly loaded has a higher stability margin than a generator that is heavily loaded. In fig2.18a the load on the generator was Pm before a three phase fault occurred and this made the acceleration area 1-2-3-4 less the available deceleration area 4-5-6-7. However with the same fault type and fault clearing time, a generator load of 2Pm in fig 2.18b accelerates the rotor angle rapidly to make the acceleration area 1-2-3-4 greater than the available deceleration area 4-5-8 making the system lose transient stability.

The pre-fault load is an important factor with regards to determining the critical clearing time and generator stability. The higher the load on the generator, the smaller the critical clearing time.

2.2.3.5 Effect of fault distance on transient stability

The description given so far assumes the fault occurs at the bus. If the point of the fault is along the transmission line then the reactance of the line up to the fault (ΔX_L) is added to the fault impedance (ΔX_F) to calculate the actual fault impedance seen from the bus. The longer the fault distance, the less severe the fault.

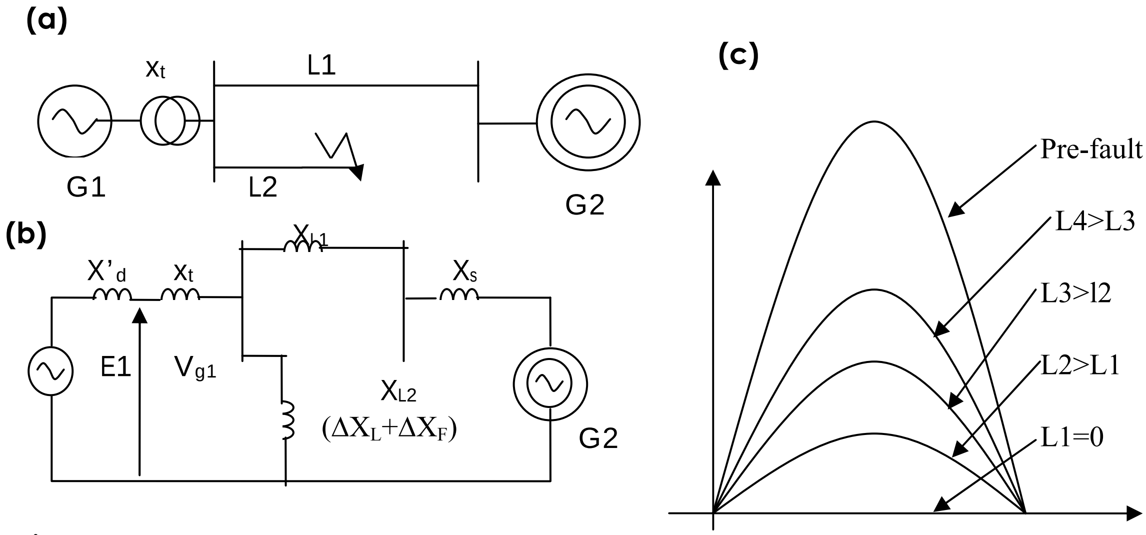


Fig 2.19 Influence of fault distance (a) Schematic diagram; (b) equivalent circuit diagram; (c) power-angle characteristics before the fault and for various fault distances

Fig 2.19c shows the family of power-angle characteristics for three-phase fault, occurring at increasing distance along the line. Here it can also be deduced that the critical fault clearing time increases as the fault distance increases from the bus.

In case of unbalanced faults $\Delta X_F \neq 0$,the magnitude of the power-angle characteristic during the fault is further increased compared to the three-phase fault case. As a result the effect of the fault is less severe. In the case of a remote single-phase fault the disturbance to the generator may be very small.

2.2.3.5 The effect of post fault transmission system reactance and auto re-closures on transient stability

Considering fig 2.20 where the two lines L1 and L2 are both in operation and a fault occurred on one line L2 which was later opened to isolate the fault. In this case the post fault transmission reactance will be different from the pre-fault reactance considered earlier.

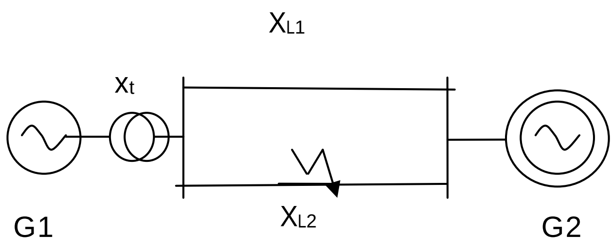


Fig 2. 20 Schematic diagram showing a fault line on line Xl2

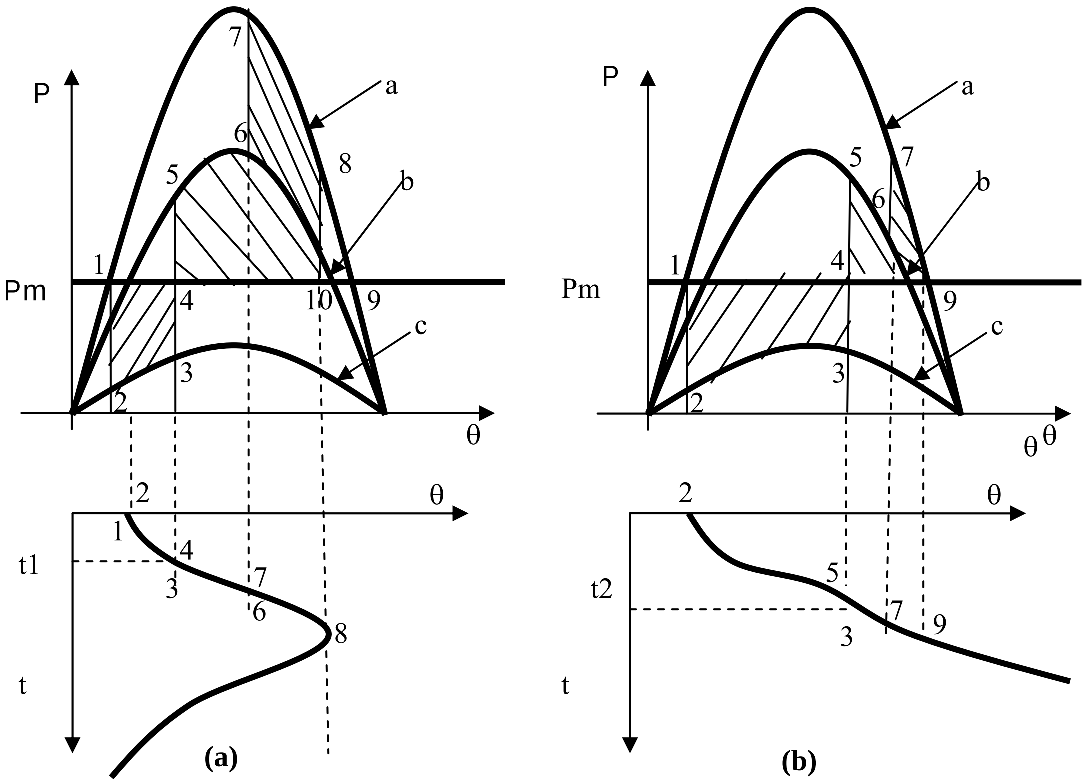


Fig 2. 21 The acceleration and deceleration areas for successful auto-reclosing. (a) Stable case (b) Unstable case

Consider the following sequence of events

- Both lines L1 and L2 are in operation
- Fault occurs on line L2
- L2 is opened to isolate the fault whilst L1 is in operation
- L2 could be closed again automatically on both ends if the line is equipped with re-closures
- L2 could open again if the fault still persists.

2.2.3.6 Effect of post fault impedance on transient stability

By only isolating the faulted line L2, the stability of the system depends on whether the acceleration area 1234 in fig 2.21 is smaller than the available deceleration area 4-5-6-10. During the fault, the reactance between the generator G1 and the system increases and the power angle characteristic follows curve C in fig 2.21 (a). The generator power moves from point 1 before the fault to 2 immediately after the fault and move along curve c during the fault to point 3. It then jumps to point 5 immediately the fault is cleared. With only L1 in operation, reactance between the generator and the system is less than its value during the fault condition but greater than the pre-fault condition. The generator then follows curve b after point 5. This means that stability is improved when the post fault impedance is quite close to the pre-fault impedance. The transient stability of the generator apart from other factors discussed, in addition, depends on the post-fault transmission system reactance. This has a significant effect on both the acceleration and deceleration area and therefore the stability margin.

2.2.3.7 Effect of auto reclosing on transient stability

(a) Transient fault

Majority of faults on transmission lines are intermittent so that, after clearing the fault by opening the necessary circuit breakers, the faulty line can be switched back after allowing sufficient time for the arc across the breaker points to be extinguished. This process is known as auto reclosing.

After isolating the fault, reclosing L2 at point 6 in fig 21a, causes that line reactance to be the same as the pre-fault value assuming the initial fault was transient. The generator power angle characteristic than follows curve **a** in fig 2.21a. This action increases the available deceleration area by area 6-7-9-10 increasing the stability margin. Therefore from fig2.21a auto reclosing improve transient stability compared to the case without auto reclosing. However if the fault is not isolated on time as shown in fig 2.21b auto reclosing will not make the system stable as the available deceleration area will be too small to absorbed the rotor energy so as to stop the generator from losing synchronism.

(b) Bolted fault

Auto reclosing generally increases stability margin, however if the fault is a bolted fault it could reduce stability margin. This is because reclosing into the fault causes the rotor to acquire additional kinetic energy increasing the acceleration area and reducing the available deceleration area. Stability margin can be improved by reducing the pre-fault load on the generator as well as reducing the fault clearing time of the auto-reclosing action (1).

From the discussion so far we can summarised the following factors as affecting transient stability(3)

- How heavily the generator is loaded.
- The generator output during the fault. This depends on the fault location and type.
- The fault clearing time.
- The post-fault transmission system reactance.
- The generator reactance. A lower reactance increases peak power and reduces initial rotor angle.

- The generator inertia. The higher the inertia the slower the rate of change in angle. This reduces the kinetic energy gained during fault (acceleration area).
- The generator internal voltage magnitude (E').This depends of excitation. Fast Automatic Voltage Regulator reduces the acceleration area and increases the deceleration area.
- The infinite bus voltage magnitude V2.

2.2.4 Voltage Stability

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

Voltage stability can further be divided into two, Large-disturbances and small disturbance voltage stability.

• ***Large-disturbance voltage stability*** refers to the system's ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. This ability is determined by the system load characteristics and the interactions of both continuous and discrete controls and protections. Determination of large-disturbance voltage stability requires the examination of the nonlinear response of the power system over a period of time sufficient to capture the performance and interactions of such devices as motors, under load transformer tap changers and generator field-current limiters. The study period of interest may extend from a few seconds to tens of minutes.

• ***Small-disturbance voltage stability*** refers to the system's ability to maintain steady voltages when subjected to small perturbations such as incremental changes in system load. This form of stability is influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. This concept is useful in determining, at any instant, how the system voltages will respond to small system changes. With appropriate assumptions, system equations can be linearized for analysis.

Depending on the time frame voltage stability can be classified as

• ***Short-term voltage stability*** involves dynamics of fast acting load components such as induction motors, electronically controlled loads, and HVDC converters. The study period of interest is in the order of several seconds, and analysis requires solution of appropriate system differential equations; this is similar to analysis of rotor angle stability.

• ***Long-term voltage stability*** involves slower acting equipment such as tap-changing transformers, thermostatically controlled loads, and generator current limiters. The study period of interest may extend to several or many minutes, and long-term simulations are required for analysis of system dynamic performance.

2.2.4.1 Causes of voltage instability

The following are some of the causes of voltage instability

- Excessive loading on the transmission line causing high voltage drops on the line.
- Voltage sources too far from the load centre, resulting in low voltages at load centres
- Insufficient load reactive compensation.
- Very low source voltages.

2.2.4.2 Criterion for voltage stability

The criterion for voltage stability is that, at a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased .A system is voltage unstable if, for at least one bus in the system, the bus voltage magnitude (V) decreases as the reactive power injection (Q) at the same bus is increased.

2.2.4.3 Factors influences voltage stability

(a)Influence of Generator Characteristics

Generator AVRs(Automatic Voltage Regulators) are the most important means of voltage control in the power system. Under normal conditions they maintain constant voltages at the generator terminals. However, under conditions of low system voltages, reactive power demand may exceed generator capabilities (either generator field or stator currents) and the terminal voltages are no longer held constant. If reactive power (VAr) output is limited by field current limit, the point of constant voltage is behind the generator synchronous reactance. This increases the overall network reactance, further aggravating the voltage control problem. If the VAr output is limited by the armature current limit, the generator terminal voltage drops and the allowable VAr output drops due to the voltage reduction, further aggravating the situation.

(b)Influence of load characteristics

Load characteristics and distribution system voltage control devices are also key factors that influence voltage stability. Both the loads and the transmission system have reactive and (to a lesser extent in the case of the transmission system) active power requirements, both of which depend on voltage. Thus these two subsystems interact with one another and affect each other – the system as a whole will settle at whatever voltage value is determined by the composite characteristic of the transmission system and loads. Substation Under Load Tap Changers (ULTCs) and distribution voltage regulators try to keep constant voltage at the points of consumption. Hence, within normal control range the loads appear effectively as constant MVA loads which may have a destabilising effect during conditions of voltage collapse. When ULTCs reach the end of their control range, distribution system voltages begin to drop. The effect of this drop depends very much on the load type as follows:

- In residential loads, P and Q (active and reactive load)will drop, thereby reducing line loading and reactive power losses;
- Industrial loads (particularly those with large percentage of induction motors) change little, but the shunt capacitors in the industrial system will supply less VArs due to lower system voltage and hence the overall effect is an increase in reactive power load.

If the distribution system voltage remains low for a few minutes, thermostats and other load regulators tend to start restoring load.

- More such devices will operate at any given time.
- Loads restored to normal full voltage within 10 – 15 minutes.
- Voltage drops further.

Industrial and commercial motors usually controlled by magnetically held contactors:

- voltage drop then causes motors to drop out;
- loss of load results in voltage recovery;
- motors restored (contactors come back in) after some time; voltage drops again if original cause of low voltage persists.

These actions causes further voltage drop increasing system exposure to voltage collapse

(c)Influence of compensating devices

(i)Shunt Capacitors

Shunt capacitors are the most inexpensive method of providing VArs and voltage support, and they are effective up to a point in extending voltage stability. This is achieved in two ways:

- ❖ Correcting receiving-end power factor;
- ❖ Freeing up reactive power spinning reserve of the system generators.

However shunt capacitors have the following important limitations:

- ❖ In heavily shunt compensated systems, voltage regulation tends to be poor;
- ❖ VAr generation is proportional to the square of voltage and under low voltage conditions (when it is needed most) VAr generation is poor thus compounding the problem;
- ❖ Beyond a certain maximum shunt compensation level, stable operation is unattainable.

(ii)Static var compensators (SVCs)

SVC of finite size (ie. VAr capability) regulates voltage up to its maximum capacitive (leadingVAr) output without control or stability problems. Outside of this limit SVC becomes a shunt capacitor with the same limitations describe earlier.

(iii)Synchronous condensors / STATCOMS

Unlike SVC, a synchronous condensor has an internal voltage source and can therefore continue to supply VArs at relatively low voltages (where VAr support is most needed), contributing to more stable voltage performance.

A STATCOM is a controlled shunt VAr compensator based on a voltage source inverter and its characteristics (and advantages over traditional, thyristor-based SVCs) are similar to those of a synchronous condensor.

(iv)Series Capacitors

Series capacitors are self-regulating. The VArs supplied are proportional to square of the line current and independent of system voltages, a very favourable effect on voltage stability. Series capacitors are ideally used for shortening both the characteristic impedance and electrical length of a transmission line, thus improving both voltage regulation and stability significantly.

(v)Under-Load Tap Changers (ULTCs)

ULTC transformers try to maintain constant secondary (load-side) voltage and thus making the load appear as a constant active and reactive power load (P,Q load). This is done by decreasing the effective turns ratio of the transformer when there is a lower transmission voltage on the primary side. For constant power at this lower transmission voltage there must be a higher transmission line current and consequently an increase in reactive power loss in the line. At times of low voltage, reactive power reserves may be at a minimum and this increased reactive loading can initiate a voltage collapse.

2.2.4.4 Voltage collapse

Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system.

Practical aspects of voltage collapse

When a power system is subjected to a sudden increase of reactive power demand following a system contingency, the additional demand are met as follows:

- The additional demand is met by the reactive power reserves carried by the generators and compensators in the system;
- Generally there are sufficient VAr reserves and the system settles to a stable voltage level.

However, it is possible that, as a result of a combination of events and system conditions, the additional reactive power demand cannot be met by the system reactive power resources . This leads to voltage collapse, resulting in a major breakdown of part or all of the system.

2.2.4.5 Measure to improve voltage stability

The following are some design and operational measures for improving voltage stability;

(a)System design measures

- **Application of reactive power compensating device**

  When applying compensating devices, the selection of sizes, rating and locations should be based on a detailed study covering the most onerous system condition for which the system is required to operate satisfactorily.
- **Control of network and generator reactive output**

  Employing secondary outer loop control of generator excitation can help to regulate network side voltage. The control should be much slower than normal regulation of generator terminal voltage to minimize adverse interaction between AVR controls. A response time of 10seconds is normally recommended for the outer loop control.
- **Coordination of protections and controls**

  Adequate coordination of the protections and controls based on dynamic simulation studies should be done. This is because one of the causes of voltage collapse is lack of coordination between equipment protection and control and power system requirement.

- **Control of transformer tap changers**

  Tap changers can be controlled, either locally or centrally, so as to reduce the risk of voltage collapse. Where tap changing is detrimental, a simple method is to block tap changing when the source side voltage sags and unblock when it recovers.

- **Under-voltage load shedding**

  This is dropping of load when there is under voltage condition. This is similar to under frequency load shedding which is used to cater for extreme situations resulting in generation deficiency and under frequency. Load shedding provides a low-cost means of preventing widespread system collapse. Load-shedding schemes should be designed so as to distinguish between faults, transient voltage dips, and low voltage condition leading to voltage collapse.

(b)System-operating measures

Stability margin

The system should be operated with an adequate stability margin by the appropriate scheduling of reactive power resources and voltage profile. If however the required margin cannot be met by using available reactive power resources and voltage control facilities, it may be necessary to limit power transfers and to start up additional generating units to provide voltage support at critical areas.

Spinning reserve

Adequate spinning reactive-power reserve must be ensured by operating generators, at moderate or low excitation and switching in shunt capacitors to maintain the desired voltage profile. The required reserve must be identified and maintained with each voltage control area.

Operator's action

Operators must be able to recognize voltage stability-related symptoms and take appropriate remedial actions such as voltage and power transfer controls and, possibly as a last resort, load curtailment. Operating strategies that prevent voltage collapse need to be established.

2.2.5 Frequency Stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain and restore equilibrium between system generation and load, with minimum unintentional loss of load.

Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads. Severe system upsets generally result in large excursions of frequency, power flows, voltage, and other system variables, thereby invoking the actions of processes, controls, and protections that are not modelled in conventional transient stability or voltage stability studies.

2.3 METHODS OF IMPROVING STABILITY (2,3)

Instability can result in partial or total system collapse, it is therefore very important to maintain system stability. Various methods that are used to improve system stability are discussed below. For optimal results, sometimes combinations of these methods are employed.

2.3.1 Transient Stability Enhancement

2.3.1.1 High-speed fault clearing.

The kinetic energy acquired by the rotor during the fault is proportional to the fault clearing time. Also the longer the fault clearing time the smaller the available deceleration areas in the power-angle characteristic curve, to maintain stability. Therefore stability can be improved by using high speed protection equipment and circuit breakers to isolate the fault as fast as possible. Protection equipment should also be very selective in clearing faults. It should detect correctly the faulty element and isolate it alone.

2.3.1.2 Single pole switching

Single pole switching employs operation of circuit breakers that allow single pole to be operated independently. This enables circuit breakers to be controlled to clear a single phase fault followed by a fast re-closuring within 0.5-1.5 seconds, with the un-faulted phases remaining intact.

There are however potential problems that need to be considered in applying a single pole switching

- Secondary-arc extinction.
- Fatigue duty on turbine-generator shafts and turbine blades
- Thermal duty on nearby generators due to negative sequence

2.3.1.3 Reserves in transmission capacity and generation capacity

Operating the generation and transmission system with some reserves improves stability. This is because the system will have the capacity to re-distribute the loading when there is a disturbance leading to loss of generation or transmission. The reserves will ensure that the remaining un-faulted elements after the fault has been isolated will not be overloaded.

2.3.1.4 Reduction of transmission system reactance

Reducing the reactances of various elements of the transmission network improves transient stability. This can be achieved by the following methods:

- ❖ Use of transformers with lower leakage reactance
- ❖ Series Capacitor compensation of transmission lines
- ❖ Re-enforcing the transmission network by adding parallel transmission lines

Traditionally, series capacitors have been used to compensate for very long overhead lines. Recently, there has been an increasing recognition of the advantages of compensation shorter, but heavily loaded, lines by using series capacitors.

For transient stability applications, the use of switched series capacitors offers some advantages. Upon detection of a fault or power swing, a series capacitor bank can be switched in and then removed about 0.5 seconds later. Such a switched bank can be located in a substation where it can serve several lines

2.3.1.5 Generator tripping

A disturbance leading to the isolation of load creates an imbalance between electrical and mechanical torque causing the rest of the generators in the system to over speed. Tripping one or more generators from a group of generators that are operating in parallel on a common bus bar is perhaps the simplest and most effective means of rapidly changing the torque balance on the generator rotor. Tripping generators without going through the shutdown procedure instantly reduces the mechanical torque. In the power angle characteristic, this reduces the acceleration area and increases the deceleration areas of the rotor of the remaining units, thereby increasing stability margin.

However this type of control measure in improving stability should not be used indiscriminately because of the following major turbine-generator concerns;

- ❖ The over speed resulting from tripping of the generator causes mechanical stress and metal fatigue turbine-generator assemble.
- ❖ Thermal stresses caused by the rapid load changes.

2.3.1.6 Controlled system separation and load shedding

Controlled separation may be used to prevent a major disturbance in one part of an interconnected system from propagating into the rest of the system and causing a severe system breakup.

When there is a disturbance in one system, which may be due to the loss of critical transmission lines, the resulting instability is usually characterised by sudden changes in the tie line power. The impending instability is detected with a relay capable of recognizing sudden changes in power flow, changes in bus angles, rate of power change and other system quantities. The two systems are them separated by opening the tie breaker. This could lead to one system having more generation whilst the other system lacks generation. To prevent the frequency from collapsing in the generation deficient area, some loads are shed automatically using under frequency relays. Under frequency relay are normally installed on load feeders to isolate them, depending on the rate at which the frequency falls or how low the frequency is.

2.3.1.7 High speed excitation system

Significant improvement in transient stability can be achieved through rapid temporary increase of generator excitation by the automatic voltage regulator. The increase of generator field voltage during a transient disturbance has the effect of increasing the internal voltage of the machine, thus increasing the synchronising power. However, the fast response of the AVR to the terminal voltage variation required for improvement of transient stability often leads to degrading of damping of local plant oscillation. These oscillations can be damped with a supplementary excitation control, commonly referred to as power system stabilizer (PSS). The use of high-initial response excitation systems supplemented with PSS is by far the most effective and economical method of enhancing the overall system stability.

2.3.1.8 Steam turbine fast-valving

Fast-valving (or early valving, as it is sometimes referred to) is a technique applicable to thermal unit to assist in maintaining power system transient stability. It involves rapid closing and opening of steam valves in a prescribed manner to reduce the generator accelerating power following the recognition of severe transmission fault. Such fast control is not possible with hydro turbines due to the large change in pressure and huge torque, necessary to move the control gates.

2.3.1.9 Regulated Shunt Compensation

Shunt compensation capable of maintaining voltages at selected points of the transmission system can improve system stability by increasing the flow of synchronising power among interconnected generators. Regulated shunt compensation includes:

- Static Var Compensators
- Synchronous condensers: The inertia of synchronous condenser helps in damping oscillations
- Superconducting magnetic energy storage(SMES)
- Control Breaking resistors

2.3.1.10 Reactor Switching

Shunt reactors near generators provide a simple and convenient means of improving transient stability. The reactor normally remains connected to the network. The resulting reactive load increases the generator internal voltage, and this is beneficial to stability. Following a fault, switching out the reactor further improves stability.

2.3.2 Small-Signal Stability Enhancement

The problem of small-signal stability is usually insufficient damping of system oscillation. The following methods are used to provide damping torque which consequently improves small—signal stability.

2.3.2.1 Application of power system stabilizers (PSS).

The function of a PSS is to add damping to the generator rotor oscillation. This is achieved by modulating the generator excitation so as to develop a component of electrical torque in phase with the rotor speed deviation. Shaft speed, integral of power and terminal frequency are among the commonly used signal to PSS. The use of power system stabilizers to control generator excitation systems is the most cost-effective method of enhancing the small-signal stability of power systems. Because this thesis is mainly about achieving stability by the application of PSS, the next chapter will mainly be focused on PSS.

2.3.2.1 Supplementary Control of Static Var Compensators

Static Var Compensators can also be used to improved small signal stability. By rapidly controlling the voltage and reactive power, SVC can contribute to the enhancement of power system dynamic performance. Normally voltage regulation is the primary mode of control and this improves voltage stability and transient stability. However, the contribution of SVC to damping of system oscillations resulting from voltage regulation alone is usually small; supplementary control is necessary to achieve significant damping. The effectiveness of a SVC in enhancing small-signal stability depends on the location of the SVC, input signal used, and controller design.

CHAPTER THREE

3.0 POWER SYSTEM STABILIZERS

3.1 Introduction

An interconnected power system, depending on its size, has hundreds to thousands of modes of oscillations. In the analysis and control of system stability, two distinct types of system oscillations are usually recognized. One type is associated with units at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as "local plant mode" oscillations. The frequencies of these oscillations are typically in the range 0.8 to 2.0 Hz. The second type of oscillations is associated with the swinging of many machines in one part of the system against machines in other parts. These are referred to as "inter-area mode" oscillations and have frequencies in the range 0.1 to 0.7 Hz (4). In some cases, this presented a limitation on the amount of power which is able to be transmitted within the system. If this mode of oscillations are not controlled or well damped they can grow in amplitude and result in system instability. One way of damping theses oscillations is the use of Power System Stabilizer(PSS).

The basic function of the PSS is to add damping to the generator rotor oscillations. This is achieved by modulating the generator excitation so as to develop a component of electrical torque in phase with rotor speed deviations. Shaft speed, integral of power and terminal frequency are among the commonly used input signals to the PSS. PSS is known to be one of the most cost-effective methods of enhancing power system stability.

This chapter examines the design, operations and the basic functions of PSS. Different types of PSS as well as various inputs used have been discussed. Various tuning processes for optimal performance of the PSS have been reviewed. Power system stability improvements using PSS and the different model that exist have also been discussed in this chapter.

3.2 Power System Stabiliser Design and Operation

A power system stabiliser (PSS) is a device which provides additional control loops to the Automatic Voltage Regulator of a generator excitation in order to add damping to the generator rotor oscillations and thereby enhancing both small-signal(steady state) and transient stability.

Different type of power system stabilizer exist for stability enhancement; the conventional power system stabilizer (Lead-lag PSS), the optimal stabilizer and the PI stabilizer (5). However for this thesis I will only look at the conventional stabiliser.

3.2.1 PSS Theory of Operation

Modulation of generator excitation can produce transient changes in the generator's electrical output power. Fast-responding exciters equipped with high-gain automatic voltage regulators (AVRs) use their speed and forcing to increase a generator's synchronizing torque, resulting in improved steady-state and transient stability limits. Unfortunately, improvements in synchronizing torque are often achieved at the expense of damping torque, resulting in reduced levels of oscillatory or small-signal stability. To counteract this effect, many units that utilize high-gain AVRs are also equipped with power system stabilizers to increase the damping coefficient and improve oscillatory stability.

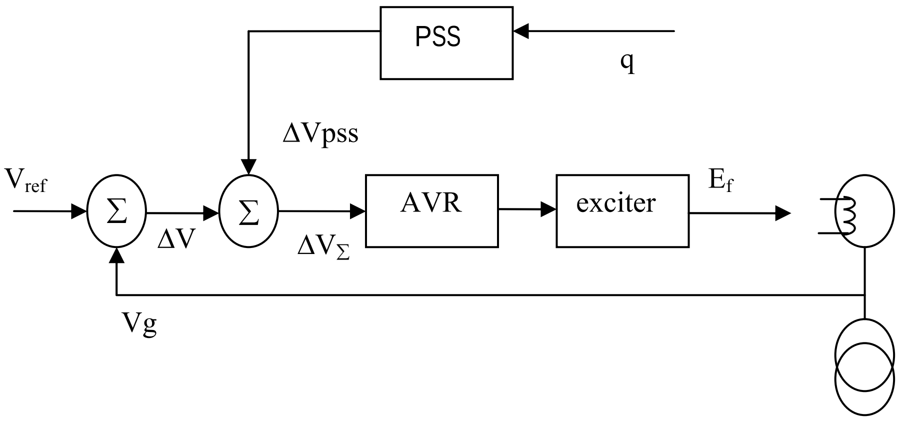


Fig 3.1 Block diagram for supplementary control loop for the AVR system

3.2.1.1 Achieving stability with PSS

The main idea of power system stabilization is to recognise that in steady state, that when the speed deviation is zero or nearly zero, the voltage controller should be driven by voltage error ΔV only. However in the transient state the generator speed is not constant, the rotor swings and ΔV undergoes oscillation caused by the change in rotor angle. The task of the PSS is to add additional signal which compensates for ΔV oscillations and provides a damping component that is in phase with Δω(speed deviation).This is illustrated in fig 3.1 where the signal Vpss is added to the main voltage error signal ΔV. In steady state Vpss must be zero so that it does not distort the voltage regulation process.

The block diagram in fig 3.2 gives the general structure of PSS, where the PSS input signal can be provided from a number of different input signal measured at the generator terminals. The measured quantity (or signal) is passed through low pass and high pass filters. The filtered signal is then passed through a lead and or lag element in order to obtain the required phase shift and, finally amplified and sent to a limiter and then to AVR.

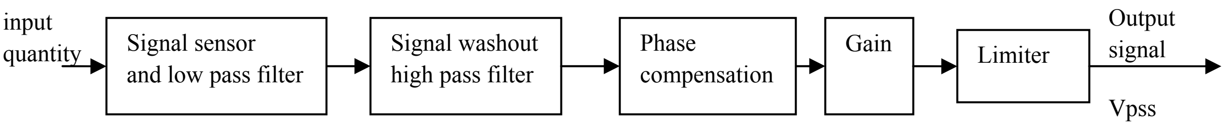


Fig 3.2 The major element of PSS

Typically the measured quantities used as input signal to the PSS are the rotor speed deviation, the generator active power or the frequency of generator terminal voltage. There are different types of lead-lag PSS construction depending on the input chosen.

3.2.2 Design Consideration of PSS(6)

To enhance the reliable operation of power systems, the PSS must satisfy the following basic requirements:

A high degree of functional reliability*:* The PSS should operate as expected with a high degree of probability, with the consequences of any component failure being minimal.

Enhancement of the overall power system dynamic performance: The PSS should contribute to the damping of electro-mechanical modes of oscillation, without adversely affecting other aspects of system performance.

Robustness of control design: The PSS should perform as intended over the range of operating conditions that the power system is likely to experience.

Coordination with other controls and protections*:* The design and tuning of PSS should be coordinated with those of other controls and protective systems *so* as to have no adverse interaction with them. As far as possible, the PSS should complement other controls in enhancing the power system performance.

The effectiveness of PSS in achieving the desired objectives depends on the hardware design, method of deriving the input signal, selection of control parameters, commissioning procedures and field verification.

3.2.3 Functions of PSS major components

Fig 3.2 shows the major components of the PSS in a functional block diagram. The following are the description of the functions of the major components of PSS.

Phase Compensation Block: This provides the appropriate phase-lead characteristic to compensate for the phase lag between the exciter and the generator electrical torque. This electrical torque provided by the generator is approximately in phase with the speed deviation. Normally the frequency range of interest is 0.1to 2Hz and the phase lead network should provide compensation over this entire frequency range.

Stabilizer Gain Block: This determines the amount of damping introduced by the PSS. Damping increases with an increase in stabilizer gain up to a certain point beyond which further increase in gain results in a decrease in damping. Ideally the gain is normally set at a value corresponding to maximum damping. However the gain is often limited by other considerations like the type of input signal.

Signal Washout Block: This serves as a high-pass filter, with time constant T_w high enough to allow signals associated with oscillations in rotor speed ω_r to pass unchanged. Without it steady changes in speed would modify the terminal voltage. It allows the PSS to respond only to changes in speed.

Signal sensor and low pass filter: This is a transducer which converts input quantity to the PSS into electrical signal and removes noise before it is processed by the washout.

Stabilizer limits: A good practice is to set the positive output limit of the stabilizer at a relatively large value in the range of 0.1 to 0.2 pu. This allows a high level of contribution from the PSS during large swings. With such a high value of stabilizer output limit, it is essential to have a means 'of limiting the generator terminal voltage to its maximum allowable value, typically in the 1.12 to 1.15 pu range. Therefore, a terminal voltage limiter is used to achieve this. On the negative side, a limit of -0.05 to -0.1 pu is appropriate. This allows sufficient control range while providing satisfactory transient response. In the unlikely event of the PSS output being held at the negative limit because of a failure of the stabilizer, this will not result in a unit trip.

3.3 Types of Power System Stabiliser (1)

The classification of PSS is based on the type of input quantity such as shaft speed, frequency and power. The following are the different type of PSS presently being used.

3.3.1 Stabilizer based on shaft speed signal (delta-omega)

This type of PSS that uses generator shaft speed deviation as input signal has been used successfully on hydraulic unit since the mid 1960(2). The shaft speed is measured using speed sensor such as a magnetic-probe and gear-wheel arrangement. The measured signal is converted into a dc voltage proportional to the speed. High-pass filter, filters the resulting signal to remove the average speed level, producing a change-in-speed signal. This ensures that the stabilizer reacts only to changes in speed and does not permanently alter the generator terminal voltage. However the main disadvantage of this type of PSS is that , it is frequently difficult to produce a noise-free speed signal that does not contain other components of shaft motion such as lateral shaft run-out (hydroelectric units) or torsional oscillations (steamdriven turbogenerators).

The presence of these components in the input of a speed-based stabilizer can result in excessive modulation of the generator's excitation and, for the case of torsional components, in the production of potentially damaging electrical torque variations (6). In addition, the stabilizer has to be custom-designed for each type of generating unit depending on its characteristics (2). One way around this problem in long shaft is to measure speed deviation at a number of points along the shaft and use this information to calculate the average speed deviation. Fig 3.3 is the functional block diagram of speed-based stabiliser.

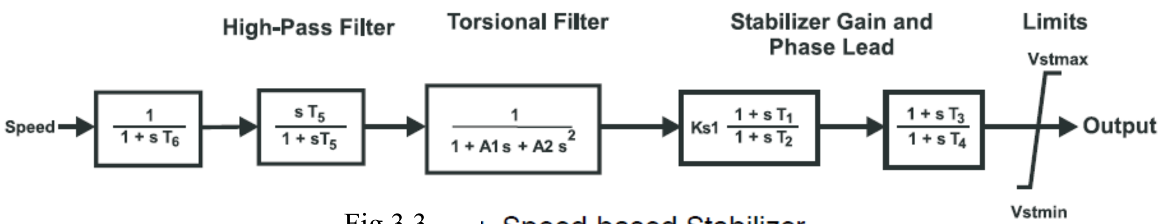


Fig 3.3 : Speed-based Stabilizer

3.3.2 Stabilizer based on calculated speed and power signal (delta-P-omega)

The need to measure the speed deviation at a number of points along the shaft can be avoided by calculating the average speed deviation from measured electrical quantities. This method calculates the equivalent speed deviation $\Delta\omega_{eq}$ indirectly from the integral of the acceleration power:

$$\Delta\omega_{eq} = \frac{1}{M}\int\left(\Delta P_m - \Delta P_e\right)dt$$

and ΔP_e is calculated from measurement of the generated real electrical power (P_e). The integral of the change in mechanical power ΔP_m can be obtained from

$$\int \Delta P_m dt = M\,\Delta\omega_{measured} + \int \Delta P_e dt$$

Where ω $_{measured}$ is based on end shaft speed sensing system. Due to the fact that the mechanical power changes are relatively slow the derived integral of the mechanical power can be passed through a low-pass filter to remove the torsional frequencies from the speed measurement. The resulting PSS contains two input signals, $\Delta\omega_{measured}$ and ΔP_e, which are used to calculate $\Delta\omega_{eq.}$ The final Vpss signal is designed to lead $\Delta\omega_{eq.}$ The block diagram of the system is shown in fig 3.4.

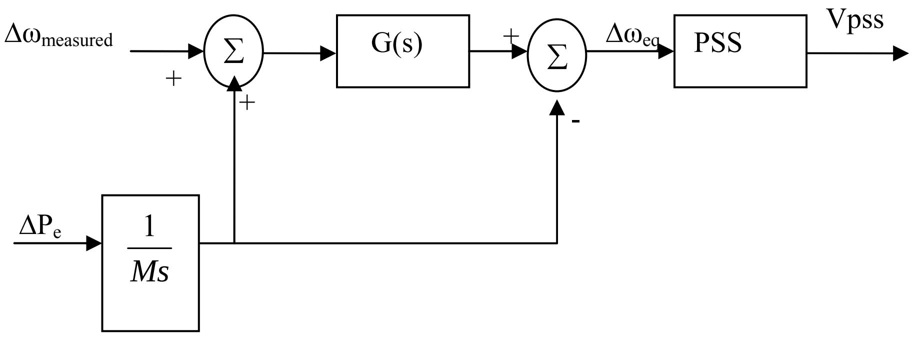


Fig3.4 Block diagram of PSS using speed deviation and real power as input signal (1)

3.3.3 PSS based on generator electrical power

A simplified form of PSS shown in fig 3.4 can be obtained by neglecting the shaft speed measurement and measuring the generator real power Pe. With this arrangement only one input signal is required but it can only be used when the mechanical power can be assumed to be constant. If the mechanical power does change, for example due to secondary frequency control, this solution produces transient oscillations in the voltage and reactive power that are unnecessarily forced by the PSS as it sees the change in the mechanical power as a power swing.

3.3.4 PSS based on generator terminal voltage fvg

The measure of shaft speed can be replaced by a measurement of the generator terminal voltage frequency fvg (8). A disadvantage of this solution is that the terminal voltage waveform can contain noise produced by large industrial loads such as arc furnaces. The accuracy of this measured speed signal can be improved by adding the voltage drop across the transient reactance to the generator voltage to obtain the transient emf E' and its frequency. The PSS now receives two signals, the generator current and voltage. As in the case of the PSS utilising the measured shaft speed deviation, the PSS gain is limited by the effect of shaft torsional oscillations. The advantage of this solution compared with other types of stabilizers is that it improves the damping of inter-area oscillations in interconnected power systems.

3.5 Locating PSS in a power System

Selecting the right location for a PSS in a power system contribute significantly in improving system stability. However it is a very difficult task in selecting optimal location of PSS. The PSS location selection problem has been studied for a long time. The right-eigenvector method, which uses the right eigenvector information of a mode (the relative amplitude of its entries) to identify the best PSS location, was proposed in [9]. This approach is based on the consideration that the right-eigenvector entries measure the activity of the state variables participating in an oscillation mode[10] and these state variables may be used as PSS input (for example machine speed). Participation factors were used in Ref.[11] to select the PSS location. The participation factor according to its definition [10] is equal to the sensitivity of a mode with respect to the change of machine's damping coefficient. The participation factor method may bear some relation to the fact that, in a single-machine infinite-bus system at swing frequency, PSS effect can be considered as a supplemental damping coefficient [12].
Ref(13) also used theory based on right and left eigenvector the SPE (Sensitivity of PSS Effect) for selecting the best PSS locations.

The most popular method is using participation factors corresponding to speed deviations of generating units for initial screening of generating units on which to add stabilizer(2). However, a high participation factor is necessary, but not a sufficient, condition for PSS at the unit to effectively damp inter area oscillation. Following the initial screening based on participation factors, a more rigorous evaluation using residues and frequency responses should be carried out to determine appropriate locations for stabilizer (14).

In some countries PSS is mandatory for generating units with capacity more than certain MVA. In western part of USA , use of power system stabilizers is being mandated for all machines rated 35 MVA and above or groups of machines in a plant that total 75 MVA and above(6) .

3.5.1 Location of PSS in the power system of Ghana

There are only two plants in Ghana that are equipped with PSS. These stations are Akosombo Hydro Generating Station (1070MW) and Takoradi Thermal Generating Station (550MW). However since Akosombo GS generates more than 50% of the power in Ghana, it is believed that it is the best candidate as far as the activation of the PSS is concerned. This will be confirmed by carrying out dynamic simulation on the impact of PSS of the two locations on the dynamic performance of the system. The location that produces optimal damping on the modes of oscillation was selected.

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3.6 Tuning of PSS

In general tuning PSS consist of setting of control parameter and verifying the proper functionality of all aspects of the PSS equipment. This includes the compensating features, limits, and protections. PSS tuning has a significant influence on its effectiveness in providing the required damping (15). However if the PSS is not well tuned, it has the ability of introducing system instability. The main challenge of tuning is the determination of the appropriate stabilizer gain and time constants of the various functional blocks such as washout, phase compensation and etc to damp the critical mode of oscillations under different operating condition and thereby improving dynamic stability.

There has been considerable research in the area of PSS tuning. Some common PSS tuning techniques have been extensively discussed in the literature. Reference (16) discusses the pole placement method. This method provides a good graphical representation of the amount of damping that a particular controller contributes to each of the modes considered. However, it often results in parameters outside of practical ranges. In addition, the pole placement method becomes complex when dealing with oscillations associated with large systems and assigning poles in such situations can be a difficult task. The H_∞ method [17] is a well-known robust controller design method and it has been applied for PSS tuning. The difficulty associated with the choice of weighting functions often limits the application of this technique. Moreover, with this method, poorly damped pole-zero cancellations could be problematic [18]. Reference (19) describes a technique based on the state space feedback, which may be difficult to implement in some practical situations.

The predominant PSS tuning method used by the industry is a technique that combines the application of frequency response and gain margin (2). This method is simple in its principles, and it is capable of handling large system models and solving complex problems. Best of all, it has proven track records with many successful field applications [20]. Nevertheless, when dealing with different problems, the use of this method requires the considerations of various factors that may not be all clear to a practicing engineer. It is thus not uncommon that an engineer faced with the prospect of applying PSS to damp oscillations easily becomes overwhelmed by the information to be processed and the details in every step of the tuning process [21]. Moreover, working on an actual PSS application requires the familiarity with the utilities' production system models and advanced use of specialized analysis software tools.

All of these can make a PSS tuning task lengthy and sometime unable to achieve the optimal performance. There are a lot of on-going research do develop automatic tuning (23). This is because machine parameters change with loading, making the dynamic behaviour of the machine quite different at different operating conditions [24]–[26]. Consequently a set of power system stabilizer [PSS] parameters which stabilizes the system under a certain operating condition may no longer yield satisfactory results when there is a drastic change in the operating point.

For this thesis none of the above methods were used. Reference 31 makes recommendation for certain values of gain and time constant for proper operation of the PSS. Ranges of recommended values were used for stimulation until optimal results were obtained.

3.7 PSS modelling and Block diagram

Fig 3.6 shows the transfer function of the major functional blocks in a PSS. Power System Simulation for Engineering, PSSE the software used for the simulation in this thesis has a family of PSS models in its library. The one that best fit the two stations equipped with PSS is PSS2A.Therefore PSS2A was selected when modelling the PSS for the Akosombo GS and Takoradi GS. Fig 3.7 shows the functional block diagram for PSS2A and Table 4.21 describes the constant and its range of values.

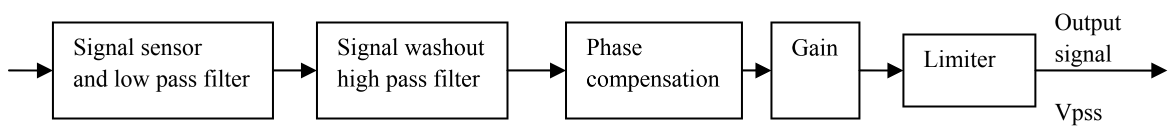

Fig 3.5 The major element of PSS

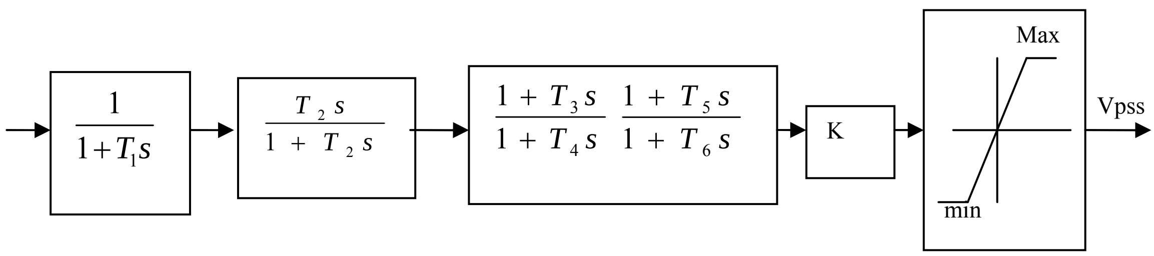

Fig 3.6.Transfer function of the major elements in PSS

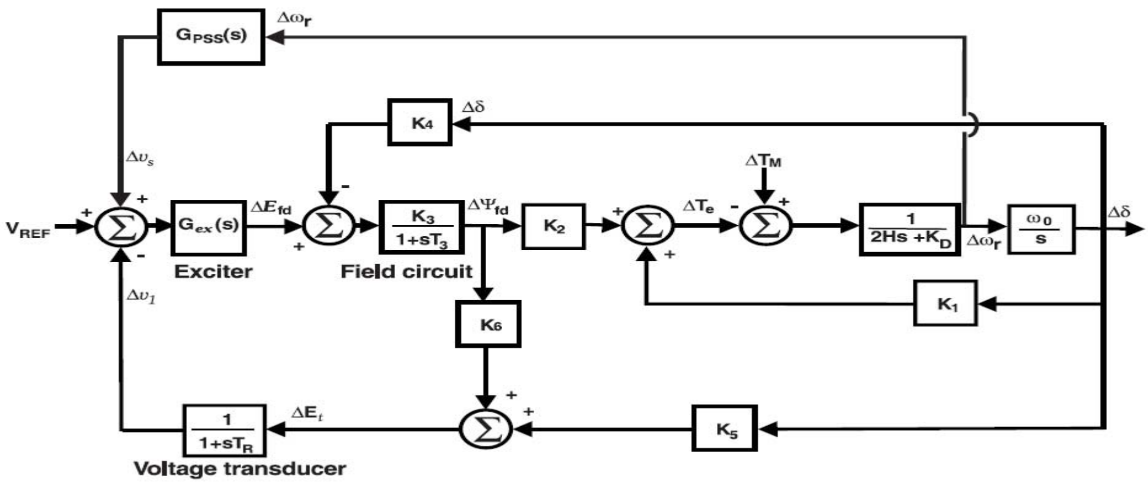

Fig 3.7 PSS with AVR, Exciter, and Generator

Stabilizer type PSS2A

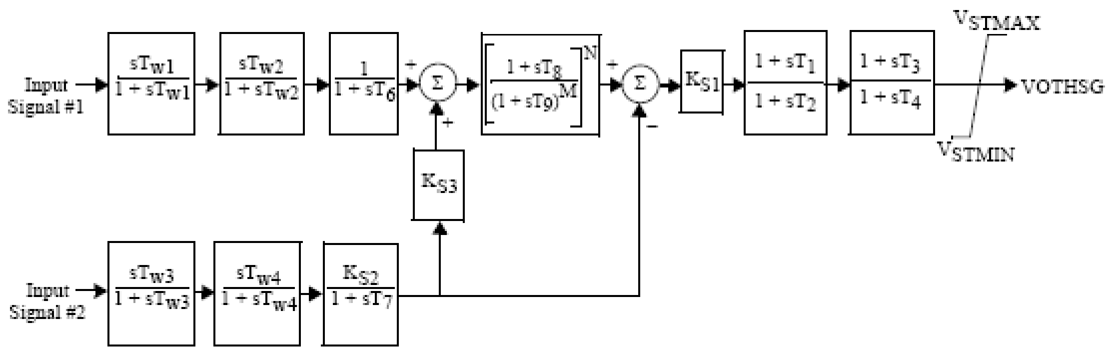

Fig 3.8 Transfer function block diagram for stabilizer type PSS2A(31)

CHAPTER FOUR

4.0 IMPROVING STABILITY OF GHANA'S POWER SYSTEM WITH POWER SYSTEM STABILISER (PSS)

4.1 Introduction

This chapter discusses the load flow results of five different base cases used in the steady state stability studies of the Ghana system. These included peak and average load conditions with and without transmission contingency. Results and observation made from steady state stability studies have been discussed in this chapter. Some measures to improve steady state operation have been highlighted. Transient stability studies were also performed using the five base cases described above. The results of transient stability studies which assessed the effect of activating the PSS on Akosombo and Aboadze generating units on system dynamic performance have also been discussed in this chapter.

4.2 Steady State Stability Studies

Steady state stability studies of Ghana's power system were carried out using Power System Simulator for Engineering PSSE. This is a software tool from Siemens Power Transmission and Distribution for power system simulation and analysis.

4.2.1 Generation Plants Availability

The following are the available generating sources for the VRA(Ghana) system

Table 4.1 Generating Plants Capacity

Plant	Type	No of Machine/MW	Total MW
Akosombo GS	Hydro	6 @145	870
Kpong GS	Hydro	4@35	140
Tema Thermal Plant	Thermal	100	100
Siemens Plant	Thermal	50	50
Mine Reserve Plant	Thermal	40	40
Aboadze Thermal Plant	Thermal	5@110	550
Osagyefo Power Barge	Thermal	110	110
Imports (from Cote d'Ivoire)		200	200

4.2.2 VRA System Demand

The following are the peak demand estimate for 2009 totalling 1554MW

Table 4.2 Ghana system peak demand

Costumer	Load(MW)
VALCO	140
ECG	997
NED	189
Mines	117
Others	30

4.2.3 System Load modelling

All loads were modelled on the high voltage (HV) side of the power transformers with an estimated power factor (pf) of 90%. However a power factor of 95% was also used to assess the impact of the reactive power compensation at the local level on steady state stability of Ghana's system.

The system peak period was estimated to cover a four hour period starting from 6pm to about 10pm. It has also been established that for the rest of the day, the system load is about 80% of the system peak.

The Average Day Load (ADL) was therefore modelled as;

100% of the peak load for big industrial company that have a 24hour operations

- VALCO – 100% of peak
- Mines - 100% of peak
- All other loads reduced till total load equals 80% of peak

4.2.4 Load flow cases for steady stability studies

The following load flow cases were used for the steady state stability studies of the VRA system

Case1: Peak load condition with no transmission contingency

Case 2: Peak load condition with Prestea-Obuasi contingency

Case 3: Average load condition with no transmission contingency

Case4: Average load condition with Konongo-Kumasi transmission contingency

Case5: Average load condition with Akosombo-Kumasi transmission contingency

4.2.5 Results and finding of steady state stability studies

4.2.5.1 Operating strategy for Case 1 and Case 2

These cases are typical peak load operating condition with and without transmission contingency. They show the 2009 system peak conditions with total system load estimated to be 1554MW. The generating units in service for this case are;

- Akosombo Plants – 6 Units, 145MW each: Total 870MW
- Kpong Plants – 4 Units , 35MW each: Total 140MW
- Aboadze T1-3 Units at 100MW each: Total 300MW
- Aboadze T2- 2 Units at 100MW each: Total 200MW
- Tema Plant TT1PP – 100MW total

This operating strategy was used based on the assumption that it is the most economical operation during peak

4.2.5.2 Findings of Case1 (Peak load condition with on transmission contingency)

- The Loading on the major lines were acceptable and found to be within limits. Some few lines were observed to have their loading above 50%. This included Takoradi-Tarkwa (70%), Prestea-Bogosu (69%) and Aboadze-Takoradi (54%). The operations of these major lines are crucial for the steady state stability of the system.

- Generally with a power factor of 0.9, the bus voltages were within acceptable limits (0.95-1.05pu). Voltages from Kumasi towards the northern part of Ghana were less than 0.95pu but not too low to cause voltage instability. However when the power factor was improved to 0.95 the system voltages improved considerably.

- The total system transmission losses were 64.7MW making 4.6% of the total power generated. Improving the power factor to 0.95 reduced the losses to 60.24MW.

- A contingency on most of the lines from Akosombo towards Kumasi line made the system steady state unstable. These lines included Akosombo-Kumasi, Nkwakwa-Tafo, Nkwakwa-Konogo, Konogo-Kumasi and etc. However with a PF of 0.95 the system was found to be steady state stable with any of the above contingency during peak load condition, but some few lines were found overloaded. Investment is therefore recommended for the improvement of power factor at the local level.

- After a number of branches were tested during the peak, at a power of 0.9, the following lines were observed to be critical and had serious effect on steady state stability.

  - ✓ Kumasi-Obuasi-line
  - ✓ Akosombo-Kumasi line
  - ✓ Prestea-Obuasi line
  - ✓ Aboadze-Cape Coast or Aboadze –Winneba

When operating the system with any of the above contingency during peak load condition, some loads may have to be shed to avoid partial or total voltage collapse.

4.2.5.3 Findings of Case2 (Peak load condition with Prestea-Obuasi contingency)

- Partial voltage collapse was observed from the central transmission network to the northern part of Ghana at a power factor of 90%. However by improving the power factor to 0.95 the system bus voltages improved considerably and found to be within acceptable range.

- Prestea-Bogoso line was found over loaded by 23% above its thermal rating at a power factor of 0.90. With a power factor of 0.95 the over loading of the line was reduced to 0.3%

- The total system transmission losses were 97MW which was 6.1% of the power generated.

- At a power factor of 0.9, the system could not withstand any further contingency on any of the critical lines without shedding load.

- There were very high reactive power generation from all the generating units compared with Case1 at the same power factor.

4.2.5.4 Summary of results : Case 1 and Case2

A summary of key substations voltages and line loadings are as tabulated as follows. The rest of the results can be found in the Appendix

Table 4.4 Summary of Key Substation Voltages

Bus Names	Voltages (pu)		Voltages (kV)	
	Case1	Case 2	Case1	Case 2
Akosombo	1.047	1.027	168.5	165.5
Volta	1.004	0.990	161.7	159.49
Aboadze	1.044	1.035	168.2	166.71
Kumasi	0.943	0.741	151.9	119.42
Prestea	0.999	0.967	160.8	155.68
Techiman	0.947	0.691	152.5	111.37
Tamale	0.930	0.576	148.9	92.84

Table 4.5 Summary of Power Outputs from Generators

Generating Station	Total Active Power(MW)		Total Reactive power(MVAr)	
	Case1	Case2	Case1	Case 2
Akosombo GS	813.4	841	372	513
Kpong GS	140	140	39.4	60
Aboadze GS	500	500	118.5	170
Tema TT1PP	100	100	15.3	15.3

Table 4.6 Summary of Major Line Loadings

Lines	Loading (MVA)		Percentage Loading (%)	
	Case1	Case2	Case1	Case 2
Aboadze – Cape Coast	77.4	88.6	44	50
Akosombo - Kumasi	126.2	170	33	45
Prestea - Bogosu	116.2	201.6	68	123
Prestea- Obuasi	89.7	0	26	0
Achimota - Mallam	46.3	38.6	26	23
Achimota-Winneba	50.9	62.5	31	38
Kumasi – Techiman	58.9	83.1	34	45
Aboadze – Prestea	169.5	160	45	42
Aboadze – Takoradi	97.4	95	55	54
Takoradi – Tarkwa	132.2	132.1	78	77
Kumasi -Obuasi	96.6	108.4	60	64

Table 4.7 Summary of Generators Total Reactive Power(MVAr)

Generating Station	Case1		Case 2	
	Pf 90	Pf 95	Pf 90	Pf 95
Akosombo GS	372	224.74	513	327.24
Kpong GS	39.4	12.00	60	32.6
Aboadze GS	118.5	24.78	170	65.08
Tema TT1PP	15.3	0	15.3	2.57

Table 4.8 Summary of Key Substation Voltages at power factors of 0.9 and 0.95

Bus Names	Case1(KV)		Case2(KV)	
	Pf 90	**Pf 95**	**Pf 90**	**Pf95**
Akosombo	168.5	171.3	165.5	169.5
Volta	161.7	165.7	159.49	162.4
Aboadze	168.2	170.3	166.71	169.5
Kumasi	151.9	167.4	119.42	162.3
Prestea	160.8	167.3	155.68	165.3
Techiman	152.5	171.3	111.37	166.9
Tamale	148.9	175.5	92.84	170.2

Table 4.9 Summary of system losses at different power factors

	Case1		Case 2	
Power factor	0.9	0.95	0.9	0.95
Losses(MW)	64.7	60.24	97	68.75

4.2.5.5 Operating Strategy for Case 3 and case 4

These cases represent 2009 system average load conditions with total a system load of 1178MW representing about 80% of peak load conditions. Case3 represents a normal average load without any transmission contingency but Case 4 has a single transmission contingency. The generating units in service used for these cases are as follows:

- Akosombo Plants – 4 Units, 145MW each
- Kpong Plants – 4 Units , 35MW each
- Aboadze T1-3 Units at 100MW each
- Aboadze T2- 2 Units at 100MW each
- TT1PP – 100MW

4.2.5.6 Findings of Case3 (Average load condition with no transmission contingency)

- The bus voltages and branch currents were acceptable and found to be within limits. Some few lines were observed to have their loading above 50%. This included Takoradi-Tarkwa (72%), Prestea-Bogosu (64%) and Kumasi-Obuasi (55%).

- The total system transmission losses were reduced to 48.17MW, representing 3.6% of total generation compared to Case 1.

- The system was found to be steady state stable even after a single line contingency of critical lines. However this contingency made some of the critical lines overloaded by 10-60% of its thermal rating and in addition a partial voltage collapse was observed from the central transmission network to the northern part of Ghana.

- The reactive power generation by the generation units were found to be within limits.

4.2.5.7 Finding of Case 4 (Average load condition with Konongo-Kumasi transmission contingency)

- Most bus voltages and branch currents were acceptable and found to be within limits. There were generally a small increase in the line current and a small reduction in the bus voltages as compared to Case 3.

- The total system transmission losses increased to 53.4MW making 4.05% of total generation compared with Case 3.

- A small increase in the reactive power generation by the generation units was observed.

4.2.5.8 Summary of Results, Case 3 and Case4

A summary of key substations voltages and line loadings are as tabulated as follows. The rest of the results can be found in the Appendix.

Table 4.10 Summary of Key Substation Voltages Case 3 and Case 4

Bus Names	**Voltages (pu)**		**Voltages (kV)**	
	Case3	**Case 4**	**Case3**	**Case 4**
Akosombo	1.046	1.038	168.3	167.12
Volta	1.012	1.001	162.9	161.22
Aboadze	1.052	1.045	169.3	168.21
Kumasi	0.9907	0.948	159.9	152.56
Prestea	1.0143	1.001	164.3	161.12
Techiman	1.009	0.961	162.5	154.64
Tamale	1.025	0.953	165.0	153.39

Table 4.11 Summary of power outputs from Generators for Cases3 and 4

Generating Station	**Total Active Power(MW)**		**Total Reactive power(MVAr)**	
	Case3	**Case4**	**Case3**	**Case 4**
Akosombo GS	577	583	254.8	271
Kpong GS	140	140	37	40
Aboadze GS	500	500	71	95
Tema TT1PP	100	100	-6.1	0.22

Table 4.12 Summary of system losses for Cases 3 and 4

	Case3		Case 4	
Power factor	MW	%	MW	%
Losses(MW)	**48.17**	**3.6%**	**53.4**	**4.05**

Table 4.13 Summary of Major Line Loadings

Lines	**Loading (MVA)**		**Percentage Loading (%)**	
	Case3	**Case4**	**Case3**	**Case 4**
Aboadze – Cape Coast	83.9	78.6	48	44
Akosombo - Kumasi	91.3	123	24	32
Prestea – Bogosu	111.1	118	64	69
Prestea- Obuasi	94.2	103.6	25	46
Achimota – Mallam	18.8	22.6	11	13
Achimota-Winneba	67.2	59.5	40	35
Kumasi – Techiman	55.4	51.8	31	30
Aboadze – Prestea	161.6	170.1	42	45
Aboadze – Takoradi	87.0	90.9	49	51
Takoradi – Tarkwa	128.1	135.6	72	77
Kumasi –Obuasi	92.1	123.1	55	78

4.2.5.9 Operating Strategy for Case 5

Case5 is a normal average load with Kumasi-Akosombo contingency. The generating units in service are the same as in Cases 3 and 4

4.2.5.10 Findings of Case 5

- A partial voltage collapse was observed from the central transmission network to the northern part of Ghana.
- Obuasi-Kumasi line was found over loaded by 23% above its thermal rating. Some few lines were found loaded above 80%. These included ,Akosombo-Tafo, Takoradi-Tarkwa, Kumasi-Konongo , Prestea-Bogoso line
- The total system transmission losses were 88.21MW equal to 6.5% of the power generated, higher than Cases 3 and 4
- Heavy reactive power generation were observed on all the generating units, especially from Akosombo generating units compared to Case 3 and Case 4.

4.2.5.11 Summary of Results, Case 5

Table 4.14 Summary of Key Substation Voltages

Bus Names	Voltages (pu)	Voltages (kV)
Akosombo	1.026	165.2
Volta	0.997	161.1
Aboadze	1.030	165.8
Kumasi	0.676	108.9
Prestea	0.930	149.7
Techiman	0.633	101.4
Tamale	0.548	88.2

Table 4.15 Summary of Some Line Loadings

Bus Names	**Loading (MVA)**	**Percentage Loading (%)**
Akosombo – Tafo	160	87.9
Takoradi – Tarkwa	142	83.7
Prestea – Bogosu	150	88.3
Obuasi-Kumasi	209	123.1
Kumas-Konongo	149	87.8
Nkwakwa-Tafo	164.3	96.7
Nkwakwa – Konongo	154	90.7

Table 4.16 Summary of Power Outputs from Generators

Generating Station	**Total Active Power(MW)**	**Total Reactive Power(MVAr)**
Akosombo GS	609	355
Kpong GS	140	58
Aboadze GS	500	203
Tema TT1PP	100	33

4.2.6 Discussions on Steady State Stability

VRA system from the steady state stability studies operates with a very low steady state stability margin during the peak period. This is because there is a very high risk of voltage collapse during N-1 contingency especially on any of the critical line. A transmission outage reduces the lines contribution to system reactive power requirement thereby increasing the reactive power demand on the generators. This increases system voltage drop, line losses and the lines ability to produces reactive power is further reduced, making system vulnerable to voltage collapse. However, the risk of voltage collapse can be reduced considerably by improving the steady state stability operation using power factor correction devices to improve the power factor to 0.95 at the local level.

By improving the power factor at the local level, system voltages are improved, line loses are reduced, reactive power generation from generating stations are reduced and line current are also reduced. Capacitor banks are one of the cheapest means of providing reactive power at the substation stations. Capacitor banks can be used and switched in and out at different capacities when it becomes necessary. Determination of the correct reactive power compensation at the various bus is beyond the scope of this study and was therefore not considered. Consequently investment in reactive power compensation devices is highly recommended at the local substation for improving system steady state stability margin. The reduction in losses, coupled with the improvement in steady state stability could be used as justification for any investment in the power factor correction devices at the local level.

With the Ghana system operating with a very low steady state stability margin, reviewing line over current relays settings to delay tripping during overload conditions will improve stability considerably. This is because there is a very high probability of overload on some critical lines during peak load condition following N-1 contingency. This delay, will give the system operators' time to carryout manual loading shedding to prevent a sudden and wide spread voltage collapse.

The possibility of installing under voltage load shedding should be considered in addition to the existing under frequency loading shedding.

The construction of new transmission line along the coast of Ghana as part of the West African Power Pool Project to be operated at 330KV will have a significant improvement in the steady state stability of the VRA system and should be pursue vigorously.

4.3 Transient Stability Studies

4.3.1 Modelling of the dynamic System of Ghana

Power System Simulator for Engineering (PSSE) was used for this study. PSSE library has a family of generator, exciter and governor models and some of these models were used in modelling VRA dynamic system. The following models were selected from the PSSE library based on the recommendation made in the PSSE manual based on equipment type and manufacturer. The selected model also fits the dynamic behaviour of the various units. The model parameter settings used in the modelling can be found in the appendix.

Table 4.17 Selected Generator Models for the VRA Generating Units

Station	Units	Manufacturer/Type	Model used in PSS/E	Reasons(31)
Kpong GS	1,2,3&4	Toshiba/salient pole rotor	GENSAL	This model is used for salient pole generators for hydro power plants
Aboadze GS	1,2,3,4,5	GE CAD/round rotor	GENROU	This model is used for round rotor generators in thermal plants
Akosombo GS	1,2,3,4,5,6	GE power system/salient pole rotor	GENSAL	This model is used for salient pole generator for hydro power plants
Tema GS	1	GE power system/round rotor	GENROU	This model is used for round rotor generators in thermal plants

Table 4.18 Selected Exciter model for VRA generating units

Station	Units	Manufacturer/type	Model used in PSS/E	Reasons(31)
Kpong GS	1,2,3&4	Toshiba/ Static bus fed	EXST1	This is used to represent static exciter systems manufactured by Toshiba
Aboadze GS	1,2,3,4,5	GE power system/EX2000 Busfed	ESST4B	This is used to represent static systems with both potential and compound source rectifier excitation. Recommended for GE

				static exciters
Akosombo GS	1,2,3,4,5,6	General Electric/Silco 5	ESST4B	This is used to represent static systems with both potential and compound source rectifier excitation. Recommended for GE static exciters
Tema GS	1	GE power system/EX2000 Busfed	ESST4B	Recommended for GE static exciters

Table 4.19 Selected Governor models for VRA generating units

Station	Units	Manufacturer/type	Model used in PSS/E	Reasons(31)
Kpong	1,2,3&4	ASEA/ KK831-125E (Electro-hydraulic governor)	PIDGOV	This is a recommended model for electro-hydraulic governors in hydro plants with gate position or electrical power as feedback signal.
Takoradi	1-2 & 4-5	Gas turbine	GAST	This model is used for gas turbines with speed deviation approximately ±5%
	3	Steam turbine	IEEEG1	This is the IEEE recommended general model for steam turbine speed governing system
Akosombo	1-6	VOEST-ALPINE /EKR 89 (Electro-hydraulic governor)	PIDGOV	This is the recommended model for electro-hydraulic governors in hydro plants with gate position or electrical power as feedback signal.
Tema	1	Gas turbine	GAST	This is model is used for gas turbines with speed deviation approximately ±5%

Photo 4.1: Front view of 160MW Kong Generating Station, downstream on the Volta Lake in Ghana

Photo 4.2: Static electronic exciter of Kpong Generating Station manufactured by Toshiba. This exciter is not equipped with PSS

Photo 4.3 :Electro-hydraulic governor of Kpong GS manufactured by Asea.

4.3.1.1 Stabiliser Model

The excitation system of two generating stations, Akosombo and Aboadze are equipped with stabilisers. The PSSE manual recommends a stabilizer model PSS2A for GE static exciters. This is a dual input stabilizer using speed deviation and electrical power as input. PSS2A was therefore selected during stabiliser modelling. The functional block diagram of PSS2A is shown in fig 4.5.

Table 4.20 Selected Stabilizer model for VRA generating units

Station	Units	Manufacturer/type	PSSE stabiliser model used	Comment
Kpong GS	1,2,3&4	Toshiba/ Static bus fed	None	This is electronic analog exciter which is not equipped with PSS
Aboadze GS	1,2,3,4,5	GE power system/EX2000 Busfed	PSS2A	This is digital exciter equipped with PSS.
Akosombo GS	1,2,3,4,5,6	General Electric/Silco 5	PSS2A	This is digital exciter equipped with PSS.
Tema GS	1	GE power system/EX2000 Busfed	None	Do not have information whether is equipped with PSS

4.3.1.1 Selection of Stabiliser location

As earlier mentioned there are only two power plants in Ghana that are equipped with PSS. These stations are Akosombo Hydro Generating Station (1070MW) and Takoradi Thermal Generating Station (TTPS, Aboadze, 550MW). However since Akosombo GS generates more than 50% of the power in Ghana and the generator rotors have very high inertia, it is believed that it is the best candidate as far as the activation of the PSS is concerned. Simulation results in fig 4.a shows that PSS at TTPS contributes very little in damping system oscillations. However PSS at Akosombo GS effectively damped oscillation and therefore the study will only look at the impact of activation the PSS at Akosombo on system dynamic performance .The rest of the stimulation results on the best location of PSS can be found in the appendix.

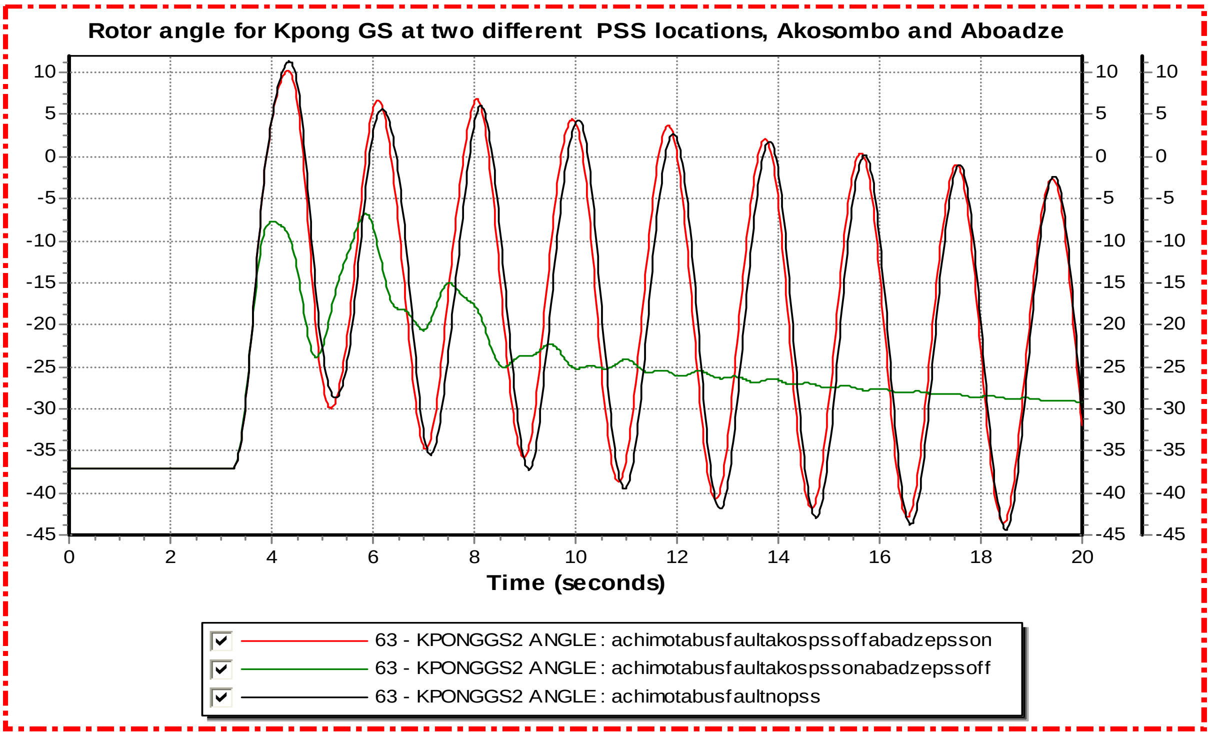

Fig4a Kpong GS rotor angle behaviour following a three phase bus fault at Achimota lasting 5cycles with PSS at two different location, (Akosombo and Aboadze) and no PSS at any station.

Graphical Legend interpretation

Throughout the graphical results for the transient studies the legends used, first indicates the parameter or quantity being monitored, the bus where the fault occurred and whether the PSS is activated indicated as 'psson' or PSS is not activated as 'pssoff'. Also information on the gain is also added to the legend. However if gain is not added to the legend, it is then assumed to be 25.

4.3.2 Tuning of PSS and selection of stabiliser gain at Akosombo

This section discusses how the stabiliser gain was selected to achieve optimal dynamic performance of the VRA system. The value of the gain selected was tested at different operating conditions particularly peak and average load conditions with no transmission contingency using seven different fault conditions. The same test was performed on the system under stressed condition caused by a line outage of some critical lines during peak and average load condition. The selected value of the stabiliser gain that gave the best damping of all oscillations due to small signal and transient disturbance under the different operation condition was considered as optimal.

Five different values of stabilizer gain selected based on standard recommended values are 10, 20 ,25 , 30 and 40.The performance of the stabiliser depends significantly on the gain. The other parameters of the PSS were selected based on standard industrial recommended values obtained from PSSE manual. After series of simulation to obtain the best gain for the PSS, the responses of some system quantities or parameters at different gains are shown figure 4.1 to figure 4.4.

4.3.2.1 Analysis of Stabiliser gain simulation results

From the simulation results in fig 4.1-4.3, it is obvious that a stabilizer gain of 30 and 40 make the post fault conditions quite unstable. The bus voltage at Akosombo GS oscillates beyond the 0.95 to 1.15pu which is worse than the system without PSS. Also the power and speed deviation of the same unit indicated in fig 4.2 and 4.3 are poorly damped. A PSS gain of 10 is not able to damp the oscillation effectively. The best gain for the stabilizer to effectively damp post fault oscillation is between 20 -25. However further simulation shows in fig 4.4 that a stabilizer gain of 25 is more effective than a gain of 20 because it gives a better and smoother damping. Based on these results a stabiliser gain of 25 was used throughout the simulation.

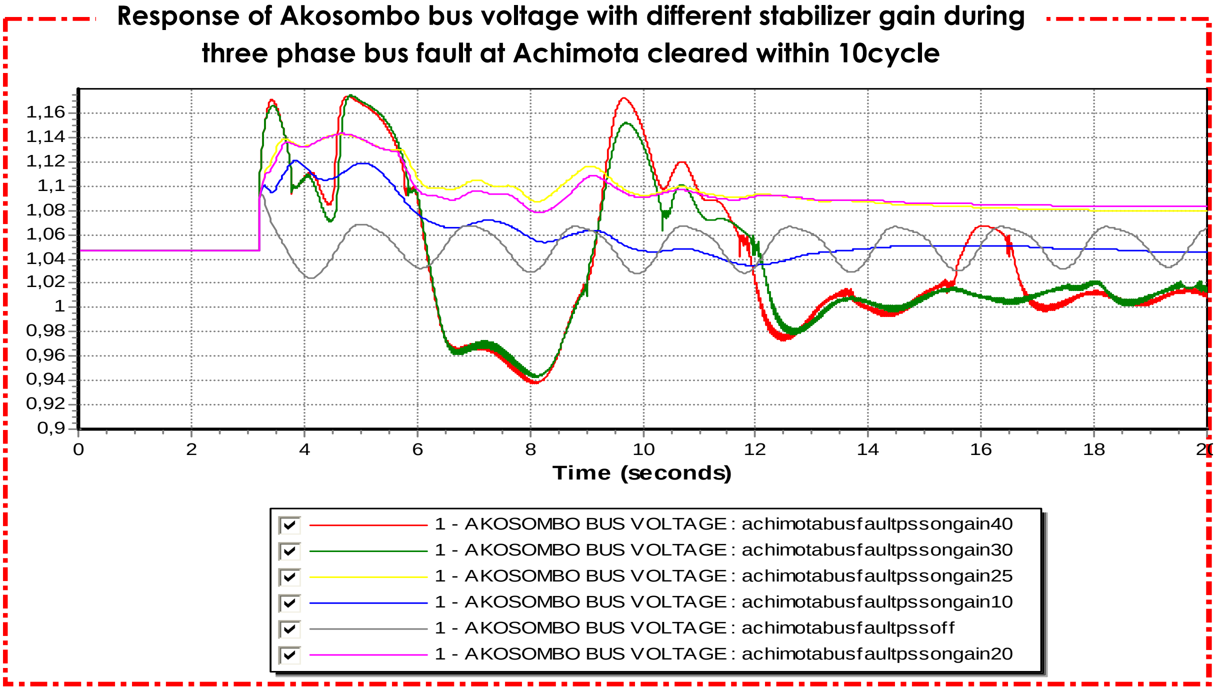

Fig 4.1. Behaviour of Akosombo bus voltage for different stabilizer gain during a three phase bus fault lasting for 5cycle

Responses of Akosombo unit1 power output for different values of stabilizer gain during three phase fault at Achimota cleared within 10cycles

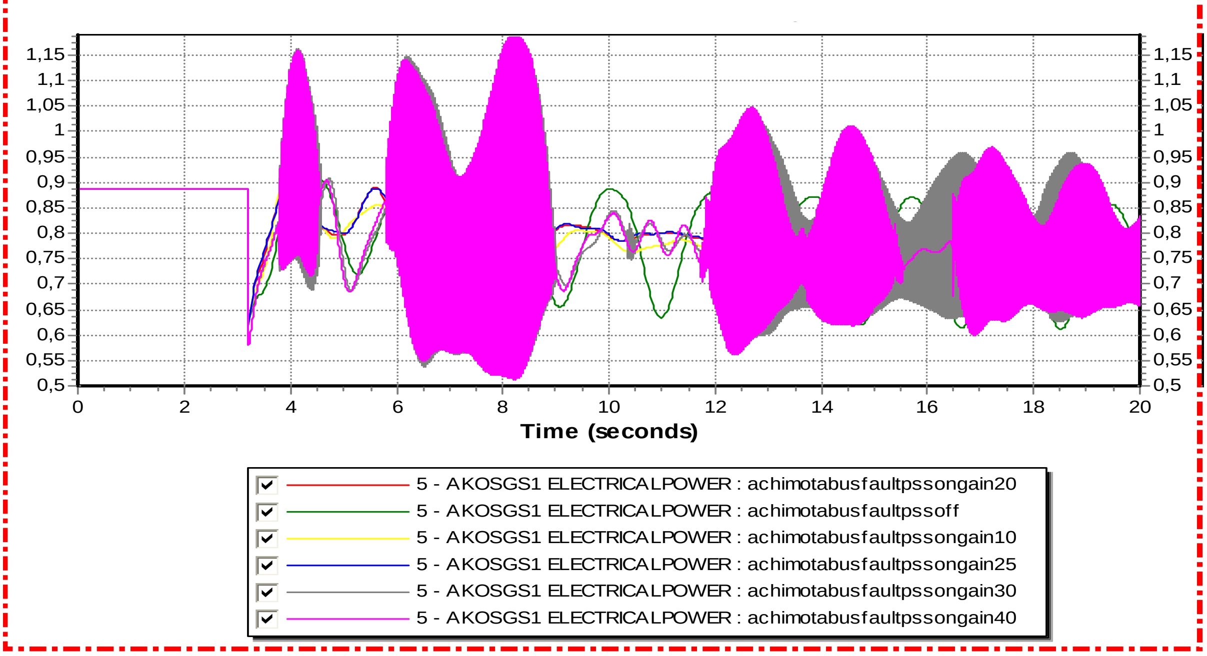

Fig 4.2 Akosombo Unit 1 electrical power output for different stabilizer gain during a three phase bus fault at Achimota lasting for 5 cycles

Speed deviation of Akosombo unit for different values of stabilizer gain during three phase bus fault at Achimota, cleared within 10cycles

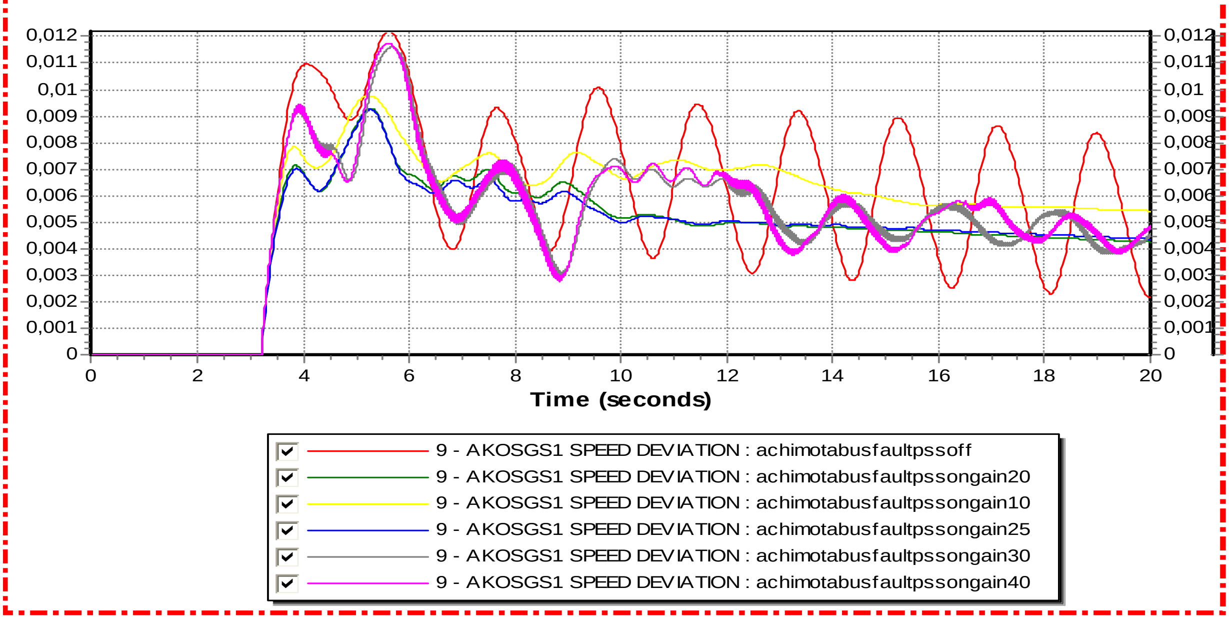

Fig 4.3 Speed deviation in pu of Akosombo GS unit1 for different stabilizer gain during a three phase bus fault at Achimota lasting for 5cycles.

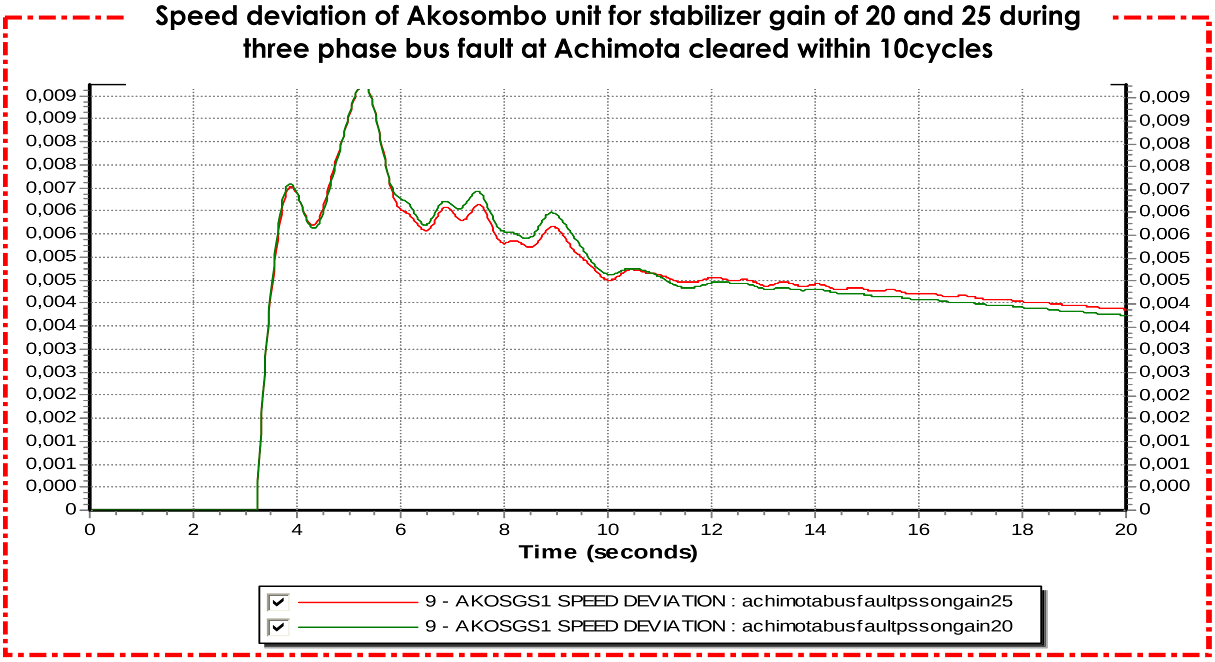

Fig 4.4 Speed deviation in pu of Akosombo unit1 for a stabilizer gain of 20 and 25 during a three phase bus fault at Achimota lasting for 5cycles

Stabilizer type PSS2A

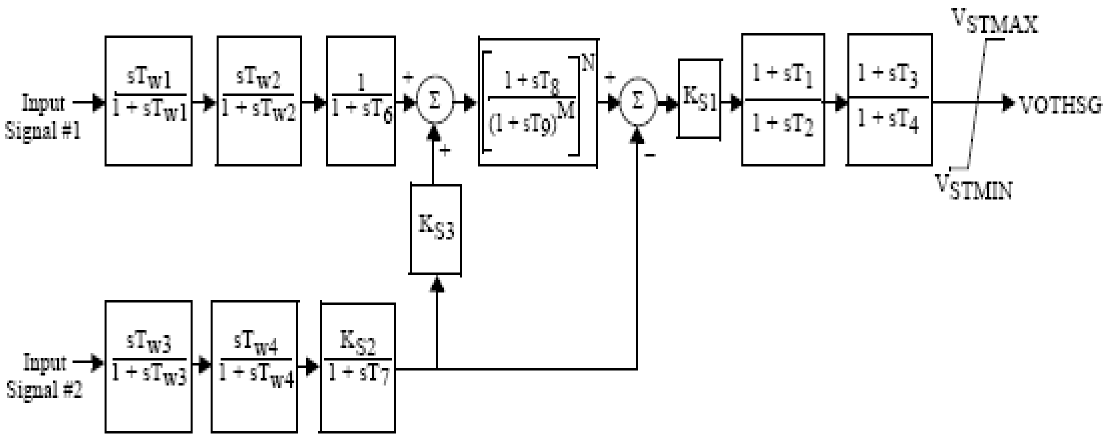

Fig 4.5 Transfer function block diagram for stabilizer type PSS2A(31)

Table 4.21 Selected values for PSS parameters used in the simulation (31)

No	symbol	Description	Selected values	Range of recommended Values
1	Tw1(>0)	Washout time constant -signal 1	10	1.5<Tw1<15
2	Tw2	Washout time constant -signal 1	10	1.5<Tw2<15
3	T6	Lag time constant –signal 1	0.035	2XDelta<T6
4	Tw3(>0)	Washout time constant -signal 2	10	1.5<Tw3<15
5	Tw4	Washout time constant -signal 2	2	1.5<Tw4<15
6	T7	Lag time constant –signal 2	10	2XDelta<T7
7	Ks2	Gain-signal 2	0.064	
8	Ks3	Gain-signal 2	1.00	
9	T8	Ramp tracking filter lead time constant	0.5	2XDelta<T8≤2
10	T9(>0)	Ramp tracking filter lead time constant	0.1	2XDelta<T9≤2
11	Ks1	Stabilizer gain	25	
12	T1	Lead time constant-phase comp block1	0.15	2XDelta<T1≤2
13	T2	Lead time constant-phase comp block1	0.02	2XDelta≤T2≤6
14	T3	Lead time constant-phase comp block2	0.15	2XDelta<T3≤2
15	T4	Lead time constant-phase comp block1	0.025	2XDelta≤T4≤6
16	VSTMAX	Stabilizer output maximum	0.1	0.<VSTMAX<0.99
17	VSTMIN	Stabilizer output minimum	-0.1	-0.3<VSTMIN≤0
18	M	Ramp tracking filter	5	MxN≤8
19	N	Ramp tracking filter	1	MXN≤8
20	Input sig #1	Rotor speed deviation(pu)		
21	Input sig#2	Generator electrical power (PU)		
22	Delta	Integration step	0.01	<0.1

Photo 4.4 :Overview of Akosombo Generating Station with generating units equipped with PSS

Photo 4.5: Silco 5 static excitation System from GE for Akosombo generating units equipped with PSS

Photo 4.6: Master card of Akosombo exciter with PSS circuitry having dual input, speed and electrical power

4.3.3 Results -Effect of PSS on Transient Stability Simulation

This section discusses the simulation results of transient stability before and after the application of PSS on Akosombo Generating Units for Volta River Authority System (VRA). Five different steady state operating conditions Cases1 to Case 5 were subjected to the following transient disturbance.

- A three phase bus fault at Kumasi 161KV Substation, cleared within 10cyle by isolating the bus from the system.
- A three phase bus fault at Achimota 161KV Substation cleared within 10cycles by isolating the bus from the system.
- A three phase bus fault at Takoradi 161KV substation, cleared within 10cycles by isolating the bus from the system.
- A three phase bus fault at Prestea 225KV substation, cleared within 10cycle by isolating the bus from the system.
- One generator operating at 145MW tripped at Akosombo Generating station.
- One generator operating at 35MW tripped at Kpong Generating station.
- One generator operating at 100MW tripped at Aboadze Generating Station.

The behaviours of system operating parameters like generator speed deviation, power flow, line loading, bus voltages, generator rotor angles and etc, before and after the application of PSS at Akosombo GS were analysed. The analysis was done to assess the effectiveness of PSS at Akosombo GS in damping oscillation resulting from transient disturbance.

4.3.3.1 Case 1: Normal Peak load condition with no contingency

Findings of Case1 (a)

(a) A three phase bus fault at Kumasi 161KV Substation, cleared within 10cyle by isolating the Kumasi bus

For Case1, a three phase bus fault at Kumasi 161KV bus cleared in 100ms by isolating the bus caused severe oscillations in the system. The oscillations were participated by all the running units as observed from fig 4.4-4.8 and continued for more than 17sec after the fault was cleared. However from the simulation results the oscillation was damped completely, 7sec after the disturbance when PSS on Akosombo units were activated. This clearly shows that the activation of PSS at Akosombo GS will greatly improve transient stability as it is capable of damping effectively system oscillation trigged by faults.

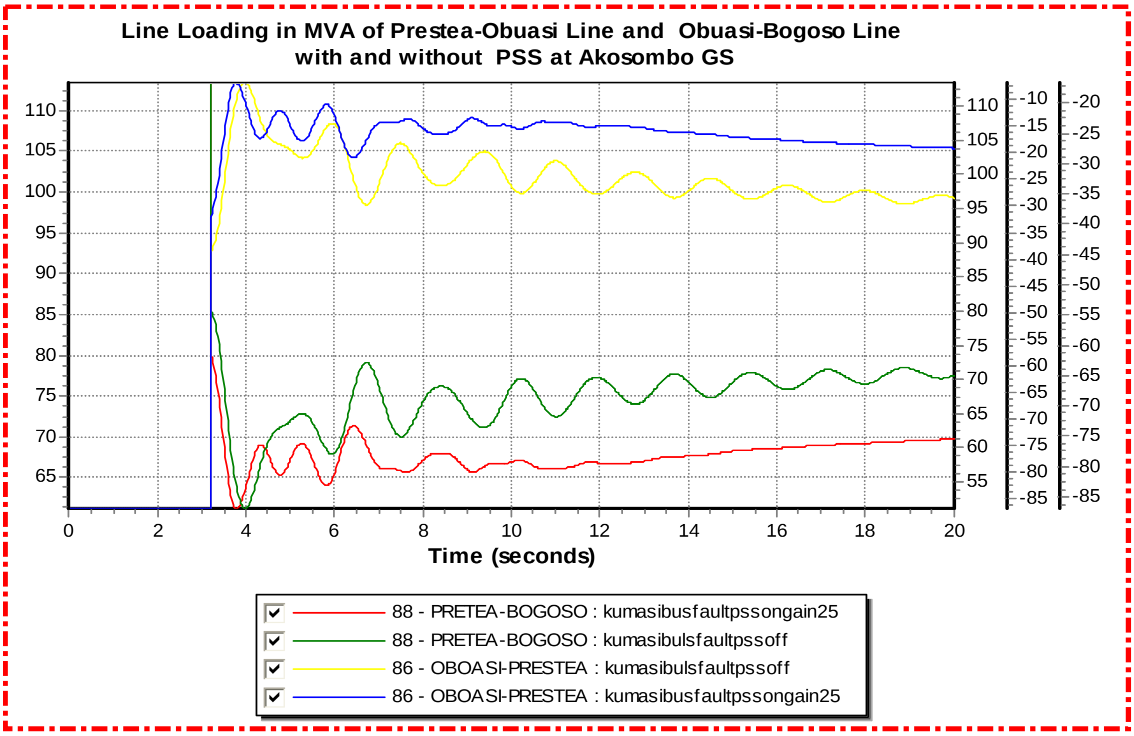

Fig 4.5 Loading in MVA of Prestea-Obuasi and Obuasi-Bogoso lines with and without PSS at Akosombo GS during a three phase bus fault at Kumasi lasting 100ms

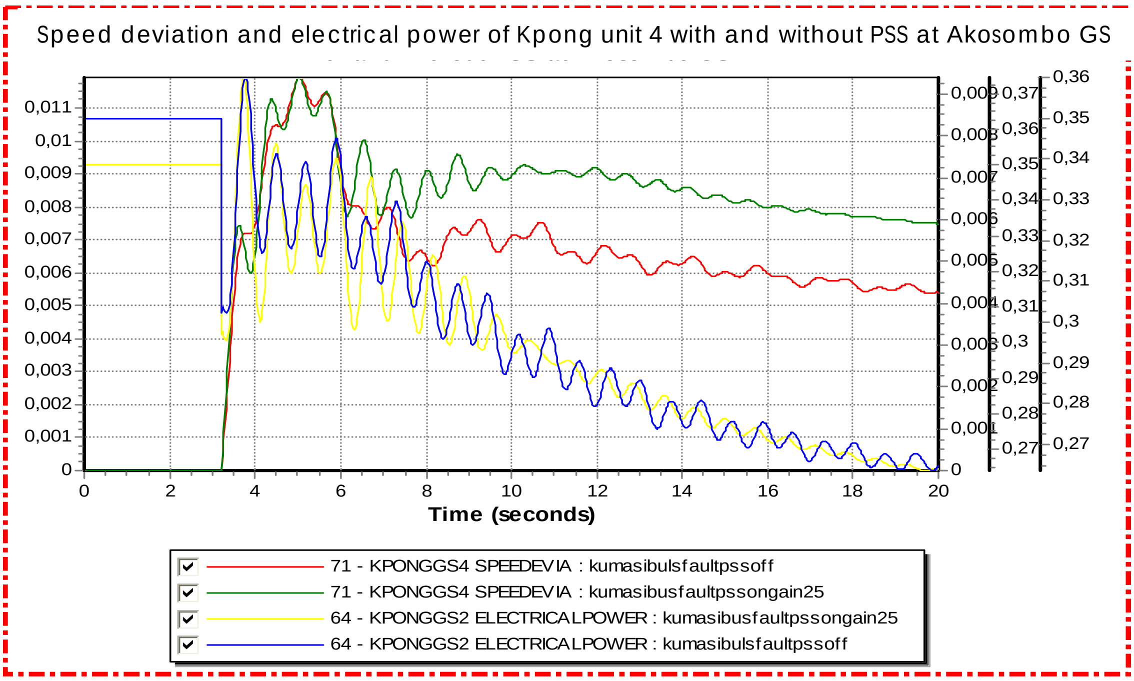

Fig4.6 Kpong GS unit 4 speed deviation(pu) and electrical power (pu) with and without PSS at Akosombo GS for a three phase bus fault at Kumasi lasting 100ms

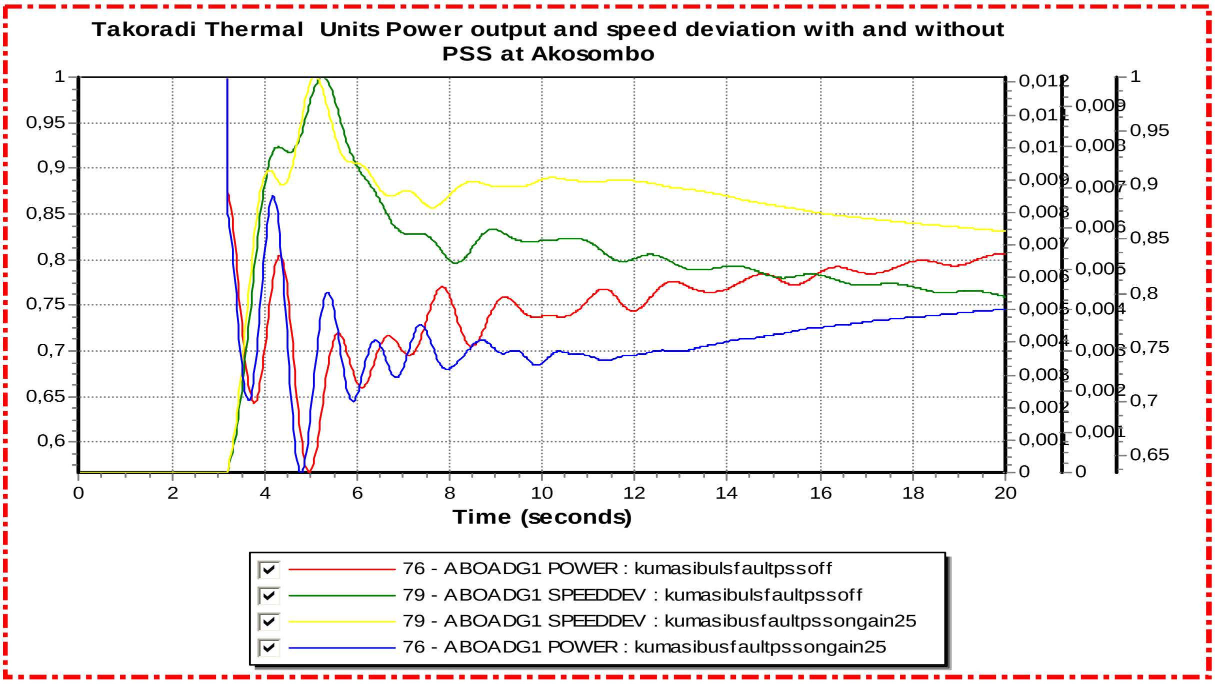

Fig 4.7 Takoradi(Aboadze) unit 1 power output(pu) and speed deviation(pu) with and without PSS at Akosombo GS following a three phase bus fault at Kumasi lasting 100ms

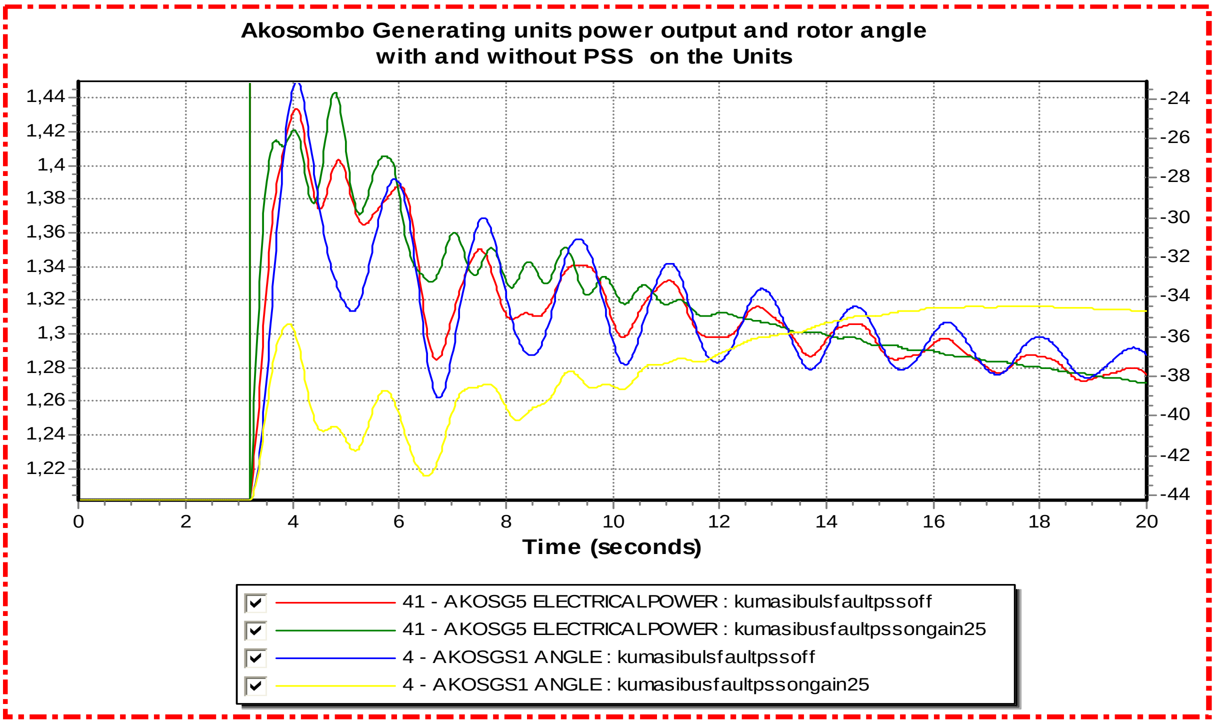

Fig 4.8 Electrical power and rotor angle of Akosombo units with and without PSS following a three phase bus fault at Kumasi lasting 100ms

Findings of Case1 (b)

(b) A three phase bus fault at Achimota 161KV Substation ,cleared within 10cycles by isolating Achimota 161KV bus

A three phase bus fault at Achimota substation, cleared within 100ms had severe impact on the system. This is because in addition to high fault current, about 300MW of load was dropped in clearing the fault. The system continued to oscillate with considerable amplitude 17sec after the fault was cleared. Oscillations were observed on the line loading, generator terminal and excitation voltages and generator power outputs. These oscillations were poorly damped and some even observed to be increasing in amplitude like Kumasi-Akosombo line loading. However after the application of the PSS, almost all the oscillations were damped 9seconds after the fault was cleared showing the effectiveness of PSS at Akosombo in improving system dynamic performance.

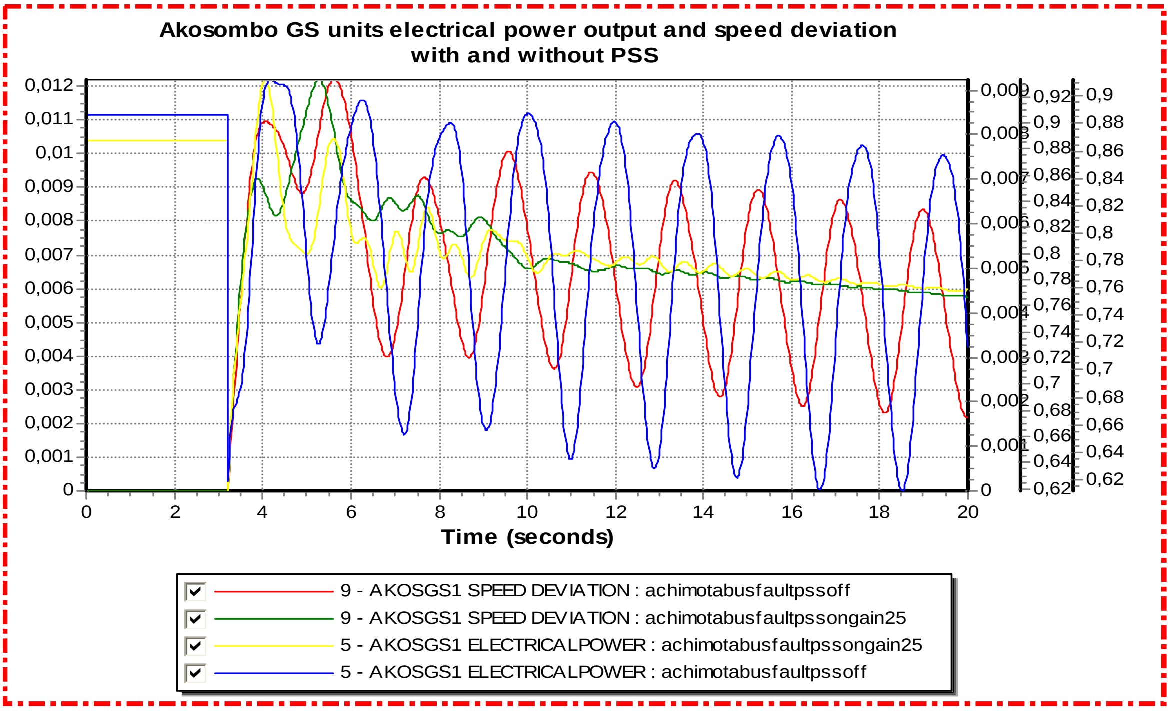

Fig 4.9 Akosombo GS unit 1 speed deviation and electrical power with and without PSS following a three phase bus fault at Achimota lasting 100ms

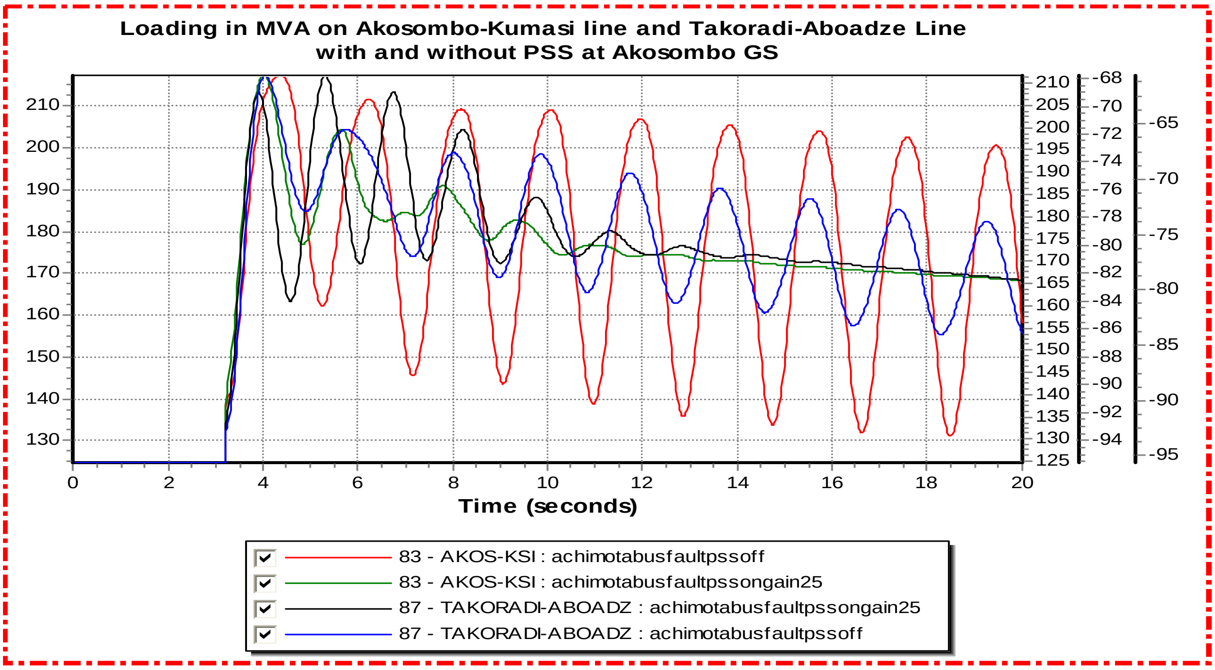

Fig 4.10 Loading in MVA on Akosombo-Kumasi and Takoradi Aboadze lines with and without PSS, following a three phase bus fault at Achimota lasting 100ms

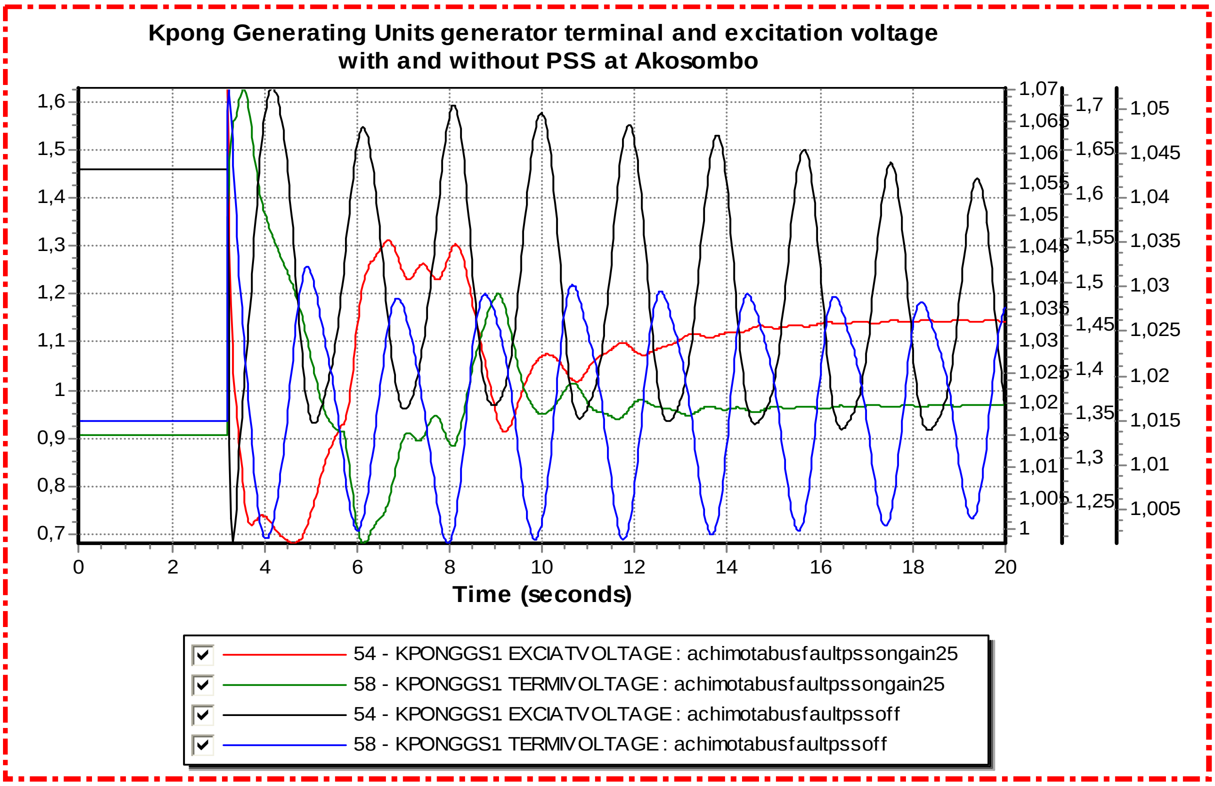

Fig4.11 Kpong GS unit 1 terminal and excitation voltages with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

.**Findings of case 1(c)**

(c***) One generator operating at 145MW tripped at Akosombo***

With a disturbance caused by a unit trip at Akosombo, oscillations were observed in almost all the system parameters monitored. The severity of this disturbance on the system was quite less compared with a bus fault at Kumasi and Achimota. With the PSS activated at Akosombo GS the damping in the oscillations improved considerably. With the PSS activated, most of the oscillations were damped completely 9seconds after the unit tripped. These results demonstrate the positive impact of activating PSS at Akosombo for a case of this nature.

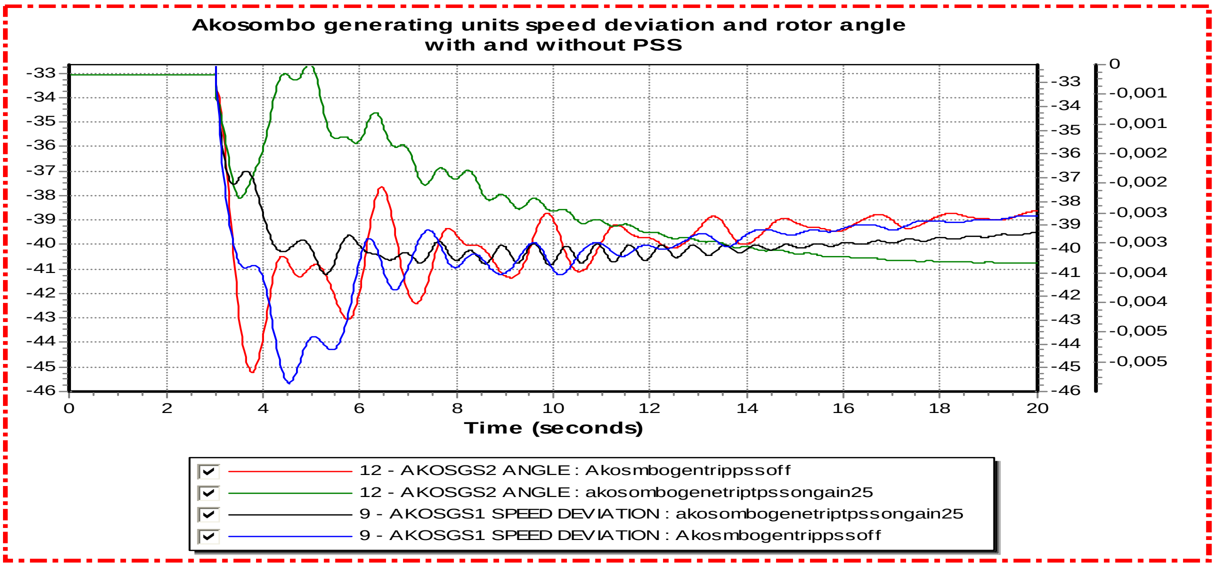

Fig 4.12. Akosombo units speed deviation and rotor angle with and without PSS following a unit trip at Akosombo GS

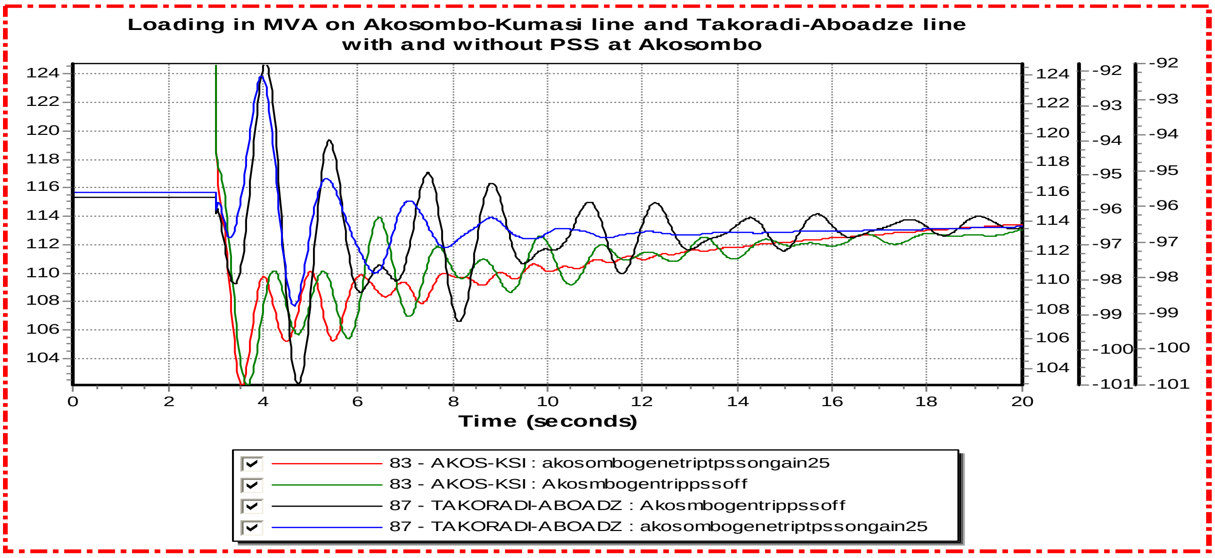

Fig 4.13. Loading in MVA on Akosombo-Kumasi and Takoradi-Aboadze lines with and without PSS following a unit trip at Akosombo GS

4.3.3.2 Case 2: Stressed Peak load condition (Prestea-Obuasi contingency)

Findings of Case 2(a)

(a)A three phase bus fault at Achimota 161KV Substation, cleared within 10cycles by isolating Achimota 161KV bus

The simulation results clearly show that PSS at Akosombo GS can prevent a partial system collapse. In the case under consideration, the system was operating under stressed condition, very close to its stability limit. Without a PSS at Akosombo, a three phase bus fault at Achimota 161kv lasting 100ms, tripped all Akosombo and Akuse generating units as shown in fig 4.14 , fig 4.15 and fig 4.19 causing a partial system collapse. However all the generating units at Takoradi Thermal Power station (Aboadze Station) continued to operate after the disturbance as shown in fig 4.16 and fig4.19.This means that the system got separated into two, the western part which did not experience a collapse and the rest of the system which collapsed. Fig 4.14, fig4.15, fig4.18 and fig 4.19 show that the activation of PSS at Akosombo GS clearly prevented the tripping of Akosombo and Kpong generating units avoiding a partial system collapse. These results show that PSS at Akosombo GS will significantly improve transient stability of the VRA system.

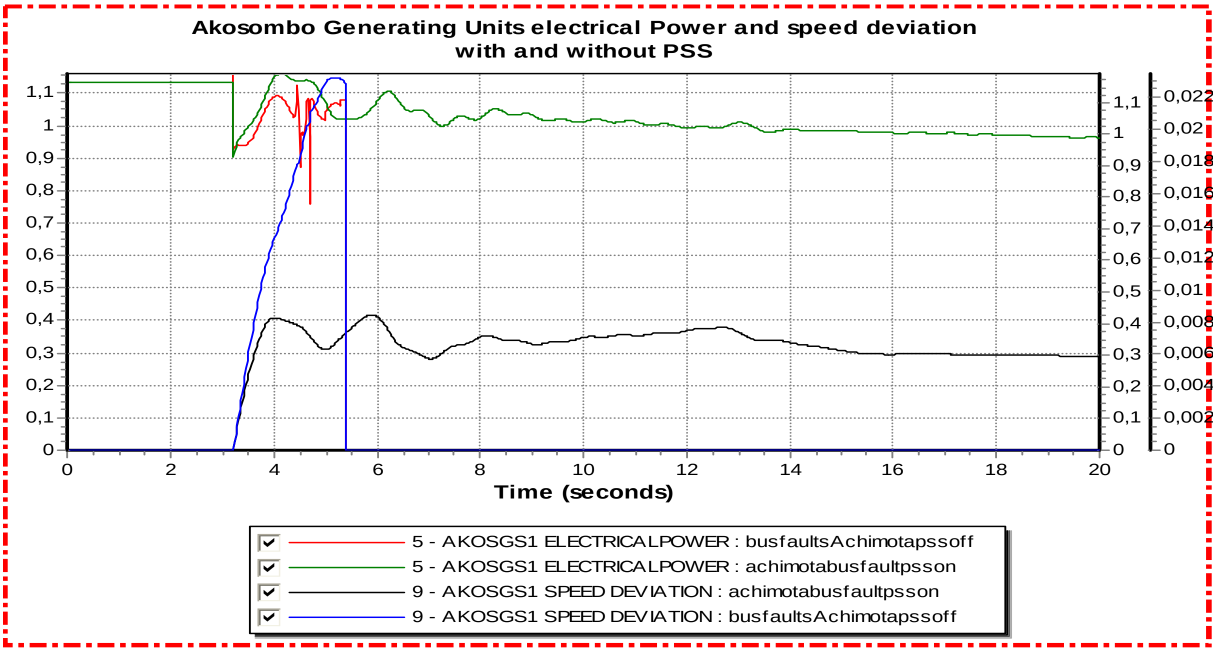

Fig 4.14 Akosombo GS Unit 1 electrical power and speed deviation with and without PSS following a three phase bus fault at Achimota lasting 100ms

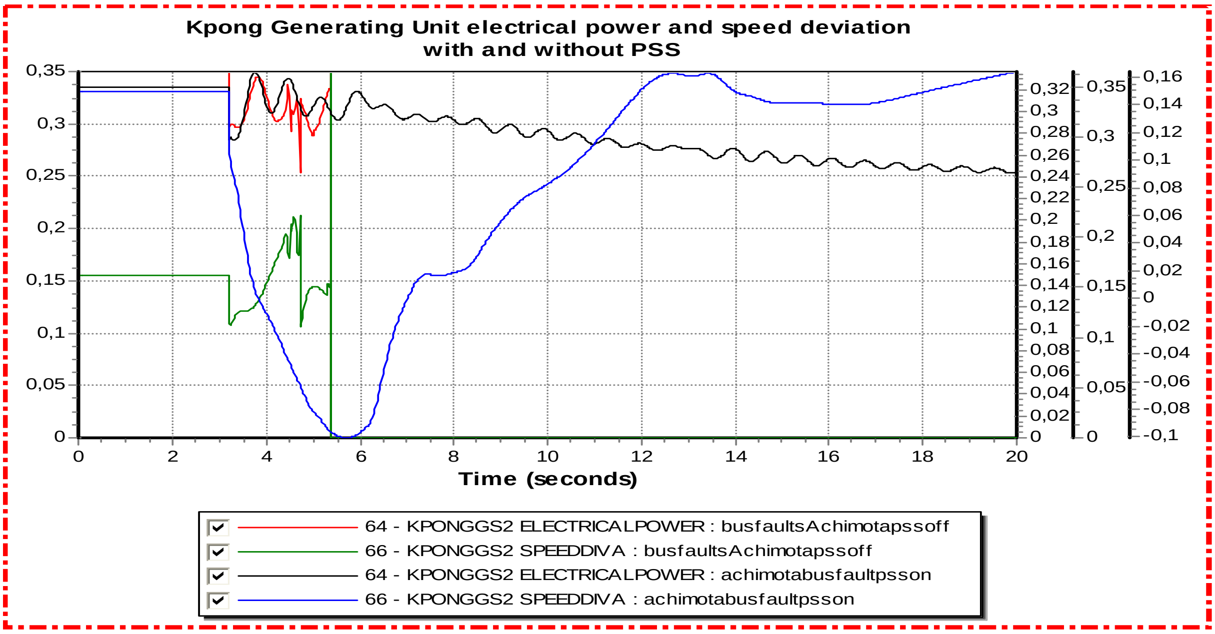

Fig4. 15 Kpong GS Unit 2 electrical power and speed deviation with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

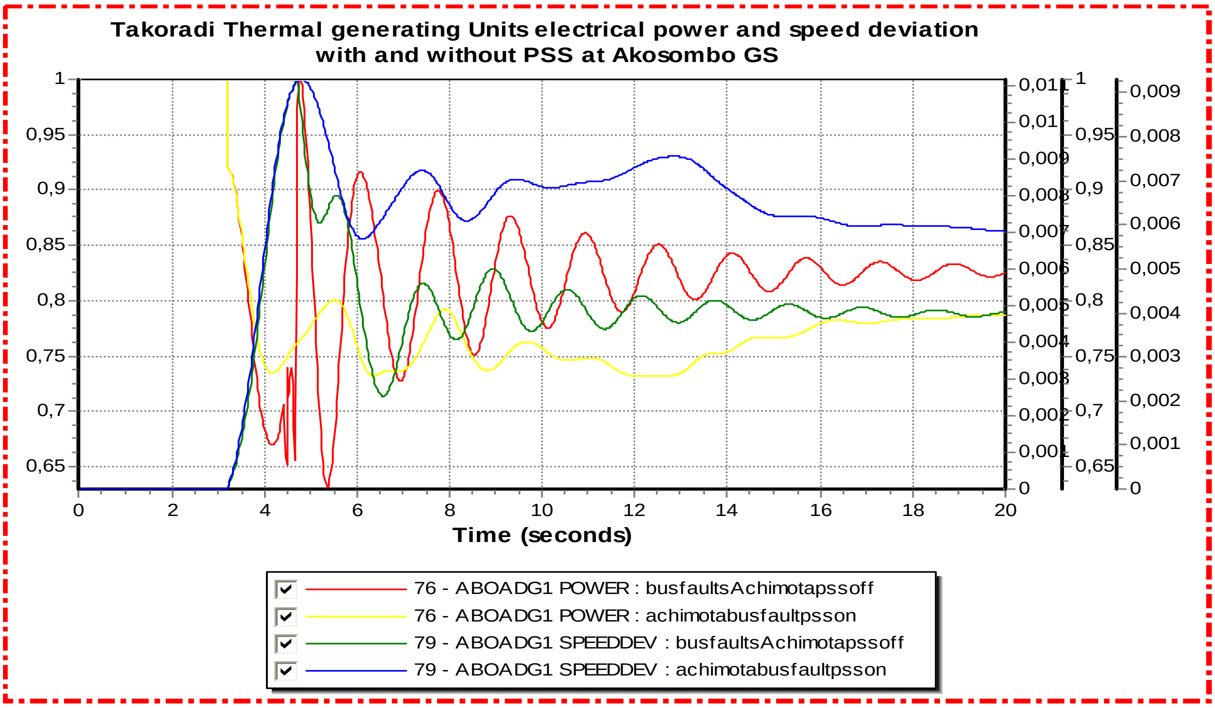

Fig4. 16: Aboadze GS Unit 2 electrical power and speed deviation with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

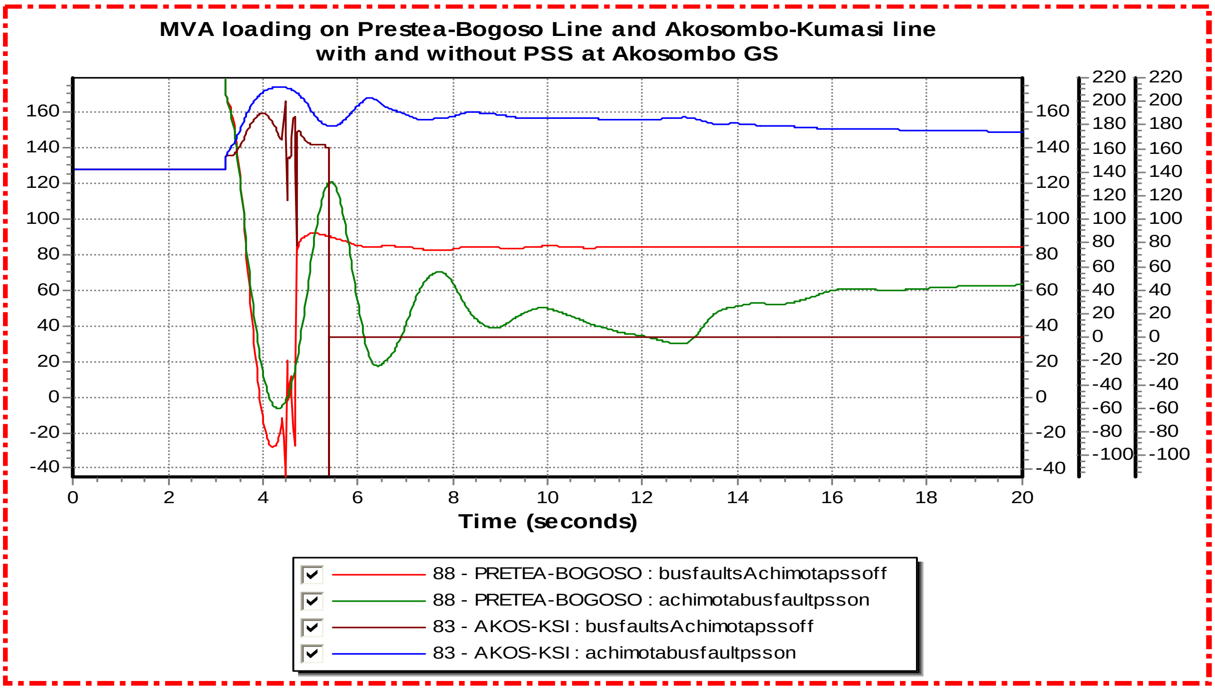

Fig 4.17 :Loading in MVA on Prestea-Bogoso and Akosombo-Kumasi lines with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

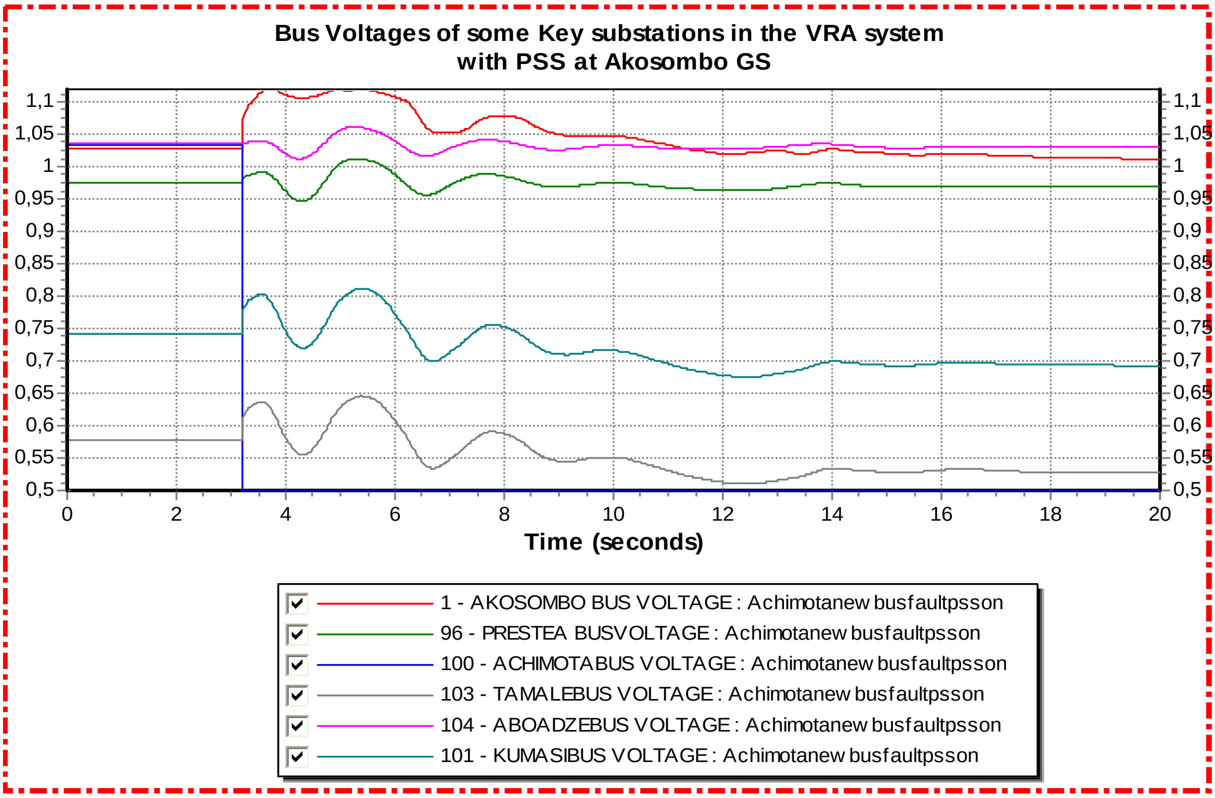

Fig 4.18 Bus voltages of some key substation in the VRA system with PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

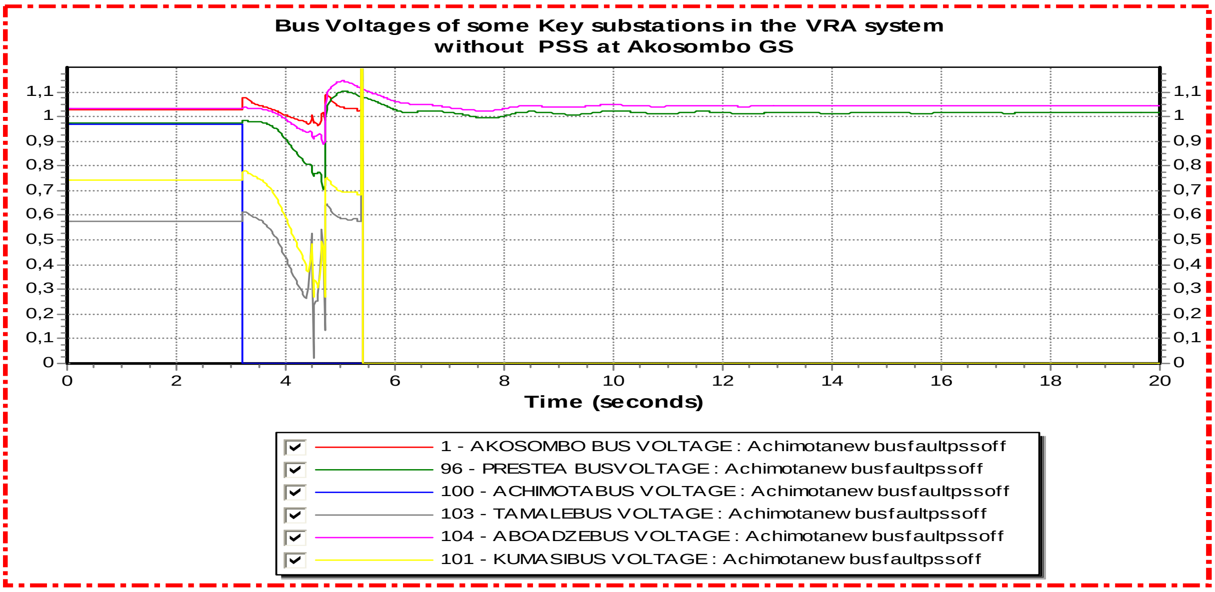

Fig 4.19 Bus voltages of some key substation in the VRA system without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

Finding of Case 2(b)

(b)A three phase bus fault at Takoradi 161KV Substation, cleared within 10cycles by isolating the bus

A disturbance caused by a three phase bus fault at Takoradi 161KV substation is considerably damped after the application of PSS at Akosombo Generating Station. The oscillations stabilized 7sec after the fault was cleared as shown by the simulation results in fig 4.20 and fig 4.21.

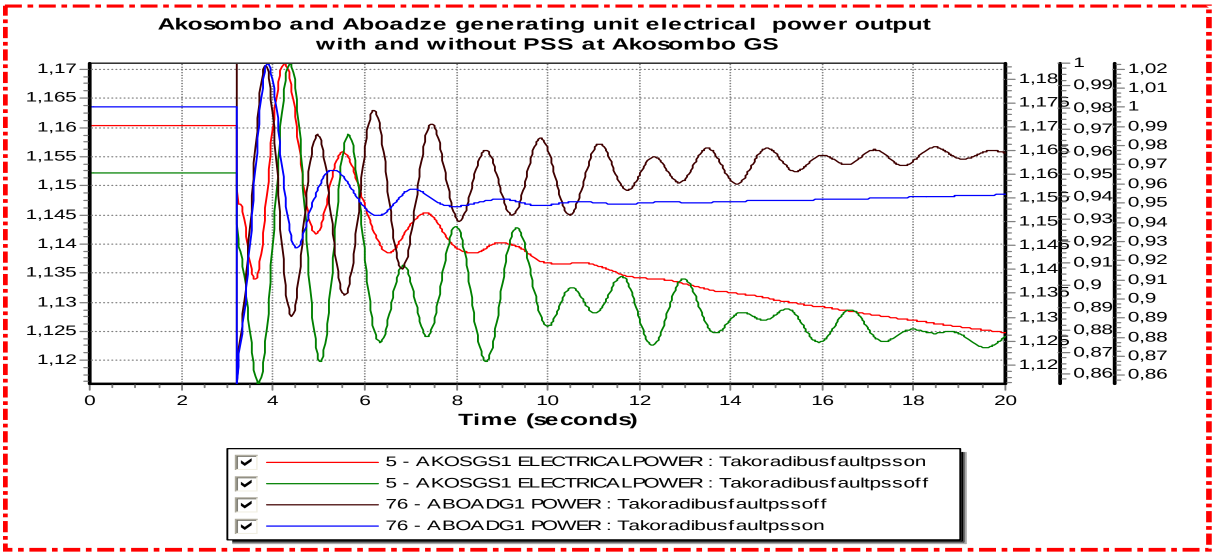

Fig 4.20 Akosombo and Aboadze Unit1 electrical power output with and without PSS at Akosombo Gs following a three phase bus fault at Takoradi lasting 100ms

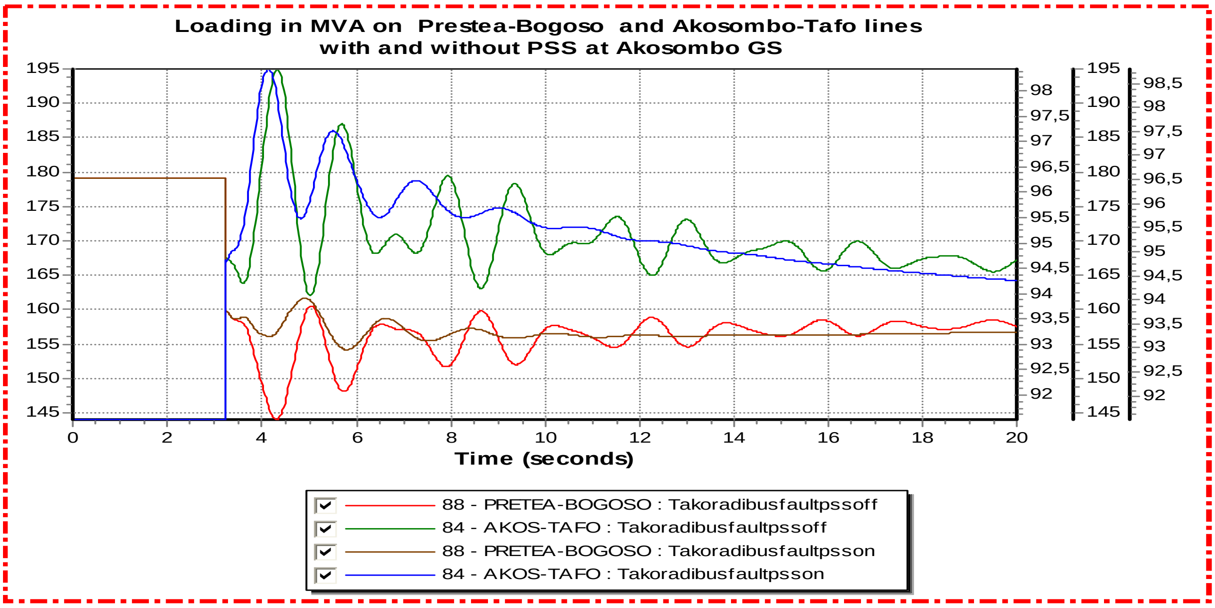

Fig 4.21 Loading in MVA of Prestea-Bogoso and Akosombo-Tafo lines with and without PSS at Akosombo Gs following a three phase bus fault at Takoradi lasting 100ms

Finding of Case 2(c)

(c)***A three phase bus fault at Prestea 225KV substation, cleared in 100ms by isolating the bus***

A three phase fault on the Prestea 225 bus cleared within 10cycles caused the generators to loss synchronism after sometime. The rotor angle of the generator started increasing immediately after the fault and continued even when the fault was cleared. The application of PSS had no impact because of the nature of the fault.

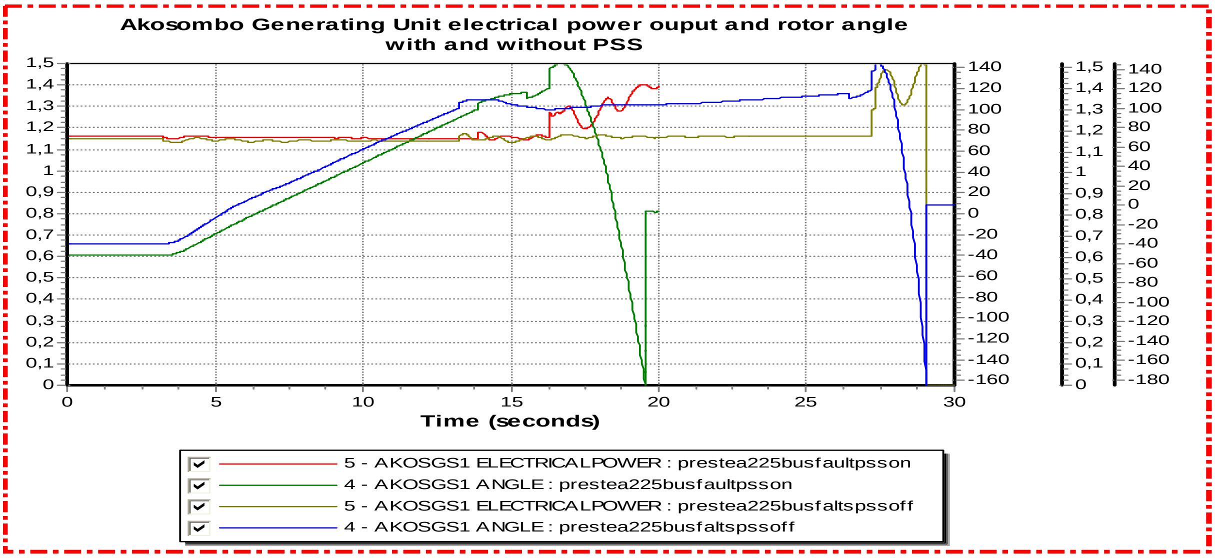

Fig4.22 Akosombo GS unit1 electrical power and rotor angle with and without PSS following a three phase bus fault at Prestea 225kV substation lasting 100ms

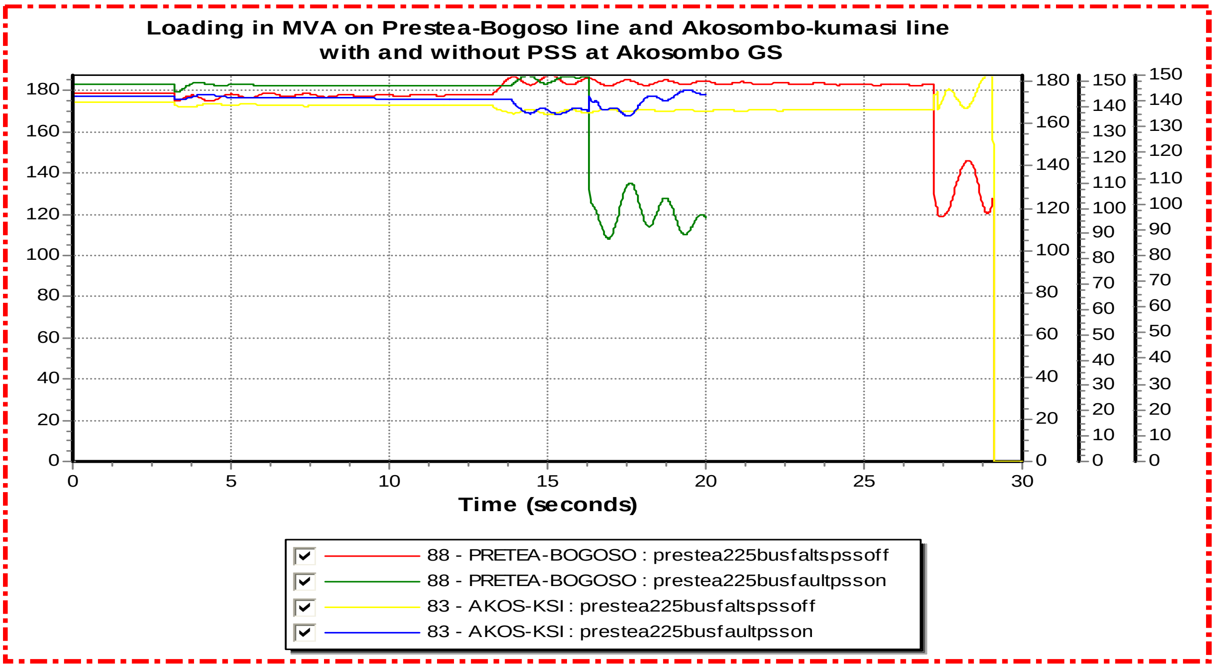

Fig4.23 Loading in MVA on Prestea –Bogoso and Akosombo-Kumasi lines with and without PSS following a three phase bus fault at Prestea 225kV substation lasting 100ms

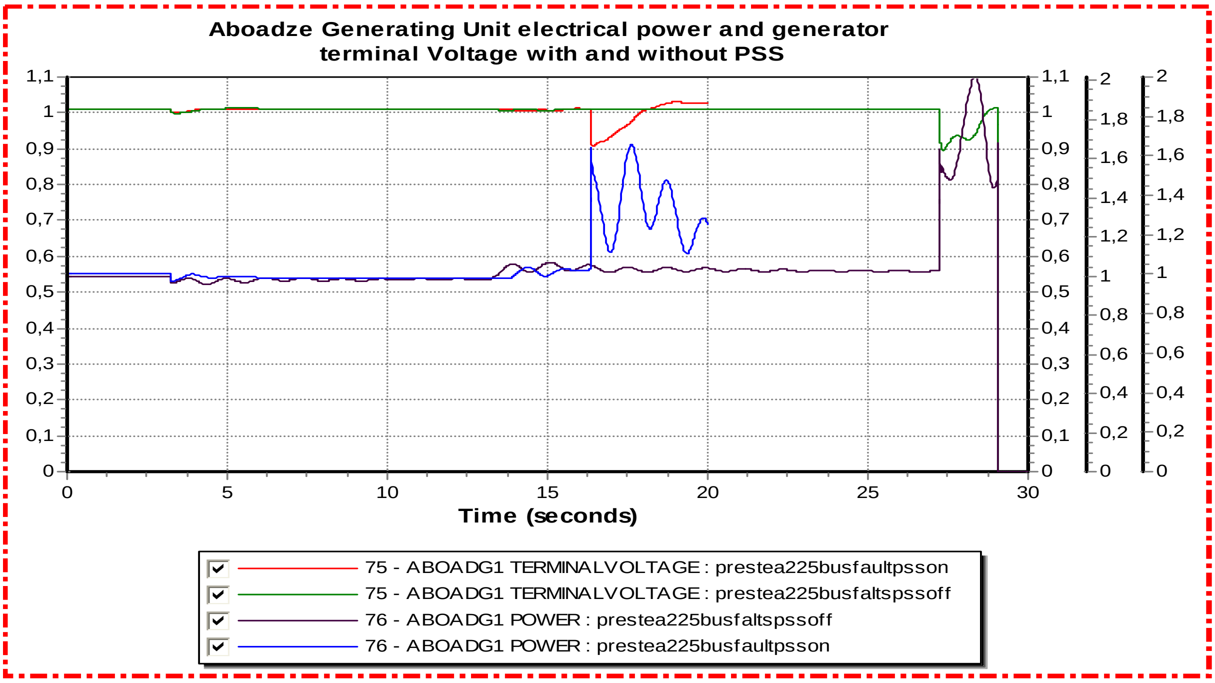

Fig4.24 Aboadze GS unit1 electrical power and terminal voltage with and without PSS following a three phase bus fault at Prestea 225kV substation lasting 100ms

4.3.3.3 Case 3: Normal Average load condition

Findings of Case3 (a)

(a)A three phase bus fault at Achimota 161KV Substation, cleared within 10cycles by isolating Achimota 161KV bus

Fig 4.26-fig 4.30 show the positive impact of PSS at Akosombo GS in damping oscillations in the VRA system initiated by the above disturbance. Fig 4.27 even shows that the oscillations in the mechanical power (governor) of the Aboadze units were damped after 5 seconds after the fault was cleared showing the positive impact of PSS on the performance of the unit governor. Fig4.30 also shows the impact of PSS in damping oscillations in the bus voltages of key substations in the VRA system within 9seconds after the faults was cleared as compared with fig 4.29 with no PSS, where oscillation continued even after 17sec after the fault was cleared.

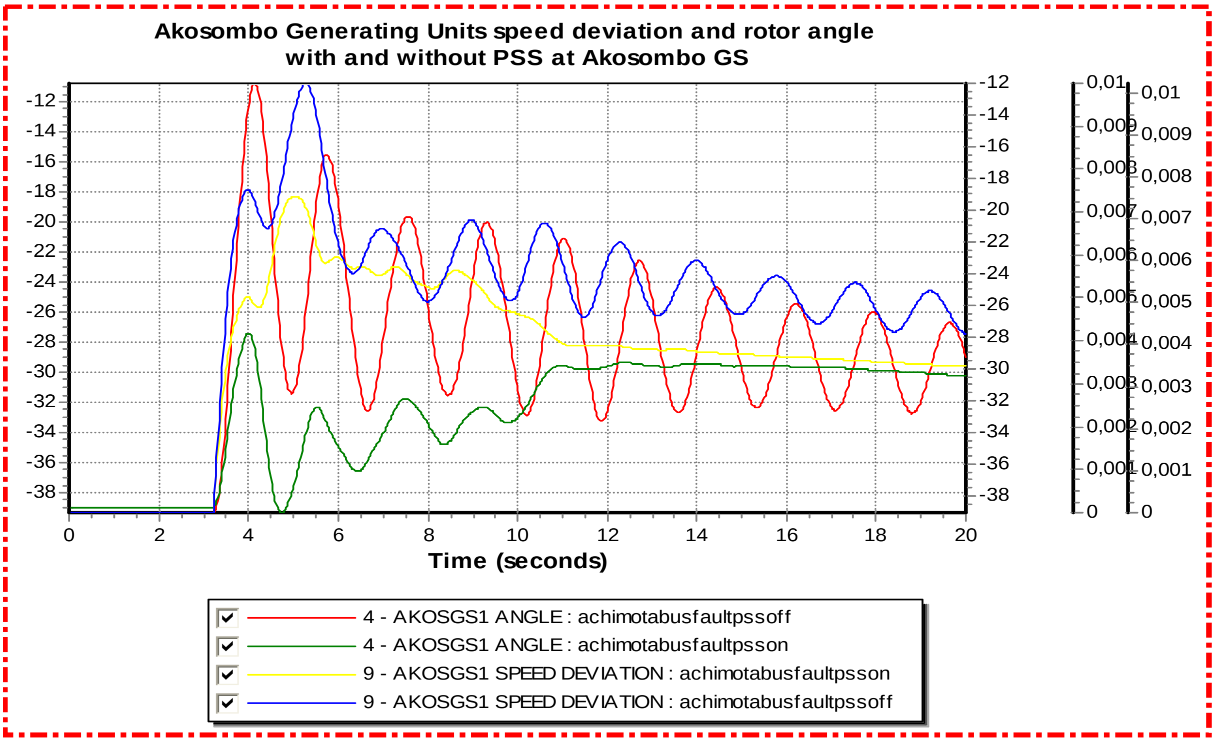

Fig4.26 Akosombo GS unit1 speed deviation and rotor angle with and without PSS following a three phase bus fault at Achimota substation lasting 100ms

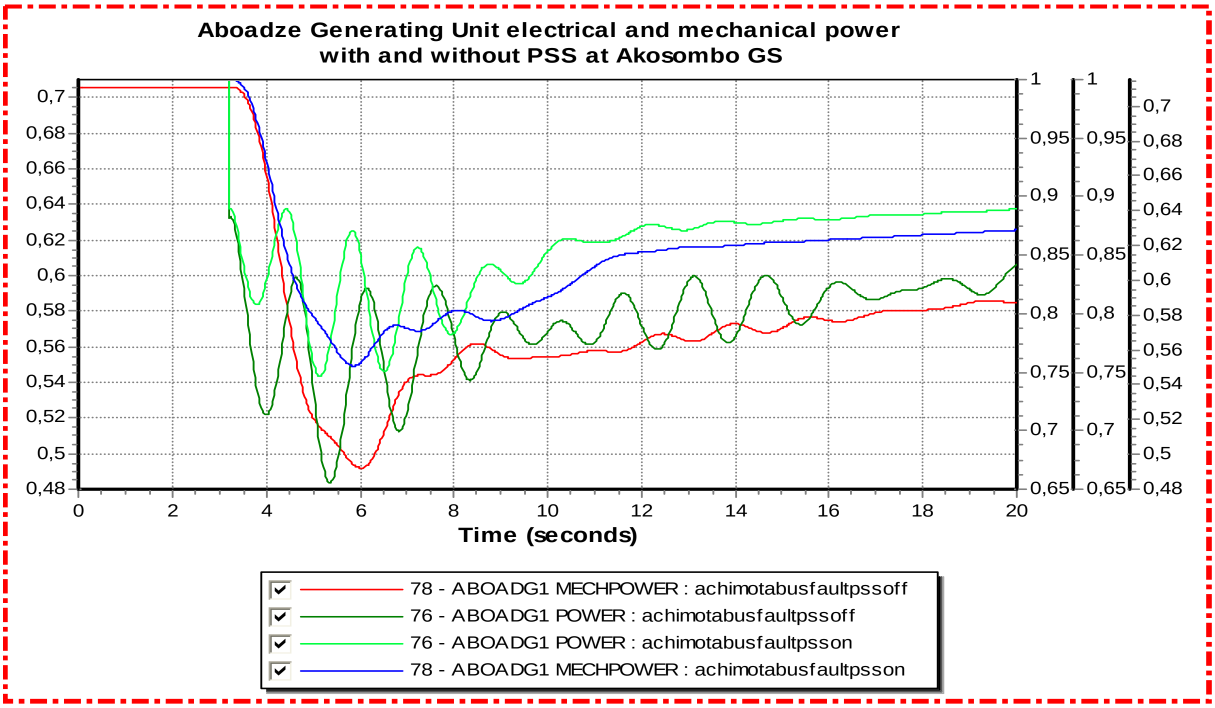

Fig4.27 Aboadze GS unit1 electrical power and mechanical power with and without PSS following a three phase bus fault at Achimota lasting 100ms

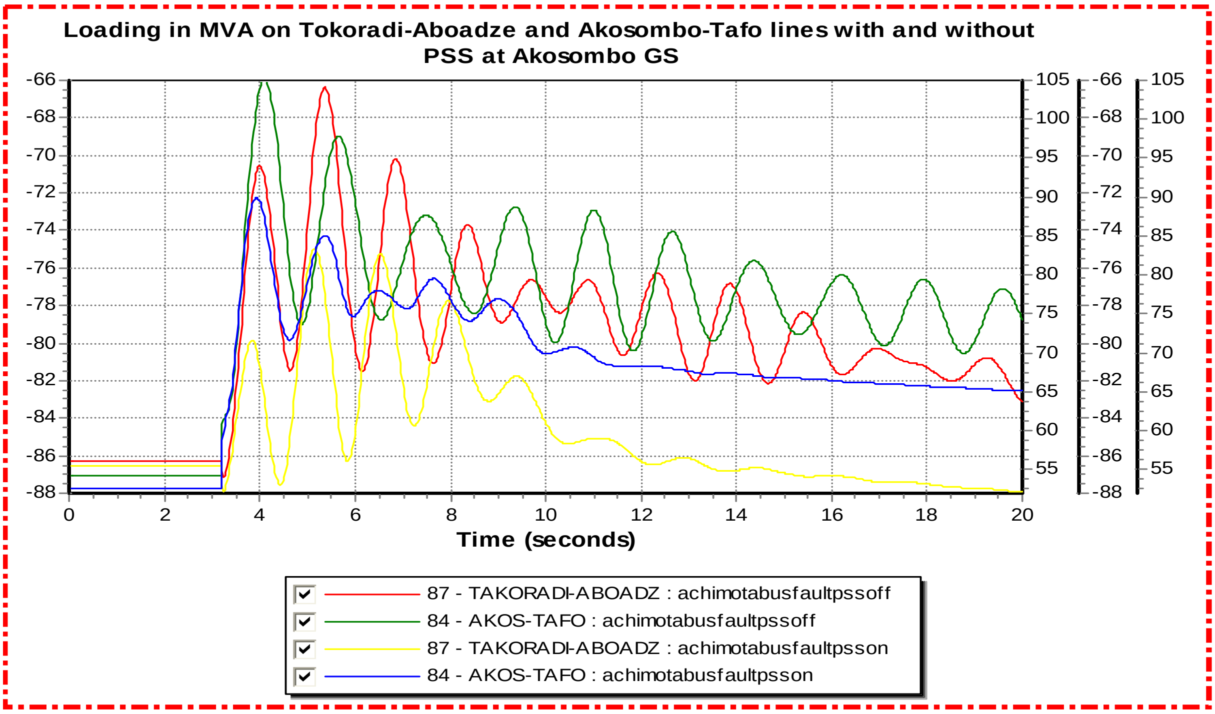

Fig4.28 Loading in MVA on Takoradi-Aboadze and Akosombo Tafo lines with and without PSS following a three phase bus fault at Achimota lasting 100ms

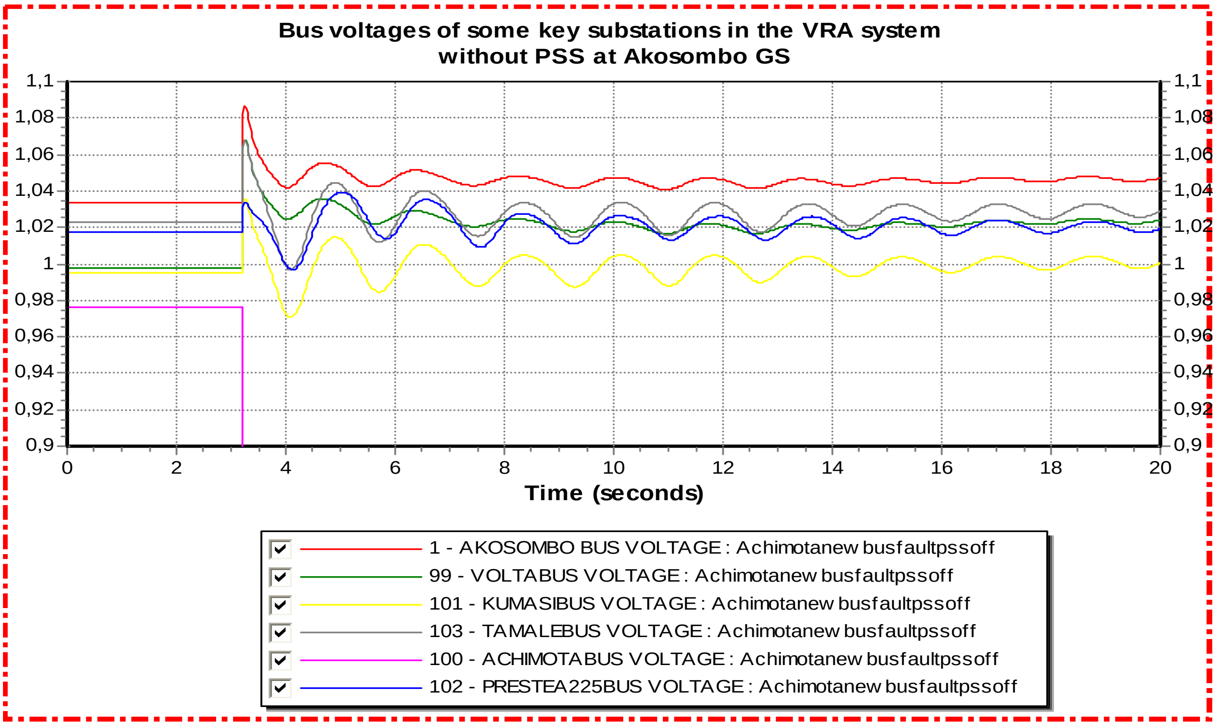

Fig4.29 Bus voltages of some key substations without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

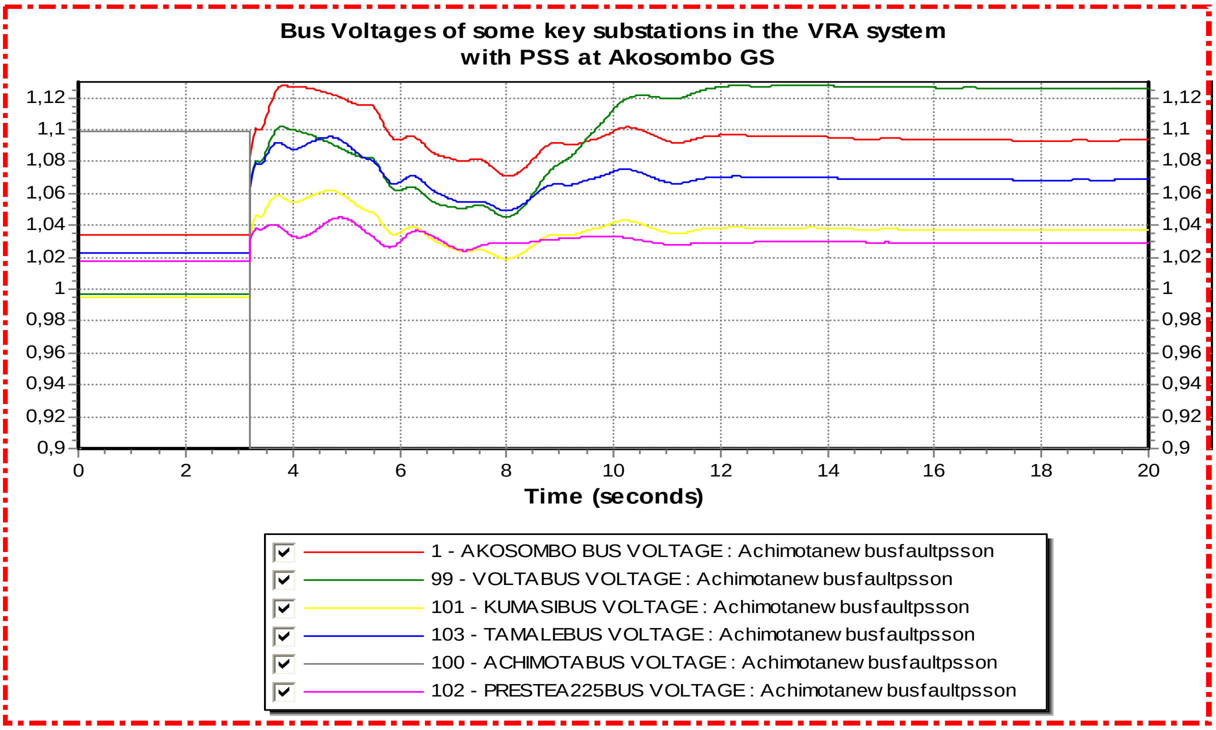

Fig4.30 Bus voltages of some key substations with PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

Findings of Case 3(b)

(b)A generator operating at 35MW trips at Kpong Generating Station

The lost of 35MW unit at Kpong Generating Station subjected the system to a small disturbance with an initial speed deviation within 0.001pu for all the major generating units in Ghana. With such small oscillation the PSS at Akosombo still contributed in damping the oscillations .This means that a PSS at Akosombo Generating station will enhance both small signal and transient stability of the VRA system.

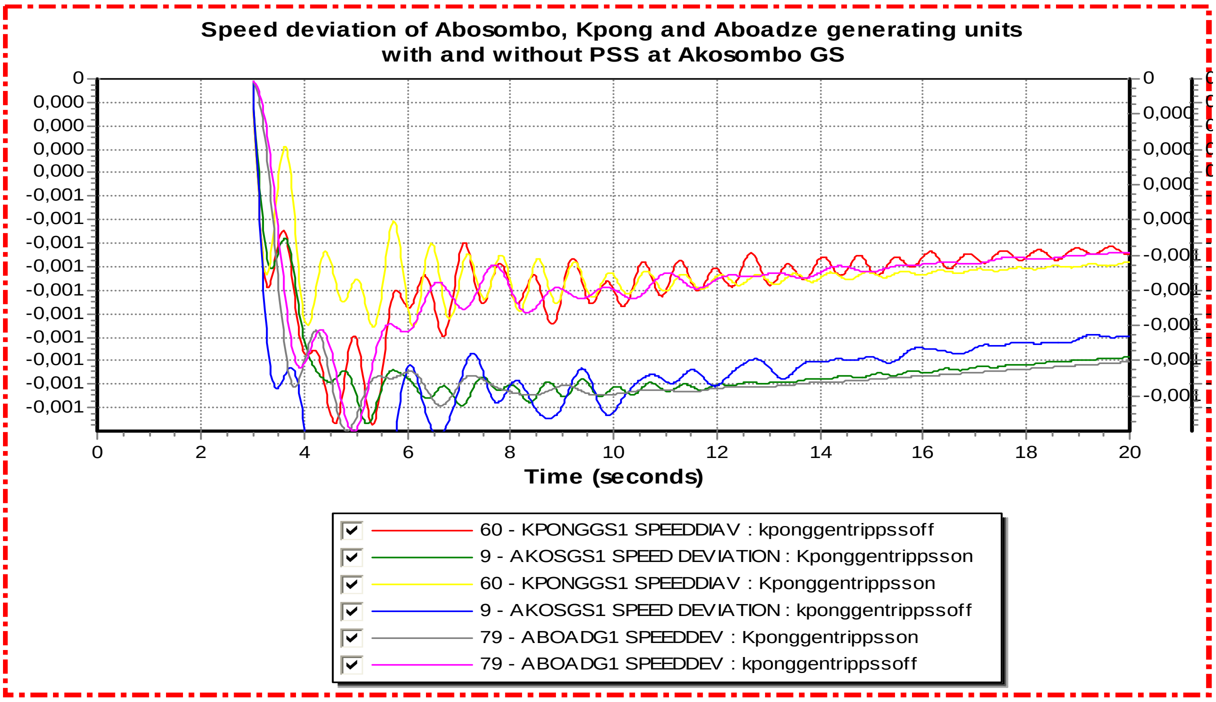

Fig4.31 Speed deviation of Akosombo , Kpong and Aboadze units with and without PSS at Akosombo GS following a unit trip at Kpong GS.

Finding of Case 3(C)

(c)A three phase bus fault at Prestea 225KV substation, cleared within 10cycle by isolating the bus

A three phase bus fault at Prestea 225KV substation during average system load condition did not cause a system collapse (fig 4.32-fig4.33) as compared to that during peaking load condition (fig 4.22 - fig 4.23). This is because during average system load condition, both the generating and transmission facilities have higher capacity of reserves, to accommodate sudden changes in generation and transmissions power, thereby improving system stability. The electromechanical oscillation associated with the disturbance was damped by the application of PSS at Akosombo.

Fig4.33 and fig4.34 show how the PSS at Akosombo GS changes the bus voltage behaviour of the system. Units without PSS like Kpong GS units have the excitation system responding only to the system bus voltage. For units without PSS the excitation voltage increases when the bus voltage decreases and decreases when the bus voltage increases. However, units with PSS like Akosombo units have their excitation voltage responding to unit speed deviation in addition to system voltage as observed in fig 3.35. This illustrates the main principle of PSS, modulating unit excitation voltage using inputs like speed deviation to improve damping of electromechanical oscillations.

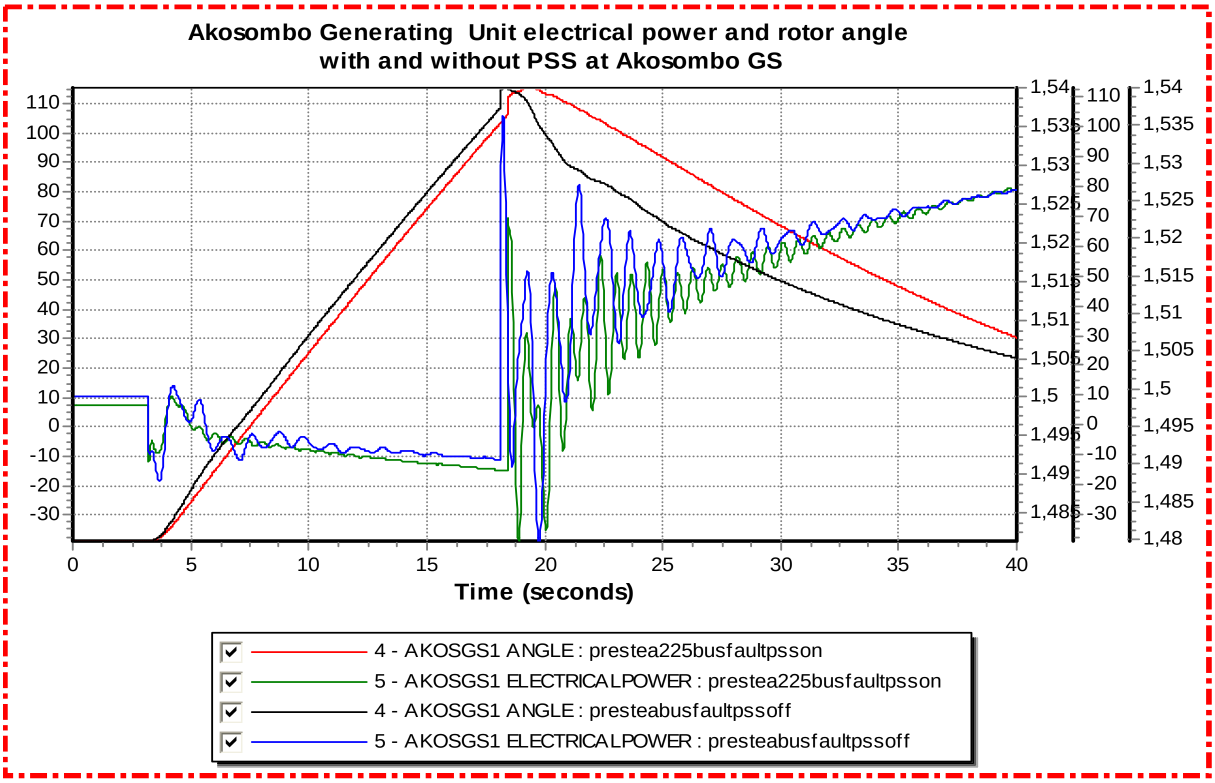

Fig4.32 Akosombo GS electrical power and rotor angle with and without PSS following a three phase bus fault at Prestea 225KV substation lasting 100ms.

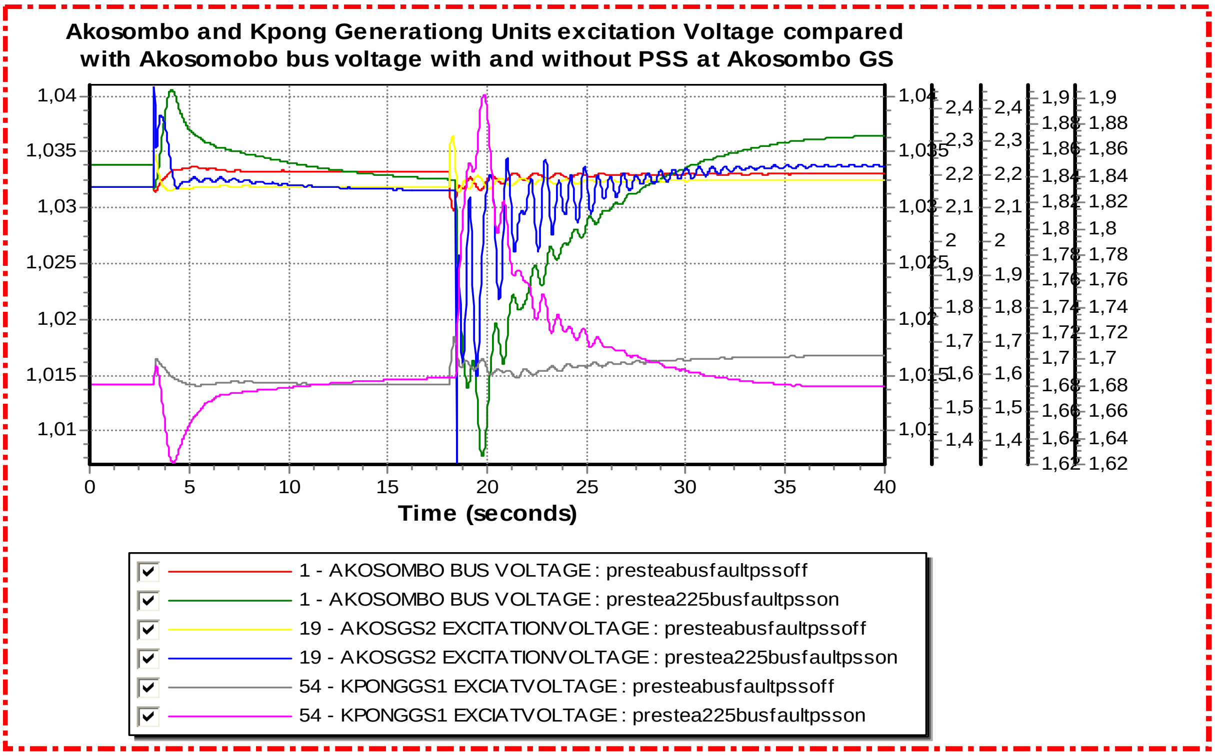

Fig4.33 AKosombo and Kpong GS units excitation voltage compared with Akosombo bus voltage with and without PSS following a three phase bus fault at Prestea 225KV substation lasting 100ms.

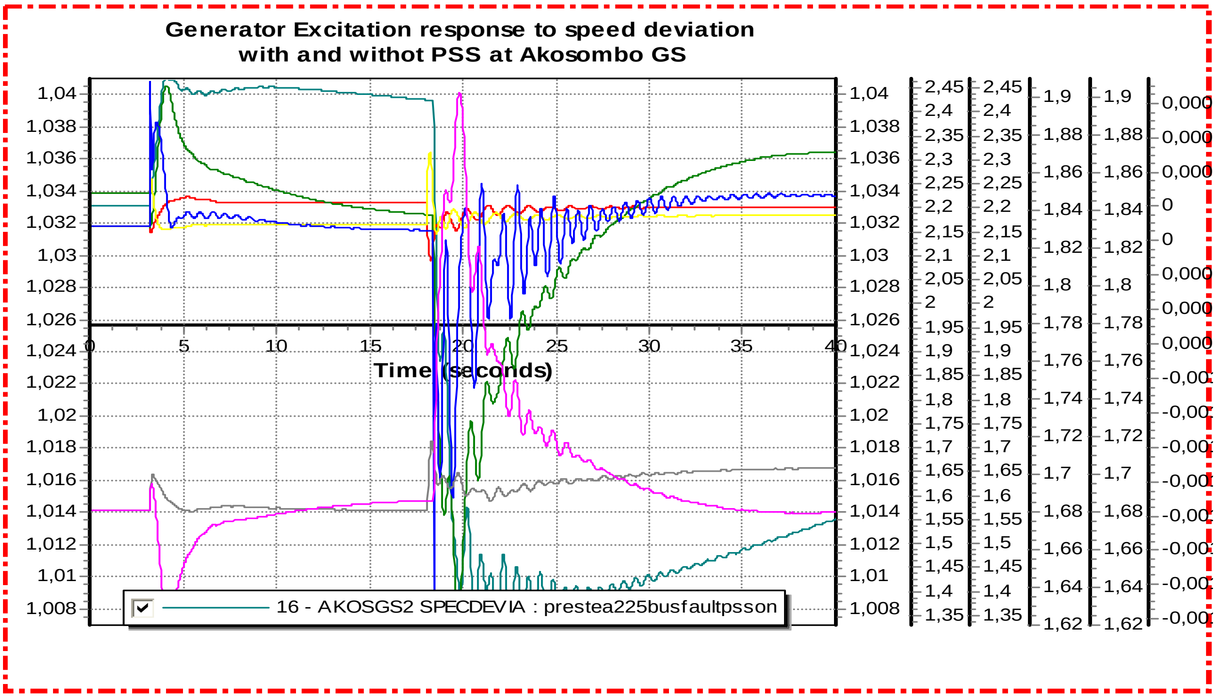

Fig4.34 Akosombo and Kpong GS units excitation responses to unit speed deviation with and without PSS following a three phase bus fault at Prestea 225KV substation lasting 100ms,

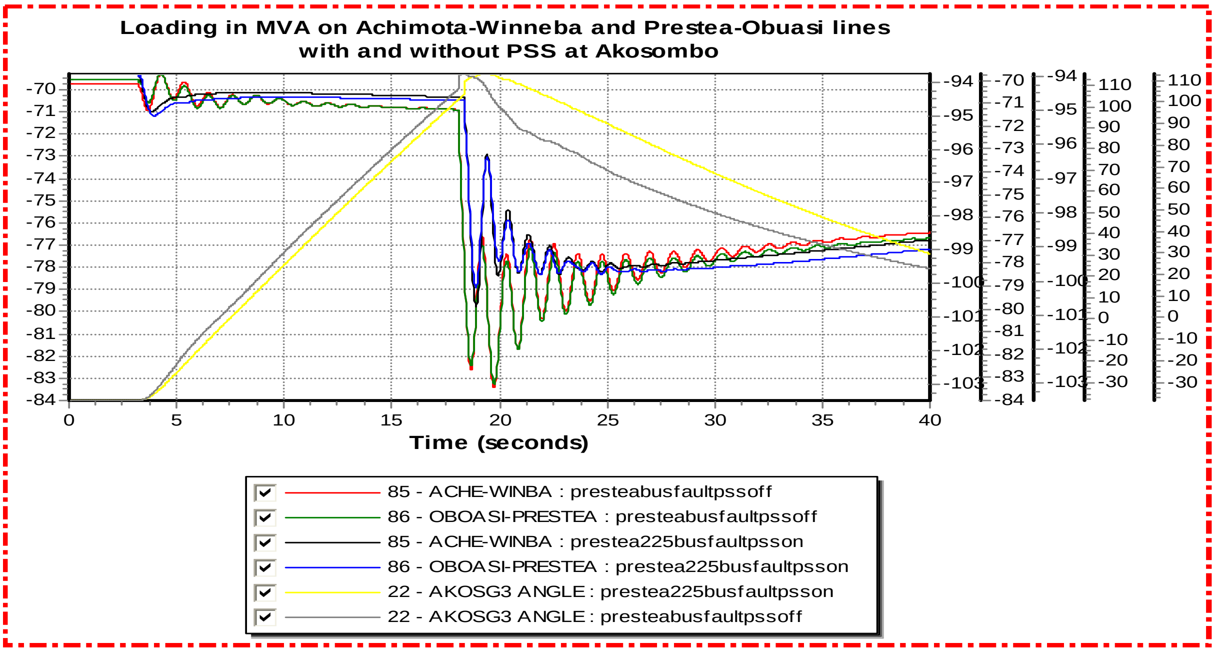

Fig4.35 Line loading in MVA of Achimota-Winneba, Prestea-Obuasi line and Akosombo units 3 rotor angle following a three phase bus fault at Prestea 225KV substation lasting 100ms.

4.3.3.4 Case 4: Average load condition(Konongo-Kumasi contingency)

Findings of case 4(a)

(a)A three phase bus fault at Achimota cleared within 10cycles

Fig4.38 shows that all the units in Akosombo GS oscillate together with Kpong GS units in Ghana against Aizto units in Cote d'Ivoire even after 17sec after the fault was cleared. This is an example of inter-area oscillation, with a frequency of about 0.5Hz. The hydro units in Ghana were also observed oscillating against Aboadze units at a frequency of about 0.7Hz (Inter-area oscillations). With the activation of the PSS at Akosombo GS all the oscillation were completely damped 9ec after the fault was cleared. Fig4.37 shows that Kpong GS unit governors (represented by mechanical Power) participate in the oscillations by hunting. Hunting increases the wearing of the governor seals increasing maintenance cost. With PSS at Akosombo GS the hunting of the Kpong GS governor was damped completely 7seconds after the faults.

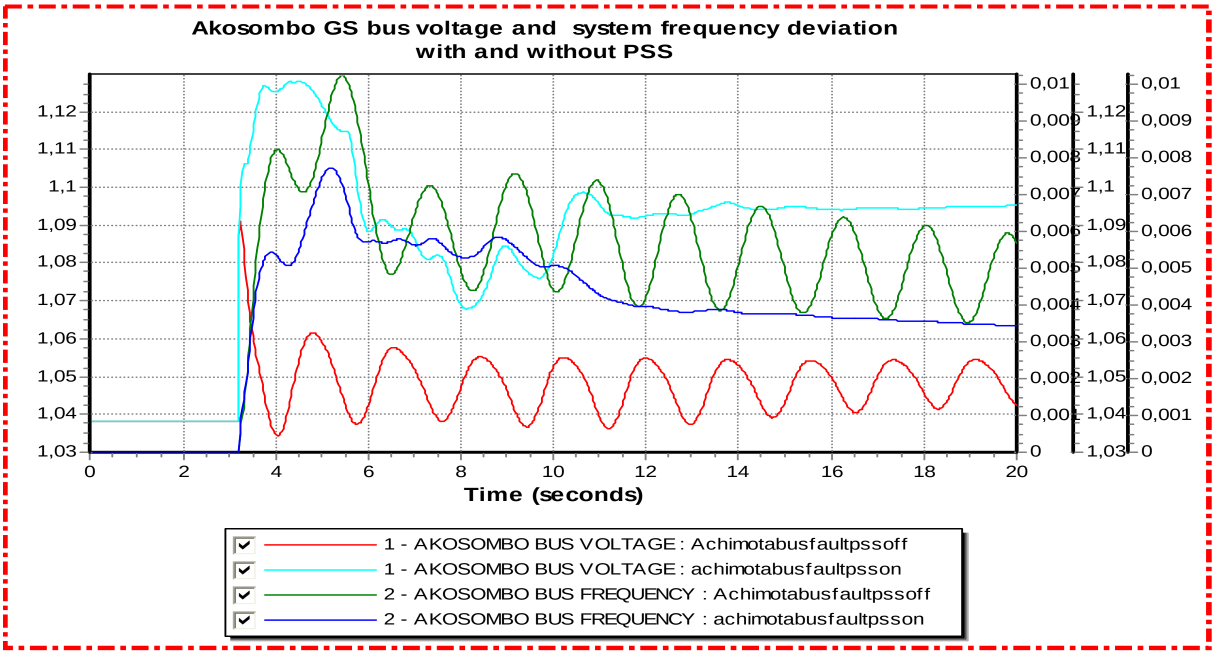

Fig4.36 Akosombo GS bus voltage and system frequency deviation with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms

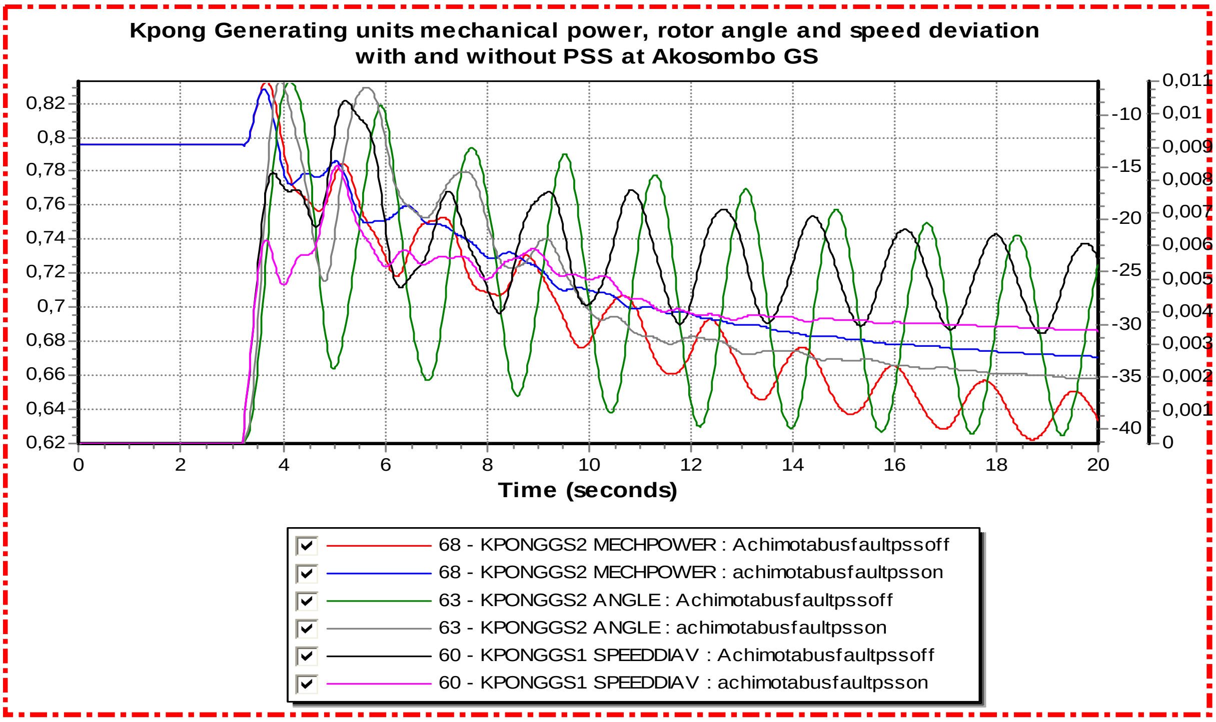

Fig4.37 Kpong GS unit mechanical power (pu), rotor angle (degree) and speed deviation (pu) with and without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms.

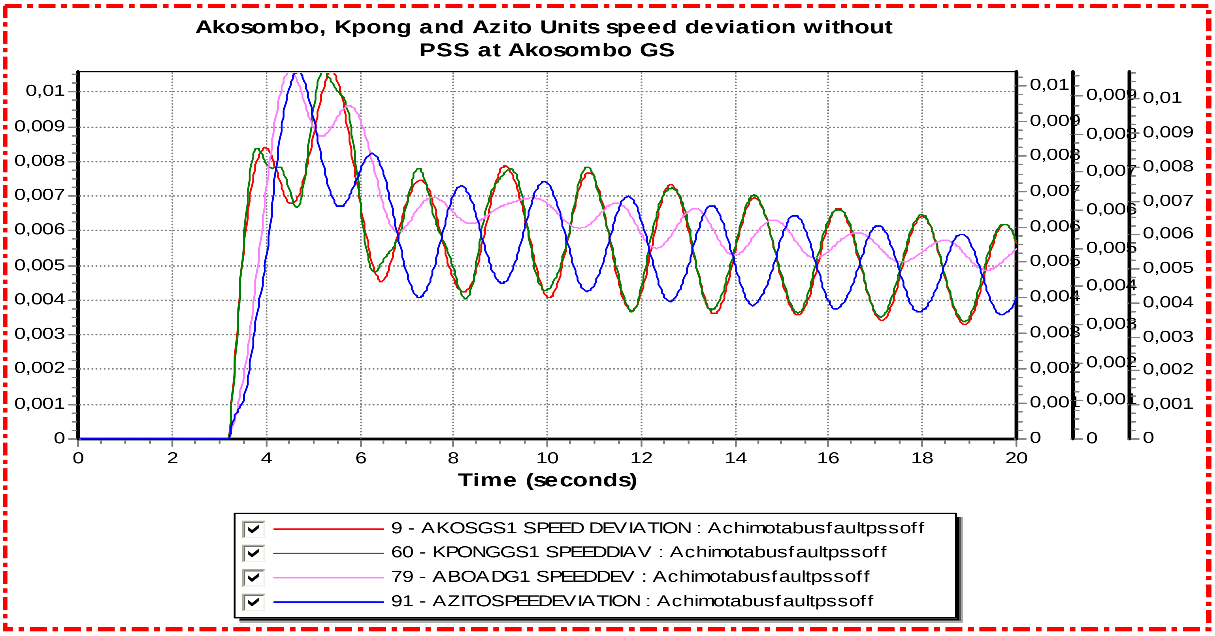

Fig4.38 Akosombo, Aboadze, Kpong and Azito units speed deviation (pu) without PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms.

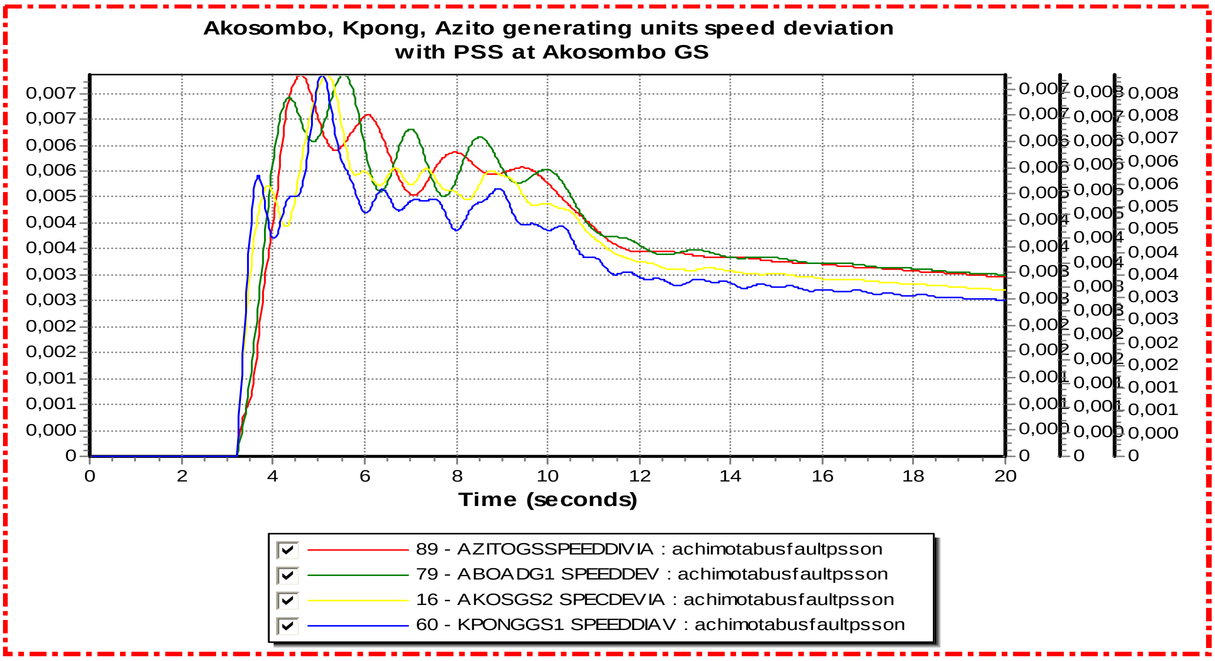

Fig4.39 Akosombo, Aboadze, Kpong and Azito units speed deviation (pu) with PSS at Akosombo GS following a three phase bus fault at Achimota lasting 100ms.

Findings of Case4 (b)

(b) One generator operating at 100MW tripped at Aboadze

The results of this simulations show that PSS at Akosombo improves the damping of all system quantities monitored. A disturbance initiated by a unit trip in Aboadze is seen by all the generating units in-service but it does not have serve impact on system. The PSS was able to damp completely all oscillations within 7seconds after the disturbance.

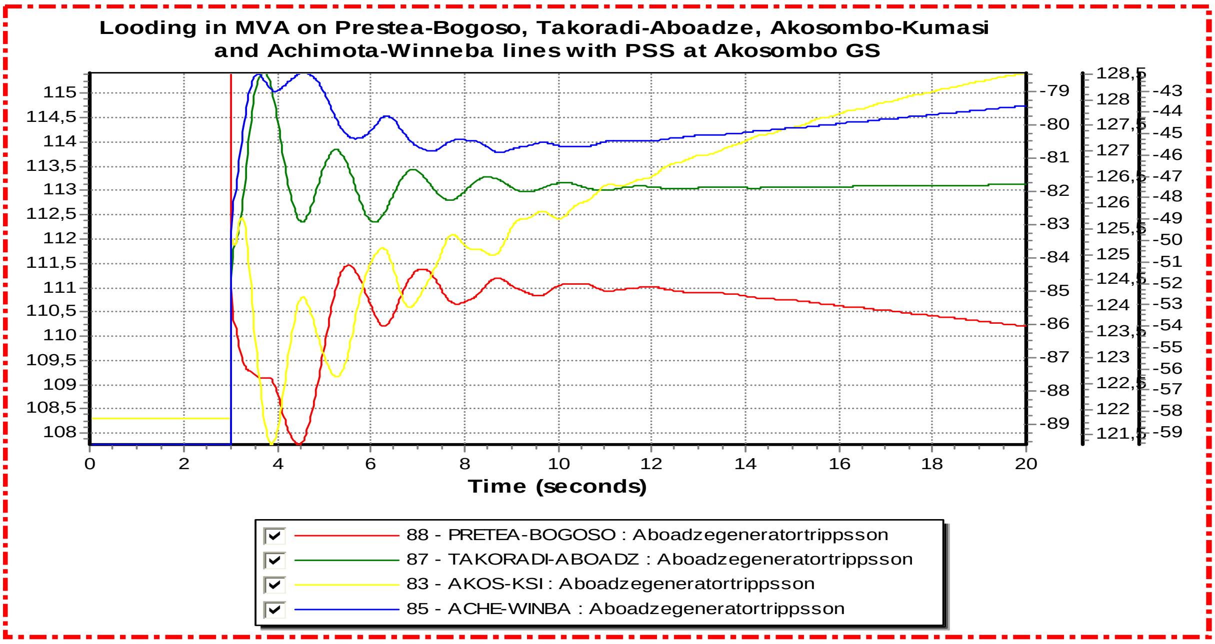

Fig4.40: Loading in MVA on Prestea Bogoso, Takoradi-Aboadze, Akosombo-Kumasi and Achimota-Winneba lines with PSS at Akosombo, following a 100MW unit trip at Aboadze.

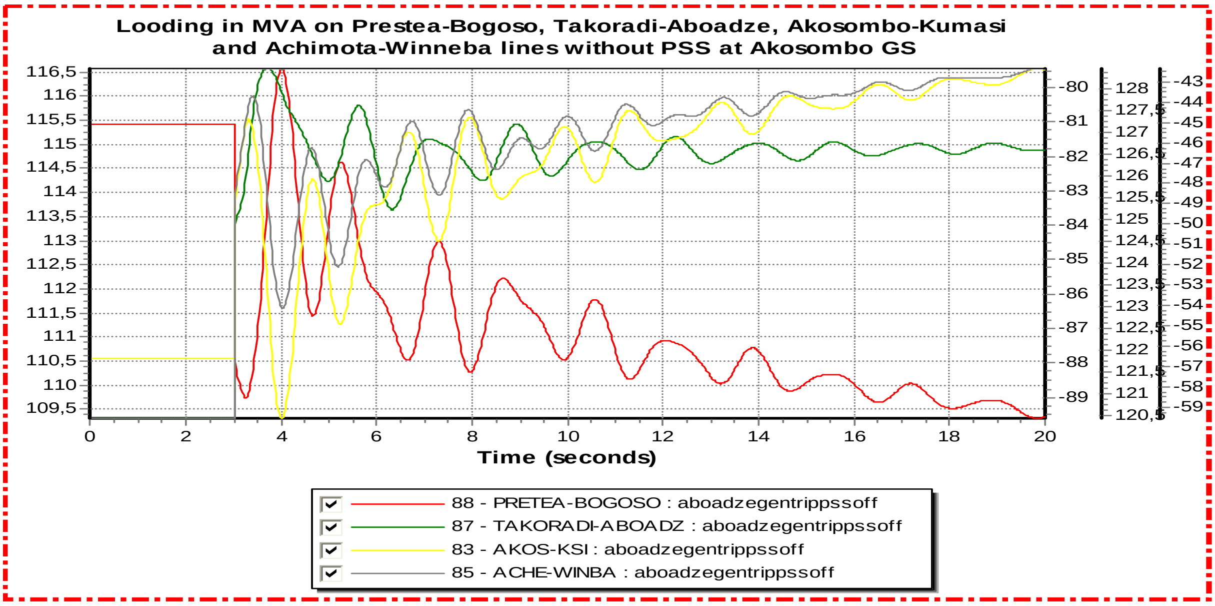

Fig4.41 Loading in MVA on Prestea Bogoso, Takoradi-Aboadze, Akosombo-Kumasi and Achimota-Winneba lines without PSS at Akosombo following a 100MW unit trip at Aboadze.

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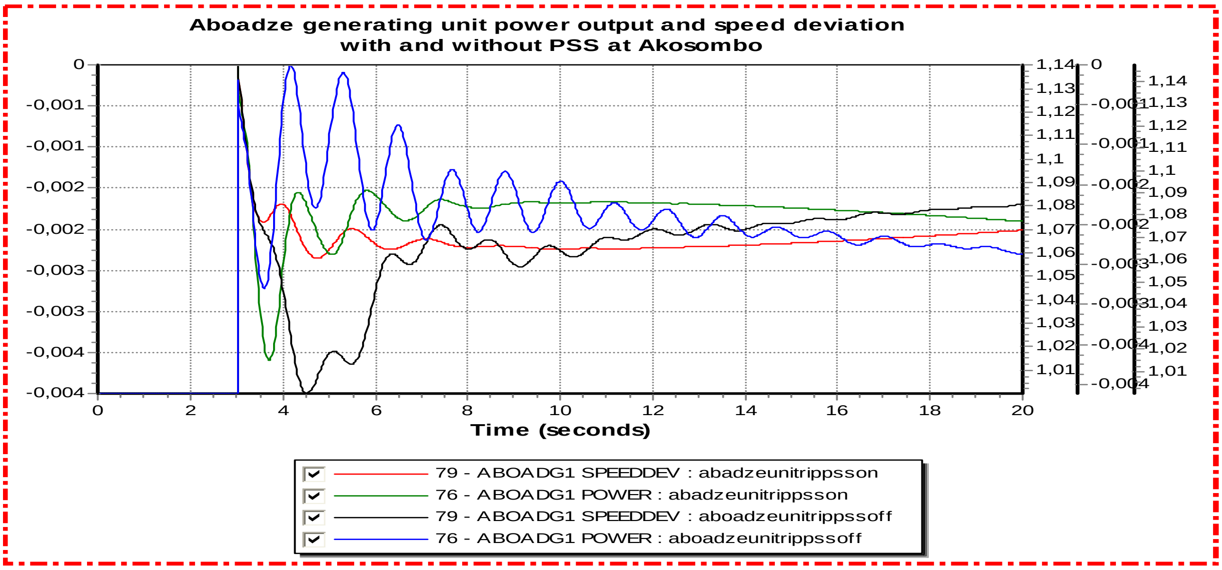

Fig 4.42: Aboadze unit 1 electrical power output and speed deviation with and without PSS at Akosombo GS following one unit trip at Aboadze.

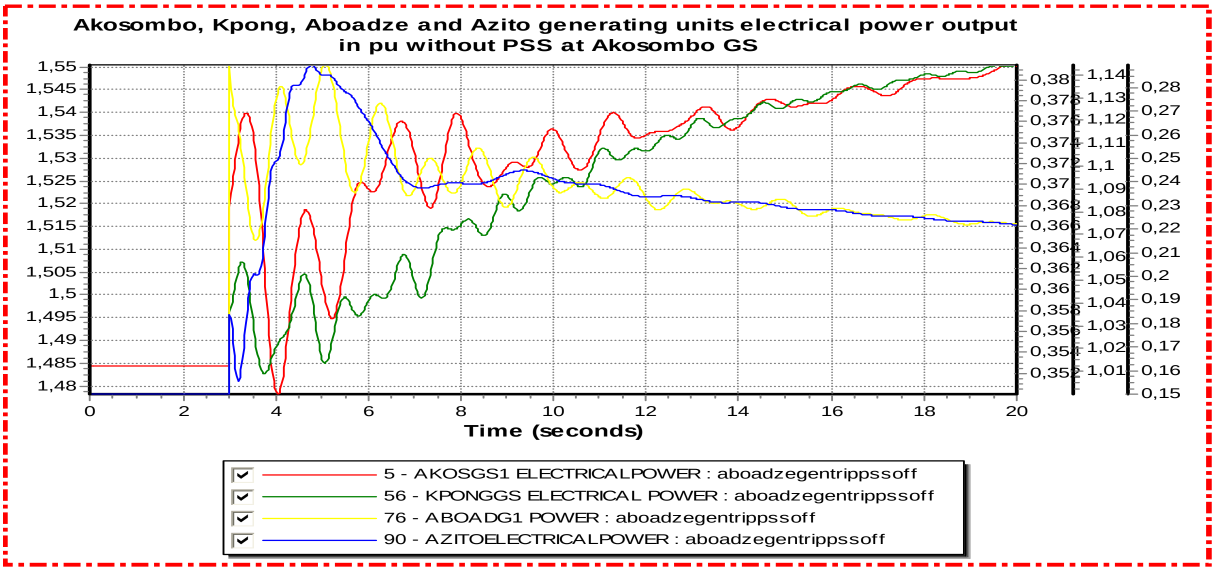

Fig4.43 Akosombo, Kpong , Aboadze and Azito generating units electrical power without PSS at Akosombo GS following a 100MW unit trip at Aboadze

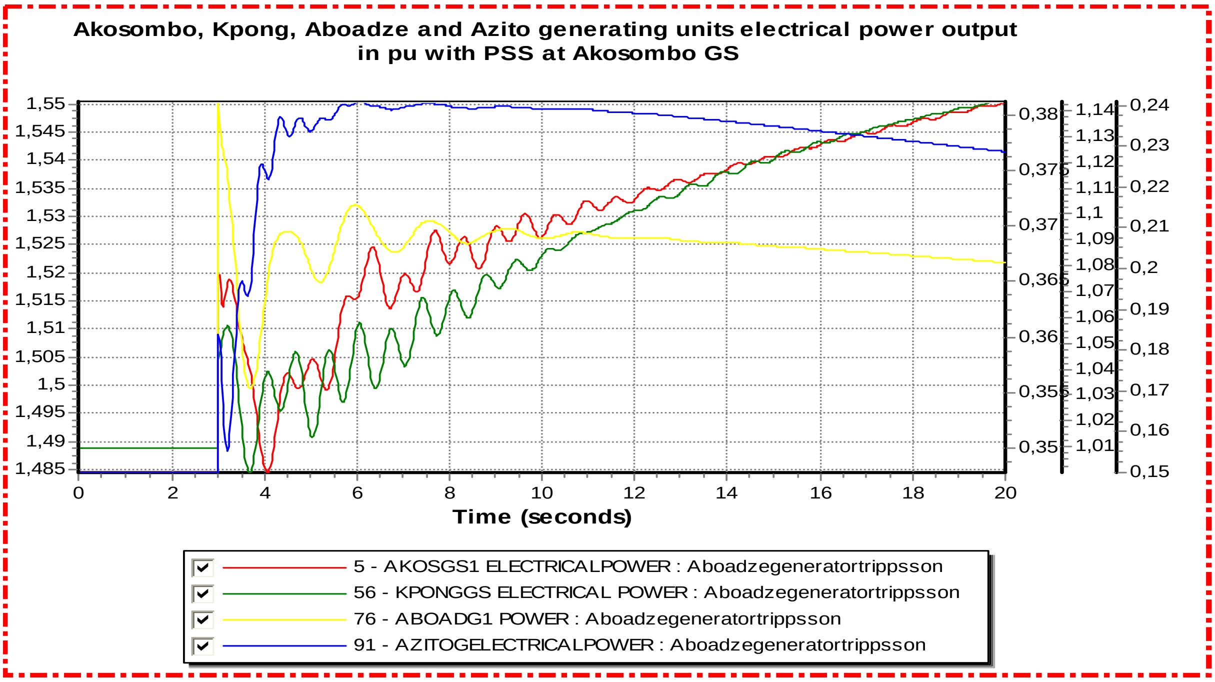

Fig4.44 : Akosombo, Kpong , Aboadze and Azita generating units electrical power with PSS at Akosombo GS following a 100MW unit trip at Aboadze

Finding of Case 4(c)

(c)A three phase bus fault at Kumasi 161KV Substation, cleared within 10cyle by isolating the Kumasi bus

PSS at Akosombo GS proved to be effective in damping oscillations caused by a bus fault at Kumasi. The oscillations associated with the disturbance were completely damped within 8seconds

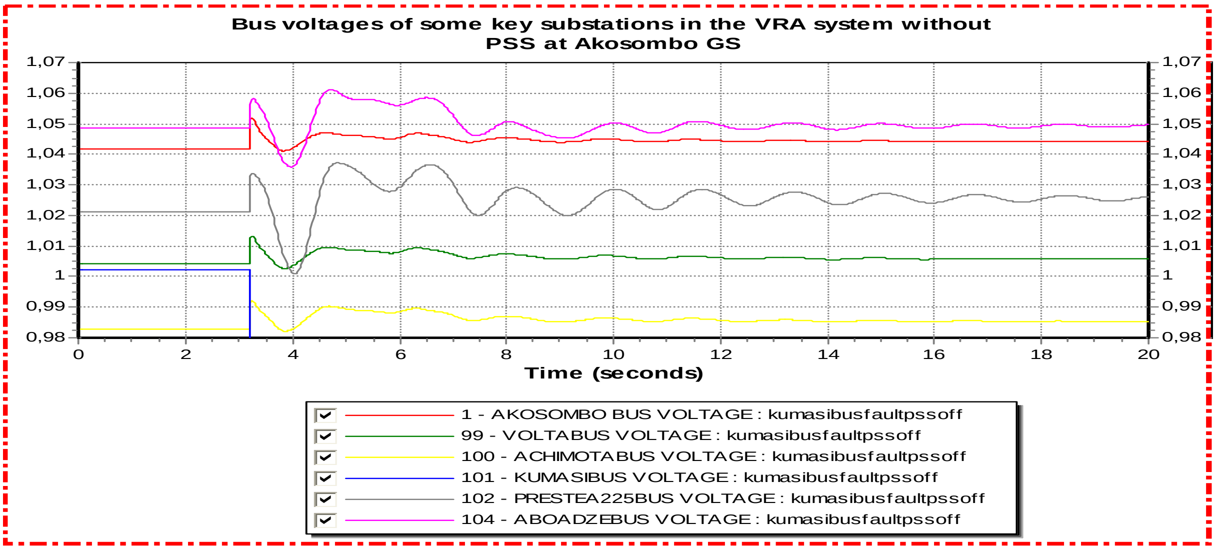

Fig4.45 Bus voltages of some key substations in the VRA system without PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms.

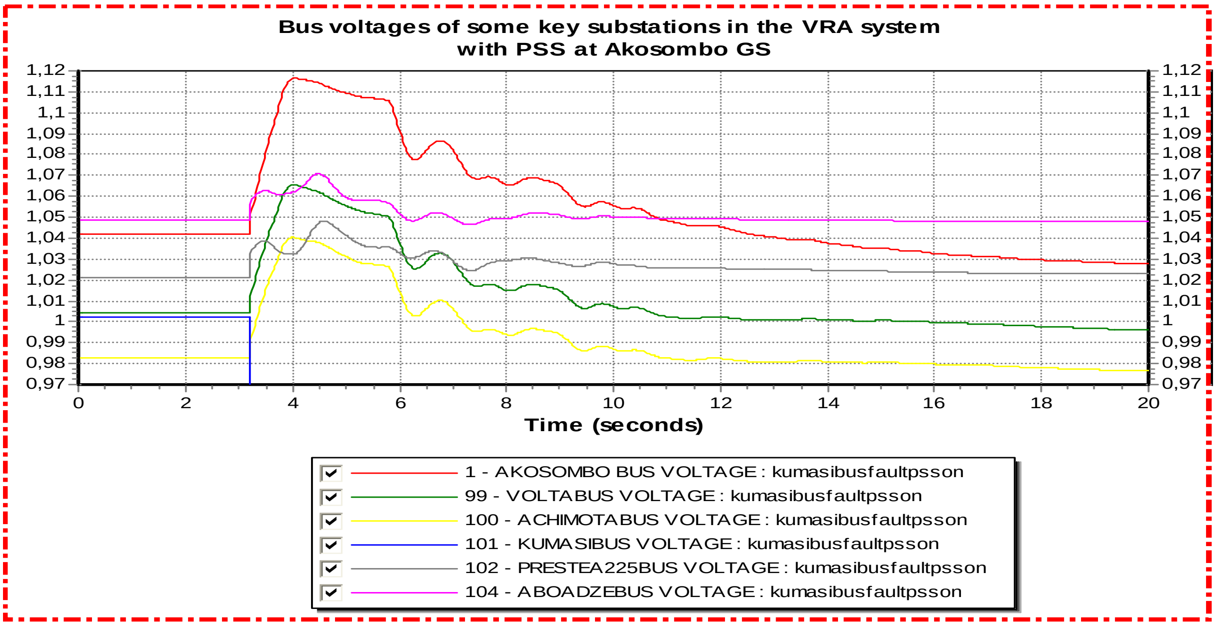

Fig4.46 Bus voltages of some key substations in the VRA system with PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms.

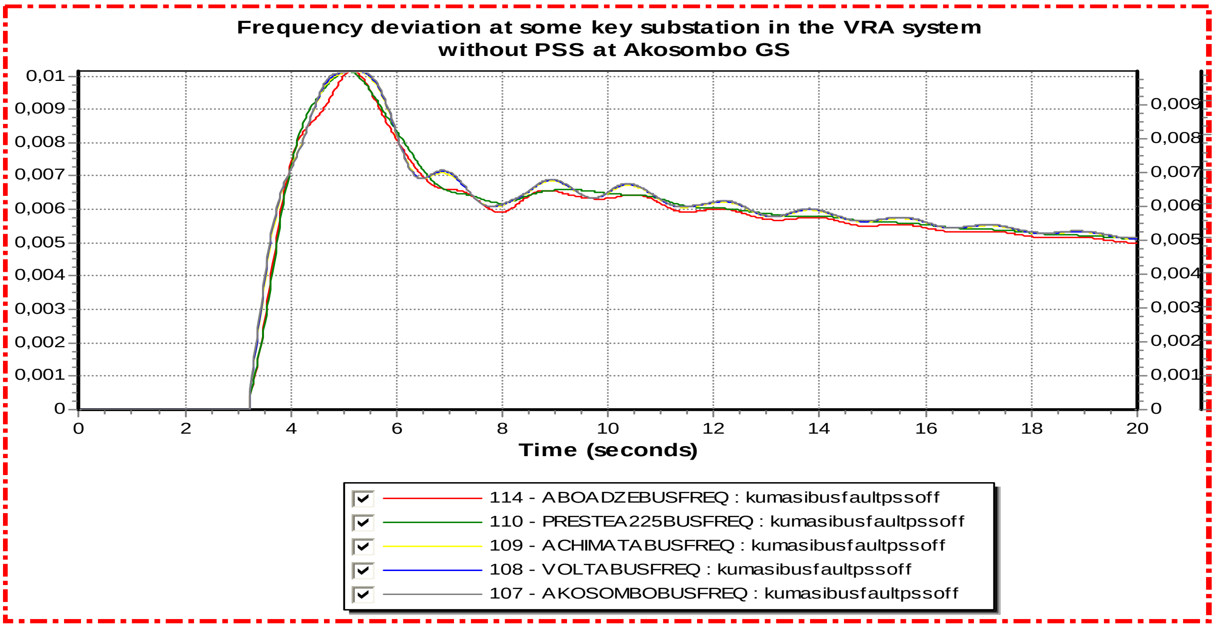

Fig4.47 frequency deviation monitored on some key substations in the VRA system without PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms.

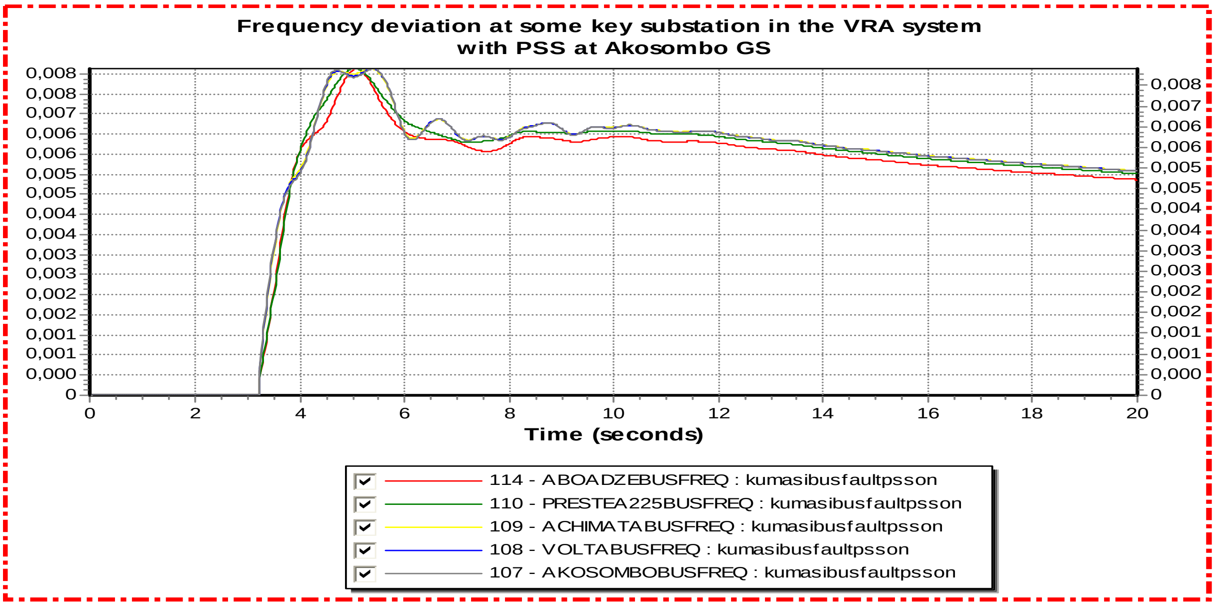

Fig4.48.frequency deviation monitored on some key substations in the VRA system with PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms.

4.3.3.5 Case 5: Average load condition (Akosombo-Kumasi contingency)

Finding of Case 5 (a)

(a)A three phase bus fault at Achimota substation cleared within 10cycle

In this case, it was observed that the application PSS at Akosombo GS prevented a partial system collapse as shown in fig4.49 and fig4.50. Without the application of PSS at Akosombo all the hydro generating units in operation at Akosombo and Kpong tripped following the fault from fig4.51 However Aboadze units survived the disturbance after the system was separated into two as was the case in Case2 (a).The only difference between this scenario and Case 2(a) is that the voltage did not collapse completely in Kumasi. A total voltage collapse was observed towards the northern part of Ghana.

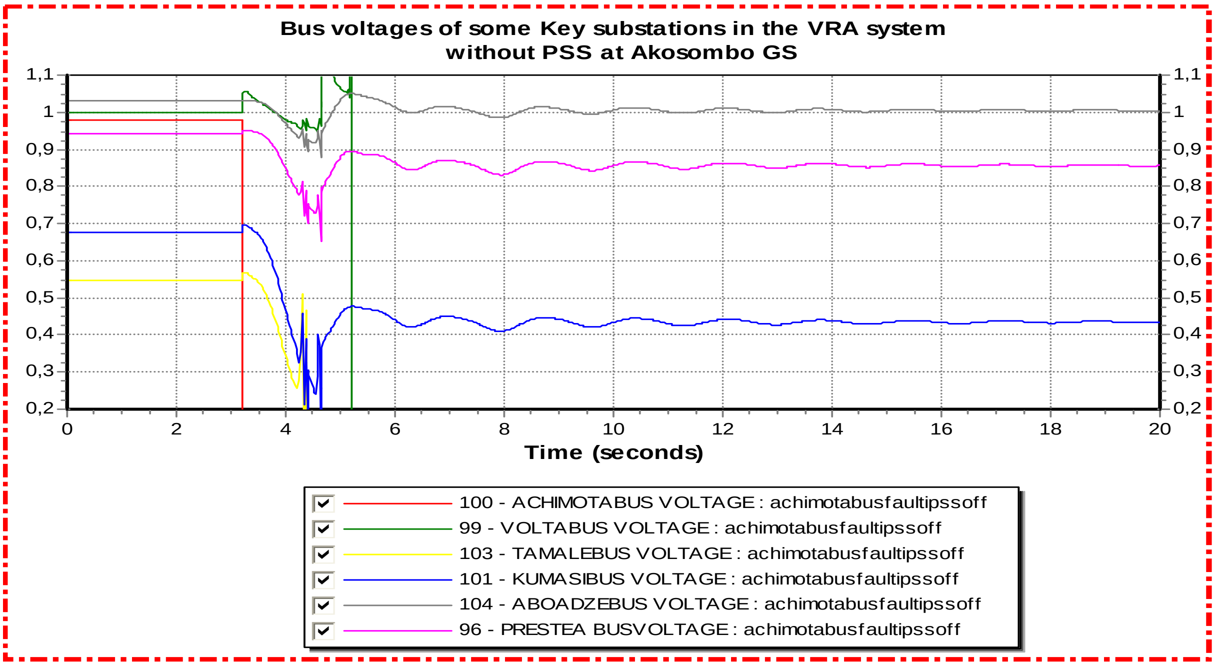

Fig4.49 Bus voltages of some key substations in the VRA system without PSS at Akosombo GS following a three phase bus fault at Achimota substation lasting 100ms

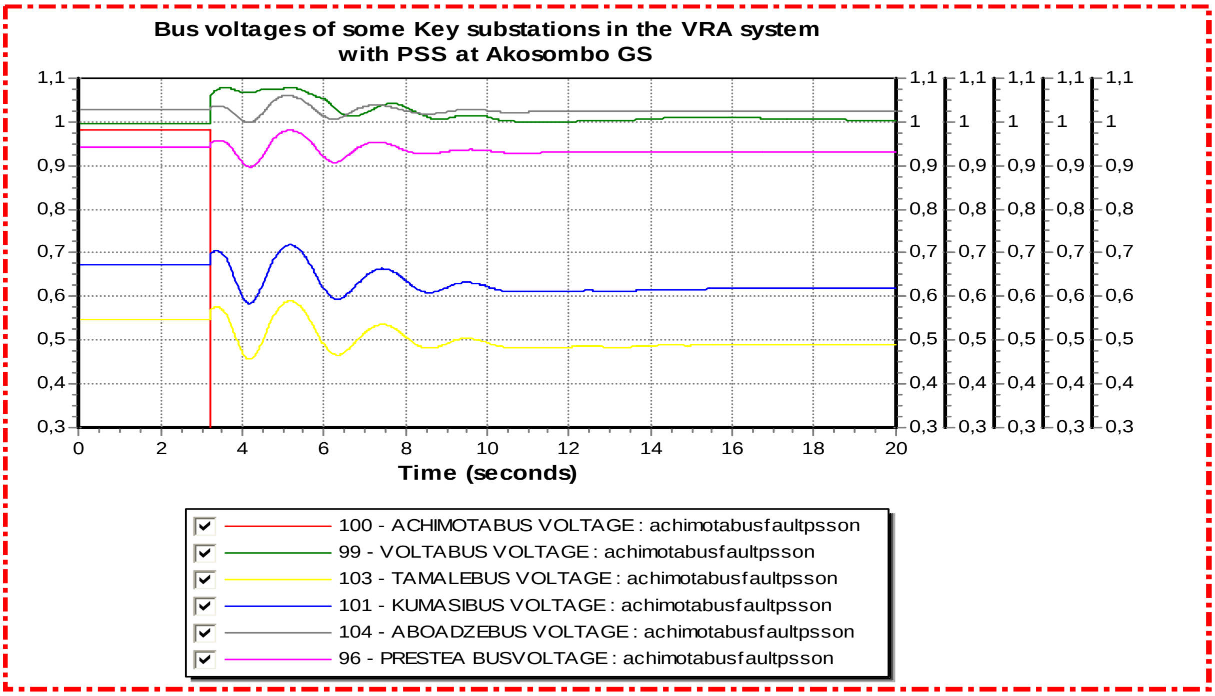

Fig4.50 Bus voltages of some key substations in the VRA system with PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms

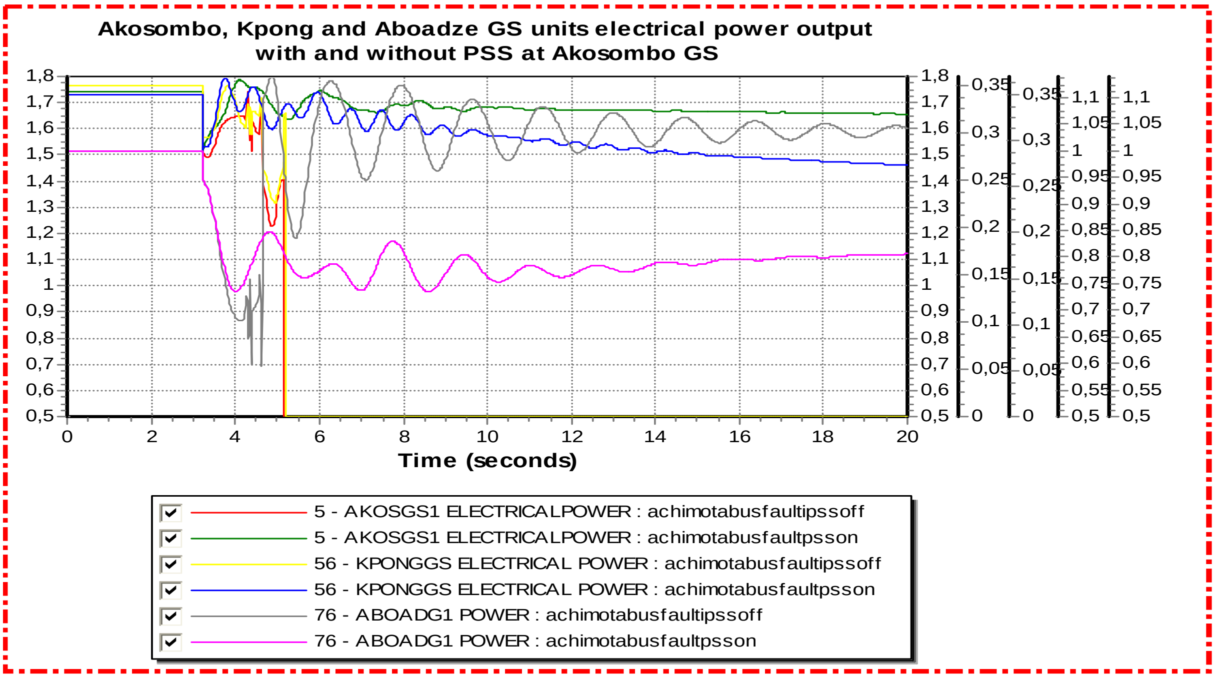

Fig4.51 Akosombo, Kpong and Aboadze units electrical power with and without PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms

Finding of Case 5(b)

(b)One unit loaded at 145 trips at Akosombo GS

A disturbance caused by the tripping of one unit at Akosombo GS made the rest of the generators in Akosombo and Kpong to oscillate together against Aboadze units at a frequency of about 0.7Hz as shown in fig4.52. This is an example of local area oscillation. However with a PSS at Akosombo the local area oscillation got damped completely, 7seconds after the fault but inter-units oscillations were introduced on the Akosombo units. Unit1 was found oscillating against units 2 and 3 at a frequency of 1.5Hz with low amplitude and some degree of damping (fig 4.53). The introduction of the inter-units oscillation means that a set of power system stabilizer [PSS] parameters which stabilizes the system under a certain operating condition may no longer yield satisfactory results when there is a drastic change in the operating point. This is why PSS with automatic tuning is being developed to correct this phenomenon.

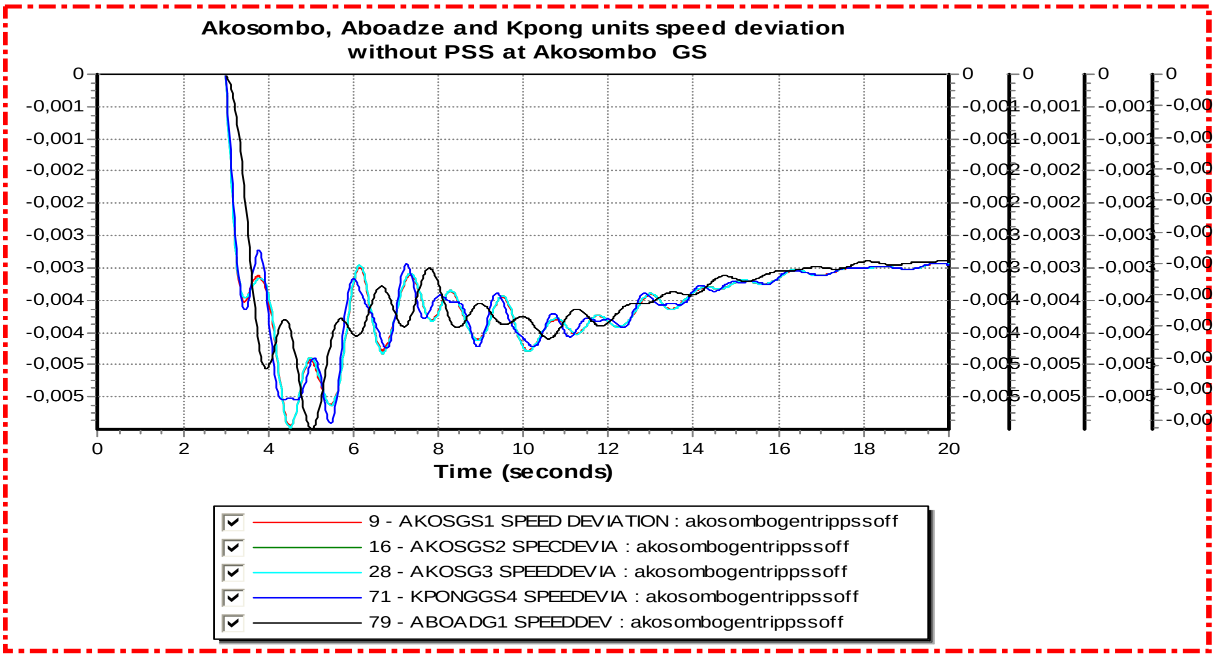

Fig4.52 Akosombo, Kpong and Aboadze units speed deviation without PSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms

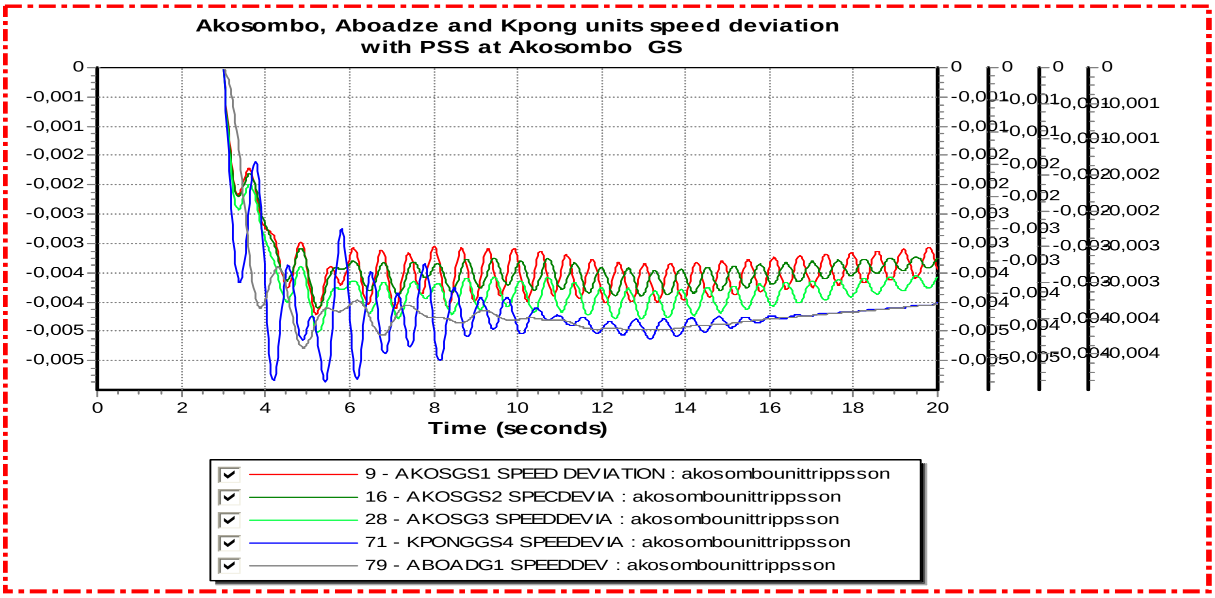

Fig4.53 Akosombo, Kpong and Aboadze units speed deviation withPSS at Akosombo GS following a three phase bus fault at Kumasi substation lasting 100ms

4.3.4 Discussion on the Effect of PSS at Akosombo on Transient Stability

From the all the simulation results it is very clear that PSS at Akosombo GS will enhance the dynamic performance of the VRA interconnected power system. All the generating units had their oscillation damped by a PSS at Akosombo GS during a disturbance. PSS improved system damping by adjusting the excitation voltage of the unit it is installed according to the unit speed deviation and the system voltage (fig4.35). The results also show that activating PSS at Aboadze units have very little impact in damping system oscillations (fig 4a).

The study assumed that, none of the units in the interconnected system have their PSS active, however, if the PSS of other generating units have to be activated then, the PSS at Akosombo has to be re-tuned to avoid any negative interaction. Presently none of the units equipped with PSS are activated. The effect of the operations of automatic frequency load shedding (AFLS) and line relays on the PSS were not considered in the study. However in practice PSS should be coordinated with system protection and control devices (2) such as AFLS, line protection, excitation protection and etc. for optimal performance.

PSS activated on all units at Akosombo GS damped all the oscillations observed in system parameters monitored in the all the scenarios studied. In two cases, the PSS prevented partial system collapse. The first case was a three phase bus fault at Achimota lasting 100ms during stressed peak load condition (Prestea –Obuasi contingency). The second case observed was during stressed average load condition (Akosombo-Kumasi contingency) with a three phase bus fault at Achimota lasting 100ms.

A three phase bus fault at Prestea 225KV bus during peak load condition caused all the generators to go out of step some seconds after the fault has been cleared. The activation of PSS at Akosombo GS did not have any effect in preventing the system collapse. Inter-area oscillations at a frequency of about 0.5Hz which was poorly damped were observed between the hydro units in Ghana and Azito Units in Cote d'Ivoire. Local area oscillations at a frequency of about 0.7Hz were also observed between Akosombo and Kpong units and Aboadze unit in Ghana. The PSS was able to damp both modes of oscillation completely, 9 seconds after clearing the fault.

In all the scenarios simulated, there was only one case where PSS damped completely inter-area and local area oscillation, but however introduced inter-units oscillations. This was observed after a unit trip at Akosombo GS during stressed average load condition (Akosombo-Kumasi contingency). In Akosombo GS, Unit1 oscillated against units 2 and 3 at a frequency of 1.5Hz with low amplitude and some degree of damping. This occurred because machine parameters change with loading, making the dynamic behaviour of the machine quite different at different operating conditions [24]–[26]. Consequently a set of power system stabilizer [PSS] parameters which stabilize the system under a certain operating condition may no longer yield satisfactory results when there is a drastic change in the operating point. This is why PSS with automatic tuning is being developed to correct this phenomenon. Many simulations had to be carried out because, with few simulations, many modes of oscillation will not be observed. However, modal analysis is able to displace the all modes at a goal.

Photo 4.7: 550MW Takoradi Thermal Power Station at Aboadze, Ghana. The excitation system EX2000 from General Electric is equipped with power system stabiliser(PSS)

Photo 4.8: The static excitation system, EX2000, at Takoradi Thermal Power Station,

Photo 4.9 The Master control card of EX2000 equipped with PSS controls

4.4 Small Signal Stability Studies

So far the method that has been used for dynamic stability analysis is the simulation method in the time domain using PSSE. This simulation method is suitable for both large and small signal stabilities analysis. Another method that can be used is the modal or eigenvalues analysis in the frequency domain which is exclusively suitable for small signal stability studies. The time simulation method is not able to capture at all the oscillatory modes that exist in a load flow condition, it is therefore not an exhaustive method for stability analysis. However with modal analysis, inherent properties of a studied dynamic system are revealed by eigenvalues. Rich information regarding frequency and damping of oscillation, mode observability and controllability, controller location and tuning are easily made available. The comparison of the two methods is shown in Table 4.22

In a multi-machine power system like Ghana's system, modal analysis can give the degree of participation of the various machines to a particular oscillatory mode and this information can be used in siting controllers like PSS. A units with very high participation factor to oscillatory modes are very good candidate for locating PSS. For this study, two locations considered for PSS are Akosombo and Aboadze GS. Results from transient simulation studies showed that Aboadze units contribute very little in damping oscillations and was therefore disqualified. Modal analysis is expected to confirm the observations made from transient simulation and give further rich information about the system.

4.4.1 Program Used For Small Signal Stability Studies(34)

NEVA, the program used for the modal analysis is from Siemens Power Transmission and Distribution the same company that produced PSSE. NEVA offers a comprehensive tool box of modal analysis. The tools include damping evaluation, mode observability and controllability, participation factors, transfer function residues, controller siting indices, frequency response plots, and linear impulse and step response. All modal results are visualized in graphics and this makes it easy to understand.

4.4.1.1 Challenge with the NEVA program

The NEVA program used for small signal stability studies did not work as it should. The program gave error massages found in Appendix 8 and stopped, anytime it was launched from PSSE platform for each of the five cases considered. Siemens was therefore contacted and they attributed it to defect in the software which there were correcting. However I did not receive the corrected version of the NEVA program before the dead line for the submission for thesis. Appendix 7 shows the email from Siemens explaining the defect in the software. I will however explain how I would have used the program to perform small signal stability studies. Fig 4.54 was sent by Siemens for Case1 and it represents the distribution of the eigenvalues for peak load condition with PSS activated on Akosombo units. Other tools like participation factors, controller siting indices, mode observability and controllability could not be performed on all the cases because of the defect in the software.

Table 4.22 Comparison of simulation method and modal analysis

	Simulation method (time domain)	Modal analysis (frequency domain)
Advantages of Modal analysis	Trial-and-Error approach by applying disturbances and observing plotted responses	Systematic approach which reveals rules behind complicated phenomena of system dynamics
	Different disturbances have to be applied	There is no need to apply disturbances
	Certain weakly damped and unstable modes may not be excited or observed during one simulation. A lot of simulations are required	For each load flow condition, one modal calculation is generally sufficient
	Modes of different frequencies and damping are mixed with each other and are difficult to identify	Weakly damped and unstable modes are picked out and analyzed in detail
	Evaluation of results is often difficult or can be misleading	Individual modes are analysed. For each mode, its pattern of oscillations is indicated unambiguously.
	No systematic information is available regarding most effective sites of damping controllers	Indices are provided for siting and tuning damping controllers, such as PSS and FACTS elements
Disadvantages of modal analyses	Wide application fields	Only suitable for small signal stability
	Nonlinearities are represented in detail	Nonlinearities are not well reflected
	There are basically no modelling limitations	Frequency domain modal results are not familiar to many people
	Time domain results in curves are taken for granted	Application-grade programs are seldom
	Application-grade programs are well established and available worldwide	System modelling and Eigenvalue algorithms are sophisticated

4.4.1.2 Interpretation of results from NEVA

NEVA calculates the eigenvalues and presents the results in the format shown in fig 4.54. This format shows how the various modes of oscillation (eigenvalues) are distributed in complex s-plane .The real part of the eigenvalue called sigma is represented on the X axis and it shows the degree of damping of the mode. The imaginary part called omega is represented on the Y axis (imaginary axis) and it shows the frequency of oscillations of the mode. If a mode is located on the right side of the plane with a positive sigma, it indicates unstable oscillatory mode or negative damping. When a mode located on the right side of the complex s-plan is excited, it grows in amplitude with time and the power system becomes unstable. To ensure a stable power system all modes must be located on the left side of the S-plane. It is also desired that modes lies far away leftwards from the imaginary axis so that the modes are damped out quickly.

Figure 4.54 also shows the classification of the different swing modes. Modes with frequency less than 0.1Hz and with high degree of damping are classified as controller mode. The controller mode is associated with controllers of voltage regulators, generator speed governor systems, FACTS and etc. Fig 4.54 shows location of modes from controllers on the complex S-plan. Frequencies between 1.5-3Hz are referred to as inter-units oscillations, frequencies 0.7 to 2Hz are local mode oscillation and frequencies below 0.5Hz are inter-area mode.

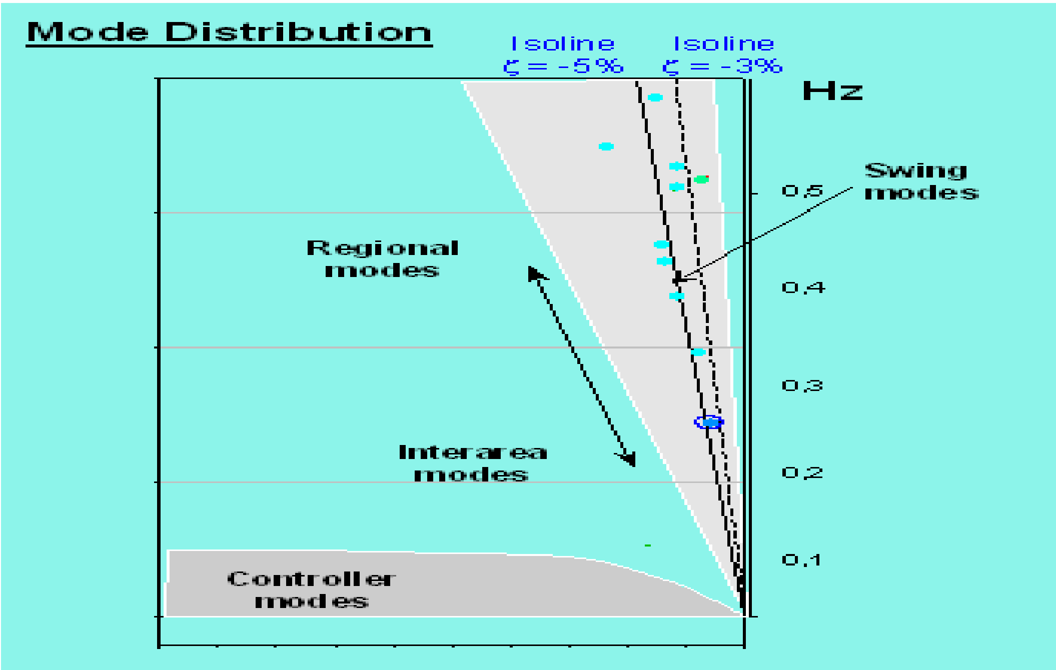

Fig 4.54Typical mode distribution on the complex s-plane for an interconnected powers system

4.4.2 Methodology for small signal stability

The five cases, Case1 to Case 5 that were used in the steady state and the transient stability studies were also used in the small signal stability studies. Each of the cases were opened with the PSSE and NEVA was then lunched from the PSSE platform. However the NEVA stopped because of a defect in the conversion process describe earlier. If the program had worked then eigenvalues would have been calculated with NEVA for each of the cases with and without PSS at Akosombo.

The distribution of the eigenvalues for each case with and without PSS at Akosombo would then be analysed. It is expected that the application of the PSS at Akosombo will generally shift all the eigenvalues leftwards from the imaginary axis and even if there were an unstable swing mode the PSS would have brought it to the stable area ie from right to the left. Controller siting indices, tool in NEVA that is used to identify the best location for controller like PSS could have also been used to confirm the suitability of Akosombo location.

4.4.3 Analysis of results for small signal stability

Fig 4.55 shows the distribution of the various modes in the complex s-plan for Case1. In the same figure 380 modes were identified and none of the eigenvalues were found in the unstable area. Most of the modes were controller modes from the controllers of the governors and automatic voltage regulators. These modes are not problematic modes because they are highly damped. However, the following modes were observed to be poorly damped because they had their damping ratio magnitude less than 5%. The modes that are poorly damped are circled in red in fig 4.55. Swing modes lying on the right side of the -3% line are generally not acceptable and none of the modes was found in that area.

Table.4.12. poorly damped eigenvalues for Case1.

Mode number	sigma	omega	Zeta (damping ratio)	frequency
2	-0.180	3.710	-4.9	0.590
3	-0.208	6.516	-3.8	0.878
16	-0.408	9.791	-4.2	1.558
17	-0.409	9.803	-4.2	1.560
18	-0.409	9.803	-4.2	1.560
19	-0.426	9.397	-4.5	1.496

Six modes were observed to be poorly damped as shown in Table 4.12. However because of the defect in the NEVA program, the participation index of each generating unit for the poorly damped mode could not be evaluated. In NEVA selection of participation factor in modal analysis gives a bar chart (fig 4.56) representing the scalar contribution of each unit to a particular mode of oscillations. The unit with the highest contribution to a problematic mode or high participation factor is a good candidate for

PSS and Akosombo units would have had a very high participation factor to poorly damped modes. This would have confirmed the results obtained from transient studies.

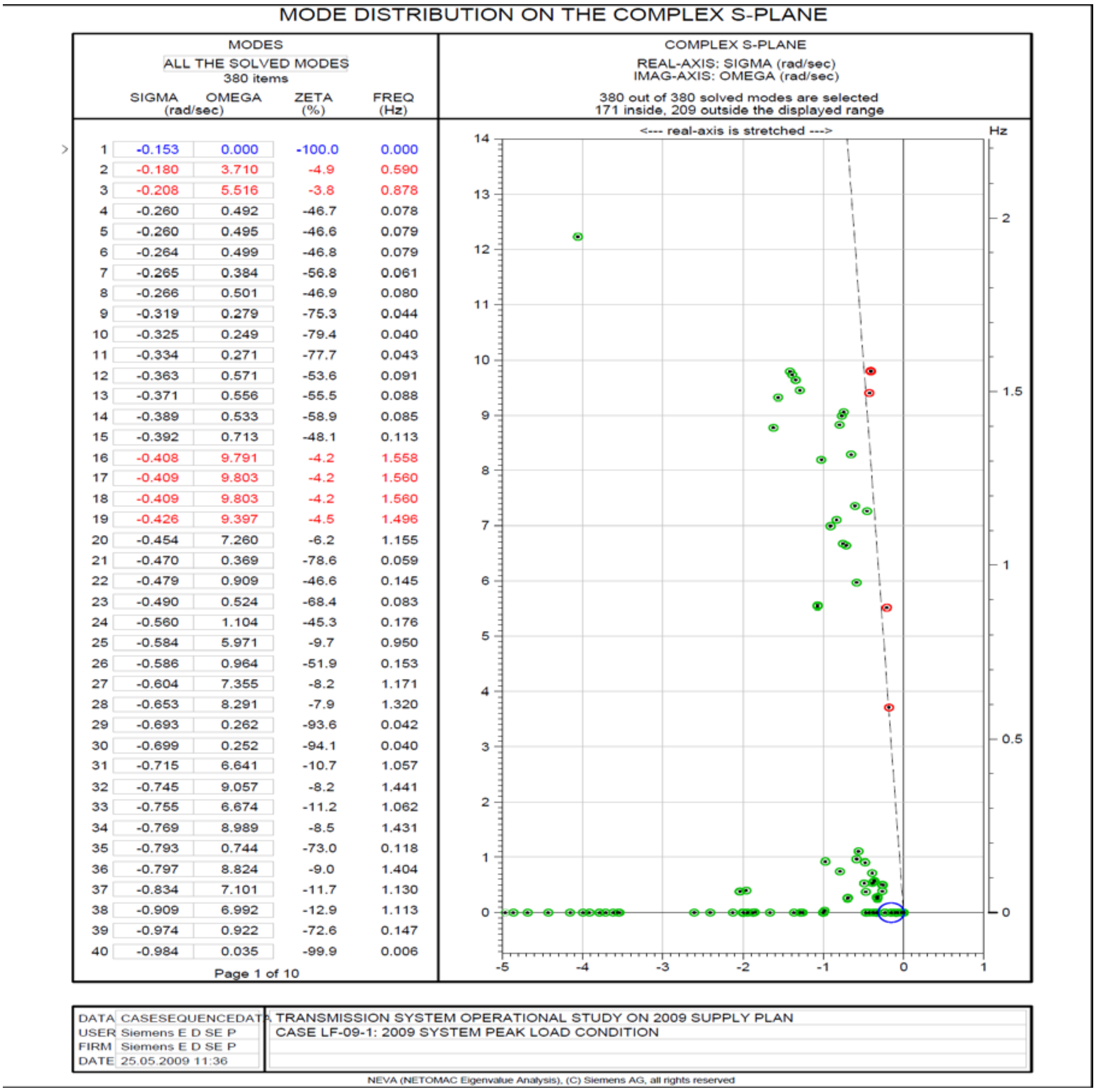

Fig 4.55. Mode distribution on the complex s-plan for Case1 with PSS activated at Akosombo GS

In NEVA, mode shape (mode observability) also gives bar chart results (fig4.57) showing how the unit oscillate with respect to one another to a particular mode. Units oscillating together have their bar directed in the same direction while units oscillating against one another have the bars in opposite directions .Units with no bar means they do participate in the oscillation at all. For example in fig 4.57 unit1 to 4 oscillate together for a particular eigenvalue against unit 5and 6.

Without mode shape analysis, it would be difficult to classify the poorly damped mode in table 4.12 and know the oscillatory behaviour of the generators with respect to each mode. With modal shape analysis it would have been easier to know how all the units in Ghana and the interconnected system participate in oscillations, and particularly it would have been helpful in identifying clearly the different types of oscillation. (Inter-units, local area or inter-area).

However during transient simulation, the frequency of mode 2(table 4.12) 0.59Hz was observed to be similar to oscillation between hydro units in Ghana and Azito units in Cote d'Ivoire shown in fig4.38 , an example of inter-area oscillation. Mode 3 with frequency 0.878Hz, has a similar frequency to oscillation observed between the hydro units and the thermal units in Ghana (fig 4.52) during transient simulation, an example of local-area oscillation. Mode 16-19 also had a similar frequency to inter-units oscillation between the Akosombo GS hydro units during transient as shown in fig 4.53.

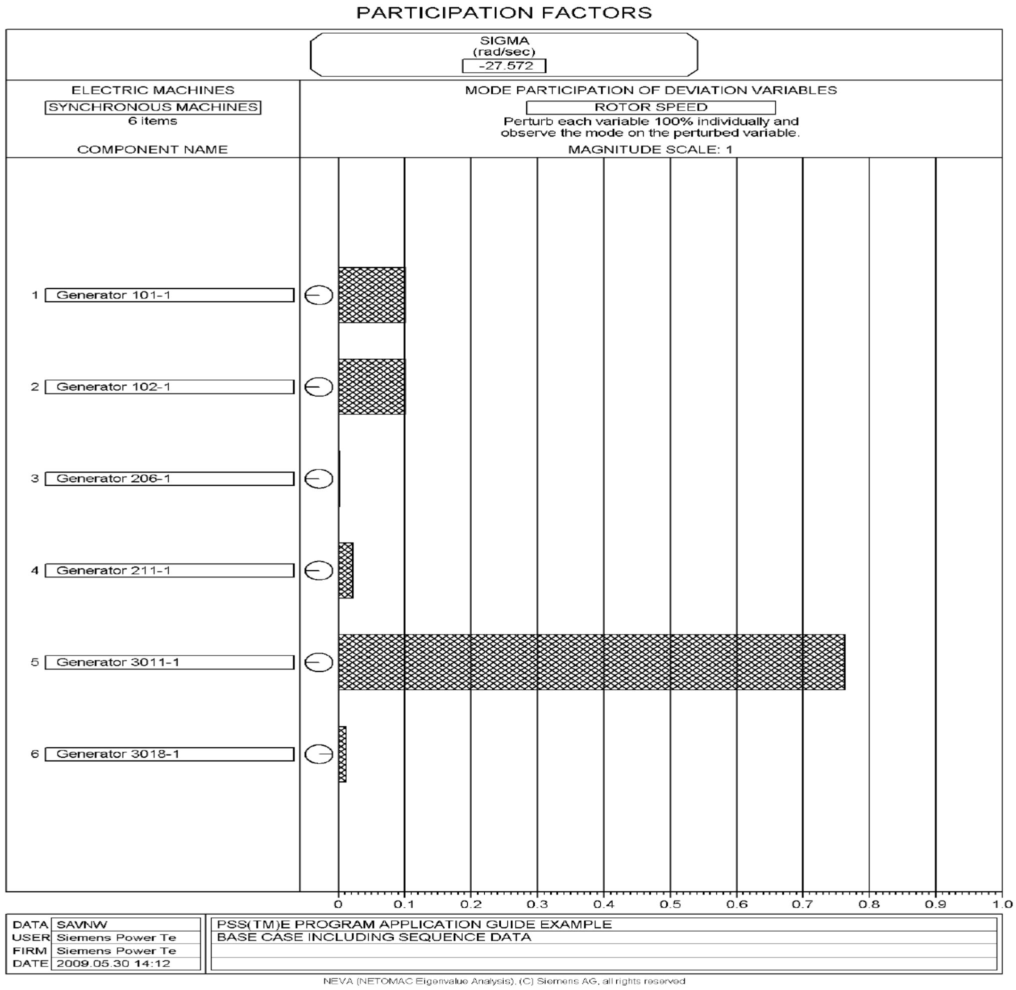

Fig 4.56: An example of results from NEVA showing the participation factors of individual generators to a particular mode due to rotor speed deviation.

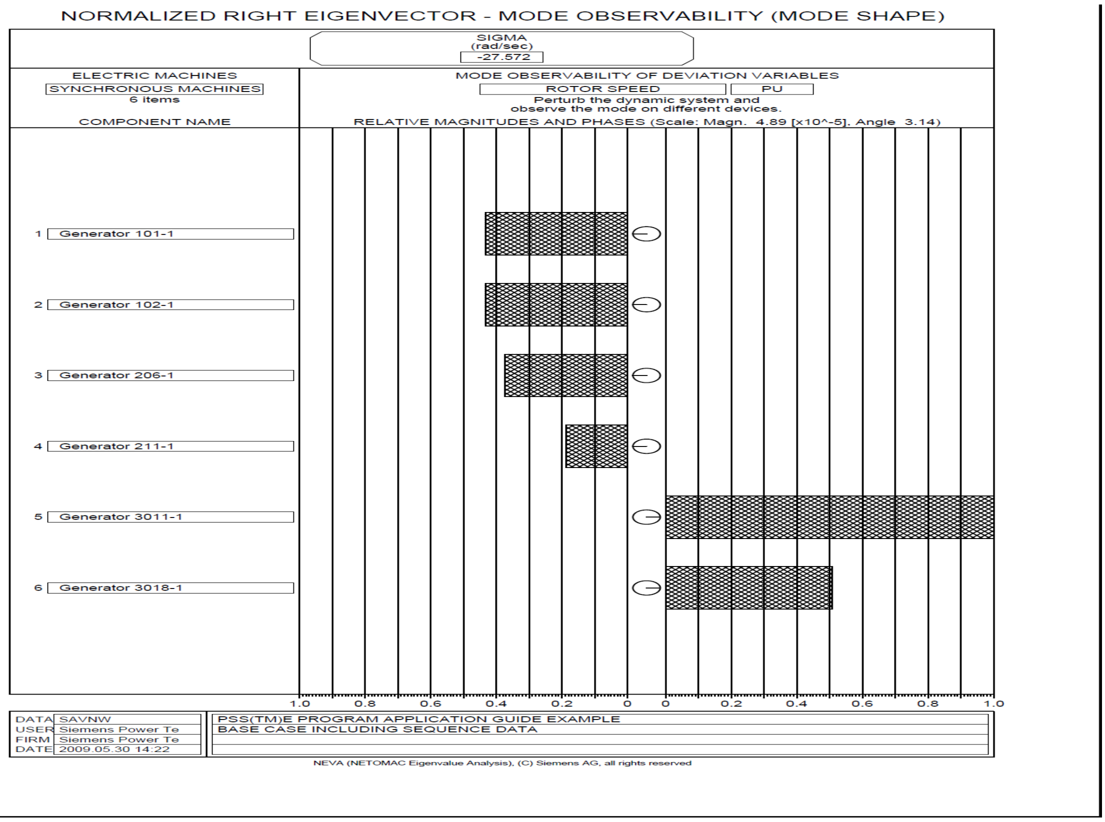

Fig 4.57: An example of results from NEVA showing mode observability of individual generators for a particular mode due to rotor speed deviation.

4.4.4 Discussions on small signal stability

Small signal stability analysis with NEVA even though gives rich information about a system, it is not appropriate to use it along to carry out a study of this nature because of the disadvantages enumerated in table4.12. It is therefore necessary to use both small signal and transient stabilities to assess the impact of PSS on the dynamic performance of Ghana power system.

The right Eigenvector of a mode indicates relative mode observability, while the left indicates the controllability. Both reflect relative influences of different system variables on the associated modes. Additionally they indicate which generator groups swing against which other generator groups and which generator play significant roles and which not.

To ensure a stable power system, all modes must be located on the left side of the complex s-plane. The damping ratio is often better measured than other indices. A damping ratio indicates the relation between the number of oscillations and the decayed amplitude. The modes on the right side of the isoline line on complex s-plane are displayed in red indication bad damping, the modes on the left side are shown in green. In analysis of low frequency oscillations in interconnected power systems, it is desired that swing modes lie on the left side of the -5% line. Swing modes lying on the right side of the -3% line are generally not acceptable.

CHAPTER FIVE

5.0 CONCLUSION, RECOMMENDATIONS AND FURTHER SCOPE OF WORK

5.1 Conclusion

From the results of the studies the following conclusions can be made

- Ghana's system from the steady state stability studies operates with very low steady state stability margin during the peak period. This is because there is a very high risk of voltage collapse during N-1 contingency especially on any critical line, unless some loads are shed. Very high reactive power generation were also observed from generation units during peak load condition due to inadequate local reactive power compensation devices. However this risk can be reduced considerably by improving the steady state stability operation using power factor correction devices to correct the power factor from 0.9 to 0.95 at the local level. Improving the system steady state operation will also improve system transient stability.

- Commissioning of additional transmission lines in the VRA system will also improve steady state operating condition during peak. The present 330KV costal line being constructed as part of the West African power pool project is expected to improve steady state stability.

- The dynamic performance of the VRA system is greatly enhanced by the application of PSS on Akosombo Generating units. Almost all the oscillations associated with system disturbance were effectively damped with the PSS. Effective damping was observed for all system parameters monitored. The application of PSS at Akosombo was observed to have prevented a partial system collapse of the VRA interconnected system during stressed operating conditions for some of the cases considered. A PSS at Aboadze units have very little impact in damping system oscillations

- From transient stability studies, an inter-area oscillation at a frequency of 0.5Hz was observed between the hydro units in Ghana and Azito in Cote d'Ivoire. Local area oscillations at a frequency of 0.8Hz was also observed between the hydro units and Aboadze units in Ghana. PSS at Akosombo GS damped those modes of oscillation as well. In one operating condition the PSS introduced some small amount of inter-units oscillation on some units at Akosombo. However PSS was able to damp effectively the other modes of oscillation. Not many results were obtained from small signal stability studies due to a defect in the NEVA program used for the study. However the few results obtained seems to support the conclusion made in from the transient stability study.

5.2 Recommendations

Based on the results of this study it is recommended that the PSS on the excitation system of all the Akosombo units be activated with their appropriate control parameter settings since their application has a positive impact on the dynamic performance of the VRA system.

The proposed dynamic model together with its parameters that were used in the simulation for the VRA system be validated using field test results on the units before activating the stabilizers on the units at Akosombo GS.

To optimise the performance of the PSS, a comprehensive study should be conducted to coordinate the existing system protection and control devices such as line relays, AFLS, with the PSS. Also adequate coordination of the protections and controls based on dynamic simulation studies should be done .This is because one of the causes of voltage collapse is lack of coordination between equipment protection and control and power system requirement.

It is also recommended that the steady state operation be improved by the installation of more power factor correction devices at the various substations to improve the power factor from 0.9 to 0.95. This is expected to optimise the performance of the PSS at Akosombo GS .The PSS and the power factor correction devices will improve the overall system stability.

Line over current relays settings should be reviewed to delay tripping time during overload conditions. This is because there is a very high probability of line overload during N-1 contingency on some critical line at peak period. This will give the system operators' time to carryout manual loading shedding to prevent a sudden and wide spread voltage collapse.

The possibility of installing under voltage load shedding should be considered in addition to the existing under frequency loading shedding.

Single pole fast re-closures are being used to improve transient stability in most networks worldwide. A study is therefore recommended, to be conducted to know how this technology could be implemented on new or existing transmission lines to improve transient stability of VRA system.

The construction of new transmission line along the coast of Ghana as part of the West African Power Pool Project (WAPP) to be operated at 330KV will have a significant improvement in the steady state stability of the VRA system and should be pursue vigorously.

5.2 Further Scope of work

This study did not include the effect or interaction of some protection and control devices such as automatic frequency load shedding (AFLS) , line protection relays on the performance of power system stabilizer. If these devices are not well coordinated, the stability of the system can be compromised. System protection and control devices therefore need to be coordinated effectively to avoid premature cascaded tripping of transmission lines and sustained system swings. The PSS to be installed on Akosombo units should be coordinated effectively with the system protection and control devices so that they all work together to enhance and optimise overall system stability.

Ghana's network is going to be part of the West African Interconnected Network called West African power pool. The power systems of individual counties in West Africa have their own inadequacies. This interconnection will therefore have effect on the stability of Ghana's power system.

A comprehensive study therefore needs to be conducted to make Ghana's system ready for the interconnection and institute measures that will insulate Ghana system from the problems of the other network from propagating into Ghana's network. The study should first review the coordination of all the system protection and control devices and the impact of these devices on the performance of the PSS on Ghana's system.

REFERENCES

1. Power system dynamics and stability Jan Machowshi,Janusz W.Bialek, James R Bumby
2. Power System Stability and Control Prabha Kundur
3. Definitions and classification of Power System Stability,IEEE/CIGRE Joint Task force on Stability
4. Application of power system stabilizers for enhancement of overall system stability; IEEE Transactions on Power Systems, Vol4 No.2 May 1989
5. Design of a proportional-integral power system stabilser IEEE Transactions on Power system Vol. PWRS-1.
6. Understanding Power System Stability, Michael J. Basler Richard C. Schaefer Members, IEEE Basler Electric Company
7. Practical Utility Experience with and Effective Use of Power System Stabilizers P. Kundur, G.R. BiruM, L.M. Hajagos,
8. Applying Power System Stabilizers , Parts I, II and III IEEE trans PAS 100 , Larsen, E.V, Swan D.V
9 Coordinated Application of Stabilizers in Multimachine Power Systems, IEEE T-PAS, F.P.deMello, et al
10 Selective Modal Analysis with Application to Electric Power System, ..J.Perez-Arriaga, et al, IEEE T- PAS, Vol.101, Sep. 1982
11 An Efficient Algorithm for Design of Decentralized Output Feedback Power System Stabilizer" C.L.Chen and Y.Y.Hsu , IEEE T-PWRS Vo1.3, Aug. 1988
12 Concepts of Synchronous Machine Stability as Affected by Excitation Controller, .C.Concordia and F.P.deMello, IEEE T-PAS, Vo1.88, Apr. 1969
13 Theory and Method for Selection of Power System Stabilizer Location , G.S. Hope
. C.Concordia and F.P.deMello, IEEE Transactions on Energy Conversion, Vol. 6, No. 1, March
14. Analytical Investigation of Factors Influencing Power System Stabilizer performance. IEEE trans Vol EC-7 ,M. Klein, G.J Rogers, S. Moorty and P. Kundur,
15 A PSS Tuning Toolbox and Its Applications, Lili Bu, Studetit, Wilsun Xu, Lei Wang , Frederic Howell, and Prabha Kundur,
16 Investigation of Low Frequency Inter-area Oscillation Problems in Lvge Interconnected Power Systems, Report for the Canadian ElectricaI Association. May 1993. CEA Project 294 T
17 H, damping controller design in large power system. M.Klein, G.J.Rogers. S.Frrokhpay. N.J.Balu. " IEEE Trans. Power System. vol. I, No.1. pp. 158.165, Feb.1995.
18 Robust design of electrical powerbased stabilizers using tabu search, M.A.Abida. Y.L.AbdeLMagid. Portel session 2001 IEEE Power.
19. Power system stabilizer design using optimal reduced order models Part I and Part II , Ali Feliachi. Xiaafan Z h e . Craie S . Sims Power System., Nov. 1988.

20. Application of power system stabililizers for Enhancement of overall system stability, P. Kundur, M.Klien, G.J.Rogers and M.S Zywwono .IEEE Trans., Vol..PWRS-4

21. Power system Stability tuning and testing at the Teside power project, R. J. Kooessler, R. C. Gough, J. D. Hurley 1999 IEEE Power Engineering society Summer Meeting. Edmonton.

23 Robust Tuning of Power System Stabilizers in Multimachine Power Systems , Y. L. Abdel-Magid, M. A. Abido, and A. H. Mantawy, IEEE Transactions on Power Systems, vol. 15, no. 2, may 2000

24 Concepts of synchronous machine stability as affected by excitation control, F.P. de Mello and C. Concordia, " IEEE Transactions on Power Appparatus and Systems, vol. PAS-88, 1969.

25 Dynamic Systems stability – investigation of the effect of different loadings and excitation systems, M. K. El-Sherbini and D. M. Mehta, IEEE Transactions on Power Appparatus and Systems, vol. PAS-92, 1973.

26, "Variable structure power stabilizer to supplement static-excitation Y. L. Abdel-Magid and G.W. Swift

27 www.cia.gov/library/publications/the-world-factbook

28. Study to access the state of transmission network in supporting planned generation, VRA

29. Final Report West Africa Regional Transmission Stability study, Master plan report

30. Volta River Authority Transmission and Generation Master Plan, Acres International, Canada

31. PSSE 31 Application guide VolumeI& II

32. PSSE 31 Program operation Manual Volume I&II

33 PSSE 31 User Manual

34 NEVA user Manual

APPENDIX

A1: Transient Stability Results

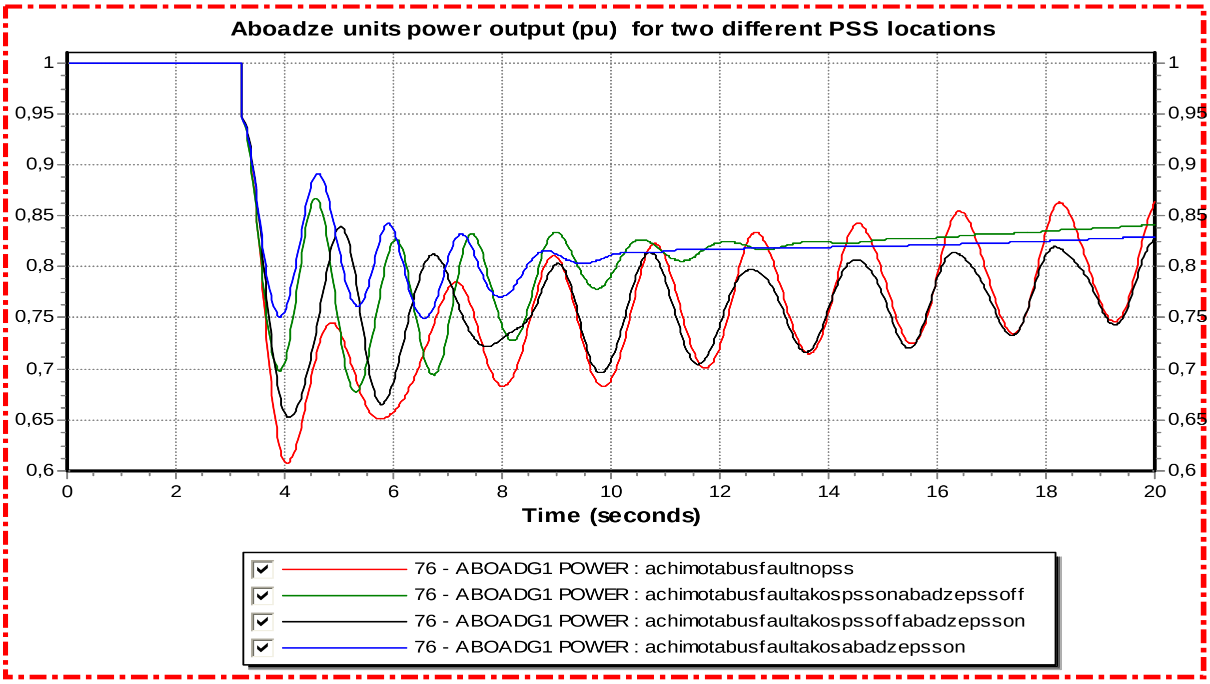

Fig A.1 Aboadze unit1 power output following a three phase fault at Achimota lasting 100ms with two different PSS location, Aboadze and Akosombo.

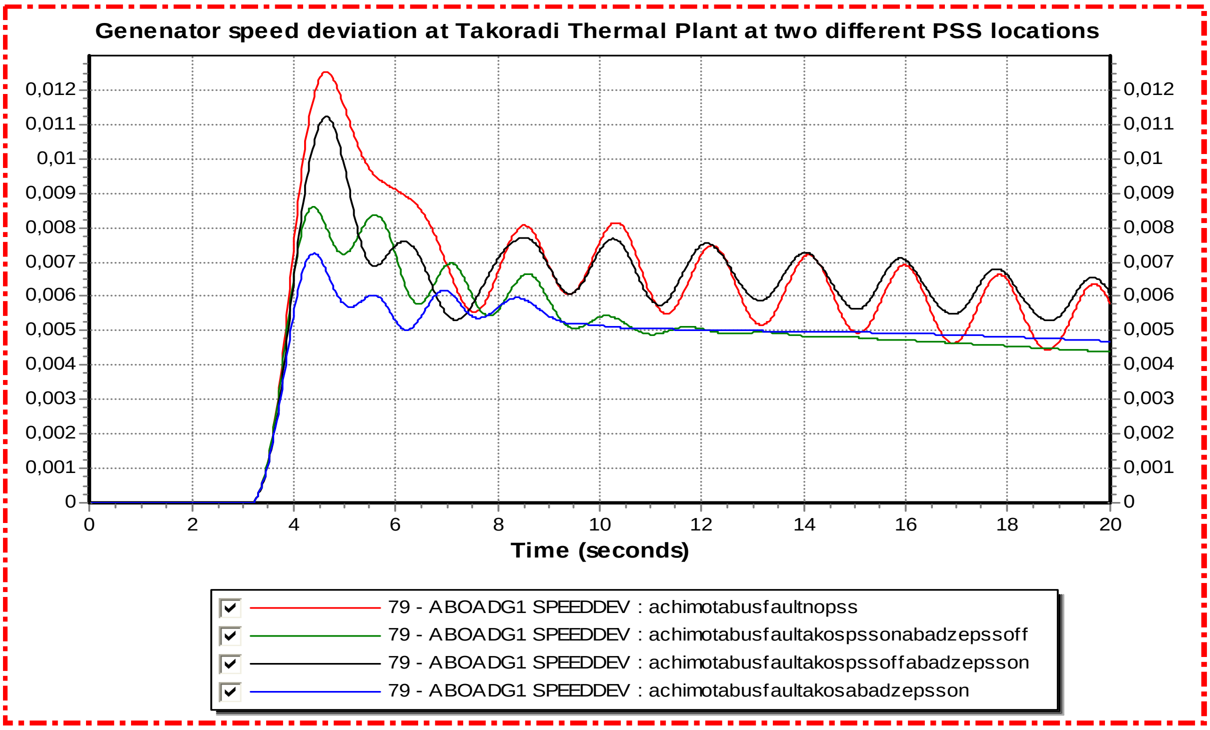

Fig A.2 Aboadze unit1 speed deviation following a three phase fault at Achimota lasting 100ms with two different PSS location, Aboadze and Akosombo

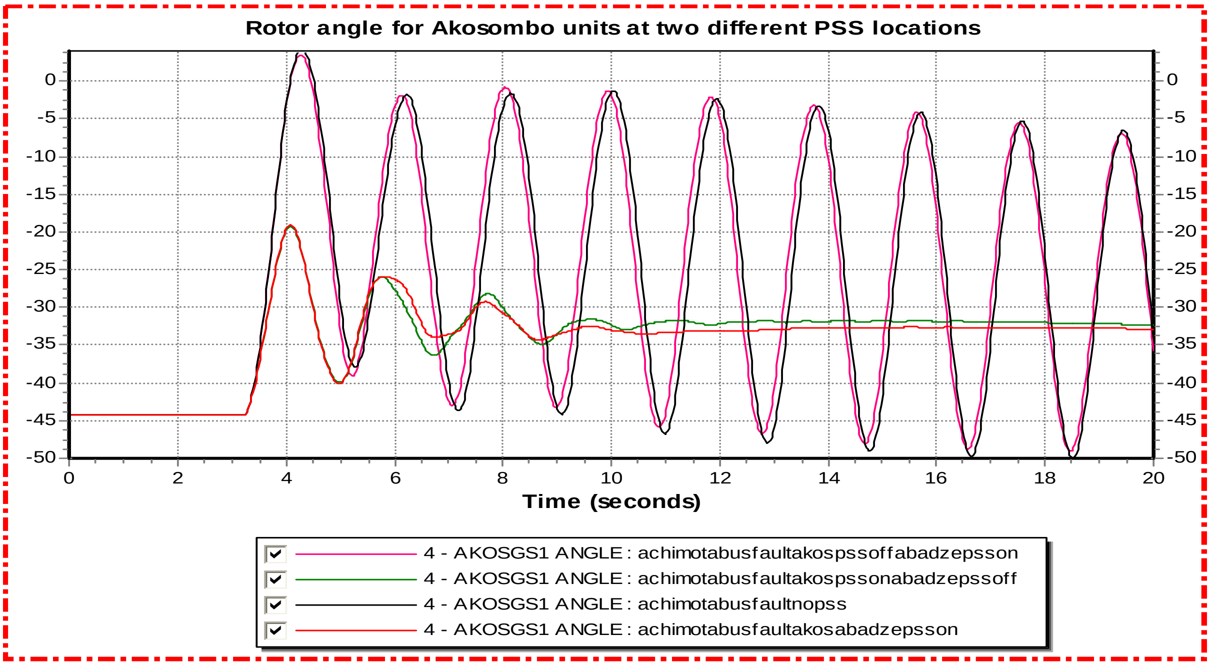

Fig A.3 Akosombo unit1 speed deviation following a three phase fault at Achimota lasting 100ms with two different PSS location, Aboadze and Akosombo

A2: Generator Models And Parameter Settings

```
                REPORT FOR GENERATOR MODELS IN AREA 1 [VRA          ]

 ** GENSAL **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
               1011 AKOS-GS1      14.400 1      1-12          1-5

              MBASE      Z S O R C E          X T R A N       GENTAP
              179.5   0.00000+J 0.21000   0.00000+J 0.00000   1.00000

   T'D0    T''D0    T''Q0       H     DAMP     XD       XQ       X'D     X''D      XL
  6.640    0.048    0.100    2.97     0.00   1.3900   0.7600   0.3100   0.2100   0.1450

                                   S(1.0)   S(1.2)
                                   0.0827   0.3233

 ** GENSAL **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
               1012 AKOS-GS2      14.400 1     13-24          6-10

              MBASE      Z S O R C E          X T R A N       GENTAP
              179.5   0.00000+J 0.21000   0.00000+J 0.00000   1.00000

   T'D0    T''D0    T''Q0       H     DAMP     XD       XQ       X'D     X''D      XL
  6.640    0.048    0.100    2.97     0.00   1.3900   0.7600   0.3100   0.2100   0.1450

                                   S(1.0)   S(1.2)
                                   0.0827   0.3233

 ** GENSAL **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
               1013 AKOS-GS3      14.400 1     25-36         11-15

              MBASE      Z S O R C E          X T R A N       GENTAP
              179.5   0.00000+J 0.21000   0.00000+J 0.00000   1.00000

   T'D0    T''D0    T''Q0       H     DAMP     XD       XQ       X'D     X''D      XL
  6.640    0.048    0.100    2.97     0.00   1.3900   0.7600   0.3100   0.2100   0.1450

                                   S(1.0)   S(1.2)
                                   0.0827   0.3233
```

```
** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1014 AKOS-GS4     14.400 1      37-48         16-20

            MBASE     Z S O R C E         X T R A N       GENTAP
            179.5  0.00000+J 0.21000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 6.640   0.048   0.100   2.97   0.00  1.3900  0.7600  0.3100  0.2100  0.1450

                              S(1.0)  S(1.2)
                              0.0827  0.3233

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1015 AKOS-GS5     14.400 1      49-60         21-25

            MBASE     Z S O R C E         X T R A N       GENTAP
            179.5  0.00000+J 0.21000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 6.640   0.048   0.100   2.97   0.00  1.3900  0.7600  0.3100  0.2100  0.1450

                              S(1.0)  S(1.2)
                              0.0827  0.3233

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1016 AKOS-GS6     14.400 1      61-72         26-30

            MBASE     Z S O R C E         X T R A N       GENTAP
            179.5  0.00000+J 0.21000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 6.640   0.048   0.100   2.97   0.00  1.3900  0.7600  0.3100  0.2100  0.1450

                              S(1.0)  S(1.2)
                              0.0827  0.3233

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1191 KPONGS1      13.800 1      73-84         31-35

            MBASE     Z S O R C E         X T R A N       GENTAP
             44.0  0.00000+J 0.27000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 4.500   0.045   0.045   2.90   0.00  0.8820  0.6000  0.3200  0.2700  0.1800

                              S(1.0)  S(1.2)
                              0.1107  0.3644

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1192 KPONGS2      13.800 1      85-96         36-40

            MBASE     Z S O R C E         X T R A N       GENTAP
             44.0  0.00000+J 0.27000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 4.500   0.045   0.045   2.89   0.00  0.8820  0.6000  0.3200  0.2700  0.1800

                              S(1.0)  S(1.2)
                              0.1107  0.3644

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1193 KPONGS3      13.800 1      97-108        41-45

            MBASE     Z S O R C E         X T R A N       GENTAP
             44.0  0.00000+J 0.27000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 4.500   0.045   0.045   2.89   0.00  0.8820  0.6000  0.3200  0.2700  0.1800

                              S(1.0)  S(1.2)
                              0.1107  0.3644

** GENSAL **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1194 KPONGS4      13.800 1     109-120        46-50

            MBASE     Z S O R C E         X T R A N       GENTAP
             44.0  0.00000+J 0.27000  0.00000+J 0.00000  1.00000

  T'D0   T''D0   T''Q0     H    DAMP    XD      XQ      X'D    X''D     XL
 4.500   0.045   0.045   2.89   0.00  0.8820  0.6000  0.3200  0.2700  0.1800

                              S(1.0)  S(1.2)
                              0.1107  0.3644
```

```
** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1321 ABOAD-G1     13.800 1     121-134        51-56

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.21400  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.035  0.60 0.038   7.78  0.00 2.4260 2.3440 0.3270 0.4120 0.2140 0.1780

                               S(1.0)  S(1.2)
                               0.0269  0.1252

** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1322 ABOAD-G2     13.800 1     135-148        57-62

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.21400  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.022  0.60 0.038   7.78  0.00 2.4260 2.3440 0.3270 0.4120 0.2140 0.1780

                               S(1.0)  S(1.2)
                               0.0269  0.1252


** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1323 ABOA-G3      13.800 1     149-162        63-68

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.22000  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.035  0.60 0.038   4.84  0.00 2.4880 2.4030 0.3350 0.4190 0.2200 0.1830

                               S(1.0)  S(1.2)
                               0.0269  0.1252

** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1324 ABOA-G4      13.800 1     163-176        69-74

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.21400  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.022  0.60 0.038   7.78  0.00 2.4260 2.3440 0.3270 0.4120 0.2140 0.1780

                               S(1.0)  S(1.2)
                               0.0269  0.1252

** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1325 ABOAD-G5     13.800 1     177-190        75-80

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.21400  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.022  0.60 0.038   7.78  0.00 2.4260 2.3440 0.3270 0.4120 0.2140 0.1780

                               S(1.0)  S(1.2)
                               0.0269  0.1252

** GENROU **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
             1510 TT1PP-G1     13.800 1    1827-1840      699-704

            MBASE     Z S O R C E         X T R A N       GENTAP
            141.7  0.00000+J 0.21400  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 7.64 0.035  0.60 0.380   7.78  0.00 2.4260 2.3440 0.3270 0.4120 0.2410 0.1780

                               S(1.0)  S(1.2)
                               0.0269  0.1252
```

A3 : Exciter Models And Parameter Settings

```
               REPORT FOR EXCITER MODELS IN AREA 1 [VRA         ]

** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
```

```
           1011 AKOS-GS1     14.400 1     610-633       302-308

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160


** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1012 AKOS-GS2     14.400 1     634-657       309-315

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160

** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1013 AKOS-GS3     14.400 1     658-681       316-322

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160

** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1014 AKOS-GS4     14.400 1     682-705       323-329

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160

** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1015 AKOS-GS5     14.400 1     706-729       330-336

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160

** EXPIC1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1016 AKOS-GS6     14.400 1     730-753       337-343

       TR      KA     TA1     VR1      VR2     TA2     TA3     TA4
     0.000     2.0  10.000   1.000   -0.870   0.010   0.000   0.000

         VRMAX   VRMIN     KF     TF1     TF2    EFDMAX   EFDMIN
         1.000  -0.870   0.000   1.000   0.000    4.810   -4.810

     KE      TE      E1   SE(E1)     E2   SE(E2)     KP      KI      KC
   1.000   0.000   1.000   0.100   1.200   0.300   3.850   0.000   0.160

** EXST1 **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1191 KPONGS1      13.800 1     754-765       344-347

            TR    VIMAX   VIMIN     TC      TB      KA      TA
          0.020   0.200  -0.200   0.025   0.175   100.0   0.025

                  VRMAX   VRMIN     KC      KF      TF
                  5.300  -3.000   0.000   0.056   0.762


** EXST1 **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
           1192 KPONGS2      13.800 1     766-777       348-351

            TR    VIMAX   VIMIN     TC      TB      KA      TA
          0.020   0.200  -0.200   0.025   0.175   100.0   0.025
```

```
                VRMAX   VRMIN     KC      KF      TF
                5.300  -3.000   0.000   0.056   0.762

** EXST1 **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1193 KPONGS3      13.800 1     778-789       352-355

          TR    VIMAX   VIMIN     TC      TB      KA      TA
        0.020   0.200  -0.200   0.025   0.175   100.0   0.025

                VRMAX   VRMIN     KC      KF      TF
                5.300  -3.000   0.000   0.056   0.762

** EXST1 **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1194 KPONGS4      13.800 1     790-801       356-359

          TR    VIMAX   VIMIN     TC      TB      KA      TA
        0.020   0.200  -0.200   0.025   0.175   100.0   0.025

                VRMAX   VRMIN     KC      KF      TF
                5.300  -3.000   0.000   0.056   0.762

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1321 ABOAD-G1     13.800 1     802-818       360-363

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.000

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1322 ABOAD-G2     13.800 1     819-835       364-367

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.000

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1323 ABOA-G3      13.800 1     836-852       368-371

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.000

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1324 ABOA-G4      13.800 1     853-869       372-375

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.000

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1325 ABOAD-G5     13.800 1     870-886       376-379

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.000

** ESST4B **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S
          1510 TT1PP-G1     13.800 1    1841-1857      705-708

   TR    KPR     KIR     VRMAX    VRMIN    TA     KPM     KIM    VMMAX   VMMIN
 0.000   2.590   2.590   1.000  -0.870   0.010   1.000   0.000   1.000  -0.870

         KG       KP      KI    VBMAX     KC      XL    THETAP
       0.000   7.720   0.000    9.660   0.070  0.0000   0.00
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A4 : Governor Models And Parameter Settings

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              REPORT FOR GOVERNOR MODELS IN AREA 1 [VRA         ]

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1011 AKOS-GS1     14.400 1    1270-1289      496-502        28     31
    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700
    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000
    VELMAX     VELMIN
     0.167    -0.167
              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL
** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1012 AKOS-GS2     14.400 1    1290-1309      503-509        29     32
    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700
    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
    0.167    -0.167
              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1013 AKOS-GS3     14.400 1    1310-1329      510-516        30     33

    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1014 AKOS-GS4     14.400 1    1330-1349      517-523        31     34

    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1015 AKOS-GS5     14.400 1    1350-1369      524-530        32     35

    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
             1016 AKOS-GS6     14.400 1    1370-1389      531-537        33     36

    RPERM   TREG     KP       KI      KD       TA       TB    DTURB
   0.0300   0.050  3.5000   0.5000   0.000   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL
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** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
            1191 KPONGS1      13.800 1    1390-1409      538-544        34     37

    RPERM   TREG     KP       KI      KD       TA      TB    DTURB
   0.0400   0.050  2.0000   2.0000   2.200   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
            1192 KPONGS2      13.800 1    1410-1429      545-551        35     38

    RPERM   TREG     KP       KI      KD       TA      TB    DTURB
   0.0400   0.050  2.0000   2.0000   2.200   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
            1193 KPONGS3      13.800 1    1430-1449      552-558        36     39

    RPERM   TREG     KP       KI      KD       TA      TB    DTURB
   0.0400   0.050  2.0000   2.0000   2.200   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** PIDGOV **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR   ICON
            1194 KPONGS4      13.800 1    1450-1469      559-565        37     40

    RPERM   TREG     KP       KI      KD       TA      TB    DTURB
   0.0400   0.050  2.0000   2.0000   2.200   0.100   0.300   0.700

    G0      G1       P1      G2       P2      P3     GMAX    GMIN    ATW     TW
   0.220   0.600   0.480   0.850   0.880   1.000   1.000   0.000   1.000   1.000

    VELMAX     VELMIN
     0.167    -0.167

              ICON(M)=1; PIDGOV USES GATE POSITION AS FEEDBACK SIGNAL

** GAST **    BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR
            1321 ABOAD-G1     13.800 1    1470-1478      566-568        38

      R      T1     T2      T3   LOAD LIM   KT     VMAX    VMIN     DT
    0.040  0.460  0.200   3.000   0.783   3.000   1.063   0.136   0.000

** GAST **    BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR
            1322 ABOAD-G2     13.800 1    1479-1487      569-571        39

      R      T1     T2      T3   LOAD LIM   KT     VMAX    VMIN     DT
    0.040  0.046  0.200   3.000   0.783   3.000   1.063   0.136   0.000

** IEEEG1 **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S
            1323 ABOA-G3      13.800 1    1488-1507      572-577        40-41

     K      T1      T2      T3     UO      UC     PMAX   PMIN     T4      K1
  20.00   0.000   0.000   1.150  0.250  -0.250 0.8500 0.0000   0.400   1.000

   K2      T5      K3      K4      T6      K5      K6      T7      K7      K8
 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000

** GAST **    BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR
            1324 ABOA-G4      13.800 1    1508-1516      578-580        42

      R      T1     T2      T3   LOAD LIM   KT     VMAX    VMIN     DT
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    0.040  0.460  0.200   3.000   0.783   3.000   1.063   0.136   0.000

 ** GAST **    BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR
             1325 ABOAD-G5     13.800 1    1517-1525      581-583        43

      R      T1     T2      T3   LOAD LIM   KT     VMAX    VMIN     DT
    0.040  0.460  0.200   3.000   0.783   3.000   1.063   0.136   0.000

 ** GAST **    BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     VAR
             1510 TT1PP-G1     13.800 1    1858-1866      709-711        93

      R      T1     T2      T3   LOAD LIM   KT     VMAX    VMIN     DT
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A5: Stabiliser Models and Parameter Settings

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                    REPORT FOR STABILIZER MODELS AT ALL BUSES

 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
             1011 AKOS-GS1     14.400 1    1867-1883      712-727        94-97         61-66
                   IC1 REMBUS1     IC2 REMBUS2       M       N
                     1       0       3       0       5       1

      TW1      TW2      T6      TW3      TW4      T7       KS2      KS3
    10.000   10.000    0.035   10.000    2.000   10.000    0.640    1.000

      T8       T9      KS1       T1       T2       T3       T4      VSTMAX   VSTMIN
     0.500    0.100   25.000    0.150    0.020    0.150    0.025    0.100   -0.100

 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
             1012 AKOS-GS2     14.400 1    1884-1900      728-743        98-101        67-72
                   IC1 REMBUS1     IC2 REMBUS2       M       N
                     1       0       3       0       5       1

      TW1      TW2      T6      TW3      TW4      T7       KS2      KS3
    10.000   10.000    0.035   10.000    2.000   10.000    0.640    1.000

      T8       T9      KS1       T1       T2       T3       T4      VSTMAX   VSTMIN
     0.500    0.100   25.000    0.150    0.020    0.150    0.025    0.100   -0.100

 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
             1013 AKOS-GS3     14.400 1    1901-1917      744-759       102-105        73-78
                   IC1 REMBUS1     IC2 REMBUS2       M       N
                     1       0       3       0       5       1

      TW1      TW2      T6      TW3      TW4      T7       KS2      KS3
    10.000   10.000    0.035   10.000    2.000   10.000    0.640    1.000

      T8       T9      KS1       T1       T2       T3       T4      VSTMAX   VSTMIN
     0.500    0.100   25.000    0.150    0.020    0.150    0.025    0.100   -0.100

 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
             1014 AKOS-GS4     14.400 1    1918-1934      760-775       106-109        79-84
                   IC1 REMBUS1     IC2 REMBUS2       M       N
                     1       0       3       0       5       1

      TW1      TW2      T6      TW3      TW4      T7       KS2      KS3
    10.000   10.000    0.035   10.000    2.000   10.000    0.640    1.000

      T8       T9      KS1       T1       T2       T3       T4      VSTMAX   VSTMIN
     0.500    0.100   25.000    0.150    0.020    0.150    0.025    0.100   -0.100

 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
             1015 AKOS-GS5     14.400 1    1935-1951      776-791       110-113        85-90

                   IC1 REMBUS1     IC2 REMBUS2       M       N
                     1       0       3       0       5       1

      TW1      TW2      T6      TW3      TW4      T7       KS2      KS3
    10.000   10.000    0.035   10.000    2.000   10.000    0.640    1.000

      T8       T9      KS1       T1       T2       T3       T4      VSTMAX   VSTMIN
     0.500    0.100   25.000    0.150    0.020    0.150    0.025    0.100   -0.100


 ** PSS2A  **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S     V A R S      I C O N
S
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1016 AKOS-GS6	14.400 1	1952-1968	792-807	114-117	91-96	

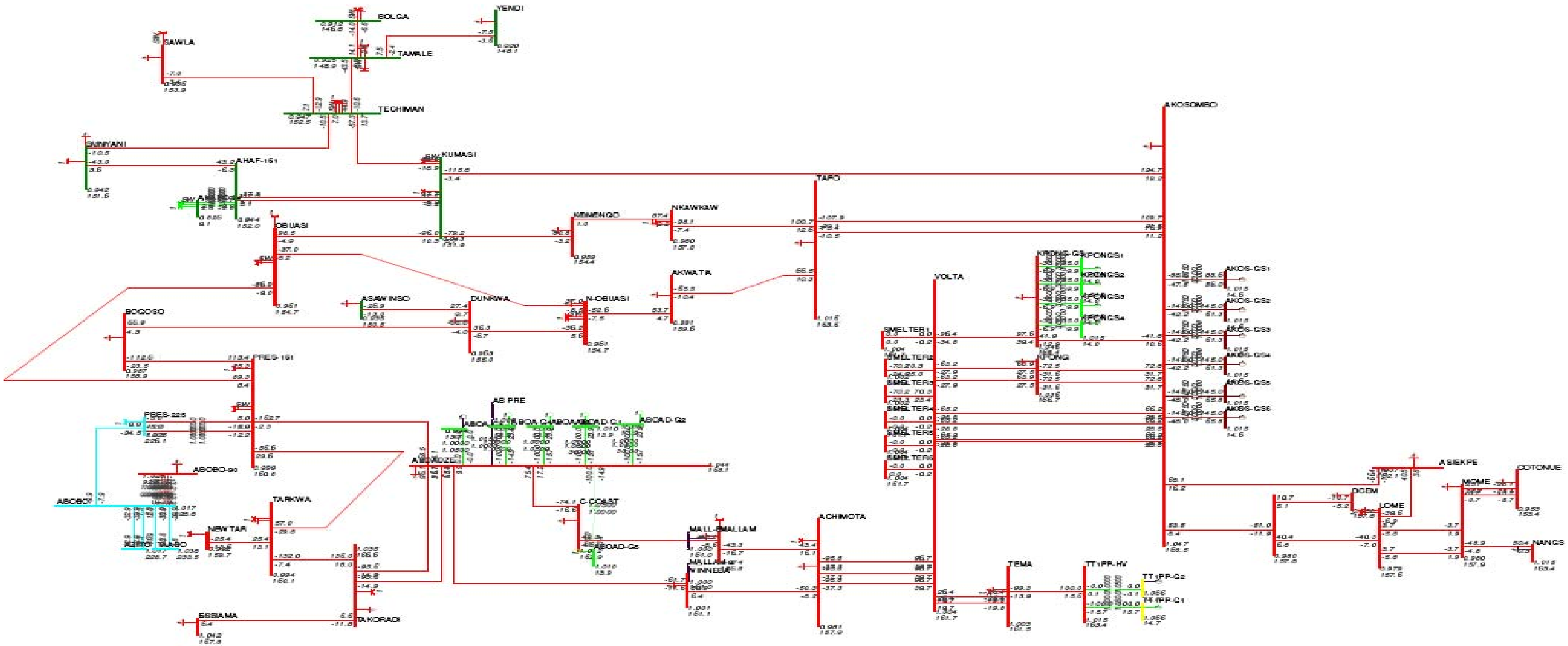
IC1	REMBUS1	IC2	REMBUS2	M	N
1	0	3	0	5	1

TW1	TW2	T6	TW3	TW4	T7	KS2	KS3
10.000	10.000	0.035	10.000	2.000	10.000	0.640	1.000

T8	T9	KS1	T1	T2	T3	T4	VSTMAX	VSTMIN
0.500	0.100	25.000	0.150	0.020	0.150	0.025	0.100	-0.100

A6: Load Flow Results

Peak Load Condition at power factor of 0.9 on single line diagram (case1)



Peak load condition at power factor of 0.9 (case1 table results)

BUS	1010	AKOSOMBO	161.00	CKT	MW	MVAR	MVA	%	1.0467PU	25.92	X--- LOSSES	---X	X---- AREA -----X	X---- ZONE -----X	1010
									168.52KV		MW	MVAR	1 VRA	1	
TO	LOAD-PQ				11.9	5.8	13.2								
TO	1011	AKOS-GS1	14.400	1	-88.6	-47.5	100.6	50	1.0750LK	30.00LK	0.00	8.47	1 VRA	1	
TO	1012	AKOS-GS2	14.400	1	-145.0	-42.2	151.0	76	1.0750LK	30.00LK	0.00	19.10	1 VRA	1	
TO	1013	AKOS-GS3	14.400	1	-145.0	-42.2	151.0	76	1.0750LK	30.00LK	0.00	19.10	1 VRA	1	
TO	1014	AKOS-GS4	14.400	1	-145.0	-42.2	151.0	76	1.0750LK	30.00LK	0.00	19.10	1 VRA	1	
TO	1015	AKOS-GS5	14.400	1	-145.0	-48.0	152.7	76	1.0750LK	30.00LK	0.00	17.77	1 VRA	1	
TO	1016	AKOS-GS6	14.400	1	-145.0	-48.0	152.7	76	1.0750LK	30.00LK	0.00	17.77	1 VRA	1	
TO	1020	VOLTA	161.00	1	66.2	28.5	72.1	32			1.04	5.03	1 VRA	1	
TO	1020	VOLTA	161.00	2	66.2	28.5	72.1	32			1.04	5.03	1 VRA	1	
TO	1020	VOLTA	161.00	3	66.2	28.5	72.1	32			1.04	5.03	1 VRA	1	
TO	1020	VOLTA	161.00	4	66.2	28.5	72.1	32			1.04	5.03	1 VRA	1	
TO	1130	KUMASI	161.00	1	124.7	19.2	126.2	33			8.90	38.86	1 VRA	3	
TO	1150	TAFO	161.00	1	76.9	11.2	77.7	44			1.51	5.42	1 VRA	3	
TO	1150	TAFO	161.00	2	109.7	21.5	111.8	59			1.81	7.90	1 VRA	3	
TO	1170	KPONG	161.00	1	72.8	31.7	79.5	36			0.30	1.42	1 VRA	1	
TO	1170	KPONG	161.00	2	72.8	31.7	79.5	36			0.30	1.42	1 VRA	1	
TO	1190	KPONG-GS	161.00	1	-41.8	10.6	43.1	19			0.13	0.65	1 VRA	1	
TO	1220	ASIEKPE	161.00	1	68.1	16.2	70.1	52			1.79	4.04	1 VRA	1	
TO	1392	AFTAP	161.00	1	53.5	8.4	54.1	40			2.45	5.61	1 VRA	1	

BUS	1020	VOLTA	161.00	CKT	MW	MVAR	MVA	%	1.0043PU	22.56	X--- LOSSES	---X	X---- AREA -----X	X---- ZONE -----X	1020
									161.69KV		MW	MVAR	1 VRA	1	
TO	1010	AKOSOMBO	161.00	1	-65.2	-28.8	71.3	33			1.04	5.03	1 VRA	1	
TO	1010	AKOSOMBO	161.00	2	-65.2	-28.8	71.3	33			1.04	5.03	1 VRA	1	
TO	1010	AKOSOMBO	161.00	3	-65.2	-28.8	71.3	33			1.04	5.03	1 VRA	1	
TO	1010	AKOSOMBO	161.00	4	-65.2	-28.8	71.3	33			1.04	5.03	1 VRA	1	
TO	1031	SMELTER1	161.00	1	0.0	-0.2	0.2	0			0.00	0.00	1 VRA	3	
TO	1032	SMELTER2	161.00	1	70.3	25.0	74.6	35			0.05	0.27	1 VRA	3	
TO	1033	SMELTER3	161.00	1	70.3	23.4	74.0	35			0.05	0.27	1 VRA	3	
TO	1034	SMELTER4	161.00	1	0.0	-0.2	0.2	0			0.00	0.00	1 VRA	3	
TO	1035	SMELTER5	161.00	1	0.0	-0.2	0.2	0			0.00	0.00	1 VRA	3	
TO	1036	SMELTER6	161.00	1	0.0	-0.2	0.2	0			0.00	0.00	1 VRA	3	
TO	1040	TEMA	161.00	1	26.4	19.7	32.9	15			0.01	0.05	1 VRA	1	
TO	1040	TEMA	161.00	2	26.4	19.7	32.9	15			0.01	0.05	1 VRA	1	
TO	1050	ACHIMOTA	161.00	1	96.7	39.7	104.5	49			0.88	4.34	1 VRA	1	
TO	1050	ACHIMOTA	161.00	2	96.7	39.7	104.5	49			0.88	4.34	1 VRA	1	
TO	1050	ACHIMOTA	161.00	3	96.7	39.7	104.5	49			0.88	4.34	1 VRA	1	
TO	1170	KPONG	161.00	1	-63.2	-27.9	69.1	32			0.75	3.62	1 VRA	1	
TO	1170	KPONG	161.00	2	-63.2	-27.9	69.1	32			0.75	3.62	1 VRA	1	
TO	1190	KPONG-GS	161.00	1	-96.4	-34.8	102.5	37			1.17	8.67	1 VRA	1	

BUS	1031	SMELTER1	161.00	CKT	MW	MVAR	MVA	%	1.0043PU	22.56	X--- LOSSES	---X	X---- AREA -----X	X---- ZONE -----X	1031
									161.69KV		MW	MVAR	1 VRA	3	
TO	1020	VOLTA	161.00	1	0.0	0.0	0.0	0			0.00	0.00	1 VRA	1	
TO	10311	VALCO-1	13.800	1	0.0	0.0	0.0	0	1.0250LK	30.00LK	0.00	0.00	1 VRA	3	
TO	10317	VALCO-7	13.800	1	0.0	0.0	0.0	0	1.0250LK	30.00LK	0.00	0.00	1 VRA	3	

BUS	1032	SMELTER2	161.00	CKT	MW	MVAR	MVA	%	1.0023PU	22.38	X--- LOSSES	---X	X---- AREA -----X	X---- ZONE -----X	1032
									161.38KV		MW	MVAR	1 VRA	3	

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 TO   1020 VOLTA       161.00  1    -70.2   -24.9    74.5  35                          0.05    0.27    1 VRA             1
 TO  10312 VALCO-2     13.800  1     70.2    24.9    74.5  88 1.0250LK   30.00LK    0.00    8.81    1 VRA             3
 TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 1.0024PU   22.38  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                            161.39KV                 MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1    -70.2   -23.3    74.0  35                          0.05    0.27    1 VRA             1
 TO  10313 VALCO-3     13.800  1     70.2    23.3    74.0  87 1.0000LK   30.00LK    0.00    8.26    1 VRA             3

BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 1.0043PU   22.56  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                            161.69KV                 MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA             1
 TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 1.0043PU   22.56  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                            161.69KV                 MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA             1
 TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 1.0043PU   22.56  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                            161.69KV                 MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA             1
 TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 1.0030PU   22.50  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                            161.48KV                 MW     MVAR    1 VRA             1
 TO LOAD-PQ                         152.2    73.7   169.1
 TO SHUNT                             0.0   -20.1    20.1
 TO   1020 VOLTA       161.00  1    -26.4   -19.8    33.1  15                          0.01    0.05    1 VRA             1
 TO   1020 VOLTA       161.00  2    -26.4   -19.8    33.1  15                          0.01    0.05    1 VRA             1
 TO   1500 TT1PP-HV    161.00  1    -99.3   -13.9   100.3  47                          0.70    3.42    1 VRA             1

BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9809PU   20.52  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                            157.93KV                 MW     MVAR    1 VRA             1
 TO LOAD-PQ                         294.2   142.5   326.9
 TO SHUNT                             0.0   -38.5    38.5
 TO   1020 VOLTA       161.00  1    -95.8   -37.3   102.8  49                          0.88    4.34    1 VRA             1
 TO   1020 VOLTA       161.00  2    -95.8   -37.3   102.8  49                          0.88    4.34    1 VRA             1
 TO   1020 VOLTA       161.00  3    -95.8   -37.3   102.8  49                          0.88    4.34    1 VRA             1
 TO   1060 WINNEBA     161.00  1    -50.3    -8.2    50.9  31                          0.69    2.41    1 VRA             2
 TO   1370 MALLAM      161.00  1     43.4    16.1    46.3  28                          0.15    0.53    1 VRA             1

BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 1.0008PU   23.08  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                            161.13KV                 MW     MVAR    1 VRA             2
 TO LOAD-PQ                          10.8     5.2    12.0
 TO   1050 ACHIMOTA    161.00  1     50.9     6.4    51.3  30                          0.69    2.41    1 VRA             1
 TO   1320 ABOADZE     161.00  1    -61.7   -11.6    62.8  37                          1.63    6.29    1 VRA             2

BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0119PU   24.95  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                            162.91KV                 MW     MVAR    1 VRA             2
 TO LOAD-PQ                          24.9    12.0    27.6
 TO   1320 ABOADZE     161.00  1    -74.1   -16.6    76.0  44                          1.32    5.06    1 VRA             2
 TO   1370 MALLAM      161.00  1     49.3     4.6    49.5                              1.27    4.48    1 VRA             1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0349PU   27.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                              166.62KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          48.5     23.5     53.9
 TO   1090 TARKWA      161.00  1    136.0     18.0    137.2  78                       4.04   14.48    1 VRA             2
 TO   1320 ABOADZE     161.00  1    -95.6    -14.9     96.8  55                       0.53    2.05    1 VRA             2
 TO   1320 ABOADZE     161.00  2    -95.6    -14.9     96.8  55                       0.53    2.05    1 VRA             2
 TO   1360 ESSIAMA     161.00  1      6.6    -11.8     13.5                           0.04    0.13    1 VRA             3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 0.9944PU   21.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                              160.09KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          49.7     24.0     55.2
 TO   1080 TAKORADI    161.00  1   -132.0     -7.4    132.2  78                       4.04   14.48    1 VRA             2
 TO   1095 NEWTAR      161.00  1     25.4     13.1     28.6  17                       0.03    0.11    1 VRA             3
 TO   1100 PRES-161    161.00  1     57.0    -29.8     64.3  38                       0.38    1.35    1 VRA             2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 0.9917PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                              159.66KV               MW     MVAR    1 VRA             3
 TO   1090 TARKWA      161.00  1    -25.4    -13.6     28.8  17                       0.03    0.11    1 VRA             2
 TO  10951 NTAR-LV     11.500  1     12.7      6.8     14.4  44 1.0000LK              0.00    0.68    1 VRA             3
 TO  10951 NTAR-LV     11.500  2     12.7      6.8     14.4  44 1.0000LK              0.00    0.68    1 VRA             3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 0.9988PU   20.07  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                              160.81KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                           6.6      3.2      7.3
 TO SHUNT                             0.0    -20.0     20.0
 TO SWITCHED SHUNT                    0.0    -20.0     20.0
 TO   1090 TARKWA      161.00  1    -56.6     29.6     63.9  38                       0.38    1.35    1 VRA             2
 TO   1109 PRES-225    225.00  1      5.0    -12.2     13.1   7 1.0000UN              0.00    0.08    1 VRA             2
 TO   1109 PRES-225    225.00  2      5.0    -12.2     13.1   7 1.0000UN              0.00    0.08    1 VRA             2
 TO   1120 OBUASI      161.00  1     89.3      8.4     89.7                           2.41   10.53    1 VRA             3
 TO   1300 BOGOSO      161.00  1    113.4     25.3    116.2  68                       0.79    2.81    1 VRA             2
 TO   1320 ABOADZE     161.00  1   -162.7     -2.3    162.7  45                       5.85   24.60    1 VRA             2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 1.0047PU   19.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                              226.07KV               MW     MVAR    1 VRA             2
 TO   1100 PRES-161    161.00  1     -5.0     12.3     13.2   7 1.0000LK              0.00    0.08    1 VRA             2
 TO   1100 PRES-161    161.00  2     -5.0     12.3     13.2   7 1.0000LK              0.00    0.08    1 VRA             2
 TO   2010 ABOBO       225.00  1      9.9    -24.5     26.4                           0.04    0.29    2 CIE             1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.9626PU   14.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                              154.98KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                           1.9      0.9      2.1
 TO   1200 ASAWINSO    161.00  1     27.4      9.7     29.0  21                       0.49    1.08    1 VRA             3
 TO   1210 N-OBUASI    161.00  1     36.3     -6.7     36.9  11                       0.16    0.58    1 VRA             3
 TO   1300 BOGOSO      161.00  1    -65.6     -4.0     65.7                           1.37    4.88    1 VRA             2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.9607PU   13.46  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                              154.68KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                          25.4     12.3     28.2
 TO SHUNT                             0.0     -6.6      6.6
 TO   1100 PRES-161    161.00  1    -86.9     -9.0     87.4                           2.41   10.53    1 VRA             2
 TO   1130 KUMASI      161.00  1     98.5     -4.9     98.6  60                       2.48    8.91    1 VRA             3
 TO   1210 N-OBUASI    161.00  1    -37.0      8.2     37.9  11                       0.05    0.18    1 VRA             3
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BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 0.9433PU    8.13  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                              151.87KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                          157.2    76.2   174.7
 TO SHUNT                              0.0   -53.4    53.4
 TO   1010 AKOSOMBO    161.00  1   -115.8    -3.4   115.9  34                        8.90   38.86    1 VRA            1
 TO   1120 OBUASI      161.00  1    -96.0    10.3    96.6  60                        2.48    8.91    1 VRA            3
 TO   1180 KONONGO     161.00  1    -79.2     5.7    79.4  50                        1.63    5.83    1 VRA            3
 TO   1260 TECHIMAN    161.00  1     58.5   -18.9    61.4  36                        1.19    5.21    1 VRA            5
 TO   1413 AHAF-161    161.00  1     37.7    -8.2    38.6  17                        0.33    2.06    1 VRA            1
 TO   1413 AHAF-161    161.00  2     37.7    -8.2    38.6  17                        0.33    2.06    1 VRA            1

BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 0.9803PU   16.81  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                              157.84KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                           10.7     5.2    11.9
 TO   1150 TAFO        161.00  1    -98.1    -7.4    98.3  59                        2.66    9.51    1 VRA            3
 TO   1180 KONONGO     161.00  1     87.4     2.2    87.4  52                        1.88    6.74    1 VRA            3

BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 1.0163PU   22.08  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                              163.62KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                           16.0     7.8    17.8
 TO   1010 AKOSOMBO    161.00  1    -75.4   -10.5    76.1  44                        1.51    5.42    1 VRA            1
 TO   1010 AKOSOMBO    161.00  2   -107.9   -20.1   109.8  59                        1.81    7.90    1 VRA            1
 TO   1140 NKAWKAW     161.00  1    100.7    12.6   101.5  59                        2.66    9.51    1 VRA            3
 TO   1160 AKWATIA     161.00  1     66.5    10.3    67.3  39                        1.08    3.86    1 VRA            3

BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 0.9913PU   18.95  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                              159.59KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                           11.8     5.7    13.1
 TO   1150 TAFO        161.00  1    -65.5   -10.4    66.3  39                        1.08    3.86    1 VRA            3
 TO   1210 N-OBUASI    161.00  1     53.7     4.7    53.9  22                        1.08    5.04    1 VRA            3

BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0357PU   25.06  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                              166.74KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                           17.2     8.4    19.2
 TO   1010 AKOSOMBO    161.00  1    -72.5   -31.6    79.1  36                        0.30    1.42    1 VRA            1
 TO   1010 AKOSOMBO    161.00  2    -72.5   -31.6    79.1  36                        0.30    1.42    1 VRA            1
 TO   1020 VOLTA       161.00  1     63.9    27.5    69.6  32                        0.75    3.62    1 VRA            1
 TO   1020 VOLTA       161.00  2     63.9    27.5    69.6  32                        0.75    3.62    1 VRA            1

BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 0.9587PU   12.36  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                              154.36KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                            4.7     2.3     5.2
 TO   1130 KUMASI      161.00  1     80.8    -3.2    80.9  50                        1.63    5.83    1 VRA            3
 TO   1140 NKAWKAW     161.00  1    -85.5     1.0    85.5  53                        1.88    6.74    1 VRA            3

BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0457PU   26.80  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                              168.35KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                            0.5     0.3     0.6
 TO   1010 AKOSOMBO    161.00  1     41.9   -12.0    43.6  20                        0.13    0.65    1 VRA            1
 TO   1020 VOLTA       161.00  1     97.6    39.4   105.2  37                        1.17    8.67    1 VRA            1
 TO   1191 KPONGS1     13.800  1    -35.0    -6.9    35.7  70 1.0500LK   30.00LK     0.00    2.94    1 VRA            1
 TO   1192 KPONGS2     13.800  1    -35.0    -6.9    35.7  70 1.0500LK   30.00LK     0.00    2.94    1 VRA            1
 TO   1193 KPONGS3     13.800  1    -35.0    -6.9    35.7  70 1.0500LK   30.00LK     0.00    2.94    1 VRA            1
 TO   1194 KPONGS4     13.800  1    -35.0    -6.9    35.7  70 1.0500LK   30.00LK     0.00    2.94    1 VRA            1
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BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.9346PU   13.10  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
                                                              150.47KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                          26.9    13.0    29.9
 TO   1110 DUNKWA      161.00  1    -26.9   -13.0    29.9  22                       0.49    1.08    1 VRA             2

BUS   1210 N-OBUASI    161.00 CKT     MW     MVAR     MVA   % 0.9610PU   13.73  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                              154.72KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                          51.7    25.1    57.5
 TO SHUNT                             0.0   -14.6    14.6
 TO   1110 DUNKWA      161.00  1    -36.2     5.6    36.6  10                       0.16    0.58    1 VRA             2
 TO   1120 OBUASI      161.00  1     37.0    -8.5    38.0  11                       0.05    0.18    1 VRA             3
 TO   1160 AKWATIA     161.00  1    -52.6    -7.5    53.1  23                       1.08    5.04    1 VRA             3

BUS   1220 ASIEKPE     161.00 CKT     MW     MVAR     MVA   % 1.0067PU   23.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                              162.08KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                          25.8    12.5    28.7
 TO   1010 AKOSOMBO    161.00  1    -66.4   -16.3    68.3  53                       1.79    4.04    1 VRA             1
 TO   1221 ASIEKP-6    69.000  1      0.0     0.0     0.0     0.9874LK              0.00    0.00    1 VRA             1
 TO   3010 LOME        161.00  1     40.5     3.8    40.7  32                       0.89    2.00    3 CEB             1

BUS   1260 TECHIMAN    161.00 CKT     MW     MVAR     MVA   % 0.9475PU    3.06  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                              152.54KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          15.8     7.7    17.6
 TO SHUNT                             0.0    -4.8     4.8
 TO   1130 KUMASI      161.00  1    -57.3    13.7    58.9  34                       1.19    5.21    1 VRA             3
 TO   1270 SUNYANI     161.00  1    -10.5     7.0    12.6   7                       0.04    0.18    1 VRA             5
 TO   1280 TAMALE      161.00  1     44.9   -10.6    46.1  27                       1.40    6.16    1 VRA             5
 TO   1380 SAWLA       161.00  1      7.1   -12.9    14.7   9                       0.07    0.24    1 VRA             5

BUS   1270 SUNYANI     161.00 CKT     MW     MVAR     MVA   % 0.9417PU    3.72  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                              151.62KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          32.5    15.7    36.1
 TO SHUNT                             0.0    -8.9     8.9
 TO   1260 TECHIMAN    161.00  1     10.5   -10.5    14.9   9                       0.04    0.18    1 VRA             5
 TO   1413 AHAF-161    161.00  1    -43.0     3.6    43.2  13                       0.22    0.95    1 VRA             1

BUS   1280 TAMALE      161.00 CKT     MW     MVAR     MVA   % 0.9250PU   -4.99  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                              148.93KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          21.8    10.6    24.2
 TO   1260 TECHIMAN    161.00  1    -43.5    -5.3    43.8  26                       1.40    6.16    1 VRA             5
 TO   1290 BOLGA       161.00  1     14.1    -2.8    14.4   6                       0.12    0.57    1 VRA             5
 TO   1350 YENDI       161.00  1      7.5    -2.4     7.9   5                       0.04    0.11    1 VRA             5

BUS   1290 BOLGA       161.00 CKT     MW     MVAR     MVA   % 0.9119PU   -7.22  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                              146.82KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          13.0     6.3    14.4
 TO   1280 TAMALE      161.00  1    -14.0    -6.6    15.5   7                       0.12    0.57    1 VRA             5
 TO 3WNDTR              WND 1  1      1.0     0.4     1.1   7 1.0000LK              0.00    0.01

BUS   1300 BOGOSO      161.00 CKT     MW     MVAR     MVA   % 0.9871PU   18.80  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                              158.93KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          35.5    17.2    39.5
 TO   1100 PRES-161    161.00  1   -112.6   -23.5   115.0  69                       0.79    2.81    1 VRA             2
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 TO   1110 DUNKWA      161.00  1     66.9     4.3    67.1                           1.37    4.88    1 VRA            2
 TO   1309 WEXFORD     161.00  1     10.2     1.9    10.4   6                       0.03    0.10    1 VRA            3

BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 0.9816PU   18.36  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                             158.05KV                MW     MVAR    1 VRA            3
 TO   1300 BOGOSO      161.00  1    -10.1    -5.4    11.5   6                       0.03    0.10    1 VRA            2
 TO  13091 WEX-LV      34.500  1     10.1     5.4    11.5  35 1.0000LK   30.00LK    0.00    0.46    1 VRA            3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0440PU   28.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                             168.09KV                MW     MVAR    1 VRA            2
 TO LOAD-PQ                           0.4     0.2     0.4
 TO   1060 WINNEBA     161.00  1     63.4     9.9    64.1  36                       1.63    6.29    1 VRA            2
 TO   1070 C-COAST     161.00  1     75.4    17.2    77.4  44                       1.32    5.06    1 VRA            2
 TO   1080 TAKORADI    161.00  1     96.1    15.7    97.4  55                       0.53    2.05    1 VRA            2
 TO   1080 TAKORADI    161.00  2     96.1    15.7    97.4  55                       0.53    2.05    1 VRA            2
 TO   1100 PRES-161    161.00  1    168.5    18.1   169.5  45                       5.85   24.60    1 VRA            2
 TO   1321 ABOAD-G1    13.800  1   -100.0   -15.7   101.2  70 1.0500LK   30.00LK    0.00    8.23    1 VRA            1
 TO   1322 ABOAD-G2    13.800  1   -100.0   -15.7   101.2  70 1.0500LK   30.00LK    0.00    8.23    1 VRA            1
 TO   1323 ABOA-G3     13.800  1   -100.0   -15.7   101.2  70 1.0500LK              0.00    8.23    1 VRA            1
 TO   1324 ABOA-G4     13.800  1   -100.0   -14.9   101.1  70 1.0500LK              0.00    8.50    1 VRA            1
 TO   1325 ABOAD-G5    13.800  1   -100.0   -14.9   101.1  70 1.0500LK              0.00    8.50    1 VRA            1
 TO   1326 ABOA-G6     13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA            1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 0.9495PU    1.00  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                             152.87KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                           5.5     2.7     6.1
 TO   1380 SAWLA       161.00  1     -5.5    -2.7     6.1   4                       0.02    0.06    1 VRA            5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 0.9196PU   -5.77  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                             148.06KV                MW     MVAR    1 VRA            5
 TO LOAD-PQ                           7.5     3.6     8.3
 TO   1280 TAMALE      161.00  1     -7.5    -3.6     8.3   5                       0.04    0.11    1 VRA            5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0423PU   26.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                             167.81KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                           6.6     3.2     7.3
 TO   1080 TAKORADI    161.00  1     -6.6     6.4     9.2                           0.04    0.13    1 VRA            2
 TO   1600 OPB-HV      161.00  1      0.0    -9.6     9.6   3                       0.00    0.02    1 VRA            3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9740PU   19.97  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                             156.82KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                          91.3    44.2   101.4
 TO SHUNT                             0.0   -19.0    19.0
 TO   1050 ACHIMOTA    161.00  1    -43.3   -16.7    46.4  28                       0.15    0.53    1 VRA            1
 TO   1070 C-COAST     161.00  1    -48.0    -8.6    48.8                           1.27    4.48    1 VRA            2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 0.9559PU    1.43  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                             153.90KV                MW     MVAR    1 VRA            5
 TO LOAD-PQ                           1.5     0.7     1.7
 TO   1260 TECHIMAN    161.00  1     -7.0    -3.4     7.8   4                       0.07    0.24    1 VRA            5
 TO   1340 WA          161.00  1      5.5     2.7     6.1   4                       0.02    0.06    1 VRA            1
 TO   1381 SAW-34.5    34.500  1      0.0     0.0     0.0   0 1.1000HI              0.00    0.00    1 VRA            1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9800PU   20.51  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
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                                                        157.78KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                          10.7      5.2     11.8
 TO   1392  AFTAP      161.00  1    -10.7     -5.2     11.8   7                0.00    0.00    1 VRA             1

BUS   1392  AFTAP      161.00 CKT     MW     MVAR     MVA   % 0.9802PU   20.52  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                        157.81KV               MW     MVAR    1 VRA             1
 TO   1010 AKOSOMBO    161.00  1    -51.0    -11.9     52.4  42                2.45    5.61    1 VRA             1
 TO   1390 DCEM        161.00  1     10.7      5.1     11.8   7                0.00    0.00    1 VRA             1
 TO   3010 LOME        161.00  1     40.4      6.8     40.9  33                0.05    0.11    3 CEB             1

BUS   1413 AHAF-161    161.00 CKT     MW     MVAR     MVA   % 0.9442PU    5.00  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                        152.02KV               MW     MVAR    1 VRA             1
 TO   1130 KUMASI      161.00  1    -37.3      5.1     37.7  16                0.33    2.06    1 VRA             3
 TO   1130 KUMASI      161.00  2    -37.3      5.1     37.7  16                0.33    2.06    1 VRA             3
 TO   1270 SUNYANI     161.00  1     43.2     -6.3     43.7  13                0.22    0.95    1 VRA             5
 TO   1412 AHAFO-LV    11.000  1     15.7     -2.0     15.8  35 1.1500HI       0.00    0.67    1 VRA             5
 TO   1412 AHAFO-LV    11.000  2     15.7     -2.0     15.8  35 1.1500HI       0.00    0.67    1 VRA             5

BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR     MVA   % 1.0150PU   24.36  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                        163.41KV               MW     MVAR    1 VRA             1
 TO   1040 TEMA        161.00  1    100.0     15.6    101.2  47                0.70    3.42    1 VRA             1
 TO   1510 TT1PP-G1    13.800  1   -100.0    -15.7    101.2  61 1.0000UN       0.00    0.01    1 VRA             1
 TO   1520 TT1PP-G2    13.800  1      0.0      0.1      0.1   0 1.0000UN       0.00    0.00    1 VRA             1

BUS   1600 OPB-HV      161.00 CKT     MW     MVAR     MVA   % 1.0468PU   26.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                        168.53KV               MW     MVAR    1 VRA             3
 TO   1360 ESSIAMA     161.00  1      0.0      0.0      0.0   0                0.00    0.02    1 VRA             3
 TO   1601 OPB-G1      13.800  1      0.0      0.0      0.0   0 1.0500LK       0.00    0.00    1 VRA             3
```
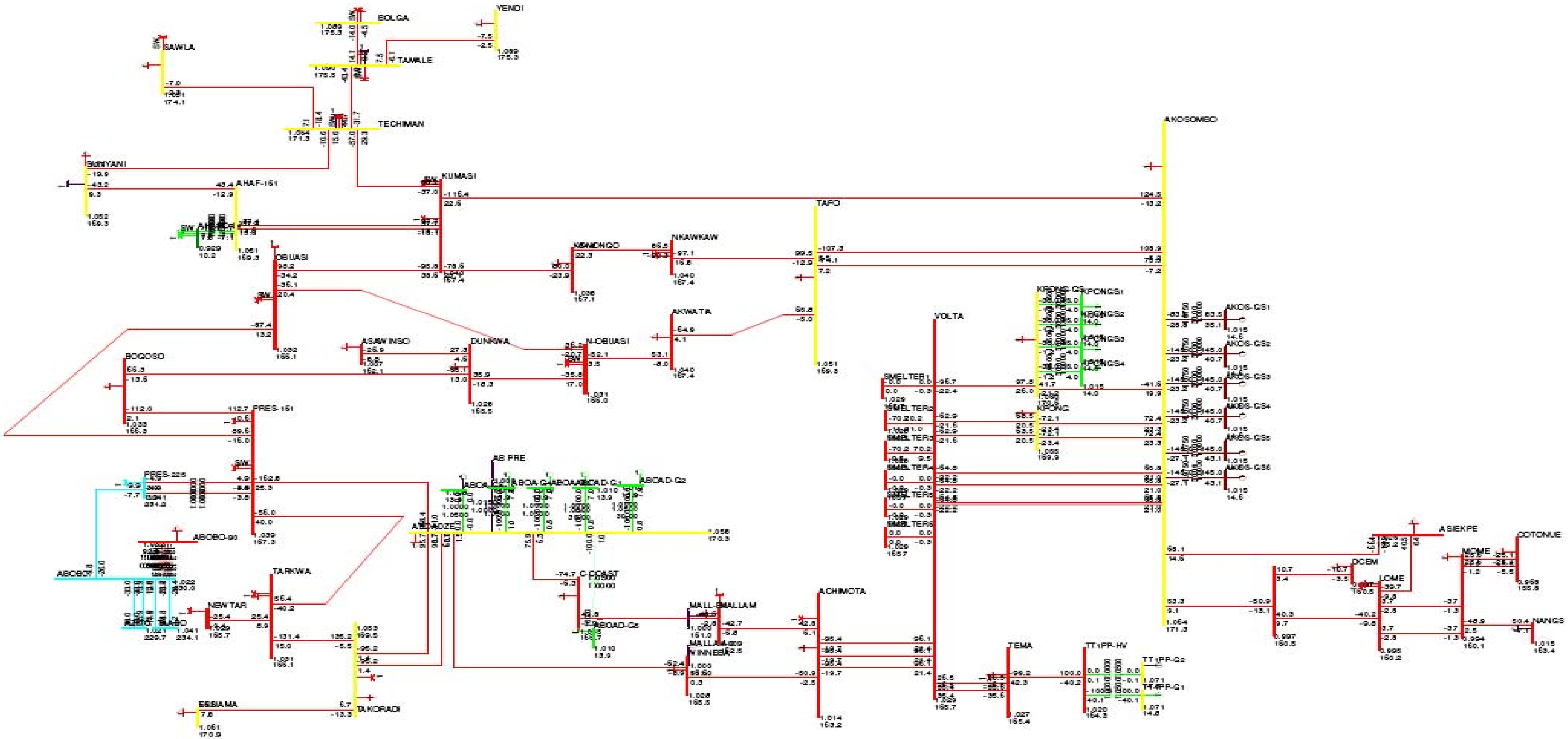

Peak Load Condition at power factor of 0.95 on single line diagram (case1- no contingency)



Peak Load Condition at power factor of 0.95(Case1-no contingency, table results)

```
BUS    1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0639PU   26.22  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                               171.29KV                 MW     MVAR    1 VRA             1
 TO LOAD-PQ                          11.9      3.9     12.5
 TO    1011 AKOS-GS1    14.400  1    -83.5    -28.8     88.3  44 1.0750LK   30.00LK    0.00    6.32    1 VRA             1
 TO    1012 AKOS-GS2    14.400  1   -145.0    -23.2    146.8  73 1.0750LK   30.00LK    0.00   17.48    1 VRA             1
 TO    1013 AKOS-GS3    14.400  1   -145.0    -23.2    146.8  73 1.0750LK   30.00LK    0.00   17.48    1 VRA             1
 TO    1014 AKOS-GS4    14.400  1   -145.0    -23.2    146.8  73 1.0750LK   30.00LK    0.00   17.48    1 VRA             1
 TO    1015 AKOS-GS5    14.400  1   -145.0    -27.1    147.5  74 1.0750LK   30.00LK    0.00   16.04    1 VRA             1
 TO    1016 AKOS-GS6    14.400  1   -145.0    -27.1    147.5  74 1.0750LK   30.00LK    0.00   16.04    1 VRA             1
 TO    1020 VOLTA       161.00  1     65.8     21.0     69.0  30                         0.92    4.45    1 VRA             1
 TO    1020 VOLTA       161.00  2     65.8     21.0     69.0  30                         0.92    4.45    1 VRA             1
 TO    1020 VOLTA       161.00  3     65.8     21.0     69.0  30                         0.92    4.45    1 VRA             1
 TO    1020 VOLTA       161.00  4     65.8     21.0     69.0  30                         0.92    4.45    1 VRA             1
 TO    1130 KUMASI      161.00  1    124.5    -13.2    125.2  32                         8.05   35.15    1 VRA             3
 TO    1150 TAFO        161.00  1     75.5     -7.2     75.8  42                         1.37    4.92    1 VRA             3
 TO    1150 TAFO        161.00  2    108.9     -5.2    109.1  56                         1.65    7.17    1 VRA             3
 TO    1170 KPONG       161.00  1     72.4     23.3     76.0  34                         0.26    1.26    1 VRA             1
 TO    1170 KPONG       161.00  2     72.4     23.3     76.0  34                         0.26    1.26    1 VRA             1
 TO    1190 KPONG-GS    161.00  1    -41.6     19.9     46.1  20                         0.15    0.73    1 VRA             1
 TO    1220 ASIEKPE     161.00  1     68.1     14.6     69.6  51                         1.71    3.86    1 VRA             1
 TO    1392  AFTAP      161.00  1     53.3      9.1     54.1  40                         2.37    5.44    1 VRA             1

BUS    1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 1.0294PU   22.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                               165.73KV                 MW     MVAR    1 VRA             1
 TO    1010 AKOSOMBO    161.00  1    -64.8    -22.2     68.5  31                         0.92    4.45    1 VRA             1
 TO    1010 AKOSOMBO    161.00  2    -64.8    -22.2     68.5  31                         0.92    4.45    1 VRA             1
 TO    1010 AKOSOMBO    161.00  3    -64.8    -22.2     68.5  31                         0.92    4.45    1 VRA             1
 TO    1010 AKOSOMBO    161.00  4    -64.8    -22.2     68.5  31                         0.92    4.45    1 VRA             1
 TO    1031 SMELTER1    161.00  1      0.0     -0.3      0.3   0                         0.00    0.00    1 VRA             3
 TO    1032 SMELTER2    161.00  1     70.2     11.0     71.1  32                         0.05    0.24    1 VRA             3
 TO    1033 SMELTER3    161.00  1     70.2      9.5     70.9  32                         0.05    0.23    1 VRA             3
 TO    1034 SMELTER4    161.00  1      0.0     -0.3      0.3   0                         0.00    0.00    1 VRA             3
 TO    1035 SMELTER5    161.00  1      0.0     -0.3      0.3   0                         0.00    0.00    1 VRA             3
 TO    1036 SMELTER6    161.00  1      0.0     -0.3      0.3   0                         0.00    0.00    1 VRA             3
 TO    1040 TEMA        161.00  1     26.5     35.4     44.2  20                         0.02    0.09    1 VRA             1
 TO    1040 TEMA        161.00  2     26.5     35.4     44.2  20                         0.02    0.09    1 VRA             1
 TO    1050 ACHIMOTA    161.00  1     96.1     21.4     98.5  45                         0.74    3.66    1 VRA             1
 TO    1050 ACHIMOTA    161.00  2     96.1     21.4     98.5  45                         0.74    3.66    1 VRA             1
 TO    1050 ACHIMOTA    161.00  3     96.1     21.4     98.5  45                         0.74    3.66    1 VRA             1
 TO    1170 KPONG       161.00  1    -62.9    -21.6     66.5  30                         0.66    3.20    1 VRA             1
 TO    1170 KPONG       161.00  2    -62.9    -21.6     66.5  30                         0.66    3.20    1 VRA             1
 TO    1190 KPONG-GS    161.00  1    -96.7    -22.4     99.3  35                         1.05    7.77    1 VRA             1

BUS    1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 1.0294PU   22.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                               165.73KV                 MW     MVAR    1 VRA             3
 TO    1020 VOLTA       161.00  1      0.0      0.0      0.0   0                         0.00    0.00    1 VRA             1
 TO   10311 VALCO-1     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3
 TO   10317 VALCO-7     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3

BUS    1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 1.0282PU   22.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
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                                                                  165.53KV                 MW     MVAR    1 VRA           3
  TO   1020 VOLTA       161.00  1    -70.2   -11.0    71.1  32                           0.05    0.24    1 VRA           1
  TO  10312 VALCO-2     13.800  1     70.2    11.0    71.1  84 1.0250LK   30.00LK    0.00    7.61    1 VRA           3
  TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA           3

 BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 1.0282PU   22.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                                  165.55KV                 MW     MVAR    1 VRA           3
  TO   1020 VOLTA       161.00  1    -70.2    -9.5    70.8  32                           0.05    0.23    1 VRA           1
  TO  10313 VALCO-3     13.800  1     70.2     9.5    70.8  83 1.0000LK   30.00LK    0.00    7.20    1 VRA           3

 BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 1.0294PU   22.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                                  165.73KV                 MW     MVAR    1 VRA           3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                           0.00    0.00    1 VRA           1
  TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA           3

 BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 1.0294PU   22.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                                  165.73KV                 MW     MVAR    1 VRA           3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                           0.00    0.00    1 VRA           1
  TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA           3

 BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 1.0294PU   22.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                                  165.73KV                 MW     MVAR    1 VRA           3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                           0.00    0.00    1 VRA           1
  TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA           3

 BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 1.0274PU   22.89  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                                  165.41KV                 MW     MVAR    1 VRA           1
  TO LOAD-PQ                         152.2    50.0   160.2
  TO SHUNT                             0.0   -21.1    21.1
  TO   1020 VOLTA       161.00  1    -26.5   -35.6    44.4  20                           0.02    0.09    1 VRA           1
  TO   1020 VOLTA       161.00  2    -26.5   -35.6    44.4  20                           0.02    0.09    1 VRA           1
  TO   1500 TT1PP-HV    161.00  1    -99.2    42.3   107.8  49                           0.78    3.80    1 VRA           1

 BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 1.0138PU   20.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                                  163.22KV                 MW     MVAR    1 VRA           1
  TO LOAD-PQ                         294.2    96.7   309.7
  TO SHUNT                             0.0   -41.1    41.1
  TO   1020 VOLTA       161.00  1    -95.4   -19.7    97.4  45                           0.74    3.66    1 VRA           1
  TO   1020 VOLTA       161.00  2    -95.4   -19.7    97.4  45                           0.74    3.66    1 VRA           1
  TO   1020 VOLTA       161.00  3    -95.4   -19.7    97.4  45                           0.74    3.66    1 VRA           1
  TO   1060 WINNEBA     161.00  1    -50.9    -2.5    51.0  30                           0.65    2.28    1 VRA           2
  TO   1370 MALLAM      161.00  1     42.8     6.1    43.2  25                           0.12    0.43    1 VRA           1

 BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 1.0280PU   23.47  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                                  165.51KV                 MW     MVAR    1 VRA           2
  TO LOAD-PQ                          10.8     3.6    11.4
  TO   1050 ACHIMOTA    161.00  1     51.6     0.3    51.6  30                           0.65    2.28    1 VRA           1
  TO   1320 ABOADZE     161.00  1    -62.4    -3.9    62.5  36                           1.55    5.98    1 VRA           2

 BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0354PU   25.33  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                                  166.71KV                 MW     MVAR    1 VRA           2
  TO LOAD-PQ                          24.9     8.2    26.2
  TO   1320 ABOADZE     161.00  1    -74.7    -6.3    74.9  43                           1.23    4.74    1 VRA           2
  TO   1370 MALLAM      161.00  1     49.8    -1.9    49.8                               1.20    4.25    1 VRA           1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0526PU   27.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                              169.48KV               MW     MVAR    1 VRA                2
 TO LOAD-PQ                          48.5     16.0     51.1
 TO   1090 TARKWA      161.00  1    135.2     -5.5    135.3  76                      3.78   13.54    1 VRA                2
 TO   1320 ABOADZE     161.00  1    -95.2      1.4     95.2  53                      0.50    1.92    1 VRA                2
 TO   1320 ABOADZE     161.00  2    -95.2      1.4     95.2  53                      0.50    1.92    1 VRA                2
 TO   1360 ESSIAMA     161.00  1      6.7    -13.3     14.9                          0.05    0.16    1 VRA                3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 1.0314PU   21.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                              166.05KV               MW     MVAR    1 VRA                2
 TO LOAD-PQ                          49.7     16.3     52.3
 TO   1080 TAKORADI    161.00  1   -131.4     15.0    132.3  75                      3.78   13.54    1 VRA                2
 TO   1095 NEWTAR      161.00  1     25.4      8.9     26.9  15                      0.03    0.09    1 VRA                3
 TO   1100 PRES-161    161.00  1     56.4    -40.2     69.3  40                      0.41    1.46    1 VRA                2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 1.0293PU   21.61  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                              165.72KV               MW     MVAR    1 VRA                3
 TO   1090 TARKWA      161.00  1    -25.4     -9.4     27.1  15                      0.03    0.09    1 VRA                2
 TO  10951 NTAR-LV     11.500  1     12.7      4.7     13.5  41 1.0000LK             0.00    0.55    1 VRA                3
 TO  10951 NTAR-LV     11.500  2     12.7      4.7     13.5  41 1.0000LK             0.00    0.55    1 VRA                3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 1.0390PU   20.58  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                              167.28KV               MW     MVAR    1 VRA                2
 TO LOAD-PQ                           6.6      2.2      6.9
 TO SHUNT                             0.0    -21.6     21.6
 TO SWITCHED SHUNT                    0.0    -21.6     21.6
 TO   1090 TARKWA      161.00  1    -56.0     40.0     68.8  39                      0.41    1.46    1 VRA                2
 TO   1109 PRES-225    225.00  1      4.9     -3.8      6.3   3 1.0000UN             0.00    0.02    1 VRA                2
 TO   1109 PRES-225    225.00  2      4.9     -3.8      6.3   3 1.0000UN             0.00    0.02    1 VRA                2
 TO   1120 OBUASI      161.00  1     89.6    -16.0     91.1                          2.21    9.67    1 VRA                3
 TO   1300 BOGOSO      161.00  1    112.7     -0.6    112.7  64                      0.68    2.43    1 VRA                2
 TO   1320 ABOADZE     161.00  1   -162.8     25.3    164.8  44                      5.60   23.54    1 VRA                2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 1.0408PU   20.45  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                              234.19KV               MW     MVAR    1 VRA                2
 TO   1100 PRES-161    161.00  1     -4.9      3.9      6.3   3 1.0000LK             0.00    0.02    1 VRA                2
 TO   1100 PRES-161    161.00  2     -4.9      3.9      6.3   3 1.0000LK             0.00    0.02    1 VRA                2
 TO   2010 ABOBO       225.00  1      9.9     -7.7     12.5                          0.05    0.31    2 CIE                1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 1.0279PU   15.40  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                              165.48KV               MW     MVAR    1 VRA                2
 TO LOAD-PQ                           1.9      0.6      2.0
 TO   1200 ASAWINSO    161.00  1     27.3      4.6     27.7  19                      0.38    0.84    1 VRA                3
 TO   1210 N-OBUASI    161.00  1     35.9    -18.3     40.3  11                      0.17    0.60    1 VRA                3
 TO   1300 BOGOSO      161.00  1    -65.1     13.0     66.4                          1.25    4.45    1 VRA                2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 1.0319PU   14.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                              166.14KV               MW     MVAR    1 VRA                3
 TO LOAD-PQ                          25.4      8.3     26.7
 TO SHUNT                             0.0     -7.7      7.7
 TO   1100 PRES-161    161.00  1    -87.4     13.2     88.4                          2.21    9.67    1 VRA                2
 TO   1130 KUMASI      161.00  1     98.2    -34.2    104.0  59                      2.37    8.48    1 VRA                3
 TO   1210 N-OBUASI    161.00  1    -36.1     20.4     41.5  11                      0.05    0.18    1 VRA                3
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BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 1.0396PU    9.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                              167.37KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                         157.2    51.7   165.5
 TO SHUNT                             0.0   -64.8    64.8
 TO   1010 AKOSOMBO    161.00  1   -116.4    22.6   118.6  31                       8.05   35.15    1 VRA              1
 TO   1120 OBUASI      161.00  1    -95.8    38.6   103.3  58                       2.37    8.48    1 VRA              3
 TO   1180 KONONGO     161.00  1    -78.6    25.1    82.5  47                       1.46    5.24    1 VRA              3
 TO   1260 TECHIMAN    161.00  1     58.2   -37.0    68.9  36                       1.18    5.14    1 VRA              5
 TO   1413 AHAF-161    161.00  1     37.7   -18.1    41.8  16                       0.31    1.92    1 VRA              1
 TO   1413 AHAF-161    161.00  2     37.7   -18.1    41.8  16                       0.31    1.92    1 VRA              1

BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 1.0398PU   17.29  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                              167.41KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                          10.7     3.5    11.2
 TO   1150 TAFO        161.00  1    -97.1    16.8    98.6  56                       2.40    8.59    1 VRA              3
 TO   1180 KONONGO     161.00  1     86.5   -20.3    88.8  50                       1.70    6.11    1 VRA              3

BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 1.0513PU   22.38  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                              169.26KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                          16.0     5.3    16.9
 TO   1010 AKOSOMBO    161.00  1    -74.1     7.2    74.4  42                       1.37    4.92    1 VRA              1
 TO   1010 AKOSOMBO    161.00  2   -107.3     5.5   107.4  56                       1.65    7.17    1 VRA              1
 TO   1140 NKAWKAW     161.00  1     99.5   -12.9   100.4  56                       2.40    8.59    1 VRA              3
 TO   1160 AKWATIA     161.00  1     65.8    -5.0    66.0  37                       0.95    3.42    1 VRA              3

BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 1.0399PU   19.34  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                              167.42KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                          11.8     3.9    12.4
 TO   1150 TAFO        161.00  1    -64.9     4.1    65.0  37                       0.95    3.42    1 VRA              3
 TO   1210 N-OBUASI    161.00  1     53.1    -8.0    53.7  21                       0.94    4.38    1 VRA              3

BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0551PU   25.37  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                              169.86KV                MW     MVAR    1 VRA              1
 TO LOAD-PQ                          17.2     5.7    18.2
 TO   1010 AKOSOMBO    161.00  1    -72.1   -23.4    75.8  34                       0.26    1.26    1 VRA              1
 TO   1010 AKOSOMBO    161.00  2    -72.1   -23.4    75.8  34                       0.26    1.26    1 VRA              1
 TO   1020 VOLTA       161.00  1     63.5    20.5    66.8  30                       0.66    3.20    1 VRA              1
 TO   1020 VOLTA       161.00  2     63.5    20.5    66.8  30                       0.66    3.20    1 VRA              1

BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 1.0377PU   13.17  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                              167.07KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                           4.7     1.6     5.0
 TO   1130 KUMASI      161.00  1     80.0   -23.9    83.5  47                       1.46    5.24    1 VRA              3
 TO   1140 NKAWKAW     161.00  1    -84.8    22.3    87.7  50                       1.70    6.11    1 VRA              3

BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0596PU   27.10  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                              170.59KV                MW     MVAR    1 VRA              1
 TO LOAD-PQ                           0.5     0.2     0.6
 TO   1010 AKOSOMBO    161.00  1     41.7   -21.2    46.8  21                       0.15    0.73    1 VRA              1
 TO   1020 VOLTA       161.00  1     97.8    26.0   101.1  35                       1.05    7.77    1 VRA              1
 TO   1191 KPONGS1     13.800  1    -35.0    -1.2    35.0  69 1.0500LK   30.00LK    0.00    2.76    1 VRA              1
 TO   1192 KPONGS2     13.800  1    -35.0    -1.2    35.0  69 1.0500LK   30.00LK    0.00    2.76    1 VRA              1
 TO   1193 KPONGS3     13.800  1    -35.0    -1.2    35.0  69 1.0500LK   30.00LK    0.00    2.76    1 VRA              1
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 TO   1194 KPONGS4     13.800  1    -35.0     -1.2     35.0  69 1.0500LK   30.00LK    0.00    2.76    1 VRA             1

BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 1.0069PU   13.91  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
                                                              162.11KV                   MW     MVAR    1 VRA             3
 TO LOAD-PQ                          26.9      8.8     28.3
 TO   1110 DUNKWA      161.00  1    -26.9     -8.8     28.3  20                          0.38    0.84    1 VRA             2

BUS   1210 N-OBUASI    161.00 CKT     MW     MVAR     MVA   % 1.0308PU   14.52  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                              165.96KV                   MW     MVAR    1 VRA             3
 TO LOAD-PQ                          51.7     17.0     54.5
 TO SHUNT                             0.0    -16.8     16.8
 TO   1110 DUNKWA      161.00  1    -35.8     17.0     39.6  11                          0.17    0.60    1 VRA             2
 TO   1120 OBUASI      161.00  1     36.2    -20.7     41.7  11                          0.05    0.18    1 VRA             3
 TO   1160 AKWATIA     161.00  1    -52.1      3.5     52.3  21                          0.94    4.38    1 VRA             3

BUS   1220 ASIEKPE     161.00 CKT     MW     MVAR     MVA   % 1.0260PU   23.39  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                              165.18KV                   MW     MVAR    1 VRA             1
 TO LOAD-PQ                          25.8      8.5     27.2
 TO   1010 AKOSOMBO    161.00  1    -66.4    -14.9     68.0  52                          1.71    3.86    1 VRA             1
 TO   1221 ASIEKP-6    69.000  1      0.0      0.0      0.0     0.9874LK                 0.00    0.00    1 VRA             1
 TO   3010 LOME        161.00  1     40.5      6.4     41.0  31                          0.87    1.97    3 CEB             1

BUS   1260 TECHIMAN    161.00 CKT     MW     MVAR     MVA   % 1.0641PU    5.08  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                              171.32KV                   MW     MVAR    1 VRA             5
 TO LOAD-PQ                          15.8      5.2     16.7
 TO   1130 KUMASI      161.00  1    -57.0     29.3     64.1  33                          1.18    5.14    1 VRA             3
 TO   1270 SUNYANI     161.00  1    -10.6     15.6     18.9  10                          0.07    0.32    1 VRA             5
 TO   1280 TAMALE      161.00  1     44.7    -31.7     54.8  28                          1.27    5.58    1 VRA             5
 TO   1380 SAWLA       161.00  1      7.1    -18.4     19.7  10                          0.09    0.31    1 VRA             5

BUS   1270 SUNYANI     161.00 CKT     MW     MVAR     MVA   % 1.0518PU    5.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                              169.35KV                   MW     MVAR    1 VRA             5
 TO LOAD-PQ                          32.5     10.7     34.2
 TO   1260 TECHIMAN    161.00  1     10.7    -19.9     22.6  12                          0.07    0.32    1 VRA             5
 TO   1413 AHAF-161    161.00  1    -43.2      9.3     44.2  12                          0.19    0.81    1 VRA             1

BUS   1280 TAMALE      161.00 CKT     MW     MVAR     MVA   % 1.0902PU   -1.53  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                              175.52KV                   MW     MVAR    1 VRA             5
 TO LOAD-PQ                          21.8      7.2     23.0
 TO   1260 TECHIMAN    161.00  1    -43.4      8.0     44.2  22                          1.27    5.58    1 VRA             5
 TO   1290 BOLGA       161.00  1     14.1     -9.2     16.8   6                          0.09    0.41    1 VRA             5
 TO   1350 YENDI       161.00  1      7.5     -6.1      9.7   5                          0.03    0.08    1 VRA             5

BUS   1290 BOLGA       161.00 CKT     MW     MVAR     MVA   % 1.0886PU   -3.22  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                              175.26KV                   MW     MVAR    1 VRA             5
 TO LOAD-PQ                          13.0      4.3     13.7
 TO   1280 TAMALE      161.00  1    -14.0     -4.5     14.7   6                          0.09    0.41    1 VRA             5
 TO 3WNDTR              WND 1  1      1.0      0.3      1.0   7 1.0000LK                 0.00    0.01

BUS   1300 BOGOSO      161.00 CKT     MW     MVAR     MVA   % 1.0330PU   19.34  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                              166.31KV                   MW     MVAR    1 VRA             2
 TO LOAD-PQ                          35.5     11.7     37.4
 TO   1100 PRES-161    161.00  1   -112.0      2.1    112.0  64                          0.68    2.43    1 VRA             2
 TO   1110 DUNKWA      161.00  1     66.3    -13.6     67.7                              1.25    4.45    1 VRA             2
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 TO   1309 WEXFORD     161.00  1     10.2    -0.1    10.2   5                        0.02    0.08    1 VRA             3

BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 1.0292PU   18.92  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                              165.71KV                 MW     MVAR    1 VRA             3
 TO   1300 BOGOSO      161.00  1    -10.1    -3.7    10.8   6                        0.02    0.08    1 VRA             2
 TO  13091 WEX-LV      34.500  1     10.1     3.7    10.8  33 1.0000LK   30.00LK    0.00    0.37    1 VRA             3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0579PU   28.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                              170.33KV                 MW     MVAR    1 VRA             2
 TO LOAD-PQ                           0.4     0.1     0.4
 TO   1060 WINNEBA     161.00  1     63.9     1.5    63.9  36                        1.55    5.98    1 VRA             2
 TO   1070 C-COAST     161.00  1     75.9     6.3    76.2  42                        1.23    4.74    1 VRA             2
 TO   1080 TAKORADI    161.00  1     95.7    -0.7    95.7  53                        0.50    1.92    1 VRA             2
 TO   1080 TAKORADI    161.00  2     95.7    -0.7    95.7  53                        0.50    1.92    1 VRA             2
 TO   1100 PRES-161    161.00  1    168.4   -11.0   168.8  44                        5.60   23.54    1 VRA             2
 TO   1321 ABOAD-G1    13.800  1   -100.0     0.8   100.0  69 1.0500LK   30.00LK    0.00    7.82    1 VRA             1
 TO   1322 ABOAD-G2    13.800  1   -100.0     0.8   100.0  69 1.0500LK   30.00LK    0.00    7.82    1 VRA             1
 TO   1323 ABOA-G3     13.800  1   -100.0     0.8   100.0  69 1.0500LK              0.00    7.82    1 VRA             1
 TO   1324 ABOA-G4     13.800  1   -100.0     1.0   100.0  69 1.0500LK              0.00    8.10    1 VRA             1
 TO   1325 ABOAD-G5    13.800  1   -100.0     1.0   100.0  69 1.0500LK              0.00    8.10    1 VRA             1
 TO   1326 ABOA-G6     13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA             1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 1.0767PU    3.29  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                              173.35KV                 MW     MVAR    1 VRA             1
 TO LOAD-PQ                           5.5     1.8     5.8
 TO   1380 SAWLA       161.00  1     -5.5    -1.8     5.8   3                        0.01    0.04    1 VRA             5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 1.0891PU   -2.15  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                              175.35KV                 MW     MVAR    1 VRA             5
 TO LOAD-PQ                           7.5     2.5     7.9
 TO   1280 TAMALE      161.00  1     -7.5    -2.5     7.9   4                        0.03    0.08    1 VRA             5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0614PU   27.09  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                              170.89KV                 MW     MVAR    1 VRA             3
 TO LOAD-PQ                           6.6     2.2     6.9
 TO   1080 TAKORADI    161.00  1     -6.6     7.8    10.2                            0.05    0.16    1 VRA             2
 TO   1600 OPB-HV      161.00  1      0.0    -9.9     9.9   3                        0.00    0.02    1 VRA             3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 1.0094PU   20.40  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                              162.52KV                 MW     MVAR    1 VRA             1
 TO LOAD-PQ                          91.3    30.0    96.1
 TO SHUNT                             0.0   -20.4    20.4
 TO   1050 ACHIMOTA    161.00  1    -42.7    -6.8    43.2  25                        0.12    0.43    1 VRA             1
 TO   1070 C-COAST     161.00  1    -48.6    -2.8    48.7                            1.20    4.25    1 VRA             2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 1.0812PU    3.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                              174.08KV                 MW     MVAR    1 VRA             5
 TO LOAD-PQ                           1.5     0.5     1.6
 TO   1260 TECHIMAN    161.00  1     -7.0    -2.3     7.4   4                        0.09    0.31    1 VRA             5
 TO   1340 WA          161.00  1      5.5     1.8     5.8   3                        0.01    0.04    1 VRA             1
 TO   1381 SAW-34.5    34.500  1      0.0     0.0     0.0   0 1.1000HI              0.00    0.00    1 VRA             1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9966PU   21.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                              160.45KV                 MW     MVAR    1 VRA             1
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  TO LOAD-PQ                            10.7      3.5     11.2
  TO   1392  AFTAP      161.00  1      -10.7     -3.5     11.2   6                      0.00    0.00    1 VRA            1

 BUS   1392  AFTAP      161.00 CKT      MW     MVAR      MVA   % 0.9968PU   21.05  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                                 160.48KV                MW     MVAR    1 VRA            1
  TO   1010 AKOSOMBO    161.00  1      -50.9    -13.1     52.6  41                      2.37    5.44    1 VRA            1
  TO   1390 DCEM        161.00  1       10.7      3.4     11.2   6                      0.00    0.00    1 VRA            1
  TO   3010 LOME        161.00  1       40.3      9.7     41.4  32                      0.05    0.11    3 CEB            1

 BUS   1413 AHAF-161    161.00 CKT      MW     MVAR      MVA   % 1.0515PU    6.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                                 169.29KV                MW     MVAR    1 VRA            1
  TO   1130 KUMASI      161.00  1      -37.4     13.6     39.8  16                      0.31    1.92    1 VRA            3
  TO   1130 KUMASI      161.00  2      -37.4     13.6     39.8  16                      0.31    1.92    1 VRA            3
  TO   1270 SUNYANI     161.00  1       43.4    -12.9     45.2  12                      0.19    0.81    1 VRA            5
  TO   1412 AHAFO-LV    11.000  1       15.7     -7.1     17.3  38 1.1500HI             0.00    0.64    1 VRA            5
  TO   1412 AHAFO-LV    11.000  2       15.7     -7.1     17.3  38 1.1500HI             0.00    0.64    1 VRA            5

 BUS   1500 TT1PP-HV    161.00 CKT      MW     MVAR      MVA   % 1.0204PU   24.92  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                                 164.29KV                MW     MVAR    1 VRA            1
  TO   1040 TEMA        161.00  1      100.0    -40.2    107.8  50                      0.78    3.80    1 VRA            1
  TO   1510 TT1PP-G1    13.800  1     -100.0     40.1    107.7  65 1.0000UN             0.00    0.01    1 VRA            1
  TO   1520 TT1PP-G2    13.800  1        0.0      0.1      0.1   0 1.0000UN             0.00    0.00    1 VRA            1

 BUS   1600 OPB-HV      161.00 CKT      MW     MVAR      MVA   % 1.0660PU   27.03  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                                 171.63KV                MW     MVAR    1 VRA            3
  TO   1360 ESSIAMA     161.00  1        0.0      0.0      0.0   0                      0.00    0.02    1 VRA            3
  TO   1601 OPB-G1      13.800  1        0.0      0.0      0.0   0 1.0500LK             0.00    0.00    1 VRA            3
  TO   1602 OPB-G2      13.800  1        0.0      0.0      0.0   0 1.0500LK             0.00    0.00    1 VRA            3
```
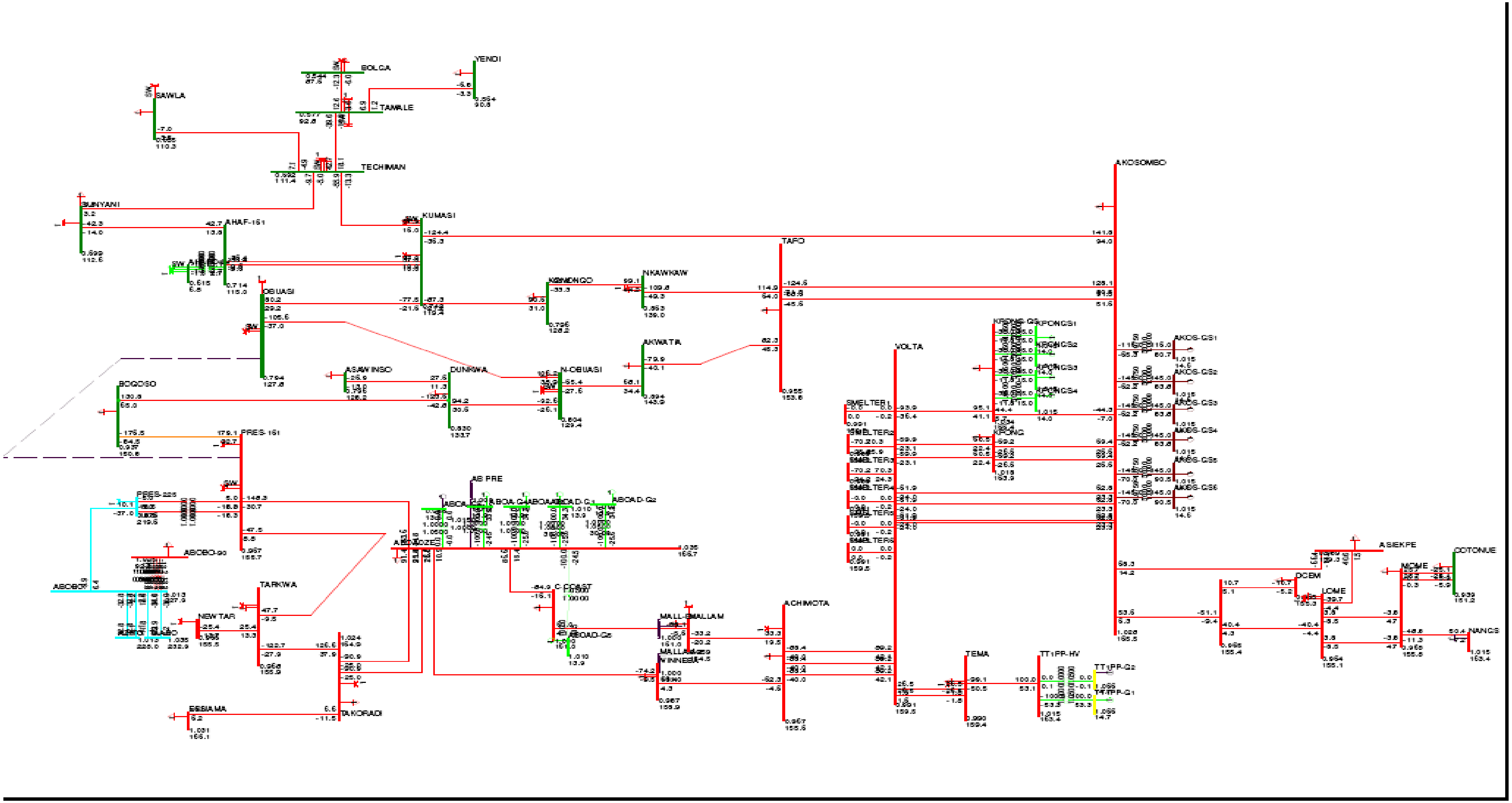

Peak Load Condition at power factor of 0.9, Prestea-Obuasi contingency on single line diagram (case 2)



Peak Load Condition at power factor of 0.90with Prestea-Obuasi contingency (table results ,Case2)

```
 BUS    1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0279PU   24.55  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                                165.49KV                MW     MVAR    1 VRA            1
  TO LOAD-PQ                          11.9      5.8    13.2
  TO    1011 AKOS-GS1    14.400  1  -116.0   -65.3   133.1  67 1.0750LK   30.00LK    0.00   15.39    1 VRA            1
  TO    1012 AKOS-GS2    14.400  1  -145.0   -62.2   157.8  79 1.0750LK   30.00LK    0.00   21.62    1 VRA            1
  TO    1013 AKOS-GS3    14.400  1  -145.0   -62.2   157.8  79 1.0750LK   30.00LK    0.00   21.62    1 VRA            1
  TO    1014 AKOS-GS4    14.400  1  -145.0   -62.2   157.8  79 1.0750LK   30.00LK    0.00   21.62    1 VRA            1
  TO    1015 AKOS-GS5    14.400  1  -145.0   -70.0   161.0  81 1.0750LK   30.00LK    0.00   20.48    1 VRA            1
  TO    1016 AKOS-GS6    14.400  1  -145.0   -70.0   161.0  81 1.0750LK   30.00LK    0.00   20.48    1 VRA            1
  TO    1020 VOLTA       161.00  1    62.8    23.3    67.0  31                       0.93    4.50    1 VRA            1
  TO    1020 VOLTA       161.00  2    62.8    23.3    67.0  31                       0.93    4.50    1 VRA            1
  TO    1020 VOLTA       161.00  3    62.8    23.3    67.0  31                       0.93    4.50    1 VRA            1
  TO    1020 VOLTA       161.00  4    62.8    23.3    67.0  31                       0.93    4.50    1 VRA            1
  TO    1130 KUMASI      161.00  1   141.8    94.0   170.2  45                      17.49   76.37    1 VRA            3
  TO    1150 TAFO        161.00  1    91.5    51.6   105.1  60                       2.90   10.40    1 VRA            3
  TO    1150 TAFO        161.00  2   128.1    80.5   151.3  81                       3.48   15.17    1 VRA            3
  TO    1170 KPONG       161.00  1    69.4    26.6    74.3  34                       0.27    1.29    1 VRA            1
  TO    1170 KPONG       161.00  2    69.4    26.6    74.3  34                       0.27    1.29    1 VRA            1
  TO    1190 KPONG-GS    161.00  1   -44.3    -7.0    44.8  20                       0.15    0.72    1 VRA            1
  TO    1220 ASIEKPE     161.00  1    68.3    14.2    69.7  53                       1.84    4.14    1 VRA            1
  TO    1392  AFTAP      161.00  1    53.6     6.3    54.0  41                       2.50    5.74    1 VRA            1

 BUS    1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 0.9906PU   21.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                                159.49KV                MW     MVAR    1 VRA            1
  TO    1010 AKOSOMBO    161.00  1   -61.9   -24.0    66.4  31                       0.93    4.50    1 VRA            1
  TO    1010 AKOSOMBO    161.00  2   -61.9   -24.0    66.4  31                       0.93    4.50    1 VRA            1
  TO    1010 AKOSOMBO    161.00  3   -61.9   -24.0    66.4  31                       0.93    4.50    1 VRA            1
  TO    1010 AKOSOMBO    161.00  4   -61.9   -24.0    66.4  31                       0.93    4.50    1 VRA            1
  TO    1031 SMELTER1    161.00  1     0.0    -0.2     0.2   0                       0.00    0.00    1 VRA            3
  TO    1032 SMELTER2    161.00  1    70.3    25.9    74.9  35                       0.06    0.28    1 VRA            3
  TO    1033 SMELTER3    161.00  1    70.3    24.3    74.3  35                       0.06    0.28    1 VRA            3
  TO    1034 SMELTER4    161.00  1     0.0    -0.2     0.2   0                       0.00    0.00    1 VRA            3
  TO    1035 SMELTER5    161.00  1     0.0    -0.2     0.2   0                       0.00    0.00    1 VRA            3
  TO    1036 SMELTER6    161.00  1     0.0    -0.2     0.2   0                       0.00    0.00    1 VRA            3
  TO    1040 TEMA        161.00  1    26.5     1.6    26.6  13                       0.01    0.04    1 VRA            1
  TO    1040 TEMA        161.00  2    26.5     1.6    26.6  13                       0.01    0.04    1 VRA            1
  TO    1050 ACHIMOTA    161.00  1    89.2    42.1    98.6  47                       0.81    3.98    1 VRA            1
  TO    1050 ACHIMOTA    161.00  2    89.2    42.1    98.6  47                       0.81    3.98    1 VRA            1
  TO    1050 ACHIMOTA    161.00  3    89.2    42.1    98.6  47                       0.81    3.98    1 VRA            1
  TO    1170 KPONG       161.00  1   -59.9   -23.1    64.2  30                       0.67    3.22    1 VRA            1
  TO    1170 KPONG       161.00  2   -59.9   -23.1    64.2  30                       0.67    3.22    1 VRA            1
  TO    1190 KPONG-GS    161.00  1   -93.9   -36.4   100.7  37                       1.16    8.60    1 VRA            1

 BUS    1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 0.9906PU   21.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                                159.49KV                MW     MVAR    1 VRA            3
  TO    1020 VOLTA       161.00  1     0.0     0.0     0.0  0                        0.00    0.00    1 VRA            1
  TO   10311 VALCO-1     13.800  1     0.0     0.0     0.0  0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3
  TO   10317 VALCO-7     13.800  1     0.0     0.0     0.0  0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3

 BUS    1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 0.9886PU   21.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
                                                                159.16KV                MW     MVAR    1 VRA            3
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 TO   1020 VOLTA       161.00  1    -70.2   -25.8    74.8  36                        0.06    0.28    1 VRA             1
 TO  10312 VALCO-2     13.800  1     70.2    25.8    74.8  88 1.0250LK   30.00LK    0.00    9.13    1 VRA             3
 TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 0.9887PU   21.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                           159.18KV                MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1    -70.2   -24.2    74.3  35                        0.06    0.28    1 VRA             1
 TO  10313 VALCO-3     13.800  1     70.2    24.2    74.3  87 1.0000LK   30.00LK    0.00    8.56    1 VRA             3

BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 0.9906PU   21.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                           159.49KV                MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 0.9906PU   21.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                           159.49KV                MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 0.9906PU   21.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                           159.49KV                MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 0.9902PU   21.15  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                           159.43KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                         152.2    73.7   169.1
 TO SHUNT                             0.0   -19.6    19.6
 TO   1020 VOLTA       161.00  1    -26.5    -1.8    26.6  13                        0.01    0.04    1 VRA             1
 TO   1020 VOLTA       161.00  2    -26.5    -1.8    26.6  13                        0.01    0.04    1 VRA             1
 TO   1500 TT1PP-HV    161.00  1    -99.1   -50.5   111.3  53                        0.89    4.30    1 VRA             1

BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9665PU   19.31  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                           155.61KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                         294.2   142.5   326.9
 TO SHUNT                             0.0   -37.4    37.4
 TO   1020 VOLTA       161.00  1    -88.4   -40.0    97.0  47                        0.81    3.98    1 VRA             1
 TO   1020 VOLTA       161.00  2    -88.4   -40.0    97.0  47                        0.81    3.98    1 VRA             1
 TO   1020 VOLTA       161.00  3    -88.4   -40.0    97.0  47                        0.81    3.98    1 VRA             1
 TO   1060 WINNEBA     161.00  1    -62.3    -4.6    62.5  38                        1.07    3.77    1 VRA             2
 TO   1370 MALLAM      161.00  1     33.3    19.5    38.6  23                        0.11    0.38    1 VRA             1

BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 0.9873PU   22.66  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                           158.95KV                MW     MVAR    1 VRA             2
 TO LOAD-PQ                          10.8     5.2    12.0
 TO   1050 ACHIMOTA    161.00  1     63.4     4.3    63.5  38                        1.07    3.77    1 VRA             1
 TO   1320 ABOADZE     161.00  1    -74.2    -9.5    74.8  45                        2.40    9.24    1 VRA             2

BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0001PU   25.22  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                           161.01KV                MW     MVAR    1 VRA             2
 TO LOAD-PQ                          24.9    12.0    27.6
 TO   1320 ABOADZE     161.00  1    -84.9   -16.1    86.4  51                        1.75    6.72    1 VRA             2
 TO   1370 MALLAM      161.00  1     60.0     4.1    60.2                            1.90    6.72    1 VRA             1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0242PU   28.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                            164.90KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                          48.5    23.5    53.9
 TO   1090 TARKWA      161.00  1    126.6    37.9   132.1  76                    3.84   13.77    1 VRA            2
 TO   1320 ABOADZE     161.00  1    -90.9   -25.0    94.3  54                    0.52    1.98    1 VRA            2
 TO   1320 ABOADZE     161.00  2    -90.9   -25.0    94.3  54                    0.52    1.98    1 VRA            2
 TO   1360 ESSIAMA     161.00  1      6.6   -11.5    13.2                        0.04    0.13    1 VRA            3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 0.9684PU   22.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                            155.92KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                          49.7    24.0    55.2
 TO   1080 TAKORADI    161.00  1   -122.7   -27.9   125.9  76                    3.84   13.77    1 VRA            2
 TO   1095 NEWTAR      161.00  1     25.4    13.3    28.6  17                    0.03    0.11    1 VRA            3
 TO   1100 PRES-161    161.00  1     47.7    -9.5    48.6  30                    0.23    0.82    1 VRA            2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 0.9657PU   22.58  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                            155.47KV               MW     MVAR    1 VRA            3
 TO   1090 TARKWA      161.00  1    -25.4   -13.7    28.8  18                    0.03    0.11    1 VRA            2
 TO  10951 NTAR-LV     11.500  1     12.7     6.9    14.4  44 1.0000LK           0.00    0.71    1 VRA            3
 TO  10951 NTAR-LV     11.500  2     12.7     6.9    14.4  44 1.0000LK           0.00    0.71    1 VRA            3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 0.9669PU   21.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                            155.68KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                           6.6     3.2     7.3
 TO SHUNT                             0.0   -18.7    18.7
 TO SWITCHED SHUNT                    0.0   -18.7    18.7
 TO   1090 TARKWA      161.00  1    -47.5     8.8    48.3  29                    0.23    0.82    1 VRA            2
 TO   1109 PRES-225    225.00  1      5.0   -18.3    19.0   9 1.0000UN           0.00    0.19    1 VRA            2
 TO   1109 PRES-225    225.00  2      5.0   -18.3    19.0   9 1.0000UN           0.00    0.19    1 VRA            2
 TO   1300 BOGOSO      161.00  1    179.1    92.7   201.6 123                    2.53    9.02    1 VRA            2
 TO   1320 ABOADZE     161.00  1   -148.3   -30.7   151.4  43                    5.35   22.52    1 VRA            2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 0.9761PU   21.60  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                            219.63KV               MW     MVAR    1 VRA            2
 TO   1100 PRES-161    161.00  1     -5.0    18.5    19.2  10 1.0000LK           0.00    0.19    1 VRA            2
 TO   1100 PRES-161    161.00  2     -5.0    18.5    19.2  10 1.0000LK           0.00    0.19    1 VRA            2
 TO   2010 ABOBO       225.00  1     10.1   -37.0    38.3                        0.16    1.06    2 CIE            1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.8302PU   11.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                            133.66KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                           1.9     0.9     2.1
 TO   1200 ASAWINSO    161.00  1     27.6    11.3    29.8  25                    0.68    1.51    1 VRA            3
 TO   1210 N-OBUASI    161.00  1     94.2    30.6    99.0  33                    1.58    5.67    1 VRA            3
 TO   1300 BOGOSO      161.00  1   -123.6   -42.8   130.8                        7.24   25.88    1 VRA            2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.7941PU    7.16  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                            127.85KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                          25.4    12.3    28.2
 TO SHUNT                             0.0    -4.5     4.5
 TO   1130 KUMASI      161.00  1     80.2    29.2    85.4  63                    2.76    9.88    1 VRA            3
 TO   1210 N-OBUASI    161.00  1   -105.6   -37.0   111.9  39                    0.63    2.24    1 VRA            3

BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 0.7418PU    1.24  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                            119.42KV               MW     MVAR    1 VRA            3
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  TO LOAD-PQ                              157.2    76.2   174.7
  TO SHUNT                                  0.0   -33.0    33.0
  TO   1010 AKOSOMBO    161.00  1    -124.4   -36.3   129.6  48                         17.49   76.37    1 VRA            1
  TO   1120 OBUASI      161.00  1     -77.5   -21.6    80.4  64                          2.76    9.88    1 VRA            3
  TO   1180 KONONGO     161.00  1     -87.3   -21.2    89.8  71                          3.34   11.96    1 VRA            3
  TO   1260 TECHIMAN    161.00  1      57.9    16.0    60.1  44                          1.99    8.69    1 VRA            5
  TO   1413 AHAF-161    161.00  1      37.0    10.0    38.3  21                          0.55    3.45    1 VRA            1
  TO   1413 AHAF-161    161.00  2      37.0    10.0    38.3  21                          0.55    3.45    1 VRA            1

 BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 0.8634PU   13.85  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                               139.01KV                 MW     MVAR    1 VRA            3
  TO LOAD-PQ                               10.7     5.2    11.9
  TO   1150 TAFO        161.00  1    -109.8   -49.3   120.3  82                          5.09   18.20    1 VRA            3
  TO   1180 KONONGO     161.00  1      99.1    44.2   108.5  74                          3.77   13.50    1 VRA            3

 BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 0.9553PU   20.21  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                               153.81KV                 MW     MVAR    1 VRA            3
  TO LOAD-PQ                               16.0     7.8    17.8
  TO   1010 AKOSOMBO    161.00  1     -88.6   -45.6    99.6  61                          2.90   10.40    1 VRA            1
  TO   1010 AKOSOMBO    161.00  2    -124.6   -71.5   143.6  83                          3.48   15.17    1 VRA            1
  TO   1140 NKAWKAW     161.00  1     114.9    64.0   131.5  81                          5.09   18.20    1 VRA            3
  TO   1160 AKWATIA     161.00  1      82.3    45.3    93.9  58                          2.39    8.58    1 VRA            3

 BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 0.8937PU   16.16  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                               143.89KV                 MW     MVAR    1 VRA            3
  TO LOAD-PQ                               11.8     5.7    13.1
  TO   1150 TAFO        161.00  1     -79.9   -40.1    89.4  59                          2.39    8.58    1 VRA            3
  TO   1210 N-OBUASI    161.00  1      68.1    34.4    76.3  35                          2.73   12.69    1 VRA            3

 BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0181PU   23.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                               163.91KV                 MW     MVAR    1 VRA            1
  TO LOAD-PQ                               17.2     8.4    19.2
  TO   1010 AKOSOMBO    161.00  1     -69.2   -26.6    74.1  34                          0.27    1.29    1 VRA            1
  TO   1010 AKOSOMBO    161.00  2     -69.2   -26.6    74.1  34                          0.27    1.29    1 VRA            1
  TO   1020 VOLTA       161.00  1      60.5    22.4    64.5  30                          0.67    3.22    1 VRA            1
  TO   1020 VOLTA       161.00  2      60.5    22.4    64.5  30                          0.67    3.22    1 VRA            1

 BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 0.7962PU    7.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                               128.19KV                 MW     MVAR    1 VRA            3
  TO LOAD-PQ                                4.7     2.3     5.2
  TO   1130 KUMASI      161.00  1      90.6    31.0    95.8  71                          3.34   11.96    1 VRA            3
  TO   1140 NKAWKAW     161.00  1     -95.3   -33.3   101.0  75                          3.77   13.50    1 VRA            3

 BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0336PU   25.44  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                               166.41KV                 MW     MVAR    1 VRA            1
  TO LOAD-PQ                                0.5     0.3     0.6
  TO   1010 AKOSOMBO    161.00  1      44.4     5.7    44.8  20                          0.15    0.72    1 VRA            1
  TO   1020 VOLTA       161.00  1      95.1    41.1   103.5  37                          1.16    8.60    1 VRA            1
  TO   1191 KPONGS1     13.800  1     -35.0   -11.8    36.9  72 1.0500LK   30.00LK    0.00    3.22    1 VRA            1
  TO   1192 KPONGS2     13.800  1     -35.0   -11.8    36.9  72 1.0500LK   30.00LK    0.00    3.22    1 VRA            1
  TO   1193 KPONGS3     13.800  1     -35.0   -11.8    36.9  72 1.0500LK   30.00LK    0.00    3.22    1 VRA            1
  TO   1194 KPONGS4     13.800  1     -35.0   -11.8    36.9  72 1.0500LK   30.00LK    0.00    3.22    1 VRA            1

 BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.7963PU    8.93  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
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                                                             128.21KV               MW     MVAR    1 VRA            3
  TO LOAD-PQ                             26.9    13.0     29.9
  TO   1110 DUNKWA      161.00  1     -26.9   -13.0     29.9  26                   0.68    1.51    1 VRA            2

 BUS   1210 N-OBUASI    161.00 CKT     MW     MVAR      MVA   % 0.8037PU    8.12  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                             129.39KV               MW     MVAR    1 VRA            3
  TO LOAD-PQ                             51.7    25.1     57.5
  TO SHUNT                                0.0   -10.2     10.2
  TO   1110 DUNKWA      161.00  1     -92.6   -26.1     96.2  33                   1.58    5.67    1 VRA            2
  TO   1120 OBUASI      161.00  1     106.2    38.9    113.1  39                   0.63    2.24    1 VRA            3
  TO   1160 AKWATIA     161.00  1     -65.4   -27.6     71.0  36                   2.73   12.69    1 VRA            3

 BUS   1220 ASIEKPE     161.00 CKT     MW     MVAR      MVA   % 0.9891PU   21.49  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                             159.25KV               MW     MVAR    1 VRA            1
  TO LOAD-PQ                             25.8    12.5     28.7
  TO   1010 AKOSOMBO    161.00  1     -66.4   -14.0     67.9  54                   1.84    4.14    1 VRA            1
  TO   1221 ASIEKP-6    69.000  1       0.0     0.0      0.0     0.9874LK          0.00    0.00    1 VRA            1
  TO   3010 LOME        161.00  1      40.6     1.5     40.6  32                   0.91    2.05    3 CEB            1

 BUS   1260 TECHIMAN    161.00 CKT     MW     MVAR      MVA   % 0.6918PU   -6.45  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                             111.37KV               MW     MVAR    1 VRA            5
  TO LOAD-PQ                             15.8     7.7     17.6
  TO SHUNT                                0.0    -2.6      2.6
  TO   1130 KUMASI      161.00  1     -55.9   -13.3     57.5  46                   1.99    8.69    1 VRA            3
  TO   1270 SUNYANI     161.00  1      -9.7    -5.0     11.0   9                   0.04    0.19    1 VRA            5
  TO   1280 TAMALE      161.00  1      42.7    18.1     46.4  37                   3.14   13.82    1 VRA            5
  TO   1380 SAWLA       161.00  1       7.1    -4.9      8.6   7                   0.10    0.32    1 VRA            5

 BUS   1270 SUNYANI     161.00 CKT     MW     MVAR      MVA   % 0.6992PU   -5.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                             112.58KV               MW     MVAR    1 VRA            5
  TO LOAD-PQ                             32.5    15.7     36.1
  TO SHUNT                                0.0    -4.9      4.9
  TO   1260 TECHIMAN    161.00  1       9.8     3.2     10.3   8                   0.04    0.19    1 VRA            5
  TO   1413 AHAF-161    161.00  1     -42.3   -14.0     44.5  17                   0.42    1.79    1 VRA            1

 BUS   1280 TAMALE      161.00 CKT     MW     MVAR      MVA   % 0.5767PU  -21.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                             92.848KV               MW     MVAR    1 VRA            5
  TO LOAD-PQ                             20.1     9.7     22.3
  TO   1260 TECHIMAN    161.00  1     -39.6   -14.5     42.2  40                   3.14   13.82    1 VRA            5
  TO   1290 BOLGA       161.00  1      12.6     3.6     13.1   9                   0.29    1.37    1 VRA            5
  TO   1350 YENDI       161.00  1       6.9     1.2      7.0   7                   0.08    0.25    1 VRA            5

 BUS   1290 BOLGA       161.00 CKT     MW     MVAR      MVA   % 0.5443PU  -26.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                             87.640KV               MW     MVAR    1 VRA            5
  TO LOAD-PQ                             11.4     5.5     12.7
  TO   1280 TAMALE      161.00  1     -12.3    -6.0     13.7  10                   0.29    1.37    1 VRA            5
  TO 3WNDTR              WND 1  1       0.9     0.4      1.0   6 1.0000LK          0.00    0.03

 BUS   1300 BOGOSO      161.00 CKT     MW     MVAR      MVA   % 0.9368PU   19.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                             150.83KV               MW     MVAR    1 VRA            2
  TO LOAD-PQ                             35.5    17.2     39.5
  TO   1100 PRES-161    161.00  1    -176.5   -84.5    195.7 123                   2.53    9.02    1 VRA            2
  TO   1110 DUNKWA      161.00  1     130.8    65.0    146.1                       7.24   25.88    1 VRA            2
  TO   1309 WEXFORD     161.00  1      10.2     2.4     10.4   6                   0.03    0.11    1 VRA            3
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BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 0.9309PU   19.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                              149.87KV                MW     MVAR    1 VRA           3
 TO   1300 BOGOSO      161.00  1    -10.1    -5.4    11.5   7                       0.03    0.11    1 VRA           2
 TO  13091 WEX-LV      34.500  1     10.1     5.4    11.5  35 1.0000LK   30.00LK    0.00    0.52    1 VRA           3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0354PU   29.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                              166.71KV                MW     MVAR    1 VRA           2
 TO LOAD-PQ                           0.4     0.2     0.4
 TO   1060 WINNEBA     161.00  1     76.6    10.9    77.4  44                       2.40    9.24    1 VRA           2
 TO   1070 C-COAST     161.00  1     86.6    18.4    88.6  50                       1.75    6.72    1 VRA           2
 TO   1080 TAKORADI    161.00  1     91.4    25.8    95.0  54                       0.52    1.98    1 VRA           2
 TO   1080 TAKORADI    161.00  2     91.4    25.8    95.0  54                       0.52    1.98    1 VRA           2
 TO   1100 PRES-161    161.00  1    153.6    44.8   160.0  42                       5.35   22.52    1 VRA           2
 TO   1321 ABOAD-G1    13.800  1   -100.0   -25.6   103.2  71 1.0500LK   30.00LK    0.00    8.70    1 VRA           1
 TO   1322 ABOAD-G2    13.800  1   -100.0   -25.6   103.2  71 1.0500LK   30.00LK    0.00    8.70    1 VRA           1
 TO   1323 ABOA-G3     13.800  1   -100.0   -25.6   103.2  71 1.0500LK              0.00    8.70    1 VRA           1
 TO   1324 ABOA-G4     13.800  1   -100.0   -24.5   103.0  71 1.0500LK              0.00    8.96    1 VRA           1
 TO   1325 ABOAD-G5    13.800  1   -100.0   -24.5   103.0  71 1.0500LK              0.00    8.96    1 VRA           1
 TO   1326 ABOA-G6     13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA           1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 0.6761PU   -9.94  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                              108.86KV                MW     MVAR    1 VRA           1
 TO LOAD-PQ                           5.5     2.6     6.1
 TO   1380 SAWLA       161.00  1     -5.5    -2.6     6.1   5                       0.03    0.12    1 VRA           5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 0.5640PU  -23.00  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                              90.809KV                MW     MVAR    1 VRA           5
 TO LOAD-PQ                           6.8     3.3     7.6
 TO   1280 TAMALE      161.00  1     -6.8    -3.3     7.6   7                       0.08    0.25    1 VRA           5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0314PU   27.65  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                              166.06KV                MW     MVAR    1 VRA           3
 TO LOAD-PQ                           6.6     3.2     7.3
 TO   1080 TAKORADI    161.00  1     -6.6     6.2     9.0                           0.04    0.13    1 VRA           2
 TO   1600 OPB-HV      161.00  1      0.0    -9.4     9.4   2                       0.00    0.02    1 VRA           3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9594PU   18.91  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                              154.46KV                MW     MVAR    1 VRA           1
 TO LOAD-PQ                          91.3    44.2   101.4
 TO SHUNT                             0.0   -18.4    18.4
 TO   1050 ACHIMOTA    161.00  1    -33.2   -20.2    38.8  24                       0.11    0.38    1 VRA           1
 TO   1070 C-COAST     161.00  1    -58.1    -5.6    58.4                           1.90    6.72    1 VRA           2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 0.6852PU   -9.11  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                              110.32KV                MW     MVAR    1 VRA           5
 TO LOAD-PQ                           1.5     0.7     1.7
 TO   1260 TECHIMAN    161.00  1     -7.0    -3.5     7.8   6                       0.10    0.32    1 VRA           5
 TO   1340 WA          161.00  1      5.5     2.8     6.1   5                       0.03    0.12    1 VRA           1
 TO   1381 SAW-34.5    34.500  1      0.0     0.0     0.0   0 1.1000HI              0.00    0.00    1 VRA           1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9647PU   18.82  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                              155.32KV                MW     MVAR    1 VRA           1
 TO LOAD-PQ                          10.7     5.2    11.8
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 TO   1392  AFTAP      161.00  1    -10.7    -5.2    11.8   7                      0.00    0.00    1 VRA            1

BUS   1392  AFTAP      161.00 CKT     MW     MVAR     MVA   % 0.9649PU   18.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                             155.36KV                MW     MVAR    1 VRA            1
 TO   1010 AKOSOMBO    161.00  1    -51.1    -9.4    52.0  42                      2.50    5.74    1 VRA            1
 TO   1390 DCEM        161.00  1     10.7     5.1    11.8   7                      0.00    0.00    1 VRA            1
 TO   3010 LOME        161.00  1     40.4     4.3    40.7  33                      0.05    0.11    3 CEB            1

BUS   1413 AHAF-161    161.00 CKT     MW     MVAR     MVA   % 0.7144PU   -3.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                             115.02KV                MW     MVAR    1 VRA            1
 TO   1130 KUMASI      161.00  1    -36.4    -9.6    37.7  22                      0.55    3.45    1 VRA            3
 TO   1130 KUMASI      161.00  2    -36.4    -9.6    37.7  22                      0.55    3.45    1 VRA            3
 TO   1270 SUNYANI     161.00  1     42.7    13.8    44.9  17                      0.42    1.79    1 VRA            5
 TO   1412 AHAFO-LV    11.000  1     15.1     2.7    15.4  34 1.1500HI             0.00    1.09    1 VRA            5
 TO   1412 AHAFO-LV    11.000  2     15.1     2.7    15.4  34 1.1500HI             0.00    1.09    1 VRA            5

BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR     MVA   % 1.0150PU   22.89  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                             163.41KV                MW     MVAR    1 VRA            1
 TO   1040 TEMA        161.00  1    100.0    53.1   113.2  52                      0.89    4.30    1 VRA            1
 TO   1510 TT1PP-G1    13.800  1   -100.0   -53.3   113.3  69 1.0000UN             0.00    0.01    1 VRA            1
 TO   1520 TT1PP-G2    13.800  1      0.0     0.1     0.1   0 1.0000UN             0.00    0.00    1 VRA            1

BUS   1600 OPB-HV      161.00 CKT     MW     MVAR     MVA   % 1.0358PU   27.60  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                             166.77KV                MW     MVAR    1 VRA            3
 TO   1360 ESSIAMA     161.00  1      0.0     0.0     0.0   0                      0.00    0.02    1 VRA            3
 TO   1601 OPB-G1      13.800  1      0.0     0.0     0.0   0 1.0500LK             0.00    0.00    1 VRA            3
 TO   1602 OPB-G2      13.800  1      0.0     0.0     0.0   0 1.0500LK             0.00    0.00    1 VRA            3
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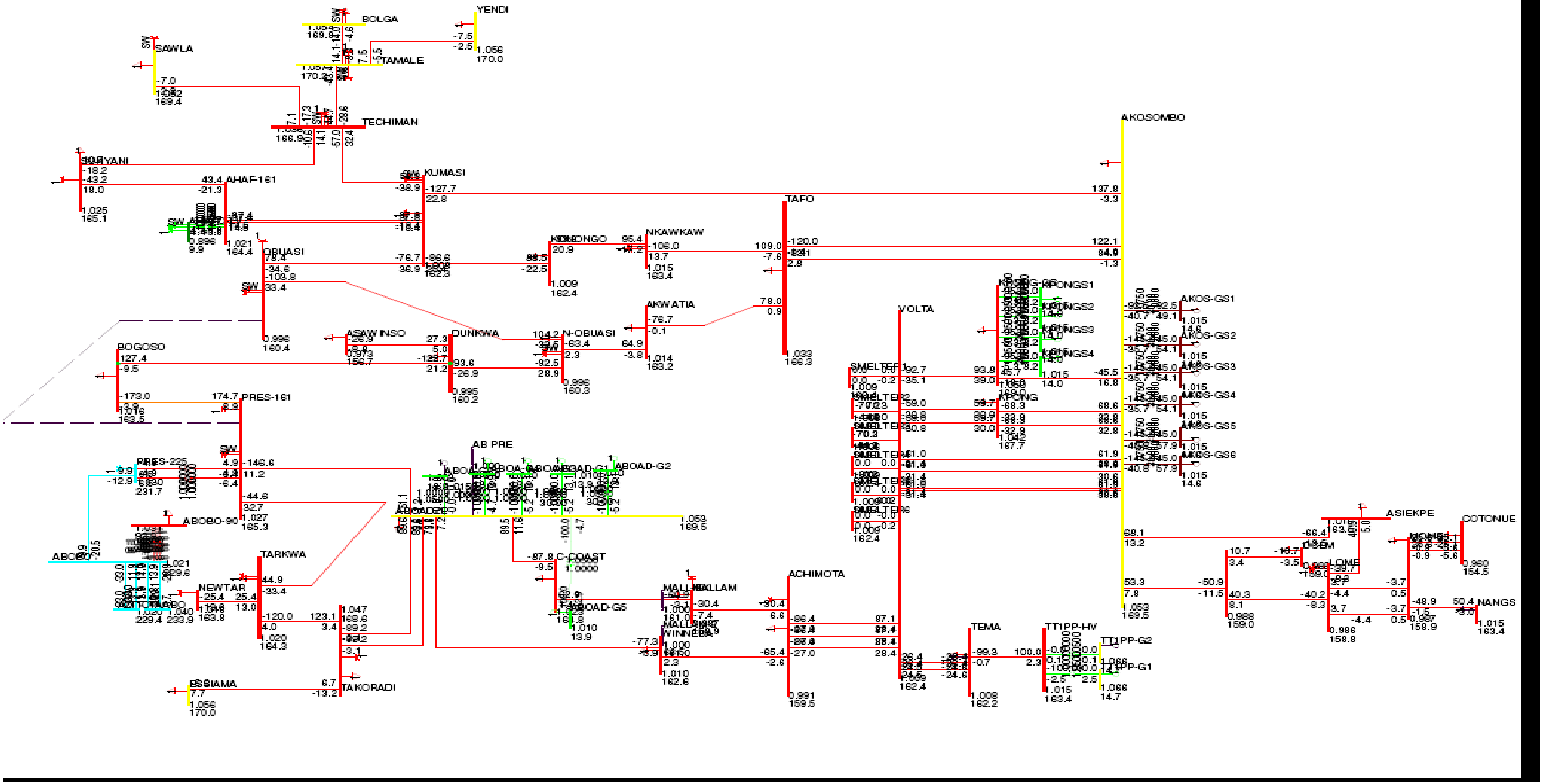
Peak Load Condition at power factor of 0.95, Prestea-Obuasi contingency on single line diagram (Case 2)



Peak Load Condition at power factor of 0.95, Prestea-Obuasi contingency (Casae 2, table results)

```
BUS   1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0527PU   25.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                              169.49KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                          11.9      3.9     12.5
 TO    1011 AKOS-GS1    14.400  1    -92.5    -40.7    101.1  51 1.0750LK   30.00LK    0.00    8.46    1 VRA             1
 TO    1012 AKOS-GS2    14.400  1   -145.0    -35.7    149.3  75 1.0750LK   30.00LK    0.00   18.46    1 VRA             1
 TO    1013 AKOS-GS3    14.400  1   -145.0    -35.7    149.3  75 1.0750LK   30.00LK    0.00   18.46    1 VRA             1
 TO    1014 AKOS-GS4    14.400  1   -145.0    -35.7    149.3  75 1.0750LK   30.00LK    0.00   18.46    1 VRA             1
 TO    1015 AKOS-GS5    14.400  1   -145.0    -40.8    150.6  75 1.0750LK   30.00LK    0.00   17.09    1 VRA             1
 TO    1016 AKOS-GS6    14.400  1   -145.0    -40.8    150.6  75 1.0750LK   30.00LK    0.00   17.09    1 VRA             1
 TO    1020 VOLTA       161.00  1     61.9     30.6     69.1  31                         0.95    4.60    1 VRA             1
 TO    1020 VOLTA       161.00  2     61.9     30.6     69.1  31                         0.95    4.60    1 VRA             1
 TO    1020 VOLTA       161.00  3     61.9     30.6     69.1  31                         0.95    4.60    1 VRA             1
 TO    1020 VOLTA       161.00  4     61.9     30.6     69.1  31                         0.95    4.60    1 VRA             1
 TO    1130 KUMASI      161.00  1    137.8     -3.3    137.9  36                        10.13   44.23    1 VRA             3
 TO    1150 TAFO        161.00  1     84.9     -1.3     84.9  47                         1.77    6.33    1 VRA             3
 TO    1150 TAFO        161.00  2    122.1      4.0    122.1  64                         2.12    9.23    1 VRA             3
 TO    1170 KPONG       161.00  1     68.6     32.8     76.0  34                         0.27    1.29    1 VRA             1
 TO    1170 KPONG       161.00  2     68.6     32.8     76.0  34                         0.27    1.29    1 VRA             1
 TO    1190 KPONG-GS    161.00  1    -45.5     16.8     48.5  22                         0.17    0.82    1 VRA             1
 TO    1220 ASIEKPE     161.00  1     68.1     13.2     69.4  51                         1.73    3.91    1 VRA             1
 TO    1392  AFTAP      161.00  1     53.3      7.8     53.9  40                         2.40    5.50    1 VRA             1

BUS   1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 1.0090PU   22.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                              162.45KV               MW     MVAR    1 VRA             1
 TO    1010 AKOSOMBO    161.00  1    -61.0    -31.4     68.6  32                         0.95    4.60    1 VRA             1
 TO    1010 AKOSOMBO    161.00  2    -61.0    -31.4     68.6  32                         0.95    4.60    1 VRA             1
 TO    1010 AKOSOMBO    161.00  3    -61.0    -31.4     68.6  32                         0.95    4.60    1 VRA             1
 TO    1010 AKOSOMBO    161.00  4    -61.0    -31.4     68.6  32                         0.95    4.60    1 VRA             1
 TO    1031 SMELTER1    161.00  1      0.0     -0.2      0.2   0                         0.00    0.00    1 VRA             3
 TO    1032 SMELTER2    161.00  1     70.3     45.0     83.5  39                         0.07    0.34    1 VRA             3
 TO    1033 SMELTER3    161.00  1     70.3     44.4     83.1  39                         0.07    0.34    1 VRA             3
 TO    1034 SMELTER4    161.00  1      0.0     -0.2      0.2   0                         0.00    0.00    1 VRA             3
 TO    1035 SMELTER5    161.00  1      0.0     -0.2      0.2   0                         0.00    0.00    1 VRA             3
 TO    1036 SMELTER6    161.00  1      0.0     -0.2      0.2   0                         0.00    0.00    1 VRA             3
 TO    1040 TEMA        161.00  1     26.4     24.5     36.0  17                         0.01    0.06    1 VRA             1
 TO    1040 TEMA        161.00  2     26.4     24.5     36.0  17                         0.01    0.06    1 VRA             1
 TO    1050 ACHIMOTA    161.00  1     87.1     28.4     91.6  43                         0.67    3.30    1 VRA             1
 TO    1050 ACHIMOTA    161.00  2     87.1     28.4     91.6  43                         0.67    3.30    1 VRA             1
 TO    1050 ACHIMOTA    161.00  3     87.1     28.4     91.6  43                         0.67    3.30    1 VRA             1
 TO    1170 KPONG       161.00  1    -59.0    -30.8     66.6  31                         0.69    3.32    1 VRA             1
 TO    1170 KPONG       161.00  2    -59.0    -30.8     66.6  31                         0.69    3.32    1 VRA             1
 TO    1190 KPONG-GS    161.00  1    -92.7    -35.1     99.1  36                         1.09    8.02    1 VRA             1

BUS   1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 1.0090PU   22.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                              162.45KV               MW     MVAR    1 VRA             3
 TO    1020 VOLTA       161.00  1      0.0      0.0      0.0   0                         0.00    0.00    1 VRA             1
 TO   10311 VALCO-1     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3
 TO   10317 VALCO-7     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3
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BUS    1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 1.0061PU   22.53  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
                                                               161.98KV                  MW     MVAR    1 VRA             3
 TO   1020 VOLTA        161.00  1    -70.2   -44.9    83.3  39                         0.07    0.34    1 VRA             1
 TO  10312 VALCO-2      13.800  1     70.2    44.9    83.3  98 1.0250LK   30.00LK    0.00   10.94    1 VRA             3
 TO  10318 VALCO-8      13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS    1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 1.0061PU   22.53  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                               161.99KV                  MW     MVAR    1 VRA             3
 TO   1020 VOLTA        161.00  1    -70.2   -44.3    83.0  39                         0.07    0.34    1 VRA             1
 TO  10313 VALCO-3      13.800  1     70.2    44.3    83.0  98 1.0000LK   30.00LK    0.00   10.33    1 VRA             3

BUS    1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 1.0090PU   22.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                               162.45KV                  MW     MVAR    1 VRA             3
 TO   1020 VOLTA        161.00  1      0.0     0.0     0.0   0                         0.00    0.00    1 VRA             1
 TO  10314 VALCO-4      13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS    1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 1.0090PU   22.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                               162.45KV                  MW     MVAR    1 VRA             3
 TO   1020 VOLTA        161.00  1      0.0     0.0     0.0   0                         0.00    0.00    1 VRA             1
 TO  10315 VALCO-5      13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS    1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 1.0090PU   22.70  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                               162.45KV                  MW     MVAR    1 VRA             3
 TO   1020 VOLTA        161.00  1      0.0     0.0     0.0   0                         0.00    0.00    1 VRA             1
 TO  10316 VALCO-6      13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS    1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 1.0075PU   22.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                               162.21KV                  MW     MVAR    1 VRA             1
 TO LOAD-PQ                          152.2    50.0   160.2
 TO   1020 VOLTA        161.00  1    -26.4   -24.6    36.1  17                         0.01    0.06    1 VRA             1
 TO   1020 VOLTA        161.00  2    -26.4   -24.6    36.1  17                         0.01    0.06    1 VRA             1
 TO   1500 TT1PP-HV     161.00  1    -99.3    -0.7    99.3  46                         0.69    3.33    1 VRA             1

BUS    1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9909PU   20.85  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                               159.54KV                  MW     MVAR    1 VRA             1
 TO LOAD-PQ                          294.2    96.7   309.7
 TO SHUNT                              0.0   -19.6    19.6
 TO   1020 VOLTA        161.00  1    -86.4   -27.0    90.5  43                         0.67    3.30    1 VRA             1
 TO   1020 VOLTA        161.00  2    -86.4   -27.0    90.5  43                         0.67    3.30    1 VRA             1
 TO   1020 VOLTA        161.00  3    -86.4   -27.0    90.5  43                         0.67    3.30    1 VRA             1
 TO   1060 WINNEBA      161.00  1    -65.4    -2.6    65.4  39                         1.12    3.95    1 VRA             2
 TO   1370 MALLAM       161.00  1     30.4     6.6    31.1  18                         0.07    0.23    1 VRA             1

BUS    1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 1.0102PU   24.24  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                               162.64KV                  MW     MVAR    1 VRA             2
 TO LOAD-PQ                           10.8     3.6    11.4
 TO   1050 ACHIMOTA     161.00  1     66.5     2.3    66.6  39                         1.12    3.95    1 VRA             1
 TO   1320 ABOADZE      161.00  1    -77.3    -5.9    77.5  45                         2.47    9.53    1 VRA             2

BUS    1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0235PU   26.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                               164.78KV                  MW     MVAR    1 VRA             2
 TO LOAD-PQ                           24.9     8.2    26.2
 TO   1320 ABOADZE      161.00  1    -87.8    -9.5    88.3  51                         1.75    6.72    1 VRA             2
 TO   1370 MALLAM       161.00  1     62.9     1.4    62.9                             1.98    6.98    1 VRA             1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0470PU   29.90  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                               168.57KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                           48.5     16.0     51.1
 TO   1090 TARKWA      161.00  1    123.1      3.4    123.2  69                      3.17   11.37    1 VRA             2
 TO   1320 ABOADZE     161.00  1    -89.2     -3.1     89.2  50                      0.44    1.71    1 VRA             2
 TO   1320 ABOADZE     161.00  2    -89.2     -3.1     89.2  50                      0.44    1.71    1 VRA             2
 TO   1360 ESSIAMA     161.00  1      6.7    -13.2     14.7                          0.05    0.15    1 VRA             3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 1.0203PU   24.54  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                               164.27KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                           49.7     16.3     52.3
 TO   1080 TAKORADI    161.00  1   -120.0      4.0    120.0  69                      3.17   11.37    1 VRA             2
 TO   1095 NEWTAR      161.00  1     25.4     13.0     28.5  16                      0.03    0.10    1 VRA             3
 TO   1100 PRES-161    161.00  1     44.9    -33.4     56.0  32                      0.28    0.97    1 VRA             2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 1.0177PU   24.39  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                               163.85KV               MW     MVAR    1 VRA             3
 TO   1090 TARKWA      161.00  1    -25.4    -13.6     28.8  17                      0.03    0.10    1 VRA             2
 TO  10951 NTAR-LV     11.500  1     12.7      6.8     14.4  44 1.0000LK             0.00    0.64    1 VRA             3
 TO  10951 NTAR-LV     11.500  2     12.7      6.8     14.4  44 1.0000LK             0.00    0.64    1 VRA             3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 1.0268PU   23.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                               165.31KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                            6.6      2.2      6.9
 TO SHUNT                              0.0    -21.1     21.1
 TO SWITCHED SHUNT                     0.0    -21.1     21.1
 TO   1090 TARKWA      161.00  1    -44.6     32.7     55.4  32                      0.28    0.97    1 VRA             2
 TO   1109 PRES-225    225.00  1      4.9     -6.4      8.1   4 1.0000UN             0.00    0.03    1 VRA             2
 TO   1109 PRES-225    225.00  2      4.9     -6.4      8.1   4 1.0000UN             0.00    0.03    1 VRA             2
 TO   1300 BOGOSO      161.00  1    174.7      8.9    175.0 100                      1.68    6.01    1 VRA             2
 TO   1320 ABOADZE     161.00  1   -146.6     11.2    147.0  39                      4.55   19.11    1 VRA             2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 1.0298PU   23.44  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                               231.71KV               MW     MVAR    1 VRA             2
 TO   1100 PRES-161    161.00  1     -4.9      6.5      8.1   4 1.0000LK             0.00    0.03    1 VRA             2
 TO   1100 PRES-161    161.00  2     -4.9      6.5      8.1   4 1.0000LK             0.00    0.03    1 VRA             2
 TO   2010 ABOBO       225.00  1      9.9    -12.9     16.3                          0.03    0.19    2 CIE             1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.9950PU   13.89  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                               160.20KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                            1.9      0.6      2.0
 TO   1200 ASAWINSO    161.00  1     27.3      5.0     27.8  20                      0.41    0.91    1 VRA             3
 TO   1210 N-OBUASI    161.00  1     93.6    -26.9     97.3  27                      1.06    3.78    1 VRA             3
 TO   1300 BOGOSO      161.00  1   -122.7     21.2    124.6                          4.64   16.58    1 VRA             2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.9962PU   10.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                               160.39KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                           25.4      8.3     26.7
 TO SHUNT                              0.0     -7.1      7.1
 TO   1130 KUMASI      161.00  1     78.4    -34.6     85.7  51                      1.72    6.15    1 VRA             3
 TO   1210 N-OBUASI    161.00  1   -103.8     33.4    109.0  30                      0.38    1.36    1 VRA             3

BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 1.0081PU    6.60  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
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                                                              162.30KV                 MW     MVAR    1 VRA            3
 TO LOAD-PQ                           157.2    51.7   165.5
 TO SHUNT                               0.0   -61.0    61.0
 TO    1010 AKOSOMBO    161.00  1    -127.7    22.8   129.7  35                     10.13   44.23    1 VRA            1
 TO    1120 OBUASI      161.00  1     -76.7    36.9    85.1  50                      1.72    6.15    1 VRA            3
 TO    1180 KONONGO     161.00  1     -86.6    25.4    90.3  53                      1.86    6.66    1 VRA            3
 TO    1260 TECHIMAN    161.00  1      58.3   -38.9    70.1  38                      1.30    5.67    1 VRA            5
 TO    1413 AHAF-161    161.00  1      37.8   -18.4    42.0  17                      0.33    2.07    1 VRA            1
 TO    1413 AHAF-161    161.00  2      37.8   -18.4    42.0  17                      0.33    2.07    1 VRA            1

BUS    1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 1.0146PU   15.69  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                              163.35KV                 MW     MVAR    1 VRA            3
 TO LOAD-PQ                            10.7     3.5    11.2
 TO    1150 TAFO        161.00  1    -106.0    13.7   106.9  62                      2.96   10.57    1 VRA            3
 TO    1180 KONONGO     161.00  1      95.4   -17.2    96.9  56                      2.14    7.66    1 VRA            3

BUS    1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 1.0327PU   21.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                              166.26KV                 MW     MVAR    1 VRA            3
 TO LOAD-PQ                            16.0     5.3    16.9
 TO    1010 AKOSOMBO    161.00  1     -83.1     2.8    83.1  47                      1.77    6.33    1 VRA            1
 TO    1010 AKOSOMBO    161.00  2    -120.0    -1.4   120.0  64                      2.12    9.23    1 VRA            1
 TO    1140 NKAWKAW     161.00  1     109.0    -7.6   109.3  62                      2.96   10.57    1 VRA            3
 TO    1160 AKWATIA     161.00  1      78.0     0.9    78.1  44                      1.39    4.98    1 VRA            3

BUS    1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 1.0138PU   17.73  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                              163.23KV                 MW     MVAR    1 VRA            3
 TO LOAD-PQ                            11.8     3.9    12.4
 TO    1150 TAFO        161.00  1     -76.7    -0.1    76.7  45                      1.39    4.98    1 VRA            3
 TO    1210 N-OBUASI    161.00  1      64.9    -3.8    65.0  26                      1.47    6.85    1 VRA            3

BUS    1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0417PU   24.97  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                              167.71KV                 MW     MVAR    1 VRA            1
 TO LOAD-PQ                            17.2     5.7    18.2
 TO    1010 AKOSOMBO    161.00  1     -68.3   -32.9    75.8  34                      0.27    1.29    1 VRA            1
 TO    1010 AKOSOMBO    161.00  2     -68.3   -32.9    75.8  34                      0.27    1.29    1 VRA            1
 TO    1020 VOLTA       161.00  1      59.7    30.0    66.8  30                      0.69    3.32    1 VRA            1
 TO    1020 VOLTA       161.00  2      59.7    30.0    66.8  30                      0.69    3.32    1 VRA            1

BUS    1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 1.0085PU   10.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                              162.37KV                 MW     MVAR    1 VRA            3
 TO LOAD-PQ                             4.7     1.6     5.0
 TO    1130 KUMASI      161.00  1      88.5   -22.5    91.3  53                      1.86    6.66    1 VRA            3
 TO    1140 NKAWKAW     161.00  1     -93.2    20.9    95.5  56                      2.14    7.66    1 VRA            3

BUS    1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0497PU   26.73  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                              169.00KV                 MW     MVAR    1 VRA            1
 TO LOAD-PQ                             0.5     0.2     0.6
 TO    1010 AKOSOMBO    161.00  1      45.7   -18.0    49.1  22                      0.17    0.82    1 VRA            1
 TO    1020 VOLTA       161.00  1      93.8    39.0   101.6  35                      1.09    8.02    1 VRA            1
 TO    1191 KPONGS1     13.800  1     -35.0    -5.3    35.4  69 1.0500LK   30.00LK   0.00    2.87    1 VRA            1
 TO    1192 KPONGS2     13.800  1     -35.0    -5.3    35.4  69 1.0500LK   30.00LK   0.00    2.87    1 VRA            1
 TO    1193 KPONGS3     13.800  1     -35.0    -5.3    35.4  69 1.0500LK   30.00LK   0.00    2.87    1 VRA            1
 TO    1194 KPONGS4     13.800  1     -35.0    -5.3    35.4  69 1.0500LK   30.00LK   0.00    2.87    1 VRA            1
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BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.9731PU   12.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
                                                              156.68KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                          26.9      8.8     28.3
 TO   1110 DUNKWA      161.00  1    -26.9     -8.8     28.3  20                      0.41    0.91    1 VRA            2

BUS   1210 N-OBUASI    161.00 CKT     MW     MVAR     MVA   % 0.9958PU   11.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                              160.32KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                          51.7     17.0     54.5
 TO SHUNT                             0.0    -15.7     15.7
 TO   1110 DUNKWA      161.00  1    -92.5     28.9     96.9  27                      1.06    3.78    1 VRA            2
 TO   1120 OBUASI      161.00  1    104.2    -32.5    109.1  30                      0.38    1.36    1 VRA            3
 TO   1160 AKWATIA     161.00  1    -63.4      2.3     63.4  26                      1.47    6.85    1 VRA            3

BUS   1220 ASIEKPE     161.00 CKT     MW     MVAR     MVA   % 1.0155PU   22.84  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                              163.50KV               MW     MVAR    1 VRA            1
 TO LOAD-PQ                          25.8      8.5     27.2
 TO   1010 AKOSOMBO    161.00  1    -66.4    -13.5     67.7  52                      1.73    3.91    1 VRA            1
 TO   1221 ASIEKP-6    69.000  1      0.0      0.0      0.0     0.9874LK             0.00    0.00    1 VRA            1
 TO   3010 LOME        161.00  1     40.5      5.0     40.8  31                      0.88    1.99    3 CEB            1

BUS   1260 TECHIMAN    161.00 CKT     MW     MVAR     MVA   % 1.0365PU    1.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                              166.87KV               MW     MVAR    1 VRA            5
 TO LOAD-PQ                          15.8      5.2     16.7
 TO SHUNT                             0.0     -5.8      5.8
 TO   1130 KUMASI      161.00  1    -57.0     32.4     65.6  35                      1.30    5.67    1 VRA            3
 TO   1270 SUNYANI     161.00  1    -10.6     14.1     17.7   9                      0.06    0.29    1 VRA            5
 TO   1280 TAMALE      161.00  1     44.7    -28.6     53.1  28                      1.29    5.69    1 VRA            5
 TO   1380 SAWLA       161.00  1      7.1    -17.3     18.7  10                      0.09    0.30    1 VRA            5

BUS   1270 SUNYANI     161.00 CKT     MW     MVAR     MVA   % 1.0253PU    2.60  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                              165.07KV               MW     MVAR    1 VRA            5
 TO LOAD-PQ                          32.5     10.7     34.2
 TO SHUNT                             0.0    -10.5     10.5
 TO   1260 TECHIMAN    161.00  1     10.7    -18.2     21.1  11                      0.06    0.29    1 VRA            5
 TO   1413 AHAF-161    161.00  1    -43.2     18.0     46.8  13                      0.23    0.96    1 VRA            1

BUS   1280 TAMALE      161.00 CKT     MW     MVAR     MVA   % 1.0571PU   -4.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                              170.19KV               MW     MVAR    1 VRA            5
 TO LOAD-PQ                          21.8      7.2     23.0
 TO   1260 TECHIMAN    161.00  1    -43.4      6.6     43.9  23                      1.29    5.69    1 VRA            5
 TO   1290 BOLGA       161.00  1     14.1     -8.3     16.3   6                      0.09    0.43    1 VRA            5
 TO   1350 YENDI       161.00  1      7.5     -5.5      9.3   5                      0.03    0.08    1 VRA            5

BUS   1290 BOLGA       161.00 CKT     MW     MVAR     MVA   % 1.0544PU   -6.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                              169.76KV               MW     MVAR    1 VRA            5
 TO LOAD-PQ                          13.0      4.3     13.7
 TO   1280 TAMALE      161.00  1    -14.0     -4.6     14.7   6                      0.09    0.43    1 VRA            5
 TO 3WNDTR              WND 1  1      1.0      0.3      1.1   7 1.0000LK             0.00    0.01

BUS   1300 BOGOSO      161.00 CKT     MW     MVAR     MVA   % 1.0156PU   21.62  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                              163.51KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                          35.5     11.7     37.4
 TO   1100 PRES-161    161.00  1   -173.0     -3.9    173.1 100                      1.68    6.01    1 VRA            2
 TO   1110 DUNKWA      161.00  1    127.4     -9.5    127.7                          4.64   16.58    1 VRA            2
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 TO    1309 WEXFORD     161.00  1     10.2     1.7    10.3   6                       0.03    0.09    1 VRA             3

BUS    1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 1.0104PU   21.20  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                             162.67KV                MW     MVAR    1 VRA             3
 TO    1300 BOGOSO      161.00  1    -10.1    -5.4    11.5   6                       0.03    0.09    1 VRA             2
 TO   13091 WEX-LV      34.500  1     10.1     5.4    11.5  35 1.0000LK   30.00LK    0.00    0.44    1 VRA             3

BUS    1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0529PU   30.98  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                             169.52KV                MW     MVAR    1 VRA             2
 TO LOAD-PQ                            0.4     0.1     0.4
 TO    1060 WINNEBA     161.00  1     79.8     7.2    80.1  45                       2.47    9.53    1 VRA             2
 TO    1070 C-COAST     161.00  1     89.5    11.6    90.3  50                       1.75    6.72    1 VRA             2
 TO    1080 TAKORADI    161.00  1     89.6     3.6    89.7  50                       0.44    1.71    1 VRA             2
 TO    1080 TAKORADI    161.00  2     89.6     3.6    89.7  50                       0.44    1.71    1 VRA             2
 TO    1100 PRES-161    161.00  1    151.1    -1.2   151.1  39                       4.55   19.11    1 VRA             2
 TO    1321 ABOAD-G1    13.800  1   -100.0    -5.2   100.1  69 1.0500LK   30.00LK    0.00    7.92    1 VRA             1
 TO    1322 ABOAD-G2    13.800  1   -100.0    -5.2   100.1  69 1.0500LK   30.00LK    0.00    7.92    1 VRA             1
 TO    1323 ABOA-G3     13.800  1   -100.0    -5.2   100.1  69 1.0500LK              0.00    7.92    1 VRA             1
 TO    1324 ABOA-G4     13.800  1   -100.0    -4.7   100.1  69 1.0500LK              0.00    8.19    1 VRA             1
 TO    1325 ABOAD-G5    13.800  1   -100.0    -4.7   100.1  69 1.0500LK              0.00    8.19    1 VRA             1
 TO    1326 ABOA-G6     13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA             1

BUS    1340 WA          161.00 CKT     MW     MVAR     MVA   % 1.0478PU    0.10  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                             168.70KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                            5.5     1.8     5.8
 TO    1380 SAWLA       161.00  1     -5.5    -1.8     5.8   3                       0.01    0.04    1 VRA             5

BUS    1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 1.0556PU   -5.62  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                             169.95KV                MW     MVAR    1 VRA             5
 TO LOAD-PQ                            7.5     2.5     7.9
 TO    1280 TAMALE      161.00  1     -7.5    -2.5     7.9   4                       0.03    0.08    1 VRA             5

BUS    1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0557PU   29.32  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                             169.97KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            6.6     2.2     6.9
 TO    1080 TAKORADI    161.00  1     -6.6     7.7    10.1                           0.05    0.15    1 VRA             2
 TO    1600 OPB-HV      161.00  1      0.0    -9.8     9.8   3                       0.00    0.02    1 VRA             3

BUS    1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9872PU   20.46  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                             158.94KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                           91.3    30.0    96.1
 TO SHUNT                              0.0   -19.5    19.5
 TO    1050 ACHIMOTA    161.00  1    -30.4    -7.4    31.3  19                       0.07    0.23    1 VRA             1
 TO    1070 C-COAST     161.00  1    -60.9    -3.1    61.0                           1.98    6.98    1 VRA             2

BUS    1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 1.0525PU    0.47  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                             169.45KV                MW     MVAR    1 VRA             5
 TO LOAD-PQ                            1.5     0.5     1.6
 TO    1260 TECHIMAN    161.00  1     -7.0    -2.3     7.4   4                       0.09    0.30    1 VRA             5
 TO    1340 WA          161.00  1      5.5     1.8     5.8   3                       0.01    0.04    1 VRA             1
 TO    1381 SAW-34.5    34.500  1      0.0     0.0     0.0   0 1.1000HI              0.00    0.00    1 VRA             1

BUS    1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9876PU   20.41  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                             159.00KV                MW     MVAR    1 VRA             1
```

```
 TO LOAD-PQ                              10.7     3.5     11.2
 TO   1392  AFTAP      161.00  1    -10.7    -3.5     11.2   6                       0.00    0.00    1 VRA            1

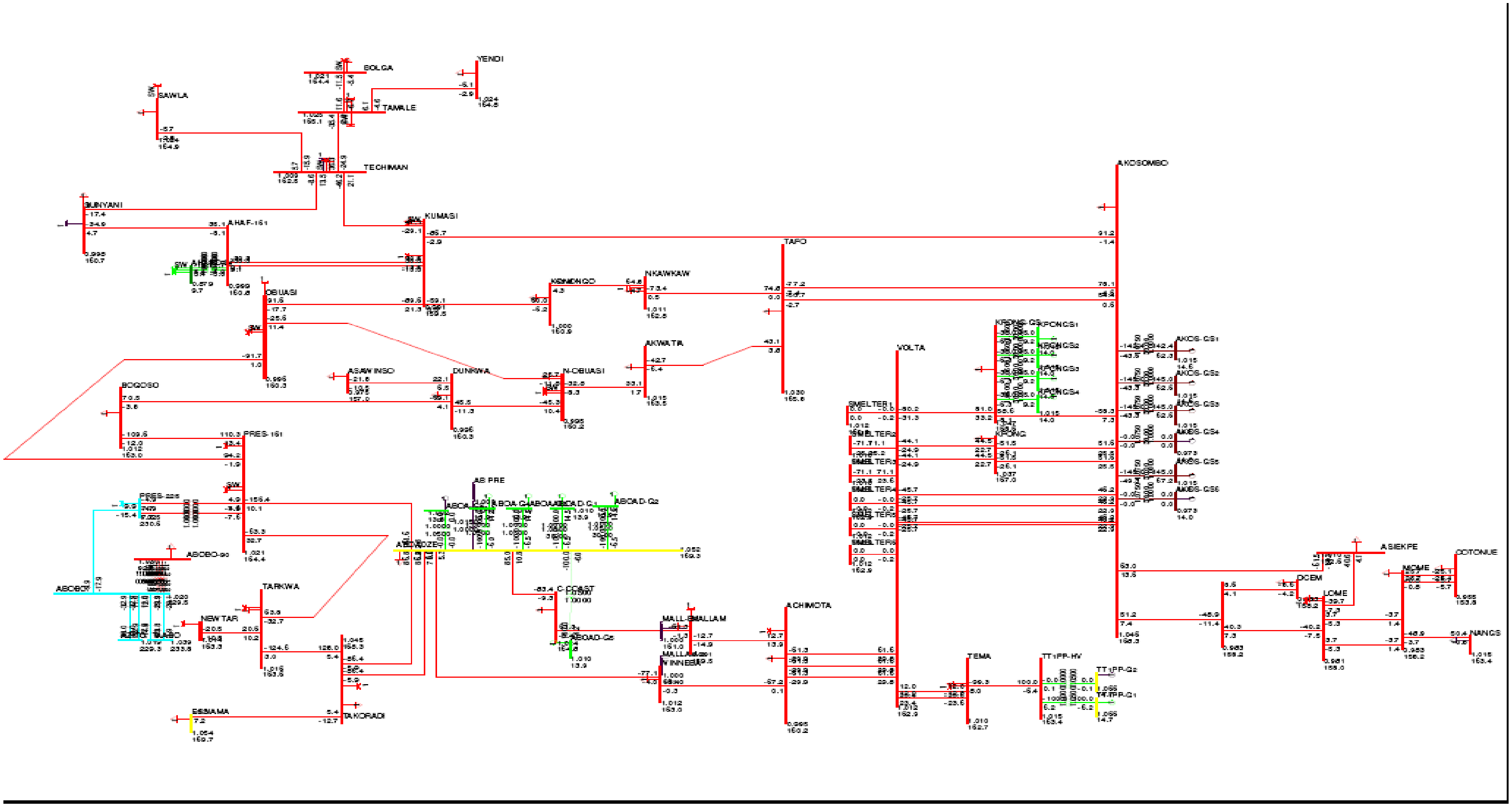
BUS   1392  AFTAP      161.00 CKT     MW     MVAR      MVA   % 0.9878PU   20.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                               159.03KV                MW     MVAR    1 VRA            1
 TO   1010 AKOSOMBO    161.00  1    -50.9   -11.5     52.2  41                       2.40    5.50    1 VRA            1
 TO   1390 DCEM        161.00  1     10.7     3.4     11.2   6                       0.00    0.00    1 VRA            1
 TO   3010 LOME        161.00  1     40.3     8.1     41.1  32                       0.05    0.11    3 CEB            1

BUS   1413 AHAF-161    161.00 CKT     MW     MVAR      MVA   % 1.0212PU    3.77  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                               164.41KV                MW     MVAR    1 VRA            1
 TO   1130 KUMASI      161.00  1    -37.4    14.5     40.1  16                       0.33    2.07    1 VRA            3
 TO   1130 KUMASI      161.00  2    -37.4    14.5     40.1  16                       0.33    2.07    1 VRA            3
 TO   1270 SUNYANI     161.00  1     43.4   -21.3     48.3  13                       0.23    0.96    1 VRA            5
 TO   1412 AHAFO-LV    11.000  1     15.7    -3.8     16.2  36 1.1500HI              0.00    0.60    1 VRA            5
 TO   1412 AHAFO-LV    11.000  2     15.7    -3.8     16.2  36 1.1500HI              0.00    0.60    1 VRA            5

BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR      MVA   % 1.0150PU   24.55  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                               163.41KV                MW     MVAR    1 VRA            1
 TO   1040 TEMA        161.00  1    100.0     2.3    100.0  46                       0.69    3.33    1 VRA            1
 TO   1510 TT1PP-G1    13.800  1   -100.0    -2.5    100.0  61 1.0000UN              0.00    0.01    1 VRA            1
 TO   1520 TT1PP-G2    13.800  1      0.0     0.1      0.1   0 1.0000UN              0.00    0.00    1 VRA            1

BUS   1600 OPB-HV      161.00 CKT     MW     MVAR      MVA   % 1.0602PU   29.26  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                               170.70KV                MW     MVAR    1 VRA            3
 TO   1360 ESSIAMA     161.00  1      0.0     0.0      0.0   0                       0.00    0.02    1 VRA            3
 TO   1601 OPB-G1      13.800  1      0.0     0.0      0.0   0 1.0500LK              0.00    0.00    1 VRA            3
 TO   1602 OPB-G2      13.800  1      0.0     0.0      0.0   0 1.0500LK              0.00    0.00    1 VRA            3
```

Average Load Condition at power factor of 0.90, no contingency on single line diagram (Case 3)



Average Load Condition at power factor of 0.90, no contingency (Case 3, table results)

```
BUS   1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0456PU   23.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                              168.35KV               MW     MVAR    1 VRA             1
  TO LOAD-PQ                          9.7      4.7     10.7
  TO    1011 AKOS-GS1    14.400  1   -142.4    -43.6    149.0  74 1.0750LK   30.00LK    0.00   18.63    1 VRA             1
  TO    1012 AKOS-GS2    14.400  1   -145.0    -43.3    151.3  76 1.0750LK   30.00LK    0.00   19.22    1 VRA             1
  TO    1013 AKOS-GS3    14.400  1   -145.0    -43.3    151.3  76 1.0750LK   30.00LK    0.00   19.22    1 VRA             1
  TO    1014 AKOS-GS4    14.400  1      0.0      0.0      0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA             1
  TO    1015 AKOS-GS5    14.400  1   -145.0    -49.3    153.1  77 1.0750LK   30.00LK    0.00   17.90    1 VRA             1
  TO    1016 AKOS-GS6    14.400  1      0.0      0.0      0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA             1
  TO    1020 VOLTA       161.00  1     46.2     22.9     51.6  23                       0.54    2.63    1 VRA             1
  TO    1020 VOLTA       161.00  2     46.2     22.9     51.6  23                       0.54    2.63    1 VRA             1
  TO    1020 VOLTA       161.00  3     46.2     22.9     51.6  23                       0.54    2.63    1 VRA             1
  TO    1020 VOLTA       161.00  4     46.2     22.9     51.6  23                       0.54    2.63    1 VRA             1
  TO    1130 KUMASI      161.00  1     91.2     -1.4     91.3  24                       4.55   19.86    1 VRA             3
  TO    1150 TAFO        161.00  1     54.4      0.6     54.4  31                       0.74    2.65    1 VRA             3
  TO    1150 TAFO        161.00  2     78.1      4.6     78.3  41                       0.89    3.86    1 VRA             3
  TO    1170 KPONG       161.00  1     51.6     25.5     57.6  26                       0.16    0.75    1 VRA             1
  TO    1170 KPONG       161.00  2     51.6     25.5     57.6  26                       0.16    0.75    1 VRA             1
  TO    1190 KPONG-GS    161.00  1    -58.3      7.3     58.8  26                       0.24    1.21    1 VRA             1
  TO    1220 ASIEKPE     161.00  1     63.0     13.6     64.5  48                       1.52    3.43    1 VRA             1
  TO    1392  AFTAP      161.00  1     51.2      7.4     51.7  39                       2.24    5.13    1 VRA             1

 BUS    1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 1.0118PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                              162.89KV               MW     MVAR    1 VRA             1
  TO    1010 AKOSOMBO    161.00  1    -45.7    -25.7     52.4  24                       0.54    2.63    1 VRA             1
  TO    1010 AKOSOMBO    161.00  2    -45.7    -25.7     52.4  24                       0.54    2.63    1 VRA             1
  TO    1010 AKOSOMBO    161.00  3    -45.7    -25.7     52.4  24                       0.54    2.63    1 VRA             1
  TO    1010 AKOSOMBO    161.00  4    -45.7    -25.7     52.4  24                       0.54    2.63    1 VRA             1
  TO    1031 SMELTER1    161.00  1      0.0     -0.2      0.2   0                       0.00    0.00    1 VRA             3
  TO    1032 SMELTER2    161.00  1     71.1     25.2     75.5  35                       0.06    0.28    1 VRA             3
  TO    1033 SMELTER3    161.00  1     71.1     23.6     74.9  35                       0.05    0.27    1 VRA             3
  TO    1034 SMELTER4    161.00  1      0.0     -0.2      0.2   0                       0.00    0.00    1 VRA             3
  TO    1035 SMELTER5    161.00  1      0.0     -0.2      0.2   0                       0.00    0.00    1 VRA             3
  TO    1036 SMELTER6    161.00  1      0.0     -0.2      0.2   0                       0.00    0.00    1 VRA             3
  TO    1040 TEMA        161.00  1     12.0     23.4     26.3  12                       0.01    0.03    1 VRA             1
  TO    1040 TEMA        161.00  2     12.0     23.4     26.3  12                       0.01    0.03    1 VRA             1
  TO    1050 ACHIMOTA    161.00  1     61.6     29.8     68.5  32                       0.38    1.85    1 VRA             1
  TO    1050 ACHIMOTA    161.00  2     61.6     29.8     68.5  32                       0.38    1.85    1 VRA             1
  TO    1050 ACHIMOTA    161.00  3     61.6     29.8     68.5  32                       0.38    1.85    1 VRA             1
  TO    1170 KPONG       161.00  1    -44.1    -24.9     50.6  23                       0.39    1.89    1 VRA             1
  TO    1170 KPONG       161.00  2    -44.1    -24.9     50.6  23                       0.39    1.89    1 VRA             1
  TO    1190 KPONG-GS    161.00  1    -80.2    -31.3     86.1  31                       0.81    6.01    1 VRA             1

 BUS    1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 1.0118PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                              162.89KV               MW     MVAR    1 VRA             3
  TO    1020 VOLTA       161.00  1      0.0      0.0      0.0   0                       0.00    0.00    1 VRA             1
  TO   10311 VALCO-1     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3
  TO   10317 VALCO-7     13.800  1      0.0      0.0      0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA             3

 BUS    1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 1.0098PU   20.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
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                                                              162.58KV                  MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1    -71.1   -25.2    75.4  35                          0.06    0.28    1 VRA            1
 TO  10312 VALCO-2     13.800  1     71.1    25.2    75.4  89 1.0250LK  30.00LK    0.00    8.89    1 VRA            3
 TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK  30.00LK    0.00    0.00    1 VRA            3

BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 1.0099PU   20.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                              162.59KV                  MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1    -71.1   -23.5    74.9  35                          0.05    0.27    1 VRA            1
 TO  10313 VALCO-3     13.800  1     71.1    23.5    74.9  88 1.0000LK  30.00LK    0.00    8.34    1 VRA            3

BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 1.0118PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                              162.89KV                  MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA            1
 TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK  30.00LK    0.00    0.00    1 VRA            3

BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 1.0118PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                              162.89KV                  MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA            1
 TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK  30.00LK    0.00    0.00    1 VRA            3

BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 1.0118PU   21.14  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                              162.89KV                  MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                          0.00    0.00    1 VRA            1
 TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK  30.00LK    0.00    0.00    1 VRA            3

BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 1.0105PU   21.12  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                              162.69KV                  MW     MVAR    1 VRA            1
 TO LOAD-PQ                         123.3    59.7   136.9
 TO SHUNT                             0.0   -20.4    20.4
 TO   1020 VOLTA       161.00  1    -12.0   -23.6    26.5  12                          0.01    0.03    1 VRA            1
 TO   1020 VOLTA       161.00  2    -12.0   -23.6    26.5  12                          0.01    0.03    1 VRA            1
 TO   1500 TT1PP-HV    161.00  1    -99.3     8.0    99.6  46                          0.69    3.34    1 VRA            1

BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9949PU   19.89  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                              160.18KV                  MW     MVAR    1 VRA            1
 TO LOAD-PQ                         238.3   115.4   264.8
 TO SHUNT                             0.0   -39.6    39.6
 TO   1020 VOLTA       161.00  1    -61.3   -29.9    68.2  32                          0.38    1.85    1 VRA            1
 TO   1020 VOLTA       161.00  2    -61.3   -29.9    68.2  32                          0.38    1.85    1 VRA            1
 TO   1020 VOLTA       161.00  3    -61.3   -29.9    68.2  32                          0.38    1.85    1 VRA            1
 TO   1060 WINNEBA     161.00  1    -67.2     0.1    67.2  40                          1.18    4.14    1 VRA            2
 TO   1370 MALLAM      161.00  1     12.7    13.9    18.8  11                          0.02    0.09    1 VRA            1

BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 1.0122PU   23.38  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                              162.97KV                  MW     MVAR    1 VRA            2
 TO LOAD-PQ                           8.8     4.2     9.7
 TO   1050 ACHIMOTA    161.00  1     68.4    -0.3    68.4  40                          1.18    4.14    1 VRA            1
 TO   1320 ABOADZE     161.00  1    -77.1    -4.0    77.2  45                          2.45    9.44    1 VRA            2

BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0238PU   26.20  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                              164.83KV                  MW     MVAR    1 VRA            2
 TO LOAD-PQ                          20.1     9.8    22.4
 TO   1320 ABOADZE     161.00  1    -83.4    -9.3    83.9  48                          1.58    6.07    1 VRA            2
 TO   1370 MALLAM      161.00  1     63.3    -0.4    63.3                              1.99    7.02    1 VRA            1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0454PU   29.11  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                            168.31KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                         39.3     19.0    43.7
 TO   1090 TARKWA      161.00  1    128.0      5.4   128.1  72                       3.44   12.33    1 VRA             2
 TO   1320 ABOADZE     161.00  1    -86.4     -5.9    86.6  49                       0.42    1.61    1 VRA             2
 TO   1320 ABOADZE     161.00  2    -86.4     -5.9    86.6  49                       0.42    1.61    1 VRA             2
 TO   1360 ESSIAMA     161.00  1      5.4    -12.7    13.8                           0.04    0.13    1 VRA             3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 1.0164PU   23.53  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                            163.64KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                         40.2     19.5    44.7
 TO   1080 TAKORADI    161.00  1   -124.6      3.0   124.6  72                       3.44   12.33    1 VRA             2
 TO   1095 NEWTAR      161.00  1     20.6     10.2    23.0  13                       0.02    0.07    1 VRA             3
 TO   1100 PRES-161    161.00  1     63.8    -32.7    71.7  42                       0.46    1.61    1 VRA             2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 1.0143PU   23.40  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                            163.30KV               MW     MVAR    1 VRA             3
 TO   1090 TARKWA      161.00  1    -20.5    -10.8    23.2  13                       0.02    0.07    1 VRA             2
 TO  10951 NTAR-LV     11.500  1     10.3      5.4    11.6  35 1.0000LK              0.00    0.42    1 VRA             3
 TO  10951 NTAR-LV     11.500  2     10.3      5.4    11.6  35 1.0000LK              0.00    0.42    1 VRA             3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 1.0211PU   22.21  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                            164.39KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          5.3      2.6     5.9
 TO SHUNT                            0.0    -20.9    20.9
 TO SWITCHED SHUNT                   0.0    -20.9    20.9
 TO   1090 TARKWA      161.00  1    -63.3     32.7    71.3  41                       0.46    1.61    1 VRA             2
 TO   1109 PRES-225    225.00  1      4.9     -7.6     9.1   5 1.0000UN              0.00    0.04    1 VRA             2
 TO   1109 PRES-225    225.00  2      4.9     -7.6     9.1   5 1.0000UN              0.00    0.04    1 VRA             2
 TO   1120 OBUASI      161.00  1     94.2     -1.9    94.2                           2.51   10.95    1 VRA             3
 TO   1300 BOGOSO      161.00  1    110.3     13.4   111.1  64                       0.69    2.45    1 VRA             2
 TO   1320 ABOADZE     161.00  1   -156.4     10.1   156.7  42                       5.22   21.94    1 VRA             2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 1.0247PU   22.08  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                            230.56KV               MW     MVAR    1 VRA             2
 TO   1100 PRES-161    161.00  1     -4.9      7.7     9.1   5 1.0000LK              0.00    0.04    1 VRA             2
 TO   1100 PRES-161    161.00  2     -4.9      7.7     9.1   5 1.0000LK              0.00    0.04    1 VRA             2
 TO   2010 ABOBO       225.00  1      9.9    -15.4    18.3                           0.02    0.17    2 CIE             1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.9958PU   16.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                            160.33KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          1.5      0.7     1.7
 TO   1200 ASAWINSO    161.00  1     22.1      6.5    23.0  16                       0.29    0.64    1 VRA             3
 TO   1210 N-OBUASI    161.00  1     45.5    -11.3    46.9  13                       0.24    0.87    1 VRA             3
 TO   1300 BOGOSO      161.00  1    -69.1      4.1    69.2                           1.43    5.11    1 VRA             2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.9956PU   15.45  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                            160.29KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                         25.7     12.4    28.5
 TO SHUNT                            0.0     -7.1     7.1
 TO   1100 PRES-161    161.00  1    -91.7      1.0    91.7                           2.51   10.95    1 VRA             2
 TO   1130 KUMASI      161.00  1     91.6    -17.7    93.3  55                       2.06    7.38    1 VRA             3
 TO   1210 N-OBUASI    161.00  1    -25.6     11.4    28.1   8                       0.03    0.09    1 VRA             3
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BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 0.9907PU   10.73  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                              159.50KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                          127.4    61.7   141.5
 TO SHUNT                              0.0   -29.4    29.4
 TO   1010 AKOSOMBO    161.00  1    -86.7    -2.9    86.7  24                       4.55   19.86    1 VRA             1
 TO   1120 OBUASI      161.00  1    -89.6    21.3    92.1  55                       2.06    7.38    1 VRA             3
 TO   1180 KONONGO     161.00  1    -59.1     5.5    59.4  35                       0.83    2.97    1 VRA             3
 TO   1260 TECHIMAN    161.00  1     47.1   -29.1    55.4  31                       0.83    3.62    1 VRA             5
 TO   1413 AHAF-161    161.00  1     30.5   -13.5    33.3  14                       0.21    1.34    1 VRA             1
 TO   1413 AHAF-161    161.00  2     30.5   -13.5    33.3  14                       0.21    1.34    1 VRA             1

BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 1.0109PU   16.78  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                              162.75KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            8.6     4.2     9.6
 TO   1150 TAFO        161.00  1    -73.4     0.5    73.4  43                       1.40    5.00    1 VRA             3
 TO   1180 KONONGO     161.00  1     64.8    -4.7    64.9  38                       0.97    3.48    1 VRA             3

BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 1.0299PU   20.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                              165.81KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                           13.0     6.3    14.4
 TO   1010 AKOSOMBO    161.00  1    -53.7    -2.7    53.7  31                       0.74    2.65    1 VRA             1
 TO   1010 AKOSOMBO    161.00  2    -77.2    -7.4    77.6  41                       0.89    3.86    1 VRA             1
 TO   1140 NKAWKAW     161.00  1     74.8     0.0    74.8  43                       1.40    5.00    1 VRA             3
 TO   1160 AKWATIA     161.00  1     43.1     3.8    43.3  25                       0.43    1.56    1 VRA             3

BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 1.0154PU   18.66  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                              163.47KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            9.5     4.6    10.6
 TO   1150 TAFO        161.00  1    -42.7    -6.4    43.2  25                       0.43    1.56    1 VRA             3
 TO   1210 N-OBUASI    161.00  1     33.1     1.7    33.2  13                       0.40    1.84    1 VRA             3

BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0370PU   22.82  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                              166.96KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                           14.0     6.8    15.5
 TO   1010 AKOSOMBO    161.00  1    -51.5   -26.1    57.7  26                       0.16    0.75    1 VRA             1
 TO   1010 AKOSOMBO    161.00  2    -51.5   -26.1    57.7  26                       0.16    0.75    1 VRA             1
 TO   1020 VOLTA       161.00  1     44.5    22.7    49.9  23                       0.39    1.89    1 VRA             1
 TO   1020 VOLTA       161.00  2     44.5    22.7    49.9  23                       0.39    1.89    1 VRA             1

BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 0.9996PU   13.63  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                              160.93KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            3.8     1.9     4.2
 TO   1130 KUMASI      161.00  1     60.0    -6.2    60.3  35                       0.83    2.97    1 VRA             3
 TO   1140 NKAWKAW     161.00  1    -63.8     4.3    63.9  38                       0.97    3.48    1 VRA             3

BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0471PU   24.62  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                              168.59KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                            0.4     0.2     0.5
 TO   1010 AKOSOMBO    161.00  1     58.6    -8.1    59.1  26                       0.24    1.21    1 VRA             1
 TO   1020 VOLTA       161.00  1     81.0    33.2    87.5  31                       0.81    6.01    1 VRA             1
 TO   1191 KPONGS1     13.800  1    -35.0    -6.3    35.6  70 1.0500LK   30.00LK    0.00    2.91    1 VRA             1
 TO   1192 KPONGS2     13.800  1    -35.0    -6.3    35.6  70 1.0500LK   30.00LK    0.00    2.91    1 VRA             1
 TO   1193 KPONGS3     13.800  1    -35.0    -6.3    35.6  70 1.0500LK   30.00LK    0.00    2.91    1 VRA             1
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 TO   1194 KPONGS4     13.800  1    -35.0     -6.3    35.6  70 1.0500LK   30.00LK    0.00    2.91    1 VRA             1

BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.9748PU   15.56  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
                                                              156.95KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                          21.8     10.5    24.2
 TO   1110 DUNKWA      161.00  1    -21.8    -10.5    24.2  17                       0.29    0.64    1 VRA             2

BUS   1210 N-OBUASI    161.00 CKT     MW     MVAR     MVA   % 0.9951PU   15.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                              160.21KV               MW     MVAR    1 VRA             3
 TO LOAD-PQ                          52.4     25.4    58.2
 TO SHUNT                             0.0    -15.6    15.6
 TO   1110 DUNKWA      161.00  1    -45.3     10.4    46.5  13                       0.24    0.87    1 VRA             2
 TO   1120 OBUASI      161.00  1     25.7    -11.8    28.3   8                       0.03    0.09    1 VRA             3
 TO   1160 AKWATIA     161.00  1    -32.8     -8.3    33.8  14                       0.40    1.84    1 VRA             3

BUS   1220 ASIEKPE     161.00 CKT     MW     MVAR     MVA   % 1.0096PU   20.72  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                              162.55KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                          20.9     10.1    23.2
 TO   1010 AKOSOMBO    161.00  1    -61.5    -14.3    63.1  49                       1.52    3.43    1 VRA             1
 TO   1221 ASIEKP-6    69.000  1      0.0      0.0     0.0     0.9874LK              0.00    0.00    1 VRA             1
 TO   3010 LOME        161.00  1     40.6      4.1    40.8  32                       0.89    2.00    3 CEB             1

BUS   1260 TECHIMAN    161.00 CKT     MW     MVAR     MVA   % 1.0094PU    6.87  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                              162.51KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          12.8      6.2    14.2
 TO   1130 KUMASI      161.00  1    -46.2     21.1    50.8  28                       0.83    3.62    1 VRA             3
 TO   1270 SUNYANI     161.00  1     -8.6     13.5    16.0   9                       0.06    0.26    1 VRA             5
 TO   1280 TAMALE      161.00  1     36.3    -24.9    44.0  24                       0.89    3.94    1 VRA             5
 TO   1380 SAWLA       161.00  1      5.7    -15.9    16.9   9                       0.07    0.23    1 VRA             5

BUS   1270 SUNYANI     161.00 CKT     MW     MVAR     MVA   % 0.9980PU    7.43  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                              160.68KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          26.3     12.7    29.2
 TO   1260 TECHIMAN    161.00  1      8.6    -17.4    19.4  11                       0.06    0.26    1 VRA             5
 TO   1413 AHAF-161    161.00  1    -34.9      4.7    35.2  10                       0.13    0.57    1 VRA             1

BUS   1280 TAMALE      161.00 CKT     MW     MVAR     MVA   % 1.0254PU    0.93  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                              165.09KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          17.7      8.6    19.6
 TO   1260 TECHIMAN    161.00  1    -35.4      2.8    35.5  19                       0.89    3.94    1 VRA             5
 TO   1290 BOLGA       161.00  1     11.6     -6.7    13.4   5                       0.07    0.31    1 VRA             5
 TO   1350 YENDI       161.00  1      6.1     -4.6     7.6   4                       0.02    0.06    1 VRA             5

BUS   1290 BOLGA       161.00 CKT     MW     MVAR     MVA   % 1.0211PU   -0.61  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                              164.40KV               MW     MVAR    1 VRA             5
 TO LOAD-PQ                          10.5      5.1    11.7
 TO   1280 TAMALE      161.00  1    -11.5     -5.4    12.7   5                       0.07    0.31    1 VRA             5
 TO 3WNDTR              WND 1  1      1.0      0.3     1.1   7 1.0000LK              0.00    0.01

BUS   1300 BOGOSO      161.00 CKT     MW     MVAR     MVA   % 1.0122PU   20.99  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                              162.97KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          28.8     13.9    32.0
 TO   1100 PRES-161    161.00  1   -109.6    -12.0   110.2  64                       0.69    2.45    1 VRA             2
 TO   1110 DUNKWA      161.00  1     70.5     -3.8    70.6                           1.43    5.11    1 VRA             2
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 TO   1309 WEXFORD     161.00  1     10.3     1.8    10.5   6                       0.03    0.09    1 VRA            3

BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 1.0069PU   20.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                              162.11KV                MW     MVAR    1 VRA            3
 TO   1300 BOGOSO      161.00  1    -10.3    -5.4    11.6   6                       0.03    0.09    1 VRA            2
 TO  13091 WEX-LV      34.500  1     10.3     5.4    11.6  35 1.0000LK   30.00LK    0.00    0.45    1 VRA            3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0518PU   30.15  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                              169.34KV                MW     MVAR    1 VRA            2
 TO LOAD-PQ                           0.3     0.1     0.3
 TO   1060 WINNEBA     161.00  1     79.6     5.3    79.8  45                       2.45    9.44    1 VRA            2
 TO   1070 C-COAST     161.00  1     85.0    10.8    85.7  48                       1.58    6.07    1 VRA            2
 TO   1080 TAKORADI    161.00  1     86.8     6.2    87.0  49                       0.42    1.61    1 VRA            2
 TO   1080 TAKORADI    161.00  2     86.8     6.2    87.0  49                       0.42    1.61    1 VRA            2
 TO   1100 PRES-161    161.00  1    161.6     2.8   161.6  42                       5.22   21.94    1 VRA            2
 TO   1321 ABOAD-G1    13.800  1   -100.0    -6.5   100.2  69 1.0500LK   30.00LK    0.00    7.95    1 VRA            1
 TO   1322 ABOAD-G2    13.800  1   -100.0    -6.5   100.2  69 1.0500LK   30.00LK    0.00    7.95    1 VRA            1
 TO   1323 ABOA-G3     13.800  1   -100.0    -6.5   100.2  69 1.0500LK              0.00    7.95    1 VRA            1
 TO   1324 ABOA-G4     13.800  1   -100.0    -6.0   100.2  69 1.0500LK              0.00    8.22    1 VRA            1
 TO   1325 ABOAD-G5    13.800  1   -100.0    -6.0   100.2  69 1.0500LK              0.00    8.22    1 VRA            1
 TO   1326 ABOA-G6     13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA            1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 1.0194PU    5.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                              164.12KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                           4.4     2.1     4.9
 TO   1380 SAWLA       161.00  1     -4.4    -2.1     4.9   3                       0.01    0.03    1 VRA            5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 1.0235PU    0.38  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                              164.79KV                MW     MVAR    1 VRA            5
 TO LOAD-PQ                           6.1     2.9     6.8
 TO   1280 TAMALE      161.00  1     -6.1    -2.9     6.8   4                       0.02    0.06    1 VRA            5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0541PU   28.60  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                              169.71KV                MW     MVAR    1 VRA            3
 TO LOAD-PQ                           5.3     2.6     5.9
 TO   1080 TAKORADI    161.00  1     -5.3     7.2     9.0                           0.04    0.13    1 VRA            2
 TO   1600 OPB-HV      161.00  1      0.0    -9.8     9.8   3                       0.00    0.02    1 VRA            3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9907PU   19.77  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                              159.50KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                          74.0    35.8    82.2
 TO SHUNT                             0.0   -19.6    19.6
 TO   1050 ACHIMOTA    161.00  1    -12.7   -14.9    19.6  12                       0.02    0.09    1 VRA            1
 TO   1070 C-COAST     161.00  1    -61.3    -1.3    61.3                           1.99    7.02    1 VRA            2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 1.0242PU    5.57  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                              164.90KV                MW     MVAR    1 VRA            5
 TO LOAD-PQ                           1.2     0.6     1.4
 TO   1260 TECHIMAN    161.00  1     -5.7    -2.8     6.3   3                       0.07    0.23    1 VRA            5
 TO   1340 WA          161.00  1      4.4     2.2     4.9   3                       0.01    0.03    1 VRA            1
 TO   1381 SAW-34.5    34.500  1      0.0     0.0     0.0   0 1.1000HI              0.00    0.00    1 VRA            1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9825PU   18.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                              158.19KV                MW     MVAR    1 VRA            1
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  TO LOAD-PQ                          8.6      4.2      9.6
  TO   1392  AFTAP      161.00  1    -8.6     -4.2      9.6   5                      0.00    0.00    1 VRA            1

 BUS   1392  AFTAP      161.00 CKT     MW     MVAR      MVA   % 0.9827PU   18.24  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                                158.22KV                   MW     MVAR    1 VRA            1
  TO   1010 AKOSOMBO    161.00  1   -48.9    -11.4     50.2  40                      2.24    5.13    1 VRA            1
  TO   1390 DCEM        161.00  1     8.6      4.1      9.5   5                      0.00    0.00    1 VRA            1
  TO   3010 LOME        161.00  1    40.3      7.3     40.9  33                      0.05    0.11    3 CEB            1

 BUS   1413 AHAF-161    161.00 CKT     MW     MVAR      MVA   % 0.9989PU    8.37  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                                160.82KV                   MW     MVAR    1 VRA            1
  TO   1130 KUMASI      161.00  1   -30.3      9.1     31.6  13                      0.21    1.34    1 VRA            3
  TO   1130 KUMASI      161.00  2   -30.3      9.1     31.6  13                      0.21    1.34    1 VRA            3
  TO   1270 SUNYANI     161.00  1    35.1     -8.1     36.0  10                      0.13    0.57    1 VRA            5
  TO   1412 AHAFO-LV    11.000  1    12.7     -5.0     13.7  30 1.1500HI             0.00    0.44    1 VRA            5
  TO   1412 AHAFO-LV    11.000  2    12.7     -5.0     13.7  30 1.1500HI             0.00    0.44    1 VRA            5

 BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR      MVA   % 1.0150PU   23.06  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                                163.41KV                   MW     MVAR    1 VRA            1
  TO   1040 TEMA        161.00  1   100.0     -6.4    100.2  46                      0.69    3.34    1 VRA            1
  TO   1510 TT1PP-G1    13.800  1  -100.0      6.2    100.2  61 1.0000UN             0.00    0.01    1 VRA            1
  TO   1520 TT1PP-G2    13.800  1     0.0      0.1      0.1   0 1.0000UN             0.00    0.00    1 VRA            1

 BUS   1600 OPB-HV      161.00 CKT     MW     MVAR      MVA   % 1.0586PU   28.54  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                                170.44KV                   MW     MVAR    1 VRA            3
  TO   1360 ESSIAMA     161.00  1     0.0      0.0      0.0   0                      0.00    0.02    1 VRA            3
  TO   1601 OPB-G1      13.800  1     0.0      0.0      0.0   0 1.0500LK             0.00    0.00    1 VRA            3
  TO   1602 OPB-G2      13.800  1     0.0      0.0      0.0   0 1.0500LK             0.00    0.00    1 VRA            3
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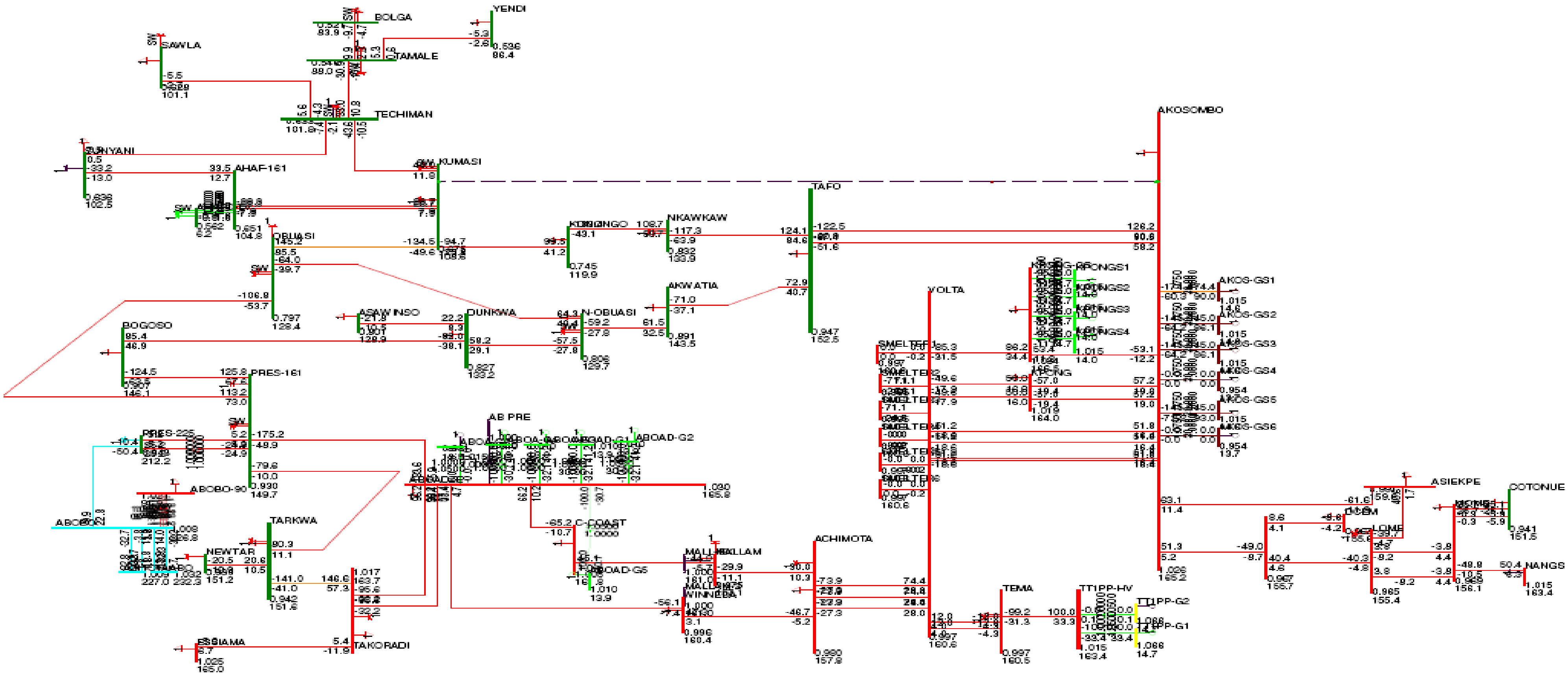
Average Load Condition at power factor of 0.90 ,Akosombo-Kumasi contingency on single line diagram (case 5)



Average Load Condition at power factor of 0.90 ,Akosombo-Kumasi contingency (Case 5, table results)

```
BUS   1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0260PU   21.78  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                              165.19KV                MW     MVAR    1 VRA            1
 TO LOAD-PQ                          9.7      4.7    10.7
 TO   1011 AKOS-GS1    14.400  1  -174.4    -60.3   184.6  92 1.0750LK   30.00LK    0.00   29.69    1 VRA            1
 TO   1012 AKOS-GS2    14.400  1  -145.0    -64.2   158.6  79 1.0750LK   30.00LK    0.00   21.92    1 VRA            1
 TO   1013 AKOS-GS3    14.400  1  -145.0    -64.2   158.6  79 1.0750LK   30.00LK    0.00   21.92    1 VRA            1
 TO   1014 AKOS-GS4    14.400  1     0.0      0.0     0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA            1
 TO   1015 AKOS-GS5    14.400  1  -145.0    -72.2   162.0  81 1.0750LK   30.00LK    0.00   20.80    1 VRA            1
 TO   1016 AKOS-GS6    14.400  1     0.0      0.0     0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA            1
 TO   1020 VOLTA       161.00  1    51.8     16.4    54.4  25                       0.61    2.98    1 VRA            1
 TO   1020 VOLTA       161.00  2    51.8     16.4    54.4  25                       0.61    2.98    1 VRA            1
 TO   1020 VOLTA       161.00  3    51.8     16.4    54.4  25                       0.61    2.98    1 VRA            1
 TO   1020 VOLTA       161.00  4    51.8     16.4    54.4  25                       0.61    2.98    1 VRA            1
 TO   1150 TAFO        161.00  1    90.5     58.2   107.6  62                       3.06   10.97    1 VRA            3
 TO   1150 TAFO        161.00  2   126.2     90.0   155.0  83                       3.67   16.00    1 VRA            3
 TO   1170 KPONG       161.00  1    57.2     19.0    60.3  28                       0.18    0.85    1 VRA            1
 TO   1170 KPONG       161.00  2    57.2     19.0    60.3  28                       0.18    0.85    1 VRA            1
 TO   1190 KPONG-GS    161.00  1   -53.1    -12.2    54.5  25                       0.22    1.07    1 VRA            1
 TO   1220 ASIEKPE     161.00  1    63.1     11.4    64.1  49                       1.56    3.52    1 VRA            1
 TO   1392  AFTAP      161.00  1    51.3      5.2    51.6  39                       2.29    5.25    1 VRA            1

BUS   1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 0.9973PU   19.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                              160.57KV                MW     MVAR    1 VRA            1
 TO   1010 AKOSOMBO    161.00  1   -51.2    -18.6    54.5  26                       0.61    2.98    1 VRA            1
 TO   1010 AKOSOMBO    161.00  2   -51.2    -18.6    54.5  26                       0.61    2.98    1 VRA            1
 TO   1010 AKOSOMBO    161.00  3   -51.2    -18.6    54.5  26                       0.61    2.98    1 VRA            1
 TO   1010 AKOSOMBO    161.00  4   -51.2    -18.6    54.5  26                       0.61    2.98    1 VRA            1
 TO   1031 SMELTER1    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO   1032 SMELTER2    161.00  1    71.1     26.1    75.8  36                       0.06    0.29    1 VRA            3
 TO   1033 SMELTER3    161.00  1    71.1     24.5    75.2  35                       0.06    0.28    1 VRA            3
 TO   1034 SMELTER4    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO   1035 SMELTER5    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO   1036 SMELTER6    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO   1040 TEMA        161.00  1    12.0      4.0    12.7   6                       0.00    0.01    1 VRA            1
 TO   1040 TEMA        161.00  2    12.0      4.0    12.7   6                       0.00    0.01    1 VRA            1
 TO   1050 ACHIMOTA    161.00  1    74.4     28.0    79.5  37                       0.52    2.55    1 VRA            1
 TO   1050 ACHIMOTA    161.00  2    74.4     28.0    79.5  37                       0.52    2.55    1 VRA            1
 TO   1050 ACHIMOTA    161.00  3    74.4     28.0    79.5  37                       0.52    2.55    1 VRA            1
 TO   1170 KPONG       161.00  1   -49.6    -17.9    52.7  25                       0.44    2.14    1 VRA            1
 TO   1170 KPONG       161.00  2   -49.6    -17.9    52.7  25                       0.44    2.14    1 VRA            1
 TO   1190 KPONG-GS    161.00  1   -85.3    -31.5    90.9  33                       0.93    6.90    1 VRA            1

BUS   1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 0.9973PU   19.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                              160.57KV                MW     MVAR    1 VRA            3
 TO   1020 VOLTA       161.00  1     0.0      0.0     0.0   0                       0.00    0.00    1 VRA            1
 TO  10311 VALCO-1     13.800  1     0.0      0.0     0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3
 TO  10317 VALCO-7     13.800  1     0.0      0.0     0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3

BUS   1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 0.9953PU   18.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
                                                              160.25KV                MW     MVAR    1 VRA            3
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```
 TO   1020 VOLTA       161.00  1    -71.1   -26.1    75.7  36                        0.06    0.29    1 VRA             1
 TO  10312 VALCO-2     13.800  1     71.1    26.1    75.7  89 1.0250LK   30.00LK    0.00    9.23    1 VRA             3
 TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 0.9954PU   18.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                            160.26KV               MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1    -71.1   -24.5    75.2  35                        0.06    0.28    1 VRA             1
 TO  10313 VALCO-3     13.800  1     71.1    24.5    75.2  88 1.0000LK   30.00LK    0.00    8.66    1 VRA             3

BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 0.9973PU   19.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                            160.57KV               MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 0.9973PU   19.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                            160.57KV               MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 0.9973PU   19.02  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                            160.57KV               MW     MVAR    1 VRA             3
 TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                        0.00    0.00    1 VRA             1
 TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA             3

BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 0.9970PU   18.99  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                            160.52KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                         123.3    59.7   136.9
 TO SHUNT                             0.0   -19.9    19.9
 TO   1020 VOLTA       161.00  1    -12.0    -4.3    12.7   6                        0.00    0.01    1 VRA             1
 TO   1020 VOLTA       161.00  2    -12.0    -4.3    12.7   6                        0.00    0.01    1 VRA             1
 TO   1500 TT1PP-HV    161.00  1    -99.2   -31.3   104.1  49                        0.77    3.72    1 VRA             1

BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9801PU   17.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                            157.80KV               MW     MVAR    1 VRA             1
 TO LOAD-PQ                         238.3   115.4   264.8
 TO SHUNT                             0.0   -38.4    38.4
 TO   1020 VOLTA       161.00  1    -73.9   -27.3    78.8  38                        0.52    2.55    1 VRA             1
 TO   1020 VOLTA       161.00  2    -73.9   -27.3    78.8  38                        0.52    2.55    1 VRA             1
 TO   1020 VOLTA       161.00  3    -73.9   -27.3    78.8  38                        0.52    2.55    1 VRA             1
 TO   1060 WINNEBA     161.00  1    -46.7    -5.2    47.0  28                        0.59    2.07    1 VRA             2
 TO   1370 MALLAM      161.00  1     30.0    10.3    31.7  19                        0.07    0.25    1 VRA             1

BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 0.9963PU   19.86  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                            160.40KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                           8.8     4.2     9.7
 TO   1050 ACHIMOTA    161.00  1     47.3     3.1    47.4  28                        0.59    2.07    1 VRA             1
 TO   1320 ABOADZE     161.00  1    -56.1    -7.4    56.6  33                        1.34    5.17    1 VRA             2

BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0052PU   21.71  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                            161.83KV               MW     MVAR    1 VRA             2
 TO LOAD-PQ                          20.1     9.8    22.4
 TO   1320 ABOADZE     161.00  1    -65.2   -10.7    66.1  39                        1.01    3.89    1 VRA             2
 TO   1370 MALLAM      161.00  1     45.1     1.0    45.1                            1.06    3.73    1 VRA             1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0165PU   23.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                            163.66KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                           39.3    19.0    43.7
 TO   1090 TARKWA      161.00  1     146.6    57.3   157.4  91                       5.54   19.83    1 VRA            2
 TO   1320 ABOADZE     161.00  1     -95.6   -32.2   100.9  58                       0.60    2.31    1 VRA            2
 TO   1320 ABOADZE     161.00  2     -95.6   -32.2   100.9  58                       0.60    2.31    1 VRA            2
 TO   1360 ESSIAMA     161.00  1       5.4   -11.9    13.0                           0.04    0.12    1 VRA            3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 0.9416PU   17.35  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                            151.60KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                           40.2    19.5    44.7
 TO   1080 TAKORADI    161.00  1    -141.0   -41.0   146.9  92                       5.54   19.83    1 VRA            2
 TO   1095 NEWTAR      161.00  1      20.6    10.5    23.1  14                       0.02    0.08    1 VRA            3
 TO   1100 PRES-161    161.00  1      80.3    11.1    81.0  51                       0.69    2.43    1 VRA            2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 0.9393PU   17.21  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                            151.23KV               MW     MVAR    1 VRA            3
 TO   1090 TARKWA      161.00  1     -20.5   -10.9    23.3  15                       0.02    0.08    1 VRA            2
 TO  10951 NTAR-LV     11.500  1      10.3     5.5    11.6  35 1.0000LK              0.00    0.49    1 VRA            3
 TO  10951 NTAR-LV     11.500  2      10.3     5.5    11.6  35 1.0000LK              0.00    0.49    1 VRA            3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 0.9300PU   15.71  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                            149.73KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                            5.3     2.6     5.9
 TO SHUNT                              0.0   -17.3    17.3
 TO SWITCHED SHUNT                     0.0   -17.3    17.3
 TO   1090 TARKWA      161.00  1     -79.6   -10.0    80.2  51                       0.69    2.43    1 VRA            2
 TO   1109 PRES-225    225.00  1       5.2   -24.9    25.4  13 1.0000UN              0.00    0.36    1 VRA            2
 TO   1109 PRES-225    225.00  2       5.2   -24.9    25.4  13 1.0000UN              0.00    0.36    1 VRA            2
 TO   1120 OBUASI      161.00  1     113.2    73.0   134.7                           6.43   28.08    1 VRA            3
 TO   1300 BOGOSO      161.00  1     125.8    67.6   142.8  90                       1.37    4.90    1 VRA            2
 TO   1320 ABOADZE     161.00  1    -175.2   -48.9   181.9  54                       8.35   35.12    1 VRA            2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 0.9430PU   15.54  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                            212.17KV               MW     MVAR    1 VRA            2
 TO   1100 PRES-161    161.00  1      -5.2    25.2    25.7  13 1.0000LK              0.00    0.36    1 VRA            2
 TO   1100 PRES-161    161.00  2      -5.2    25.2    25.7  13 1.0000LK              0.00    0.36    1 VRA            2
 TO   2010 ABOBO       225.00  1      10.4   -50.4    51.5                           0.42    2.81    2 CIE            1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.8273PU    8.44  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                            133.19KV               MW     MVAR    1 VRA            2
 TO LOAD-PQ                            1.5     0.7     1.7
 TO   1200 ASAWINSO    161.00  1      22.2     8.3    23.7  20                       0.44    0.97    1 VRA            3
 TO   1210 N-OBUASI    161.00  1      58.2    29.1    65.1  22                       0.69    2.48    1 VRA            3
 TO   1300 BOGOSO      161.00  1     -82.0   -38.1    90.4                           3.46   12.35    1 VRA            2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.7974PU    6.20  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                            128.38KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                           25.7    12.4    28.5
 TO SHUNT                              0.0    -4.6     4.6
 TO   1100 PRES-161    161.00  1    -106.8   -53.7   119.5                           6.43   28.08    1 VRA            2
 TO   1130 KUMASI      161.00  1     145.2    85.5   168.5 124                      10.62   38.05    1 VRA            3
 TO   1210 N-OBUASI    161.00  1     -64.0   -39.7    75.4  26                       0.29    1.01    1 VRA            3
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BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 0.6747PU   -4.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                            108.63KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                          126.9    61.5   141.0
 TO SHUNT                              0.0   -13.7    13.7
 TO   1120 OBUASI      161.00  1   -134.5   -49.6   143.4 125                    10.62   38.05    1 VRA            3
 TO   1180 KONONGO     161.00  1    -94.7   -25.8    98.2  86                     4.83   17.28    1 VRA            3
 TO   1260 TECHIMAN    161.00  1     45.0    11.8    46.6  38                     1.45    6.31    1 VRA            5
 TO   1413 AHAF-161    161.00  1     28.7     7.9    29.7  18                     0.40    2.52    1 VRA            1
 TO   1413 AHAF-161    161.00  2     28.7     7.9    29.7  18                     0.40    2.52    1 VRA            1

BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 0.8319PU   10.66  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                            133.93KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                            8.6     4.2     9.6
 TO   1150 TAFO        161.00  1   -117.3   -63.9   133.6  95                     6.76   24.16    1 VRA            3
 TO   1180 KONONGO     161.00  1    108.7    59.7   124.0  88                     5.30   18.98    1 VRA            3

BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 0.9471PU   17.55  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                            152.48KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                           13.0     6.3    14.4
 TO   1010 AKOSOMBO    161.00  1    -87.4   -51.6   101.5  63                     3.06   10.97    1 VRA            1
 TO   1010 AKOSOMBO    161.00  2   -122.5   -80.0   146.3  85                     3.67   16.00    1 VRA            1
 TO   1140 NKAWKAW     161.00  1    124.1    84.6   150.2  93                     6.76   24.16    1 VRA            3
 TO   1160 AKWATIA     161.00  1     72.9    40.7    83.5  52                     1.93    6.91    1 VRA            3

BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 0.8912PU   13.93  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                            143.48KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                            9.5     4.6    10.6
 TO   1150 TAFO        161.00  1    -71.0   -37.1    80.1  53                     1.93    6.91    1 VRA            3
 TO   1210 N-OBUASI    161.00  1     61.5    32.4    69.5  32                     2.29   10.65    1 VRA            3

BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0185PU   21.07  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                            163.99KV               MW     MVAR    1 VRA            1
 TO LOAD-PQ                           14.0     6.8    15.5
 TO   1010 AKOSOMBO    161.00  1    -57.0   -19.4    60.2  28                     0.18    0.85    1 VRA            1
 TO   1010 AKOSOMBO    161.00  2    -57.0   -19.4    60.2  28                     0.18    0.85    1 VRA            1
 TO   1020 VOLTA       161.00  1     50.0    16.0    52.6  24                     0.44    2.14    1 VRA            1
 TO   1020 VOLTA       161.00  2     50.0    16.0    52.6  24                     0.44    2.14    1 VRA            1

BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 0.7449PU    3.47  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                            119.92KV               MW     MVAR    1 VRA            3
 TO LOAD-PQ                            3.8     1.9     4.2
 TO   1130 KUMASI      161.00  1     99.5    41.2   107.7  85                     4.83   17.28    1 VRA            3
 TO   1140 NKAWKAW     161.00  1   -103.4   -43.1   112.0  88                     5.30   18.98    1 VRA            3

BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0343PU   22.83  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                            166.53KV               MW     MVAR    1 VRA            1
 TO LOAD-PQ                            0.4     0.2     0.5
 TO   1010 AKOSOMBO    161.00  1     53.4    11.3    54.5  25                     0.22    1.07    1 VRA            1
 TO   1020 VOLTA       161.00  1     86.2    34.4    92.8  33                     0.93    6.90    1 VRA            1
 TO   1191 KPONGS1     13.800  1    -35.0   -11.5    36.8  72 1.0500LK   30.00LK    0.00    3.20    1 VRA            1
 TO   1192 KPONGS2     13.800  1    -35.0   -11.5    36.8  72 1.0500LK   30.00LK    0.00    3.20    1 VRA            1
 TO   1193 KPONGS3     13.800  1    -35.0   -11.5    36.8  72 1.0500LK   30.00LK    0.00    3.20    1 VRA            1
 TO   1194 KPONGS4     13.800  1    -35.0   -11.5    36.8  72 1.0500LK   30.00LK    0.00    3.20    1 VRA            1
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BUS    1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.8006PU    6.72  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
                                                               128.89KV              MW     MVAR    1 VRA             3
 TO LOAD-PQ                           21.8    10.5     24.2
 TO    1110 DUNKWA      161.00  1    -21.8   -10.5     24.2  21                     0.44    0.97    1 VRA             2

BUS    1210 N-OBUASI    161.00 CKT     MW     MVAR     MVA   % 0.8056PU    6.73  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                               129.70KV              MW     MVAR    1 VRA             3
 TO LOAD-PQ                           52.4    25.4     58.2
 TO SHUNT                              0.0   -10.3     10.3
 TO    1110 DUNKWA      161.00  1    -57.5   -27.8     63.9  22                     0.69    2.48    1 VRA             2
 TO    1120 OBUASI      161.00  1     64.3    40.4     76.0  26                     0.29    1.01    1 VRA             3
 TO    1160 AKWATIA     161.00  1    -59.2   -27.8     65.4  33                     2.29   10.65    1 VRA             3

BUS    1220 ASIEKPE     161.00 CKT     MW     MVAR     MVA   % 0.9913PU   18.92  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                               159.60KV              MW     MVAR    1 VRA             1
 TO LOAD-PQ                           20.9    10.1     23.2
 TO    1010 AKOSOMBO    161.00  1    -61.6   -11.9     62.7  49                     1.56    3.52    1 VRA             1
 TO    1221 ASIEKP-6    69.000  1      0.0     0.0      0.0     0.9874LK            0.00    0.00    1 VRA             1
 TO    3010 LOME        161.00  1     40.6     1.7     40.7  32                     0.91    2.04    3 CEB             1

BUS    1260 TECHIMAN    161.00 CKT     MW     MVAR     MVA   % 0.6326PU  -11.98  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                               101.84KV              MW     MVAR    1 VRA             5
 TO LOAD-PQ                           12.5     6.1     13.9
 TO    1130 KUMASI      161.00  1    -43.6   -10.5     44.8  39                     1.45    6.31    1 VRA             3
 TO    1270 SUNYANI     161.00  1     -7.4    -2.1      7.7   7                     0.03    0.12    1 VRA             5
 TO    1280 TAMALE      161.00  1     33.0    10.8     34.7  30                     2.08    9.18    1 VRA             5
 TO    1380 SAWLA       161.00  1      5.6    -4.3      7.0   6                     0.07    0.24    1 VRA             5

BUS    1270 SUNYANI     161.00 CKT     MW     MVAR     MVA   % 0.6364PU  -11.12  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                               102.46KV              MW     MVAR    1 VRA             5
 TO LOAD-PQ                           25.7    12.4     28.6
 TO    1260 TECHIMAN    161.00  1      7.5     0.5      7.5   6                     0.03    0.12    1 VRA             5
 TO    1413 AHAF-161    161.00  1    -33.2   -13.0     35.6  15                     0.33    1.38    1 VRA             1

BUS    1280 TAMALE      161.00 CKT     MW     MVAR     MVA   % 0.5464PU  -25.47  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                               87.969KV              MW     MVAR    1 VRA             5
 TO LOAD-PQ                           15.6     7.6     17.3
 TO    1260 TECHIMAN    161.00  1    -30.9   -10.4     32.6  33                     2.08    9.18    1 VRA             5
 TO    1290 BOLGA       161.00  1      9.9     2.3     10.2   8                     0.20    0.92    1 VRA             5
 TO    1350 YENDI       161.00  1      5.3     0.6      5.4   5                     0.06    0.17    1 VRA             5

BUS    1290 BOLGA       161.00 CKT     MW     MVAR     MVA   % 0.5208PU  -29.85  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                               83.854KV              MW     MVAR    1 VRA             5
 TO LOAD-PQ                            8.9     4.3      9.9
 TO    1280 TAMALE      161.00  1     -9.7    -4.7     10.8   9                     0.20    0.92    1 VRA             5
 TO 3WNDTR               WND 1  1      0.8     0.4      0.9   6 1.0000LK            0.00    0.03

BUS    1300 BOGOSO      161.00 CKT     MW     MVAR     MVA   % 0.9073PU   14.21  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                               146.08KV              MW     MVAR    1 VRA             2
 TO LOAD-PQ                           28.8    13.9     32.0
 TO    1100 PRES-161    161.00  1   -124.5   -63.5    139.7  91                     1.37    4.90    1 VRA             2
 TO    1110 DUNKWA      161.00  1     85.4    46.9     97.4                         3.46   12.35    1 VRA             2
 TO    1309 WEXFORD     161.00  1     10.3     2.7     10.6   6                     0.04    0.12    1 VRA             3
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BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 0.9009PU   13.69  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                            145.05KV                MW     MVAR    1 VRA              3
 TO   1300 BOGOSO      161.00  1    -10.3     -5.5    11.7   7                     0.04    0.12    1 VRA              2
 TO  13091 WEX-LV      34.500  1     10.3      5.5    11.7  35 1.0000LK   30.00LK  0.00    0.57    1 VRA              3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0298PU   24.87  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                            165.80KV                MW     MVAR    1 VRA              2
 TO LOAD-PQ                           0.3      0.1     0.3
 TO   1060 WINNEBA     161.00  1     57.4      4.7    57.6  33                     1.34    5.17    1 VRA              2
 TO   1070 C-COAST     161.00  1     66.2     10.2    67.0  38                     1.01    3.89    1 VRA              2
 TO   1080 TAKORADI    161.00  1     96.2     33.4   101.9  58                     0.60    2.31    1 VRA              2
 TO   1080 TAKORADI    161.00  2     96.2     33.4   101.9  58                     0.60    2.31    1 VRA              2
 TO   1100 PRES-161    161.00  1    183.6     75.9   198.6  53                     8.35   35.12    1 VRA              2
 TO   1321 ABOAD-G1    13.800  1   -100.0    -32.1   105.0  72 1.0500LK   30.00LK  0.00    9.10    1 VRA              1
 TO   1322 ABOAD-G2    13.800  1   -100.0    -32.1   105.0  72 1.0500LK   30.00LK  0.00    9.10    1 VRA              1
 TO   1323 ABOA-G3     13.800  1   -100.0    -32.1   105.0  72 1.0500LK            0.00    9.10    1 VRA              1
 TO   1324 ABOA-G4     13.800  1   -100.0    -30.7   104.6  72 1.0500LK            0.00    9.35    1 VRA              1
 TO   1325 ABOAD-G5    13.800  1   -100.0    -30.7   104.6  72 1.0500LK            0.00    9.35    1 VRA              1
 TO   1326 ABOA-G6     13.800  1      0.0      0.0     0.0   0 1.0500LK            0.00    0.00    1 VRA              1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 0.6204PU  -15.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                            99.881KV                MW     MVAR    1 VRA              1
 TO LOAD-PQ                           4.3      2.1     4.8
 TO   1380 SAWLA       161.00  1     -4.3     -2.1     4.8   4                     0.02    0.08    1 VRA              5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 0.5365PU  -26.95  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                            86.377KV                MW     MVAR    1 VRA              5
 TO LOAD-PQ                           5.3      2.6     5.9
 TO   1280 TAMALE      161.00  1     -5.3     -2.6     5.9   6                     0.06    0.17    1 VRA              5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0247PU   23.23  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                            164.98KV                MW     MVAR    1 VRA              3
 TO LOAD-PQ                           5.3      2.6     5.9
 TO   1080 TAKORADI    161.00  1     -5.3      6.7     8.6                         0.04    0.12    1 VRA              2
 TO   1600 OPB-HV      161.00  1      0.0     -9.3     9.3   2                     0.00    0.02    1 VRA              3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9755PU   17.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                            157.05KV                MW     MVAR    1 VRA              1
 TO LOAD-PQ                          74.0     35.8    82.2
 TO SHUNT                             0.0    -19.0    19.0
 TO   1050 ACHIMOTA    161.00  1    -29.9    -11.1    31.9  19                     0.07    0.25    1 VRA              1
 TO   1070 C-COAST     161.00  1    -44.0     -5.7    44.4                         1.06    3.73    1 VRA              2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 0.6281PU  -14.49  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                            101.13KV                MW     MVAR    1 VRA              5
 TO LOAD-PQ                           1.2      0.6     1.3
 TO   1260 TECHIMAN    161.00  1     -5.5     -2.7     6.1   5                     0.07    0.24    1 VRA              5
 TO   1340 WA          161.00  1      4.3      2.2     4.8   4                     0.02    0.08    1 VRA              1
 TO   1381 SAW-34.5    34.500  1      0.0      0.0     0.0   0 1.1000HI            0.00    0.00    1 VRA              1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9667PU   16.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                            155.63KV                MW     MVAR    1 VRA              1
 TO LOAD-PQ                           8.6      4.2     9.6
 TO   1392  AFTAP      161.00  1     -8.6     -4.2     9.6   6                     0.00    0.00    1 VRA              1
```

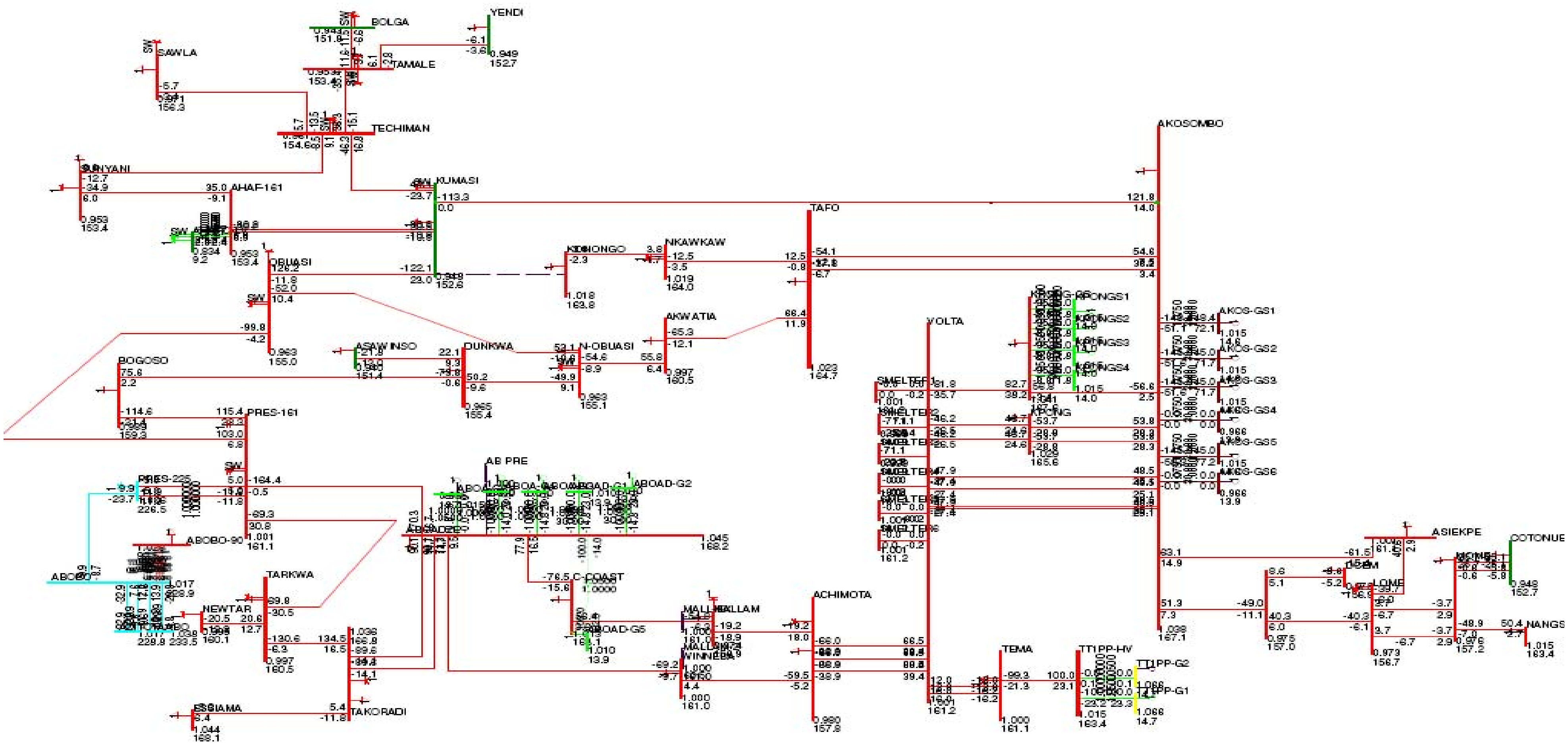
```
BUS   1392  AFTAP      161.00 CKT     MW     MVAR     MVA   % 0.9668PU   16.27  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                              155.66KV                MW     MVAR    1 VRA             1
 TO   1010 AKOSOMBO    161.00  1    -49.0    -8.7    49.8  40                        2.29    5.25    1 VRA             1
 TO   1390 DCEM        161.00  1      8.6     4.1     9.5   5                        0.00    0.00    1 VRA             1
 TO   3010 LOME        161.00  1     40.4     4.6    40.6  33                        0.05    0.11    3 CEB             1

BUS   1413 AHAF-161    161.00 CKT     MW     MVAR     MVA   % 0.6508PU   -9.25  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                              104.78KV                MW     MVAR    1 VRA             1
 TO   1130 KUMASI      161.00  1    -28.3    -7.9    29.4  18                        0.40    2.52    1 VRA             3
 TO   1130 KUMASI      161.00  2    -28.3    -7.9    29.4  18                        0.40    2.52    1 VRA             3
 TO   1270 SUNYANI     161.00  1     33.5    12.7    35.8  15                        0.33    1.38    1 VRA             5
 TO   1412 AHAFO-LV    11.000  1     11.5     1.6    11.6  26 1.1500HI               0.00    0.76    1 VRA             5
 TO   1412 AHAFO-LV    11.000  2     11.5     1.6    11.6  26 1.1500HI               0.00    0.76    1 VRA             5

BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR     MVA   % 1.0150PU   20.79  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                              163.41KV                MW     MVAR    1 VRA             1
 TO   1040 TEMA        161.00  1    100.0    33.3   105.4  49                        0.77    3.72    1 VRA             1
 TO   1510 TT1PP-G1    13.800  1   -100.0   -33.4   105.4  64 1.0000UN               0.00    0.01    1 VRA             1
 TO   1520 TT1PP-G2    13.800  1      0.0     0.1     0.1   0 1.0000UN               0.00    0.00    1 VRA             1

BUS   1600 OPB-HV      161.00 CKT     MW     MVAR     MVA   % 1.0291PU   23.17  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                              165.69KV                MW     MVAR    1 VRA             3
 TO   1360 ESSIAMA     161.00  1      0.0     0.0     0.0   0                        0.00    0.02    1 VRA             3
 TO   1601 OPB-G1      13.800  1      0.0     0.0     0.0   0 1.0500LK               0.00    0.00    1 VRA             3
```

Average Load Condition at power factor of 0.9, Konongo-Kumasi contingency on single line diagram (Case4)



Average Load Condition at power factor of 0.90 , Konongo-Kumasi contingency (Case 4, table results)

```
BUS    1010 AKOSOMBO    161.00 CKT     MW     MVAR     MVA   % 1.0380PU   23.09  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1010
                                                             167.12KV               MW     MVAR    1 VRA            1
 TO LOAD-PQ                           9.7      5.8    11.2
 TO    1011 AKOS-GS1    14.400  1  -148.4    -51.1   157.0  79 1.0750LK   30.00LK    0.00   20.99    1 VRA            1
 TO    1012 AKOS-GS2    14.400  1  -145.0    -51.6   153.9  77 1.0750LK   30.00LK    0.00   20.17    1 VRA            1
 TO    1013 AKOS-GS3    14.400  1  -145.0    -51.6   153.9  77 1.0750LK   30.00LK    0.00   20.17    1 VRA            1
 TO    1014 AKOS-GS4    14.400  1     0.0      0.0     0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA            1
 TO    1015 AKOS-GS5    14.400  1  -145.0    -58.3   156.3  78 1.0750LK   30.00LK    0.00   18.92    1 VRA            1
 TO    1016 AKOS-GS6    14.400  1     0.0      0.0     0.0   0 1.0750LK   30.00LK    0.00    0.00    1 VRA            1
 TO    1020 VOLTA       161.00  1    48.5     25.1    54.6  25                       0.61    2.98    1 VRA            1
 TO    1020 VOLTA       161.00  2    48.5     25.1    54.6  25                       0.61    2.98    1 VRA            1
 TO    1020 VOLTA       161.00  3    48.5     25.1    54.6  25                       0.61    2.98    1 VRA            1
 TO    1020 VOLTA       161.00  4    48.5     25.1    54.6  25                       0.61    2.98    1 VRA            1
 TO    1130 KUMASI      161.00  1   121.8     14.0   122.6  32                       8.48   37.05    1 VRA            3
 TO    1150 TAFO        161.00  1    38.2      3.4    38.3  22                       0.38    1.35    1 VRA            3
 TO    1150 TAFO        161.00  2    54.6      7.5    55.1  29                       0.45    1.96    1 VRA            3
 TO    1170 KPONG       161.00  1    53.8     28.3    60.8  28                       0.18    0.85    1 VRA            1
 TO    1170 KPONG       161.00  2    53.8     28.3    60.8  28                       0.18    0.85    1 VRA            1
 TO    1190 KPONG-GS    161.00  1   -56.6      2.5    56.7  26                       0.23    1.14    1 VRA            1
 TO    1220 ASIEKPE     161.00  1    63.1     14.9    64.8  49                       1.56    3.52    1 VRA            1
 TO    1392  AFTAP      161.00  1    51.3      7.3    51.8  39                       2.27    5.21    1 VRA            1

BUS    1020 VOLTA       161.00 CKT     MW     MVAR     MVA   % 1.0014PU   20.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1020
                                                             161.22KV               MW     MVAR    1 VRA            1
 TO    1010 AKOSOMBO    161.00  1   -47.9    -27.4    55.2  26                       0.61    2.98    1 VRA            1
 TO    1010 AKOSOMBO    161.00  2   -47.9    -27.4    55.2  26                       0.61    2.98    1 VRA            1
 TO    1010 AKOSOMBO    161.00  3   -47.9    -27.4    55.2  26                       0.61    2.98    1 VRA            1
 TO    1010 AKOSOMBO    161.00  4   -47.9    -27.4    55.2  26                       0.61    2.98    1 VRA            1
 TO    1031 SMELTER1    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO    1032 SMELTER2    161.00  1    71.1     25.4    75.5  35                       0.06    0.28    1 VRA            3
 TO    1033 SMELTER3    161.00  1    71.1     23.8    75.0  35                       0.06    0.28    1 VRA            3
 TO    1034 SMELTER4    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO    1035 SMELTER5    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO    1036 SMELTER6    161.00  1     0.0     -0.2     0.2   0                       0.00    0.00    1 VRA            3
 TO    1040 TEMA        161.00  1    12.0     16.0    20.0   9                       0.00    0.02    1 VRA            1
 TO    1040 TEMA        161.00  2    12.0     16.0    20.0   9                       0.00    0.02    1 VRA            1
 TO    1050 ACHIMOTA    161.00  1    66.5     39.4    77.3  36                       0.49    2.40    1 VRA            1
 TO    1050 ACHIMOTA    161.00  2    66.5     39.4    77.3  36                       0.49    2.40    1 VRA            1
 TO    1050 ACHIMOTA    161.00  3    66.5     39.4    77.3  36                       0.49    2.40    1 VRA            1
 TO    1170 KPONG       161.00  1   -46.2    -26.5    53.3  25                       0.44    2.14    1 VRA            1
 TO    1170 KPONG       161.00  2   -46.2    -26.5    53.3  25                       0.44    2.14    1 VRA            1
 TO    1190 KPONG-GS    161.00  1   -81.8    -35.7    89.3  33                       0.89    6.59    1 VRA            1

BUS    1031 SMELTER1    161.00 CKT     MW     MVAR     MVA   % 1.0014PU   20.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1031
                                                             161.22KV               MW     MVAR    1 VRA            3
 TO    1020 VOLTA       161.00  1     0.0      0.0     0.0   0                       0.00    0.00    1 VRA            1
 TO   10311 VALCO-1     13.800  1     0.0      0.0     0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3
 TO   10317 VALCO-7     13.800  1     0.0      0.0     0.0   0 1.0250LK   30.00LK    0.00    0.00    1 VRA            3

BUS    1032 SMELTER2    161.00 CKT     MW     MVAR     MVA   % 0.9994PU   20.48  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1032
                                                             160.91KV               MW     MVAR    1 VRA            3
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  TO   1020 VOLTA       161.00  1    -71.1   -25.3    75.5  35                            0.06    0.28    1 VRA              1
  TO  10312 VALCO-2     13.800  1     71.1    25.3    75.5  89 1.0250LK   30.00LK    0.00    9.09    1 VRA              3
  TO  10318 VALCO-8     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA              3

 BUS   1033 SMELTER3    161.00 CKT     MW     MVAR     MVA   % 0.9995PU   20.48  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1033
                                                             160.92KV                  MW     MVAR    1 VRA              3
  TO   1020 VOLTA       161.00  1    -71.1   -23.7    74.9  35                            0.06    0.28    1 VRA              1
  TO  10313 VALCO-3     13.800  1     71.1    23.7    74.9  88 1.0000LK   30.00LK    0.00    8.53    1 VRA              3

 BUS   1034 SMELTER4    161.00 CKT     MW     MVAR     MVA   % 1.0014PU   20.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1034
                                                             161.22KV                  MW     MVAR    1 VRA              3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                            0.00    0.00    1 VRA              1
  TO  10314 VALCO-4     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA              3

 BUS   1035 SMELTER5    161.00 CKT     MW     MVAR     MVA   % 1.0014PU   20.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1035
                                                             161.22KV                  MW     MVAR    1 VRA              3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                            0.00    0.00    1 VRA              1
  TO  10315 VALCO-5     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA              3

 BUS   1036 SMELTER6    161.00 CKT     MW     MVAR     MVA   % 1.0014PU   20.67  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1036
                                                             161.22KV                  MW     MVAR    1 VRA              3
  TO   1020 VOLTA       161.00  1      0.0     0.0     0.0   0                            0.00    0.00    1 VRA              1
  TO  10316 VALCO-6     13.800  1      0.0     0.0     0.0   0 1.0000LK   30.00LK    0.00    0.00    1 VRA              3

 BUS   1040 TEMA        161.00 CKT     MW     MVAR     MVA   % 1.0005PU   20.64  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1040
                                                             161.07KV                  MW     MVAR    1 VRA              1
  TO LOAD-PQ                         123.3    73.7   143.6
  TO SHUNT                             0.0   -20.0    20.0
  TO   1020 VOLTA       161.00  1    -12.0   -16.2    20.1   9                            0.00    0.02    1 VRA              1
  TO   1020 VOLTA       161.00  2    -12.0   -16.2    20.1   9                            0.00    0.02    1 VRA              1
  TO   1500 TT1PP-HV    161.00  1    -99.3   -21.3   101.5  48                            0.73    3.52    1 VRA              1

 BUS   1050 ACHIMOTA    161.00 CKT     MW     MVAR     MVA   % 0.9802PU   19.32  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1050
                                                             157.81KV                  MW     MVAR    1 VRA              1
  TO LOAD-PQ                         238.3   142.5   277.6
  TO SHUNT                             0.0   -38.4    38.4
  TO   1020 VOLTA       161.00  1    -66.0   -38.9    76.6  37                            0.49    2.40    1 VRA              1
  TO   1020 VOLTA       161.00  2    -66.0   -38.9    76.6  37                            0.49    2.40    1 VRA              1
  TO   1020 VOLTA       161.00  3    -66.0   -38.9    76.6  37                            0.49    2.40    1 VRA              1
  TO   1060 WINNEBA     161.00  1    -59.5    -5.2    59.8  36                            0.95    3.35    1 VRA              2
  TO   1370 MALLAM      161.00  1     19.2    18.0    26.4  16                            0.05    0.18    1 VRA              1

 BUS   1060 WINNEBA     161.00 CKT     MW     MVAR     MVA   % 1.0003PU   22.42  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1060
                                                             161.05KV                  MW     MVAR    1 VRA              2
  TO LOAD-PQ                           8.8     5.2    10.2
  TO   1050 ACHIMOTA    161.00  1     60.5     4.4    60.7  36                            0.95    3.35    1 VRA              1
  TO   1320 ABOADZE     161.00  1    -69.2    -9.7    69.9  41                            2.04    7.85    1 VRA              2

 BUS   1070 C-COAST     161.00 CKT     MW     MVAR     MVA   % 1.0129PU   24.88  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1070
                                                             163.07KV                  MW     MVAR    1 VRA              2
  TO LOAD-PQ                          20.1    12.0    23.5
  TO   1320 ABOADZE     161.00  1    -76.5   -15.6    78.1  45                            1.39    5.34    1 VRA              2
  TO   1370 MALLAM      161.00  1     56.4     3.6    56.5                                1.64    5.79    1 VRA              1
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BUS   1080 TAKORADI    161.00 CKT     MW     MVAR     MVA   % 1.0363PU   27.40  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1080
                                                              166.84KV               MW     MVAR    1 VRA              2
 TO LOAD-PQ                          39.3    23.5    45.8
 TO   1090 TARKWA      161.00  1    134.5    16.5   135.5  77                      3.93   14.08    1 VRA              2
 TO   1320 ABOADZE     161.00  1    -89.6   -14.1    90.7  52                      0.47    1.80    1 VRA              2
 TO   1320 ABOADZE     161.00  2    -89.6   -14.1    90.7  52                      0.47    1.80    1 VRA              2
 TO   1360 ESSIAMA     161.00  1      5.4   -11.8    13.0                          0.04    0.12    1 VRA              3

BUS   1090 TARKWA      161.00 CKT     MW     MVAR     MVA   % 0.9972PU   21.51  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1090
                                                              160.54KV               MW     MVAR    1 VRA              2
 TO LOAD-PQ                          40.2    24.0    46.9
 TO   1080 TAKORADI    161.00  1   -130.6    -6.3   130.7  77                      3.93   14.08    1 VRA              2
 TO   1095 NEWTAR      161.00  1     20.6    12.7    24.2  14                      0.02    0.08    1 VRA              3
 TO   1100 PRES-161    161.00  1     69.8   -30.5    76.2  45                      0.54    1.89    1 VRA              2

BUS   1095 NEWTAR      161.00 CKT     MW     MVAR     MVA   % 0.9947PU   21.38  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1095
                                                              160.15KV               MW     MVAR    1 VRA              3
 TO   1090 TARKWA      161.00  1    -20.5   -13.3    24.4  14                      0.02    0.08    1 VRA              2
 TO  10951 NTAR-LV     11.500  1     10.3     6.6    12.2  37 1.0000LK             0.00    0.48    1 VRA              3
 TO  10951 NTAR-LV     11.500  2     10.3     6.6    12.2  37 1.0000LK             0.00    0.48    1 VRA              3

BUS   1100 PRES-161    161.00 CKT     MW     MVAR     MVA   % 1.0007PU   20.04  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1100
                                                              161.12KV               MW     MVAR    1 VRA              2
 TO LOAD-PQ                           5.3     3.2     6.2
 TO SHUNT                             0.0   -20.0    20.0
 TO SWITCHED SHUNT                    0.0   -20.0    20.0
 TO   1090 TARKWA      161.00  1    -69.3    30.8    75.8  45                      0.54    1.89    1 VRA              2
 TO   1109 PRES-225    225.00  1      5.0   -11.8    12.8   6 1.0000UN             0.00    0.08    1 VRA              2
 TO   1109 PRES-225    225.00  2      5.0   -11.8    12.8   6 1.0000UN             0.00    0.08    1 VRA              2
 TO   1120 OBUASI      161.00  1    103.0     6.8   103.2                          3.16   13.80    1 VRA              3
 TO   1300 BOGOSO      161.00  1    115.4    23.3   117.8  69                      0.80    2.87    1 VRA              2
 TO   1320 ABOADZE     161.00  1   -164.4    -0.5   164.4  45                      5.96   25.04    1 VRA              2

BUS   1109 PRES-225    225.00 CKT     MW     MVAR     MVA   % 1.0064PU   19.90  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1109
                                                              226.45KV               MW     MVAR    1 VRA              2
 TO   1100 PRES-161    161.00  1     -5.0    11.9    12.9   6 1.0000LK             0.00    0.08    1 VRA              2
 TO   1100 PRES-161    161.00  2     -5.0    11.9    12.9   6 1.0000LK             0.00    0.08    1 VRA              2
 TO   2010 ABOBO       225.00  1      9.9   -23.7    25.7                          0.04    0.27    2 CIE              1

BUS   1110 DUNKWA      161.00 CKT     MW     MVAR     MVA   % 0.9653PU   14.05  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1110
                                                              155.41KV               MW     MVAR    1 VRA              2
 TO LOAD-PQ                           1.5     0.9     1.8
 TO   1200 ASAWINSO    161.00  1     22.1     9.3    24.0  18                      0.34    0.75    1 VRA              3
 TO   1210 N-OBUASI    161.00  1     50.2    -9.6    51.1  15                      0.31    1.11    1 VRA              3
 TO   1300 BOGOSO      161.00  1    -73.8    -0.6    73.8                          1.72    6.15    1 VRA              2

BUS   1120 OBUASI      161.00 CKT     MW     MVAR     MVA   % 0.9629PU   12.37  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1120
                                                              155.02KV               MW     MVAR    1 VRA              3
 TO LOAD-PQ                          25.7    12.3    28.5
 TO SHUNT                             0.0    -6.7     6.7
 TO   1100 PRES-161    161.00  1    -99.8    -4.2    99.9                          3.16   13.80    1 VRA              2
 TO   1130 KUMASI      161.00  1    126.2   -11.8   126.7  77                      4.08   14.62    1 VRA              3
 TO   1210 N-OBUASI    161.00  1    -52.0    10.4    53.1  15                      0.10    0.34    1 VRA              3
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```
BUS   1130 KUMASI      161.00 CKT     MW     MVAR     MVA   % 0.9476PU    5.51  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1130
                                                              152.56KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                          127.4    76.2   148.4
 TO SHUNT                              0.0   -53.9    53.9
 TO   1010 AKOSOMBO    161.00  1  -113.3     0.0   113.3  33                        8.48   37.05    1 VRA             1
 TO   1120 OBUASI      161.00  1  -122.1    23.0   124.2  77                        4.08   14.62    1 VRA             3
 TO   1260 TECHIMAN    161.00  1    47.1   -23.7    52.8  31                        0.84    3.66    1 VRA             5
 TO   1413 AHAF-161    161.00  1    30.5   -10.8    32.3  14                        0.22    1.40    1 VRA             1
 TO   1413 AHAF-161    161.00  2    30.5   -10.8    32.3  14                        0.22    1.40    1 VRA             1

BUS   1140 NKAWKAW     161.00 CKT     MW     MVAR     MVA   % 1.0187PU   20.54  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1140
                                                              164.00KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            8.6     5.2    10.1
 TO   1150 TAFO        161.00  1   -12.5    -3.5    13.0   7                        0.04    0.14    1 VRA             3
 TO   1180 KONONGO     161.00  1     3.8    -1.7     4.2   2                        0.00    0.01    1 VRA             3

BUS   1150 TAFO        161.00 CKT     MW     MVAR     MVA   % 1.0232PU   21.17  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1150
                                                              164.73KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                           13.0     7.8    15.1
 TO   1010 AKOSOMBO    161.00  1   -37.8    -6.7    38.4  22                        0.38    1.35    1 VRA             1
 TO   1010 AKOSOMBO    161.00  2   -54.1   -12.1    55.5  30                        0.45    1.96    1 VRA             1
 TO   1140 NKAWKAW     161.00  1    12.5    -0.8    12.5   7                        0.04    0.14    1 VRA             3
 TO   1160 AKWATIA     161.00  1    66.4    11.9    67.5  39                        1.07    3.83    1 VRA             3

BUS   1160 AKWATIA     161.00 CKT     MW     MVAR     MVA   % 0.9969PU   18.11  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1160
                                                              160.50KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            9.5     5.7    11.1
 TO   1150 TAFO        161.00  1   -65.3   -12.1    66.5  39                        1.07    3.83    1 VRA             3
 TO   1210 N-OBUASI    161.00  1    55.8     6.4    56.2  23                        1.17    5.43    1 VRA             3

BUS   1170 KPONG       161.00 CKT     MW     MVAR     MVA   % 1.0286PU   22.46  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1170
                                                              165.60KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                           14.0     8.4    16.3
 TO   1010 AKOSOMBO    161.00  1   -53.7   -28.8    60.9  28                        0.18    0.85    1 VRA             1
 TO   1010 AKOSOMBO    161.00  2   -53.7   -28.8    60.9  28                        0.18    0.85    1 VRA             1
 TO   1020 VOLTA       161.00  1    46.7    24.6    52.8  24                        0.44    2.14    1 VRA             1
 TO   1020 VOLTA       161.00  2    46.7    24.6    52.8  24                        0.44    2.14    1 VRA             1

BUS   1180 KONONGO     161.00 CKT     MW     MVAR     MVA   % 1.0175PU   20.37  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1180
                                                              163.82KV                MW     MVAR    1 VRA             3
 TO LOAD-PQ                            3.8     2.3     4.5
 TO   1140 NKAWKAW     161.00  1    -3.8    -2.3     4.5   3                        0.00    0.01    1 VRA             3

BUS   1190 KPONG-GS    161.00 CKT     MW     MVAR     MVA   % 1.0411PU   24.25  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1190
                                                              167.62KV                MW     MVAR    1 VRA             1
 TO LOAD-PQ                            0.4     0.3     0.5
 TO   1010 AKOSOMBO    161.00  1    56.8    -3.4    56.9  26                        0.23    1.14    1 VRA             1
 TO   1020 VOLTA       161.00  1    82.7    38.2    91.1  32                        0.89    6.59    1 VRA             1
 TO   1191 KPONGS1     13.800  1   -35.0    -8.8    36.1  71 1.0500LK   30.00LK    0.00    3.03    1 VRA             1
 TO   1192 KPONGS2     13.800  1   -35.0    -8.8    36.1  71 1.0500LK   30.00LK    0.00    3.03    1 VRA             1
 TO   1193 KPONGS3     13.800  1   -35.0    -8.8    36.1  71 1.0500LK   30.00LK    0.00    3.03    1 VRA             1
 TO   1194 KPONGS4     13.800  1   -35.0    -8.8    36.1  71 1.0500LK   30.00LK    0.00    3.03    1 VRA             1

BUS   1200 ASAWINSO    161.00 CKT     MW     MVAR     MVA   % 0.9404PU   12.86  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1200
```

```
                                                              151.40KV              MW     MVAR    1 VRA             3
  TO LOAD-PQ                              21.8    13.0     25.4
  TO    1110 DUNKWA      161.00  1     -21.8   -13.0     25.4  19                     0.34    0.75    1 VRA             2

 BUS    1210 N-OBUASI    161.00 CKT     MW      MVAR      MVA   % 0.9634PU   12.76  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1210
                                                              155.10KV              MW     MVAR    1 VRA             3
  TO LOAD-PQ                              52.4    25.1     58.1
  TO SHUNT                                 0.0   -14.7     14.7
  TO    1110 DUNKWA      161.00  1     -49.9     9.1     50.7  14                     0.31    1.11    1 VRA             2
  TO    1120 OBUASI      161.00  1      52.1   -10.6     53.2  15                     0.10    0.34    1 VRA             3
  TO    1160 AKWATIA     161.00  1     -54.6    -8.9     55.4  24                     1.17    5.43    1 VRA             3

 BUS    1220 ASIEKPE     161.00 CKT     MW      MVAR      MVA   % 1.0006PU   20.37  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1220
                                                              161.10KV              MW     MVAR    1 VRA             1
  TO LOAD-PQ                              20.9    12.5     24.4
  TO    1010 AKOSOMBO    161.00  1     -61.5   -15.4     63.4  49                     1.56    3.52    1 VRA             1
  TO    1221 ASIEKP-6    69.000  1       0.0     0.0      0.0     0.9874LK            0.00    0.00    1 VRA             1
  TO    3010 LOME        161.00  1      40.6     2.9     40.7  32                     0.89    2.02    3 CEB             1

 BUS    1260 TECHIMAN    161.00 CKT     MW      MVAR      MVA   % 0.9605PU    1.35  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1260
                                                              154.64KV              MW     MVAR    1 VRA             5
  TO LOAD-PQ                              12.8     7.7     14.9
  TO SHUNT                                 0.0    -5.0      5.0
  TO    1130 KUMASI      161.00  1     -46.3    16.8     49.2  28                     0.84    3.66    1 VRA             3
  TO    1270 SUNYANI     161.00  1      -8.5     9.1     12.5   7                     0.04    0.18    1 VRA             5
  TO    1280 TAMALE      161.00  1      36.3   -15.1     39.3  22                     0.90    3.95    1 VRA             5
  TO    1380 SAWLA       161.00  1       5.7   -13.5     14.6   8                     0.06    0.19    1 VRA             5

 BUS    1270 SUNYANI     161.00 CKT     MW      MVAR      MVA   % 0.9526PU    1.92  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1270
                                                              153.37KV              MW     MVAR    1 VRA             5
  TO LOAD-PQ                              26.3    15.7     30.6
  TO SHUNT                                 0.0    -9.1      9.1
  TO    1260 TECHIMAN    161.00  1       8.6   -12.7     15.3   9                     0.04    0.18    1 VRA             5
  TO    1413 AHAF-161    161.00  1     -34.9     6.0     35.4  10                     0.15    0.63    1 VRA             1

 BUS    1280 TAMALE      161.00 CKT     MW      MVAR      MVA   % 0.9527PU   -5.03  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1280
                                                              153.39KV              MW     MVAR    1 VRA             5
  TO LOAD-PQ                              17.7    10.6     20.6
  TO    1260 TECHIMAN    161.00  1     -35.4    -4.0     35.6  21                     0.90    3.95    1 VRA             5
  TO    1290 BOLGA       161.00  1      11.6    -3.7     12.2   5                     0.08    0.36    1 VRA             5
  TO    1350 YENDI       161.00  1       6.1    -2.8      6.7   4                     0.02    0.07    1 VRA             5

 BUS    1290 BOLGA       161.00 CKT     MW      MVAR      MVA   % 0.9426PU   -6.75  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1290
                                                              151.75KV              MW     MVAR    1 VRA             5
  TO LOAD-PQ                              10.5     6.3     12.3
  TO    1280 TAMALE      161.00  1     -11.5    -6.6     13.3   6                     0.08    0.36    1 VRA             5
  TO 3WNDTR               WND 1  1       1.0     0.3      1.1   7 1.0000LK            0.00    0.01

 BUS    1300 BOGOSO      161.00 CKT     MW      MVAR      MVA   % 0.9894PU   18.74  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1300
                                                              159.29KV              MW     MVAR    1 VRA             2
  TO LOAD-PQ                              28.8    17.2     33.5
  TO    1100 PRES-161    161.00  1    -114.6   -21.4    116.6  69                     0.80    2.87    1 VRA             2
  TO    1110 DUNKWA      161.00  1      75.6     2.2     75.6                         1.72    6.15    1 VRA             2
  TO    1309 WEXFORD     161.00  1      10.3     1.9     10.5   6                     0.03    0.10    1 VRA             3
```

```
BUS   1309 WEXFORD     161.00 CKT     MW     MVAR     MVA   % 0.9839PU   18.30  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1309
                                                              158.40KV               MW     MVAR    1 VRA              3
 TO   1300 BOGOSO      161.00  1    -10.3     -5.4     11.6   6                     0.03    0.10    1 VRA              2
 TO  13091 WEX-LV      34.500  1     10.3      5.4     11.6  35 1.0000LK   30.00LK  0.00    0.47    1 VRA              3

BUS   1320 ABOADZE     161.00 CKT     MW     MVAR     MVA   % 1.0448PU   28.47  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1320
                                                              168.21KV               MW     MVAR    1 VRA              2
 TO LOAD-PQ                           0.3      0.2      0.3
 TO   1060 WINNEBA     161.00  1     71.3      9.5     71.9  41                     2.04    7.85    1 VRA              2
 TO   1070 C-COAST     161.00  1     77.9     16.5     79.6  45                     1.39    5.34    1 VRA              2
 TO   1080 TAKORADI    161.00  1     90.1     14.7     91.3  51                     0.47    1.80    1 VRA              2
 TO   1080 TAKORADI    161.00  2     90.1     14.7     91.3  51                     0.47    1.80    1 VRA              2
 TO   1100 PRES-161    161.00  1    170.3     16.7    171.2  45                     5.96   25.04    1 VRA              2
 TO   1321 ABOAD-G1    13.800  1   -100.0    -14.8    101.1  70 1.0500LK   30.00LK  0.00    8.19    1 VRA              1
 TO   1322 ABOAD-G2    13.800  1   -100.0    -14.8    101.1  70 1.0500LK   30.00LK  0.00    8.19    1 VRA              1
 TO   1323 ABOA-G3     13.800  1   -100.0    -14.8    101.1  70 1.0500LK            0.00    8.19    1 VRA              1
 TO   1324 ABOA-G4     13.800  1   -100.0    -14.0    101.0  70 1.0500LK            0.00    8.46    1 VRA              1
 TO   1325 ABOAD-G5    13.800  1   -100.0    -14.0    101.0  70 1.0500LK            0.00    8.46    1 VRA              1
 TO   1326 ABOA-G6     13.800  1      0.0      0.0      0.0   0 1.0500LK            0.00    0.00    1 VRA              1

BUS   1340 WA          161.00 CKT     MW     MVAR     MVA   % 0.9652PU   -0.32  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1340
                                                              155.40KV               MW     MVAR    1 VRA              1
 TO LOAD-PQ                           4.4      2.7      5.2
 TO   1380 SAWLA       161.00  1     -4.4     -2.7      5.2   3                     0.01    0.04    1 VRA              5

BUS   1350 YENDI       161.00 CKT     MW     MVAR     MVA   % 0.9487PU   -5.63  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1350
                                                              152.73KV               MW     MVAR    1 VRA              5
 TO LOAD-PQ                           6.1      3.6      7.1
 TO   1280 TAMALE      161.00  1     -6.1     -3.6      7.1   4                     0.02    0.07    1 VRA              5

BUS   1360 ESSIAMA     161.00 CKT     MW     MVAR     MVA   % 1.0442PU   26.90  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1360
                                                              168.11KV               MW     MVAR    1 VRA              3
 TO LOAD-PQ                           5.3      3.2      6.2
 TO   1080 TAKORADI    161.00  1     -5.3      6.4      8.4                         0.04    0.12    1 VRA              2
 TO   1600 OPB-HV      161.00  1      0.0     -9.6      9.6   3                     0.00    0.02    1 VRA              3

BUS   1370 MALLAM      161.00 CKT     MW     MVAR     MVA   % 0.9744PU   19.12  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1370
                                                              156.89KV               MW     MVAR    1 VRA              1
 TO LOAD-PQ                          74.0     44.2     86.2
 TO SHUNT                             0.0    -19.0     19.0
 TO   1050 ACHIMOTA    161.00  1    -19.2    -18.9     27.0  16                     0.05    0.18    1 VRA              1
 TO   1070 C-COAST     161.00  1    -54.8     -6.3     55.1                         1.64    5.79    1 VRA              2

BUS   1380 SAWLA       161.00 CKT     MW     MVAR     MVA   % 0.9711PU    0.00  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1380
                                                              156.35KV               MW     MVAR    1 VRA              5
 TO LOAD-PQ                           1.2      0.7      1.4
 TO   1260 TECHIMAN    161.00  1     -5.7     -3.4      6.6   4                     0.06    0.19    1 VRA              5
 TO   1340 WA          161.00  1      4.4      2.7      5.2   3                     0.01    0.04    1 VRA              1
 TO   1381 SAW-34.5    34.500  1      0.0      0.0      0.0   0 1.1000HI            0.00    0.00    1 VRA              1

BUS   1390 DCEM        161.00 CKT     MW     MVAR     MVA   % 0.9747PU   17.81  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1390
                                                              156.93KV               MW     MVAR    1 VRA              1
 TO LOAD-PQ                           8.6      5.2     10.1
```

```
 TO   1392  AFTAP      161.00  1     -8.6    -5.2    10.1   6                       0.00    0.00    1 VRA            1

BUS   1392  AFTAP      161.00 CKT     MW     MVAR     MVA   % 0.9749PU   17.81  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1392
                                                              156.96KV                 MW     MVAR    1 VRA            1
 TO   1010 AKOSOMBO    161.00  1    -49.0   -11.1    50.2  40                       2.27    5.21    1 VRA            1
 TO   1390 DCEM        161.00  1      8.6     5.1    10.0   6                       0.00    0.00    1 VRA            1
 TO   3010 LOME        161.00  1     40.3     6.0    40.8  33                       0.05    0.11    3 CEB            1

BUS   1413 AHAF-161    161.00 CKT     MW     MVAR     MVA   % 0.9529PU    2.96  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1413
                                                              153.42KV                 MW     MVAR    1 VRA            1
 TO   1130 KUMASI      161.00  1    -30.2     6.9    31.0  13                       0.22    1.40    1 VRA            3
 TO   1130 KUMASI      161.00  2    -30.2     6.9    31.0  13                       0.22    1.40    1 VRA            3
 TO   1270 SUNYANI     161.00  1     35.0    -9.1    36.2  10                       0.15    0.63    1 VRA            5
 TO   1412 AHAFO-LV    11.000  1     12.7    -2.4    13.0  29 1.1500HI              0.00    0.44    1 VRA            5
 TO   1412 AHAFO-LV    11.000  2     12.7    -2.4    13.0  29 1.1500HI              0.00    0.44    1 VRA            5

BUS   1500 TT1PP-HV    161.00 CKT     MW     MVAR     MVA   % 1.0150PU   22.48  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1500
                                                              163.41KV                 MW     MVAR    1 VRA            1
 TO   1040 TEMA        161.00  1    100.0    23.1   102.6  47                       0.73    3.52    1 VRA            1
 TO   1510 TT1PP-G1    13.800  1   -100.0   -23.2   102.7  62 1.0000UN              0.00    0.01    1 VRA            1
 TO   1520 TT1PP-G2    13.800  1      0.0     0.1     0.1   0 1.0000UN              0.00    0.00    1 VRA            1

BUS   1600 OPB-HV      161.00 CKT     MW     MVAR     MVA   % 1.0486PU   26.85  X--- LOSSES ---X X---- AREA -----X X---- ZONE -----X   1600
                                                              168.83KV                 MW     MVAR    1 VRA            3
 TO   1360 ESSIAMA     161.00  1      0.0     0.0     0.0   0                       0.00    0.02    1 VRA            3
 TO   1601 OPB-G1      13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA            3
 TO   1602 OPB-G2      13.800  1      0.0     0.0     0.0   0 1.0500LK              0.00    0.00    1 VRA            3
```

Appendix 7: Defect in NEVA program

From: Ruhle, Olaf [mailto:olaf.ruhle@siemens.com]
Sent: 25. mai 2009 13:19
To: Olav Bjarte Fosso
Cc: fosso@elkraft.ntnu.no
Subject: AW: NEVA - PSSE

E D SE PTI SW-de0084/Ru

May 25, 2009

Dear Olav Bjarte,

I checked your dataset and I found out that there is a bug in the program that writes the interface file from PSS®E to NEVA for the controller PIDGOV. Our converter creates a wrong order of the parameter names and parameter data. This bug causes that the PIDGOV controller got a "division by zero" and NEVA stops. We will correct our software and send you an update / patch as soon as possible.

Best regards,

Olaf Ruhle

Dr.-Ing. Olaf Ruhle

Senior Consultant / Senior Product Manager

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Appendix 8: Error message from NEVA

SIEMENS POWER TECHNOLOGIES INTERNATIONAL

12000 BUS POWER SYSTEM SIMULATOR--PSS(tm)E-31.0.0
INITIATED ON SUN, MAY 17 2009 21:41

Recording started in file C:\Documents and Settings\kwakusar\Desktop\linearanlysis\linearanalysisrecording.py
TRANSMISSION SYSTEM OPERATIONAL STUDY ON 2009 SUPPLY PLAN
CASE LF-09-1: 2009 SYSTEM PEAK LOAD CONDITION
CASE C:\Documents and Settings\...\Thesis files\workingfilenew\casesequencedatadynarevised100loadfinal.sav WAS SAVED ON WED, APR 29 2009 1:48

DEFAULT OPTIONS MODIFIED:
GRAPHICS TERMINAL TYPE: 0
TRANSMISSION SYSTEM OPERATIONAL STUDY ON 2009 SUPPLY PLAN
CASE LF-09-1: 2009 SYSTEM PEAK LOAD CONDITION

SNAPSHOT C:\Documents and Settings\...\Thesis files\PSSE case file\cases\fullload\finalrevisedpssoffksmew3.snp WAS SAVED ON MON, APR 27 2009 16:37
NUMBER OF ELEMENTS RESTORED:
CONS STATES VARS ICONS CHANNELS
1968 807 117 96 88
Executing Python file:C:\PTI\PSSE31\PSSBIN\pssneva.pyc

*** n_args= 2
OUTPUT COMPLETED
OUTPUT COMPLETED

Check for NETOMAC/NEVA error condition(s):
E R R O R: *.raw file not found
E R R O R : NEVA input file(s) not created - check installation!
(C:\Documents and Settings\kwakusar\Desktop\linearanlysis\090517_214357_NEVA_Casesequencedatadynarevised100Loadfinal\Casesequencedatadynarevised100Loadfinal.dat)
Number of warnings = 0
Number of errors = 2
Recording terminated for file C:\Documents and Settings\kwakusar\Desktop\linearanlysis\linearanalysisrecording.py