Green and Hybrid Microgrid for Rural Electrification

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***Abstract*—Green power generation technologies' interconnection to form hybrid Microgrids are seen as promising option for rural electrification in developing countries like Nepal. The use of distributed energy resources like micro-hydropower plant (MHP), Wind Turbines (WT) and photovoltaic (PV) systems are common for rural communities and there are possibilities of interconnection of these sources to form Green and Hybrid Microgrids. The paper presents the viable options and technical aspects of Green and Hybrid Microgrid. The paper also presents two cases of Green and Hybrid Microgrid installed for rural electrification in Nepal.**

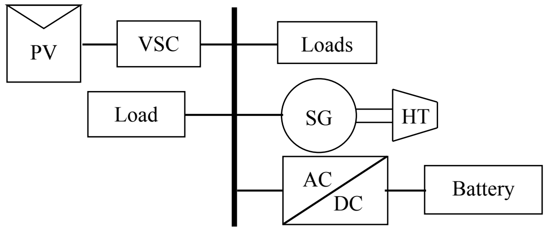
Keywords- Microgrid; Hybrid; Rural; Electrification; Nepal

I. INTRODUCTION

Electrification in rural communities is still a major concern in many developing countries. Distributed generations like wind turbines (WT), photovoltaics (PV), micro hydro power plants (MHP), diesel generators, microturbines, fuel cells etc. are deployed for fulfillment of rural electric power. The rural parts of Nepal get electrical power mostly from microhydro power plants, solar photovolatic systems and wind turbines [1,2,3,4]. There are there are 329849 numbers of solar home systems with total installed capacity of 8.43MWp, 22605 numbers of small solar home systems (>10Wp) with total installed capacity of 113kWp, 2155 numbers of institutional solar PV systems with total installed capacity of 2949.35kWp, and 111 numbers of solar photovoltaic water pumping systems fullfilling the rural electricity demand in Nepal [1]. There are 1287 numbers of MHP with installed capacity of 24.606MW, 1634 numbers of pico hydro power plant with installed capacity of 3.703MW, and 24 numbers of small WT with installed capacity of 26.7kW for rural electrification in Nepal [1].

Distributed generations like wind turbines (WT), photovoltaics (PV), micro hydro power plants (MHP), diesel generators, microturbines, fuel cells etc. can be interconnected to form a Microgrids and serve larger rural communitiy loads[2-11]. A Green microgrid is an interconnetion of renewable energy sources like(WT), photovoltaics (PV), and micro hydro power plants (MHP). These renewable energy sources reduce the carbon emission due to electricity generation as compared to thermal plants using coal, diesel etc. A Green and Hybrid microgrid posseses two or more renewable energy sources to supply the local electrical load. For developing countries like Nepal where fossil fuels like diesel, petrol, coal etc. are to be imported, clean green renewable energy sources are the major sources for hybrid microgrid. In Nepal there are prospects and possibilities to interconnect these green energy sources like MHP, WT or PV systems to supply a larger electrical load demand of the rural villages[2,3,4].

There are several possibilities of forming a green and hybrid rural microgrid in Nepal. Some of the interconnection possibilities are as depicted in Fig.1, Fig.2 and Fig.3 [2]. A green hybrid microgrid in Nepal can be formed by interconnection of a PV system with a voltage source converter (VSC), a battery bank with DC to AC converter and a MHP as in Fig.1. Also as peresented in Fig.2, PV with VSC,



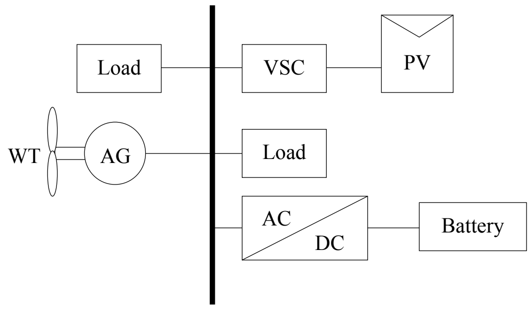
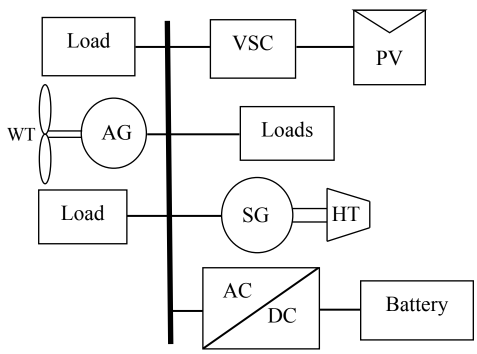


Fig. 2 A hybrid microgrid with PV, WT, battery bank and loads[2]



a battery bank with DC to AC converter and a WT can be interconnected to form a microgrid to supply the village load. A MHP, a PV system, a battery bank , WT and local loads would all be connected to form a microgrid as depicted in Fig.3 .

II. TECHNICAL ASPECTS OF GREEEN AND HYBRID MICROGRID

The major technical aspects to be considered for the formation of Green and Hybrid Microgrid are as follows:

A. Types of generation

The types of generation from the hybrid microgrid can be either ac or dc or ac-dc combined. A green and hybrid ac microgrid would be as depicted in Fig.1, Fig.2 and Fig.3, where the interconnected grid bus is ac, and the connected loads are ac [2].The distributed generations like wind turbines and micro hydro power plants produce ac and are connected directly to the grid bus. The generations from photovoltaic arrays and the storage device like battery supplies dc which in converted to ac and fed to the interconnected grid bus. Thus all the sources in the green and hybrid ac microgrid provides ac generation to the interconnected grid bus and that is futher fed to operate the ac loads connected in the system.

The green and hybrid dc microgrid is as presented in Fig. 4. In this case the interconnected grid bus is dc and all the loads connected are dc. The generations from ac sources like wind turbines and micro hydropower plants are converted to dc and fed to the interconnected grid bus. The dc generation from phtovoltaic array and dc supply from storage device like battery are directly fed to the interconnected grid bus. Thus the

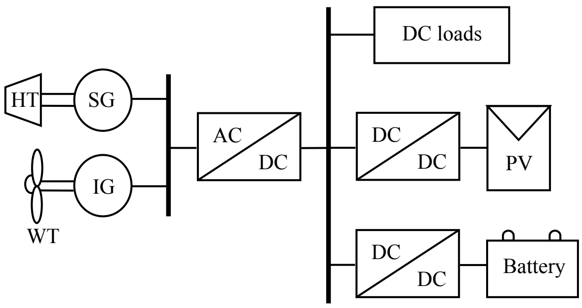


Fig. 4 A green and hybrid DC microgrid

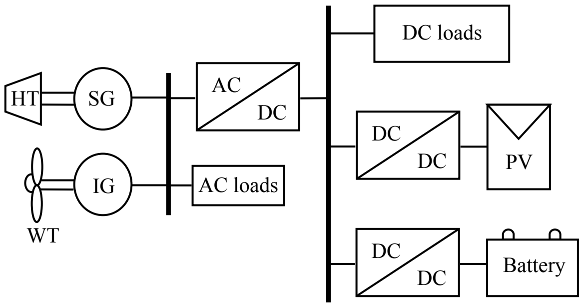


Fig. 5 A green and hybrid AC-DC microgrid

grid provides dc supply to the connected loads. A green and hybrid AC-DC microgrid provides power supply to both ac loads and dc loads as in Fig. 5.

B. Intermittent sources and prime movers

Green renewable energy sources like solar, wind and water vary with time and seasons [7,8,9]. Solar radiation varies with time during day time as depicted in Fig. 6 (for a rural site in Nepal), and is zero during the night time. Thus power generated from a photovoltaic array will vary at different time of a day. Wind speed at any site varies with time and accordingly the power generated form a wind turbine will vary. Fig. 7 presents a typical data of wind speed at a rural site in Nepal. Water in rivers varies with seasons and accordingly the power generated from a hydro turbine will vary. Fig. 8 presents the water balance of a typical river in Nepal.

Use of green and renewable sources for a hybrid microgrid thus needs proper planning. Power from wind turbine and photovoltaic arrays vary with time and can compensate each other when interconnected together at site where favorable wind speed and solar radiation has been predicted [4,9]. Micro-hydro power plant, wind turbine and or photovoltaic array can also be interconnected to form a microgrid [2,4]. Thus selection of prime movers either rotating like wind turbine or water turbine or non-rotating like solar photovoltaic systems or batteries [12] depends upon the availability of the energy source at the rural community.

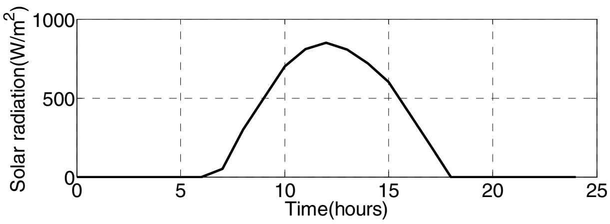


Fig. 6 Daily solar radiation at a rural site in Nepal [13]

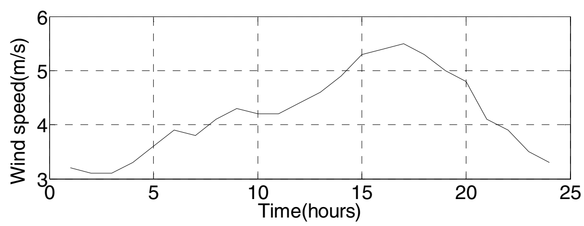


Fig. 7 Wind speed data at a rural site in Nepal [13]

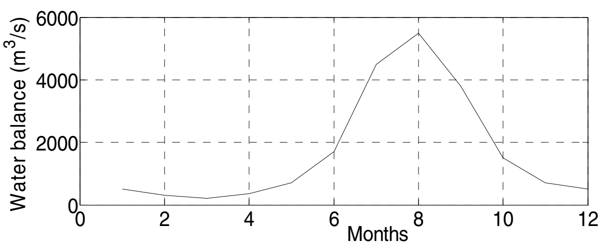


Fig. 8 Water balance (m^3/s) for a typical river in Nepal [14]

C. Power Conversion technologies

Synchronous generators or induction generators needs to be selected for rotating prime movers and inverters and static power converters for non-rotating prime movers [12]. For micro-hydro power plants in Nepal mostly synchronous generators are being used and for pico-hydropower plants induction motors as generators are being used. Wind turbines uses induction generators as power conversion device mostly. Reactive compensators are required with induction generators as they absorb reactive power [11,12]. Static power converters like dc to ac power converters are required with solar PV systems or batteries. The non-regulated dc voltage from the source is converted to a regulated ac output by a dc to ac power converter. AC to dc converters are used for dc microgrid or dc load in an ac microgrid. AC to ac or dc to dc converters is used to meet the frequency and or voltage output of the power supply [12].

D. Electrical Energy Storage

Electric energy storage devices like batteries are used to improve the reliability of a microgrid. During the off peak hours of the microgrid the batteries can be charged and during the peak hours the stored energy can be used to supply the peak demand. With intermittent energy sources like wind turbines and PV systems batteries are used as backup when the sources are not available [2,12]. In Nepal mostly lead acid batteries are for electrical energy storage for rural electrification projects. Supercapacitors are being used nowadays as electrical energy devices.

E. Technical issues

While forming a hybrid microgrid for rural electrification the following technical issues of interconnection are to be resolved:

1) Voltage and frequency control

The voltage and frequency of the microgrid is to be within the predefined limit and as per the standard within the country. The reliability of a rural microgrid depends mostly on the voltage control of the system [2,5-11]. The voltage level of the microgrid would fluctuate with the change in load as well as while switching on or off a generator in the system. The reactive power requirement of the system may change and compensating devices are to be switched on. Voltage regulator as well as voltage versus reactive power droop controller is required [2,5-11]. With the change in load the frequency of the system varies and thus active power versus frequency droop controller is to be installed [2,5-10]. Electronic load controllers or induction generator controller are used in micro hydro power systems to maintain the frequency requirement [2]. Frequency droop control are to be placed with individual generating sources as plug and play of renewable energy based generator would be common depending upon the availability of the renewable energy sources[12].

2) Protection and operation during system fault

A reliable microgrid requires an uninterrupted supply to the community load. On the occurrence of fault at any generator or a section of transmission or distribution line, the faulty section is to be disconnected from the microgrid while the other part of the system would be receiving quality power supply. Controllers are required to maintain the voltage and frequency requirement of the load even during partial system fault conditions [2,5-10,12]. Generating sources supplying local load should be able to deliver power in isolated mode during faults on the transmission lines, with the help of suitable controllers. Current limiting devices and circuit breaker are to be used with every distributed generator and at transmission and distribution lines for protection of the system. The selection of protecting devices is to be done considering both interconnected as well as isolated DGs operation [2,12].

3) Expandability of the distribution system

With the increase of community population and expansion of the village the load of the system would increase and the expansion of distribution network and or addition of generating sources may be required. The hybrid microgrid deployed for rural community and working in isolated mode most have a provision of expansion [2,5].

III. Green and Hybrid Microgrids Cases in Nepal

A. Case I – Thingan Miteri Hybrid Microgrid

The Thingan-Miteri rural microgrid was installed in 2012 in Makawanpur district of Nepal. It consists of three DGs a 20kW MHP, a 5kWp PV systems, a 3kW WT and a battery bank for storage. The PV systems, WT and battery bank are installed at Thingan village, and the MHP is installed at Kolkhop village 7km away from the PV-WT installation site. Fig.9 shows the installation site of PV and WT, and Fig.10 depicts the installed MHP system. The interconnection of the three DGs to form a microgrid and supply a larger rural load is as depicted in Fig.11. The rural microgrid supplies power to 170 houses, two poultry farm and a grinding mill of the village. Each house has been provided three LED lamps of 8W each. The tariff to be paid by each house is Nepalese rupees 150 (USD 1.4) per month for energy comsumption upto 5kWh. The energy consumed above that is to be paid with a tariff of Nepalese rupees 10 (USD 0.093) per kWh. For industrial comsumers during the day time the tariff is Nepalese rupees 10 (USD 0.093) per kWh.

B. Case II –Hybrid Microgrid at Nawalparasi

The hybrid microgrid was installed in 2011 at Dhauwadi village of Nawalparasi district of Nepal. The system consists of two wind turbines (WT) with rated capacity of 5kW each and a solar photovoltaic (PV) array of 2.16kWp. The system supplies power to 46 households with an estimated load of 33.6kWh per day. The system also has a battery bank for which can store and supply 40kWh per day. The estimated energy consumption per day is 11.1kWh for households, 4.9kWh for school, 11kWh for agro-processing mill, 4.2kWh for control purpose in the power house and 2.3 kWh for other purposes. Fig.12 shows the installation site of PV, WT and the

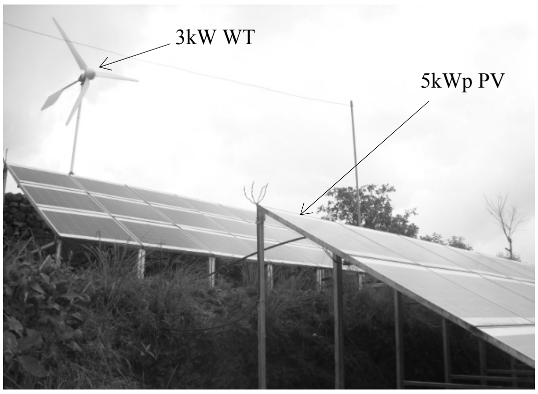


Fig. 9 Installation site of PV and WT at Thingan village [4]

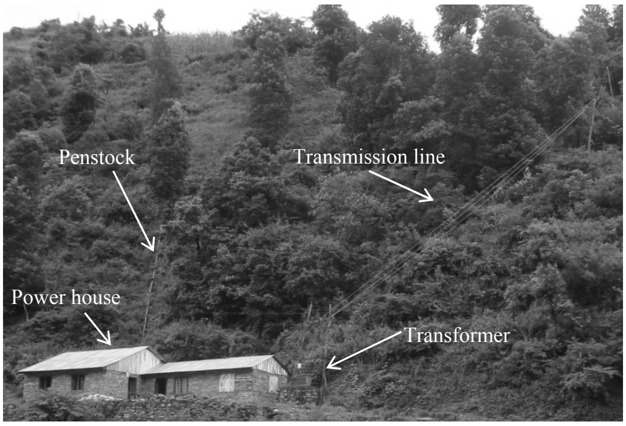


Fig. 10 Installation site of MHP at Kolkhop village [4]

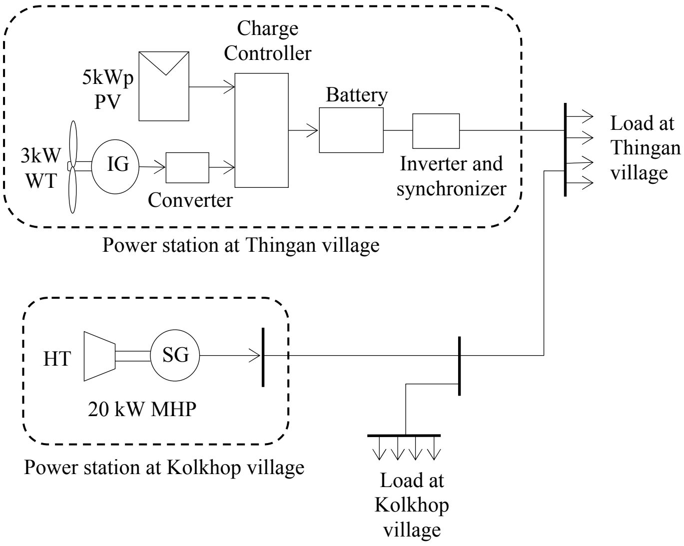


Fig. 11 Thingan-Miteri Rural Hybrid microgrid [4]

power house. The interconnection of the wind turbines, photovoltaic array, battery and load is as depicted in Fig.13.

IV. Socio-economic Benefits and Challenges

The installation of a green and hybrid rural microgrid brings social as well as economical benefits to the local commuity as well presents challenges to the commuity for the operation of the system. The user's survey conducted by the author in the rural communities of Nepal with green and hybrid microgrid shows the following benefits[4]:

- Use of modern electronic devices like TV, radio, mobile phones, laptops, sound systems and chargeable torch lights is increasing.
- Use of electrical apliances like pressing iron and refrigerators is being common.
- Use of computers at school is made possible due to sufficient power from the microgrid.
- Study during the night hours has been made possible.
- Adult education has been made possible during the evening hours with power from the microgrid
- The information access has increased due to us eof mobile phones , televisions and radios.
- Women participation in social gathering , adult education, decision in children health and education, and household savings has increased due to evening working hours
- Pumping of water and.storing for drinking as well as other household purpose has been made possible due to surplus electricty from the microgrid during the day time.

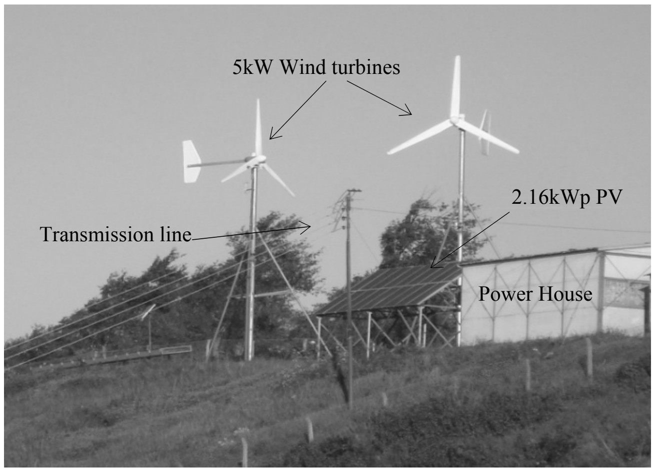


Fig. 12 Installation site of Hybrid microgrid at Nawalparasi

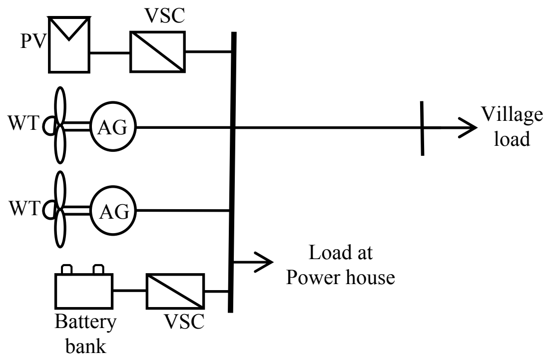


Fig. 13 Hybrid Microgrid at Nawalparasi

- Smoke less clean lighting has decreased the respiratory dieaseses and eye problems.
- Use of renewable energy sources for power production has decreased the CO_2 emissions.
- Income generating activities like operation of grinding mill, poultry farms, and growing of cash crops has increased.
- Self employement works like basket and chair weaving, tailoring and stitching during night hours has increased.
- Savings from not purchasing of kerosene, batteries and small solar photovoltaic systems for lighting purpose has been possible.

These socio-economic benefits have promoted the installation of green and hybrid microgrids in rural communities of Nepal, despites of the following operational challenges [4]:

- Regular collection and update of tariff in rural community is being difficult.
- The plant factor of the system is very less due to insufficient end uses.
- The use of electrical appliances like refrigerators and pressing iron has not been possible during the evening hours due limited power production.
- Cost for major repairs cannot be afforded by the community and needs financial support.

The challenges of rural microgrid operation are to be resolved by formulating proper regulatory policies and establishing proper revenue generation schemes.

V. Conclusions

A green and hybrid microgrid for rural electrification is established depending upon the availability of local resources and local demand. For developing countries like Nepal which has enough water sources, solar radiation and or wind throughout the year, Green and Hybrid Microgrid is a proper solution for the power demand of the rural community. The type of generation, prime mover to be used, conversion technologies and the interconnection issues are to be resolved depending upon the availability of green renewable energy sources and the local technology for installation of microgrid. The two green and hybrid microgrid installed in Nepal has helped to increase the living standard of the rural community. The communities' health, education, information exchange, income generation and women empowerment are the major benefits of the green hybrid electrification projects. Despites of some operational challenges the Green and Hybrid Microgrid has been electrifying the rural communities and serving for its all round growth. Proper regulatory policies and guidelines once formulated will help the microgrid for longer years of operation.

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