Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Electric Power Engineering

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Model Development for DSO-TSO Coordination in a Local Flexibility Market

Master's thesis in Electric Power Engineering
Supervisor: Irina Oleinikova
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Abstract

The main objective of this master thesis was to develop a multi-period hybrid AC/DC-OPF model as a planning tool. This planning tool can be used in the local flexibility market, which serves as a platform for the transmission and distribution system operator's information exchange and flexibility activation from the distribution grid. To prove the multi-period hybrid AC/DC-OPF model concept, several test cases have been developed with different grid problems in the distribution and transmission grid. The model was so employed to solve these grid problems with available flexibility in the distribution grid.

To better understand why the local flexibility market and optimal power flow tool are needed, different grid problems that can occur in the distribution and transmission grid are introduced. Different distributed energy resources are also presented that can be used in order to solve these problems. The grid problems revolve around congestion for both the transmission and distribution grid, voltage problems in the distribution grid, and overall optimization of the distribution grid's operation. There exist several different distributed flexibility resources that can be used. This thesis focuses on batteries, distributed generation, load shifting, and load shedding.

The multi-period hybrid AC/DC-OPF model can used as a planning tool for the local flexibility market's operation and its coordination. Different roles and responsibilities occurring in this coordination are also presented. The strategy is based on the concept of rolling-horizon, where the planning of operation with a given uncertainty is performed the day before operation based on two-stage stochastic optimization. During the actual operation, the rolling-horizon technique will be used to re-schedule the operation based on new and more accurate data. To better showcase this, flowcharts are developed to show the market's planning and operation process and coordination between all participants.

The multi-period hybrid AC/DC-OPF model combines two optimal power flow methods in the same optimization program, where a SOC-ACOPF is mathematically formulated and applied for the distribution and DC-OPF for the transmission grid. To combine these two optimal power flow methods, a connection constraint is formulated, which defines the distribution grid as a load for the transmission grid. Thus any changes occurring in one grid will affect the other. The model was then further extended by formulating the power balance equation to include flexibility assets in the distribution grid and criteria for how the flexibility should be activated. Moreover, to perform multi-period simulations, the model was modified to perform optimization for extended periods in a single simulation.

A test grid consisting of a distribution and transmission grid was developed to showcase the model's capabilities. Based on this test grid, different test cases with grid situations like congestion or voltage problems were produced. The test was carried out by letting the model solve these grid problems with and without flexibility and voltage regulation. When comparing results, the model was able to solve these grid situations with and without flexibility. With flexibility, load shedding was kept to a minimum or not used at all, which is a more desirable outcome.

Sammendrag

Denne masteroppgaven har som hovedmål å utvikle en flerperiodisk hybrid AC/DC-OPF modell som et planleggingsverktøy i et lokalt fleksibilitetsmarked. Intensjonen med markedet er å opprette en plattform for transmisjons og distribusjons operatørs informasjonsutveksling og aktivering av fleksibilitet fra distribusjonsnettet som igjen vil gi bedre utnytelses og reguleringsevne i kraftsystemet. Flere test caser med forskjellige nettproblemer i distribusjons- og overføringsnettet ble så utviklet. Ved bruk av fleksibiliteten i distribusjonsnettet har modellen løst disse nettproblemene på best mulig økonomisk måte.

For å bedre forstå hvorfor et lokalt fleksibilitetsmarked og optimal kraft flyt verktøy er nødvending vil det gis en introduksjon til forskjellige nettproblemer som kan oppstå i distribusjons- og overføringsnettet, samt forskjellige distribuerte fleksibilitetsressurser som kan brukes til å løse disse problemene. Nettproblemene vil være overbelastning for både overførings- og distribusjonsnettet, spenningsproblemer i distribusjonsnettet og generell optimalisering av distribusjonsnettet. I denne oppgaven vil fokus være å bruke distribuerte fleksibilitetsressurser som batterier, distribuert generering, lastforskyvning og lastkutting for å løse nettproblemer.

For å få en bedre forståelse for hvordan den flerperiodiske hybride AC/DC-OPF-modellen brukes som et planleggingsverktøy vil det gis en omfattende forklaring for hvordan strategien for drift av lokalt fleksibilitetsmarked vil foregå, samt hvordan de lokale fleksibilitetsdeltakerne vil utføre deres roller og ansvaret i markedet. Strategien er basert på konseptet ”rullende horisont”, der planleggingen av operasjonen med en gitt usikkerhet utføres dagen før operasjonen basert på totrinns stokastisk optimalisering. Under selve operasjonen vil rullende horisontsteknikken brukes til å oppdatere den allerede planlagte operasjonen basert på ny og mer nøyaktige data. For å gjøre disse prosessen mer forståelig har flytskjemaer blitt laget for å vise hvordan LFM planleggingsprosessen og koordinering mellom lokale fleksibilitetsdeltakerne skal utføres.

Den flerperiodiske hybride AC/DC-OPF-modellen er basert på å kombinere to optimal kraft flyt metoder i ett og samme optimaliseringsprogram, der en SOC-ACOPF metode er matematisk formulert og brukt for distribusjonsnettet og DC-OPF metode for overføringsnett. Ett matematisk tilknytningsvilkår hvor distribusjonsnettet defineres som en last for overføringsnettet ble definert. Så når en endringer skjer i distribusjonsnettet, vil overføringsnettet bli påvirket, og omvendt ved forandring i overføringsnettet. Modellen ble utvidet ytterligere ved å formulere kraftbalanseligningen som inkludere fleksibilitet i distribusjonsnettet, samt kriterier for hvordan fleksibiliteten skal aktiveres. Videre, for å kunne utføre flerperiodesimuleringer, ble modellen modifisert for å kjøre flere optimal kraft flyt simuleringer.

For å vise modellens bruksområder ble det utviklet et testnett som består av et distribusjons- og overføringsnett. Basert på dette testnettet ble forskjellige testtilfeller med nettproblemer som overbelastning og spenningsproblemer konstruert. Testene ble utført ved å la modellen prøve å løse disse nettproblemene med og uten bruk av fleksibilitet. Ved sammenligning av resultatet viste det seg at modellen var i stand til å løse disse nettproblemene med og uten fleksibilitet. Med fleksibilitet derimot, ble lastkutt redusert til et minimum eller ikke brukt i det hele tatt, noe som er et mer ønskelig resultat.

Preface

The master thesis is a work carried out at the Department of Electric Power Engineering at the Norwegian University of Science and Technology. The master thesis attains as a final work that completes this two-year master's study, which has given the authors a whole new perspective and knowledge of the power industry and the problems it faces.

To start, we would like to thank our supervisor Irina Oleinikova for the guidance regarding the thesis layout and recommendation for the content material. we would also like to thank our co-supervisor, Hossein Farahmand, who has not only provided guidance but given us the privilege to take part in the NTNU-HONOR R&D project. This privilege has allowed us to research a highly relevant and fascinating power system problem.

Moreover, we would like to thank Dymtro Ivanko for providing valuable feedback and support when writing the SEST21 paper and master thesis. A thanks also have to go out to Kasper Emil Thorvaldsen for helping the us the time of need when programming difficulties have occurred.

Last but not least, we would like to thank our friends and families for the support in finalizing this thesis. Your continuous encouragement have helped us tremendously throughout this last semester of our master studies.

Trondheim, June 2021.
Damian Sieraszewski
and
Ole Kjærland Olsen

Content

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Abbreviations

$ACOPF$	AC Optimal Power Flow
$ACPF$	AC Power Flow
BRP	Balancing Responsible Parties
$DC-OPF$	DC Optimal Power Flow
$DCOPF$	DC Optimal Power Flow
$DCPF$	DC Power Flow
$DEMRS$	Distributed Energy Resource Management System
DER	Distributed Energy Resource
$DESS$	Distributed Energy Storage System
DFR	Distributed Flexibility Resource
DG	Distributed Generation
DR	Demand Response
DSO	Distribution System Operator
ESS	Energy Storage System
EV	Electric Vehicle
LFM	Local Flexibility Market
$LFMO$	Local Flexibility Market Operator
$LFMP$	Local Flexibility Market Participants
OPF	Optimal Power Flow
QC	Quadratic Convex
SDP	Semi-Definite Programming
$SOC-ACOPF$	Second-Order Cone AC Optimal Power Flow
SOS	Sum-of-Square
TSO	Transmission System Operator
VPP	Virtual Power Plant

1 Introduction

1.1 Motivation

This master thesis builds on the idea and concept from several previous works, one being the research paper [1] published for the conference on smart energy systems and technologies, whose part of the introduction has been reused here. The electricity landscape in Europe is undergoing profound changes. Renewable and Distributed Energy Resources (DER) penetration, located closer to electricity consumption, e.g., households or commercial buildings, has increased considerably in the last years. In addition, the electrification of heating systems and the transport sector is becoming more widespread in many countries. Combining these effects poses significant challenges to the Distribution System Operators (DSOs) and Transmission System Operators (TSOs) in this ecosystem. To deal with these challenges, solutions related to the grid upgrades or operating increasingly constrained grids, with a reliance on utilizing DER, are required. Among the possible solutions, using DER as a form of flexibility or Distributed Flexibility Resource (DFR) from the consumer side is a powerful and efficient resource for solving transmission and distribution grid problems.

In order to unlock flexibility from the consumer side, millions of small-scale and large-scale energy consumers and prosumers must be further incentivized to activate the potential of flexibility assets. These flexibility assets can then be offered on a new market platform, where TSOs and DSOs will be the most critical buyers. A new role that emerges with implementing this Local Flexibility Market (LFM) is the Aggregator. Their role is to combine and coordinate the flexibility provided by consumers. Ensuring that all participants play their respective roles will depend on a practical TSO-DSO-Aggregator cooperation. Ensuring this will significantly benefit the system's operation and all parties involved in this new LFM.

The success of tomorrow's electricity grid is desperately dependent on establishing a marketplace for flexibility. The establishment will define roles and responsibilities for each Local Flexibility Market Participant (LFMP) and develop a market strategy for planning DFR usage and LFMP coordination. In this market, load forecasting and scenario generation will play a crucial role.

An essential tool in simulating these scenarios is an optimization model, which can simultaneously run Optimal Power Flow (OPF) calculations for both the transmission and distribution grid. At the same time, this approach brings complications which the model needs to resolve. These complications arise from the different physical attributes of the two grids, which result in a need to establish different OPF formulations and the connection between them. This specific requirement led to the need to create an own model which can yield the necessary results. When used in an LFM environment, this model can effectively showcase how flexibility may benefit the transmission and distribution system's operation. Combining this tool with a proper marked strategy will better prepare the power system for future needs and obstacles that may arise.

NTNU is taking part in a larger project called HONOR. This project collaborates with several institutions researching the holistic integration of cross-sectoral energy sources in a flexibility market. It is an ERA-Net funded research project aimed at the development and evaluation of a trans-regional flexibility market mechanism, integrating cross-sectoral energy flexibility at a community-wide level [2]. This thesis is a part of this project and will use some of the concepts and ideas present in other projects published by NTNU HONOR. Some of these concepts are two-stages stochastic optimization and strategies for LFM operation, which this thesis will expand on.

1.2 Preliminary work with Specialization Projects

Each author of this thesis has written their specialization project with a different focus on the same issue. These projects revolve around how grid balancing can be improved with better coordination between DSO and TSO and the flexibility provided through an LFM. Both project's focus lies on the LFM coordination, but with two different perspectives, as explained below:

- **Interoperability Concept for Demand and Distributed Generation Flexibility:** In this specialization project, the interaction between consumers and aggregators has been researched by studying the smart grid architecture model and several European projects based on this concept. These projects include InteGrid, MIGRATE, SmartNet, CoordiNet, and INTERRFACE. This study made it possible to draw correlations and similarities between these projects, further enhancing the understanding of the consumer's possibilities in providing ancillary services.

- **Coordination Scheme for Market Participant Collaboration in a Distribution Grid:** The goal of the specialization project [3] was to conduct a literature research study to obtain an in-depth understanding of the needed processes, operations, and coordination to establish an LFM. Using the gathered knowledge from the conducted research has been used to develop a coordination scheme that showcases LFM operation.

What differs between these two projects is the approach to the problem. The first project has a bottom-up approach, focusing more on DFRs coordination from the consumer side. The second project has a top-down approach, where coordination between DSO, TSO, and consumers is in focus. Combining these two approaches has led to a joint effort to write this master thesis, which ensured more thorough research on a specified LFM problem regarding the planning of the operation.

1.3 Aims and Objectives

Developing the concept of an LFM is a broad task, which includes several important objectives. In this thesis, the part which corresponds to the planning phase in the LFM and TSO-DSO model development will be the topic of interest. This thesis will give insight into the execution of operation planning in an LFM, with both market strategy description and procurement of flexibility. This aim will explore two objectives within the planning phase, which are:

- Propose a market strategy for planning DFR usage to solve grid problems through DSO-TSO coordination in an LFM platform. The proposed market strategy will include a short explanation of roles and responsibilities for each LFMP and a potential coordination scheme between them. It will also look into a planning strategy for finding and deciding optimal DFR dispatch in a distribution grid based on the rolling-horizon technique and the two-stage stochastic optimization approach.

- Develop an OPF analysis tool in the form of a multi-period hybrid AC/DC-OPF model. This model will generate grid scenarios that obtain optimal DFR dispatch for the LFM to solve potential grid problems. After developing the model, verification of the model's applicability will be achieved through different test cases designed as proof of concept.

The described objectives are closely correlated with each other. This is because the chosen LFM strategy will determine functionality criteria for the developed multi-period hybrid AC/DC-OPF model. The OPF model is not the only tool needed for operation planning in the LFM. Load forecasting for predicting consumption in the distribution grid and efficient market clearing algorithms for handling bids and offers from BRPs and aggregators will also be crucial. Due to the comprehensiveness of the LFM topics, the thesis's scope had to be limited to these two described objectives.

1.4 Structure of the Thesis

The thesis's structure is organized in the manner of 6 chapters that comprise the following categories: introduction, theory, approach and method, results and discussion, and conclusion.

Chapter 2 describes the theoretical framework of the thesis, which includes an overview of common grid problems that can occur in both the distribution and transmission grid and the reason for their occurrence. This also includes the benefits and operation approaches for different types of DFRs.

Chapter 3 continues with the theory of LFM strategy and the explanation of the different LFMP and their roles and responsibilities in the flexibility market. This explanation will lead to a better understanding of the market strategy and coordination and the two-stage stochastic optimization, which is the main focus of the following parts. In addition, this will also lead to a better understanding of the choices made behind the implementation of the multi-period hybrid AC/DC-OPF.

Chapter 4 describes the approach and method, which encompasses the analysis and explanation for choosing the given power flow models in the distribution and transmission grid. These models are then combined to make a single hybrid AC/DC-OPF model. The last extension of the model is to implement the multi-period approach, which results in a single multi-period hybrid AC/DC-OPF model. This model allowed the implementation of DFR with their respective operational possibilities and limitations.

Chapter 5 demonstrates the capabilities of the developed multi-period hybrid AC/DC-OPF model through different test cases, which involve solving different grid problems, as discussed in Chapter 2.

Lastly, Chapter 6, will conclude the LFM strategy and performance of the multi-period hybrid AC/DC-OPF model and what this thesis has achieved using this model. The combined results will also provide recommendations for further expansion of the model and better test cases.

2 Flexibility Analysis for Improving Grid Operation

With the increasing electrification of society and integration of DERs, the distribution grid is undergoing profound changes. On the positive side, electrification and DERs can lead to a more efficient, sustainable, and low-carbon society. Unfortunately, this sudden evolution also introduces particular challenges for the distribution grid's operation. Analysis from Navigant report [4] predicts that the amount of installed DER will increase in the coming years as shown in figure 1. The main DERs predicted by the report to be increase are distributed generation, Distributed Energy Storage System (DESS), Electric Vehicle (EV) charging load, Demand Response (DR), energy efficiency, and Distributed Energy Resource Management System (DEMRS). So, preparing the distribution grid for the implementation of DERs will allow for a smooth transition to a more complicated but efficient distribution grid. This chapter will discuss how the distribution grid can benefit from DER usage in solving impending grid problems and challenges.

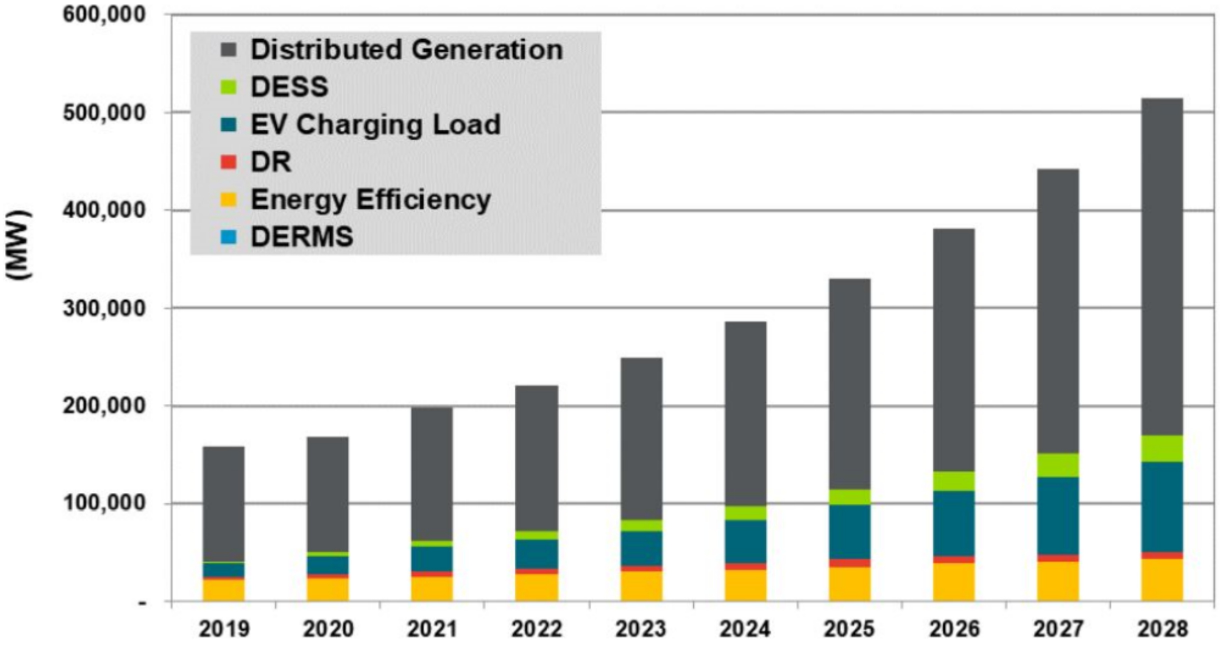

Figure 1: Predicted increase of installed power from different DER in the coming years, as analysed by Navigant report [5].

2.1 Flexibility Resources in Distribution Grid

When talking about flexible resources in the distribution grid, we refer to the usage of DERs. These can be defined as production and supply resources connected directly to the distribution grid for energy management [6]. Since these DERs are being used as flexibility, they will be referred to as distributed flexibility resources (DFR) from here on in this thesis. These assets include Energy Storage System (ESS), DGs, load shifting, and load shedding, which will provide flexibility for the own developed multi-period hybrid AC/DC-OPF model. This chapter will also include a theoretical introduction to these flexibility assets and explain their activation and form of operation. In addition to several other papers studied during this thesis, this explanation will mainly encompass the proceeding work conducted in [3].

2.1.1 Energy Storage System

ESS are defined as equipment that can store electric energy over time in a given state until converted back to electric energy [7]. Adapting this type of DFR can benefit the power system in several ways. The specialization project [3] describes the operation and activation of ESS, with five categories as potential ways to improve the grid efficiency. This thesis will focus on three of these categories:

- **Ancillary services:** Using ESS for purposes like voltage control, load following, and supply reserve.
- **Grid system:** Using ESS to solve disturbances in the power grid and congestion management.
- **End-user/Utility customer:** Using ESS to reduce overloading of the grid by utilizing load shifting.

ESS can have different attributes depending on their location in the grid, how much energy they can store, and other properties related to the operation. Based on these attributes, ESS can suit different roles. The capacity of the ESS utilized in this thesis will be in the range of medium capacity and will therefore suit the roles of:

- Medium-power applications in isolated areas, such as individual electric systems and towns that utilize ESS for electric supply and end-user/utility customers.
- Network connection application with peak leveling, which suits the role of grid system management and renewable integration.
- Power-quality control applications so solve grid system disturbances.

ESS can be viewed as a consumption or production unit from the grid's perspective, depending on its situation. In simple terms, when the prices are high, ESS should try to sell its power, and when prices are low, it should try to purchase power. The balance between the demand and supply will also influence the operation of ESS. In order to avoid load shedding, storing and discharging of ESS can occur despite the prices not being optimal for its operation to achieve cost minimization. Based on these premises, the use of ESS as load leveling assets [8] can solve both congestion and voltage problems by discharging itself according to the grid situation. Figure 2 presents a concept of load-leveling, where power is stored during low demand and released during high demand.

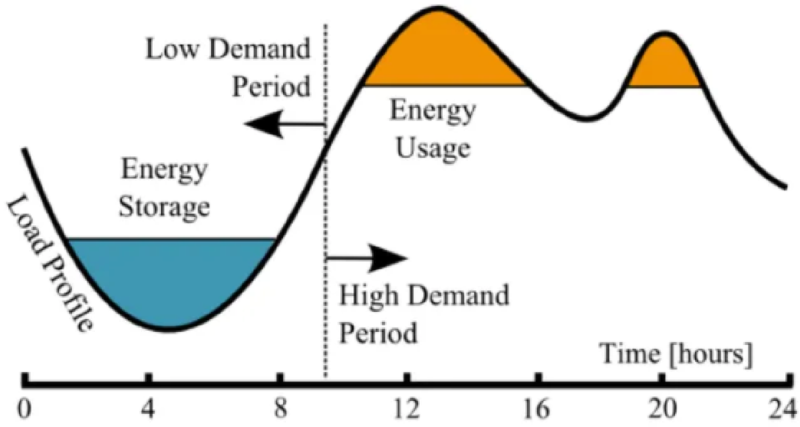

Figure 2: The concept of load leveling during peak hour consumption [9].

2.1.2 Distributed Generation

There can be a wide range of DG's with different criteria and operational conditions in a distribution grid. A common definition for a DG is an electric power source connected directly to the distribution network or on the customer side of the meter [6]. Instead of listing the numerous DG types, they are sorted based on one of two categories: intermittent and non-intermittent DG. Intermittent DG means that a DFR is not available on-demand; there are external factors that decide production. DFR can then be anything from a small, intermittent, and renewable photovoltaic array used by end-users to large combustion turbines that are non-intermittent and non-renewable operated by a commercial producer [10].

The use of intermittent production from solar and wind will allow for an entirely new complexity level for operation planning. Therefore, only non-intermittent DGs are considered in test cases performed later in the thesis. In regards to capacity, if using [6] as a standard for DG's rating, their capacity in this thesis will be of medium and large magnitude. DGs have many of the same properties as ESS when solving grid problems such as congestion and low voltage magnitudes. Their advantages come from the higher capacity and the ability of on-demand production without the need to store energy in advance. This advantage enables a more selective operation relative to prices. Based on this, DG's activation has been deemed more expensive than ESS for the performed test cases.

2.1.3 Load-Shifting

Instead of regulating the production to match the consumption, load shifting tries to regulate the consumption to even the system's capacity. This technique shifts a part of the consumption during load peak hours to off-peak hours, preventing the occurrence of grid problems in the first place [11]. This way, power-intensive tasks which are flexible with their time of use can shift their operation to off-peak hours. The result of this action is that consumption is more evenly distributed throughout the day, while the total energy consumption remains unchanged. In regards to solving grid problems, load shifting can significantly reduce congestion in both the distribution and transmission grid due to the reduced consumption during peak hours. Voltage problems in the distribution grid can also be solved with load shifting if the active power is the dominant factor for voltage regulation. Figure 3 illustrates the concept behind load shifting, where the solid line indicates the original load profile while the dashed line illustrates the load profile after load shifting.

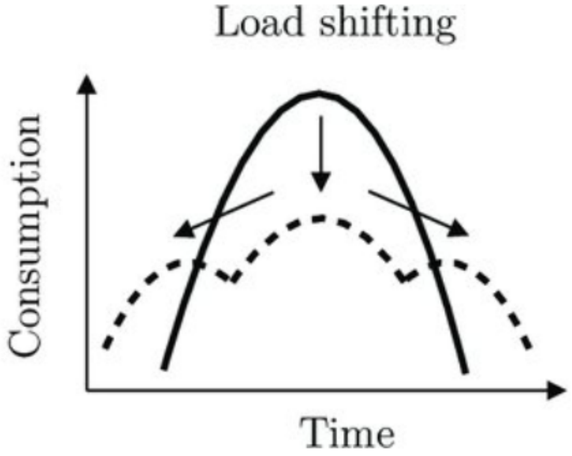

Figure 3: Visualisation of how load shifting reduces the load during peak hour consumption [12].

2.1.4 Load Shedding

Load shedding is not a novel concept in the power industry. Considering load shedding as a DFR might not be entirely correct, as the action is not entirely ”flexible”. The action of load shedding is the deliberate shutdown of electric power in part, or parts of a power distribution system [13]. This shutdown is the last resort action the system operator can do in extreme grid situations, which, if not treated, could potentially lead to severe grid damage and cascading outages. Unlike ESS, DG, and load shifting in the LFM, load shedding is not supposed to be a planned action, and thus all use of this measure should be avoided. Therefore, in the LFM, load shedding should only be utilized in handling extreme grid situations where no other measures are available.

2.2 Challenges Regarding the Use of DFRs in Distribution Grid

So far, DFR can seemingly bring numerous benefits for grid operation. As explained in the specialization project [3] and now recited in the list here, there are various technical and regulatory challenges regarding the operation of DFR in a distribution grid that requires further research. The list below addresses some of these challenges:

- Many DFRs are intermittent, which reduces the possibility for on-demand production.
- DFRs can be located all over the grid, complicating the flow of power in a radial grid. Today’s distribution grid may not being suited to handle bidirectional power flow.
- Small DGs might be located at low load areas or far away from high load areas.
- The scarcity of DFRs in the distribution grid might lead to a shortage of energy to cover the demand.

- As of today, DSO has limited technology for the operation of DFR in a distribution grid.

- Lack of coordination scheme and regulation complicates the execution of operational planning.

Many of these problems correlate to the technical challenges of DFRs within a distribution grid. Since this thesis employs a customized test system to showcase the OPF model's basic solving capabilities, many of the technical challenges related to DFRs have deliberately been avoided. Two critical choices in that matter are the use of only non-intermittent DFRs and the assumption that the distribution grid can handle bidirectional power flows.

2.3 Solving Voltage Problems in the Distribution Grid

In today's distribution grid, there are mainly two reasons for the increasing occurrence of voltage problems. One is the number of intermittent energy resources, leading to voltage variations in the grid. The other one is the problem of over-voltage and under-voltage during off-peak-hours and peak-hours, respectively. Voltage drop (ΔU) can be calculated based on equation 1, which is affected by load voltage (U_L), active power (P), reactive power (Q), short circuit resistance (R_k), and short circuit reactance (X_k). Due to the high resistance in the low voltage distribution grid, active power will be the dominant factor regarding voltage regulation. Reactive power management will thus have little to no effect on the resulting voltage magnitudes. This changes when voltage levels exceed 66kV, leading to increased line reactance and decreased R/X ratio. From this point on, reactive power management for voltage control becomes a more viable option [14]. Here, DSOs with DGs connected to a medium voltage distribution grid (between 66kV and 132kV) can perform voltage regulation by increasing reactive power production. At the low voltage distribution grid (below 66kV), where reactive power has a limited effect, active power injection from DFRs will control the voltage magnitudes. So depending on the R/X ratio of the grid, either active or reactive power can be utilized for voltage control. The DFRs used in this thesis will be typically small capacity batteries, synchronous generators, and load shifting located at the end-users where the R/X ratio is high. Due to the location and production capability, voltage regulation through active power will be the preferred choice. These voltage problems have been explored in the specialization project [3], which is the basis for the explanation provided in this chapter.

$$\Delta U = \frac{1}{U_L} \cdot (P \cdot R_k + Q \cdot X_k) \tag{1}$$

2.4 Solving Congestion Problems in the Transmission Grid

The distribution grid is not the only infrastructure that is affected by the overall increase in power consumption. The deregulation of the power market has paved the way for new power market participants who provide or purchase energy. A significant result of this development is the possible congestions and overloads of lines in the transmission grid [15]. A common solution in solving these issues is to reinforce the grid [16], which is an expensive measure for both consumers and the grid company. With the rise of DFR and more active grid management, new economically efficient alternatives have emerged to solve potential grid congestions. Solving this problem will be of interest to TSO, whose duty is to maintain a proper operation of the transmission grid. For these issues, the distribution grid can potentially act as additional support for the transmission system. For the TSO, the combined flexibility present in the distribution grid would appear as a single asset, which often is defined in literature as a Virtual Power Plant (VPP) [17]. This VPP could then increase or decrease the power flow between these two grids, such that the congestion would be diminished or alleviated. Any congestions occurring in the interconnection point between the transmission and distribution grid could also be alleviated.

This solution is not only limited to a single TSO to DSO cooperation. Since the transmission grid connects several distribution grids, more advanced cooperation could be established, including several DSOs competing to provide services to the transmission grid. For this purpose, a need arise for a detailed cooperation framework that can facilitate the interaction properly. In addition, each participating DSO needs to ensure a sufficient flexible capacity which will be made available to the TSO. Establishing these notions will result in a secure and effective TSO-DSO cooperation, bringing value to both parties and the power system in general.

2.5 Increasing System's Efficiency with the Use of DFR

The DFR's benefits are not limited to solely providing ancillary services for solving grid challenges. The flexible capacity offered to the LFM can also be a more efficient and sustainable alternative to cover the changing demand than today's balancing market. For this purpose, OPF modeling can be used with the objective function to optimize production based on DFRs and regular commercial production units. Such a strategy would find an optimal generation dispatch, covering the demand to a much higher degree due to its closer to the real-time operation than day-ahead market. A significant drawback of this approach is that it reduces the available flexible capacity to solve potential grid situations like voltage and congestion problems. This concern creates the need to obtain a proper balance between the amount of capacity used for different purposes.

3 Flexibility Market Operation and Coordination

DFR as an energy resource commodity differs from more common energy resources like large hydropower plants, wind farms, gas-fired power plants in the power system. This difference stems from location, capacity, and regulation. Due to these properties and how power markets operate today, DFR services are not well adjusted for such markets. Thus, a need for a new market arises that can satisfy these properties and facilitate DFR's procurement and efficient utilization. Establishing this market will also lead to new roles and responsibilities coming into place, which will reinforce its proper operation.

The complete market strategy will determine the procedure for flexibility planning and procurement, as discussed later in this chapter. The division of roles and responsibilities between market participants and overall coordination will depend on the chosen market model. SmartNet [18] has suggested five market models which can bolster the market's operation and coordination. Out of these models, the local market design has appeared to be the most fitting choice for this thesis. This design will thus be adopted and further customized to suit the purpose of the LFM strategy. With this market model, TSO and DSO will have access to a new market platform with a localized aggregation of flexible resources. In this market, DSO will have priority when it comes to the reservation of flexible capacity. The remaining resources will be made available to a centralized market platform, where TSO may procure them for their use. For this market to operate securely, it is essential to confirm that flexibility activation will not harm the operation of either transmission or distribution grid.

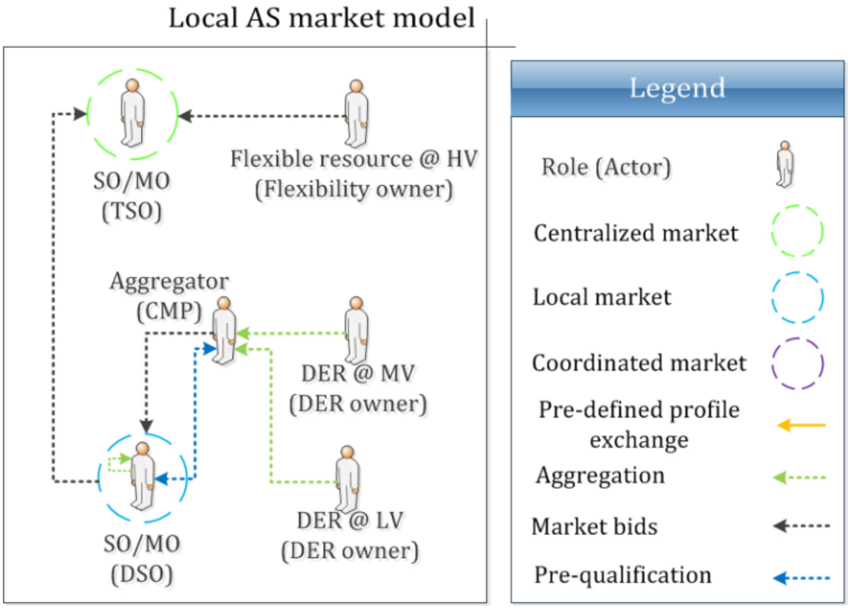

Figure 4: Visualisation of coordination between different market participants in a local ancillary service market model [18].

3.1 Roles and Responsibilities for Flexibility Market Participants

Both a distribution grid and a market platform require dedicated roles and responsibilities for different market participants. The definition of a LFMP is an operator in a given distribution system who serves a specific role in performing services or tasks regarding the power system's operation [3]. Figure 5 presents an illustration of the different LFMP and their basic responsibilities in an LFM.

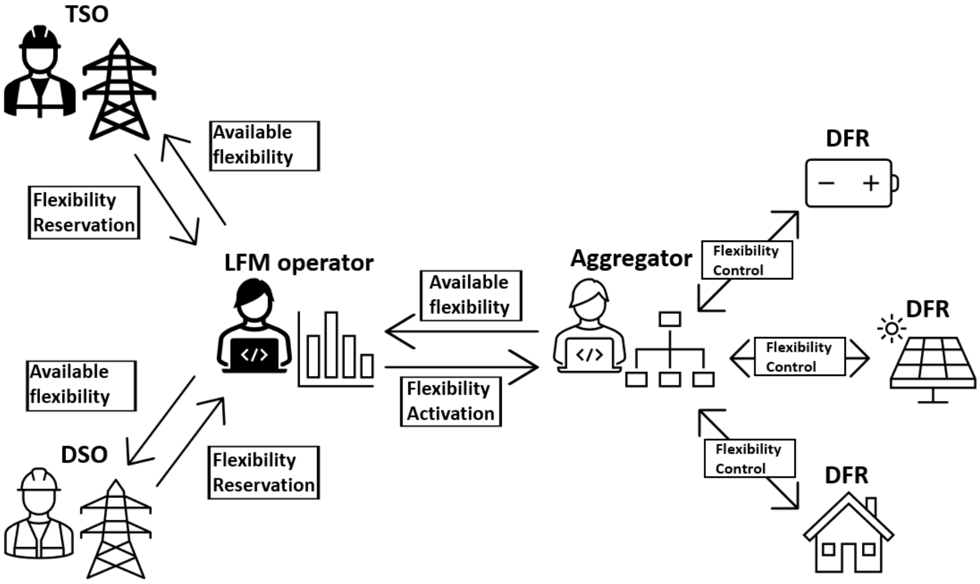

Figure 5: Coordination between different LFMP in a LFM.

3.1.1 Balance Responsible Parties

The two primary purchasers in this market will be the DSO and TSO, who aim to balance their system, hence giving them the role of Balancing Responsible Parties (BRP). BRP defines an entity that strives to balance or help the power system to be balanced [19]. The identification and exploration of background material for TSO and DSO are founded on the preliminary work in [3]. Thus, to some extent, that material will be directly used in this chapter.

Distribution System Operator (DSO)

European Distribution System Operators [20], define DSO as the operating manager of an energy distribution grid, which normally ranges from low to medium voltage levels. As of today, DSO deals with responsibilities that are necessary for distribution grid operation [21], which includes:

- Connection and disconnection of DERs.
- Planning, maintenance, and management of networks.
- Management of supply outage.
- Sorting out energy billings.

Further proliferation of DERs, presents the DSO with new grid challenges which require novel solutions. Emerging roles will lead to more active distribution grid management, requiring better communication with TSO and the Local Flexibility Market Operator (LFMO). Active management means that DSO will be more responsible for balancing their distribution grid. This balancing, according to [21], will consist of solving different grid situations like:

- Peak load management through DERs.
- Network congestion management.
- Provide reactive and active power support to TSO.
- Procure voltage support.
- Technical validation for power market.
- Perform forecasting of load scenarios.
- Conduct OPF simulation for scenario generation.

This active management of the distribution grid brings both advantages and challenges. The main benefit is the possibility of solving distribution grid problems more independently and efficiently. A challenge accompanied by this benefit is how to perform this management. Valuable tools for DSO in solving this issue will be load scenario forecasting and OPF simulations, which will help determine potential grid problems. This will involve DSO integrating more advanced control systems for monitoring the grid and performing the necessary measures. In addition to controlling the system, communication technologies for information exchange between all market participants will secure their proper cooperation [22].

Transmission System Operator (TSO)

The transmission system operator's (TSO) main task in the power system is to ensure the security of supply. Tasks that correspond with the security of supply include system balancing, solving congestion in the transmission grid, and ensuring that all grid regions have sufficient power. TSO can do so by having the tools and authority to perform frequency regulation and voltage control in their respective grid structures [23], [24].

The introduction of LFM allows for increased possibilities and enables DSO to control their grid and the available energy resources to a higher degree. For the proposed LFM in this master thesis, the balancing of the distribution grid is delegated to the DSO. Consequently, TSO will have to let go of some balancing authority while maintaining their duties regarding the transmission grid and the system as a whole. For the transmission system's balancing, the present flexibility in the new LFM may be acquired by the TSO. This will require them to compete in this market in order to procure the needed capacity. The advantage of a new LFM is that it brings more possibilities for TSO to solve balancing problems in the transmission grid, such as:

- Reduced interconnection power flow between distribution grid and transmission grid (congestion management).

- DFR use as an alternative for solving power shortage or power excess (frequency balancing).
- TSO usage of DFRs from distribution grid to reduce the power injection to certain distribution grid to configure power flow and solve line congestion, instead of only utilizing generation rescheduling from larger power plants [25].

Coordination between TSO and DSO
With more duties falling on the DSO, communication and standardized operation scheme between DSO and TSO will be essential to facilitate the success of this transition. The LFM is the attempt to solve these two challenges. These measures can be realized with the development of a platform with standard rules for interaction and communication. The details of how this market platform works will be further explained later in chapter 3.2.1.

3.1.2 Aggregator's Role in the Power Market

An aggregator is a relatively new entity in the power market, and therefore no single definition has yet been established. For this thesis, an aggregator is a market participant in the power system that operates as an intermediary between end-users, small DER owners, and power system participants [26]. With this definition, the aggregator links the DFR's capacity provided by prosumers and consumers to the power market. As explored in the projects [3], and [27], aggregator's main responsibilities will correspond to:

- Establishing contracts with prosumer and consumers regarding usage and mapping of DFRs.
- Forecasting production and capacity each DFR will have for a given day.
- Sending in bids and offers based on the use and available capacity for each DFR.
- Ensure proper activation of DFRs according to the operation plan acquired from the LFM.
- Collaborate with DSO and LFM to acquire proper activation signal and to facilitate settlement process.
- Perform settlement process with prosumers and consumers for utilization of their DFRs.

The identity of an aggregator is still up for discussion. Their role may be covered by an already existing actor or a whole new entity in the power market. The determining factor in this issue will be their ability to cover all responsibilities mentioned in the list above.

3.1.3 Local Flexibility Market Operator

The LFMO will have a central role when it comes to the process of coordinating the market operation. Their main tasks will consist of coordinating and performing the operation of the LFM [28]. These necessary tasks consist of:

- Gathering market bids.
- Performing market-clearing functions.
- Communicating market results.

- Performing settlement process.
- Submitting activation bids from aggregators and grid operators.
- Exchanging information regarding services between market participants.

From previous projects and papers like [18] and [29], the entity that takes the role as LFMO is often correlated with LFM model. Alternative for LFMO range from DSO, DSO and TSO collaborating, and an independent entity. Each of these alternatives has advantages and disadvantages when it comes to acting as LFMO as described in [18]. Again, it comes down to what services the platform provides and the utilized LFM model.

3.2 Local Flexibility Market

The concept of LFM is an ongoing field of research and development to explore different market strategies and the benefits they may bring. Examples of this are [30], [18], and [29], which are projects that have developed different ways for an LFM to be coordinated. LFM can be given a generalized definition as an electricity trading platform to provide flexibility in geographically limited areas such as neighborhoods, communities, towns, and small cities [28].

The goal of the LFM is two-folded. The first goal is to unlock the potential of DER to be used in the power market. The second is for the LFM to provide more regulating and grid-solving opportunities for both the distribution and transmission grid. How this newly founded market will differ from other already established markets is as listed below:

- It will allow for the utilization of DFR to solve more specific grid problems like voltage problems and congestion in the distribution grid.
- It will provide TSO with more alternatives to balancing the system, which will improve the efficiency of the whole power system.
- It will allow greater participation of energy consumers in the energy market, leading to their empowerment and higher awareness of their energy consumption
- It will create monetary value for all market participants

If using the Nordic market called Nord Pool [31] as a reference, the timeframe for when this market is to operate is between the intraday and balancing markets. After day-ahead market clearing, the planning process will commence, determining the operation for the coming day. This operation is split into quarter-hour time slots, and the whole process will last for 24 hours.

3.2.1 Local Flexibility Market Strategy

The LFM strategy can be divided into two phases; the planning phase and the operation phase. The planning phase attempts to find possible grid problems that will occur the day before operation and a potential solution based on forecasted DFR availability. The operation phase will consist of DFR activation for different periods, an evaluation of the system's conditions based on the new data, and the procurement of additional flexibility.

There will always be some uncertainty regarding planning ahead of the operation, resulting in errors in the scheduled dispatch. In order to handle this uncertainty, a technique called rolling-horizon can be implemented in the operation phase. For each quarter, a new optimization procedure is conducted, taking into account future time slots. This way, the simulation always considers the same duration of the operation. During operation, only the solutions for the current time step are implemented [32]. Since the re-scheduling of DFR activation through rolling-horizon takes place close to the operation, the variables will become more certain, leading to a more accurate prediction for DFR activation. Figure 6 shows the process of the rolling-horizon technique, where (P_{sch}) is the scheduled DFR activation, (P_{re-sch}) is update schedule, and (P_{activ}) is the actual DFR activation performed during operation.

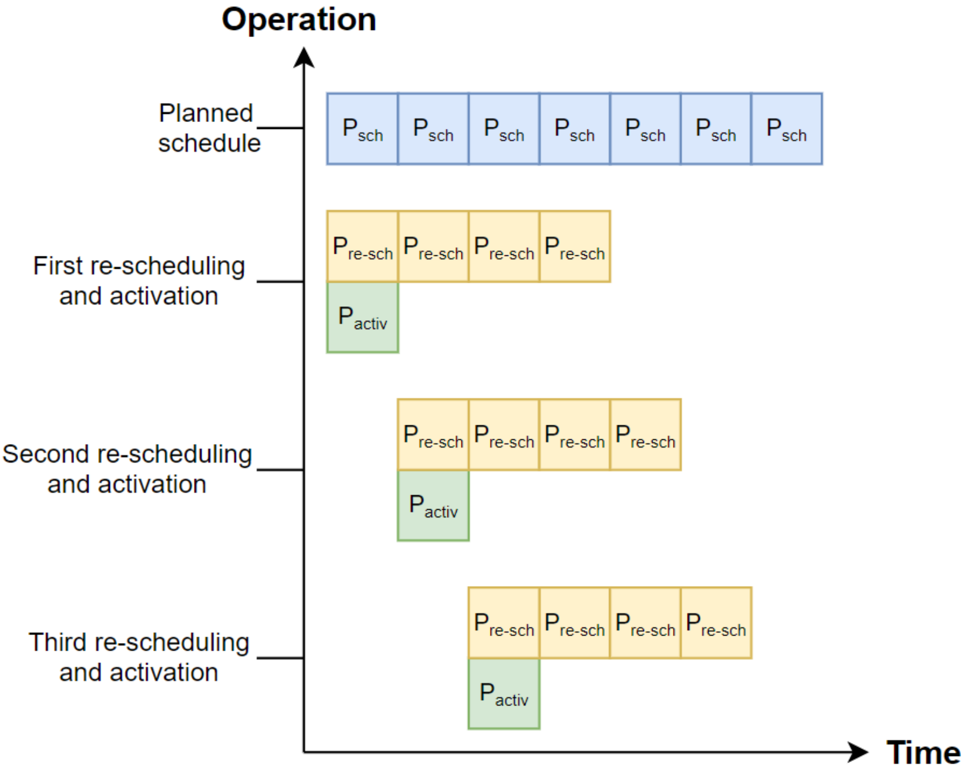

Figure 6: The concept of rolling-horizon for scheduling of DFR activation.

The rolling-horizon process start by establishing a planned schedule based on determines potential grid issues and the flexibility needed to resolve them. This planning is performed day-ahead and will result in deviation from the actual operation. During operation, the rolling-horizon technique is employed to re-schedule the operation according to the updated grid information. DFR activation will then be executed based on this updated schedule. The actual optimization in order to find the optimal use of DFR is explored in chapter 3.2.3.

3.2.2 Local Flexibility Market Coordination

The LFM coordination facilitates the interaction between all LFMP in the LFM ecosystem. A visualization of the LFM coordination is presented in attachment A, as well as figure 7 and 8, to illustrate all the necessary steps in the LFM. The main participants in this LFM will be the DSO, TSO, LFMO, and aggregator. Here, DSO and TSO will act as BRP, who will purchase flexibility for balancing purposes. The LFMO will, in that case, have the responsibility of controlling the market platform and coordinate the information flow. Lastly, the aggregators will offer the available DFR capacity to the market and ensure its proper activation.

Figure 7 showcases the whole planning phase in the LFM platform. The entire phase starts after the day-ahead market is cleared. Aggregators will then calculate DFR capacity for the coming operation and provide offers to the LFMO, which again will communicate this information to the DSO. At the same time aggregators performs flexibility forecasting, DSO will perform forecasting of load scenarios. These scenarios are then used as input for the OPF simulation, determining potential grid issues and the necessary flexibility to alleviate them. DSO can then decide the right course of action to either reserve this capacity or wait to see how the situation unfolds. Any desire to reserve flexibility will then be communicated back to the LFMO. TSO will receive both the OPF result from DSO and the information regarding the remaining flexibility. Based on this data, TSO can evaluate reserving flexibility for their use. Based on the flexibility reservation from DSO and TSO, LFMO will construct an operation schedule for the coming day. This schedule will be provided to the aggregators, informing them of their respective flexibility dispatch.

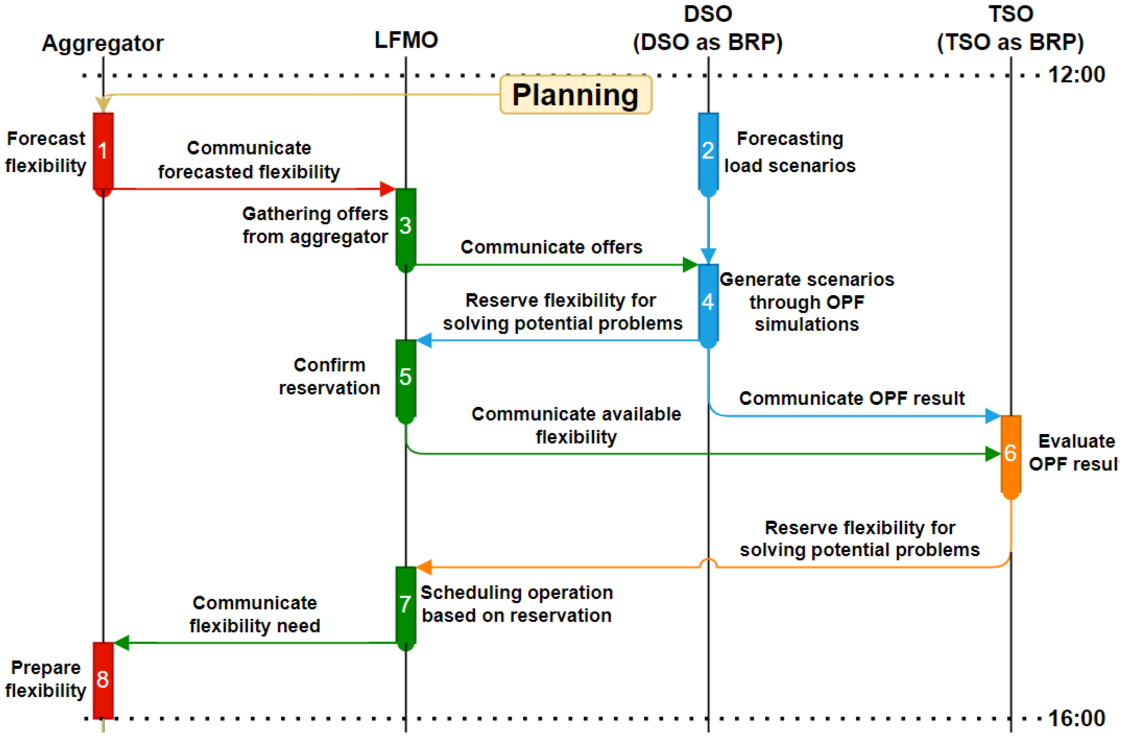

Figure 7: Flowchart showing the planning phase in the LFM.

After the completion of the planning phase, the operation phase will commence at 00:00, as shown in figure 8. Before activation, DSO will evaluate the grid's situation by performing monitoring and metering. This new information will be provided as input to the OPF to acquire more accurate results for the DFR activation, which will then be communicated to LFMO. This is where the strategy of rolling-horizon comes into play by re-scheduling the operation based on this new information to execute a more accurate and updated DFR activation. Information regarding DFR's activation will then be forwarded to aggregators, which will result in the flexibility provision. In the case of insufficient DFR capacity activation, LFMO will communicate this to TSO, who can acquire additional capacity from the balancing market. While conducting this activation, DSO will again evaluate the grid's situation. This whole process only applies for one quarter-hour (15 minutes). When the following timeframe begins at 00:15, the whole process from 1 to 6 will start over. This procedure repeats for each quarter of the entire day.

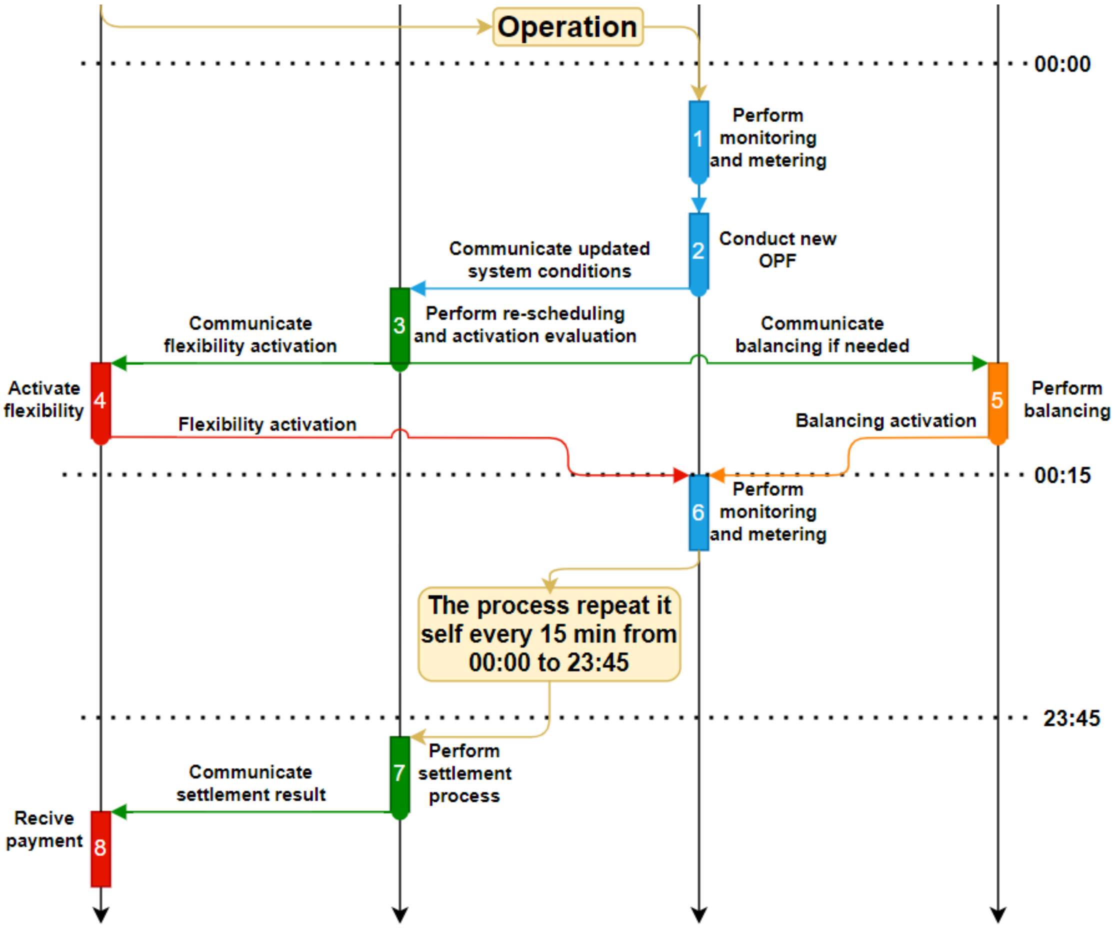

Figure 8: Flowchart showing the operation phase in the LFM.

After the operation has ended, the settlement process begins. LFMO will receive information regarding the metering from the BRPs. Based on this information, LFMO will confirm the proper activation of DFRs. In the last step, aggregators will receive their required payment from the LFMO accordingly to the provided flexibility.

3.2.3 Two-Stage Stochastic Optimization

This chapter will further expand on the idea of flexibility procurement by the DSO in the planning phase, as described presented in figure 7. In order to effectively determine the necessary flexible capacity, two-stage stochastic optimization is considered as the preferable LFM strategy. Figure 9 visualizes this concept. This strategy consists of two recursive stages, where the BRP, like TSO or DSO, can reserve flexibility for later use. This practice begins with creating numerous scenarios representing possible grid situations that may unfold during the coming operation day, including their probability of occurrence. In figure 9, each branch in stage two illustrates a scenario, where the variables (P_L), (P_G), (P_{ch}) and (P_{dch}) depict the load, the flexibility provided from generation and charging and discharging of the battery for each market time slot. In addition, the variable (p_n) depicts the probability for each scenario to occur. In order to optimize the grid, OPF analysis is conducted, including the available flexibility from the LFM. This way, flexibility dispatch can be acquired for each particular scenario. Results from each scenario can then be multiplied with their respective probability of occurrence to determine a single average power dispatch. This resulting flexibility dispatch will again influence the BRP's decision to reserve flexibility in stage 1 and possibly procure additional flexibility in stage 2. In two-stage stochastic optimization, the stochasticity embodies the numerous scenarios with their corresponding probability and the flexible capacity provided by DFRs.

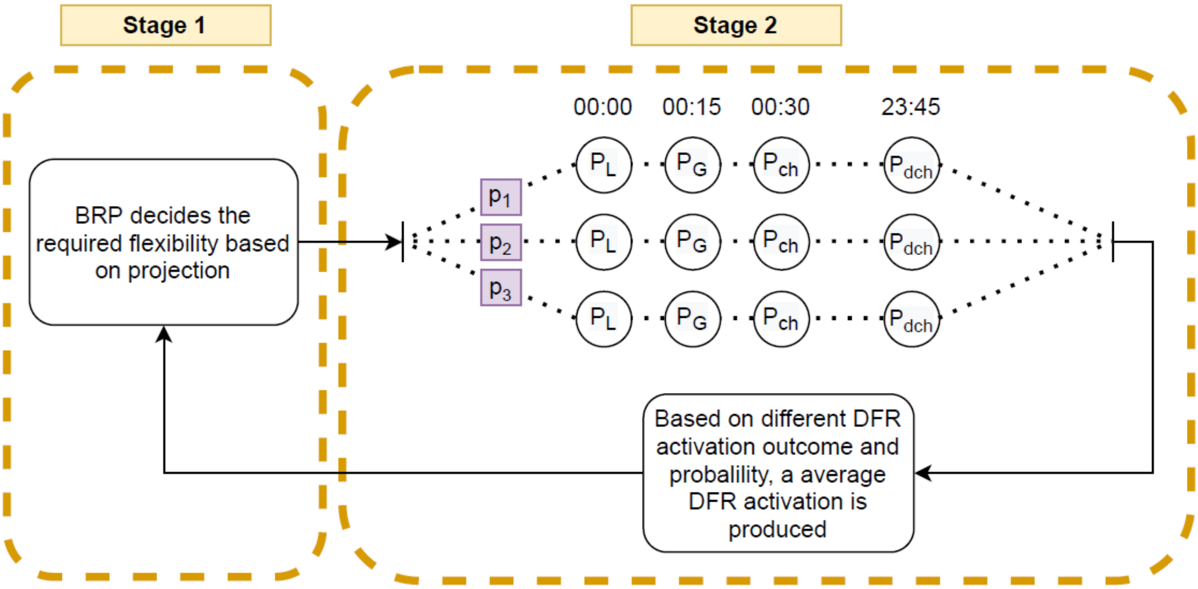

Figure 9: Flowchart showing the two-stage stochastic optimization used as a LFM strategy.

During the operation phase, rolling-horizon may be used as a means to procure flexibility. The exact approach may also be formed as a two-stage stochastic optimization, similarly to the planning phase. Due to the close to the real-time operation, this requires additional safety measures and better cooperation between all LFMP before this could take place. Even so, this is a rather broad topic that falls outside of the scope of this thesis. No further explanation will thus be provided with regards to this topic.

4 Interaction Model for Flexibility Acquirement in the Distribution Grid

Chapters 3 and 4 discussed the potential of flexibility and benefits for both DSO and TSO from procuring these assets. A question remains on how to analyze grid challenges and decide what measures are needed to utilize available flexibility to overcome said challenges. Solving this problem is the primary goal of the interaction model provided in this chapter. One way to do this, which is also the adopted approach in this thesis, is to utilize OPF simulation as a planning tool to analyze the use of flexibility.

4.1 Interaction Model in the Form of an Optimal Power Flow Formulation

The use of OPF simulation tools is widely spread across the different market participants in the power industry. OPF analysis is a subcategory of power system analysis, where the purpose is to solve power system power flow, optimize system operating conditions, and adjust control variable settings while ensuring system constraints not being violated. [33]. OPF analysis is an essential aspect of power system planning as it ensures a safe and efficient operation.

In the interaction model between TSO and DSO, the OPF simulation tool will be used to analyze how flexibility procured from the distribution grid will affect the power system. This flexibility comes in the form of DFRs that can either be DG, ESS, load-shifting, and, in the worst case, load shedding. Depending on technical and economic factors like DFR location, DFR pricing, and DFR capacity, each DFR unit contribution can affect the grid's power flow and total production. It is this effect that will be determined through OPF simulation. By performing different operation scenarios through OPF simulation based on demand and production forecasting, one can unveil potential operational problems. These problems can then be analyzed and alleviated by employing flexibility from DFRs. There are mainly three problems this OPF analysis will focus on, which are to:

- Utilize the flexibility in the distribution grid to minimize the power injected from the transmission grid when this is economically feasible.
- Alleviate violation of voltage levels in the distribution grid due to a weak grid, large load variations, or other factors.
- Solve congestion problems that can occur during times with heavy consumption in the distribution grid.

4.2 Requirements for Power Flow Simulation in a Distribution Grid

Several methods and algorithms can be applied for power flow calculation, each having its unique properties that can bring certain advantages and disadvantages. When deciding upon which power flow technique to use, it is vital to have these different properties in mind depending on the system's characteristics one wants to solve.

In this thesis, performing power flow analysis for both the distribution and transmission grid is of interest. Between the two networks, the requirements for the distribution grid are most complex when considering production in sub-branches. A common feature in distribution grids is the radial structure where power provision occurs from a single substation and is transferred down several branches and sub-branches to loads (consumers). Such a system is often described in the literature as a so-called radial distribution system [34]. Operating a grid in this manner is very cost-efficient and simplifies the operation process, which is why so many DSOs have decided to follow this concept. Distribution grids still provide certain difficulties that complicate power flow simulation for traditional methods, such as:

- High R/X ratio than in the transmission grid, due to shorter distances between nodes and the use of smaller line cross-section [34].
- Significant number of unbalanced loads in the system due to consumer's use of single-phase electronics [35]. Integration of DG, which gives rise to production in sub-branches [34], and may result in reverse power flow.

These factors may contribute to the radial system being ill-conditioned for different power flow methods. For the most accurate method, the AC Power Flow (ACPF), commonly used algorithms are the Newton-Raphson, Gauss-Seidel, and the fast-decoupled method. Although these algorithms' initial design was to solve power flow in the transmission grid, they may be applicable for specific distribution systems. One of the issues that may arise is the convergence problem due to the high R/X ratio [36]. A method that can handle this issue is the Backward-Forward sweep method. So as of today, this method is commonly utilized when performing power flow analysis in a distribution grid. A significant drawback of this method is its poor capability in handling active distribution grids [34]. Thus, this method will not be applicable for this thesis's purpose due to its need to include DFR down in the distribution grid's sub-branches. The need to include these assets is to provide flexibility and showcase the increasing penetration of smart grids in the distribution grid [37].

Since a transmission system can be too computationally heavy to solve for the ACPF on some occasions, an approximation method called DC Power Flow (DCPF) can be an alternative. DCPF is a non-iterative, linearization of the ACPF method where specific assumptions are made to ease the computational effort. Some of these assumptions are neglecting resistance leading to no power losses, as well as neglecting reactive power in the system [38]. These assumptions are only applicable to transmission grids due to the distribution grid's high R/X ratio. If applied, these assumptions would lead to significant inaccuracies between the ACPF and DCPF results.

So it seems that the equivalent ACPF method has convergence problems and the approximation DCPF method is too inaccurate for an active distribution grid. This problem gave rise to implementing an approach that lay somewhere in between the ACPF and DCPF methods. Instead of using approximation like the DCPF method, this method is based on relaxation of the ACPF method. This relaxation extends the feasibility area of the ACPF and gives this method a better convergence area than the ACPF while also being more accurate than the DCPF [39]. There are mainly four convex relaxation approaches that are used for power flow purposes, which are:

- Nonlinear (convex) relaxation
  - Second-Order Cone (SOC)
  - Semi-Definite Programming (SDP)
  - Quadratic Convex (QC)
  - Sum-of-Square programming (SOS)

Each of these methods has its advantages and disadvantages. The SOC relaxation is easier to compute but has less accuracy than methods like the QC method. The general benefits for the different convex relaxation methods are that they are fast and stable, have better accuracy than the DC-OPF, and always provide lower or upper bound, which assures global optimum or minimum for the objective function. Since this method always provides lower or upper bound, their use can guarantee that a given case is feasible or infeasible [40]. In figure 10 is the visualization of the convergence area for each method. The copper plate method corresponds to the DC-OPF problem and has the largest convergence area but is less accurate. The AC method has the smallest convergence area but has the highest accuracy.

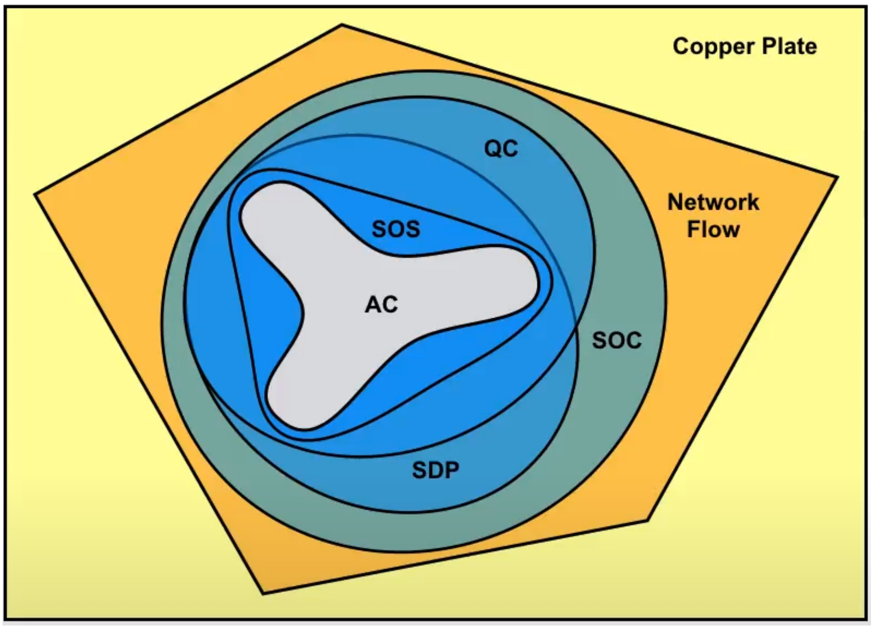

Figure 10: Convergence area for different relaxation methods [41].

4.3 Second-Order Cone AC Optimal Power Flow

In order to satisfy the needs of the active distribution grid, the choice fell on the convex relaxation method based on SOC programming. The development of this Second-Order Cone AC Optimal Power Flow (SOC-ACOPF) allowed to efficiently solve the OPF problems with the characteristic of an ill-conditioned distribution grid [42]. The author of the paper has described the implication of the conic programming formulation as threefold:

- The solution of the distribution OPF problem can be obtained in polynomial time using interior-point methods. Polynomial-time is also referred to as a P-problem (polynomial problem) [43] and is significantly easier and faster to solve than an NP-problem (non-polynomial problem). In some cases, ACOPF may be such a problem [44]. P-problem can then be solved by the interior-point method, which is a tried and true algorithm utilized for solving linear and convex optimization problems [45].
- Numerical ill-conditioned distribution grids can be automatically alleviated by the use of scaling in the interior-point algorithm. This technique increases the feasibility of a problem enhancing the solving process for the interior point method [46].
- Since the original power flow equation is non-linear, it can not be directly utilized for conic programming. Through convex relaxation, it is possible to formulate the equation to be suited for conic programming [47]. This relaxation comes at the cost of the accuracy of the solution but will still be a reasonably accurate representation of a radial system.

This method assumes that power injection only occurs from one feeder node, hence the substation. This assumption will not suffice in an active power grid where production also occurs in the sub-branches. The optimization model has therefore been modified based on the paper [48] to handle an active power grid while maintaining the core method of the optimization model from [42].

4.3.1 Convex Relaxation of the SOC-ACOPF

The method takes a starting point in the two ACPF equations for active and reactive power flow as shown in equation 2 and 3. Here, (G) is the conductance, (B) the susceptance, (V) the voltage magnitude, (θ) the voltage angle, and (P) and (Q) are the variables representing active and reactive power flows. The notation (m) and (j) indicate the sending and receiving node, respectively.

$$P_{mj} = G_{mj}V_{mj}^2 - G_{mj}V_mV_jcos\theta_{mj} + B_{mj}V_mV_jsin\theta_{mj} \tag{2}$$

$$Q_{mj} = B_{mj}V_{mj}^2 - B_{mj}V_mV_jcos\theta_{mj} - G_{mj}V_mV_jsin\theta_{mj} \tag{3}$$

These equations are non-linear due to the squared voltage and trigonometric function sinus and cosines, making the equation unfit for conic programming. Through the convex relaxation technique, the non-linear part of the equation can be alleviated with the use of auxiliary variables [49]. For this case, the convex relaxation of the power flow equation will lead to three auxiliary variables:

$$\begin{aligned} u &= \frac{V^2}{\sqrt{2}} \\ R_{mj} &= V_m V_j cos\theta_{mj} \\ I_{mj} &= V_m V_j sin\theta_{mj} \end{aligned} \tag{4}$$

When implementing the auxiliary variables in the power flow equation 2 and 3, the equation will go from being non-linear to linear as shown in equation 5 and 6 for active and reactive power flow, respectively.

$$P_{mj} = \sqrt{2} G_{mj} u_m - G_{mj} R_{mj} + B_{mj} I_{mj} \tag{5}$$

$$Q_{mj} = \sqrt{2} B_{mj} u_m - B_{mj} R_{mj} - G_{mj} I_{mj} \tag{6}$$

Since $R_{mj} = R_{jm}$ and $I_{mj} = -I_{jm}$, the system consists of three variables, but only two equations, a third equation is thus needed for the problem to be solvable. This third equation comes as a quadratic equation that defines the problems as a convex system. This quadratic equation will also operate as a mismatch equation that approaches zero as the system draws near its true solution [50].

$$2u_m u_j = R_{mj}^2 + I_{mj}^2 \tag{7}$$

The three equation 5, 6, and 7 define the convex relaxed radial power flow problem, which in this case will be in the form of a SOC-ACOPF. Formulating the problem in this manner only accounts for a system of one single line. For a radial system of several lines, the formulation of the power flow equation is as follows:

$$P_m^L - P_m^G = -\sum_{j \in k(m)} P_{mj} = -\sqrt{2} u_m \sum_{j \in k(m)} G_{mj} + \sum_{j \in k(j)} (G_{mj} R_{mj} - B_{mj} I_{mj}) \tag{8}$$

$$Q_m^L - Q_m^G = -\sum_{j \in k(m)} Q_{mj} = -\sqrt{2} u_m \sum_{j \in k(m)} B_{mj} + \sum_{j \in k(m)} (B_{mj} R_{mj} + G_{mj} I_{mj}) \tag{9}$$

Equations 8 and 9 state that the total power flow for all lines in or out for a given node, should be equal to the difference between load (P_m^L/Q_m^L) and the production (P_m^G/Q_m^G) on a said node, making this a power balance equation. It is assumed that the voltage on node one is known as it is connected to a given substation. The number of power balance equations needed to be calculated will be $(m = 1...M)$, where "M" refers to the numbers of nodes in a system.

4.3.2 SOC-ACOPF Through a Convex Optimization

The SOC-ACOPF formulation creates an optimization problem based on one objective function and three equations that define the convex relaxed power flow problem. Moreover, four constraints ensure that variables and equations are kept inside their boundaries so that the system will converge to one true power flow. For constraint 11e, node number 1 is assumed to be known and is, therefore, set as a parameter. Additionally, variable (c_m) is defined as cost variable for a given production unit.

SOC-ACOPF Model Formulation

SOC-ACOPF Variables: $u_m,\ R_{mj},\ I_{mj},\ P^G_m,\ Q^G_m$

Minimize:

$$\sum_{m=1...M} P^G_m \cdot c_m \tag{10}$$

Subject to:

$$P^L_m - P^G_m = -\sqrt{2}u_m \sum_{j\in k(m)} G_{mj} + \sum_{j\in k(j)} (G_{mj}R_{mj} - B_{mj}I_{mj}), \qquad m = 1, ..., M, \tag{11a}$$

$$Q^L_m - Q^G_m = -\sqrt{2}u_m \sum_{j\in k(m)} B_{mj} + \sum_{j\in k(m)} (B_{mj}R_{mj} + G_{mj}I_{mj}), \qquad m = 1, ..., M, \tag{11b}$$

$$2u_m u_j \geq R^2_{mj} + I^2_{mj}, \qquad \textit{for all mj lines}, \tag{11c}$$

$$R_{mj} \geq 0, \qquad \textit{for all mj lines}, \tag{11d}$$

$$u_1 = V^2_1/\sqrt{2}, \quad u_m \geq 0, \qquad m = 2, ..., M, \tag{11e}$$

$$P^{G,min}_m \leq P^G_m \leq P^{G,max}_m, \qquad m = 1, ..., M, \tag{11f}$$

$$Q^{G,min}_m \leq Q^G_m \leq Q^{G,max}_m, \qquad m = 1, ..., M, \tag{11g}$$

In this optimization problem, the goal is to minimize the operational cost in the grid until all inequality constraints (11c) approach zero and become active. As the inequality constraint approach zero, the power flow for a system will converge towards a true power flow solution. The solutions provided by this program have been proven to be accurate by performing different test cases with an own developed SOC-ACOPF model. These test cases have then later been compared with a power flow simulation conducted with the package pandapower [51], which can calculate the exact ACOPF solution. Both simulations have used Python as the programming language. Table 1 presents a benchmark for different test cases which compare the SOC-ACOPF against the exact solution. The table shows numbers of nodes, base voltage, and the highest voltage error between the exact ACOPF and the SOC-ACOPF solution for a given system. In addition, the table also provides information regarding the Gurobi solver [52] and the necessary references.

Table 1: Power flow benchmark for different radial grid cases.

Number of nodes	Base voltage [kV]	$\lvert V\rvert$ Error [pu]	Gurobi iterations	Gurobi time [s]	Data acquired from
15	11,00	6,92E-5	52	0,01	[53]
29	11,55	4,6E-5	62	0,02	[54]
30	11,00	5,18E-4	24	0,01	[55]
33	12,66	7,7E-9	22	0,01	[56]
90	11,00	3,6E-5	88	0,07	[57]

An interesting observation is that the accuracy of the solution will vary with the cost of production for the generator on the feeder node. A high-cost parameter will increase accuracy but will require additional computation by the optimization program and vice versa with low-cost parameters. It is also possible to set the objective function to maximize the variable (R) and get the same result with less computational time and iterations. In this thesis, maximizing variable R will not be the object of interest, and therefore, the approach will minimize the overall costs while satisfying the load.

4.3.3 Limitations of The SOC-ACOPF model

As described in this chapter, SOC-ACOPF has numerous benefits for solving power flow problems. It is important to keep in mind that this method is not an exact representation of the actual power flow solution but instead a relaxation that increases the feasibility area of the solution. This increase in the feasible area leads to an "optimality gap" between the exact and convex solutions. This gap results in that the relaxation SOC-ACOPF solution will not be equal to the actual power flow solution [58].

A famous problem in computer science, which is yet to be solved, is the question that asks if P=NP. This problem declares that all non-polynomial problems that can easily be verified also can be solved quickly as a polynomial problem [59]. As of today, it is assumed that this is false. Convex relaxation is a case of taking an NP-problem in order to solve it like a P-problem. Based on the assumption that P=NP is false, some grid systems can not be solved through convexification and will therefore fail to provide physically meaningful results [60]. Contrary to a non-convex problem, a convex problem can still be formulated and utilized to prove no solution for a given problem.

As the formulation of the conic optimization problems is presented so far in this chapter, this model is only suited for grids that are radial, balanced, and can be represented by their equivalent single line diagram. Hence, three-phase unsymmetrical systems may not be applicable for this model. Some references such as [42] state that the formulation can indeed be extended to cope with an unbalanced system. Nevertheless, this is not a topic that this thesis will focus on any further.

Another limitation is that the model is only suited for the radial grid. For meshed grids, models based on convex conic programming are not applicable. As stated in [61], this is due to the presence of non-convex arctangent equality constraint, which is needed to solve meshed grids.

4.4 Combined Optimization Model For Distribution and Transmission Grid

The main goal of the OPF model is to explore how flexibility in the distribution grid can benefit DSO and consumers and for TSO who operate the transmission grid. Therefore, including the transmission grid in the optimization model will be necessary to analyze the impact resource activation in the distribution grid will have on the transmission grid. A convex conic program like the SOC-ACOPF is not suited for a meshed grid, which often is how a transmission grid is structured. The focus of the transmission grid is to analyze production and congestion management, which are information that does not require a detailed grid description like voltage magnitude and reactive power. A common method used for such application in the transmission grid and market operation is the DC-OPF method [62]. Thus, this method will be integrated within the optimization model to solve the power flow in the transmission grid.

The mathematical formulation of the DC-OPF is less comprehensive than the SOC-ACOPF due to the possibility of neglecting voltage magnitudes and reactive power. The optimization objective will be the same as in the SOC-ACOPF, which minimizes production cost while still respecting the grid constraints. The first constraint is a balancing equation (12), where the sum of susceptance (B) multiplied with voltage angle (θ) dictate the power flow in and out of the node. This sum should then be equal to the difference between production (P_n^G) and the load (P_n^L) on that said node.

$$P_n^G - P_n^L = - \sum_{j \in k(n)} B_{nj}\theta_j \tag{12}$$

Equation (13) dictate the flow of power for each line. Variable representing the power flow for each line (P_{nj}^{fl}) is decided by the voltage angle between each node and the susceptance of the line connecting these two nodes.

$$P_{nj}^{fl} = B_{nj}(\theta_n - \theta_j) \tag{13}$$

Each generator can not produce infinite amount of power, so each generator requires a maximum and minimum constraint which limits the production as shown in equation (14).

$$P_n^{G,min} \leq P_n^G \leq P_n^{G,max} \tag{14}$$

In the same way there are limitation on generators, power flow can also be limited. Equation (15) dictates the upper and lower boundary for power flow for each line.

$$P_{nj}^{min} \leq P_{nj} \leq P_{nj}^{max} \tag{15}$$

Lastly, one node need to be defined as the slack node, which is a node used to provide balance to the whole grid [63]. This is done by defining the voltage angle on this node to be equal to 0, as shown with equation (16).

$$\theta_n^{slack} = 0 \tag{16}$$

The combined model for the distribution and transmission grid will come in the form of a hybrid DC/AC-OPF model where the DC-OPF will apply for the transmission grid and SOC-ACOPF to the distribution grid. This model gives rise to the formulated optimization problem as shown on the next page.

Hybrid AC/DC Optimization Model Formulation

DC-OPF Variables: $P_n^{G,DC},\ P_{nj}^{fl},\ \theta_n$

SOC-ACOPF Variables: $u_m,\ R_{mj},\ I_{mj},\ P_m^{G,AC},\ Q_m^{G,AC}$

Minimize:

$$\sum_{n=1...N} P_n^{G,DC} \cdot c_n^{DC} + \sum_{m=2...M} P_m^{G,AC} \cdot c_m^{AC} \tag{17}$$

Subject to SOC-ACOPF Constraint:

$$P_m^{L,AC} - P_m^{G,AC} = -\sqrt{2}u_m \sum_{j\in k(m)} G_{mj} + \sum_{j\in k(j)} (G_{mj}R_{mj} - B_{mj}I_{mj}), \qquad m = 1, ..., M, \tag{18a}$$

$$Q_m^{L,AC} - Q_m^{G,AC} = -\sqrt{2}u_m \sum_{j\in k(m)} B_{mj} + \sum_{j\in k(m)} (B_{mj}R_{mj} + G_{mj}I_{mj}), \qquad m = 1, ..., M, \tag{18b}$$

$$2u_m u_j \geq R_{mj}^2 + I_{mj}^2, \qquad \textit{for all mj lines}, \tag{18c}$$

$$R_{mj} \geq 0, \qquad \textit{for all mj lines}, \tag{18d}$$

$$u_1 = V_1^2/\sqrt{2}, \quad u_m \geq 0, \qquad m = 2, ..., M, \tag{18e}$$

$$P_m^{G,AC,min} \leq P_m^{G,AC} \leq P_m^{G,AC,max}, \qquad m = 1, ..., M, \tag{18f}$$

$$Q_m^{G,AC,min} \leq Q_m^{G,AC} \leq Q_m^{G,AC,max}, \qquad m = 1, ..., M, \tag{18g}$$

Subject to SOC-ACOPF to DC-OPF Connection Constraint:

$$P_n^{G,DC} - P_m^{G,AC} = -\sum_{j\in kn} B_{nj}\theta_j, \qquad \substack{P_m^{G,AC}=P_n^{L,DC} \\ if \\ n_{DC} = m_{AC}}, \tag{19}$$

Subject to DC-OPF Constraint:

$$P_n^{G,DC} - P_n^{L,DC} = -\sum_{j\in k(n)} B_{nj}\theta_j, \qquad \substack{n = 1...N \\ \wedge \\ n_{DC} \neq m_{AC}}, \tag{20a}$$

$$P_n^{G,DC,min} \leq P_n^{G,DC} \leq P_n^{G,DC,max} \qquad n = 1, ..., N, \tag{20b}$$

$$P_{nj}^{fl} = B_{nj}(\theta_n - \theta_j), \qquad \textit{for all nj}, \tag{20c}$$

$$P_{nj}^{fl,min} \leq P_{nj}^{fl} \leq P_{nj}^{fl,max} \qquad \textit{for all nj}, \tag{20d}$$

$$\theta_n^{slack} = 0, \qquad \substack{\exists!\ n_{DC} \\ \wedge \\ n_{DC} \neq m_{AC}}, \tag{20e}$$

The combination of all the variables from the SOC-ACOPF and DC-OPF leads to a system with eight variables. These consist of auxiliary variables, active and reactive production, power flow, and voltage angle. The optimization objective will remain the same as for the standalone SOC-ACOPF and DC-OPF methods. The two objectives will be combined to minimize operational costs for both the distribution and transmission grid simultaneously. Nothing has changed for SOC-ACOPF constraint, besides marking the power production variable and load parameters with "AC" to distinguish between the two power flow methods.

One new constraint is the AC to DC connection constraint, which connects the distribution grid to the transmission grid. This constraint requires one distribution node to be defined as a feeder/slack node that supplies the power to the grid. While the distribution grid sees this node as a production node, it appears as a single load from the transmission grid's perspective. The criteria for activation of this constraint is that the production for feeder node ($P_m^{G,AC}$) needs to be equal to the transmission system's load ($P_n^{L,DC}$) if a connection between these nodes is established. This constraint resembles a DC power-balance constrain, where the DC load parameter ($P_n^{L,DC}$) has been replaced by the AC production variable ($P_m^{G,AC}$) in the distribution grid.

In the same way, the SOC-ACOPF parameters and variables have been marked with "AC", so will the DC-ACOPF parameters and variables be marked with "DC." Another modification is the reformulated constraint criteria for the power balance equation and slack bus voltage angle. The new criteria for the power balance constraint are that activating this constraint will only happen as long as the transmission node is not connected to a distribution node. Moreover, the slack voltage angle can only be applied to a node not connected to the distribution feeder/slack node.

4.4.1 Hybrid AC/DC-OPF Model Verification

This chapter will provide a comparison between power flow models to prove that the hybrid AC/DC-OPF model will converge towards a true power flow solution. This comparison will analyze if the combined hybrid AC/DC-OPF model will yield the same power flow and production results as a SOC-AC and DCOPF for the same distribution and transmission grid, run separately. This approach is as follows:

- Perform power flow simulation for the distribution grid with the SOC-ACOPF method.
- Utilize the feeder node production found with the SOC-ACOPF as load in the transmission grid and run DC-OPF simulation.
- Conduct simulation for the combined system with the hybrid AC/DC-OPF model.
- Compare the power flow results found in both the distribution and transmission grid with the result found with the SOC-AC and DC-OPF.

The test system in use, is a 33 node distribution grid [64], and a 9 node transmission grid system [65]. These systems will also be utilized further in this thesis and will be given a more thorough explanation in chapter 5.

Table 2: Result comparison between the combined hybrid AC/DC-OPF model and the standalone DC-OPF and SOC-ACOPF models.

	Active power production [pu]	Reactive power Production [pu]	Voltage angle [deg]	Voltage magnitude [pu]
Deviation from DC-OPF	4,87E-05	-	6,30E-04	-
Deviation from SOC-ACOPF	7,00E-05	4,00E-05	1,35E-04	5,49E-05

Table 2 presents the most significant deviations for different values between the hybrid AC/DC-OPF model and the SOC-ACOPF and DC-OPF model. As it appears, there are some minor deviations between the values produced by the different models. The SOC-ACOPF and DC-OPF method are already confirmed to be correct. The only new concept is the connection constraint. Thus, the comparison demonstrates that the connection between the two methods by setting the feeder node's production equal to the transmission node's load is correct.

4.5 Multi-Period Problem Formulation and Description

Efficient optimization of flexibility use requires the system's operation to be determined for an extended period within a single simulation. For this purpose, the hybrid AC/DC-OPF model has been expanded to include a multi-period optimization approach. The periods within the model are hours (h) and units (u) due to the hourly nature of the day-ahead market and quarterly time units of the flexibility market. This way, the model can find the optimal objective value for a predefined period, which included each variable across every hour and time unit within each hour.

For including the multi-period approach, the equations 18a to 20e are extended with two indices corresponding to the hour and time unit of simulation. Another addition is the implementation of the flexible assets and their corresponding constraints. The first modification will be of the objective function, which mathematically reformulates the optimization model to minimize the total costs of flexibility use from all sources, as shown by equation (21). Thus, the day-ahead production will no longer be a variable but a parameter provided to the model. Regarding the SOC-ACOPF constraints, since the flexibility sources directly contribute to the power balance within each node, they have been added to the node balance equation (18a). To ensure feasibility in the case production can not meet demand, load shedding has also been implemented as shown by constraint (25). This constraint gives the possibility to shed the entire load within each node. This formulation will not be possible in a real-life scenario due to some loads like hospitals being crucial for society. For this thesis, load shedding is considered the last option to reach feasibility and should never be fully used.

Regarding the DFRs, both the flexible generation and load have been furnished with a constraint determining their upper and lower limits. In addition, the implementation of the constraint shown with equation

(27b) provided the model with the ability of load shifting. This constraint calculates the total volume of load shifting used for balancing and ensures that its sum is equal to zero. This way, the model also negates the possibility of exploiting the load's flexibility to minimize the costs by minimizing the load.

Modeling the battery requires a more refined design due to the physical operation of this flexibility unit. The battery state of charge is defined by equation (28a), while its charging and discharging capacities are defined by equations (28b) and (28c). In addition, these two constraints include a variable (δ), which ensures that the battery can not be charged and discharged simultaneously. The next step in the modeling procedure is establishing a link between every unit of the entire simulation for the battery's state. This constraint is split threefold, as shown by equations (28d) (28e) and (28f). In this model, the state of charge of the battery is determined for the end of each quarter unit. Equation (28d) sets the battery's charge during hour 1 and unit 1 to be equal to the initial state of charge and the amount that has been charged or discharged during that time unit. The formulation also includes charging and discharging efficiencies with the parameters (η^{ch}) and (η^{disch}). Following, equation (28e) links the current state of charge with the one of the previous time unit and the amount that has been charged and discharged during this time unit. If that time unit is the first one of the hour, the state of charge is instead linked to the last one of the previous hour, as shown by (28f). Lastly, the constraint (28g) is implemented that ensures that the battery's state of charge at the end of the simulation is equal to the initial state of charge.

The resulting model is shown below, which consists of numerous variables and their corresponding indices. Indices (n) and (m) represent the transmission and distribution grid node, respectively, while (t) and (u) characterize the simulation's specific hour and time unit. The last index (j) is used for the variables concerning power flow and represents the "sending node" of the power flow. When it comes to variables themselves, the DC-OPF part of the model includes variables ($P^{fl}_{nj,t,u}$) and ($\theta_{n,t,u}$), which represent the active power flow and the angle, respectively. For SOC-ACOPF the auxiliary variables are represented with ($u_{m,t,u}$), ($R_{mj,t,u}$) and ($I_{mj,t,u}$). For flexibility, each asset comes with its respective variables. The flexible generation and load are described with variables ($P^{G,Flex}_{m,t,u}$) and ($P^{L,Flex}_{m,t,u}$), while load shedding is described with ($P^{LS}_{m,t,u}$). The battery includes three variables. Charging and discharging is expressed with ($P^{ch}_{m,t,u}$) and ($P^{disch}_{m,t,u}$) and the state of charge with the variable ($P^{SoC}_{m,t,u}$). Lastly, the prices for each asset's discharge are expressed with ($c^{G,Flex}_{m,t,u}$), ($c^{L,Flex}_{m,t,u}$) and ($c^{batt}_{m,t,u}$) for the generation, load and battery, respectively.

Multi-Period Hybrid AC/DC Optimization Model Formulation

DCOPF Variables: $P^{fl}_{nj,t,u},\ \theta_{n,t,u}$

SOC-ACOPF Variables: $u_{m,t,u},\ R_{mj,t,u},\ I_{mj,t,u}$

Flexibility Variables: $P^{G,Flex}_{m,t,u},\ P^{L,Flex}_{m,t,u},\ P^{LS}_{m,t,u},\ P^{SoC}_{m,t,u},\ P^{ch}_{m,t,u},\ P^{disch}_{m,t,u}$

Minimize:

$$\begin{aligned}\sum_{m=2\ldots M}\sum_{t=1\ldots T}\sum_{u=1\ldots U}&(P^{G,Flex}_{m,t,u}\cdot c^{G,Flex}_{m,t,u}-P^{L,Flex}_{m,t,u}\cdot c^{L,Flex}_{m,t,u}+\\&(P^{disch}_{m,t,u}-P^{ch}_{m,t,u})\cdot c^{batt}_{m,t,u}-P^{LS}_{m,t,u}\cdot c^{LS}_{m,t,u})\end{aligned}\tag{21}$$

Subject to SOC-ACOPF constraints:

$$\begin{aligned}&P^{L,AC}_{m,t,u}+P^{L,Flex}_{m,t,u}-P^{G,AC}_{m,t,u}-\\&P^{G,Flex}_{m,t,u}+P^{ch}_{m,t,u}-P^{disch}_{m,t,u}=\sqrt{2}u_{m,t,u}\\&\sum_{j\in k(m)}G_{mj}+\sum_{j\in k(m)}(G_{mj}R_{mj,t,u}-B_{mj}I_{mj,t,u})\end{aligned}\tag{22a}$$

$$\begin{aligned}&Q^{L,AC}_{m,t,u}-Q^{G,AC}_{m,t,u}=-\sqrt{2}u_{m,t,u}\sum_{j\in k(m)}B_{mj}+\\&\sum_{j\in k(m)}(B_{mj}R_{mj,t,u}+G_{mj}I_{mj,t,u}),\end{aligned}\tag{22b}$$

$$2u_{m,t,u}u_{j,t,u}\geq R^2_{mj,t,u}I^2_{mj,t,u},\qquad for\ all\ mj\ lines,\tag{22c}$$

$$R_{mj,t,u}\geq 0,\qquad for\ all\ mj\ lines,\tag{22d}$$

$$u_1=V_1^2/\sqrt{2},\quad u_m\geq 0,\tag{22e}$$

Subject to DC-OPF constraints:

$$P^{G,DC}_{n,t,u}-P^{L,DC}_{n,t,u}=-\sum_{j\in k(n)}B_{nj,t,u}\theta_j,\qquad n_{DC}\neq m_{AC},\tag{23a}$$

$$P^{fl}_{nj,t,u}=B_{nj}(\theta_n-\theta_j),\qquad for\ all\ nj,\tag{23b}$$

$$-P^{fl,max}_{nj,t,u}\leq P^{fl}_{nj,t,u}\leq P^{fl,max}_{nj,t,u},\qquad for\ all\ nj,\tag{23c}$$

$$\theta^{slack}_{n,t,u}=0,\qquad \substack{\exists!\ n_{DC}\\ \wedge\\ n_{DC}\neq m_{AC}},\tag{23d}$$

Subject to AC to DC connection constraints:

$$P^{G,DC}_{n,t,u}-P^{G,AC}_{m,t,u}=-\sum_{j\in k(n)}B_{nj}\theta_{j,t,u},\qquad \substack{P^{G,AC}_{m,t,u}=P^{L,DC}_{n,t,u}\\ if\\ n_{DC}=m_{AC}},\tag{24}$$

Subject to load shedding constraints:

$$P^{LS}_{m,t,u}=P^{L,AC}_{m,t,u}\tag{25}$$

Subject to flexible generation constraints:

$$P^{G,Flex,min}_{m,t,u}\leq P^{G,Flex}_{m,t,u}\leq P^{G,Flex,max}_{m,t,u}\tag{26}$$

Subject to flexible load constraints:

$$P^{L,Flex,min}_{m,t,u} \leq P^{L,Flex}_{m,t,u} \leq P^{L,Flex,max}_{m,t,u} \tag{27a}$$

$$\sum_{m=2...M} \sum_{t=1...T} \sum_{u=1...U} P^{L,Flex}_{m,t,u} = 0 \tag{27b}$$

Subject to battery constraints:

$$P^{SoC,min}_{m,t,u} \leq P^{SoC}_{m,t,u} \leq P^{SoC,max}_{m,t,u} \tag{28a}$$

$$P^{ch,min}_{m,t,u} \leq P^{ch}_{m,t,u} \cdot (1 - \delta_{m,t,u}) \leq P^{ch,max}_{m,t,u} \tag{28b}$$

$$P^{disch,min}_{m,t,u} \leq P^{disch}_{m,t,u} \cdot \delta_{m,t,u} \leq P^{disch,max}_{m,t,u} \tag{28c}$$

$$P^{SoC}_{m,1,1} = P^{SoC,init}_{m} + P^{ch}_{m,1,1} \cdot \eta^{ch} - \frac{P^{disch}_{m,1,1}}{\eta^{disch}} \tag{28d}$$

$$P^{SoC}_{m,t,u} = P^{SoC}_{m,t,u-1} + P^{ch}_{m,t,u} \cdot \eta^{ch} - \frac{P^{disch}_{m,t,u}}{\eta^{disch}} \tag{28e}$$

$$P^{SoC}_{m,t,1} = P^{SoC}_{m,t-1,U} + P^{ch}_{m,t,1} \cdot \eta^{ch} - \frac{P^{disch}_{m,t,1}}{\eta^{disch}} \tag{28f}$$

$$P^{SoC}_{m,T,U} = P^{SoC,init}_{m} \tag{28g}$$

For Equation (22a-28g): $\substack{n=1...N \\ m=2...M \\ t=1...T \\ u=1...U}$

With this mathematical formulation, optimal use of flexibility can be determined for each simulation unit and the whole simulation in its entirety. In addition, this hybrid model will determine the OPF in both distribution and transmission grids in one single simulation. In order to validate this concept, this formulation will be used to perform power flow optimization for several different test cases. These test cases will attempt to show the versatility and possibilities of this optimization model in solving different gird challenges.

5 Simulation and Test Cases

In this chapter, the developed multi-period hybrid AC/DC-OPF model presents the multi-period simulation, general optimization of DFR, and DFR activation for alleviating specific grid problems. These issues are related to the problems the LFM strategy goes out to solve, which include:

- Congestion in the transmission grid
- Congestion in the distribution grid
- Voltage problems in the distribution grid

Some of the data regarding the distribution and transmission grid used for these test cases are based on standardized data developed through previous projects, and papers [64], [65]. Since this multi-period hybrid AC/DC-OPF model is a unique concept, specific customizations have been made to the existing grid models. These changes come in the form of the implementation of DFR in the grid. The execution of DFR's placement throughout the grid will affect results and the overall performance for each test case.

The main idea behind these test cases is to focus on the proof of concept rather than an implementation for one specific real-life case. The formulated optimization problem and construction of the model are generalized for different distribution and transmission grids, regardless of the grid structure. Another property implemented in the model is the bidirectional power flow, which is not common in today's distribution grid. The decision for allowing this is to showcase all possibilities of flexibility. Nonetheless, the model allows the implementation of a constraint, which prohibits bidirectional power flow.

In this master thesis, the developed multi-period hybrid AC/DC-OPF model has been written in Python. In order to formulate the optimization problem, an open-source optimization modeling language called Pyomo has been used. To be able to solve the mathematical formulated optimization problem, a solver is required. A solver is a mathematical software that takes a problem description and calculates the solution with a given algorithm [66]. In this instance, this solver was Gurobi. The chosen software combination is due to the authors' familiarity with the tools and that the said software also satisfies the given criteria for solving the optimization problem. It is worth mentioning that it is not required to use this specific combination of software to solve this problem. A vital property of the solver is the capability needed to solve convex system, which is typical quadratic programming. Appendix B presents the definition of the function, which incorporates the multi-period hybrid AC/DC-OPF model. No additional code for data acquisition or storage has been included in the appendix.

5.1 Network and Model Explanation

A network or power grid is defined as an interconnected network for delivering power from producers to consumers. Depending on the country, this grid can be divided into distribution and transmission grid. These grid types will be of interest since the multi-period hybrid AC/DC-OPF model focuses on solving the OPF for both grid types simultaneously. For simulations, two existing grid models will be used to avoid the cumbersome work of designing a grid from scratch. For the distribution grid, a typical radial grid has been chosen with 33 nodes based on the paper [64]. The transmission grid will use a meshed grid consisting of 9 nodes as designed in [65]. Table 3 presents an overview of the basic data for the two grids.

Table 3: Basic grid data for case 9 and case 33bw.

	Number of nodes	Number of lines	Number of generators	Number of loads	Base Voltage [kV]	Base Power [MVA]	Grid type
Case 33bw	33	37	0	32	12,66	100	Distribution
Case 9	9	9	2	3	345,0	100	Transmission

In order to supply the developed model with these two grids, a connection first needs to be made between them. This connection is created by merging two nodes, one from the transmission and the other from the distribution grid. In this thesis, the choice fell upon node two of the transmission and node one of the distribution grid. This way, node one will become the feeder node for the distribution grid, while transmission's grid node two will view the distribution grid as a new load. The red line in figure 11 depicts the common node between these two grids.

Both grids presented in [64] and [65] have gone through certain customizations for this thesis. The first change is removing the generator in node two of the transmission grid to induce congestion more easily. When the generator in node three reaches its maximum capacity, the remaining power production will result from node one, defined as the slack node. This change will result in a more even power flow distribution between lines 4-6 and 4-6. In addition, this will also allow for higher power flow on line 4-5, as more power can be acquired from the slack node. Implementing one extra load in node 5 is another change, further enhancing the power flows due to the load's distant placement from the generation units. The distribution grid, on the other hand, has been supplied with a range of DFRs. The DFR used in this grid is a combination of load-shifting, DGs, and batteries. The distribution of DFRs has been chosen to allow the test cases to showcase the potential solutions in solving different grid problems. Table 4, 5, and 6 presents data for different DG, load-shifting, and battery used in the distribution grid for the different test cases.

Table 4: Data for DG used in the distribution grid.

Type of DFR	Node nr.	Minimum production [pu]	Maximum production [pu]	Used as Flexibility
DG	9	0,0	0,005	No
DG	10	0,0	0,5	Yes
DG	15	0,0	0,09	No
DG	21	0,0	0,05	No
DG	25	0,0	0,08	No

Table 5: Data for nodes that use load-shifting in the distribution grid.

Type of DFR	Node nr.	Maximum load-shifting decrease [pu]	Maximum load-shifting increase [pu]
Load-shifting	5	0,0003	0,0003
Load-shifting	10	0,0003	0,0003
Load-shifting	26	0,0003	0,0003

Table 6: Data for batteries in the distribution grid.

Type of DFR	Node nr.	Initial state of charge [pu]	Minimum state of charge [pu]	Maximum state of charge [pu]	Maximum charge and discharge capacity [pu]	Charge and discharge efficiency (%)
Battery	11	0,001	0,0	0,002	0,0002	99
Battery	19	0,002	0,0	0,004	0,0003	99
Battery	33	0,0005	0,0	0,001	0,00025	99

In figure 11, comparison of the combined transmission and distribution grid can be seen. The figure presents the common grid before (left) and after (right) DFR's implementation. The red line emphasizing node 2/1 indicates the connection point between the distribution and the transmission grid.

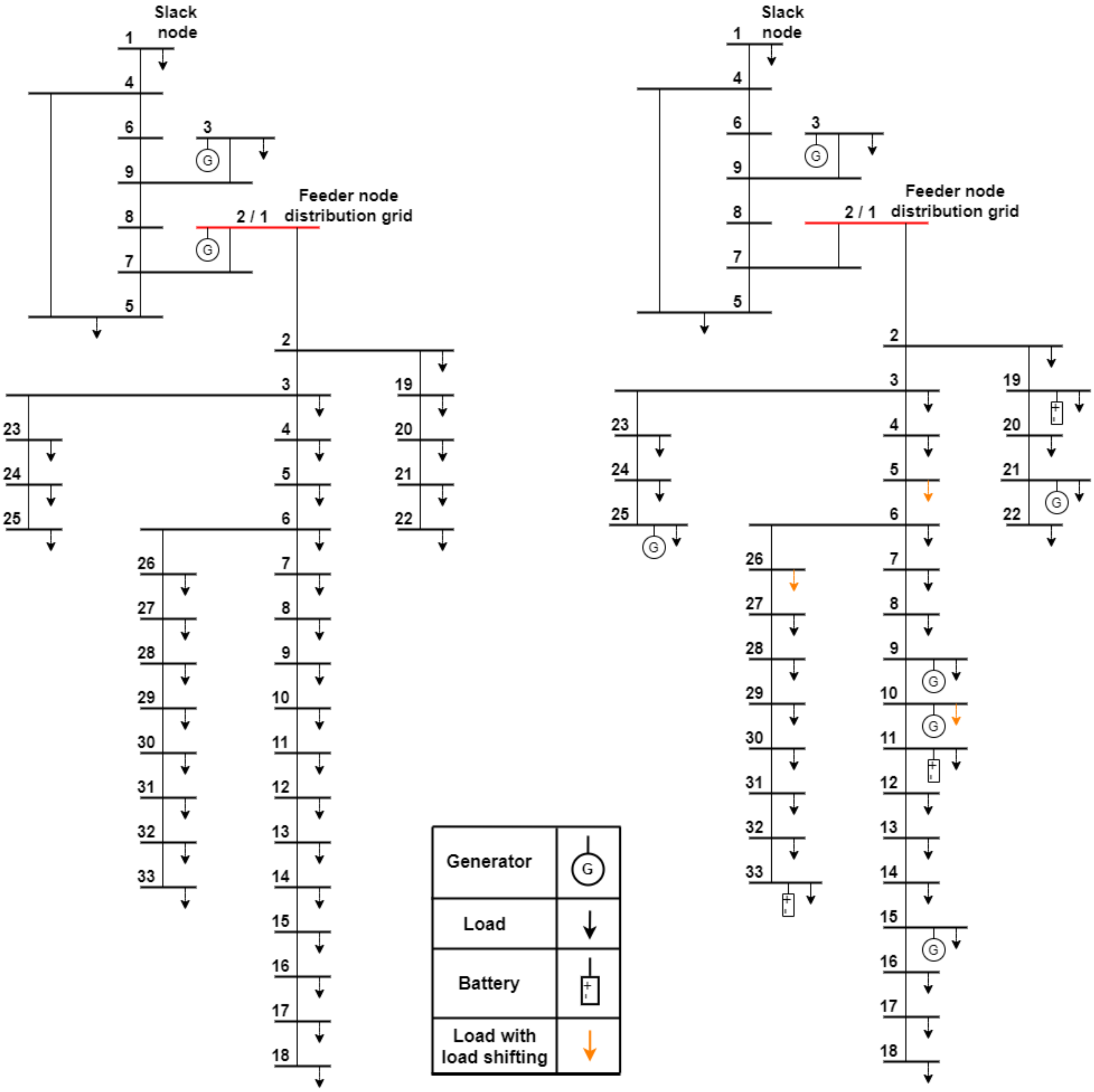

Figure 11: Combined transmission and distribution grid, with and without the applied modifications.

Table 7: Basic information regarding the used day-ahead data.

Date	Time duration	Price denomination	Volume denomination	Elspot Area
26 of April, 2021	02:00-14:00	EUR/MWh	MWh	N03

Additional modification the distribution and transmission grid has been subject to is the load profile for each node. This modification was conducted in order to perform multi-period simulations with varying load profiles. Another reason for this load modification is to ensure that test cases reflect load scenarios seen in an existing power system, where the consumption varies across the day. To achieve this, data regarding price and load from the Nordic power market, Nord Pool [31], has been used and modified in order to fit all test cases. Table 7 presents the necessary information regarding data gathered from Nord Pool.

Table 8: Price determination for each specific DFR.

	Price for Load Shifting	Price for Flexible Generation	Price for Charging and Discharging of the Battery
Day Ahead Price for a Given Period	p_t	p_t	p_t
Price factor	0,35	1	0,35
Resulting Price for each DFR	$0,35 \cdot p_t$	$1 \cdot p_t$	$0,35 \cdot p_t$

Table 8 presents the computational process behind acquiring different DFR prices. For each asset, day-ahead price (p_t) has been used as a starting point. This price has then been multiplied with a price factor for each particular type of DFR. This approach allowed to determine the price of all DFRs for each time unit while ensuring the relationship between price and demand to endure.

Creating the loads for different nodes and periods takes a similar approach to the one used for price setting, as seen in figure 13. Bought volume for each hour in the day-ahead market is used [67]. Since the day ahead market operates on a time resolution of 1 hour and the LFM operates on a quarterly-hour time resolution, equation 29 is used to generate load for these missing periods. Here, ($L_{i,n}$) is the load for a given quarter-hour, (L_i) the load for the current hour, while (L_{i+1}) is the following hour. The variable (n) lies between 1 and 4 and decides the quarter-hour of the LFM. For example, for $i = 1$ and $n = 1$, the equation will determine the load for the first simulation quarter between 02:00 and 02:15.

$$L_{i,n} = L_i + \frac{(L_{i+1} - L_i) \cdot n}{4} \tag{29}$$

Following the production of this data, it is converted to pu value with 100MVA as the reference power. Each node is then given an individual load factor multiplied with the pu value for bought volume during a given period of the day-ahead market. The load factor value also scales the load for each node to become compatible with the rest of the grid, so the load does not become too large or small. This scaling leads to a load that varies throughout the simulation period while also following the day-ahead prices as shown by figure 12. Here, one can see a load that increases and decreases according to the day ahead price set by the day-ahead market. While the load will vary on a case-to-case basis, this load profile is used as a basis for each case's creation. This entire process is summarized by figure 13.

Figure 12: Correlation between the total load profile of the distribution grid and the day ahead prices.

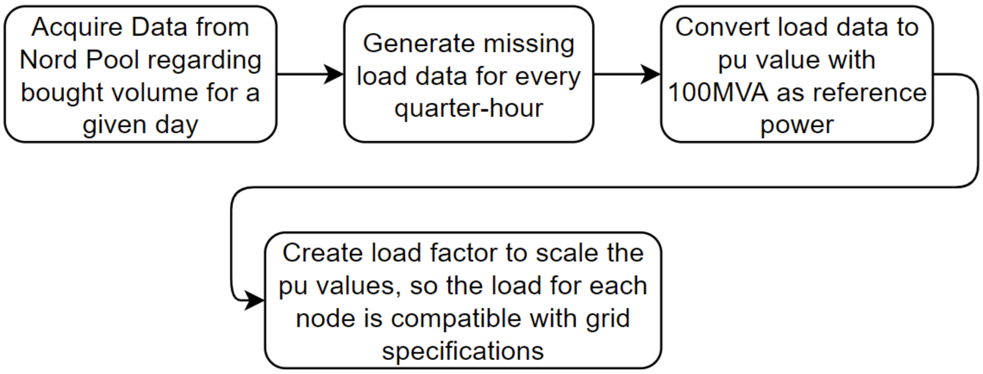

Figure 13: Explanation of the process of load data generation.

The development of realistic pricing and generating load scenarios are considerably comprehensive and complex. While this thesis's primary focus lies in developing a multi-period hybrid AC/DC-OPF model, data regarding loads and pricing is required to perform test cases. Therefore, some effort had been put in order to produce acceptable cases. The chosen approach for generating prices and load data has brought certain simplifications. Therefore, the pricing for DFRs or load scenarios may contain inaccuracies when compared to a real-life scenario. Nevertheless, the load scenarios are adequate to showcase the multi-period hybrid AC/DC-OPF model as proof of concept. For more comprehensive data which remains unchanged for each test case, see Appendix C.

For each case, the model performs two power flow optimization algorithms. The first optimization simulates the day-ahead market and attempts to find the day-ahead dispatch. This simulation would not be necessary for a real-life scenario since the LFM occurs after the day-ahead market. The day-ahead generation is then provided to the model as a parameter for the LFM optimization algorithm, where the optimization program focuses on determining the flexibility dispatch. The results for both operations are then stored in excel files, which enables their further analysis. Figure 14 presents a flowchart describing the model's operation.

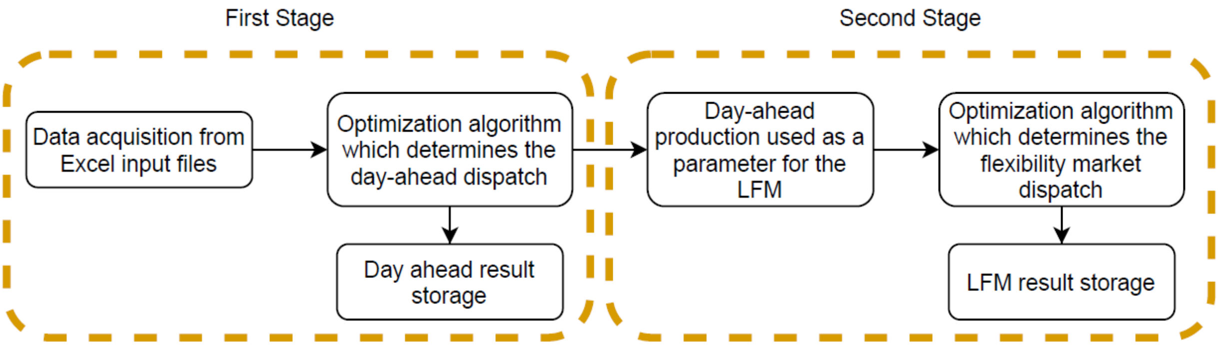

Figure 14: Optimization procedure conducted by the multi-period hybrid AC/DC-OPF model.

5.2 Flexibility Optimization in Distribution Grid

The use of flexibility to optimize the grid's operation may be considered when no ancillary services are required. This optimization is highly dependant on the flexibility prices and the available capacity. The increased use of flexibility closer to the consumption will result in a more evenly distributed power flow between nodes. These results contrast against injecting all power from the feeder node, which significantly increases power losses and voltage drops across the grid. During peak load hours, the resulting current reduction can have a highly beneficial effect on the power losses due to the quadratic relationship between power flow and losses as shown by equation 30. In this equation, (R) is the line's resistance, while (I) is the line current.

$$P_{loss} = 3 \cdot R \cdot I^2 \tag{30}$$

The increasing consumption patterns also increase the stress put on the grid, which flexibility use can alleviate. A possible benefit of this development is the possibility of postponing upgrades or expansions of the distribution system. In order to explore how the distribution grid could benefit from flexibility, a case is designed based on optimizing operation with the use of flexibility. The same grid will be simulated in two scenarios where the flexibility is both excluded and included to establish a comparison. Appendix C and D presents the necessary data used in these simulations. Firstly, figure 15 presents the resulting voltage magnitudes for both cases.

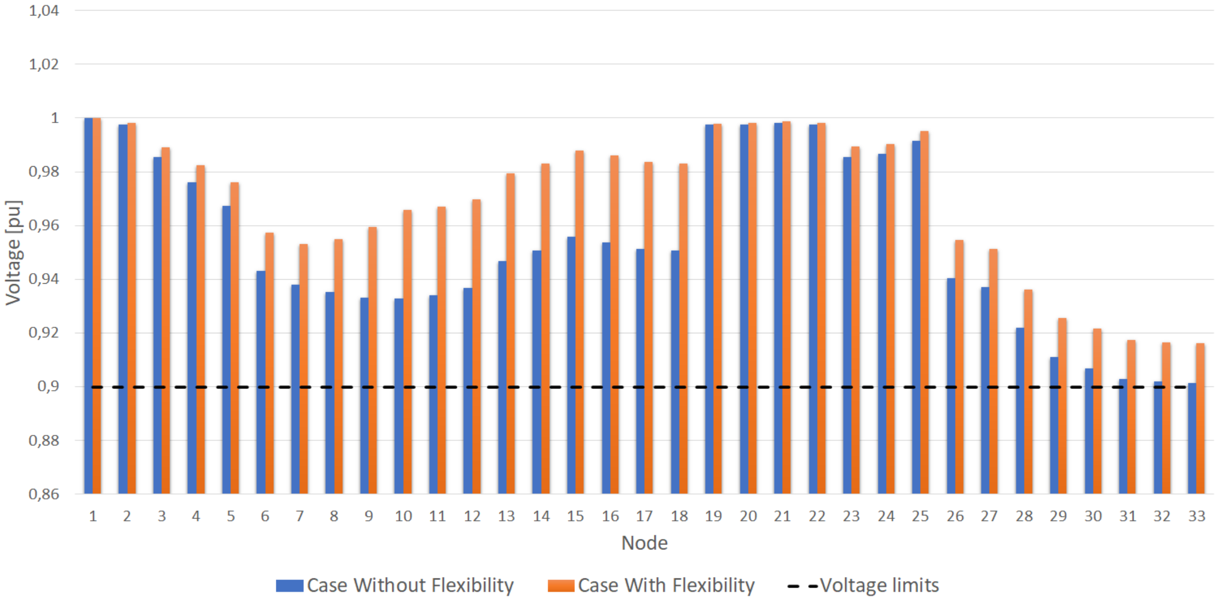

Figure 15: The resulting voltage magnitude for all nodes without voltage regulation during 09:00.

The voltage plot 15 shows that the case with included flexibility results in a voltage closer to the nominal value of 1 pu, which is the optimal outcome. The most significant benefits occur between nodes 6 and 18, where the voltage has increased by up to 0.032 pu. Another noticeable improvement is for the nodes 29 to 32, where previously close to minimum bounds voltages are now well above their required limits. For analyzing how the flexibility assets have responded to the system's optimization, plots showcasing flexibility provided from load and batteries, as well as from flexible generation, are shown in figure 16 and 17, respectively.

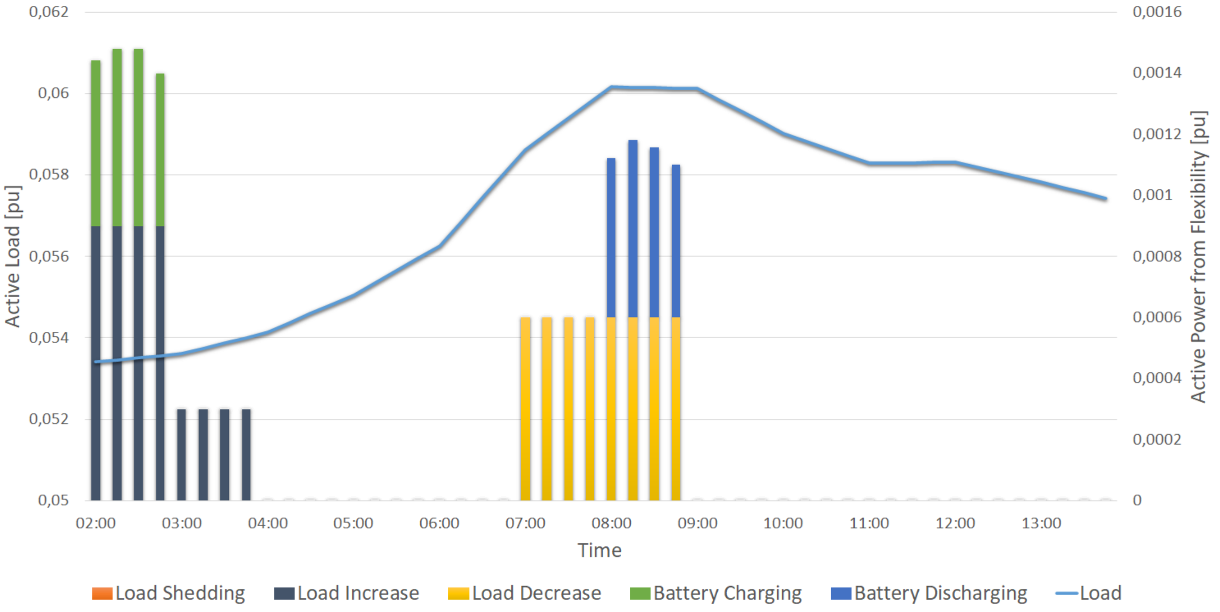

Figure 16: Load and battery flexibility used to optimize the grid.

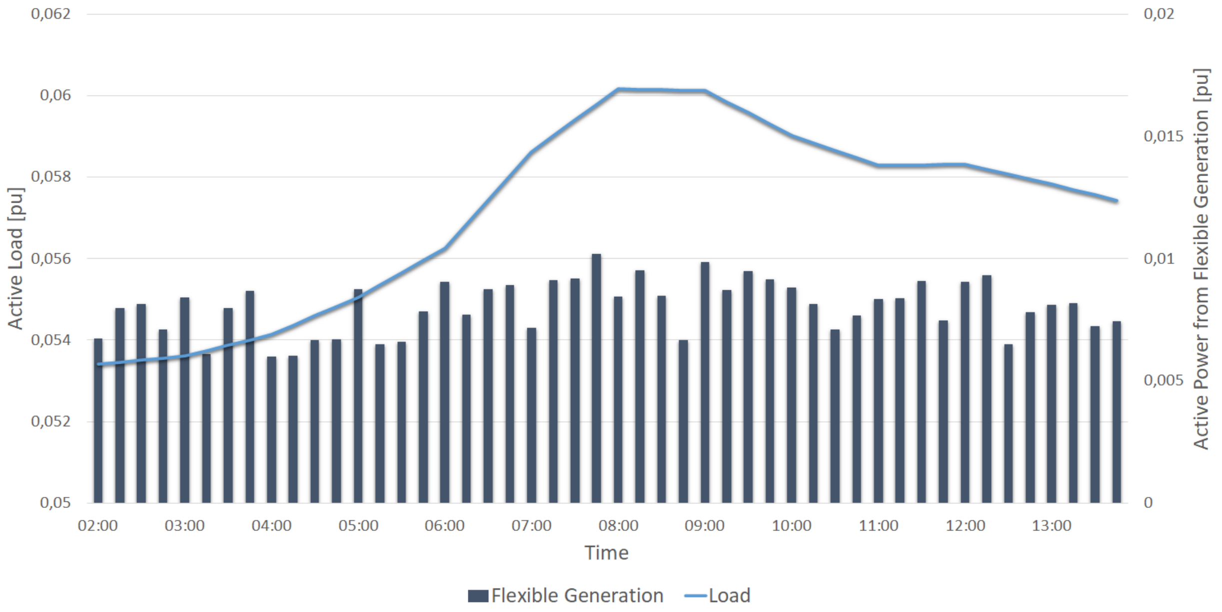

Figure 17: Flexible generation used to optimize the grid.

From figure 16, the flexibility response presents a load increase and charging of batteries during load's off-peak hours. When the peak hour occurs, an opposite response transpires where the load decreases and batteries are discharged. An important observation is that power production can cover the load, since no load shedding has been used. As shown in figure 17, the flexible generation has a reasonably constant output throughout the day due to the minor variations in load. Due to the flexible generation price, the model found it unfit to employ the total capacity of the flexible generation. The following plot will analyze the power injected from transmission to distribution grid and the resulting change in active power losses, as shown in figure 18.

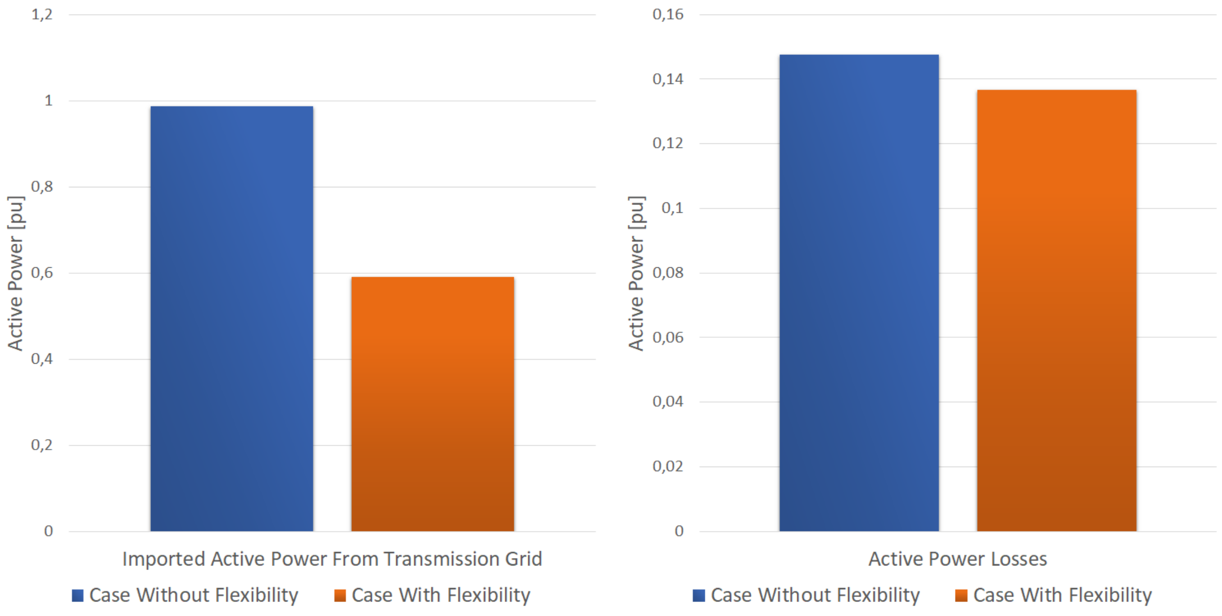

Figure 18: Imported active power from the transmission grid and power losses for both cases.

Plot 18 shows that a considerable decrease in the imported active power from the transmission grid has occurred with the inclusion of flexibility in the optimization model. This result could be a significant step towards future distribution grid self-sufficiency. A slight decrease in power losses has also occurred due to the reduced current flows within the distribution grid, as previously explained by the equation 30. The result of optimizing distribution operation with flexibility for this case is a decrease of 40 % in imported active power from the transmission grid and a 7.5% decrease in active power losses for the distribution grid.

5.3 Solving Voltage Problems in Distribution Grid

This test case presents the model's capability in providing voltage regulation. Voltage problems will occur by creating a peak-hour active power consumption in the distribution grid, leading to voltage magnitude below the allowed limits. If requirements from EN 50160 are to be followed, which is the case here, the minimum criteria are 10% above or below nominal voltage value for 10 minutes duration [68]. This voltage magnitude variation will take place during the periods 08:00, 08:15, and 08:30. Appendix E gives an overview of all load magnitudes used for this case. In addition, all other necessary data is shown in Appendix C.

The goal in this test case will focus on solving the voltage magnitude problem in two different ways. One is to restore the voltage magnitude without flexibility, while the second will include it. In order to achieve this voltage regulation, a voltage optimization constraint is implemented in the multi-period hybrid AC/DC-OPF model, or more specifically, in the SOC-ACOPF part of the optimization model. This constraint maintains the voltage magnitude within a range of ±10% of the nominal voltage, where the nominal voltage is $1.0pu$. The hypothesis is that this constraint will force the multi-period hybrid AC/DC-OPF model to use more of the active power from the DFR to maintain the voltage magnitudes. Equation 31presents the resulting formulation for the implemented voltage constraint. Here, (u_i) is the auxiliary variable for voltage magnitude for a given node, while (u_i^{min}) and (u_i^{max}) are the minimum and maximum bounds which ensure its proper magnitude.

$$u_m^{min} \leq u_m \leq u_m^{max} \tag{31}$$

5.3.1 Voltage Magnitude Without Voltage Regulation

In the first round, the results present the performance of two simulations without voltage regulation. For the first simulation, the model tries to determine voltage magnitudes without any flexibility present in the system. The same applies to the second case, but here the flexible capacity is included. The purpose of these simulations is to establish a basis for comparison. This example will also showcase how the hybrid AC/DC-OPF model will react to a high active load case, which will lead to a substantial voltage drop in the distribution grid.

Figure 19 shows pu values for each node's voltage magnitude during period 08:15. The blue and orange bar indicates voltage magnitudes for a system without and with flexibility, respectively. The black stippled line indicates the minimum voltage magnitude that is acceptable for the developed optimization model, hence 90% of nominal voltage magnitude [68]. For the cases with and without flexibility, the model can maintain voltage magnitude for nodes 1 to 27. For nodes 28 to 33, which are further down the network, as shown in 11, the voltage drops below the minimum criteria. In this case, this is an acceptable result as the voltage regulation has not yet been considered.

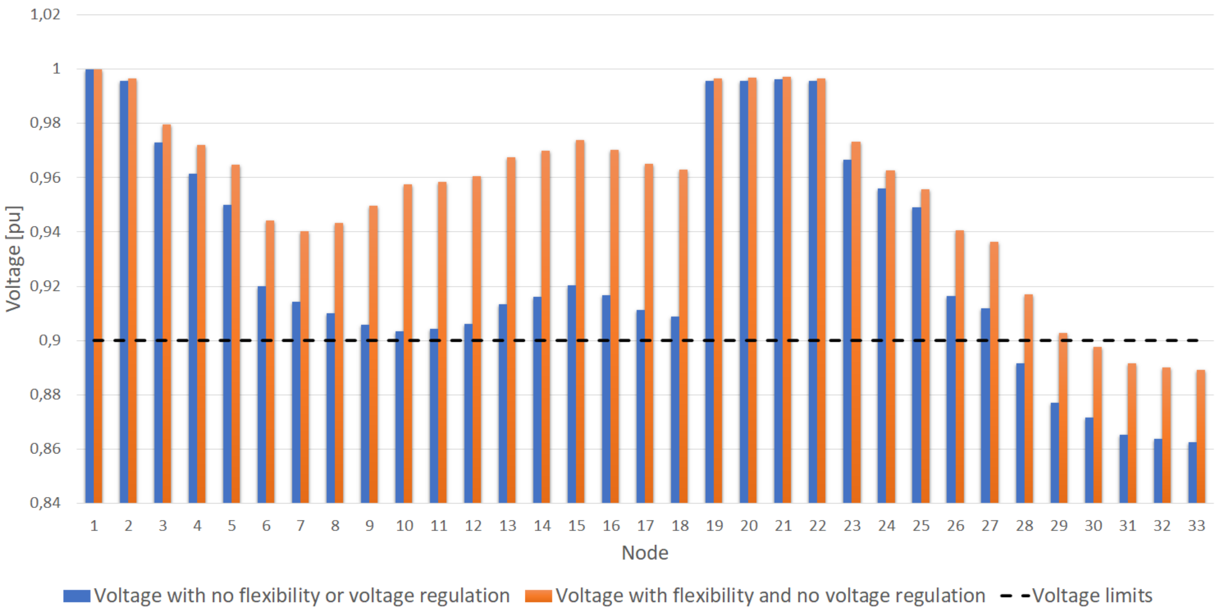

Figure 19: Voltage magnitude for all nodes without voltage regulation for time period 08:15.

The use of flexibility has provided the model with significantly improved voltage magnitudes than for the case with no flexibility. This outcome is due to increased active power production from flexibility, resulting in lower currents and lower voltage drops across the grid. In addition, this also leads to a reduced power injection from the feeder node, which further decreases the power flows between nodes 1 through 8, as seen in figure 21. Reducing the power flow in lines also agrees well with the theory explored in the sub-chapter 2.3, where reducing the active power flow over given lines will reduce the voltage drop. Figure 21 displays the comparison between power flow with and without the use of flexibility.

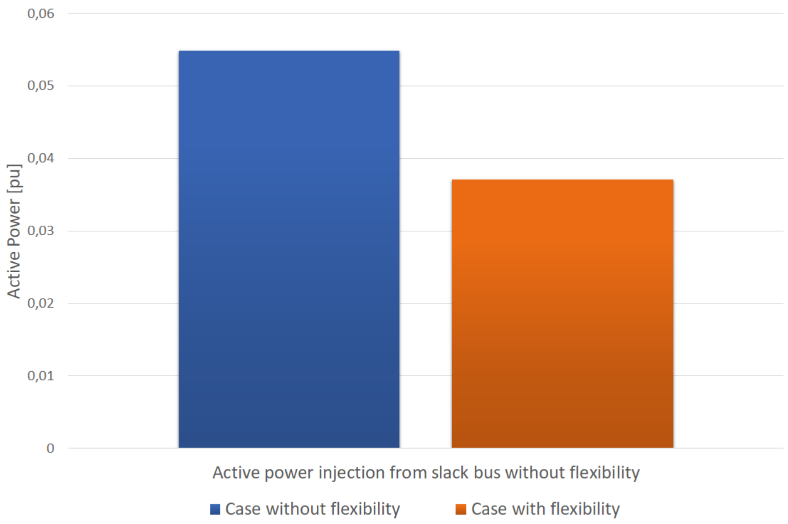

Figure 20: Active power supplied from feeder node in distribution grid for time period 08:15.

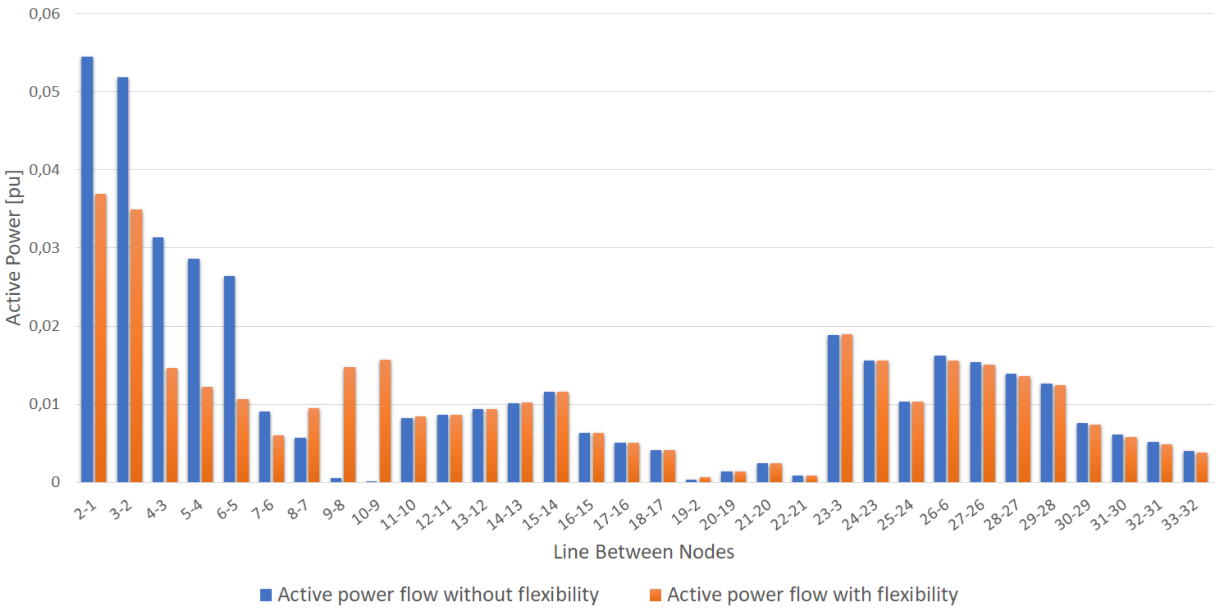

Figure 21: Active power flow in lines with and without DFR contribution.

As previously stated, the reduction in active power injection from the feeder node is affected by the active power production from the DFRs. In figures 22 and 23 a visualization is presented of how the different DFRs respond to the peak-hour consumption. From figure 22 it can be seen that battery charging, and load increase is occurring at the start of the operation. When the peak hour occurs later that day, the battery discharge and load shifting reduce consumption to contain the increased load during that period. A similar response is seen in figure 23, where the flexible generation's output has increased during the peak load period. The inclusion of these assets in the model has allowed it to cover the demand without shedding any load. The exact reason why the model has chosen to charge the batteries and increase load as it did, is due to the low prices. During 02:00, the day ahead price is at its lowest, as shown in figure 12, and thus it is most beneficial to charge batteries and increase the load at this time.

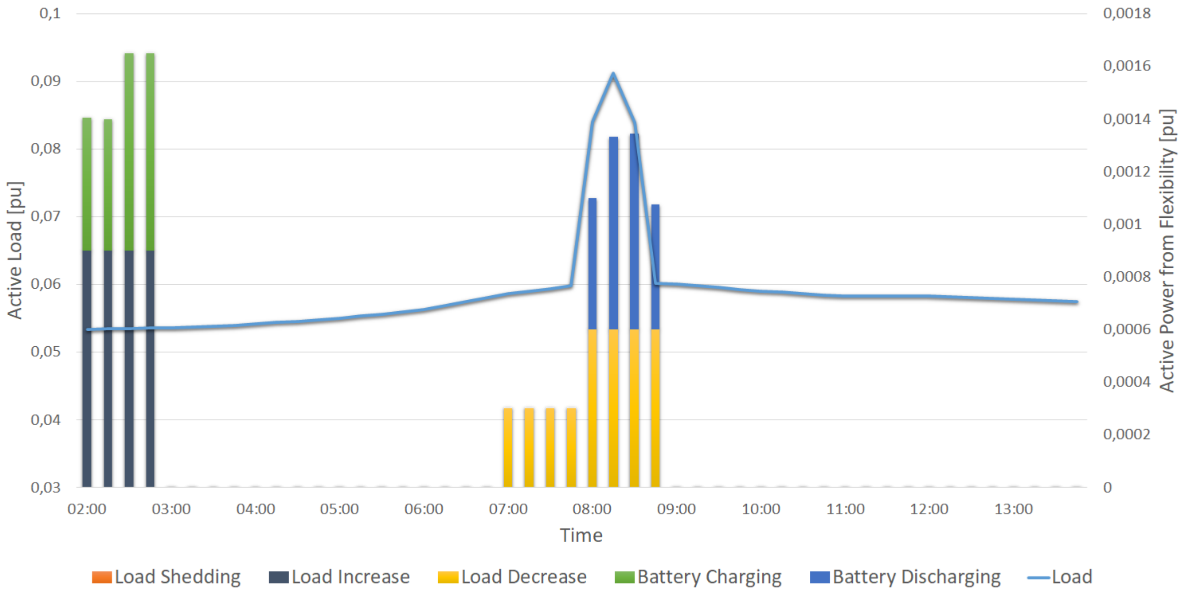

Figure 22: Total amount of load-shifting and battery response to total load in the distribution grid.

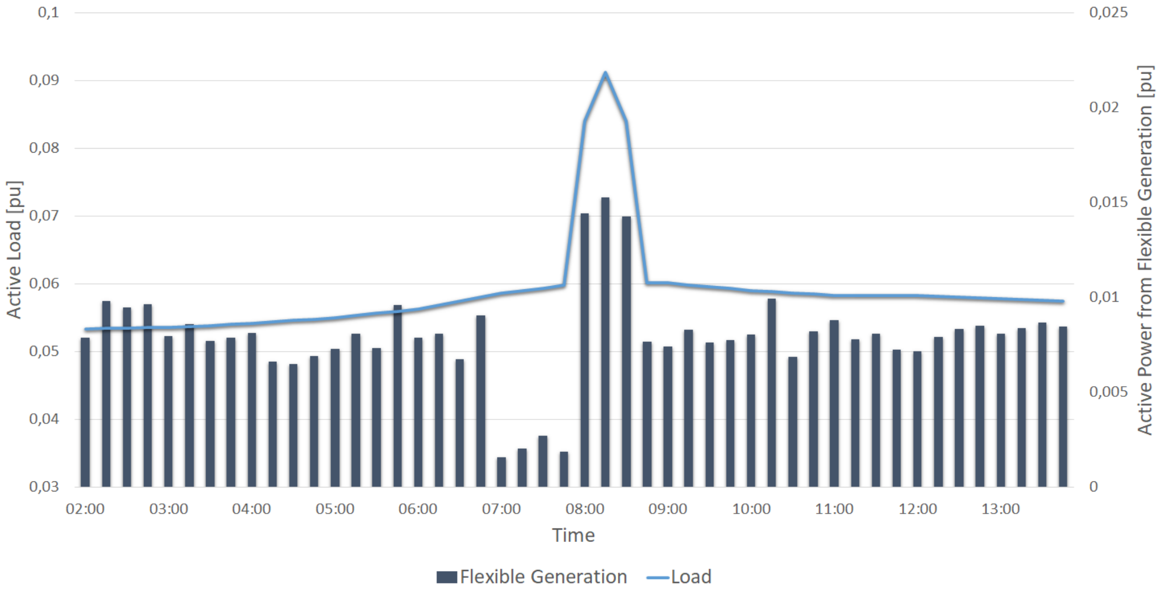

Figure 23: Flexible generation's response compared to total load in the distribution grid.

5.3.2 Voltage Magnitude With Voltage Regulation

Now that the voltage problem in the grid has been showcased, voltage regulation is implemented to increase voltage magnitudes above their minimum criteria. The simulation will take the same approach as previously, resulting in two cases where the flexibility is excluded and included. This approach enables the establishment of a comparison of how flexibility affects the system. Figure 24 presents voltage magnitude for all nodes during period 08:15. The blue and orange bars represent the voltage magnitudes without and with the use of DFRs, respectively. For nodes 28 to 33, before experiencing under-voltages, have now voltage magnitudes above the minimum criteria. The resulting voltage profile across all nodes has also improved when compared to the case without voltage regulation.

Figure 24: Voltage magnitude for all nodes with voltage regulation on node 33 for time period 08:15.

To cope with low voltage magnitudes on nodes 28 to 33 due to peak hour consumption, the multi-period hybrid AC/DC-OPF model has performed different measures for the case with and without flexibility. Without flexibility, the optimization model has taken the action of shedding part of the load on nodes 29 to 33 by $0,008163pu$, which is not a desirable outcome as described in chapter 2.1.4. This action has led to reduced power injection from the feeder node, resulting in a lower power flow and reduced voltage drop. Such response from the system has made it possible to contain the voltage magnitudes within their allowed limits. For the other case, the capacity provided from flexible assets has allowed maintaining a proper voltage without shedding the load, which is a much more suitable outcome. Figure 25 portrays the used flexibility throughout the simulation period.

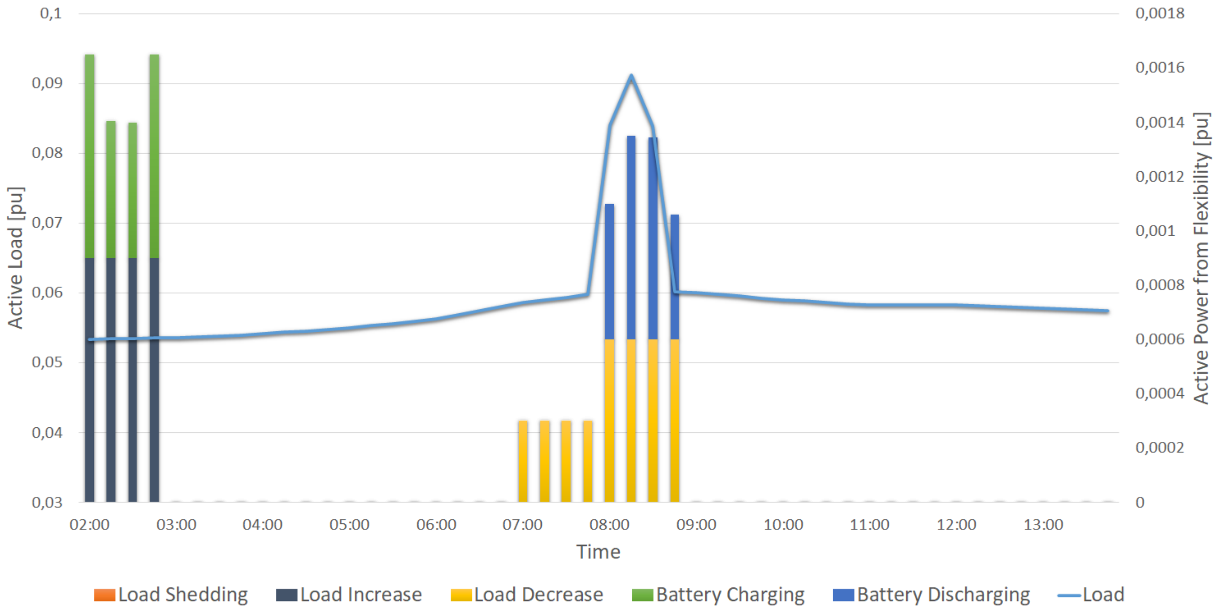

Figure 25: Total amount of load-shifting and battery response to the total load in the distribution grid.

With flexibility, more economically efficient measures are available to reduce voltage drops. From figure 25 it occurs that the flexibility activation with voltage regulation is more or less the same as without voltage regulation, as previously shown in figure 22. These results are due to the load profile not being changed between these two cases and no additional battery and load shifting capacity being available. The flexible asset that is not yet operating at maximum capacity is the flexible generation, whose response is shown in figure 26.

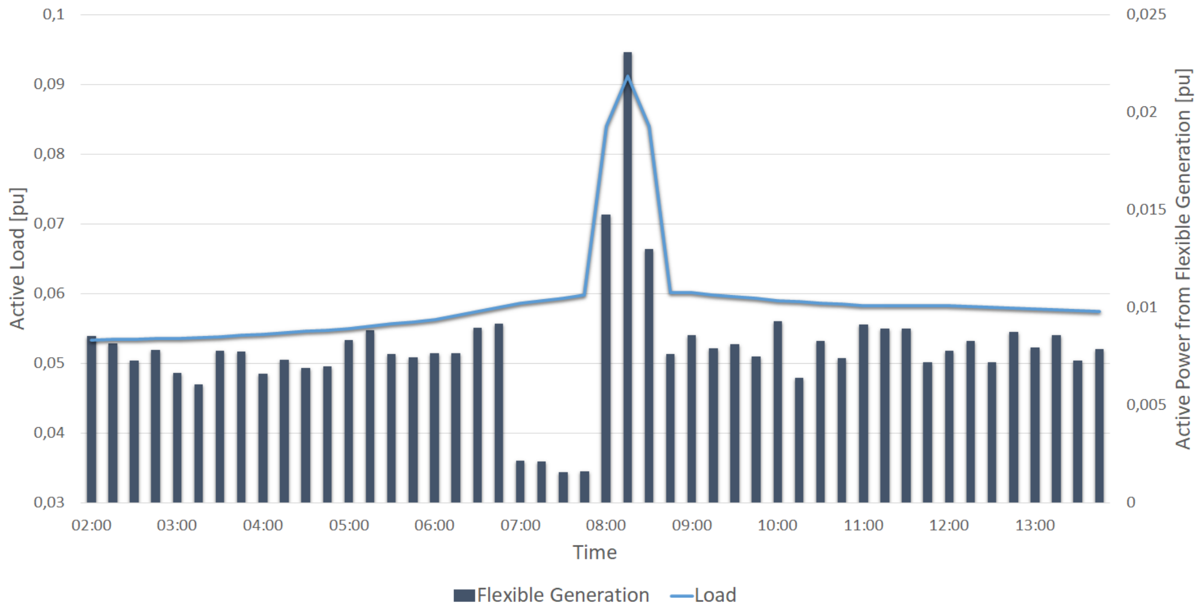

Figure 26: Flexible generation's response to the total load in the distribution grid.

During peak load hours, the flexible generation has considerably increased its active power output to help maintain the voltage. This increase from node 10 has also resulted in a lower active power injection from the feeder node before implementing the voltage regulation. Another effect of the increased production is the more even distribution of active power flow across the distribution grid. Figure 27 and 28 present these changes, with the plots of active power injection from feeder node and active power flows in the grid, respectively.

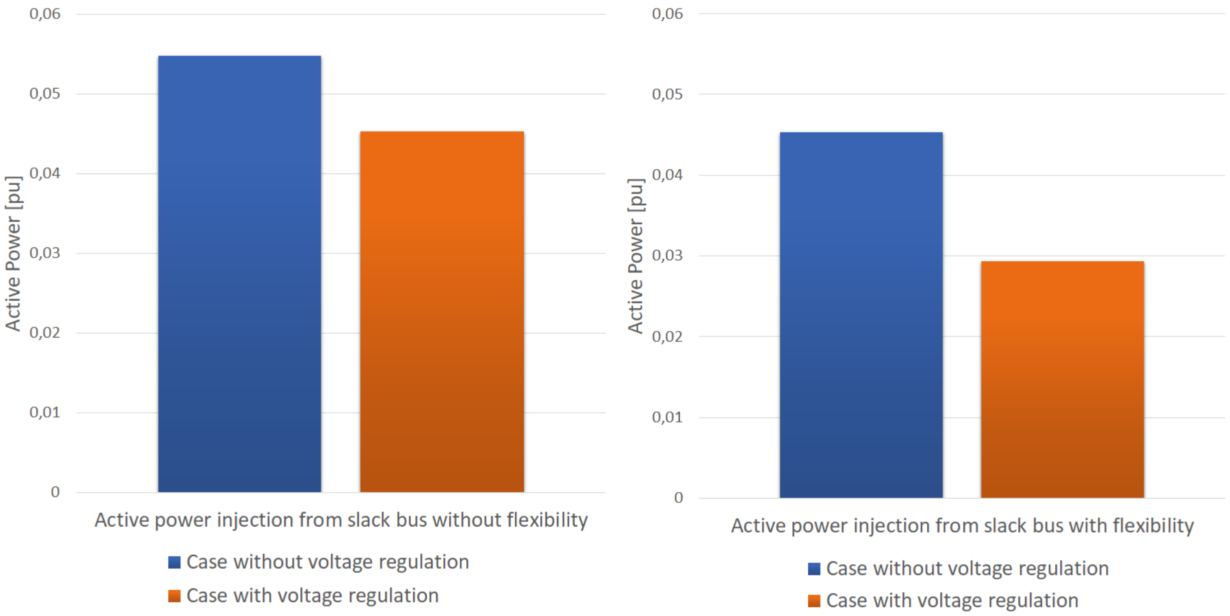

Figure 27: Comparison of active power supplied from feeder node in distribution grid for time period 08:15 with and without voltage regulation.

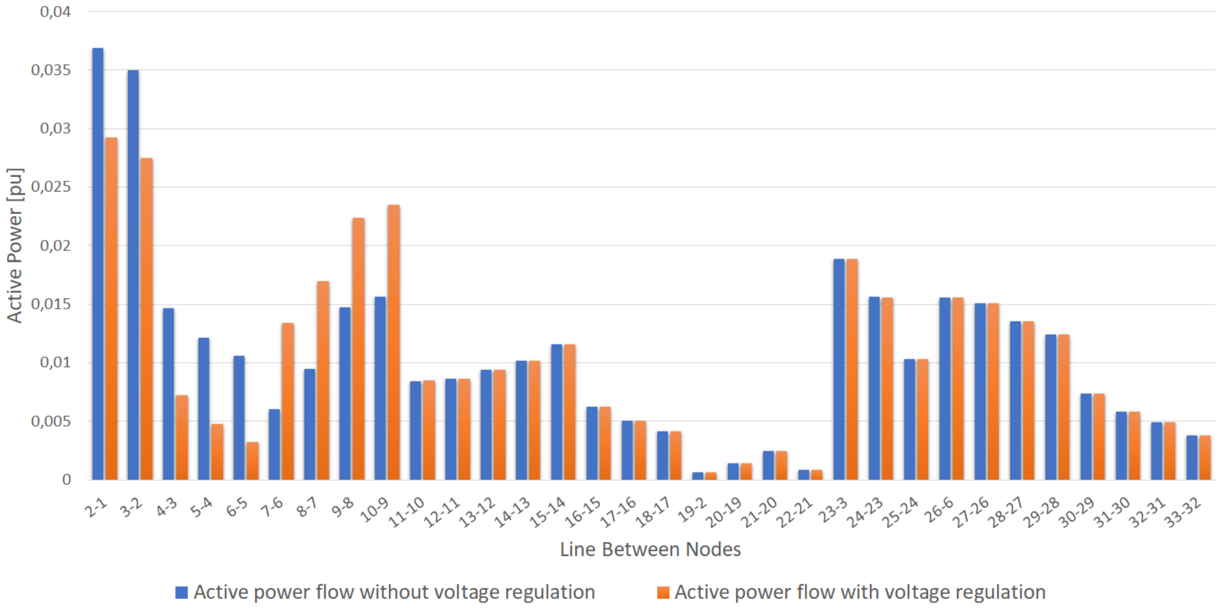

Figure 28: Active power flow in lines with and without voltage regulation.

The reduced power injection from the feeder node and more evenly distributed power flow have increased voltage magnitude across the distribution grid. This increase is of such magnitude that the model can keep the system's voltage above minimum criteria in the branch between nodes 26 and 33, which previously had voltage issues. Flexibility was thus able to increase the voltages across the distribution grid effectively.

5.4 Solving Congestion in Distribution Grid

Another plausible issue that can occur in the distribution grid is potential congestion within the grid. When such an unexpected event occurs, the use of flexibility to alleviate this issue can be highly beneficial. For this sub-chapter, a hypothetical lost grid capacity occurs due to the appearance of an unforeseen event after the day ahead production has been scheduled. The reduced capacity results in the line between nodes 26 and 27 having a new transfer limit of $0,0173$ pu. Implementing this congestion has caused some challenges due to the introduction of square root for calculation of the apparent power, as shown in equation(32).

$$S_{ij} = \sqrt{P_{ij}^2 + Q_{ij}^2} \tag{32}$$

The problem presented by this equation has been avoided by not including the square root but rather calculating the squared apparent power flow instead. The resulting inequality constraint is shown with equation (33). This equation takes into account the power flowing from node 26 to 25 shown with variable (P^{FL}) and (Q^{FL}), load ($P^{L,AC}$) and ($Q^{L,AC}$) and power provided from flexible load ($P^{L,Flex}$) and generation ($P^{G,Flex}$) within node 26.

$$(-P^{FL}_{26-25,t,u} - P^{L,AC}_{26,t,u} - P^{L,Flex}_{26,t,u} + P^{G,Flex}_{26,t,u})^2 + (-Q^{FL}_{26-25,t,u} - Q^{L,AC}_{m,t,u})^2 \leq (P^{FL,max}_{26-27,t,u})^2 \tag{33}$$

Three cases have been simulated in this chapter to answer how the model would respond to such congestion. The first case is modeled without any flexibility present in the system, manifesting what actions are necessary to acquire feasibility. In the second case, flexibility is included in the grid to alter the power flows and satisfy the new line constraint. For the third case, in addition to the flexibility, voltage regulation is also introduced. All data used for these simulations are given in Appendix C and F. The case starts by analyzing the voltage to determine its magnitudes and the effect flexibility has on it, as shown by figure 29.

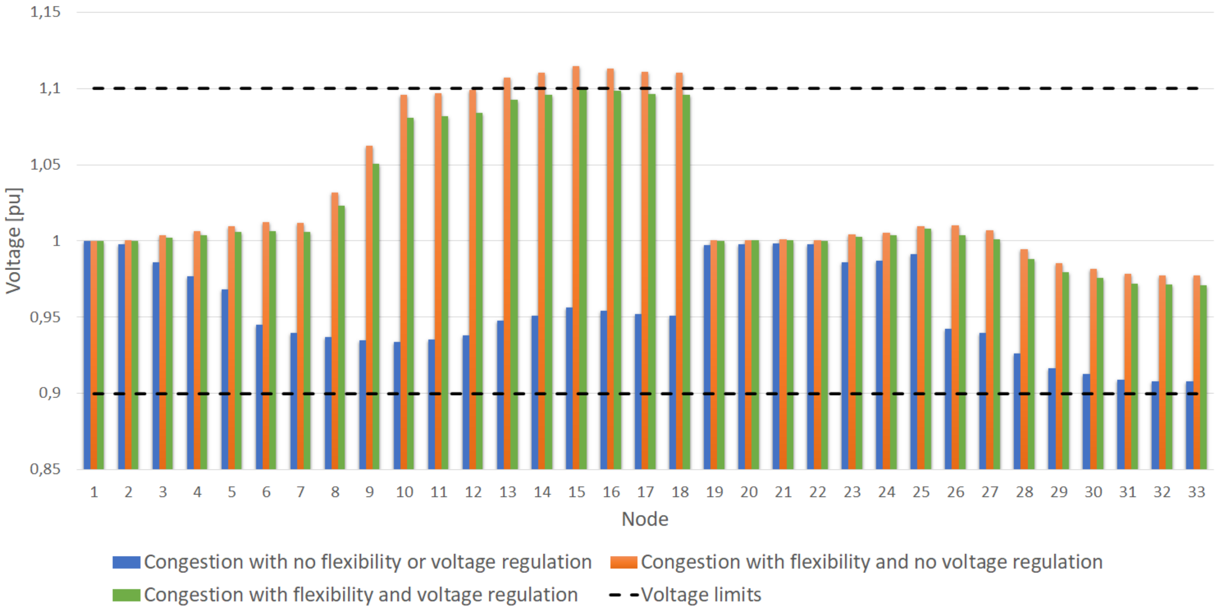

Figure 29: Voltage magnitudes for all nodes for all three cases during 09:00.

With no flexibility or voltage regulation presented in the base case in figure 29, low voltage magnitudes can be seen close to the lower bounds for nodes 31, 32, and 33. The second case improves these results with the inclusion of flexibility provided by DFRs. These improved voltage results are due to the lower voltage drops caused by a more localized production from DFRs. A similar result could be seen in 5.2, where the DFRs have been used to optimize the operation of the grid. Although the new power flow constraint has been satisfied, flexibility has introduced a new issue. During 09:00, nodes 13 to 18 experience overvoltages due to the high production from DFRs, leading to voltage violation. In order to counter this issue, case 3 presents a solution where flexibility is also supplemented by voltage regulation. The resulting voltage has a similar profile across the grid compared to case 2, with voltage magnitude on nodes 13 to 18 now below the upper voltage bound. The previous issue with low voltages for nodes 31, 32, and 33 is also alleviated, resulting in a far better voltage profile. Plots showcasing the combined used volume of each particular flexible asset are shown in figures 30 to 33. The plots also present the total load profile in the distribution grid, which is used to reference the acquired results.

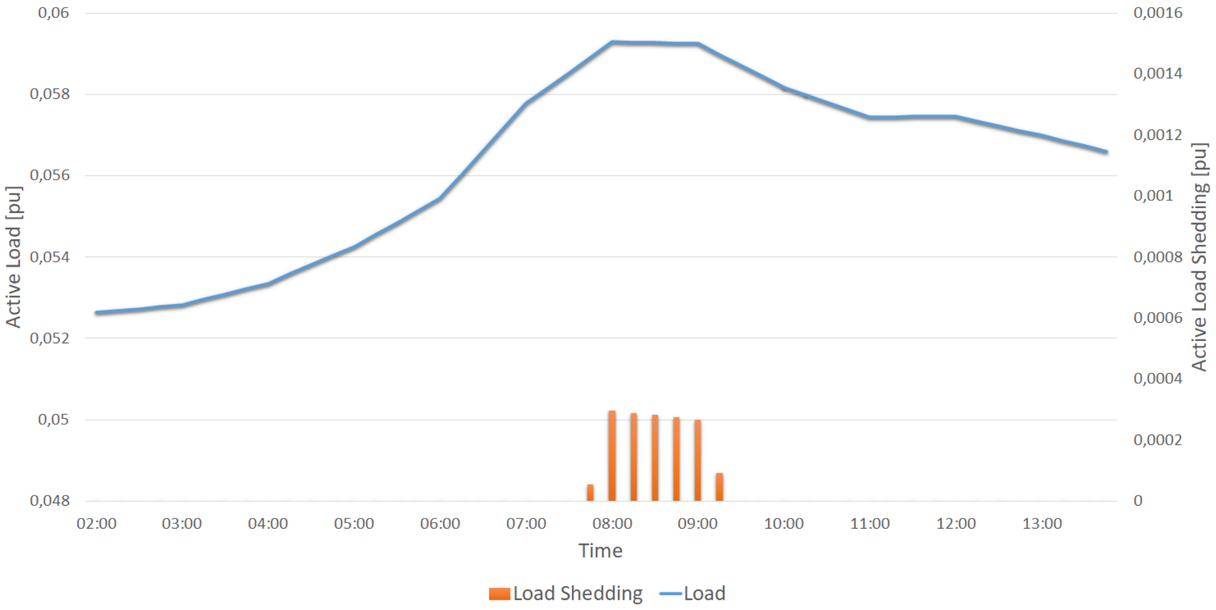

Figure 30: Load shedding used to handle the congestion for case 1.

For the first case, where no flexibility is present, the only available option to acquire feasibility in this grid situation is load shedding. Due to its high costs, this is a highly inefficient solution and DSO's last resort to handle such an issue. Flexibility is a much more attractive and cost-efficient solution, which is showcased in figure 31.

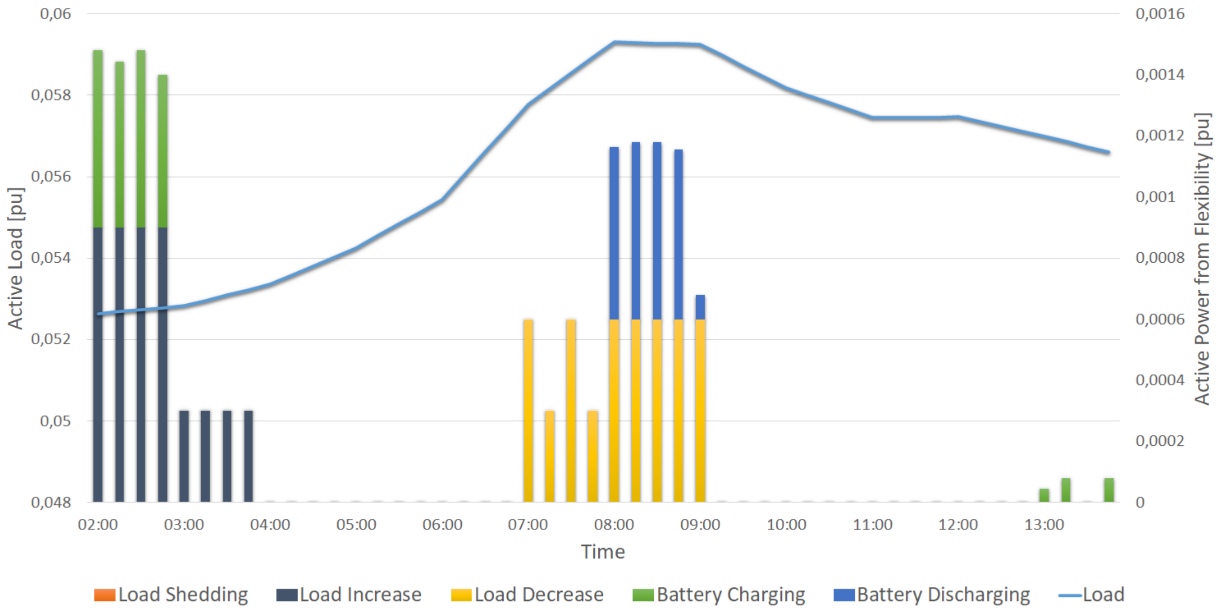

Figure 31: Flexibility and load shedding used to handle the congestion for case 2.

Figure 31 presents the required flexibility dispatch to handle the occurring congestion in the grid. The flexible load has been increased at the simulation start and decreased accordingly during peak load hours when the congestion occurs. The battery has a similar response, where it is being charged at the beginning of the simulation and discharged during peak load hours. A short charging period also takes place during the last hour of the simulation. This interval results from the battery's need to end the simulation with the same charge as the initial one. From the model, it is also apparent that no load shedding is required to acquire feasibility, which is a highly desirable outcome.

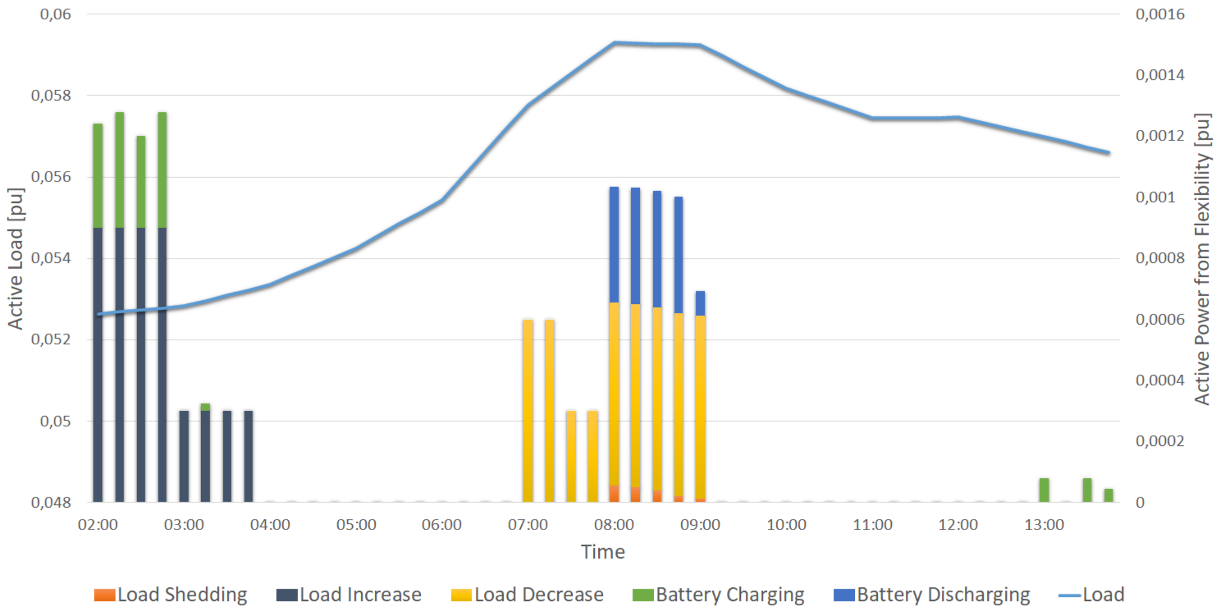

Figure 32: Flexibility and load shedding used to handle the congestion for case 3.

For case 3, voltage regulation has been applied to constraint the voltage magnitude during peak load hours, resulting in a flexibility dispatch as shown in figure 32. When comparing the flexibility dispatch between cases 2 and 3, one can see a similar response. A noticeable difference is the use of load shedding. Due to the voltage issues in case 2, re-dispatching flexibility alone was insufficient to acquire a feasible solution for case 3. Therefore, load shedding had to be used to satisfy the voltage requirements. Lastly, figure 33 present flexibility generation. Due to the higher production capacity than the other DFRs, the flexible generation is shown separately from the other results to ensure data visibility.

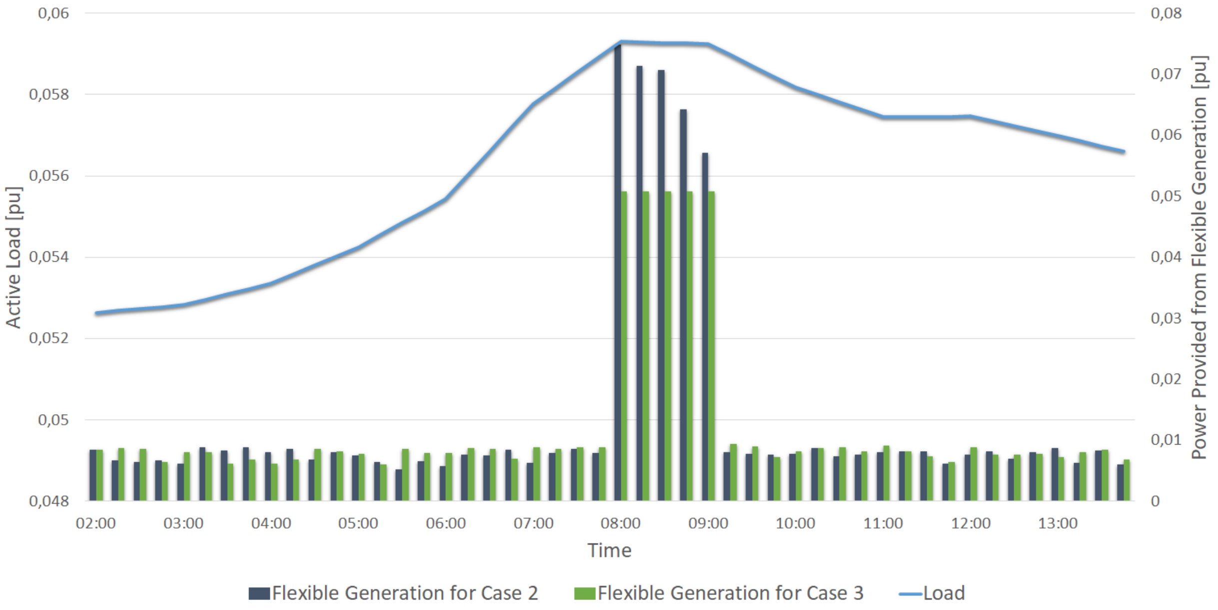

Figure 33: Flexible generation used to handle the congestion for case 2 and 3.

From the figure 33, one can see a constant provision of power from the flexible generation, with a sudden increase between 08:00 and 09:00. This increase is due to the occurring line congestion between nodes 26 and 27. This sudden increase is lower for case 3 due to the implementation of a voltage constraint.

5.5 Solving Congestion in Transmission Grid

The potential to use flexibility in providing ancillary services is not limited to the distribution grid only. Activating a sufficient amount of DFRs can impact the imported power from the transmission grid and alter its flow. With enough capacity, the power flow may also change its direction, feeding power into the transmission grid. Such a case occurs here, where unexpected congestion transpires in the transmission grid after the day-ahead market has already been cleared. This congestion occurs between nodes 7 and 8 of the transmission grid shown in figure 11, which limits its transfer capacity to 0.33 pu. Three cases are simulated to showcase the distribution grid's possibilities in supporting the transmission grid. The first case presents the dispatch for a healthy transmission grid, where no congestion has yet occurred. The second case presents the same transmission grid as for case 1, but with congestion of line between nodes 8 and 7. Lastly, in addition to congestion, the last case also includes voltage regulation for all distribution grid nodes. All data used for these simulations are given in Appendix C and G. To begin with, voltages for all nodes for operation time 03:30-03:45 are presented in figure 34.

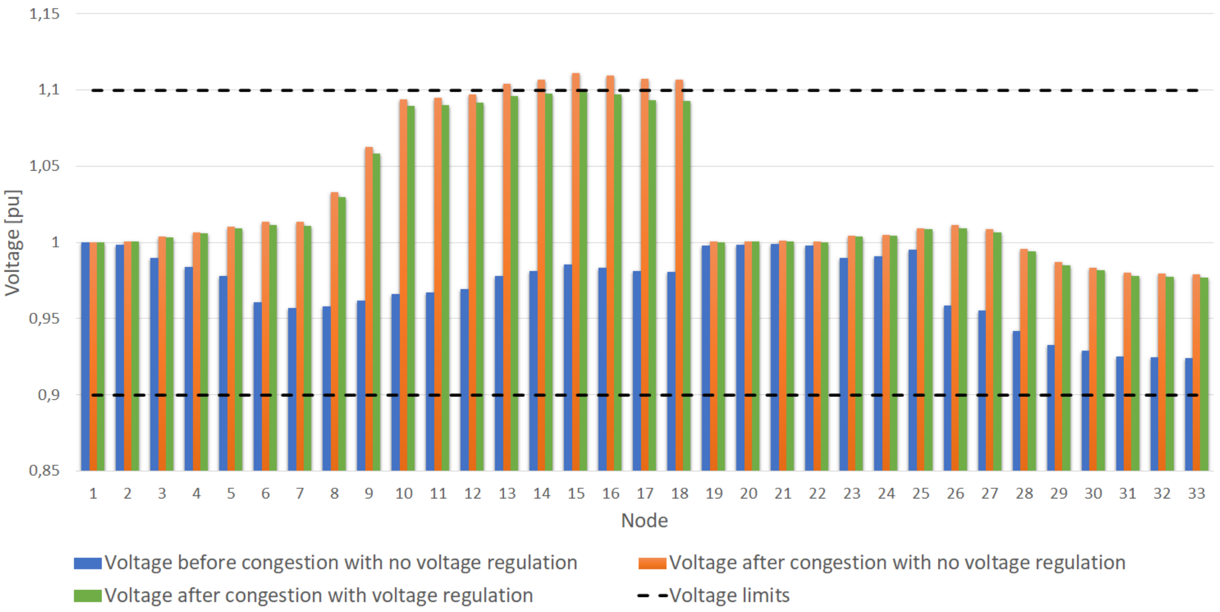

Figure 34: Voltage magnitude for all 3 cases for operation time between 03:30 and 03:45.

From figure 34, case 1 portrays a healthy transmission grid and where the voltage magnitudes are within their limits in the distribution grid. For case 2, a significant increase in overall voltages magnitude has occurred. This increase is due to the higher power production in the distribution grid caused by the congestion in the transmission grid. This development has led to over-voltages for nodes 13 to 18 between 03:30 and 03:45. This issue has been alleviated with the inclusion of voltage regulation, resulting in voltage magnitude within boundary limits, as shown by case 3. Figure 35 presents the total flexibility used for the first case. These results allow the comparison of how the flexibility dispatch has changed due to a congestion for cases 2 and 3 in figure 36 and 37, respectively.

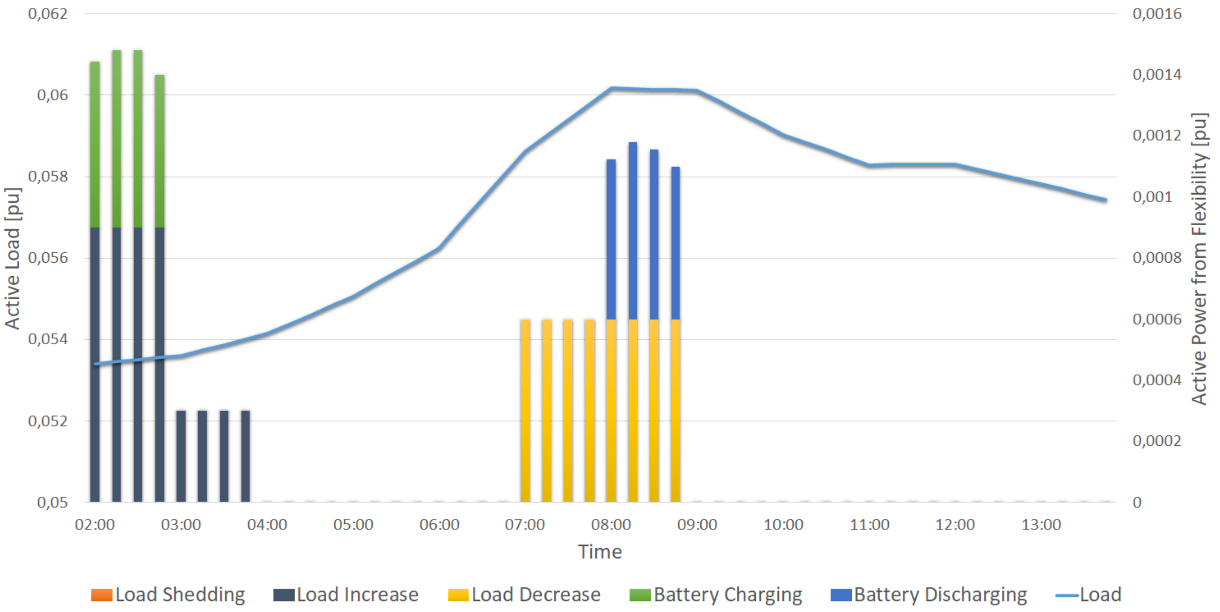

Figure 35: Flexibility and load shedding used in the distribution grid before a congestion in transmission grid has occurred.

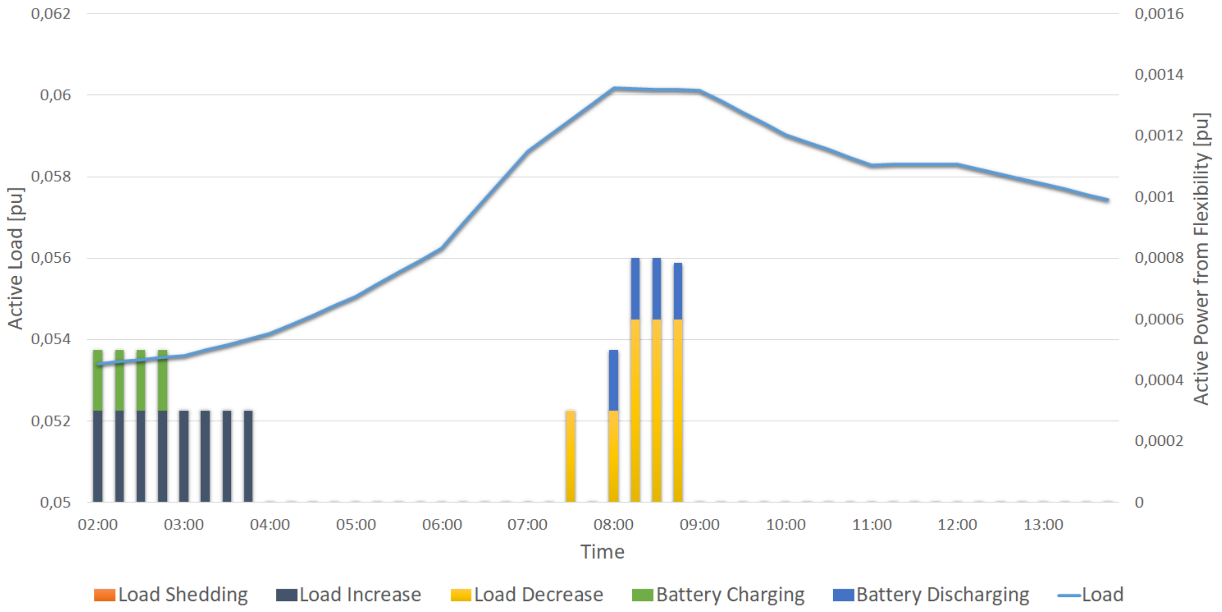

Figure 36: Flexibility and load shedding used in the distribution grid after a congestion in transmission grid has occurred, excluding voltage regulation.

By comparing figure 35 and 36, a significant change in DFR dispatch has occurred. Due to congestion, a reduction occurs in flexibility provision from the flexible load and batteries, compared to figure 35. In the following figure 37, simulation of the same situation with voltage regulation represents DFR dispatch for case 3.

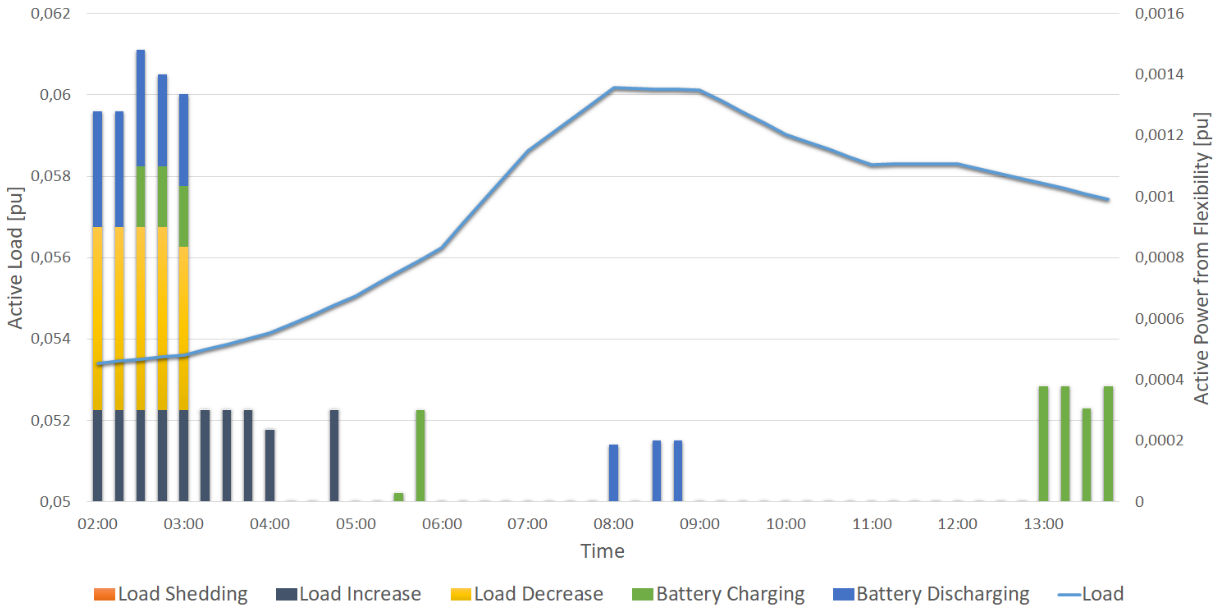

Figure 37: Flexibility and load shedding used in the distribution grid after a congestion in transmission grid has occurred including voltage regulation.

By including voltage regulation in the distribution grid, flexibility dispatch has been affected by a sizable change, as shown by figure 37. A surprising outcome can be seen in this case, between 02:00 and 03:00. During that period, load shifting has resulted in a contradicting response across the system. To support the transmission system while satisfying voltage constraints, node 10 has increased its consumption, while nodes 5 and 26 have reduced it accordingly. This action is due to the need to reduce the voltages, as shown previously in figure 34. The battery's discharge also occurs during this period before being recharged at the end of the simulation. Figure 38 presents the output for the flexibility generators for all three cases.

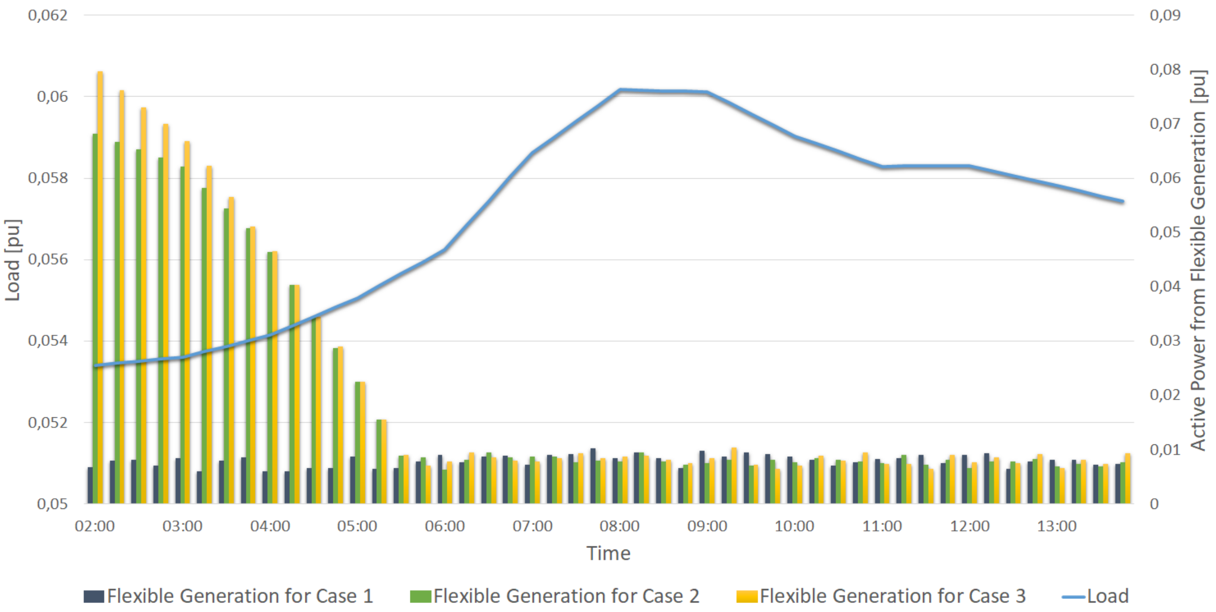

Figure 38: Flexible generation before and after congestion has occurred in the transmission grid.

From the generation dispatch for case 1, one can see a nearly constant generator output throughout the simulation period. When congestion occurs in case 2, the generation between 02:00 and 05:30 increases significantly. A lower increase happens in case 3, due to the implemented voltage constraint preventing over and under voltages in the distribution grid from occurring. This high increase in active power for both cases is caused by the high import of power that resulted from the day-ahead market, leading to a high power flow on lines 7-8 as shown by figure 39.

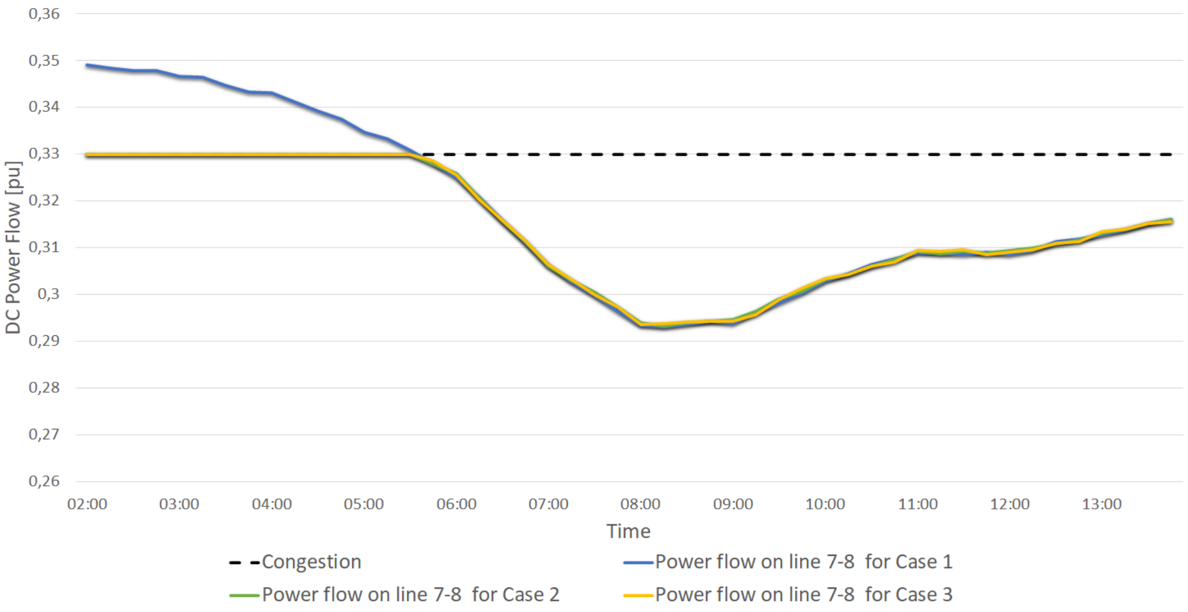

Figure 39: The planned power flow for line 7-8 for case 1, where congestion has not been taken into account.

Figure 39 illustrates the resulting power flow between nodes 7 and 8 as a result of the scheduled power production in the day-ahead market. Here, the green, blue, and yellow lines represent power flow capacity with different measures taken. The black dashed line is the maximum transfer capacity for the line connecting nodes 7 and 8. Case 1 has not taken any measures to meet the congestion requirements, resulting in power flow exceeding the line's transfer capacity, as shown through the blue line. In order to satisfy the transfer capacity in cases 2 and 3, reverse power flow is obtained in the distribution grid by increasing the DFR usage from 02:00 to 06:00. This reverse power flow from the distribution grid results in a power flow reduction between nodes 7 and 8. The green and yellow line in figure 39 displays how the power flow does not exceed the congestion limit in cases 2 and 3. Figure 40 below shows how power flow through the feeder node is effect by the measures taken to counter the congestion in the transmission grid.

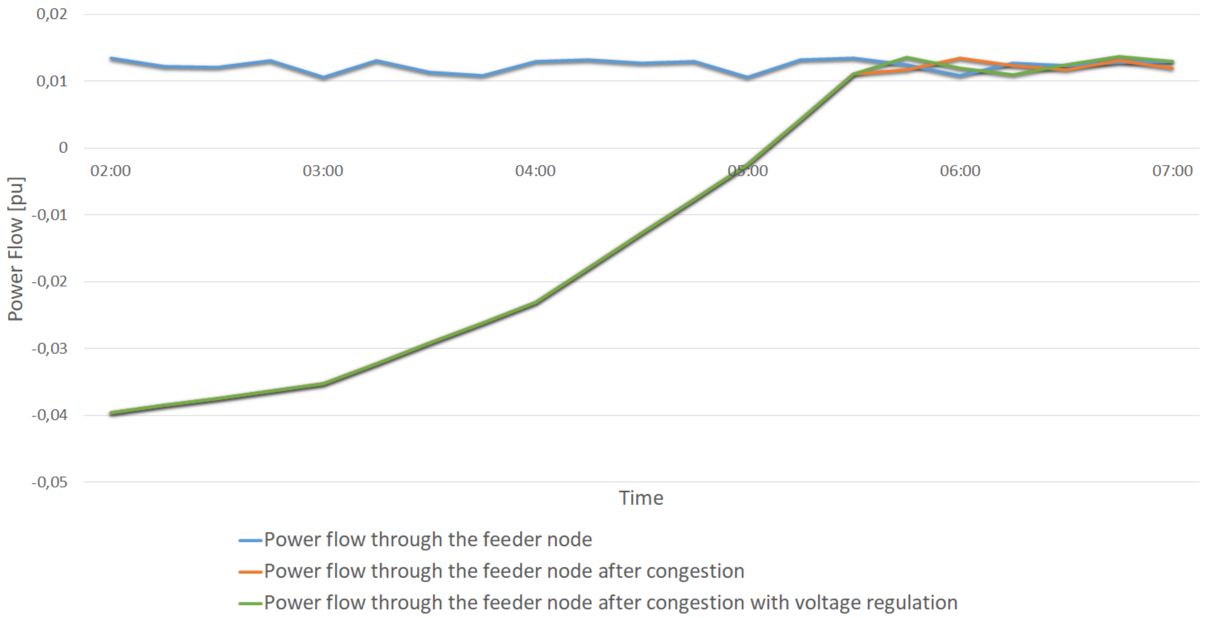

Figure 40: Power flow through the distribution slack node.

For case one in figure 40, a positive flow can be seen, representing a downstream power flow from the transmission to the distribution grid. This flow is also relatively constant throughout the simulation period. This changes when congestion for case 2 occurs, where between 02:00 to 05:00, a negative flow of power emerges. During this period, the active power flows from distribution to the transmission grid. This power flow is necessary to solve the congestion between nodes 7 and 8 of the transmission grid. During these hours, the distribution grid supports the operation of the transmission grid. Case 3 shows a similar result, where the power flow between 02:00 to 05:00 overlaps with case 2. These results also show that the difference in flexibility dispatch between cases 2 and 3 only influences the situation in the distribution grid.

5.6 Two-Stage Stochastic Optimization Example

This part presents a more practical example of how a DSO potentially could act in a flexibility market, as previously shown by figure 9, and how the developed tool can help in this process. Here, three potential future scenarios were designed with their corresponding probability of occurrence. In reality, the requirement for a higher number of scenarios would ensure more accurate results. Since the main goal of this subchapter is to showcase the principle of the flexibility market strategy, only three scenarios have been included. To better illustrate load changes that may occur in a grid, a load variation of ±5% has been added for each quarter for every node for all three scenarios. By doing this, each node for each scenario has acquired a unique load profile, which highly diversifies the presented scenarios. These small variations ensure that the resulting load profiles do not deviate from the base-load acquired from Nordpool to a high degree. This approach also maintains the correlation between day-ahead prices and the resulting load profiles. The day-ahead load remains unchanged so that the day-ahead dispatch is the same across all simulations, which results in the flexibility resources covering all load deviations. All data used for the simulations in this subchapter appears in Appendix C and H. The resulting flexibility provision from load and batteries, in relation to the load for the given scenario, is shown in figures 41, 42 and 43.

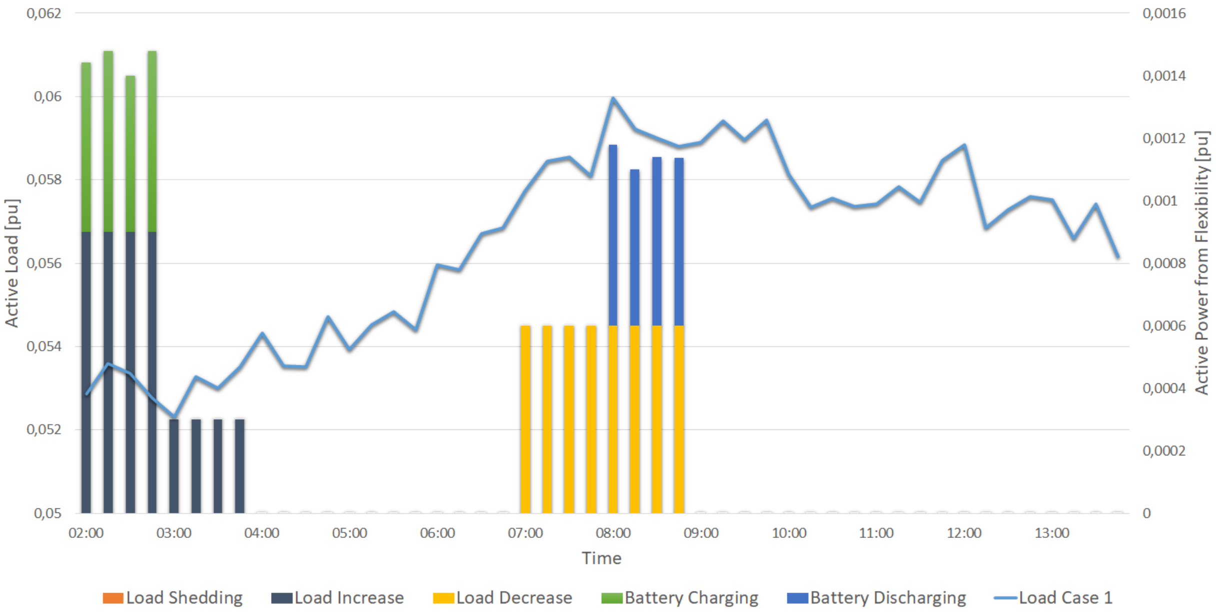

Figure 41: Flexibility used to optimize the grid's operation for scenario 1.

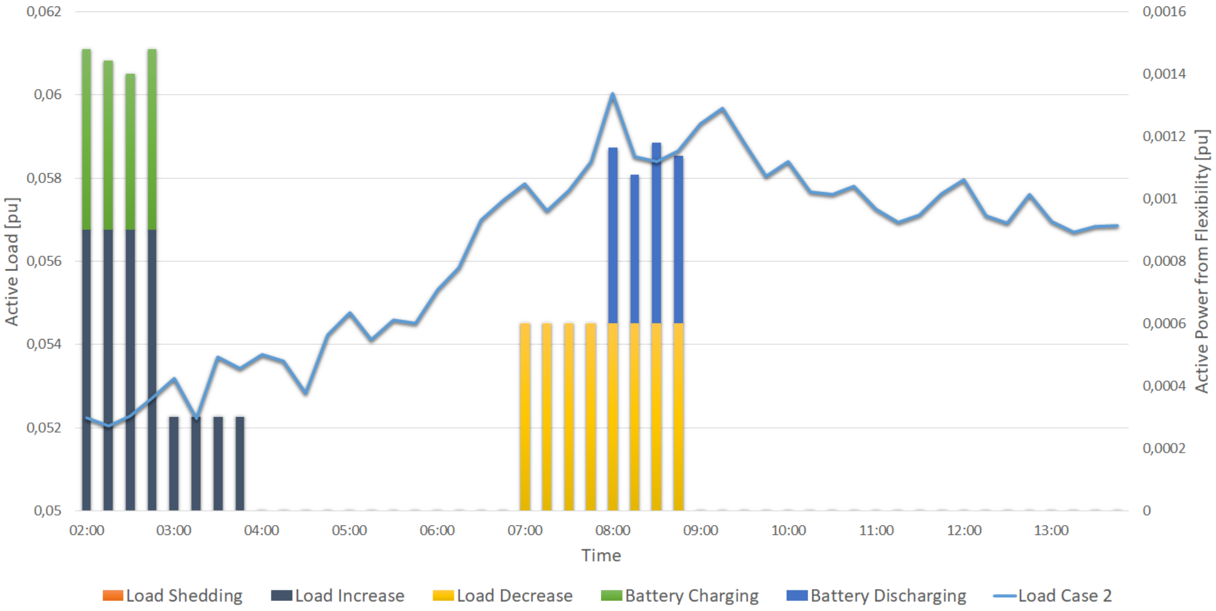

Figure 42: Flexibility used to optimize the grid's operation for scenario 2.

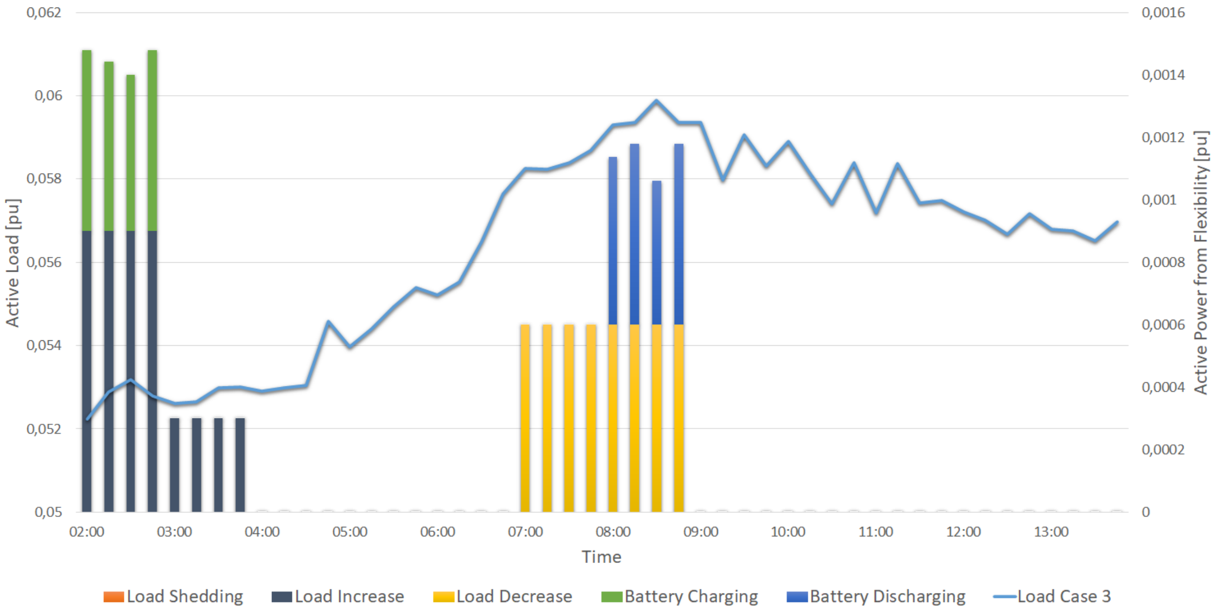

Figure 43: Flexibility used to optimize the grid's operation for scenario 3.

From these three figures, the load profile varies across all scenarios while, the flexibility dispatch remains similar. This result is due to the prices for both the flexibility and day-ahead market remaining unchanged. In addition, flexible load and batteries are already operating with their maximum capacity, and the load variations across scenarios are not high enough to result in any significant changes. Higher variations in flexibility dispatch can be seen in figure 44 presenting flexible generation and the corresponding load for all three scenarios.

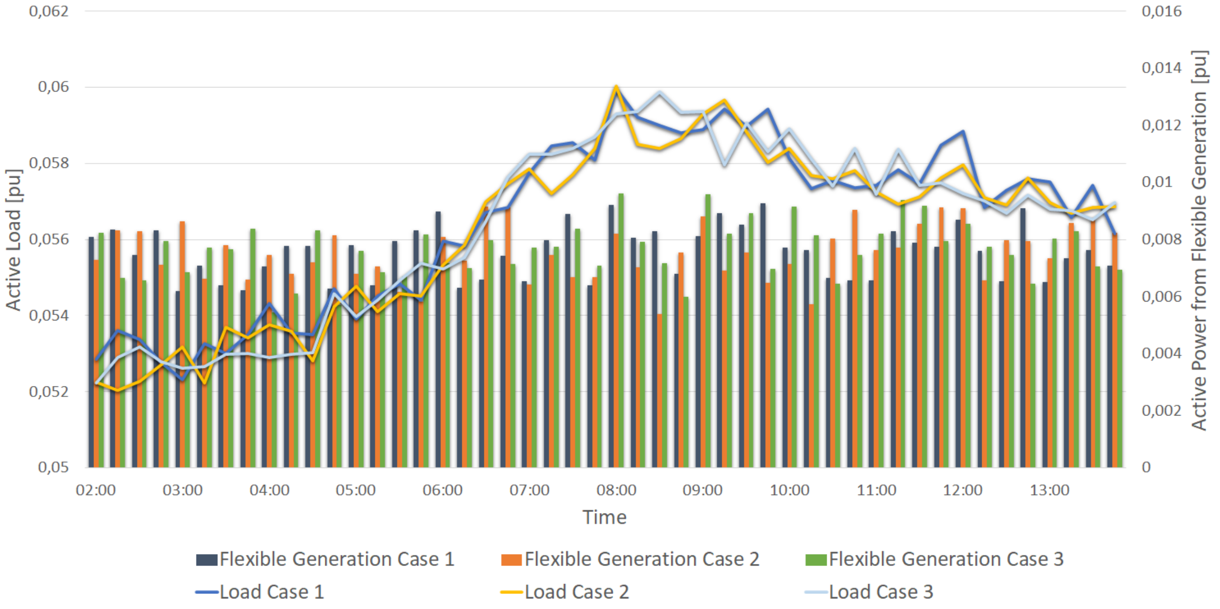

Figure 44: Flexible generation used to optimize the grid's operation for all three scenarios.

From the figure 44, the DFR with the most significant response to load deviations is the flexible generation. Across all test scenarios, flexible generation is highly dependent on the load profile applied for the flexibility market algorithm. After DSO has performed every scenario simulation, the resulting flexibility dispatch and the probability of occurrence are combined, which results in a single load profile and flexibility utilization schedule, as previously explained by figure 9. The results for flexible load, batteries, and flexible generation are shown in figure 45 and 46, respectively.

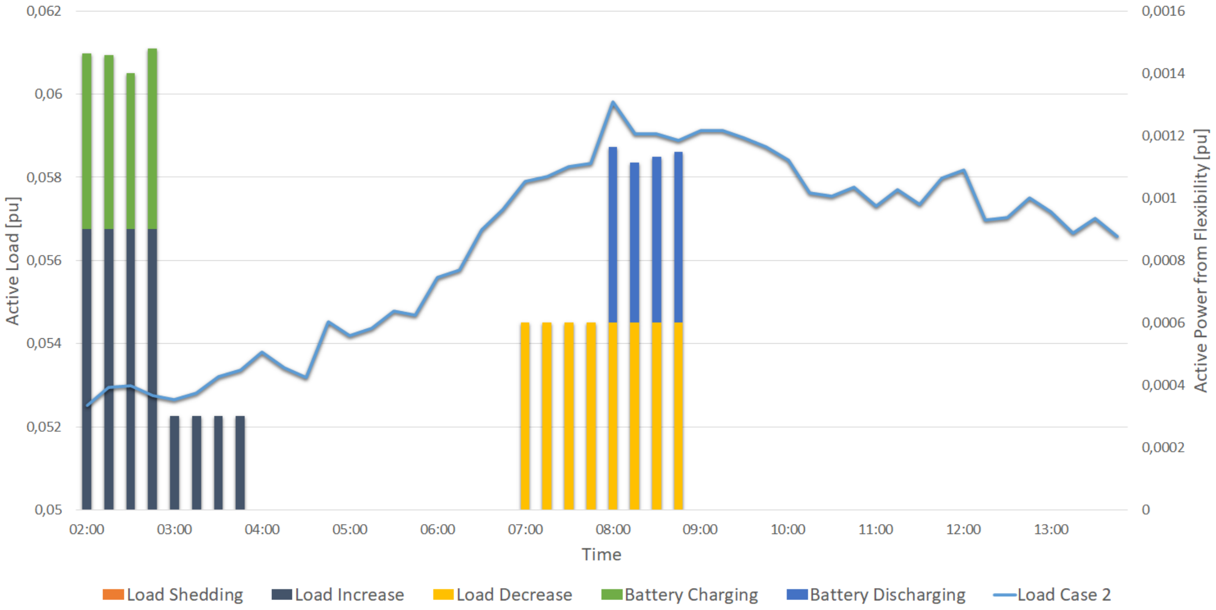

Figure 45: Combined flexibility use for all three scenarios.

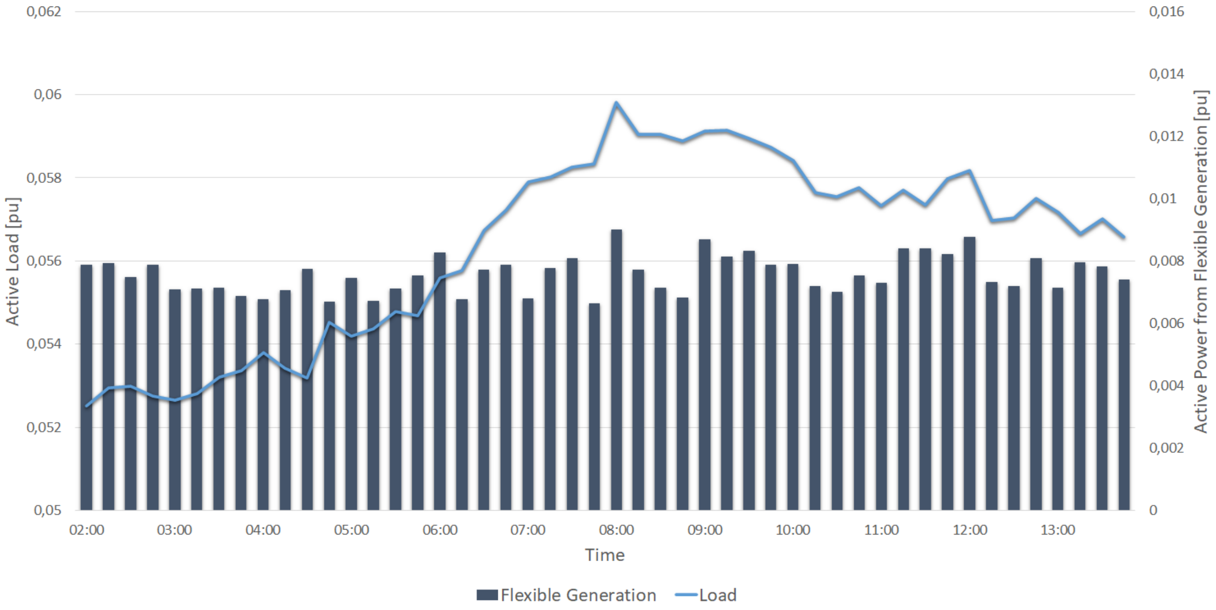

Figure 46: Combined flexible generation use for all three scenarios.

The combined results can be interpreted as an expected load profile, and its corresponding flexibility needs to supply it optimally. These results can support the DSO in deciding whether the flexibility capacity should be reserved or if it is more beneficial to wait and see how the situation in the grid unfolds. During the operation phase, this process repeats for each time interval of the LFM. The new data is used as input to the optimization program to determine a more accurate load profile and flexibility needs. This way, additional flexibility can be procured to optimize the system. This concept has been explained thoroughly with flowcharts presented in chapter 3.2.

5.7 Discussion Regarding Result

Each test case performed in this chapter shows how the multi-period hybrid AC/DC-OPF model employs the available resources in the distribution grid to solve different grid problems, both for the distribution and transmission grid. The test cases show that the use of DFRs will depend on the test cases, meaning that congestion will require different measures to be taken than low voltage problems. The different actions from the DFRs revolve around the use of active power capacity for specific time slots. The list below presents some key observations for each of these test cases:

- **Economic optimization**: Considering the flexibility's primary purpose is to support the system with ancillary services, its possibilities in optimizing the grid's operation could potentially have a beneficial effect. The possibility of reducing power losses in the grid can significantly improve the operation of the distribution grid. In addition, the use of flexibility can alleviate some of the strain put on the grid resulting from the increased number of high-power-consuming appliances. The sheer magnitude of these savings, which flexibility can acquire, is a topic that requires more extensive research. This research includes planning in both the short and long-term, which this thesis does not explore.
- **Voltage problems**: For grid challenges regarding voltage issues, different test cases have been analyzed, both with and without flexibility and voltage regulation. The recurring result from the test cases is that the models attempted to reduce the power injected from the feeder node to solve the voltage problem. These results correlate well with the previously explored theory in sub-chapter 2.3 Here, equation 1 states that voltage drop will increase proportionally with increasing active or reactive power flow. This theory also corresponds well with the model's choice to avoid high active power flows between nodes to reduce voltage drops. This assumption also reflects well with the results containing the best voltage profiles. In these cases, reduced active power injection from the feeder node and the most evenly distributed power flows across the grid occurs. In contrast, the test case with the most active power injection from the feeder node having the worst voltage profile. Overall, the data suggests that in the case of a voltage problem, the model should avoid having large active power flow in all the lines and instead attempt to distribute the active power flow in the different lines evenly.
- **Congestion in distribution grid**: By analyzing the scenarios where unexpected congestion occurs within the distribution grid, flexibility has proven to be an efficient tool for countering this issue. The result shows that flexibility may be used during the load-peak period for both cases with and without voltage regulation. This flexibility activation makes it possible to contain the effects caused by the

congestion only to affect the distribution grid. Flexibility can thus significantly increase the security of both the distribution and transmission grid's operation, and as for other cases, reduce the need for additional grid upgrades or expansions. In this example, the model has also showcased the ability to solve multiple issues in a single simulation, such as congestion and over-voltages caused by the high use of flexibility.

- **Congestion in transmission grid**: As demonstrated by the previously shown scenarios, the benefits provided from flexibility are not only limited to the distribution grid. If enough flexible capacity is available, the distribution grid could become self-sufficient or even act as a virtual power plant. This self-sufficiency of the distribution grid could lead to an upstream flow of power for a limited period, depending on the available capacity, flexibility prices, and TSO's demand for flexibility. This situation transpires in one of the presented cases, where for three hours, the distribution grid has been feeding active power to the transmission grid to help alleviate the congestion. This action requires necessary equipment and protection in the distribution grid to handle the reversed flow of power. In addition, much tighter cooperation would be necessary between the DSO and TSO to ensure that the increased flexibility provided by the distribution grid does not affect the grid negatively.
- **Two-Stage Stochastic Optimization**: This sub-chapter has shown a practical example of the two-stage stochastic optimization technique, with the development and performance of multiple scenarios. Figure 9 from chapter 3.2.3 also gave a more detailed description of the concept. By combining the three generated scenarios into one common scenario, BRP can acquire a prediction plan for the needed flexibility that can be reserved to maintain a proper operation. It is crucial to keep in mind that this chapter only shows the concept of two-stage stochastic optimization. In reality, the inclusion of a much greater number of scenarios is essential to secure a necessary amount of flexibility. In addition, the included scenarios would differ to a much higher degree, in contrast to the ones simulated in this thesis.

One assumption made for all the test cases is that prices follow the demand in the power system; hence high demand leads to high prices, and vice-versa, as shown in figure 12. That might not always be the case in a power system. Therefore, it would be interesting to see how the optimization program would react when this was not the case. A possible theory is that the model would need to find an optimal balance between minimizing the total costs while also covering the demand. Another assumption made is that the costs of DFRs have a linear relationship with the provided power. Changing the prices to include a squared term would significantly increase the dynamics in the model and how the model determines the flexibility dispatch. This change would greatly depend on the employed bid format in the future LFM.

A significant downside of the designed test cases is the high customization needed to acquire the desired results. Each test case in this thesis presents a potential grid situation as a proof of concept of the designed model. Despite the test cases' use of realistic and publicly available data, they do not showcase an existing grid with real-life data. This disadvantage comes from the lack of publicly available data due to privacy concerns and LFM not being an existing platform in today's power system. This lack of necessary data created the need to develop potential test cases to test the developed model. A significant improvement would be to equip the model with an already existing grid with historical data as a basis for the load used during simulations. This improvement could effectively showcase the possibilities of the developed model in a real-life scenario.

As an ending statement and recommendation, what appears from these test cases, is that the placement and capacity of DFRs can significantly influence the results. Better location and higher capacity of DFRs in the distribution grid can significantly improve the flexibility's potential in handling grid problems, especially for branches in the distribution grid that are more exposed to grid problems. In this thesis, the idea behind the DFR placement and their capacities was to first and foremost effectively represent the test cases as a proof of concept. These choices might have come to the detriment of acquiring optimal results. Therefore, finding the optimal conditions will have significant technical and economic benefits for the individual distribution grid and the transmission system.

6 Conclusion and Further Work

This master thesis explores two main objectives—the first being a theoretical approach regarding LFM strategy and design—and the second being the development of the multi-period hybrid DC/ACOPF model. For the first objective, rolling-horizon has been adopted as a concept describing the LFM strategy. Here planning of the operation with uncertainty is performed the day before the operation through a two-stage stochastic optimization method. During the actual operation, the rolling-horizon technique can be used to re-schedule the operation based on new and more accurate data. This whole process of planning and operation is shown through a flowchart, clarifying tasks executed by the different LFMP. This LFM presents a solution for improving TSO-TSO/TSO-DSO interaction to unlock, in a cost-effective way, the zero-emission flexibility which is available in assets connected to the transmission and distribution grid. The LFM strategy also sets criteria for what functionality the multi-period hybrid AC/DC-OPF model needs to incorporate.

The idea behind the multi-period hybrid AC/DC-OPF model was to combine two optimal power flow methods into a single program. For this purpose, the model applied the SOC-ACOPF for the distribution grid and DC-OPF method for the transmission grid. The combination of these two methods was accomplished by mathematically formulating the AC-to-DC connection constraint (19). This constraint connected two methods resulting in an action performed in one of the OPF methods affecting the other. Since this method is a new concept (as far as the authors are aware of), power flow verification was required. Comparing the hybrid AC/DC-OPF simulation results with individual SOC-ACOPF and DC-OPF methods verified the proper implementation of this constraint. After this verification, further expansion of the model took place by including flexibility assets in the distribution grid in addition to the multi-period optimization technique. These measures allowed the development of a multi-period hybrid AC/DC-OPF model capable of performing multiple optimal power flow simulations simultaneously for both the transmission and distribution grid.

In addition to the multi-period hybrid AC/DC-OPF model, the thesis resulted in discovering other necessary LFM functions, like load forecasting and scenario generation. Due to the authors' unfamiliarity with these topics, complications arose concerning the fulfillment of the thesis. A proper case development was required to present good case scenarios for the studies presented in this thesis. Scenario development has appeared to be a challenging task, which required a lot of time and effort. Thus, the designed cases only present results as a proof of concept of the developed model.

In order to prove the multi-period hybrid AC/DC-OPF model, test-cases with different grid problems were designed. Due to their lower prices, battery and flexible load capacity were the preferred choices for all performed test cases. The flexibility from DG was also used to some extent due to its local placement. Only when grid problems like congestion or voltage problems occurred did DGs increase their power output significantly. This increase in power output is presumably due to the high capacity and location of the DG. When adopting DG to solve voltage or congestion problems, the cost of operation increased significantly. This increase in cost is still a much more preferable and cheaper choice than load shedding. The acquired results might differ where load scenarios, DFR placement, and DFR cost is less customized.

Computational complexity is vital to consider when it comes to optimization. It refers to the amount of computational resources needed to solve a type of problem by a systematic application of algorithms [69]. The more complex the problem, the more time and resources will be needed to solve it. The computational time and effort that went into solving the different test cases were rather effortless, with non of the test cases using more than 20 seconds to be solved, including importing and exporting data from Excel files. Compared to a real-life distribution and transmission grid, the system is relatively small, and the simulated scenarios only contained 48 time slots. These attributes contribute to a relatively easy optimization problem. Therefore, a safe assumption is that the total time for solving the optimization will increase when applied to a more extensive and realistic system.

Through research and findings in this thesis, the authors have contributed with new knowledge regarding LFM planning and operation. This contribution includes:

- The development of the multi-period hybrid AC/DC-OPF model for DFR's scheduling to improve or solve grid situation for the transmission and distribution grid. This development will allow the improvement of decision-making in the context of green transformation and ensure new operational conditions.
- The development of the LFM strategy, which presents a TSO-TSO/TSO-DSO interaction platform. In a cost-effective way, this platform attempts to unlock the zero-emission flexibility available in assets connected to the transmission and distribution grids.
- Paper submission to the 2021 International Conference on Smart Energy Systems and Technologies (SEST), titled "Hybrid AC/DC Optimal Power Flow Modelling Approach for Coordination in Flexibility Market" [1].

The contributed knowledge to this research field is a minor part of a broad topic which is the LFM. It is far from the complete framework needed to operate an LFM, but it provides the foundation for further work presented in the next paragraph.

Further work

Further work that builds upon this master thesis will enhance the developed multi-period hybrid AC/DC-OPF model. This enhancement can come in the form of better input data or further development of the composed code. Better customization of the code to more effectively incorporate the LFM needs would significantly improve the yielded results. In the list below are some suggestions as to what this development could be:

- The multi-period hybrid AC/DC-OPF was proven to converge to true OPF with the chosen grid model. More thorough testing of the OPF method should be executed with several different test systems to show that this model is applicable for different grid topologies.
- During the development of the model, the main focus was to make a working prototype of the desired program. Not much effort was put in order to acquire an efficient and polished design. Thus, making

the multi-period hybrid AC/DC-OPF program more user-friendly and understandable would be a potential improvement. In addition, the design of better data input and output will allow for ease of use for others to make use of this program.

- A significant improvement for the model would be the development of better test cases. A thorough study of DFRs pricing and their optimal placement in the distribution grid should be conducted for these cases. Better load scenarios would also tremendously benefit the acquired results.
- A characteristic that defines the distribution grid is that the system can be unbalanced, as mentioned in chapter 4. Thus, SOC-ACOPF could potentially be further extended to cope with an unbalanced system. Therefore, this development can create a model that is more suited for a real-life distribution grid.
- Instead of working with a hypothetical test case, a great leap would be to apply the model for a real-life distribution grid. Such cases will give a better insight into potential problems that one might not consider or demonstrate with own-made test cases.
- A far-reaching extension could be for the model to gain the ability to connect several distribution grids to a single transmission grid. This addition would better illustrate the benefits TSO could gain from the LFM concept. Several distribution grids connected to the transmission grid would allow the TSO to procure resources from several locations. Such a development would increase the competition within and across the LFMs.
- The rolling-horizon technique is an exciting topic that requires comprehensive research, which was not conducted in this thesis. Additionally, its strength lies in the rescheduling during the operation phase, while this thesis focused on the planning phase. A topic to explore on a more technical aspect is how the rolling-horizon technique and two-stage stochastic optimization could be combined and performed during the operation.
- The scientific concept of the LFM proposed in this thesis is limited to theory. Technical insight is just one aspect of the problem; rules and regulations for implementing an LFM into an existing power system are another. A thorough study for how this LFM can be implemented regarding the rules and regulations in today's power system might reveal valuable insights into unknown challenges with the LFM concept.

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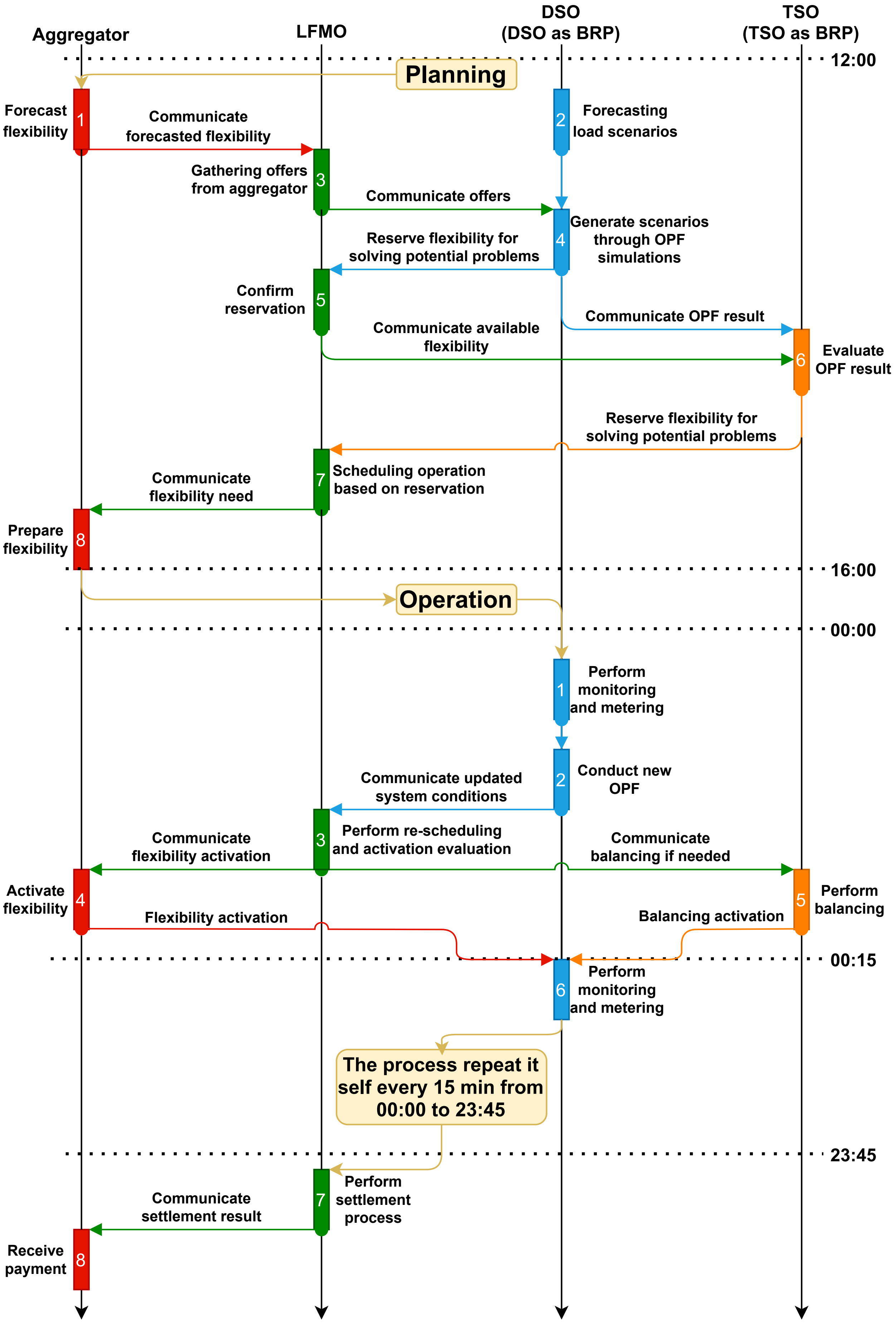
Appendix

A The Complete LFM Coordination Scheme



B Python Code for the Multi-Period Hybrid AC/DC-OPF Model

```
536 # The excluded code from line 1 to 536 above, includes all the necessary code in regards to data
537 # acquisition, reformatting, creation of matrices and the general code of the logic behind the
538 # entire program. Data storage after the main_simulation function is either not included.
539 # To reduce the length of this attachment, only the necessary code for the
540 # multi-period hybrid AC/DC OPF model is included.
541 
542 def main_simulation(data_AC, data_DC, data_flex, data_battery, data_output, Hours, Units):
543     """
544     The model works in two stages. The first model, model_DA determines the day ahead
545     schedule for generators. This generation is hourly, thus the model only contains hours
546     THe second model, model_FA, determines the production needed to balance the system.
547     This is where flexibility is utilized on a 15-min time-frame. For the case without
548     flexibility, slack in transmission system is utilized to cover the changing demand
549     ___________________________________________________________________________________________
550                           The start of the DA optimization model
551     ___________________________________________________________________________________________
552     """
553     # Creating an empty model for the convex optimization power flow problem
554     model_DA = pyo.ConcreteModel()
555 
556     # Set containing all hours in the model
557     model_DA.hours = pyo.RangeSet(0, Hours)
558 
559     """
560     Creating sets that contains all lines, nodes and line connections
561     """
562     # Set for all lines in model
563     model_DA.L_AC = pyo.Set(ordered=True, initialize=data_AC["AC_lines"]["ACList"])
564     model_DA.L_DC = pyo.Set(ordered=True, initialize=data_DC["DC_lines"]["DCList"])
565 
566     # Set for all nodes in model
567     model_DA.N_AC = pyo.Set(ordered=True, initialize=data_AC["P_Load_DA"]["NodeList"])
568     model_DA.N_DC = pyo.Set(ordered=True, initialize=data_DC["P_Load_DA"]["NodeList"])
569 
570     # Set for all line connections
571     model_DA.FT = pyo.Set(dimen=2, ordered=True,
572                           initialize=data_AC["AC_lines"]["Node Connection"])
573 
574     """
575     Parameters in the power equations
576     """
577     # Line parameters for SOC-ACOPF
578     model_DA.From_AC = pyo.Param(model_DA.L_AC, initialize=data_AC["AC_lines"]["From"])
579     model_DA.To_AC = pyo.Param(model_DA.L_AC, initialize=data_AC[ "AC_lines"]["To"])
580     model_DA.FrTo = pyo.Param(model_DA.FT, initialize=data_AC["AC_lines"]["From To"])
581 
582     # Line parameters for DCOPF
583     model_DA.From_DC = pyo.Param(model_DA.L_DC, initialize=data_DC["DC_lines"]["From"])
584     model_DA.To_DC = pyo.Param(model_DA.L_DC, initialize=data_DC[ "DC_lines"]["To"])
585     model_DA.Fl_min = pyo.Param(model_DA.L_DC, initialize=data_DC[ "DC_lines"]["F_min"])
586     model_DA.Fl_max = pyo.Param(model_DA.L_DC, initialize=data_DC[ "DC_lines"]["F_max"])
587 
588     # Node parameters DC
589     def P_load_DC_init(model_DA, n, hour):
590         return data_DC["P_Load_DA"][n][hour]
591 
592     model_DA.P_load_DC = pyo.Param(model_DA.N_DC, model_DA.hours, initialize=P_load_DC_init)
593 
594     # Gen Parameters
595     def P_gen_DC_min_init(model_DA, n, hour):
596         return data_DC["P_gen_min"][n][hour]
597 
598     def P_gen_DC_max_init(model_DA, n, hour):
599         return data_DC["P_gen_max"][n][hour]
600 
601     def C1_gen_DC_init(model_DA, hour):
602         return data_DC["C1_gen"][1][hour]
603 
604     def C1_slack_DC_init(model_DA, hour):
605         return data_DC["C1_slack"][1][hour]
606 
607     model_DA.P_gen_DC_min = pyo.Param(model_DA.N_DC, model_DA.hours,
608                                       initialize=P_gen_DC_min_init)
609     model_DA.P_gen_DC_max = pyo.Param(model_DA.N_DC, model_DA.hours,
610                                       initialize=P_gen_DC_max_init)
611 
612     model_DA.C1_gen_DC = pyo.Param(model_DA.hours, initialize=C1_gen_DC_init)
613     model_DA.C1_slack_DC = pyo.Param(model_DA.hours, initialize=C1_slack_DC_init)
```

```

    # Node parameters AC
    def P_load_AC_init(model_DA, n, hour):
        return data_AC["P_Load_DA"][n][hour]

    def Q_load_AC_init(model_DA, n, hour):
        return data_AC["Q_Load_DA"][n][hour]

    model_DA.P_load_AC = pyo.Param(model_DA.N_AC, model_DA.hours, initialize=P_load_AC_init)
    model_DA.Q_load_AC = pyo.Param(model_DA.N_AC, model_DA.hours, initialize=Q_load_AC_init)

    # Gen Parameters
    def P_gen_AC_min_init(model_DA, n, hour):
        return data_AC["P_gen_min"][n][hour]

    def P_gen_AC_max_init(model_DA, n, hour):
        return data_AC["P_gen_max"][n][hour]

    def Q_gen_AC_min_init(model_DA, n, hour):
        return data_AC["Q_gen_min"][n][hour]

    def Q_gen_AC_max_init(model_DA, n, hour):
        return data_AC["Q_gen_max"][n][hour]

    def C1_gen_AC_init(model_DA, hour):
        return data_AC["C1_gen"][1][hour]

    model_DA.P_gen_AC_min = pyo.Param(model_DA.N_AC, model_DA.hours,
                                      initialize=P_gen_AC_min_init)
    model_DA.P_gen_AC_max = pyo.Param(model_DA.N_AC, model_DA.hours,
                                      initialize=P_gen_AC_max_init)
    model_DA.Q_gen_AC_min = pyo.Param(model_DA.N_AC, model_DA.hours,
                                      initialize=Q_gen_AC_min_init)
    model_DA.Q_gen_AC_max = pyo.Param(model_DA.N_AC, model_DA.hours,
                                      initialize=Q_gen_AC_max_init)

    model_DA.C1_gen_AC = pyo.Param(model_DA.hours, initialize=C1_gen_AC_init)

    """
    Variables in the power equations
    """
    # Auxiliary Variables
    model_DA.R = pyo.Var(model_DA.L_AC, model_DA.hours)
    model_DA.I = pyo.Var(model_DA.L_AC, model_DA.hours)
    model_DA.u = pyo.Var(model_DA.N_AC, model_DA.hours)

    # Energy consumption/production variables
    model_DA.P_gen_AC = pyo.Var(model_DA.N_AC, model_DA.hours)
    model_DA.Q_gen_AC = pyo.Var(model_DA.N_AC, model_DA.hours)
    model_DA.P_slack_AC = pyo.Var(model_DA.hours)
    model_DA.Q_slack_AC = pyo.Var(model_DA.hours)

    # Variables for DCOPF
    model_DA.gen_DC = pyo.Var(model_DA.N_DC, model_DA.hours)
    model_DA.slack_DC = pyo.Var(model_DA.hours)
    model_DA.P_flow_DC = pyo.Var(model_DA.L_DC, model_DA.hours)
    model_DA.theta_DC = pyo.Var(model_DA.L_DC, model_DA.hours)

    """
    Constraint for the DCOPF
    """
    # Constraint that state which bus should be slack bus
    def slack_theta(model_DA, hour):
        return (model_DA.theta_DC[data_DC["DCOPF"]["Ref Node"], hour] ==
                data_DC["DCOPF"]["Angle"])

    model_DA.slack_theta_con = pyo.Constraint(model_DA.hours, rule=slack_theta)

    # Active power balance constraint for each node
    def P_balance_DC(model_DA, n, hour):
        # Check for connection between the distribution and transmission grid
        # if connection is true, DC load = AC production in node 1
        if data_DC["Connection"][n] == True:
            return (model_DA.gen_DC[n, hour] - model_DA.P_gen_AC[1, hour] -
                    model_DA.P_slack_AC[hour] == -sum(data_DC["B_DC"][n][m] *
                    model_DA.theta_DC[m, hour] for m in model_DA.N_DC))
        # if connection is false, DC load = DC load
        elif data_DC["Connection"][n] == False and n == 1:
```

```
        return (model_DA.gen_DC[n, hour] + model_DA.slack_DC[hour] -
                model_DA.P_load_DC[n, hour] == -sum(data_DC["B_DC"][n][m] *
                model_DA.theta_DC[m, hour] for m in model_DA.N_DC))
    # if connection is false, DC load = DC load
    elif data_DC["Connection"][n] == False:
        return (model_DA.gen_DC[n, hour] - model_DA.P_load_DC[n, hour] ==
                -sum(data_DC["B_DC"][n][m] * model_DA.theta_DC[m, hour] for m in
                model_DA.N_DC))

model_DA.P_balance_DC_con = pyo.Constraint(model_DA.N_DC, model_DA.hours, rule=P_balance_DC)

# Constraint that dictate how much power flows between two nodes
def P_flow_DC(model_DA, l, hour):
    return (model_DA.P_flow_DC[l, hour] ==
            data_DC["B_DC"][model_DA.From_DC[l]][model_DA.To_DC[l]] * (model_DA.theta_DC[
            model_DA.From_DC[l], hour] - model_DA.theta_DC[model_DA.To_DC[l], hour]))

model_DA.P_flow_DC_Con = pyo.Constraint(model_DA.L_DC, model_DA.hours, rule=P_flow_DC)

# Minimum and maximum active power production constraint for each generator unit
def P_g_DC(model_DA, n, hour):
    return (model_DA.P_gen_DC_min[n, hour], model_DA.gen_DC[n, hour],
            model_DA.P_gen_DC_max[n, hour])

model_DA.P_g_DC = pyo.Constraint(model_DA.N_DC, model_DA.hours, rule=P_g_DC)

# Minimum and minimum active power flow between two nodes
def P_Fl_DC(model_DA, l, hour):
    return (-5, model_DA.P_flow_DC[l, hour], 5)

model_DA.P_Fl_DC = pyo.Constraint(model_DA.L_DC, model_DA.hours, rule=P_Fl_DC)

"""
Constraint for the SOC-ACOPF
"""

# Flow Constraints
# Model for active power flow in the form of a constraint
def P_flow(model_DA, n, hour):
    # Equation is split into two elements (step) due to how calculations are done
    step1 = (-math.sqrt(2) * model_DA.u[n, hour] *
             sum(data_AC["G_AC"][n][l] for l in model_DA.N_AC))
    step2 = 0
    # Loop that check if a given node connection exist
    for n2 in model_DA.N_AC:
        # If connection exist, a constraint will be made based on this connection
        if data_AC["G_AC"][n][n2] != 0:
            step2 += data_AC["G_AC"][n][n2] * model_DA.R[model_DA.FrTo[n, n2], hour]
            # Depending if line connection exists
            if list(data_AC["AC_lines"]["From To"]).index((n, n2)) >= len(
                    data_AC["AC_lines"]["From To"]) / 2:
                step2 += data_AC["B_AC"][n][n2] * model_DA.I[
                    model_DA.FrTo[n, n2], hour]
            else:
                step2 -= data_AC["B_AC"][n][n2] * model_DA.I[model_DA.FrTo[n, n2], hour]
    # Each element for a given node is added and set equal to load on given node
    # if n==1 AC slack is included in the formulation
    if n == 1:
        return ((step1 + step2) + model_DA.P_gen_AC[n, hour] +
                model_DA.P_slack_AC[hour] == model_DA.P_load_AC[n, hour])
    else:
        return ((step1 + step2) + model_DA.P_gen_AC[n, hour] == model_DA.P_load_AC[n, hour])

model_DA.P_flow_con = pyo.Constraint(model_DA.N_AC, model_DA.hours, rule=P_flow)

# Model for reactive power flow in the form of a constraint
def Q_flow(model_DA, n, hour):
    step1 = (-math.sqrt(2) * model_DA.u[n, hour] *
             sum(data_AC["B_AC"][n][l] for l in model_DA.N_AC))
    step2 = 0
    # Loop that check if a given node connection exist
    for n2 in model_DA.N_AC:
        if data_AC["B_AC"][n][n2] != 0:
            step2 += data_AC["B_AC"][n][n2] * model_DA.R[model_DA.FrTo[n, n2], hour]
            # Depending if line connection exists
            if list(data_AC["AC_lines"]["From To"]).index((n, n2)) >= len(
                    data_AC["AC_lines"]["From To"]) / 2:
                step2 -= data_AC["G_AC"][n][n2] * model_DA.I[model_DA.FrTo[n, n2], hour]
```

```
            else:
                step2 += data_AC["G_AC"][n][n2] * model_DA.I[model_DA.FrTo[n, n2], hour]
    # Each element for a given node is added and set equal to load on given node
    # if n==1 AC slack is included in the formulation
    if n == 1:
        return ((step1 + step2) + model_DA.Q_gen_AC[n, hour] +
                model_DA.Q_slack_AC[hour] == model_DA.Q_load_AC[n, hour])
    else:
        return ((step1 + step2) + model_DA.Q_gen_AC[n, hour] == model_DA.Q_load_AC[n, hour])

model_DA.Q_flow_con = pyo.Constraint(model_DA.N_AC, model_DA.hours, rule=Q_flow)

# Maximum and minimum production for each node
def P_prod_G_AC(model_DA, n, hour):
    return (model_DA.P_gen_AC_min[n, hour], model_DA.P_gen_AC[n, hour],
            model_DA.P_gen_AC_max[n, hour])

model_DA.P_prod_G_AC = pyo.Constraint(model_DA.N_AC, model_DA.hours, rule=P_prod_G_AC)

def Q_prod_G_AC(model_DA, n, hour):
    return (model_DA.Q_gen_AC_min[n, hour], model_DA.Q_gen_AC[n, hour],
            model_DA.Q_gen_AC_max[n, hour])

model_DA.Q_prod_G_AC = pyo.Constraint(model_DA.N_AC, model_DA.hours, rule=Q_prod_G_AC)

# This constraint can be regarded as the mismatch equation in the form of
# squared voltage mismatch which indicate when an acceptable solution is found by
# converging to the value zero.
def Quad_equal(model_DA, l, hour):
    return ((2 * model_DA.u[model_DA.From_AC[l], hour] *
             model_DA.u[model_DA.To_AC[l], hour]) >= ((model_DA.R[l, hour]) **  2 +
                                                      (model_DA.I[l, hour]) **  2))

model_DA.Quad_equal_con = pyo.Constraint(model_DA.L_AC, model_DA.hours, rule=Quad_equal)

# None zero constraint for variable u
def u_node(model_DA, n, hour):
    # Voltage on node 1 is pre-defined
    if n == 1:
        return (model_DA.u[n, hour] == data_AC["SOC-ACOPF"]["ref volt"] ** 2 / math.sqrt(2))
    else:
        return (model_DA.u[n, hour] >= 0)

model_DA.u_node_con = pyo.Constraint(model_DA.N_AC, model_DA.hours, rule=u_node)

# None zero constraint for variable R
def R_line(model_DA, l, hour):
    return (model_DA.R[l, hour] >= 0)

model_DA.R_line_con = pyo.Constraint(model_DA.L_AC, model_DA.hours, rule=R_line)

"""
Solving the optimization problem
"""

# Objective function will be to minimize production costs
def OBJ_DA(model_DA):
    total_cost = 0

    for hour in model_DA.hours:
        for n in model_DA.N_DC:
            total_cost += (model_DA.C1_gen_DC[hour] *
                           model_DA.gen_DC[n, hour])
        # Cost of slack production is multiplied by 1.001 to prioritize the
        # use of generating units, without influencing the resulting costs
        total_cost += (model_DA.C1_slack_DC[hour] *  1.001 * model_DA.slack_DC[hour])
    for hour in model_DA.hours:
        for n in model_DA.N_AC:
            total_cost += model_DA.C1_gen_AC[hour] * model_DA.P_gen_AC[n, hour]

    return total_cost * 100

model_DA.OBJ = pyo.Objective(rule=OBJ_DA, sense=pyo.minimize)
# Line below can be run if one whats to see the formulation of constraints,
# variables and objective function
# model_DA.pprint()

# Gurobi is used as solver to find solution
```

```python
opt = SolverFactory("gurobi", keepfiles=True, log_file='/z/log', soln_file='/z/sol')
# opt.options are settings for reducing relaxation errors for the system
opt.options["mipgap"] = 0
opt.options["mipgapabs"] = 0
opt.options["PRESOS2BIGM"] = 0
# Code that shows the performance of the solver
opt.solve(model_DA, tee=True, logfile="solving_performance.log")
#model_DA.display()

"""
___________________________________________________________________________________________
                    The start of the FM optimization model
___________________________________________________________________________________________
"""

# Creating an empty model for the convex optimization power flow problem
model_FM = pyo.ConcreteModel()

# Set containing all hours and time units in the model
model_FM.hours = pyo.RangeSet(0, Hours)
model_FM.units = pyo.RangeSet(0, Units)

"""
Creating sets that contains all lines, nodes and line connections
"""
# Set for all lines in model
model_FM.L_AC = pyo.Set(ordered=True, initialize=data_AC["AC_lines"]["ACList"])
model_FM.L_DC = pyo.Set(ordered=True, initialize=data_DC["DC_lines"]["DCList"])

# Set for all nodes in model
model_FM.N_AC = pyo.Set(ordered=True, initialize=data_AC["P_Load_DA"]["NodeList"])
model_FM.N_DC = pyo.Set(ordered=True, initialize=data_DC["P_Load_DA"]["NodeList"])
# Set for all line connections
model_FM.FT = pyo.Set(dimen=2, ordered=True,
                      initialize=data_AC["AC_lines"]["Node Connection"])

"""
Parameters in the power equations
"""
# Line parameters for SOC-ACOPF
model_FM.From_AC = pyo.Param(model_FM.L_AC, initialize=data_AC["AC_lines"]["From"])
model_FM.To_AC = pyo.Param(model_FM.L_AC, initialize=data_AC[ "AC_lines"]["To"])
model_FM.FrTo = pyo.Param(model_FM.FT, initialize=data_AC["AC_lines"]["From To"])

# Line parameters for DCOPF
model_FM.From_DC = pyo.Param(model_FM.L_DC, initialize=data_DC["DC_lines"]["From"])
model_FM.To_DC = pyo.Param(model_FM.L_DC, initialize=data_DC[ "DC_lines"]["To"])
model_FM.Fl_min = pyo.Param(model_FM.L_DC, initialize=data_DC[ "DC_lines"]["F_min"])
model_FM.Fl_max = pyo.Param(model_FM.L_DC, initialize=data_DC[ "DC_lines"]["F_max"])

# Node parameters DC
def P_load_FM_init(model_FM, n, hour, unit):
    return data_DC["P_Load_FM"][n][hour][unit]

model_FM.P_load_DC = pyo.Param(model_FM.N_DC, model_FM.hours, model_FM.units,
                               initialize=P_load_FM_init)

def C1_slack_DC_init(model_FM, hour):
    return data_DC["C1_slack"][1][hour]

model_FM.C1_slack_DC = pyo.Param(model_FM.hours, initialize=C1_slack_DC_init)

# Node parameters AC
def P_load_AC_init(model_FM, n, hour, unit):
    return data_AC["P_Load_FM"][n][hour][unit]

def Q_load_AC_init(model_FM, n, hour, unit):
    return data_AC["Q_Load_FM"][n][hour][unit]

model_FM.P_load_AC = pyo.Param(model_FM.N_AC, model_FM.hours, model_FM.units,
                               initialize=P_load_AC_init)
model_FM.Q_load_AC = pyo.Param(model_FM.N_AC, model_FM.hours, model_FM.units,
                               initialize=Q_load_AC_init)

def Cost_Load_shedding_init(model_FM, n):
    return data_AC["Cost_Load_Shedding"][n]

model_FM.Cost_Load_shedding = pyo.Param(model_FM.N_AC, initialize=Cost_Load_shedding_init)
```

```python

# Voltage control
model_FM.V_hour = pyo.Param(initialize=data_AC["SOC-ACOPF"]["V_man_hour"])
model_FM.V_unit = pyo.Param(initialize=data_AC["SOC-ACOPF"]["V_man_unit"])
model_FM.u_std = pyo.Param(initialize=(data_AC["SOC-ACOPF"]["ref volt"] ** 2 /
                                       math.sqrt(2)))
model_FM.u_min = pyo.Param(initialize=data_AC["SOC-ACOPF"]["V_min"])
model_FM.u_max = pyo.Param(initialize=data_AC["SOC-ACOPF"]["V_max"])

# Flex Parameters
if Flex_included == "Y":
    # Flex cost Parameters

    def C1_flex_gen_inc_init(model_FM, hour, unit):
        return data_flex["Flex_gen_inc_C1"][1][hour][unit]

    def C1_flex_gen_dec_init(model_FM, hour, unit):
        return data_flex["Flex_gen_dec_C1"][1][hour][unit]

    def C1_flex_load_inc_init(model_FM, hour, unit):
        return data_flex["Flex_load_inc_C1"][1][hour][unit]

    def C1_flex_load_dec_init(model_FM, hour, unit):
        return data_flex["Flex_load_dec_C1"][1][hour][unit]

    model_FM.C1_flex_gen_inc = pyo.Param(model_FM.hours, model_FM.units,
                                        initialize=C1_flex_gen_inc_init)
    model_FM.C1_flex_gen_dec = pyo.Param(model_FM.hours, model_FM.units,
                                          initialize=C1_flex_gen_dec_init)
    model_FM.C1_flex_load_inc = pyo.Param(model_FM.hours, model_FM.units,
                                         initialize=C1_flex_load_inc_init)
    model_FM.C1_flex_load_dec = pyo.Param(model_FM.hours, model_FM.units,
                                           initialize=C1_flex_load_dec_init)

    # Flex Generation Parameters
    def P_flex_gen_max_init(model_FM, n, hour, unit):
        return data_flex["Flex_gen_max"][n][hour][unit]

    model_FM.P_flex_gen_max = pyo.Param(model_FM.N_AC, model_FM.hours, model_FM.units,
                                        initialize=P_flex_gen_max_init)

    # Flex Load Parameters
    def P_flex_load_max_dec_init(model_FM, n, hour, unit):
        return data_flex["Flex_load_max_dec"][n][hour][unit]

    def P_flex_load_max_inc_init(model_FM, n, hour, unit):
        return data_flex["Flex_load_max_inc"][n][hour][unit]


    model_FM.P_flex_load_max_dec = pyo.Param(model_FM.N_AC, model_FM.hours,
                                   model_FM.units, initialize=P_flex_load_max_dec_init)
    model_FM.P_flex_load_max_inc = pyo.Param(model_FM.N_AC, model_FM.hours,
                                   model_FM.units, initialize=P_flex_load_max_inc_init)

    # Battery Parameters
    def Battery_initial_SoC_init(model_FM, n):
        return data_battery["Battery_initial_SoC"][n]

    def Battery_SoC_max_init(model_FM, n, hour, unit):
        return data_battery["Battery_SoC_max"][n][hour][unit]

    def Battery_SoC_min_init(model_FM, n, hour, unit):
        return data_battery["Battery_SoC_min"][n][hour][unit]

    def Battery_charge_max_init(model_FM, n, hour, unit):
        return data_battery["Battery_charge_max"][n][hour][unit]

    def Battery_discharge_max_init(model_FM, n, hour, unit):
        return data_battery["Battery_discharge_max"][n][hour][unit]

    def C1_battery_charge_init(model_FM, hour, unit):
        return data_battery["Battery_charge_C1"][1][hour][unit]

    def C1_battery_discharge_init(model_FM, hour, unit):
        return data_battery["Battery_discharge_C1"][1][hour][unit]

    model_FM.battery_initial_SoC = pyo.Param(model_FM.N_AC,
                                         initialize=Battery_initial_SoC_init)
```

```
        model_FM.battery_SoC_max = pyo.Param(model_FM.N_AC, model_FM.hours, model_FM.units,
                                             initialize=Battery_SoC_max_init)
        model_FM.battery_SoC_min = pyo.Param(model_FM.N_AC, model_FM.hours, model_FM.units,
                                             initialize=Battery_SoC_min_init)
        model_FM.battery_charge_max = pyo.Param(model_FM.N_AC, model_FM.hours,
                                        model_FM.units,initialize=Battery_charge_max_init)
        model_FM.battery_discharge_max = pyo.Param(model_FM.N_AC, model_FM.hours,
                                        model_FM.units, initialize=Battery_discharge_max_init)

        model_FM.C1_charge_battery = pyo.Param(model_FM.hours, model_FM.units,
                                             initialize=C1_battery_charge_init)
        model_FM.C1_discharge_battery = pyo.Param(model_FM.hours, model_FM.units,
                                             initialize=C1_battery_discharge_init)

    """
    Variables in the power equations
    """
    # Auxiliary Variables
    model_FM.R = pyo.Var(model_FM.L_AC, model_FM.hours, model_FM.units)
    model_FM.I = pyo.Var(model_FM.L_AC, model_FM.hours, model_FM.units)
    model_FM.u = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units)

    # AC Slack variables
    model_FM.P_slack_AC = pyo.Var(model_FM.hours, model_FM.units)
    model_FM.Q_slack_AC = pyo.Var(model_FM.hours, model_FM.units)

    # Load Shedding
    model_FM.load_shedding = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                    within=pyo.NonNegativeReals)

    # Variables for DCOPF
    model_FM.slack_DC = pyo.Var(model_FM.hours, model_FM.units)
    model_FM.P_flow_DC = pyo.Var(model_FM.L_DC, model_FM.hours, model_FM.units)
    model_FM.theta_DC = pyo.Var(model_FM.L_DC, model_FM.hours, model_FM.units)

    if Flex_included == "Y":
        # Generation variables
        model_FM.flex_gen_inc = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                        within=pyo.NonNegativeReals)
        model_FM.flex_gen_dec = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                        within=pyo.NonNegativeReals)
        model_FM.flex_gen_use = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                        within=pyo.Binary)

        # Load Variables
        model_FM.flex_load_inc = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.NonNegativeReals)
        model_FM.flex_load_dec = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.NonNegativeReals)
        model_FM.flex_load_use = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.Binary)

        # Battery
        model_FM.battery_state_of_charge = pyo.Var(model_FM.N_AC, model_FM.hours,
                                                   model_FM.units)
        model_FM.battery_charge = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.NonNegativeReals)
        model_FM.battery_discharge = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.NonNegativeReals)
        model_FM.battery_state = pyo.Var(model_FM.N_AC, model_FM.hours, model_FM.units,
                                         within=pyo.Binary)
        # Battery Efficiency
        eff_charge = 0.99
        eff_discharge = 0.99

    """
    Constraint for the DCOPF
    """

    # Constraint that state which bus should be slack bus
    def slack_theta(model_FM, hour, unit):
        return (model_FM.theta_DC[data_DC["DCOPF"]["Ref Node"], hour, unit] ==
                data_DC["DCOPF"]["Angle"])

    model_FM.slack_theta_con = pyo.Constraint(model_FM.hours, model_FM.units, rule=slack_theta)

    # Active power balance constraint for each node
    def P_balance_DC(model_FM, n, hour, unit):
```

```python
        # Check for connection between the distribution and transmission grid
        # if connection is true, DC load = AC production in node 1
        if data_DC["Connection"][
            n] == True:
            return (model_DA.gen_DC[n, hour].value - model_DA.P_gen_AC[1, hour].value -
                    model_FM.P_slack_AC[hour, unit] == -sum(data_DC[ "B_DC"][n][m] *
                    model_FM.theta_DC[m, hour, unit] for m in model_FM.N_DC))
        # if connection is false, DC load = DC load
        elif data_DC["Connection"][n] == False and n == 1:
            return (model_FM.slack_DC[hour, unit] + model_DA.gen_DC[n, hour].value -
                    model_FM.P_load_DC[n, hour, unit] == -sum(data_DC[ "B_DC"][n][m] *
                    model_FM.theta_DC[m, hour, unit] for m in model_FM.N_DC))
        # if connection is false, DC load = DC load
        elif data_DC["Connection"][n] == False:
            return (model_DA.gen_DC[n, hour].value - model_FM.P_load_DC[n, hour, unit] ==
                    -sum(data_DC[ "B_DC"][n][m] * model_FM.theta_DC[m, hour, unit] for m in
                         model_FM.N_DC))

    model_FM.P_balance_DC_con = pyo.Constraint(model_FM.N_DC, model_FM.hours, model_FM.units,
                                               rule=P_balance_DC)

    # Constraint that dictate how much power flows between two nodes
    def P_flow_DC(model_FM, l, hour, unit):
        return (model_FM.P_flow_DC[l, hour, unit] == data_DC[ "B_DC"][model_FM.From_DC[l]][
                model_FM.To_DC[l]] * (model_FM.theta_DC[model_FM.From_DC[l], hour, unit] -
                model_FM.theta_DC[model_FM.To_DC[l], hour, unit]))

    model_FM.P_flow_DC_Con = pyo.Constraint(model_FM.L_DC, model_FM.hours, model_FM.units,
                                            rule=P_flow_DC)

    # Minimum and minimum active power flow between two nodes
    def P_Fl_DC(model_FM, l, hour, unit):
        return (-model_FM.Fl_min[l], model_FM.P_flow_DC[l, hour, unit], model_FM.Fl_max[l])

    model_FM.P_Fl_DC = pyo.Constraint(model_FM.L_DC, model_FM.hours, model_FM.units,
                                            rule=P_Fl_DC)

    """
    Constraint for the SOC-ACOPF
    """

    # Flow Constraints
    # Model for active power flow in the form of a constraint
    def P_flow(model_FM, n, hour, unit):
        # Equation is split into two elements (step) due to how calculations are done
        step1 = (-math.sqrt(2) * model_FM.u[n, hour, unit] *
                 sum(data_AC["G_AC"][n][l] for l in model_FM.N_AC))
        step2 = 0
        # Loop that check if a given node connection exist
        for n2 in model_FM.N_AC:
            # If connection exist, a constraint will be made based on this connection
            if data_AC["G_AC"][n][n2] != 0:
                step2 += data_AC[ "G_AC"][n][n2] * model_FM.R[model_FM.FrTo[n, n2], hour, unit]
                # Depending if line connection exists
                if list(data_AC["AC_lines"]["From To"]).index((n, n2)) >= len(
                        data_AC["AC_lines"]["From To"]) / 2:
                    step2 += data_AC["B_AC"][n][n2] * \
                    model_FM.I[model_FM.FrTo[n, n2], hour, unit]
                else:
                    step2 -= data_AC["B_AC"][n][n2] * \
                    model_FM.I[model_FM.FrTo[n, n2], hour, unit]
        # Each element for a given node is added and set equal to load on given node
        # if n==1 AC slack is included in the formulation
        if n == 1:
            # For a case with flexibility
            if Flex_included == "Y":
                return ((step1 + step2) + model_DA.P_gen_AC[n, hour].value +
                        model_FM.P_slack_AC[hour, unit] + (model_FM.flex_gen_inc[
                        n, hour, unit] - model_FM.flex_gen_dec[n, hour, unit]) -
                        model_FM.flex_load_inc[n, hour, unit] + model_FM.flex_load_dec[
                        n, hour, unit] - model_FM.battery_charge[n, hour, unit] +
                        model_FM.battery_discharge[n, hour, unit] + model_FM.load_shedding[
                        n, hour, unit] == model_FM.P_load_AC[n, hour, unit])
            # For a case without flexibility
            else:
                return ((step1 + step2) + model_DA.P_gen_AC[n, hour].value +
                        model_FM.P_slack_AC[hour, unit] + model_FM.load_shedding[
                        n, hour, unit] == model_FM.P_load_AC[n, hour, unit])
```

```

    # For nodes other than slack
    else:
        # For a case with flexibility
        if Flex_included == "Y":
            return ((step1 + step2) + model_DA.P_gen_AC[n, hour].value +
                    (model_FM.flex_gen_inc[n, hour, unit] - model_FM.flex_gen_dec[
                    n, hour, unit]) - model_FM.flex_load_inc[n, hour, unit] +
                    model_FM.flex_load_dec[n, hour, unit] - model_FM.battery_charge[
                    n, hour, unit] + model_FM.battery_discharge[n, hour, unit] +
                    model_FM.load_shedding[n, hour, unit] == model_FM.P_load_AC[
                    n, hour, unit])
        # For a case without flexibility
        else:
            return ((step1 + step2) + model_DA.P_gen_AC[n, hour].value +
                    model_FM.load_shedding[n, hour, unit] == model_FM.P_load_AC[
                    n, hour, unit])

model_FM.P_flow_con = pyo.Constraint(model_FM.N_AC, model_FM.hours, model_FM.units,
                                     rule=P_flow)

# Model for reactive power flow in the form of a constraint
def Q_flow(model_FM, n, hour, unit):
    step1 = (-math.sqrt(2) * model_FM.u[n, hour, unit] *
             sum(data_AC["B_AC"][n][l] for l in model_FM.N_AC))
    step2 = 0
    # Loop that check if a given node connection exist
    for n2 in model_FM.N_AC:  # Loop that check if a given node connection exist
        if data_AC["B_AC"][n][n2] != 0:
            step2 += data_AC["B_AC"][n][n2] * model_FM.R[model_FM.FrTo[n, n2], hour, unit]
            # Depending if line connection exists
            if list(data_AC["AC_lines"]["From To"]).index((n, n2)) >= len(
                    data_AC["AC_lines"]["From To"]) / 2:
                step2 -= data_AC["G_AC"][n][n2] * \
                model_FM.I[model_FM.FrTo[n, n2], hour, unit]
            else:  # node, one of two equation are used
                step2 += data_AC["G_AC"][n][n2] * \
                model_FM.I[model_FM.FrTo[n, n2], hour, unit]

    # Each element for a given node is added and set equal to load on given node
    # if n==1 AC slack is included in the formulation
    if n == 1:
        return ((step1 + step2) + model_DA.Q_gen_AC[n, hour].value +
                model_FM.Q_slack_AC[hour, unit] == model_FM.Q_load_AC[n, hour, unit])
    # For nodes other than slack
    else:
        return ((step1 + step2) + model_DA.Q_gen_AC[n, hour].value ==
                model_FM.Q_load_AC[n, hour, unit])

model_FM.Q_flow_con = pyo.Constraint(model_FM.N_AC, model_FM.hours, model_FM.units,
                                     rule=Q_flow)

def Load_shedding(model_FM, n, hour, unit):
    return model_FM.load_shedding[n, hour, unit] <= model_FM.P_load_AC[n, hour, unit]

model_FM.Load_shedding = pyo.Constraint(model_FM.N_AC, model_FM.hours, model_FM.units,
                                    rule=Load_shedding)

# Constraint implementing a bottleneck on distribution line 26-27
# Included if in input specified True
if data_AC["SOC-ACOPF"]["Const 26-27"] == True:
    def AC_flow_const(model_FM, hour, unit):
        # Calculates flow into node 26
        p_flow = pyo.sqrt(2) * data_AC["G_AC"][6][26] * model_FM.u[26, hour, unit] - \
                 data_AC["G_AC"][6][26] * model_FM.R[25, hour, unit] + \
                 data_AC["B_AC"][6][26] * model_FM.I[25, hour, unit]
        q_flow = pyo.sqrt(2) * data_AC["B_AC"][6][26] * model_FM.u[26, hour, unit] - \
                 data_AC["B_AC"][6][26] * model_FM.R[25, hour, unit] - \
                 data_AC["G_AC"][6][26] * model_FM.I[25, hour, unit]

        # Adds production, load and flexibility within node 26
        if Flex_included == "Y":
            p_flow_line = -p_flow - model_FM.P_load_AC[ 26, hour, unit] - \
                          model_FM.flex_load_inc[ 26, hour, unit] + \
                          model_FM.flex_load_dec[ 26, hour, unit] + \
                          (model_FM.flex_gen_inc[ 26, hour, unit] -
                           model_FM.flex_gen_dec[ 26, hour, unit])

```

```
                q_flow_line = -q_flow - model_FM.Q_load_AC[ 26, hour, unit]

            else:
                p_flow_line = -p_flow - model_FM.P_load_AC[ 26, hour, unit]
                q_flow_line = -q_flow - model_FM.Q_load_AC[ 26, hour, unit]

            # Returns squared apparent power flow on line 26-27,
            # the capacity specified in input file is also squared.
            # This is to avoid quadratic terms in the inequality constraint
            return p_flow_line ** 2 + q_flow_line ** 2 <= \
                   data_AC["SOC-ACOPF"]["Capacity"] ** 2

        model_FM.AC_flow_const = pyo.Constraint(model_FM.hours, model_FM.units,
                                        rule=AC_flow_const)


    if Flex_included == "Y":

        def P_flex_prod_G_inc_max(model_FM, n, hour, unit):
            return model_FM.flex_gen_inc[n, hour, unit] <= model_FM.P_flex_gen_max[
                    n, hour, unit] * model_FM.flex_gen_use[n, hour, unit]

        model_FM.P_flex_prod_G_inc_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=P_flex_prod_G_inc_max)

        def P_flex_prod_G_dec_max(model_FM, n, hour, unit):
            if data_flex["Flex_gen_use"][n]:  # If True
                return model_FM.flex_gen_dec[n, hour, unit] <= model_DA.P_gen_AC[
                        n, hour].value * (1 - model_FM.flex_gen_use[n, hour, unit])
            else:
                return model_FM.flex_gen_dec[n, hour, unit] == 0

        model_FM.P_flex_prod_G_dec_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=P_flex_prod_G_dec_max)

        def Flex_load_inc_max(model_FM, n, hour, unit):
            return model_FM.flex_load_inc[n, hour, unit] <= model_FM.P_flex_load_max_inc[
                    n, hour, unit] * model_FM.flex_load_use[n, hour, unit]

        model_FM.Flex_load_inc_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Flex_load_inc_max)

        def Flex_load_dec_max(model_FM, n, hour, unit):
            if model_FM.P_flex_load_max_dec[n, hour, unit] < model_FM.P_load_AC[n, hour, unit]:
                return model_FM.flex_load_dec[n, hour, unit] <= model_FM.P_flex_load_max_dec[
                        n, hour, unit] * (1 - model_FM.flex_load_use[n, hour, unit])
            else:
                return model_FM.flex_load_dec[n, hour, unit] <= model_FM.P_load_AC[
                        n, hour, unit] * (1 - model_FM.flex_load_use[n, hour, unit])

        model_FM.Flex_load_dec_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Flex_load_dec_max)

        def Battery_SoC_min(model_FM, n, hour, unit):
            return model_FM.battery_state_of_charge[n, hour, unit] >= \
                   model_FM.battery_SoC_min[n, hour, unit]

        model_FM.Battery_SoC_min_const = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Battery_SoC_min)

        def Battery_SoC_max(model_FM, n, hour, unit):
            return model_FM.battery_state_of_charge[n, hour, unit] <= \
                   model_FM.battery_SoC_max[n, hour, unit]

        model_FM.Battery_SoC_max_const = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Battery_SoC_max)

        def Battery_discharge_max(model_FM, n, hour, unit):
            if model_FM.battery_initial_SoC[n] == 0:
                return model_FM.battery_discharge[n, hour, unit] == \
                       0 * model_FM.battery_state[n, hour, unit]
            else:
                return model_FM.battery_discharge[n, hour, unit] <= \
                       model_FM.battery_discharge_max[n, hour, unit] * \
                       model_FM.battery_state[n, hour, unit]

        model_FM.Battery_discharge_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Battery_discharge_max)
```

```

        def Battery_charge_max(model_FM, n, hour, unit):
            if model_FM.battery_initial_SoC[n] == 0:
                return model_FM.battery_discharge[n, hour, unit] == 0
            else:
                return model_FM.battery_charge[n, hour, unit] <= model_FM.battery_charge_max[
                    n, hour, unit] * (1 - model_FM.battery_state[n, hour, unit])

        model_FM.Battery_charge_max = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Battery_charge_max)

        def Battery_state_of_charge(model_FM, n, hour, unit):
            if hour == 0 and unit == 0:
                return model_FM.battery_initial_SoC[n] + model_FM.battery_charge[n, 0, 0] * \
                       eff_charge - model_FM.battery_discharge[n, 0, 0] / eff_discharge == \
                       model_FM.battery_state_of_charge[n, 0, 0]
            elif unit == 0:
                return model_FM.battery_state_of_charge[n, hour, 0] == \
                       model_FM.battery_state_of_charge[n, hour - 1, Units] + \
                       model_FM.battery_charge[n, hour, 0] * eff_charge - \
                       model_FM.battery_discharge[n, hour, 0] / eff_discharge
            else:
                return model_FM.battery_state_of_charge[n, hour, unit] == \
                       model_FM.battery_state_of_charge[n, hour, unit - 1] + \
                       model_FM.battery_charge[n, hour, unit] * eff_charge - \
                       model_FM.battery_discharge[n, hour, unit] / eff_discharge

        model_FM.Battery_state_of_charge = pyo.Constraint(model_FM.N_AC, model_FM.hours,
                                            model_FM.units, rule=Battery_state_of_charge)

        def Battery_charge_preservation(model_FM, n):
            return model_FM.battery_state_of_charge[n, Hours, Units] == \
                   model_FM.battery_initial_SoC[n]

        model_FM.Battery_charge_preservation = pyo.Constraint(model_FM.N_AC,
                                            rule=Battery_charge_preservation)

        def Total_Load_Balance(model_FM):
            total_flex_load = 0
            for n in model_FM.N_AC:
                for hour in model_FM.hours:
                    for unit in model_FM.units:
                        total_flex_load += model_FM.flex_load_inc[n, hour, unit] - \
                                           model_FM.flex_load_dec[n, hour, unit]
            return total_flex_load == 0

        model_FM.Total_Load_Balance = pyo.Constraint(rule=Total_Load_Balance)

    # Equality constraint

    # This constraint can be regarded as the mismatch equation in the form of
    # squared voltage mismatch which indicate when an acceptable solution is found by
    # converging to the value zero.
    def Quad_equal(model_FM, l, hour, unit):
        return ((2 * model_FM.u[model_FM.From_AC[l], hour, unit] *
                 model_FM.u[model_FM.To_AC[l], hour, unit]) >=
                ((model_FM.R[l, hour, unit]) ** 2 + (model_FM.I[l, hour, unit]) ** 2))

    model_FM.Quad_equal_con = pyo.Constraint(model_FM.L_AC, model_FM.hours, model_FM.units,
                                             rule=Quad_equal)

    # Voltage constraint
    def u_node(model_FM, n, hour, unit):
        # Voltage on node 1 is pre-defined
        if n == 1:
            return (model_FM.u[n, hour, unit] == model_FM.u_std)
        else:
            if data_AC["Voltage Management"][n] == True:
                if data_AC["SOC-ACOPF"]["V_man_all"] == True:
                    return (model_FM.u_std * model_FM.u_min ** 2, model_FM.u[n, hour, unit],
                            model_FM.u_std * model_FM.u_max ** 2)
                elif (hour == model_FM.V_hour and unit == model_FM.V_unit):
                    return (model_FM.u_std * model_FM.u_min ** 2, model_FM.u[n, hour, unit],
                            model_FM.u_std * model_FM.u_max ** 2)
                else:
                    return (0, model_FM.u[n, hour, unit], model_FM.u_std * model_FM.u_max ** 2)
            elif data_AC["Voltage Management"][n] == False:
                return (0 <= model_FM.u[n, hour, unit])
```

```

model_FM.u_node_con = pyo.Constraint(model_FM.N_AC, model_FM.hours, model_FM.units,
                                     rule=u_node)

# None zero constraint for variable R
def R_line(model_FM, l, hour, unit):
    return (model_FM.R[l, hour, unit] >= 0)

model_FM.R_line_con = pyo.Constraint(model_FM.L_AC, model_FM.hours, model_FM.units,
                                     rule=R_line)

"""
Solving the optimization problem
"""

def OBJ_FM(model_FM):  # Objective function will be to minimize production costs
    total_cost = 0
    for hour in model_FM.hours:
        for unit in model_FM.units:
            total_cost += (model_FM.C1_slack_DC[hour] *
                           model_FM.slack_DC[hour, unit]) * 1 / (Units + 1)
    for n in model_FM.N_AC:
        for hour in model_FM.hours:
            for unit in model_FM.units:
                total_cost += model_FM.Cost_Load_shedding[n] * \
                              model_FM.load_shedding[n, hour, unit] *  1 / (Units + 1)

                if Flex_included == "Y":
                    flex_gen_inc_cost = (model_FM.C1_flex_gen_inc[hour, unit] *
                                        model_FM.flex_gen_inc[n, hour, unit]) * \
                                        1 / (Units + 1)

                    flex_gen_dec_cost = (model_FM.C1_flex_gen_dec[hour, unit] *
                                          model_FM.flex_gen_dec[n, hour, unit]) * \
                                        1 / (Units + 1)

                    flex_load_inc_cost = (model_FM.C1_flex_load_inc[hour, unit] *
                                          model_FM.flex_load_inc[n, hour, unit]) * \
                                         1 / (Units + 1)

                    flex_load_dec_cost = (model_FM.C1_flex_load_dec[hour, unit] *
                                          model_FM.flex_load_dec[n, hour, unit]) * \
                                         1 / (Units + 1)

                    battery_charge_cost = (model_FM.C1_charge_battery[hour, unit] *
                                           model_FM.battery_charge[n, hour, unit]) * \
                                          1 / (Units + 1)

                    battery_discharge_cost = (model_FM.C1_discharge_battery[
                                                  hour, unit] *
                                              model_FM.battery_discharge[
                                                  n, hour, unit]) *  1 / (Units + 1)


                    total_cost += flex_gen_inc_cost + flex_gen_dec_cost + \
                                  flex_load_inc_cost + flex_load_dec_cost + \
                                  battery_charge_cost + battery_discharge_cost

    return total_cost * 100

model_FM.OBJ = pyo.Objective(rule=OBJ_FM, sense=pyo.minimize)
# Line below can be run if one whats to see the formulation of constraints,
# variables and objective function
# model_FM.pprint()

# Gurobi is used as solver to find solution
opt = SolverFactory("gurobi", keepfiles=True, log_file='/z/log', soln_file='/z/sol')
# opt.options are settings for reducing relaxation errors for the system
opt.options["mipgap"] = 0
opt.options["mipgapabs"] = 0
opt.options["PRESOS2BIGM"] = 0
# Code that shows the performance of the solver
opt.solve(model_FM, tee=True, logfile="solving_performance.log")
#model_FM.display()
```

C Base Data used for All Cases

Day Ahead Price

Time Unit	1	2	3	4	5	6
Price [€/MWh]	38,2	39,34	47,01	49,51	53,95	79,33

Time Unit	7	8	9	10	11	12
Price [€/MWh]	81,33	71,93	51,98	51,07	50,12	48,99

Day-Ahead Generation Capacity in Distribution Network:

Node	Capacity [pu]
9	0,005
15	0,09
21	0,05
25	0,08

Cost Load Shedding in Distribution Network

Price [EUR/MWh]
20000

Day-Ahead Generation Capacity in Transmission Network:

Node	Capacity [pu]
3	2

Line data for Transmission Network:

From Node	To Node	B [pu]
1	4	-17,36111
4	5	-10,51068
5	6	-5,588245
3	6	-17,06485
6	7	-9,798567
7	8	-13,69798
8	2	-16
8	9	-5,975135
9	4	-11,6041

Line data for Distribution Network:

From Node	To Node	R [pu]	X [pu]
2	1	0,057526	0,029324
3	2	0,307595	0,156668
4	3	0,228357	0,1163
5	4	0,237778	0,121104
6	5	0,510995	0,441115
7	6	0,116799	0,386085
8	7	0,44386	0,146685
9	8	0,642643	0,461705
10	9	0,651378	0,461705
11	10	0,122664	0,040555
12	11	0,233598	0,077242
13	12	0,915922	0,720634
14	13	0,337918	0,444796
15	14	0,36874	0,328185
16	15	0,465635	0,340039
17	16	0,80424	1,073775
18	17	0,456713	0,358133
19	2	0,102324	0,097644
20	19	0,938508	0,845668
21	20	0,255497	0,298486
22	21	0,442301	0,584805
23	3	0,281515	0,192356
24	23	0,560285	0,442425
25	24	0,559037	0,437434
26	6	0,126657	0,064514
27	26	0,17732	0,090282
28	27	0,660737	0,582559
29	28	0,501761	0,437122
30	29	0,316642	0,161285
31	30	0,607953	0,60084
32	31	0,193729	0,225799
33	32	0,212759	0,330805

Active Load in the Transmission Network used during Day-Ahead Optimization

Node	1	2	3	4	5	6	7	8	9	10	11	12
1	0,89568	0,89895	0,90792	0,92322	0,94329	0,98310	1,00902	1,00818	0,98988	0,97746	0,97785	0,96972
3	1,49280	1,49825	1,51320	1,53870	1,57215	1,63850	1,68170	1,68030	1,64980	1,62910	1,62975	1,61620
9	1,19424	1,19860	1,21056	1,23096	1,25772	1,31080	1,34536	1,34424	1,31984	1,30328	1,30380	1,29296

Active Load in the Transmission Network used during Flexibility Market Optimization

Node	1	2	3	4	5	6	7	8	9	10	11	12
1	0,89568	0,89650	0,89732	0,89813	0,89895	0,90119	0,90344	0,90568	0,90792	0,91175	0,91557	0,91940
3	1,49280	1,49416	1,49553	1,49689	1,49825	1,50199	1,50573	1,50946	1,51320	1,51958	1,52595	1,53233
9	1,19424	1,19533	1,19642	1,19751	1,19860	1,20159	1,20458	1,20757	1,21056	1,21566	1,22076	1,22586

Node	13	14	15	16	17	18	19	20	21	22	23	24
1	0,92322	0,92824	0,93326	0,93827	0,94329	0,95324	0,96320	0,97315	0,98310	0,98958	0,99606	1,00254
3	1,53870	1,54706	1,55543	1,56379	1,57215	1,58874	1,60533	1,62191	1,63850	1,64930	1,66010	1,67090
9	1,23096	1,23765	1,24434	1,25103	1,25772	1,27099	1,28426	1,29753	1,31080	1,31944	1,32808	1,33672

Node	25	26	27	28	29	30	31	32	33	34	35	36
1	1,00902	1,00881	1,00860	1,00839	1,00818	1,00361	0,99903	0,99446	0,98988	0,98678	0,98367	0,98057
3	1,68170	1,68135	1,68100	1,68065	1,68030	1,67268	1,66505	1,65743	1,64980	1,64463	1,63945	1,63428
9	1,34536	1,34508	1,34480	1,34452	1,34424	1,33814	1,33204	1,32594	1,31984	1,31570	1,31156	1,30742

Node	37	38	39	40	41	42	43	44	45	46	47	48
1	0,97746	0,97756	0,97766	0,97775	0,97785	0,97582	0,97379	0,97175	0,96972	0,96750	0,96528	0,96306
3	1,62910	1,62926	1,62943	1,62959	1,62975	1,62636	1,62298	1,61959	1,61620	1,61250	1,60880	1,60510
9	1,30328	1,30341	1,30354	1,30367	1,30380	1,30109	1,29838	1,29567	1,29296	1,29000	1,28704	1,28408

Reactive Load in the Distirbution Network used during Day-Ahead Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001194	0,001199	0,001211	0,001231	0,001258	0,001311	0,001345	0,00134424	0,0013198	0,001303	0,001304	0,001293
3	0,000358	0,00036	0,000363	0,000369	0,000377	0,000393	0,000404	0,000403272	0,000396	0,000391	0,000391	0,000388
4	0,000717	0,000719	0,000726	0,000739	0,000755	0,000786	0,000807	0,000806544	0,0007919	0,000782	0,000782	0,000776
5	0,000358	0,00036	0,000363	0,000369	0,000377	0,000393	0,000404	0,000403272	0,000396	0,000391	0,000391	0,000388
6	0,000334	0,000336	0,000339	0,000345	0,000352	0,000367	0,000377	0,000376387	0,0003696	0,000365	0,000365	0,000362
7	0,001194	0,001199	0,001211	0,001231	0,001258	0,001311	0,001345	0,00134424	0,0013198	0,001303	0,001304	0,001293
8	0,001791	0,001798	0,001816	0,001846	0,001887	0,001966	0,002018	0,00201636	0,0019798	0,001955	0,001956	0,001939
9	0,00203	0,002038	0,002058	0,002093	0,002138	0,002228	0,002287	0,002285208	0,0022437	0,002216	0,002216	0,002198
10	0,001791	0,001798	0,001816	0,001846	0,001887	0,001966	0,002018	0,00201636	0,0019798	0,001955	0,001956	0,001939
11	0,000143	0,000144	0,000145	0,000148	0,000151	0,000157	0,000161	0,000161309	0,0001584	0,000156	0,000156	0,000155
12	0,000287	0,000288	0,000291	0,000295	0,000302	0,000315	0,000323	0,000322618	0,0003168	0,000313	0,000313	0,00031
13	0,000263	0,000264	0,000266	0,000271	0,000277	0,000288	0,000296	0,000295733	0,0002904	0,000287	0,000287	0,000284
14	0,00049	0,000491	0,000496	0,000505	0,000516	0,000537	0,000552	0,000551138	0,0005411	0,000534	0,000535	0,00053
15	0,00037	0,000372	0,000375	0,000382	0,00039	0,000406	0,000417	0,000416714	0,0004092	0,000404	0,000404	0,000401
16	0,000334	0,000336	0,000339	0,000345	0,000352	0,000367	0,000377	0,000376387	0,0003696	0,000365	0,000365	0,000362
17	0,000322	0,000324	0,000327	0,000332	0,00034	0,000354	0,000363	0,000362945	0,0003564	0,000352	0,000352	0,000349
18	0,000363	0,000364	0,000368	0,000374	0,000382	0,000398	0,000409	0,000408649	0,0004012	0,000396	0,000396	0,000393
19	0,000361	0,000362	0,000366	0,000372	0,00038	0,000396	0,000406	0,00040596	0,0003986	0,000394	0,000394	0,00039
20	0,000349	0,00035	0,000353	0,000359	0,000367	0,000383	0,000393	0,000392518	0,0003854	0,000381	0,000381	0,000378
21	0,000352	0,000354	0,000357	0,000363	0,000371	0,000387	0,000397	0,000396551	0,0003894	0,000384	0,000385	0,000381
22	0,000357	0,000358	0,000362	0,000368	0,000376	0,000392	0,000402	0,000401928	0,0003946	0,00039	0,00039	0,000387
23	0,000382	0,000384	0,000387	0,000394	0,000402	0,000419	0,000431	0,000430157	0,0004223	0,000417	0,000417	0,000414
24	0,001469	0,001474	0,001489	0,001514	0,001547	0,001612	0,001655	0,001653415	0,0016234	0,001603	0,001604	0,00159
25	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,0016803	0,0016498	0,001629	0,00163	0,001616
26	0,003941	0,003955	0,003995	0,004062	0,00415	0,004326	0,00444	0,004435992	0,0043555	0,004301	0,004303	0,004267
27	0,000299	0,0003	0,000303	0,000308	0,000314	0,000328	0,000336	0,00033606	0,00033	0,000326	0,000326	0,000323
28	0,000215	0,000216	0,000218	0,000222	0,000226	0,000236	0,000242	0,000241963	0,0002376	0,000235	0,000235	0,000233
29	0,000442	0,000443	0,000448	0,000455	0,000465	0,000485	0,000498	0,000497369	0,0004883	0,000482	0,000482	0,000478
30	0,009793	0,009829	0,009927	0,010094	0,010313	0,010749	0,011032	0,011022768	0,0108227	0,010687	0,010691	0,010602
31	0,001111	0,001115	0,001126	0,001145	0,00117	0,001219	0,001251	0,001250143	0,0012275	0,001212	0,001213	0,001202
32	0,00123	0,001235	0,001247	0,001268	0,001295	0,00135	0,001386	0,001384567	0,0013594	0,001342	0,001343	0,001332
33	0,000394	0,000396	0,000399	0,000406	0,000415	0,000433	0,000444	0,000443599	0,0004355	0,00043	0,00043	0,000427

Reactive Load in the Distirbution Network used during Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001194	0,001195	0,001196	0,001198	0,001199	0,001202	0,001205	0,00120757	0,0012106	0,001216	0,001221	0,001226
3	0,000358	0,000359	0,000359	0,000359	0,00036	0,00036	0,000361	0,000362271	0,0003632	0,000365	0,000366	0,000368
4	0,000717	0,000717	0,000718	0,000719	0,000719	0,000721	0,000723	0,000724542	0,0007263	0,000729	0,000732	0,000736
5	0,000358	0,000359	0,000359	0,000359	0,00036	0,00036	0,000361	0,000362271	0,0003632	0,000365	0,000366	0,000368
6	0,000334	0,000335	0,000335	0,000335	0,000336	0,000336	0,000337	0,00033812	0,000339	0,00034	0,000342	0,000343
7	0,001194	0,001195	0,001196	0,001198	0,001199	0,001202	0,001205	0,00120757	0,0012106	0,001216	0,001221	0,001226
8	0,001791	0,001793	0,001795	0,001796	0,001798	0,001802	0,001807	0,001811355	0,0018158	0,001823	0,001831	0,001839
9	0,00203	0,002032	0,002034	0,002036	0,002038	0,002043	0,002048	0,002052869	0,002058	0,002067	0,002075	0,002084
10	0,001791	0,001793	0,001795	0,001796	0,001798	0,001802	0,001807	0,001811355	0,0018158	0,001823	0,001831	0,001839
11	0,000143	0,000143	0,000144	0,000144	0,000144	0,000144	0,000145	0,000144908	0,0001453	0,000146	0,000146	0,000147
12	0,000287	0,000287	0,000287	0,000287	0,000288	0,000288	0,000289	0,000289817	0,0002905	0,000292	0,000293	0,000294
13	0,000263	0,000263	0,000263	0,000263	0,000264	0,000264	0,000265	0,000265665	0,0002663	0,000267	0,000269	0,00027
14	0,00049	0,00049	0,000491	0,000491	0,000491	0,000493	0,000494	0,000495104	0,0004963	0,000498	0,000501	0,000503
15	0,00037	0,000371	0,000371	0,000371	0,000372	0,000372	0,000373	0,000374347	0,0003753	0,000377	0,000378	0,00038
16	0,000334	0,000335	0,000335	0,000335	0,000336	0,000336	0,000337	0,00033812	0,000339	0,00034	0,000342	0,000343
17	0,000322	0,000323	0,000323	0,000323	0,000324	0,000324	0,000325	0,000326044	0,0003269	0,000328	0,00033	0,000331
18	0,000363	0,000363	0,000364	0,000364	0,000364	0,000365	0,000366	0,000367101	0,000368	0,00037	0,000371	0,000373
19	0,000361	0,000361	0,000361	0,000362	0,000362	0,000363	0,000364	0,000364686	0,0003656	0,000367	0,000369	0,00037
20	0,000349	0,000349	0,000349	0,00035	0,00035	0,000351	0,000352	0,00035261	0,0003535	0,000355	0,000356	0,000358
21	0,000352	0,000353	0,000353	0,000353	0,000354	0,000354	0,000355	0,000356233	0,0003571	0,000359	0,00036	0,000362
22	0,000357	0,000357	0,000358	0,000358	0,000358	0,000359	0,00036	0,000361063	0,000362	0,000363	0,000365	0,000367
23	0,000382	0,000383	0,000383	0,000383	0,000384	0,000385	0,000385	0,000386422	0,0003874	0,000389	0,000391	0,000392
24	0,001469	0,00147	0,001472	0,001473	0,001474	0,001478	0,001482	0,001485311	0,001489	0,001495	0,001502	0,001508
25	0,001493	0,001494	0,001496	0,001497	0,001498	0,001502	0,001506	0,001509463	0,0015132	0,00152	0,001526	0,001532
26	0,003941	0,003945	0,003948	0,003952	0,003955	0,003965	0,003975	0,003984981	0,0039948	0,004012	0,004029	0,004045
27	0,000299	0,000299	0,000299	0,000299	0,0003	0,0003	0,000301	0,000301893	0,0003026	0,000304	0,000305	0,000306
28	0,000215	0,000215	0,000215	0,000216	0,000216	0,000216	0,000217	0,000217363	0,0002179	0,000219	0,00022	0,000221
29	0,000442	0,000442	0,000443	0,000443	0,000443	0,000445	0,000446	0,000446801	0,0004479	0,00045	0,000452	0,000454
30	0,009793	0,009802	0,009811	0,00982	0,009829	0,009853	0,009878	0,009902074	0,0099266	0,009968	0,01001	0,010052
31	0,001111	0,001112	0,001113	0,001114	0,001115	0,001117	0,00112	0,00112304	0,0011258	0,001131	0,001135	0,00114
32	0,00123	0,001231	0,001232	0,001233	0,001235	0,001238	0,001241	0,001243797	0,0012469	0,001252	0,001257	0,001263
33	0,000394	0,000394	0,000395	0,000395	0,000396	0,000397	0,000398	0,000398498	0,0003995	0,000401	0,000403	0,000405

Reactive Load in the Distirbution Network used during Flexibility Market Optimization

Node\Time	13	14	15	16	17	18	19	20	21	22	23	24
2	0,001231	0,001238	0,001244	0,001251	0,001258	0,001271	0,001284	0,00129753	0,0013108	0,001319	0,001328	0,001337
3	0,000369	0,000371	0,000373	0,000375	0,000377	0,000381	0,000385	0,000389259	0,0003932	0,000396	0,000398	0,000401
4	0,000739	0,000743	0,000747	0,000751	0,000755	0,000763	0,000771	0,000778518	0,0007865	0,000792	0,000797	0,000802
5	0,000369	0,000371	0,000373	0,000375	0,000377	0,000381	0,000385	0,000389259	0,0003932	0,000396	0,000398	0,000401
6	0,000345	0,000347	0,000348	0,00035	0,000352	0,000356	0,00036	0,000363308	0,000367	0,000369	0,000372	0,000374
7	0,001231	0,001238	0,001244	0,001251	0,001258	0,001271	0,001284	0,00129753	0,0013108	0,001319	0,001328	0,001337
8	0,001846	0,001856	0,001867	0,001877	0,001887	0,001906	0,001926	0,001946295	0,0019662	0,001979	0,001992	0,002005
9	0,002093	0,002104	0,002115	0,002127	0,002138	0,002161	0,002183	0,002205801	0,0022284	0,002243	0,002258	0,002272
10	0,001846	0,001856	0,001867	0,001877	0,001887	0,001906	0,001926	0,001946295	0,0019662	0,001979	0,001992	0,002005
11	0,000148	0,000149	0,000149	0,00015	0,000151	0,000153	0,000154	0,000155704	0,0001573	0,000158	0,000159	0,00016
12	0,000295	0,000297	0,000299	0,0003	0,000302	0,000305	0,000308	0,000311407	0,0003146	0,000317	0,000319	0,000321
13	0,000271	0,000272	0,000274	0,000275	0,000277	0,00028	0,000283	0,000285457	0,0002884	0,00029	0,000292	0,000294
14	0,000505	0,000507	0,00051	0,000513	0,000516	0,000521	0,000527	0,000531987	0,0005374	0,000541	0,000545	0,000548
15	0,000382	0,000384	0,000386	0,000388	0,00039	0,000394	0,000398	0,000402234	0,0004063	0,000409	0,000412	0,000414
16	0,000345	0,000347	0,000348	0,00035	0,000352	0,000356	0,00036	0,000363308	0,000367	0,000369	0,000372	0,000374
17	0,000332	0,000334	0,000336	0,000338	0,00034	0,000343	0,000347	0,000350333	0,0003539	0,000356	0,000359	0,000361
18	0,000374	0,000376	0,000378	0,00038	0,000382	0,000386	0,00039	0,000394449	0,0003985	0,000401	0,000404	0,000406
19	0,000372	0,000374	0,000376	0,000378	0,00038	0,000384	0,000388	0,000391854	0,0003959	0,000398	0,000401	0,000404
20	0,000359	0,000361	0,000363	0,000365	0,000367	0,000371	0,000375	0,000378879	0,0003828	0,000385	0,000388	0,00039
21	0,000363	0,000365	0,000367	0,000369	0,000371	0,000375	0,000379	0,000382771	0,0003867	0,000389	0,000392	0,000394
22	0,000368	0,00037	0,000372	0,000374	0,000376	0,00038	0,000384	0,000387961	0,0003919	0,000395	0,000397	0,0004
23	0,000394	0,000396	0,000398	0,0004	0,000402	0,000407	0,000411	0,00041521	0,0004195	0,000422	0,000425	0,000428
24	0,001514	0,001522	0,001531	0,001539	0,001547	0,001563	0,00158	0,001595962	0,0016123	0,001623	0,001634	0,001644
25	0,001539	0,001547	0,001555	0,001564	0,001572	0,001589	0,001605	0,001621913	0,0016385	0,001649	0,00166	0,001671
26	0,004062	0,004084	0,004106	0,004128	0,00415	0,004194	0,004238	0,004281849	0,0043256	0,004354	0,004383	0,004411
27	0,000308	0,000309	0,000311	0,000313	0,000314	0,000318	0,000321	0,000324383	0,0003277	0,00033	0,000332	0,000334
28	0,000222	0,000223	0,000224	0,000225	0,000226	0,000229	0,000231	0,000233555	0,0002359	0,000237	0,000239	0,000241
29	0,000455	0,000458	0,00046	0,000463	0,000465	0,00047	0,000475	0,000480086	0,000485	0,000488	0,000491	0,000495
30	0,010094	0,010149	0,010204	0,010258	0,010313	0,010422	0,010531	0,010639746	0,0107486	0,010819	0,01089	0,010961
31	0,001145	0,001151	0,001157	0,001163	0,00117	0,001182	0,001194	0,001206703	0,001219	0,001227	0,001235	0,001243
32	0,001268	0,001275	0,001282	0,001289	0,001295	0,001309	0,001323	0,001336456	0,0013501	0,001359	0,001368	0,001377
33	0,000406	0,000408	0,000411	0,000413	0,000415	0,000419	0,000424	0,000428185	0,0004326	0,000435	0,000438	0,000441

Reactive Load in the Distirbution Network used during Flexibility Market Optimization

Node\Time	25	26	27	28	29	30	31	32	33	34	35	36
2	0,001345	0,001345	0,001345	0,001345	0,001344	0,001338	0,001332	0,00132594	0,0013198	0,001316	0,001312	0,001307
3	0,000404	0,000404	0,000403	0,000403	0,000403	0,000401	0,0004	0,000397782	0,000396	0,000395	0,000393	0,000392
4	0,000807	0,000807	0,000807	0,000807	0,000807	0,000803	0,000799	0,000795564	0,0007919	0,000789	0,000787	0,000784
5	0,000404	0,000404	0,000403	0,000403	0,000403	0,000401	0,0004	0,000397782	0,000396	0,000395	0,000393	0,000392
6	0,000377	0,000377	0,000377	0,000376	0,000376	0,000375	0,000373	0,000371263	0,0003696	0,000368	0,000367	0,000366
7	0,001345	0,001345	0,001345	0,001345	0,001344	0,001338	0,001332	0,00132594	0,0013198	0,001316	0,001312	0,001307
8	0,002018	0,002018	0,002017	0,002017	0,002016	0,002007	0,001998	0,00198891	0,0019798	0,001974	0,001967	0,001961
9	0,002287	0,002287	0,002286	0,002286	0,002285	0,002275	0,002264	0,002254098	0,0022437	0,002237	0,00223	0,002223
10	0,002018	0,002018	0,002017	0,002017	0,002016	0,002007	0,001998	0,00198891	0,0019798	0,001974	0,001967	0,001961
11	0,000161	0,000161	0,000161	0,000161	0,000161	0,000161	0,00016	0,000159113	0,0001584	0,000158	0,000157	0,000157
12	0,000323	0,000323	0,000323	0,000323	0,000323	0,000321	0,00032	0,000318226	0,0003168	0,000316	0,000315	0,000314
13	0,000296	0,000296	0,000296	0,000296	0,000296	0,000294	0,000293	0,000291707	0,0002904	0,000289	0,000289	0,000288
14	0,000552	0,000551	0,000551	0,000551	0,000551	0,000549	0,000546	0,000543635	0,0005411	0,000539	0,000538	0,000536
15	0,000417	0,000417	0,000417	0,000417	0,000417	0,000415	0,000413	0,000411041	0,0004092	0,000408	0,000407	0,000405
16	0,000377	0,000377	0,000377	0,000376	0,000376	0,000375	0,000373	0,000371263	0,0003696	0,000368	0,000367	0,000366
17	0,000363	0,000363	0,000363	0,000363	0,000363	0,000361	0,00036	0,000358004	0,0003564	0,000355	0,000354	0,000353
18	0,000409	0,000409	0,000409	0,000409	0,000409	0,000407	0,000405	0,000403086	0,0004012	0,0004	0,000399	0,000397
19	0,000406	0,000406	0,000406	0,000406	0,000406	0,000404	0,000402	0,000400434	0,0003986	0,000397	0,000396	0,000395
20	0,000393	0,000393	0,000393	0,000393	0,000393	0,000391	0,000389	0,000387174	0,0003854	0,000384	0,000383	0,000382
21	0,000397	0,000397	0,000397	0,000397	0,000397	0,000395	0,000393	0,000391152	0,0003894	0,000388	0,000387	0,000386
22	0,000402	0,000402	0,000402	0,000402	0,000402	0,0004	0,000398	0,000396456	0,0003946	0,000393	0,000392	0,000391
23	0,000431	0,00043	0,00043	0,00043	0,00043	0,000428	0,000426	0,000424301	0,0004223	0,000421	0,00042	0,000418
24	0,001655	0,001654	0,001654	0,001654	0,001653	0,001646	0,001638	0,001630906	0,0016234	0,001618	0,001613	0,001608
25	0,001682	0,001681	0,001681	0,001681	0,00168	0,001673	0,001665	0,001657425	0,0016498	0,001645	0,001639	0,001634
26	0,00444	0,004439	0,004438	0,004437	0,004436	0,004416	0,004396	0,004375602	0,0043555	0,004342	0,004328	0,004314
27	0,000336	0,000336	0,000336	0,000336	0,000336	0,000335	0,000333	0,000331485	0,00033	0,000329	0,000328	0,000327
28	0,000242	0,000242	0,000242	0,000242	0,000242	0,000241	0,00024	0,000238669	0,0002376	0,000237	0,000236	0,000235
29	0,000498	0,000498	0,000498	0,000497	0,000497	0,000495	0,000493	0,000490598	0,0004883	0,000487	0,000485	0,000484
30	0,011032	0,01103	0,011027	0,011025	0,011023	0,010973	0,010923	0,010872708	0,0108227	0,010789	0,010755	0,010721
31	0,001251	0,001251	0,001251	0,00125	0,00125	0,001244	0,001239	0,001233124	0,0012275	0,001224	0,00122	0,001216
32	0,001386	0,001385	0,001385	0,001385	0,001385	0,001378	0,001372	0,001365718	0,0013594	0,001355	0,001351	0,001347
33	0,000444	0,000444	0,000444	0,000444	0,000444	0,000442	0,00044	0,00043756	0,0004355	0,000434	0,000433	0,000431

Reactive Load in the Distirbution Network used during Flexibility Market Optimization

Node\Time	37	38	39	40	41	42	43	44	45	46	47	48
2	0,001303	0,001303	0,001304	0,001304	0,001304	0,001301	0,001298	0,00129567	0,001293	0,00129	0,001287	0,001284
3	0,000391	0,000391	0,000391	0,000391	0,000391	0,00039	0,00039	0,000388701	0,0003879	0,000387	0,000386	0,000385
4	0,000782	0,000782	0,000782	0,000782	0,000782	0,000781	0,000779	0,000777402	0,0007758	0,000774	0,000772	0,00077
5	0,000391	0,000391	0,000391	0,000391	0,000391	0,00039	0,00039	0,000388701	0,0003879	0,000387	0,000386	0,000385
6	0,000365	0,000365	0,000365	0,000365	0,000365	0,000364	0,000364	0,000362788	0,000362	0,000361	0,00036	0,00036
7	0,001303	0,001303	0,001304	0,001304	0,001304	0,001301	0,001298	0,00129567	0,001293	0,00129	0,001287	0,001284
8	0,001955	0,001955	0,001955	0,001956	0,001956	0,001952	0,001948	0,001943505	0,0019394	0,001935	0,001931	0,001926
9	0,002216	0,002216	0,002216	0,002216	0,002216	0,002212	0,002207	0,002202639	0,002198	0,002193	0,002188	0,002183
10	0,001955	0,001955	0,001955	0,001956	0,001956	0,001952	0,001948	0,001943505	0,0019394	0,001935	0,001931	0,001926
11	0,000156	0,000156	0,000156	0,000156	0,000156	0,000156	0,000156	0,00015548	0,0001552	0,000155	0,000154	0,000154
12	0,000313	0,000313	0,000313	0,000313	0,000313	0,000312	0,000312	0,000310961	0,0003103	0,00031	0,000309	0,000308
13	0,000287	0,000287	0,000287	0,000287	0,000287	0,000286	0,000286	0,000285047	0,0002845	0,000284	0,000283	0,000282
14	0,000534	0,000534	0,000534	0,000535	0,000535	0,000533	0,000532	0,000531225	0,0005301	0,000529	0,000528	0,000526
15	0,000404	0,000404	0,000404	0,000404	0,000404	0,000403	0,000402	0,000401658	0,0004008	0,0004	0,000399	0,000398
16	0,000365	0,000365	0,000365	0,000365	0,000365	0,000364	0,000364	0,000362788	0,000362	0,000361	0,00036	0,00036
17	0,000352	0,000352	0,000352	0,000352	0,000352	0,000351	0,000351	0,000349831	0,0003491	0,000348	0,000348	0,000347
18	0,000396	0,000396	0,000396	0,000396	0,000396	0,000396	0,000395	0,000393884	0,0003931	0,000392	0,000391	0,00039
19	0,000394	0,000394	0,000394	0,000394	0,000394	0,000393	0,000392	0,000391292	0,0003905	0,00039	0,000389	0,000388
20	0,000381	0,000381	0,000381	0,000381	0,000381	0,00038	0,000379	0,000378336	0,0003775	0,000377	0,000376	0,000375
21	0,000384	0,000385	0,000385	0,000385	0,000385	0,000384	0,000383	0,000382223	0,0003814	0,000381	0,00038	0,000379
22	0,00039	0,00039	0,00039	0,00039	0,00039	0,000389	0,000388	0,000387405	0,0003866	0,000386	0,000385	0,000384
23	0,000417	0,000417	0,000417	0,000417	0,000417	0,000416	0,000415	0,000414614	0,0004137	0,000413	0,000412	0,000411
24	0,001603	0,001603	0,001603	0,001604	0,001604	0,0016	0,001597	0,001593674	0,0015903	0,001587	0,001583	0,001579
25	0,001629	0,001629	0,001629	0,00163	0,00163	0,001626	0,001623	0,001619588	0,0016162	0,001613	0,001609	0,001605
26	0,004301	0,004301	0,004302	0,004302	0,004303	0,004294	0,004285	0,004275711	0,0042668	0,004257	0,004247	0,004237
27	0,000326	0,000326	0,000326	0,000326	0,000326	0,000325	0,000325	0,000323918	0,0003232	0,000323	0,000322	0,000321
28	0,000235	0,000235	0,000235	0,000235	0,000235	0,000234	0,000234	0,000233221	0,0002327	0,000232	0,000232	0,000231
29	0,000482	0,000482	0,000482	0,000482	0,000482	0,000481	0,00048	0,000479398	0,0004784	0,000477	0,000476	0,000475
30	0,010687	0,010688	0,010689	0,01069	0,010691	0,010669	0,010647	0,010624494	0,0106023	0,010578	0,010554	0,010529
31	0,001212	0,001212	0,001212	0,001212	0,001213	0,00121	0,001207	0,001204973	0,0012025	0,0012	0,001197	0,001194
32	0,001342	0,001343	0,001343	0,001343	0,001343	0,00134	0,001337	0,00133454	0,0013317	0,001329	0,001326	0,001323
33	0,00043	0,00043	0,00043	0,00043	0,00043	0,000429	0,000428	0,000427571	0,0004267	0,000426	0,000425	0,000424

Flexible Load Capacity:

Node	Capacity [pu]
Node 5	0,0003
Node 10	0,0003
Node 26	0,0003

Flexible Generation Capacity:

Node	Capacity [pu]
Node 10	0,5

Flexible Load Price:

Time Unit	1	2	3	4	5	6	7	8	9	10	11	12
Price [€/MWh]	13,37	13,37	13,37	13,37	13,769	13,769	13,769	13,769	16,4535	16,4535	16,4535	16,4535

Time Unit	13	14	15	16	17	18	19	20	21	22	23	24
Price [€/MWh]	17,3285	17,3285	17,3285	17,3285	18,8825	18,8825	18,8825	18,8825	27,7655	27,7655	27,7655	27,7655

Time Unit	25	26	27	28	29	30	31	32	33	34	35	36
Price [€/MWh]	28,4655	28,4655	28,4655	28,4655	25,1755	25,1755	25,1755	25,1755	18,193	18,193	18,193	18,193

Time Unit	37	38	39	40	41	42	43	44	45	46	47	48
Price [€/MWh]	17,8745	17,8745	17,8745	17,8745	17,542	17,542	17,542	17,542	17,1465	17,1465	17,1465	17,1465

Flexible Generation Price:

Time Unit	1	2	3	4	5	6	7	8	9	10	11	12
Price [€/MWh]	38,2	38,2	38,2	38,2	39,34	39,34	39,34	39,34	47,01	47,01	47,01	47,01

Time Unit	13	14	15	16	17	18	19	20	21	22	23	24
Price [€/MWh]	49,51	49,51	49,51	49,51	53,95	53,95	53,95	53,95	79,33	79,33	79,33	79,33

Time Unit	25	26	27	28	29	30	31	32	33	34	35	36
Price [€/MWh]	81,33	81,33	81,33	81,33	71,93	71,93	71,93	71,93	51,98	51,98	51,98	51,98

Time Unit	37	38	39	40	41	42	43	44	45	46	47	48
Price [€/MWh]	51,07	51,07	51,07	51,07	50,12	50,12	50,12	50,12	48,99	48,99	48,99	48,99

Initial Battery State of Charge:

Node	Capacity [pu]
Node 11	0,001
Node 19	0,002
Node 33	0,0008

Maximum Battery State of Charge:

Node	Capacity [pu]
Node 11	0,002
Node 19	0,004
Node 33	0,001

Maximum battery charging/discharging capacity:

Node	Capacity [pu]
Node 11	0,0002
Node 19	0,0003
Node 33	0,00008

Battery charging and discharging price:

Time Unit	1	2	3	4	5	6	7	8	9	10	11	12
Price [€/MWh]	13,37	13,37	13,37	13,37	13,769	13,769	13,769	13,769	16,4535	16,4535	16,4535	16,4535

Time Unit	13	14	15	16	17	18	19	20	21	22	23	24
Price [€/MWh]	17,3285	17,3285	17,3285	17,3285	18,8825	18,8825	18,8825	18,8825	27,7655	27,7655	27,7655	27,7655

Time Unit	25	26	27	28	29	30	31	32	33	34	35	36
Price [€/MWh]	28,4655	28,4655	28,4655	28,4655	25,1755	25,1755	25,1755	25,1755	18,193	18,193	18,193	18,193

Time Unit	37	38	39	40	41	42	43	44	45	46	47	48
Price [€/MWh]	17,8745	17,8745	17,8745	17,8745	17,542	17,542	17,542	17,542	17,1465	17,1465	17,1465	17,1465

D Load Data used for Economic Optimization Cases

Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,003605	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,002196	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001493	0,001494	0,001496	0,001497	0,001498	0,001502	0,001506	0,001509	0,001513	0,001520	0,001526	0,001532	0,001539
3	0,000896	0,000896	0,000897	0,000898	0,000899	0,000901	0,000903	0,000906	0,000908	0,000912	0,000916	0,000919	0,000923
4	0,001941	0,001942	0,001944	0,001946	0,001948	0,001953	0,001957	0,001962	0,001967	0,001975	0,001984	0,001992	0,002000
5	0,001075	0,001076	0,001077	0,001078	0,001079	0,001081	0,001084	0,001087	0,001090	0,001094	0,001099	0,001103	0,001108
6	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
7	0,002986	0,002988	0,002991	0,002994	0,002997	0,003004	0,003011	0,003019	0,003026	0,003039	0,003052	0,003065	0,003077
8	0,004478	0,004482	0,004487	0,004491	0,004495	0,004506	0,004517	0,004528	0,004540	0,004559	0,004578	0,004597	0,004616
9	0,005076	0,005080	0,005085	0,005089	0,005094	0,005107	0,005119	0,005132	0,005145	0,005167	0,005188	0,005210	0,005232
10	0,007165	0,007172	0,007179	0,007185	0,007192	0,007210	0,007227	0,007245	0,007263	0,007294	0,007325	0,007355	0,007386
11	0,000299	0,000299	0,000299	0,000299	0,000300	0,000300	0,000301	0,000302	0,000303	0,000304	0,000305	0,000306	0,000308
12	0,000597	0,000598	0,000598	0,000599	0,000599	0,000601	0,000602	0,000604	0,000605	0,000608	0,000610	0,000613	0,000615
13	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
14	0,001224	0,001225	0,001226	0,001227	0,001229	0,001232	0,001235	0,001238	0,001241	0,001246	0,001251	0,001257	0,001262
15	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954
16	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
17	0,000806	0,000807	0,000808	0,000808	0,000809	0,000811	0,000813	0,000815	0,000817	0,000821	0,000824	0,000827	0,000831
18	0,000908	0,000908	0,000909	0,000910	0,000911	0,000913	0,000915	0,000918	0,000920	0,000924	0,000928	0,000932	0,000936
19	0,000902	0,000902	0,000903	0,000904	0,000905	0,000907	0,000909	0,000912	0,000914	0,000918	0,000922	0,000926	0,000929
20	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
21	0,000881	0,000882	0,000882	0,000883	0,000884	0,000886	0,000888	0,000891	0,000893	0,000897	0,000900	0,000904	0,000908
22	0,000773	0,000774	0,000775	0,000775	0,000776	0,000778	0,000780	0,000782	0,000784	0,000787	0,000790	0,000794	0,000797
23	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
24	0,004658	0,004662	0,004666	0,004670	0,004675	0,004686	0,004698	0,004710	0,004721	0,004741	0,004761	0,004781	0,004801
25	0,003284	0,003287	0,003290	0,003293	0,003296	0,003304	0,003313	0,003321	0,003329	0,003343	0,003357	0,003371	0,003385
26	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
27	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
28	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
29	0,002000	0,002002	0,002004	0,002006	0,002008	0,002013	0,002018	0,002023	0,002028	0,002036	0,002045	0,002053	0,002062
30	0,001314	0,001315	0,001316	0,001317	0,001318	0,001322	0,001325	0,001328	0,001332	0,001337	0,001343	0,001348	0,001354
31	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
32	0,000985	0,000986	0,000987	0,000988	0,000989	0,000991	0,000994	0,000996	0,000999	0,001003	0,001007	0,001011	0,001016
33	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001547	0,001555	0,001564	0,001572	0,001589	0,001605	0,001622	0,001639	0,001649	0,001660	0,001671	0,001682	0,001681
3	0,000928	0,000933	0,000938	0,000943	0,000953	0,000963	0,000973	0,000983	0,000990	0,000996	0,001003	0,001009	0,001009
4	0,002011	0,002022	0,002033	0,002044	0,002065	0,002087	0,002108	0,002130	0,002144	0,002158	0,002172	0,002186	0,002186
5	0,001114	0,001120	0,001126	0,001132	0,001144	0,001156	0,001168	0,001180	0,001187	0,001195	0,001203	0,001211	0,001211
6	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
7	0,003094	0,003111	0,003128	0,003144	0,003177	0,003211	0,003244	0,003277	0,003299	0,003320	0,003342	0,003363	0,003363
8	0,004641	0,004666	0,004691	0,004716	0,004766	0,004816	0,004866	0,004916	0,004948	0,004980	0,005013	0,005045	0,005044
9	0,005260	0,005288	0,005317	0,005345	0,005402	0,005458	0,005515	0,005571	0,005608	0,005644	0,005681	0,005718	0,005717
10	0,007426	0,007466	0,007506	0,007546	0,007626	0,007706	0,007785	0,007865	0,007917	0,007968	0,008020	0,008072	0,008070
11	0,000309	0,000311	0,000313	0,000314	0,000318	0,000321	0,000324	0,000328	0,000330	0,000332	0,000334	0,000336	0,000336
12	0,000619	0,000622	0,000626	0,000629	0,000635	0,000642	0,000649	0,000655	0,000660	0,000664	0,000668	0,000673	0,000673
13	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
14	0,001269	0,001275	0,001282	0,001289	0,001303	0,001316	0,001330	0,001344	0,001352	0,001361	0,001370	0,001379	0,001379
15	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042
16	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
17	0,000835	0,000840	0,000844	0,000849	0,000858	0,000867	0,000876	0,000885	0,000891	0,000896	0,000902	0,000908	0,000908
18	0,000941	0,000946	0,000951	0,000956	0,000966	0,000976	0,000986	0,000996	0,001003	0,001009	0,001016	0,001022	0,001022
19	0,000934	0,000939	0,000945	0,000950	0,000960	0,000970	0,000980	0,000990	0,000996	0,001003	0,001009	0,001016	0,001016
20	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
21	0,000913	0,000918	0,000923	0,000928	0,000937	0,000947	0,000957	0,000967	0,000973	0,000979	0,000986	0,000992	0,000992
22	0,000801	0,000806	0,000810	0,000814	0,000823	0,000832	0,000840	0,000849	0,000854	0,000860	0,000866	0,000871	0,000871
23	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
24	0,004827	0,004853	0,004879	0,004905	0,004957	0,005009	0,005060	0,005112	0,005146	0,005180	0,005213	0,005247	0,005246
25	0,003404	0,003422	0,003440	0,003459	0,003495	0,003532	0,003568	0,003605	0,003628	0,003652	0,003676	0,003700	0,003699
26	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
27	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
28	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
29	0,002073	0,002084	0,002095	0,002107	0,002129	0,002151	0,002173	0,002196	0,002210	0,002225	0,002239	0,002253	0,002253
30	0,001361	0,001369	0,001376	0,001383	0,001398	0,001413	0,001427	0,001442	0,001451	0,001461	0,001470	0,001480	0,001480
31	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
32	0,001021	0,001027	0,001032	0,001038	0,001049	0,001060	0,001070	0,001081	0,001089	0,001096	0,001103	0,001110	0,001110
33	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001681	0,001681	0,001680	0,001673	0,001665	0,001657	0,001650	0,001645	0,001639	0,001634	0,001629	0,001629	0,001629
3	0,001009	0,001008	0,001008	0,001004	0,000999	0,000994	0,000990	0,000987	0,000984	0,000981	0,000977	0,000978	0,000978
4	0,002185	0,002185	0,002184	0,002174	0,002165	0,002155	0,002145	0,002138	0,002131	0,002125	0,002118	0,002118	0,002118
5	0,001210	0,001210	0,001210	0,001204	0,001199	0,001193	0,001188	0,001184	0,001180	0,001177	0,001173	0,001173	0,001173
6	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
7	0,003362	0,003361	0,003361	0,003345	0,003330	0,003315	0,003300	0,003289	0,003279	0,003269	0,003258	0,003259	0,003259
8	0,005043	0,005042	0,005041	0,005018	0,004995	0,004972	0,004949	0,004934	0,004918	0,004903	0,004887	0,004888	0,004888
9	0,005715	0,005714	0,005713	0,005687	0,005661	0,005635	0,005609	0,005592	0,005574	0,005557	0,005539	0,005539	0,005540
10	0,008069	0,008067	0,008065	0,008029	0,007992	0,007956	0,007919	0,007894	0,007869	0,007845	0,007820	0,007820	0,007821
11	0,000336	0,000336	0,000336	0,000335	0,000333	0,000331	0,000330	0,000329	0,000328	0,000327	0,000326	0,000326	0,000326
12	0,000672	0,000672	0,000672	0,000669	0,000666	0,000663	0,000660	0,000658	0,000656	0,000654	0,000652	0,000652	0,000652
13	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
14	0,001378	0,001378	0,001378	0,001372	0,001365	0,001359	0,001353	0,001349	0,001344	0,001340	0,001336	0,001336	0,001336
15	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010
16	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
17	0,000908	0,000908	0,000907	0,000903	0,000899	0,000895	0,000891	0,000888	0,000885	0,000883	0,000880	0,000880	0,000880
18	0,001022	0,001022	0,001022	0,001017	0,001012	0,001008	0,001003	0,001000	0,000997	0,000994	0,000990	0,000991	0,000991
19	0,001015	0,001015	0,001015	0,001010	0,001006	0,001001	0,000996	0,000993	0,000990	0,000987	0,000984	0,000984	0,000984
20	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
21	0,000992	0,000992	0,000991	0,000987	0,000982	0,000978	0,000973	0,000970	0,000967	0,000964	0,000961	0,000961	0,000961
22	0,000871	0,000871	0,000870	0,000866	0,000862	0,000859	0,000855	0,000852	0,000849	0,000847	0,000844	0,000844	0,000844
23	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
24	0,005245	0,005244	0,005243	0,005219	0,005195	0,005171	0,005147	0,005131	0,005115	0,005099	0,005083	0,005083	0,005084
25	0,003698	0,003697	0,003697	0,003680	0,003663	0,003646	0,003630	0,003618	0,003607	0,003595	0,003584	0,003584	0,003585
26	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
27	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
28	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
29	0,002253	0,002252	0,002252	0,002241	0,002231	0,002221	0,002211	0,002204	0,002197	0,002190	0,002183	0,002183	0,002183
30	0,001479	0,001479	0,001479	0,001472	0,001465	0,001459	0,001452	0,001447	0,001443	0,001438	0,001434	0,001434	0,001434
31	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
32	0,001109	0,001109	0,001109	0,001104	0,001099	0,001094	0,001089	0,001085	0,001082	0,001079	0,001075	0,001075	0,001075
33	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001630	0,001630	0,001626	0,001623	0,001620	0,001616	0,001613	0,001609	0,001605
3	0,000978	0,000978	0,000976	0,000974	0,000972	0,000970	0,000968	0,000965	0,000963
4	0,002118	0,002119	0,002114	0,002110	0,002105	0,002101	0,002096	0,002091	0,002087
5	0,001173	0,001173	0,001171	0,001169	0,001166	0,001164	0,001161	0,001158	0,001156
6	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
7	0,003259	0,003260	0,003253	0,003246	0,003239	0,003232	0,003225	0,003218	0,003210
8	0,004889	0,004889	0,004879	0,004869	0,004859	0,004849	0,004838	0,004826	0,004815
9	0,005541	0,005541	0,005530	0,005518	0,005507	0,005495	0,005483	0,005470	0,005457
10	0,007822	0,007823	0,007807	0,007790	0,007774	0,007758	0,007740	0,007722	0,007704
11	0,000326	0,000326	0,000325	0,000325	0,000324	0,000323	0,000323	0,000322	0,000321
12	0,000652	0,000652	0,000651	0,000649	0,000648	0,000646	0,000645	0,000644	0,000642
13	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
14	0,001336	0,001336	0,001334	0,001331	0,001328	0,001325	0,001322	0,001319	0,001316
15	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995
16	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
17	0,000880	0,000880	0,000878	0,000876	0,000875	0,000873	0,000871	0,000869	0,000867
18	0,000991	0,000991	0,000989	0,000987	0,000985	0,000983	0,000980	0,000978	0,000976
19	0,000984	0,000984	0,000982	0,000980	0,000978	0,000976	0,000974	0,000972	0,000969
20	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
21	0,000961	0,000962	0,000960	0,000958	0,000956	0,000954	0,000951	0,000949	0,000947
22	0,000844	0,000844	0,000842	0,000841	0,000839	0,000837	0,000835	0,000833	0,000831
23	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
24	0,005084	0,005085	0,005074	0,005064	0,005053	0,005043	0,005031	0,005019	0,005008
25	0,003585	0,003585	0,003578	0,003571	0,003563	0,003556	0,003548	0,003539	0,003531
26	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
27	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
28	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
29	0,002184	0,002184	0,002179	0,002175	0,002170	0,002166	0,002161	0,002156	0,002151
30	0,001434	0,001434	0,001431	0,001428	0,001425	0,001422	0,001419	0,001416	0,001412
31	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
32	0,001076	0,001076	0,001073	0,001071	0,001069	0,001067	0,001064	0,001062	0,001059
33	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995

E Load Data used for Voltage Regulation Cases

Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,004063	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,003048	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,023267	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,004817	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,003932	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001493	0,001494	0,001496	0,001497	0,001498	0,001502	0,001506	0,001509	0,001513	0,001520	0,001526	0,001532	0,001539
3	0,000896	0,000896	0,000897	0,000898	0,000899	0,000901	0,000903	0,000906	0,000908	0,000912	0,000916	0,000919	0,000923
4	0,001941	0,001942	0,001944	0,001946	0,001948	0,001953	0,001957	0,001962	0,001967	0,001975	0,001984	0,001992	0,002000
5	0,001075	0,001076	0,001077	0,001078	0,001079	0,001081	0,001084	0,001087	0,001090	0,001094	0,001099	0,001103	0,001108
6	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
7	0,002986	0,002988	0,002991	0,002994	0,002997	0,003004	0,003011	0,003019	0,003026	0,003039	0,003052	0,003065	0,003077
8	0,004478	0,004482	0,004487	0,004491	0,004495	0,004506	0,004517	0,004528	0,004540	0,004559	0,004578	0,004597	0,004616
9	0,005076	0,005080	0,005085	0,005089	0,005094	0,005107	0,005119	0,005132	0,005145	0,005167	0,005188	0,005210	0,005232
10	0,007165	0,007172	0,007179	0,007185	0,007192	0,007210	0,007227	0,007245	0,007263	0,007294	0,007325	0,007355	0,007386
11	0,000299	0,000299	0,000299	0,000299	0,000300	0,000300	0,000301	0,000302	0,000303	0,000304	0,000305	0,000306	0,000308
12	0,000597	0,000598	0,000598	0,000599	0,000599	0,000601	0,000602	0,000604	0,000605	0,000608	0,000610	0,000613	0,000615
13	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
14	0,001224	0,001225	0,001226	0,001227	0,001229	0,001232	0,001235	0,001238	0,001241	0,001246	0,001251	0,001257	0,001262
15	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954
16	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
17	0,000806	0,000807	0,000808	0,000808	0,000809	0,000811	0,000813	0,000815	0,000817	0,000821	0,000824	0,000827	0,000831
18	0,000908	0,000908	0,000909	0,000910	0,000911	0,000913	0,000915	0,000918	0,000920	0,000924	0,000928	0,000932	0,000936
19	0,000902	0,000902	0,000903	0,000904	0,000905	0,000907	0,000909	0,000912	0,000914	0,000918	0,000922	0,000926	0,000929
20	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
21	0,000881	0,000882	0,000882	0,000883	0,000884	0,000886	0,000888	0,000891	0,000893	0,000897	0,000900	0,000904	0,000908
22	0,000773	0,000774	0,000775	0,000775	0,000776	0,000778	0,000780	0,000782	0,000784	0,000787	0,000790	0,000794	0,000797
23	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
24	0,004658	0,004662	0,004666	0,004670	0,004675	0,004686	0,004698	0,004710	0,004721	0,004741	0,004761	0,004781	0,004801
25	0,003284	0,003287	0,003290	0,003293	0,003296	0,003304	0,003313	0,003321	0,003329	0,003343	0,003357	0,003371	0,003385
26	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
27	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
28	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
29	0,002000	0,002002	0,002004	0,002006	0,002008	0,002013	0,002018	0,002023	0,002028	0,002036	0,002045	0,002053	0,002062
30	0,001314	0,001315	0,001316	0,001317	0,001318	0,001322	0,001325	0,001328	0,001332	0,001337	0,001343	0,001348	0,001354
31	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
32	0,000985	0,000986	0,000987	0,000988	0,000989	0,000991	0,000994	0,000996	0,000999	0,001003	0,001007	0,001011	0,001016
33	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001547	0,001555	0,001564	0,001572	0,001589	0,001605	0,001622	0,001639	0,001649	0,001660	0,001671	0,001682	0,001681
3	0,000928	0,000933	0,000938	0,000943	0,000953	0,000963	0,000973	0,000983	0,000990	0,000996	0,001003	0,001009	0,001009
4	0,002011	0,002022	0,002033	0,002044	0,002065	0,002087	0,002108	0,002130	0,002144	0,002158	0,002172	0,002186	0,002186
5	0,001114	0,001120	0,001126	0,001132	0,001144	0,001156	0,001168	0,001180	0,001187	0,001195	0,001203	0,001211	0,001211
6	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
7	0,003094	0,003111	0,003128	0,003144	0,003177	0,003211	0,003244	0,003277	0,003299	0,003320	0,003342	0,003363	0,003363
8	0,004641	0,004666	0,004691	0,004716	0,004766	0,004816	0,004866	0,004916	0,004948	0,004980	0,005013	0,005045	0,005044
9	0,005260	0,005288	0,005317	0,005345	0,005402	0,005458	0,005515	0,005571	0,005608	0,005644	0,005681	0,005718	0,005717
10	0,007426	0,007466	0,007506	0,007546	0,007626	0,007706	0,007785	0,007865	0,007917	0,007968	0,008020	0,008072	0,008070
11	0,000309	0,000311	0,000313	0,000314	0,000318	0,000321	0,000324	0,000328	0,000330	0,000332	0,000334	0,000336	0,000336
12	0,000619	0,000622	0,000626	0,000629	0,000635	0,000642	0,000649	0,000655	0,000660	0,000664	0,000668	0,000673	0,000673
13	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
14	0,001269	0,001275	0,001282	0,001289	0,001303	0,001316	0,001330	0,001344	0,001352	0,001361	0,001370	0,001379	0,001379
15	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042
16	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
17	0,000835	0,000840	0,000844	0,000849	0,000858	0,000867	0,000876	0,000885	0,000891	0,000896	0,000902	0,000908	0,000908
18	0,000941	0,000946	0,000951	0,000956	0,000966	0,000976	0,000986	0,000996	0,001003	0,001009	0,001016	0,003498	0,004170
19	0,000934	0,000939	0,000945	0,000950	0,000960	0,000970	0,000980	0,000990	0,000996	0,001003	0,001009	0,001016	0,001016
20	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
21	0,000913	0,000918	0,000923	0,000928	0,000937	0,000947	0,000957	0,000967	0,000973	0,000979	0,000986	0,000992	0,000992
22	0,000801	0,000806	0,000810	0,000814	0,000823	0,000832	0,000840	0,000849	0,000854	0,000860	0,000866	0,000871	0,000871
23	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,002792	0,003127
24	0,004827	0,004853	0,004879	0,004905	0,004957	0,005009	0,005060	0,005112	0,005146	0,005180	0,005213	0,005247	0,005246
25	0,003404	0,003422	0,003440	0,003459	0,003495	0,003532	0,003568	0,003605	0,003628	0,003652	0,003676	0,020517	0,023875
26	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
27	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
28	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
29	0,002073	0,002084	0,002095	0,002107	0,002129	0,002151	0,002173	0,002196	0,002210	0,002225	0,002239	0,003431	0,004943
30	0,001361	0,001369	0,001376	0,001383	0,001398	0,001413	0,001427	0,001442	0,001451	0,001461	0,001470	0,001480	0,001480
31	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
32	0,001021	0,001027	0,001032	0,001038	0,001049	0,001060	0,001070	0,001081	0,001089	0,001096	0,001103	0,001110	0,001110
33	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,002724	0,004035

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001681	0,001681	0,001680	0,001673	0,001665	0,001657	0,001650	0,001645	0,001639	0,001634	0,001629	0,001629	0,001629
3	0,001009	0,001008	0,001008	0,001004	0,000999	0,000994	0,000990	0,000987	0,000984	0,000981	0,000977	0,000978	0,000978
4	0,002185	0,002185	0,002184	0,002174	0,002165	0,002155	0,002145	0,002138	0,002131	0,002125	0,002118	0,002118	0,002118
5	0,001210	0,001210	0,001210	0,001204	0,001199	0,001193	0,001188	0,001184	0,001180	0,001177	0,001173	0,001173	0,001173
6	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
7	0,003362	0,003361	0,003361	0,003345	0,003330	0,003315	0,003300	0,003289	0,003279	0,003269	0,003258	0,003259	0,003259
8	0,005043	0,005042	0,005041	0,005018	0,004995	0,004972	0,004949	0,004934	0,004918	0,004903	0,004887	0,004888	0,004888
9	0,005715	0,005714	0,005713	0,005687	0,005661	0,005635	0,005609	0,005592	0,005574	0,005557	0,005539	0,005539	0,005540
10	0,008069	0,008067	0,008065	0,008029	0,007992	0,007956	0,007919	0,007894	0,007869	0,007845	0,007820	0,007820	0,007821
11	0,000336	0,000336	0,000336	0,000335	0,000333	0,000331	0,000330	0,000329	0,000328	0,000327	0,000326	0,000326	0,000326
12	0,000672	0,000672	0,000672	0,000669	0,000666	0,000663	0,000660	0,000658	0,000656	0,000654	0,000652	0,000652	0,000652
13	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
14	0,001378	0,001378	0,001378	0,001372	0,001365	0,001359	0,001353	0,001349	0,001344	0,001340	0,001336	0,001336	0,001336
15	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010
16	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
17	0,000908	0,000908	0,000907	0,000903	0,000899	0,000895	0,000891	0,000888	0,000885	0,000883	0,000880	0,000880	0,000880
18	0,003496	0,001022	0,001022	0,001017	0,001012	0,001008	0,001003	0,001000	0,000997	0,000994	0,000990	0,000991	0,000991
19	0,001015	0,001015	0,001015	0,001010	0,001006	0,001001	0,000996	0,000993	0,000990	0,000987	0,000984	0,000984	0,000984
20	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
21	0,000992	0,000992	0,000991	0,000987	0,000982	0,000978	0,000973	0,000970	0,000967	0,000964	0,000961	0,000961	0,000961
22	0,000871	0,000871	0,000870	0,000866	0,000862	0,000859	0,000855	0,000852	0,000849	0,000847	0,000844	0,000844	0,000844
23	0,002790	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
24	0,005245	0,005244	0,005243	0,005219	0,005195	0,005171	0,005147	0,005131	0,005115	0,005099	0,005083	0,005083	0,005084
25	0,020508	0,003697	0,003697	0,003680	0,003663	0,003646	0,003630	0,003618	0,003607	0,003595	0,003584	0,003584	0,003585
26	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
27	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
28	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
29	0,003429	0,002252	0,002252	0,002241	0,002231	0,002221	0,002211	0,002204	0,002197	0,002190	0,002183	0,002183	0,002183
30	0,001479	0,001479	0,001479	0,001472	0,001465	0,001459	0,001452	0,001447	0,001443	0,001438	0,001434	0,001434	0,001434
31	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
32	0,001109	0,001109	0,001109	0,001104	0,001099	0,001094	0,001089	0,001085	0,001082	0,001079	0,001075	0,001075	0,001075
33	0,002723	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001630	0,001630	0,001626	0,001623	0,001620	0,001616	0,001613	0,001609	0,001605
3	0,000978	0,000978	0,000976	0,000974	0,000972	0,000970	0,000968	0,000965	0,000963
4	0,002118	0,002119	0,002114	0,002110	0,002105	0,002101	0,002096	0,002091	0,002087
5	0,001173	0,001173	0,001171	0,001169	0,001166	0,001164	0,001161	0,001158	0,001156
6	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
7	0,003259	0,003260	0,003253	0,003246	0,003239	0,003232	0,003225	0,003218	0,003210
8	0,004889	0,004889	0,004879	0,004869	0,004859	0,004849	0,004838	0,004826	0,004815
9	0,005541	0,005541	0,005530	0,005518	0,005507	0,005495	0,005483	0,005470	0,005457
10	0,007822	0,007823	0,007807	0,007790	0,007774	0,007758	0,007740	0,007722	0,007704
11	0,000326	0,000326	0,000325	0,000325	0,000324	0,000323	0,000323	0,000322	0,000321
12	0,000652	0,000652	0,000651	0,000649	0,000648	0,000646	0,000645	0,000644	0,000642
13	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
14	0,001336	0,001336	0,001334	0,001331	0,001328	0,001325	0,001322	0,001319	0,001316
15	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995
16	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
17	0,000880	0,000880	0,000878	0,000876	0,000875	0,000873	0,000871	0,000869	0,000867
18	0,000991	0,000991	0,000989	0,000987	0,000985	0,000983	0,000980	0,000978	0,000976
19	0,000984	0,000984	0,000982	0,000980	0,000978	0,000976	0,000974	0,000972	0,000969
20	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
21	0,000961	0,000962	0,000960	0,000958	0,000956	0,000954	0,000951	0,000949	0,000947
22	0,000844	0,000844	0,000842	0,000841	0,000839	0,000837	0,000835	0,000833	0,000831
23	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
24	0,005084	0,005085	0,005074	0,005064	0,005053	0,005043	0,005031	0,005019	0,005008
25	0,003585	0,003585	0,003578	0,003571	0,003563	0,003556	0,003548	0,003539	0,003531
26	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
27	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
28	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
29	0,002184	0,002184	0,002179	0,002175	0,002170	0,002166	0,002161	0,002156	0,002151
30	0,001434	0,001434	0,001431	0,001428	0,001425	0,001422	0,001419	0,001416	0,001412
31	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
32	0,001076	0,001076	0,001073	0,001071	0,001069	0,001067	0,001064	0,001062	0,001059
33	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995

F Load Data used for Congestion in Distribution Network Cases

Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001971	0,001978	0,001997	0,002031	0,002075	0,002163	0,002220	0,002218	0,002178	0,002150	0,002151	0,002133
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000654	0,000656	0,000663	0,000674	0,000689	0,000718	0,000737	0,000736	0,000723	0,000714	0,000714	0,000708
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,003762	0,003776	0,003813	0,003878	0,003962	0,004129	0,004238	0,004234	0,004158	0,004105	0,004107	0,004073
25	0,004060	0,004075	0,004116	0,004185	0,004276	0,004457	0,004574	0,004570	0,004487	0,004431	0,004433	0,004396
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001287	0,001291	0,001304	0,001326	0,001355	0,001412	0,001450	0,001448	0,001422	0,001404	0,001405	0,001393
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
30	0,001015	0,001019	0,001029	0,001046	0,001069	0,001114	0,001144	0,001143	0,001122	0,001108	0,001108	0,001099
31	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
32	0,000627	0,000629	0,000636	0,000646	0,000660	0,000688	0,000706	0,000706	0,000693	0,000684	0,000684	0,000679
33	0,000866	0,000869	0,000878	0,000892	0,000912	0,000950	0,000975	0,000975	0,000957	0,000945	0,000945	0,000937

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001493	0,001494	0,001496	0,001497	0,001498	0,001502	0,001506	0,001509	0,001513	0,001520	0,001526	0,001532	0,001539
3	0,000896	0,000897	0,000897	0,000898	0,000899	0,000901	0,000903	0,000906	0,000908	0,000912	0,000916	0,000919	0,000923
4	0,001941	0,001942	0,001944	0,001946	0,001948	0,001953	0,001957	0,001962	0,001967	0,001975	0,001984	0,001992	0,002000
5	0,001971	0,001972	0,001974	0,001976	0,001978	0,001983	0,001988	0,001992	0,001997	0,002006	0,002014	0,002023	0,002031
6	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
7	0,002986	0,002988	0,002991	0,002994	0,002997	0,003004	0,003011	0,003019	0,003026	0,003039	0,003052	0,003065	0,003077
8	0,004478	0,004482	0,004487	0,004491	0,004495	0,004506	0,004517	0,004528	0,004540	0,004559	0,004578	0,004597	0,004616
9	0,005076	0,005080	0,005085	0,005089	0,005094	0,005107	0,005119	0,005132	0,005145	0,005167	0,005188	0,005210	0,005232
10	0,007165	0,007172	0,007179	0,007185	0,007192	0,007210	0,007227	0,007245	0,007263	0,007294	0,007325	0,007355	0,007386
11	0,000299	0,000299	0,000299	0,000299	0,000300	0,000300	0,000301	0,000302	0,000303	0,000304	0,000305	0,000306	0,000308
12	0,000597	0,000598	0,000598	0,000599	0,000599	0,000601	0,000602	0,000604	0,000605	0,000608	0,000610	0,000613	0,000615
13	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
14	0,001224	0,001225	0,001226	0,001227	0,001229	0,001232	0,001235	0,001238	0,001241	0,001246	0,001251	0,001257	0,001262
15	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954
16	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
17	0,000806	0,000807	0,000808	0,000808	0,000809	0,000811	0,000813	0,000815	0,000817	0,000821	0,000824	0,000827	0,000831
18	0,000908	0,000908	0,000909	0,000910	0,000911	0,000913	0,000915	0,000918	0,000920	0,000924	0,000928	0,000932	0,000936
19	0,000902	0,000902	0,000903	0,000904	0,000905	0,000907	0,000909	0,000912	0,000914	0,000918	0,000922	0,000926	0,000929
20	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
21	0,000881	0,000882	0,000882	0,000883	0,000884	0,000886	0,000888	0,000891	0,000893	0,000897	0,000900	0,000904	0,000908
22	0,000654	0,000654	0,000655	0,000656	0,000656	0,000658	0,000660	0,000661	0,000663	0,000666	0,000668	0,000671	0,000674
23	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
24	0,003762	0,003765	0,003769	0,003772	0,003776	0,003785	0,003794	0,003804	0,003813	0,003829	0,003845	0,003861	0,003878
25	0,004060	0,004064	0,004068	0,004072	0,004075	0,004085	0,004096	0,004106	0,004116	0,004133	0,004151	0,004168	0,004185
26	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
27	0,001287	0,001288	0,001289	0,001290	0,001291	0,001295	0,001298	0,001301	0,001304	0,001310	0,001315	0,001321	0,001326
28	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
29	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
30	0,001015	0,001016	0,001017	0,001018	0,001019	0,001021	0,001024	0,001026	0,001029	0,001033	0,001038	0,001042	0,001046
31	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954
32	0,000627	0,000628	0,000628	0,000629	0,000629	0,000631	0,000632	0,000634	0,000636	0,000638	0,000641	0,000644	0,000646
33	0,000866	0,000867	0,000867	0,000868	0,000869	0,000871	0,000873	0,000875	0,000878	0,000881	0,000885	0,000889	0,000892

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001547	0,001555	0,001564	0,001572	0,001589	0,001605	0,001622	0,001639	0,001649	0,001660	0,001671	0,001682	0,001681
3	0,000928	0,000933	0,000938	0,000943	0,000953	0,000963	0,000973	0,000983	0,000990	0,000996	0,001003	0,001009	0,001009
4	0,002011	0,002022	0,002033	0,002044	0,002065	0,002087	0,002108	0,002130	0,002144	0,002158	0,002172	0,002186	0,002186
5	0,002042	0,002053	0,002064	0,002075	0,002097	0,002119	0,002141	0,002163	0,002177	0,002191	0,002206	0,002220	0,002219
6	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
7	0,003094	0,003111	0,003128	0,003144	0,003177	0,003211	0,003244	0,003277	0,003299	0,003320	0,003342	0,003363	0,003363
8	0,004641	0,004666	0,004691	0,004716	0,004766	0,004816	0,004866	0,004916	0,004948	0,004980	0,005013	0,005045	0,005044
9	0,005260	0,005288	0,005317	0,005345	0,005402	0,005458	0,005515	0,005571	0,005608	0,005644	0,005681	0,005718	0,005717
10	0,007426	0,007466	0,007506	0,007546	0,007626	0,007706	0,007785	0,007865	0,007917	0,007968	0,008020	0,008072	0,008070
11	0,000309	0,000311	0,000313	0,000314	0,000318	0,000321	0,000324	0,000328	0,000330	0,000332	0,000334	0,000336	0,000336
12	0,000619	0,000622	0,000626	0,000629	0,000636	0,000642	0,000649	0,000655	0,000660	0,000664	0,000668	0,000673	0,000673
13	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
14	0,001269	0,001275	0,001282	0,001289	0,001303	0,001316	0,001330	0,001344	0,001352	0,001361	0,001370	0,001379	0,001379
15	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042
16	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
17	0,000835	0,000840	0,000844	0,000849	0,000858	0,000867	0,000876	0,000885	0,000891	0,000896	0,000902	0,000908	0,000908
18	0,000941	0,000946	0,000951	0,000956	0,000966	0,000976	0,000986	0,000996	0,001003	0,001009	0,001016	0,001022	0,001022
19	0,000934	0,000939	0,000945	0,000950	0,000960	0,000970	0,000980	0,000990	0,000996	0,001003	0,001009	0,001016	0,001016
20	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
21	0,000913	0,000918	0,000923	0,000928	0,000937	0,000947	0,000957	0,000967	0,000973	0,000979	0,000986	0,000992	0,000992
22	0,000678	0,000681	0,000685	0,000689	0,000696	0,000703	0,000710	0,000718	0,000722	0,000727	0,000732	0,000737	0,000736
23	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
24	0,003899	0,003920	0,003941	0,003962	0,004004	0,004045	0,004087	0,004129	0,004156	0,004183	0,004211	0,004238	0,004237
25	0,004208	0,004231	0,004254	0,004276	0,004321	0,004366	0,004412	0,004457	0,004486	0,004515	0,004545	0,004574	0,004573
26	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
27	0,001334	0,001341	0,001348	0,001355	0,001369	0,001384	0,001398	0,001412	0,001422	0,001431	0,001440	0,001450	0,001449
28	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
29	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
30	0,001052	0,001058	0,001063	0,001069	0,001080	0,001092	0,001103	0,001114	0,001122	0,001129	0,001136	0,001144	0,001143
31	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042
32	0,000650	0,000653	0,000657	0,000660	0,000667	0,000674	0,000681	0,000688	0,000693	0,000697	0,000702	0,000706	0,000706
33	0,000897	0,000902	0,000907	0,000912	0,000921	0,000931	0,000941	0,000950	0,000957	0,000963	0,000969	0,000975	0,000975

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001681	0,001681	0,001680	0,001673	0,001665	0,001657	0,001650	0,001645	0,001639	0,001634	0,001629	0,001629	0,001629
3	0,001009	0,001008	0,001008	0,001004	0,000999	0,000994	0,000990	0,000987	0,000984	0,000981	0,000977	0,000978	0,000978
4	0,002185	0,002185	0,002184	0,002174	0,002165	0,002155	0,002145	0,002138	0,002131	0,002125	0,002118	0,002118	0,002118
5	0,002219	0,002218	0,002218	0,002208	0,002198	0,002188	0,002178	0,002171	0,002164	0,002157	0,002150	0,002151	0,002151
6	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
7	0,003362	0,003361	0,003361	0,003345	0,003330	0,003315	0,003300	0,003289	0,003279	0,003269	0,003258	0,003259	0,003259
8	0,005043	0,005042	0,005041	0,005018	0,004995	0,004972	0,004949	0,004934	0,004918	0,004903	0,004887	0,004888	0,004888
9	0,005715	0,005714	0,005713	0,005687	0,005661	0,005635	0,005609	0,005592	0,005574	0,005557	0,005539	0,005539	0,005540
10	0,008069	0,008067	0,008065	0,008029	0,007992	0,007956	0,007919	0,007894	0,007869	0,007845	0,007820	0,007820	0,007821
11	0,000336	0,000336	0,000336	0,000335	0,000333	0,000331	0,000330	0,000329	0,000328	0,000327	0,000326	0,000326	0,000326
12	0,000672	0,000672	0,000672	0,000669	0,000666	0,000663	0,000660	0,000658	0,000656	0,000654	0,000652	0,000652	0,000652
13	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
14	0,001378	0,001378	0,001378	0,001372	0,001365	0,001359	0,001353	0,001349	0,001344	0,001340	0,001336	0,001336	0,001336
15	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010
16	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
17	0,000908	0,000908	0,000907	0,000903	0,000899	0,000895	0,000891	0,000888	0,000885	0,000883	0,000880	0,000880	0,000880
18	0,001022	0,001022	0,001022	0,001017	0,001012	0,001008	0,001003	0,001000	0,000997	0,000994	0,000990	0,000991	0,000991
19	0,001015	0,001015	0,001015	0,001010	0,001006	0,001001	0,000996	0,000993	0,000990	0,000987	0,000984	0,000984	0,000984
20	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
21	0,000992	0,000992	0,000991	0,000987	0,000982	0,000978	0,000973	0,000970	0,000967	0,000964	0,000961	0,000961	0,000961
22	0,000736	0,000736	0,000736	0,000733	0,000729	0,000726	0,000723	0,000720	0,000718	0,000716	0,000714	0,000714	0,000714
23	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
24	0,004236	0,004235	0,004234	0,004215	0,004196	0,004177	0,004158	0,004144	0,004131	0,004118	0,004105	0,004106	0,004106
25	0,004572	0,004571	0,004570	0,004550	0,004529	0,004508	0,004487	0,004473	0,004459	0,004445	0,004431	0,004432	0,004432
26	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
27	0,001449	0,001449	0,001448	0,001442	0,001435	0,001429	0,001422	0,001418	0,001413	0,001409	0,001404	0,001404	0,001405
28	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
29	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
30	0,001143	0,001143	0,001143	0,001137	0,001132	0,001127	0,001122	0,001118	0,001115	0,001111	0,001108	0,001108	0,001108
31	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010
32	0,000706	0,000706	0,000706	0,000703	0,000699	0,000696	0,000693	0,000691	0,000689	0,000686	0,000684	0,000684	0,000684
33	0,000975	0,000975	0,000975	0,000970	0,000966	0,000961	0,000957	0,000954	0,000951	0,000948	0,000945	0,000945	0,000945

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001630	0,001630	0,001626	0,001623	0,001620	0,001616	0,001613	0,001609	0,001605
3	0,000978	0,000978	0,000976	0,000974	0,000972	0,000970	0,000968	0,000965	0,000963
4	0,002118	0,002119	0,002114	0,002110	0,002105	0,002101	0,002096	0,002091	0,002087
5	0,002151	0,002151	0,002147	0,002142	0,002138	0,002133	0,002129	0,002124	0,002119
6	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
7	0,003259	0,003260	0,003253	0,003246	0,003239	0,003232	0,003225	0,003218	0,003210
8	0,004889	0,004889	0,004879	0,004869	0,004859	0,004849	0,004838	0,004826	0,004815
9	0,005541	0,005541	0,005530	0,005518	0,005507	0,005495	0,005483	0,005470	0,005457
10	0,007822	0,007823	0,007807	0,007790	0,007774	0,007758	0,007740	0,007722	0,007704
11	0,000326	0,000326	0,000325	0,000325	0,000324	0,000323	0,000323	0,000322	0,000321
12	0,000652	0,000652	0,000651	0,000649	0,000648	0,000646	0,000645	0,000644	0,000642
13	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
14	0,001336	0,001336	0,001334	0,001331	0,001328	0,001325	0,001322	0,001319	0,001316
15	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995
16	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
17	0,000880	0,000880	0,000878	0,000876	0,000875	0,000873	0,000871	0,000869	0,000867
18	0,000991	0,000991	0,000989	0,000987	0,000985	0,000983	0,000980	0,000978	0,000976
19	0,000984	0,000984	0,000982	0,000980	0,000978	0,000976	0,000974	0,000972	0,000969
20	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
21	0,000961	0,000962	0,000960	0,000958	0,000956	0,000954	0,000951	0,000949	0,000947
22	0,000714	0,000714	0,000712	0,000711	0,000709	0,000708	0,000706	0,000705	0,000703
23	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
24	0,004107	0,004107	0,004098	0,004090	0,004081	0,004073	0,004064	0,004054	0,004045
25	0,004432	0,004433	0,004424	0,004414	0,004405	0,004396	0,004386	0,004376	0,004366
26	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
27	0,001405	0,001405	0,001402	0,001399	0,001396	0,001393	0,001390	0,001387	0,001384
28	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
29	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
30	0,001108	0,001108	0,001106	0,001104	0,001101	0,001099	0,001097	0,001094	0,001091
31	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995
32	0,000684	0,000684	0,000683	0,000682	0,000680	0,000679	0,000677	0,000676	0,000674
33	0,000945	0,000945	0,000943	0,000941	0,000939	0,000937	0,000935	0,000933	0,000931

G Load Data used for Congestion in Transmission Network Cases

Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,003605	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,002196	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001493	0,001494	0,001496	0,001497	0,001498	0,001502	0,001506	0,001509	0,001513	0,001520	0,001526	0,001532	0,001539
3	0,000896	0,000896	0,000897	0,000898	0,000899	0,000901	0,000903	0,000906	0,000908	0,000912	0,000916	0,000919	0,000923
4	0,001941	0,001942	0,001944	0,001946	0,001948	0,001953	0,001957	0,001962	0,001967	0,001975	0,001984	0,001992	0,002000
5	0,001075	0,001076	0,001077	0,001078	0,001079	0,001081	0,001084	0,001087	0,001090	0,001094	0,001099	0,001103	0,001108
6	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
7	0,002986	0,002988	0,002991	0,002994	0,002997	0,003004	0,003011	0,003019	0,003026	0,003039	0,003052	0,003065	0,003077
8	0,004478	0,004482	0,004487	0,004491	0,004495	0,004506	0,004517	0,004528	0,004540	0,004559	0,004578	0,004597	0,004616
9	0,005076	0,005080	0,005085	0,005089	0,005094	0,005107	0,005119	0,005132	0,005145	0,005167	0,005188	0,005210	0,005232
10	0,007165	0,007172	0,007179	0,007185	0,007192	0,007210	0,007227	0,007245	0,007263	0,007294	0,007325	0,007355	0,007386
11	0,000299	0,000299	0,000299	0,000299	0,000300	0,000300	0,000301	0,000302	0,000303	0,000304	0,000305	0,000306	0,000308
12	0,000597	0,000598	0,000598	0,000599	0,000599	0,000601	0,000602	0,000604	0,000605	0,000608	0,000610	0,000613	0,000615
13	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
14	0,001224	0,001225	0,001226	0,001227	0,001229	0,001232	0,001235	0,001238	0,001241	0,001246	0,001251	0,001257	0,001262
15	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954
16	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
17	0,000806	0,000807	0,000808	0,000808	0,000809	0,000811	0,000813	0,000815	0,000817	0,000821	0,000824	0,000827	0,000831
18	0,000908	0,000908	0,000909	0,000910	0,000911	0,000913	0,000915	0,000918	0,000920	0,000924	0,000928	0,000932	0,000936
19	0,000902	0,000902	0,000903	0,000904	0,000905	0,000907	0,000909	0,000912	0,000914	0,000918	0,000922	0,000926	0,000929
20	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
21	0,000881	0,000882	0,000882	0,000883	0,000884	0,000886	0,000888	0,000891	0,000893	0,000897	0,000900	0,000904	0,000908
22	0,000773	0,000774	0,000775	0,000775	0,000776	0,000778	0,000780	0,000782	0,000784	0,000787	0,000790	0,000794	0,000797
23	0,000955	0,000956	0,000957	0,000958	0,000959	0,000961	0,000964	0,000966	0,000968	0,000973	0,000977	0,000981	0,000985
24	0,004658	0,004662	0,004666	0,004670	0,004675	0,004686	0,004698	0,004710	0,004721	0,004741	0,004761	0,004781	0,004801
25	0,003284	0,003287	0,003290	0,003293	0,003296	0,003304	0,003313	0,003321	0,003329	0,003343	0,003357	0,003371	0,003385
26	0,000657	0,000657	0,000658	0,000659	0,000659	0,000661	0,000663	0,000664	0,000666	0,000669	0,000671	0,000674	0,000677
27	0,001045	0,001046	0,001047	0,001048	0,001049	0,001051	0,001054	0,001057	0,001059	0,001064	0,001068	0,001073	0,001077
28	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
29	0,002000	0,002002	0,002004	0,002006	0,002008	0,002013	0,002018	0,002023	0,002028	0,002036	0,002045	0,002053	0,002062
30	0,001314	0,001315	0,001316	0,001317	0,001318	0,001322	0,001325	0,001328	0,001332	0,001337	0,001343	0,001348	0,001354
31	0,000836	0,000837	0,000837	0,000838	0,000839	0,000841	0,000843	0,000845	0,000847	0,000851	0,000855	0,000858	0,000862
32	0,000985	0,000986	0,000987	0,000988	0,000989	0,000991	0,000994	0,000996	0,000999	0,001003	0,001007	0,001011	0,001016
33	0,000926	0,000926	0,000927	0,000928	0,000929	0,000931	0,000934	0,000936	0,000938	0,000942	0,000946	0,000950	0,000954

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001547	0,001555	0,001564	0,001572	0,001589	0,001605	0,001622	0,001639	0,001649	0,001660	0,001671	0,001682	0,001681
3	0,000928	0,000933	0,000938	0,000943	0,000953	0,000963	0,000973	0,000983	0,000990	0,000996	0,001003	0,001009	0,001009
4	0,002011	0,002022	0,002033	0,002044	0,002065	0,002087	0,002108	0,002130	0,002144	0,002158	0,002172	0,002186	0,002186
5	0,001114	0,001120	0,001126	0,001132	0,001144	0,001156	0,001168	0,001180	0,001187	0,001195	0,001203	0,001211	0,001211
6	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
7	0,003094	0,003111	0,003128	0,003144	0,003177	0,003211	0,003244	0,003277	0,003299	0,003320	0,003342	0,003363	0,003363
8	0,004641	0,004666	0,004691	0,004716	0,004766	0,004816	0,004866	0,004916	0,004948	0,004980	0,005013	0,005045	0,005044
9	0,005260	0,005288	0,005317	0,005345	0,005402	0,005458	0,005515	0,005571	0,005608	0,005644	0,005681	0,005718	0,005717
10	0,007426	0,007466	0,007506	0,007546	0,007626	0,007706	0,007785	0,007865	0,007917	0,007968	0,008020	0,008072	0,008070
11	0,000309	0,000311	0,000313	0,000314	0,000318	0,000321	0,000324	0,000328	0,000330	0,000332	0,000334	0,000336	0,000336
12	0,000619	0,000622	0,000626	0,000629	0,000635	0,000642	0,000649	0,000655	0,000660	0,000664	0,000668	0,000673	0,000673
13	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
14	0,001269	0,001275	0,001282	0,001289	0,001303	0,001316	0,001330	0,001344	0,001352	0,001361	0,001370	0,001379	0,001379
15	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042
16	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
17	0,000835	0,000840	0,000844	0,000849	0,000858	0,000867	0,000876	0,000885	0,000891	0,000896	0,000902	0,000908	0,000908
18	0,000941	0,000946	0,000951	0,000956	0,000966	0,000976	0,000986	0,000996	0,001003	0,001009	0,001016	0,001022	0,001022
19	0,000934	0,000939	0,000945	0,000950	0,000960	0,000970	0,000980	0,000990	0,000996	0,001003	0,001009	0,001016	0,001016
20	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
21	0,000913	0,000918	0,000923	0,000928	0,000937	0,000947	0,000957	0,000967	0,000973	0,000979	0,000986	0,000992	0,000992
22	0,000801	0,000806	0,000810	0,000814	0,000823	0,000832	0,000840	0,000849	0,000854	0,000860	0,000866	0,000871	0,000871
23	0,000990	0,000995	0,001001	0,001006	0,001017	0,001027	0,001038	0,001049	0,001056	0,001062	0,001069	0,001076	0,001076
24	0,004827	0,004853	0,004879	0,004905	0,004957	0,005009	0,005060	0,005112	0,005146	0,005180	0,005213	0,005247	0,005246
25	0,003404	0,003422	0,003440	0,003459	0,003495	0,003532	0,003568	0,003605	0,003628	0,003652	0,003676	0,003700	0,003699
26	0,000681	0,000684	0,000688	0,000692	0,000699	0,000706	0,000714	0,000721	0,000726	0,000730	0,000735	0,000740	0,000740
27	0,001083	0,001089	0,001095	0,001101	0,001112	0,001124	0,001135	0,001147	0,001155	0,001162	0,001170	0,001177	0,001177
28	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
29	0,002073	0,002084	0,002095	0,002107	0,002129	0,002151	0,002173	0,002196	0,002210	0,002225	0,002239	0,002253	0,002253
30	0,001361	0,001369	0,001376	0,001383	0,001398	0,001413	0,001427	0,001442	0,001451	0,001461	0,001470	0,001480	0,001480
31	0,000866	0,000871	0,000876	0,000880	0,000890	0,000899	0,000908	0,000918	0,000924	0,000930	0,000936	0,000942	0,000942
32	0,001021	0,001027	0,001032	0,001038	0,001049	0,001060	0,001070	0,001081	0,001089	0,001096	0,001103	0,001110	0,001110
33	0,000959	0,000964	0,000970	0,000975	0,000985	0,000995	0,001006	0,001016	0,001023	0,001029	0,001036	0,001043	0,001042

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001681	0,001681	0,001680	0,001673	0,001665	0,001657	0,001650	0,001645	0,001639	0,001634	0,001629	0,001629	0,001629
3	0,001009	0,001008	0,001008	0,001004	0,000999	0,000994	0,000990	0,000987	0,000984	0,000981	0,000977	0,000978	0,000978
4	0,002185	0,002185	0,002184	0,002174	0,002165	0,002155	0,002145	0,002138	0,002131	0,002125	0,002118	0,002118	0,002118
5	0,001210	0,001210	0,001210	0,001204	0,001199	0,001193	0,001188	0,001184	0,001180	0,001177	0,001173	0,001173	0,001173
6	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
7	0,003362	0,003361	0,003361	0,003345	0,003330	0,003315	0,003300	0,003289	0,003279	0,003269	0,003258	0,003259	0,003259
8	0,005043	0,005042	0,005041	0,005018	0,004995	0,004972	0,004949	0,004934	0,004918	0,004903	0,004887	0,004888	0,004888
9	0,005715	0,005714	0,005713	0,005687	0,005661	0,005635	0,005609	0,005592	0,005574	0,005557	0,005539	0,005539	0,005540
10	0,008069	0,008067	0,008065	0,008029	0,007992	0,007956	0,007919	0,007894	0,007869	0,007845	0,007820	0,007820	0,007821
11	0,000336	0,000336	0,000336	0,000335	0,000333	0,000331	0,000330	0,000329	0,000328	0,000327	0,000326	0,000326	0,000326
12	0,000672	0,000672	0,000672	0,000669	0,000666	0,000663	0,000660	0,000658	0,000656	0,000654	0,000652	0,000652	0,000652
13	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
14	0,001378	0,001378	0,001378	0,001372	0,001365	0,001359	0,001353	0,001349	0,001344	0,001340	0,001336	0,001336	0,001336
15	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010
16	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
17	0,000908	0,000908	0,000907	0,000903	0,000899	0,000895	0,000891	0,000888	0,000885	0,000883	0,000880	0,000880	0,000880
18	0,001022	0,001022	0,001022	0,001017	0,001012	0,001008	0,001003	0,001000	0,000997	0,000994	0,000990	0,000991	0,000991
19	0,001015	0,001015	0,001015	0,001010	0,001006	0,001001	0,000996	0,000993	0,000990	0,000987	0,000984	0,000984	0,000984
20	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
21	0,000992	0,000992	0,000991	0,000987	0,000982	0,000978	0,000973	0,000970	0,000967	0,000964	0,000961	0,000961	0,000961
22	0,000871	0,000871	0,000870	0,000866	0,000862	0,000859	0,000855	0,000852	0,000849	0,000847	0,000844	0,000844	0,000844
23	0,001076	0,001076	0,001075	0,001071	0,001066	0,001061	0,001056	0,001053	0,001049	0,001046	0,001043	0,001043	0,001043
24	0,005245	0,005244	0,005243	0,005219	0,005195	0,005171	0,005147	0,005131	0,005115	0,005099	0,005083	0,005083	0,005084
25	0,003698	0,003697	0,003697	0,003680	0,003663	0,003646	0,003630	0,003618	0,003607	0,003595	0,003584	0,003584	0,003585
26	0,000740	0,000739	0,000739	0,000736	0,000733	0,000729	0,000726	0,000724	0,000721	0,000719	0,000717	0,000717	0,000717
27	0,001177	0,001176	0,001176	0,001171	0,001166	0,001160	0,001155	0,001151	0,001148	0,001144	0,001140	0,001140	0,001141
28	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
29	0,002253	0,002252	0,002252	0,002241	0,002231	0,002221	0,002211	0,002204	0,002197	0,002190	0,002183	0,002183	0,002183
30	0,001479	0,001479	0,001479	0,001472	0,001465	0,001459	0,001452	0,001447	0,001443	0,001438	0,001434	0,001434	0,001434
31	0,000941	0,000941	0,000941	0,000937	0,000932	0,000928	0,000924	0,000921	0,000918	0,000915	0,000912	0,000912	0,000912
32	0,001109	0,001109	0,001109	0,001104	0,001099	0,001094	0,001089	0,001085	0,001082	0,001079	0,001075	0,001075	0,001075
33	0,001042	0,001042	0,001042	0,001037	0,001032	0,001028	0,001023	0,001020	0,001016	0,001013	0,001010	0,001010	0,001010

Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001630	0,001630	0,001626	0,001623	0,001620	0,001616	0,001613	0,001609	0,001605
3	0,000978	0,000978	0,000976	0,000974	0,000972	0,000970	0,000968	0,000965	0,000963
4	0,002118	0,002119	0,002114	0,002110	0,002105	0,002101	0,002096	0,002091	0,002087
5	0,001173	0,001173	0,001171	0,001169	0,001166	0,001164	0,001161	0,001158	0,001156
6	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
7	0,003259	0,003260	0,003253	0,003246	0,003239	0,003232	0,003225	0,003218	0,003210
8	0,004889	0,004889	0,004879	0,004869	0,004859	0,004849	0,004838	0,004826	0,004815
9	0,005541	0,005541	0,005530	0,005518	0,005507	0,005495	0,005483	0,005470	0,005457
10	0,007822	0,007823	0,007807	0,007790	0,007774	0,007758	0,007740	0,007722	0,007704
11	0,000326	0,000326	0,000325	0,000325	0,000324	0,000323	0,000323	0,000322	0,000321
12	0,000652	0,000652	0,000651	0,000649	0,000648	0,000646	0,000645	0,000644	0,000642
13	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
14	0,001336	0,001336	0,001334	0,001331	0,001328	0,001325	0,001322	0,001319	0,001316
15	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995
16	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
17	0,000880	0,000880	0,000878	0,000876	0,000875	0,000873	0,000871	0,000869	0,000867
18	0,000991	0,000991	0,000989	0,000987	0,000985	0,000983	0,000980	0,000978	0,000976
19	0,000984	0,000984	0,000982	0,000980	0,000978	0,000976	0,000974	0,000972	0,000969
20	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
21	0,000961	0,000962	0,000960	0,000958	0,000956	0,000954	0,000951	0,000949	0,000947
22	0,000844	0,000844	0,000842	0,000841	0,000839	0,000837	0,000835	0,000833	0,000831
23	0,001043	0,001043	0,001041	0,001039	0,001037	0,001034	0,001032	0,001030	0,001027
24	0,005084	0,005085	0,005074	0,005064	0,005053	0,005043	0,005031	0,005019	0,005008
25	0,003585	0,003585	0,003578	0,003571	0,003563	0,003556	0,003548	0,003539	0,003531
26	0,000717	0,000717	0,000716	0,000714	0,000713	0,000711	0,000710	0,000708	0,000706
27	0,001141	0,001141	0,001138	0,001136	0,001134	0,001131	0,001129	0,001126	0,001124
28	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
29	0,002184	0,002184	0,002179	0,002175	0,002170	0,002166	0,002161	0,002156	0,002151
30	0,001434	0,001434	0,001431	0,001428	0,001425	0,001422	0,001419	0,001416	0,001412
31	0,000913	0,000913	0,000911	0,000909	0,000907	0,000905	0,000903	0,000901	0,000899
32	0,001076	0,001076	0,001073	0,001071	0,001069	0,001067	0,001064	0,001062	0,001059
33	0,001010	0,001010	0,001008	0,001006	0,001004	0,001002	0,001000	0,000997	0,000995

H Load Data used for Two-stage Stochastic Optimization Cases

Case 1: Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,003605	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,002196	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001448	0,001494	0,001540	0,001422	0,001423	0,001532	0,001445	0,001509	0,001543	0,001596	0,001511	0,001517	0,001508
3	0,000878	0,000941	0,000852	0,000907	0,000854	0,000865	0,000876	0,000869	0,000863	0,000912	0,000879	0,000919	0,000951
4	0,001999	0,001865	0,001925	0,002004	0,001870	0,002011	0,001957	0,002041	0,001987	0,002054	0,002043	0,002092	0,002100
5	0,001892	0,002012	0,002033	0,001976	0,001997	0,001943	0,001888	0,002032	0,002077	0,002046	0,001934	0,002002	0,001950
6	0,000878	0,000820	0,000871	0,000880	0,000805	0,000858	0,000809	0,000828	0,000839	0,000885	0,000837	0,000884	0,000905
7	0,002956	0,003078	0,002871	0,003114	0,002967	0,003064	0,003011	0,002989	0,003178	0,003161	0,003143	0,003218	0,003016
8	0,004344	0,004527	0,004531	0,004356	0,004315	0,004326	0,004608	0,004619	0,004585	0,004468	0,004715	0,004735	0,004708
9	0,005177	0,004928	0,004932	0,005039	0,004890	0,005209	0,004863	0,005389	0,005299	0,005270	0,005136	0,005262	0,004970
10	0,007165	0,007387	0,007537	0,007472	0,007479	0,007570	0,007300	0,007101	0,007627	0,007148	0,007105	0,007502	0,007090
11	0,000299	0,000299	0,000290	0,000302	0,000303	0,000300	0,000310	0,000299	0,000294	0,000301	0,000320	0,000316	0,000308
12	0,000609	0,000592	0,000616	0,000593	0,000587	0,000571	0,000596	0,000634	0,000629	0,000602	0,000592	0,000588	0,000597
13	0,000657	0,000677	0,000691	0,000645	0,000626	0,000628	0,000636	0,000684	0,000686	0,000682	0,000665	0,000641	0,000704
14	0,001273	0,001286	0,001214	0,001166	0,001192	0,001207	0,001235	0,001188	0,001241	0,001234	0,001189	0,001231	0,001325
15	0,000907	0,000973	0,000974	0,000900	0,000947	0,000894	0,000896	0,000927	0,000901	0,000904	0,000908	0,000988	0,000925
16	0,001076	0,001088	0,001078	0,001006	0,001038	0,001062	0,001001	0,001099	0,001027	0,001053	0,001090	0,001116	0,001066
17	0,000838	0,000799	0,000848	0,000792	0,000801	0,000819	0,000854	0,000783	0,000842	0,000829	0,000832	0,000786	0,000839
18	0,000880	0,000899	0,000955	0,000956	0,000956	0,000922	0,000925	0,000890	0,000911	0,000915	0,000918	0,000932	0,000982
19	0,000875	0,000939	0,000939	0,000886	0,000950	0,000916	0,000864	0,000866	0,000932	0,000955	0,000940	0,000926	0,000901
20	0,000965	0,000985	0,000967	0,000920	0,000968	0,000990	0,000935	0,000966	0,000959	0,000934	0,000986	0,001000	0,000985
21	0,000898	0,000873	0,000874	0,000874	0,000928	0,000886	0,000897	0,000908	0,000937	0,000941	0,000882	0,000913	0,000953
22	0,000660	0,000674	0,000688	0,000688	0,000682	0,000678	0,000673	0,000694	0,000683	0,000672	0,000695	0,000664	0,000708
23	0,000955	0,000995	0,000909	0,000920	0,000911	0,000923	0,000993	0,000947	0,000968	0,001011	0,000947	0,001000	0,000975
24	0,003837	0,003954	0,003919	0,003734	0,003662	0,003709	0,003870	0,003804	0,003928	0,003676	0,003768	0,003900	0,003955
25	0,004223	0,004267	0,003986	0,004031	0,003994	0,004290	0,004259	0,004147	0,004075	0,004051	0,004151	0,004293	0,004102
26	0,000663	0,000657	0,000638	0,000665	0,000679	0,000628	0,000689	0,000664	0,000639	0,000689	0,000651	0,000708	0,000697
27	0,001300	0,001327	0,001276	0,001265	0,001240	0,001295	0,001285	0,001366	0,001239	0,001244	0,001368	0,001255	0,001340
28	0,000803	0,000853	0,000863	0,000880	0,000805	0,000883	0,000885	0,000871	0,000839	0,000876	0,000897	0,000884	0,000870
29	0,000927	0,001004	0,001005	0,000939	0,000930	0,000961	0,000925	0,000947	0,001017	0,000982	0,000996	0,000951	0,001024
30	0,001066	0,001016	0,001068	0,000977	0,001009	0,000970	0,001034	0,001026	0,001080	0,000982	0,001017	0,001042	0,001015
31	0,000935	0,000889	0,000964	0,000937	0,000975	0,000903	0,000915	0,000955	0,000957	0,000989	0,000937	0,000950	0,000954
32	0,000627	0,000640	0,000616	0,000604	0,000654	0,000606	0,000658	0,000640	0,000636	0,000606	0,000615	0,000644	0,000640
33	0,000849	0,000867	0,000893	0,000912	0,000869	0,000854	0,000917	0,000832	0,000904	0,000873	0,000841	0,000853	0,000857

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001501	0,001540	0,001579	0,001588	0,001589	0,001573	0,001703	0,001688	0,001567	0,001610	0,001721	0,001749	0,001631
3	0,000882	0,000905	0,000901	0,000981	0,000953	0,000944	0,000963	0,000954	0,001019	0,000946	0,000962	0,001059	0,000989
4	0,001971	0,001921	0,001992	0,002126	0,002107	0,002108	0,002024	0,002194	0,002123	0,002244	0,002281	0,002296	0,002142
5	0,002001	0,002156	0,002044	0,002034	0,002055	0,002098	0,002077	0,002228	0,002090	0,002279	0,002250	0,002286	0,002264
6	0,000823	0,000871	0,000849	0,000880	0,000907	0,000881	0,000917	0,000881	0,000924	0,000930	0,000964	0,000989	0,000960
7	0,003156	0,003173	0,003065	0,003207	0,003050	0,003307	0,003179	0,003310	0,003299	0,003154	0,003208	0,003498	0,003262
8	0,004734	0,004760	0,004644	0,004481	0,004909	0,004816	0,004963	0,004768	0,004948	0,004731	0,004762	0,004995	0,004994
9	0,005155	0,005183	0,005157	0,005559	0,005348	0,005294	0,005515	0,005682	0,005832	0,005588	0,005511	0,005432	0,005431
10	0,007797	0,007317	0,007806	0,007773	0,007626	0,007706	0,007474	0,007865	0,008233	0,008287	0,007619	0,008476	0,008474
11	0,000316	0,000302	0,000328	0,000327	0,000305	0,000315	0,000341	0,000321	0,000340	0,000329	0,000338	0,000340	0,000340
12	0,000613	0,000635	0,000600	0,000660	0,000616	0,000642	0,000675	0,000662	0,000653	0,000664	0,000668	0,000693	0,000666
13	0,000653	0,000684	0,000702	0,000678	0,000734	0,000671	0,000742	0,000714	0,000726	0,000730	0,000720	0,000777	0,000718
14	0,001231	0,001250	0,001231	0,001341	0,001264	0,001382	0,001263	0,001317	0,001393	0,001334	0,001329	0,001310	0,001434
15	0,000988	0,000993	0,000950	0,000945	0,001005	0,001005	0,000975	0,000996	0,000992	0,000988	0,001036	0,001095	0,001011
16	0,001126	0,001078	0,001084	0,001112	0,001123	0,001169	0,001090	0,001204	0,001108	0,001127	0,001228	0,001118	0,001212
17	0,000852	0,000815	0,000870	0,000857	0,000875	0,000841	0,000893	0,000858	0,000917	0,000914	0,000866	0,000926	0,000917
18	0,000922	0,000965	0,000922	0,000908	0,000927	0,001025	0,000966	0,000946	0,000953	0,001009	0,001036	0,001012	0,000992
19	0,000953	0,000949	0,000897	0,000978	0,001008	0,000979	0,000999	0,000940	0,001036	0,001023	0,001019	0,001026	0,001026
20	0,000980	0,000976	0,001011	0,001026	0,001027	0,001069	0,001069	0,001091	0,001013	0,001009	0,001080	0,001098	0,001119
21	0,000876	0,000964	0,000913	0,000881	0,000900	0,000919	0,000928	0,000967	0,000963	0,000940	0,000996	0,000992	0,001002
22	0,000684	0,000688	0,000685	0,000668	0,000675	0,000731	0,000746	0,000703	0,000751	0,000742	0,000695	0,000707	0,000722
23	0,000980	0,000956	0,000971	0,001006	0,000976	0,001069	0,001059	0,000996	0,001024	0,001084	0,001027	0,001022	0,001022
24	0,003782	0,003841	0,003823	0,004001	0,003803	0,004126	0,003924	0,004088	0,004198	0,004309	0,004337	0,004196	0,004195
25	0,004166	0,004400	0,004041	0,004447	0,004451	0,004454	0,004544	0,004635	0,004396	0,004515	0,004363	0,004757	0,004390
26	0,000653	0,000678	0,000654	0,000678	0,000692	0,000685	0,000678	0,000707	0,000747	0,000730	0,000765	0,000755	0,000777
27	0,001320	0,001287	0,001308	0,001315	0,001383	0,001315	0,001426	0,001441	0,001436	0,001445	0,001440	0,001508	0,001435
28	0,000832	0,000897	0,000841	0,000836	0,000899	0,000854	0,000917	0,000890	0,000942	0,000939	0,000889	0,000970	0,000989
29	0,001010	0,001005	0,000991	0,000996	0,001057	0,001027	0,001038	0,000996	0,001098	0,001116	0,001059	0,001055	0,001130
30	0,001031	0,001079	0,001063	0,001058	0,001048	0,001037	0,001081	0,001092	0,001077	0,001151	0,001159	0,001178	0,001178
31	0,000978	0,001013	0,000970	0,001014	0,000965	0,001035	0,001056	0,001046	0,000992	0,001019	0,001036	0,000991	0,001084
32	0,000624	0,000634	0,000637	0,000647	0,000667	0,000654	0,000674	0,000661	0,000707	0,000690	0,000723	0,000671	0,000699
33	0,000924	0,000920	0,000880	0,000948	0,000894	0,000978	0,000941	0,000903	0,000957	0,000972	0,001008	0,000995	0,001014

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001664	0,001647	0,001697	0,001723	0,001698	0,001724	0,001567	0,001661	0,001672	0,001553	0,001613	0,001629	0,001646
3	0,001009	0,001059	0,001059	0,000984	0,001049	0,001004	0,001039	0,001016	0,000954	0,000951	0,000938	0,001017	0,000978
4	0,002251	0,002250	0,002272	0,002153	0,002056	0,002047	0,002188	0,002159	0,002174	0,002231	0,002224	0,002076	0,002118
5	0,002152	0,002130	0,002329	0,002186	0,002176	0,002297	0,002134	0,002127	0,002099	0,002049	0,002193	0,002086	0,002108
6	0,000979	0,000894	0,000988	0,000918	0,000932	0,000891	0,000924	0,000939	0,000964	0,000924	0,000940	0,000922	0,000867
7	0,003429	0,003529	0,003293	0,003312	0,003363	0,003414	0,003234	0,003256	0,003181	0,003334	0,003128	0,003096	0,003128
8	0,005295	0,004840	0,005041	0,005068	0,004995	0,005171	0,004850	0,004737	0,005066	0,004952	0,004741	0,005132	0,004693
9	0,005601	0,005600	0,005656	0,005801	0,005548	0,005917	0,005665	0,005592	0,005351	0,005501	0,005428	0,005761	0,005817
10	0,007827	0,007744	0,007904	0,008270	0,007992	0,008035	0,007998	0,007499	0,007633	0,007766	0,007898	0,007820	0,008212
11	0,000346	0,000323	0,000350	0,000338	0,000346	0,000345	0,000346	0,000345	0,000334	0,000333	0,000332	0,000336	0,000326
12	0,000639	0,000692	0,000692	0,000649	0,000666	0,000656	0,000627	0,000625	0,000675	0,000680	0,000658	0,000645	0,000678
13	0,000710	0,000762	0,000754	0,000714	0,000733	0,000715	0,000690	0,000716	0,000729	0,000719	0,000753	0,000703	0,000703
14	0,001323	0,001419	0,001419	0,001440	0,001352	0,001305	0,001353	0,001362	0,001385	0,001407	0,001403	0,001336	0,001283
15	0,001001	0,001094	0,000990	0,000996	0,001012	0,001048	0,001054	0,000999	0,001027	0,000993	0,001040	0,001061	0,000970
16	0,001118	0,001165	0,001117	0,001136	0,001189	0,001114	0,001190	0,001128	0,001148	0,001178	0,001106	0,001106	0,001186
17	0,000871	0,000917	0,000871	0,000921	0,000908	0,000931	0,000855	0,000888	0,000885	0,000856	0,000871	0,000862	0,000897
18	0,001073	0,001022	0,001073	0,000976	0,000982	0,001028	0,000963	0,001030	0,000997	0,000964	0,001020	0,001000	0,000981
19	0,001005	0,001015	0,000964	0,000970	0,000955	0,001051	0,000996	0,000964	0,000990	0,000997	0,000964	0,001014	0,000984
20	0,001130	0,001043	0,001043	0,001017	0,001055	0,001050	0,001045	0,001084	0,001070	0,001015	0,001011	0,001043	0,001085
21	0,001002	0,000952	0,000942	0,000977	0,001022	0,000939	0,000954	0,000961	0,001006	0,000926	0,000932	0,000942	0,000933
22	0,000766	0,000773	0,000765	0,000740	0,000758	0,000748	0,000694	0,000713	0,000732	0,000680	0,000678	0,000692	0,000742
23	0,001054	0,001129	0,001022	0,001060	0,001023	0,001071	0,001077	0,001032	0,001091	0,001004	0,001063	0,001074	0,000991
24	0,004067	0,004320	0,004150	0,004299	0,004364	0,004386	0,004282	0,004227	0,004131	0,004160	0,004064	0,004311	0,004106
25	0,004709	0,004389	0,004753	0,004732	0,004755	0,004689	0,004622	0,004294	0,004281	0,004490	0,004608	0,004476	0,004210
26	0,000740	0,000776	0,000717	0,000758	0,000711	0,000766	0,000690	0,000731	0,000707	0,000741	0,000753	0,000724	0,000724
27	0,001464	0,001449	0,001376	0,001456	0,001450	0,001372	0,001365	0,001375	0,001399	0,001352	0,001334	0,001334	0,001405
28	0,000913	0,000922	0,000913	0,000918	0,000970	0,000882	0,000878	0,000949	0,000900	0,000869	0,000940	0,000867	0,000903
29	0,001087	0,001054	0,001022	0,001124	0,001108	0,001008	0,001098	0,001105	0,001049	0,001004	0,001011	0,000991	0,001043
30	0,001097	0,001143	0,001085	0,001149	0,001132	0,001082	0,001099	0,001174	0,001159	0,001111	0,001119	0,001152	0,001108
31	0,001032	0,001073	0,001011	0,000985	0,001022	0,001079	0,001013	0,000999	0,001067	0,001023	0,001040	0,000980	0,000980
32	0,000713	0,000671	0,000677	0,000681	0,000671	0,000717	0,000679	0,000718	0,000716	0,000693	0,000677	0,000705	0,000691
33	0,000926	0,001004	0,000955	0,000970	0,000975	0,000952	0,000966	0,000925	0,000989	0,000910	0,000945	0,000945	0,000964

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001597	0,001711	0,001610	0,001574	0,001636	0,001584	0,001677	0,001625	0,001589
3	0,000978	0,000997	0,000927	0,000935	0,001001	0,000950	0,000948	0,000936	0,000982
4	0,002013	0,002161	0,002114	0,002215	0,002021	0,002101	0,002033	0,001987	0,002128
5	0,002151	0,002173	0,002104	0,002164	0,002052	0,002240	0,002192	0,002187	0,002055
6	0,000931	0,000949	0,000902	0,000936	0,000943	0,000869	0,000876	0,000919	0,000872
7	0,003357	0,003292	0,003350	0,003213	0,003336	0,003135	0,003354	0,003121	0,003050
8	0,005133	0,004987	0,004635	0,005064	0,005005	0,005091	0,004741	0,004682	0,004767
9	0,005818	0,005818	0,005640	0,005297	0,005562	0,005495	0,005263	0,005689	0,005457
10	0,007822	0,008214	0,007416	0,007634	0,008085	0,008068	0,007817	0,008108	0,007704
11	0,000310	0,000319	0,000332	0,000338	0,000330	0,000333	0,000332	0,000331	0,000337
12	0,000632	0,000626	0,000638	0,000682	0,000680	0,000653	0,000619	0,000656	0,000668
13	0,000753	0,000710	0,000744	0,000728	0,000713	0,000747	0,000717	0,000694	0,000706
14	0,001350	0,001336	0,001387	0,001304	0,001355	0,001259	0,001269	0,001293	0,001303
15	0,001020	0,000980	0,001008	0,001036	0,000994	0,000982	0,000960	0,001017	0,000995
16	0,001164	0,001084	0,001184	0,001170	0,001190	0,001097	0,001084	0,001137	0,001079
17	0,000854	0,000915	0,000913	0,000894	0,000857	0,000899	0,000906	0,000851	0,000823
18	0,001021	0,001040	0,000949	0,000997	0,000935	0,001022	0,000931	0,001017	0,000927
19	0,000965	0,000965	0,001022	0,001029	0,001027	0,000976	0,000964	0,000923	0,000950
20	0,001033	0,001064	0,001010	0,001018	0,001037	0,000993	0,001053	0,001050	0,001007
21	0,000961	0,000923	0,000979	0,000977	0,000946	0,000944	0,000942	0,000921	0,000966
22	0,000728	0,000721	0,000719	0,000718	0,000738	0,000708	0,000699	0,000726	0,000724
23	0,001074	0,001095	0,001072	0,001008	0,001088	0,001076	0,001042	0,001040	0,001007
24	0,004271	0,004312	0,004139	0,004049	0,003877	0,004073	0,003942	0,004257	0,004126
25	0,004610	0,004655	0,004247	0,004503	0,004317	0,004352	0,004430	0,004551	0,004279
26	0,000724	0,000703	0,000687	0,000686	0,000734	0,000732	0,000717	0,000722	0,000678
27	0,001475	0,001433	0,001416	0,001455	0,001410	0,001351	0,001348	0,001317	0,001328
28	0,000913	0,000949	0,000947	0,000863	0,000898	0,000950	0,000894	0,000937	0,000899
29	0,001033	0,000991	0,001051	0,001039	0,001047	0,001055	0,001032	0,000988	0,001079
30	0,001119	0,001086	0,001084	0,001071	0,001156	0,001099	0,001129	0,001127	0,001113
31	0,001041	0,000990	0,000978	0,001006	0,001004	0,001002	0,001040	0,000978	0,000995
32	0,000684	0,000684	0,000663	0,000716	0,000653	0,000713	0,000684	0,000649	0,000674
33	0,000945	0,000955	0,000981	0,000970	0,000977	0,000966	0,000954	0,000980	0,000884

Case 2: Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,003605	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,002196	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001448	0,001554	0,001510	0,001452	0,001483	0,001472	0,001536	0,001479	0,001543	0,001474	0,001556	0,001594	0,001539
3	0,000896	0,000870	0,000888	0,000925	0,000917	0,000901	0,000885	0,000924	0,000926	0,000939	0,000897	0,000883	0,000905
4	0,001921	0,001884	0,001925	0,001946	0,002006	0,001953	0,001977	0,002041	0,002046	0,001877	0,001944	0,001972	0,002100
5	0,001990	0,002012	0,001895	0,002015	0,001918	0,002022	0,002007	0,001893	0,001938	0,001986	0,001994	0,001982	0,002133
6	0,000861	0,000820	0,000796	0,000805	0,000873	0,000799	0,000801	0,000871	0,000839	0,000825	0,000863	0,000884	0,000844
7	0,002896	0,002839	0,002901	0,002994	0,002997	0,003004	0,003072	0,003019	0,003057	0,003039	0,002930	0,003187	0,003108
8	0,004389	0,004258	0,004442	0,004446	0,004630	0,004281	0,004291	0,004302	0,004630	0,004741	0,004349	0,004643	0,004616
9	0,005025	0,005131	0,005237	0,005039	0,005247	0,004902	0,005375	0,005286	0,004939	0,005167	0,005033	0,005106	0,005493
10	0,007309	0,007029	0,006963	0,007185	0,007407	0,006921	0,007589	0,007245	0,007481	0,007367	0,007105	0,007649	0,007460
11	0,000305	0,000311	0,000314	0,000296	0,000312	0,000300	0,000307	0,000314	0,000303	0,000292	0,000320	0,000306	0,000305
12	0,000591	0,000568	0,000616	0,000605	0,000617	0,000619	0,000620	0,000592	0,000636	0,000608	0,000629	0,000631	0,000585
13	0,000657	0,000644	0,000632	0,000685	0,000686	0,000648	0,000689	0,000697	0,000652	0,000695	0,000692	0,000661	0,000657
14	0,001200	0,001262	0,001202	0,001227	0,001253	0,001256	0,001296	0,001213	0,001278	0,001271	0,001239	0,001269	0,001274
15	0,000898	0,000880	0,000890	0,000919	0,000882	0,000950	0,000915	0,000945	0,000957	0,000904	0,000918	0,000998	0,000964
16	0,001076	0,001056	0,001005	0,001090	0,001017	0,000999	0,001096	0,001014	0,001049	0,001117	0,001111	0,001105	0,001120
17	0,000838	0,000775	0,000775	0,000792	0,000825	0,000811	0,000789	0,000774	0,000784	0,000845	0,000791	0,000852	0,000806
18	0,000917	0,000899	0,000909	0,000947	0,000874	0,000913	0,000906	0,000927	0,000892	0,000887	0,000881	0,000950	0,000926
19	0,000857	0,000902	0,000858	0,000895	0,000869	0,000943	0,000873	0,000912	0,000914	0,000881	0,000912	0,000889	0,000976
20	0,000974	0,000966	0,000995	0,000920	0,001007	0,000923	0,000954	0,000966	0,000939	0,001011	0,000977	0,000941	0,001034
21	0,000837	0,000864	0,000847	0,000901	0,000928	0,000895	0,000897	0,000855	0,000866	0,000906	0,000900	0,000868	0,000917
22	0,000687	0,000668	0,000668	0,000629	0,000669	0,000645	0,000692	0,000628	0,000689	0,000679	0,000688	0,000691	0,000701
23	0,000927	0,000918	0,000909	0,000929	0,000997	0,000952	0,000935	0,001014	0,000988	0,000943	0,001006	0,000971	0,000985
24	0,003611	0,003841	0,003656	0,003772	0,003625	0,003785	0,003946	0,003918	0,003966	0,003829	0,003845	0,003939	0,003800
25	0,004101	0,003902	0,004149	0,003990	0,004116	0,004085	0,003973	0,004229	0,004198	0,004092	0,003943	0,004001	0,004143
26	0,000631	0,000651	0,000684	0,000672	0,000659	0,000661	0,000643	0,000658	0,000699	0,000702	0,000638	0,000667	0,000684
27	0,001274	0,001249	0,001341	0,001329	0,001227	0,001308	0,001337	0,001314	0,001239	0,001336	0,001381	0,001360	0,001260
28	0,000803	0,000862	0,000804	0,000872	0,000822	0,000807	0,000801	0,000871	0,000847	0,000808	0,000820	0,000841	0,000844
29	0,000955	0,000995	0,000967	0,000996	0,000911	0,000961	0,001012	0,000947	0,000998	0,000934	0,000938	0,000961	0,001024
30	0,001015	0,001036	0,001047	0,001018	0,000998	0,001001	0,001024	0,001026	0,001008	0,000982	0,000996	0,001011	0,001078
31	0,000879	0,000917	0,000946	0,000900	0,000910	0,000978	0,000962	0,000964	0,000957	0,000970	0,000984	0,000960	0,000944
32	0,000658	0,000628	0,000616	0,000641	0,000642	0,000631	0,000613	0,000659	0,000616	0,000638	0,000667	0,000611	0,000659
33	0,000823	0,000849	0,000893	0,000877	0,000860	0,000897	0,000882	0,000919	0,000886	0,000846	0,000876	0,000844	0,000884

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001532	0,001633	0,001579	0,001541	0,001605	0,001653	0,001606	0,001606	0,001699	0,001743	0,001721	0,001766	0,001665
3	0,000956	0,000961	0,000901	0,000896	0,000934	0,001011	0,000924	0,000973	0,000960	0,001026	0,001053	0,001019	0,000958
4	0,002112	0,002103	0,002094	0,002105	0,002127	0,002087	0,002130	0,002215	0,002101	0,002072	0,002259	0,002164	0,002251
5	0,002063	0,002156	0,001961	0,002034	0,001992	0,002098	0,002098	0,002206	0,002177	0,002082	0,002117	0,002153	0,002264
6	0,000875	0,000862	0,000832	0,000898	0,000907	0,000908	0,000899	0,000963	0,000942	0,000911	0,000982	0,000942	0,000932
7	0,003063	0,002955	0,003002	0,003270	0,003273	0,003339	0,003114	0,003146	0,003464	0,003453	0,003275	0,003296	0,003329
8	0,004456	0,004666	0,004504	0,004716	0,004576	0,005009	0,004914	0,005161	0,004849	0,004831	0,004963	0,005247	0,005044
9	0,005313	0,005288	0,005530	0,005452	0,005186	0,005676	0,005790	0,005571	0,005327	0,005644	0,005511	0,005946	0,005431
10	0,007129	0,007541	0,007206	0,007320	0,007778	0,007320	0,007629	0,007550	0,007679	0,007729	0,007700	0,008395	0,008151
11	0,000316	0,000296	0,000319	0,000327	0,000311	0,000327	0,000337	0,000331	0,000323	0,000319	0,000317	0,000340	0,000319
12	0,000644	0,000616	0,000638	0,000610	0,000610	0,000610	0,000681	0,000623	0,000633	0,000664	0,000668	0,000673	0,000706
13	0,000688	0,000671	0,000667	0,000671	0,000713	0,000678	0,000678	0,000685	0,000689	0,000760	0,000735	0,000733	0,000718
14	0,001218	0,001326	0,001346	0,001289	0,001329	0,001290	0,001330	0,001397	0,001285	0,001293	0,001343	0,001407	0,001406
15	0,000930	0,000955	0,000940	0,000945	0,000936	0,001045	0,001046	0,000996	0,000971	0,001009	0,001088	0,001011	0,001063
16	0,001040	0,001111	0,001127	0,001067	0,001157	0,001180	0,001192	0,001135	0,001143	0,001185	0,001181	0,001130	0,001165
17	0,000794	0,000832	0,000870	0,000832	0,000841	0,000884	0,000911	0,000885	0,000882	0,000932	0,000911	0,000926	0,000926
18	0,000922	0,000917	0,000951	0,000908	0,000985	0,001025	0,000966	0,001036	0,000973	0,000999	0,001067	0,001074	0,000971
19	0,000934	0,000958	0,000907	0,000988	0,000988	0,000979	0,000931	0,001029	0,000986	0,001023	0,000979	0,001067	0,000985
20	0,000951	0,001005	0,000981	0,001006	0,000966	0,001007	0,001048	0,001080	0,001034	0,001020	0,001101	0,001109	0,001076
21	0,000867	0,000872	0,000895	0,000955	0,000890	0,000919	0,000976	0,000928	0,000924	0,000930	0,001035	0,000962	0,000952
22	0,000678	0,000715	0,000651	0,000695	0,000661	0,000710	0,000718	0,000746	0,000722	0,000742	0,000703	0,000714	0,000736
23	0,000990	0,000986	0,001031	0,001046	0,001047	0,001038	0,001038	0,001007	0,001034	0,001052	0,001101	0,001076	0,001065
24	0,003938	0,003724	0,003783	0,004001	0,003884	0,004167	0,004005	0,004212	0,003948	0,004100	0,004084	0,004365	0,004025
25	0,004292	0,004019	0,004381	0,004276	0,004494	0,004323	0,004632	0,004546	0,004441	0,004290	0,004545	0,004437	0,004345
26	0,000647	0,000684	0,000674	0,000692	0,000720	0,000685	0,000749	0,000707	0,000747	0,000694	0,000728	0,000718	0,000740
27	0,001400	0,001341	0,001308	0,001328	0,001397	0,001411	0,001426	0,001384	0,001464	0,001460	0,001426	0,001392	0,001420
28	0,000823	0,000836	0,000867	0,000836	0,000907	0,000908	0,000872	0,000872	0,000905	0,000948	0,000936	0,000989	0,000904
29	0,001020	0,001005	0,000961	0,001056	0,001017	0,001007	0,001017	0,001070	0,001108	0,001052	0,001091	0,001130	0,001098
30	0,000999	0,001100	0,001074	0,001048	0,001102	0,001070	0,001125	0,001170	0,001110	0,001084	0,001148	0,001132	0,001109
31	0,000978	0,000916	0,001018	0,000936	0,001005	0,000985	0,001016	0,000996	0,000971	0,001050	0,001026	0,001095	0,001063
32	0,000663	0,000621	0,000650	0,000667	0,000634	0,000661	0,000708	0,000661	0,000713	0,000683	0,000667	0,000692	0,000713
33	0,000888	0,000911	0,000862	0,000912	0,000875	0,000978	0,000960	0,000969	0,000995	0,000934	0,000940	0,000936	0,000975

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001664	0,001748	0,001680	0,001656	0,001732	0,001624	0,001567	0,001678	0,001656	0,001553	0,001548	0,001580	0,001613
3	0,001039	0,001059	0,000968	0,001004	0,000949	0,000945	0,001029	0,000987	0,001033	0,001020	0,000987	0,001007	0,000968
4	0,002142	0,002141	0,002228	0,002283	0,002078	0,002112	0,002123	0,002117	0,002153	0,002082	0,002033	0,002224	0,002118
5	0,002152	0,002218	0,002196	0,002208	0,002286	0,002144	0,002265	0,002127	0,002207	0,002157	0,002215	0,002215	0,002258
6	0,000894	0,000951	0,000979	0,000984	0,000951	0,000947	0,000915	0,000903	0,000964	0,000888	0,000867	0,000903	0,000931
7	0,003328	0,003193	0,003260	0,003212	0,003230	0,003481	0,003300	0,003454	0,003213	0,003301	0,003193	0,003161	0,003422
8	0,004841	0,005143	0,005091	0,005269	0,004945	0,004773	0,005147	0,004983	0,004771	0,005148	0,005034	0,004986	0,004742
9	0,005544	0,005428	0,005770	0,005744	0,005944	0,005635	0,005890	0,005704	0,005407	0,005334	0,005262	0,005539	0,005429
10	0,007665	0,007825	0,008388	0,008189	0,007832	0,007558	0,007681	0,007815	0,007948	0,007766	0,007663	0,007508	0,007587
11	0,000333	0,000346	0,000343	0,000341	0,000343	0,000325	0,000330	0,000336	0,000315	0,000340	0,000323	0,000342	0,000336
12	0,000659	0,000652	0,000645	0,000682	0,000653	0,000676	0,000673	0,000664	0,000643	0,000660	0,000671	0,000632	0,000671
13	0,000769	0,000732	0,000725	0,000729	0,000696	0,000722	0,000748	0,000738	0,000685	0,000683	0,000738	0,000717	0,000731
14	0,001406	0,001447	0,001309	0,001426	0,001393	0,001400	0,001353	0,001295	0,001317	0,001354	0,001376	0,001283	0,001390
15	0,001094	0,001094	0,001052	0,001016	0,001001	0,000976	0,001064	0,001060	0,001016	0,001044	0,001040	0,001020	0,000970
16	0,001118	0,001200	0,001129	0,001159	0,001154	0,001218	0,001109	0,001163	0,001171	0,001201	0,001186	0,001198	0,001095
17	0,000917	0,000908	0,000871	0,000885	0,000935	0,000868	0,000882	0,000924	0,000868	0,000891	0,000845	0,000871	0,000845
18	0,000971	0,001032	0,000981	0,001047	0,001002	0,001038	0,001003	0,000960	0,001007	0,001004	0,001010	0,000941	0,000981
19	0,001015	0,001066	0,001066	0,001000	0,000986	0,000971	0,000987	0,001013	0,000980	0,000967	0,000935	0,000935	0,000984
20	0,001065	0,001022	0,001032	0,001049	0,001098	0,001029	0,001056	0,001021	0,001091	0,001088	0,001011	0,000991	0,001053
21	0,000992	0,001021	0,000962	0,000997	0,001022	0,000968	0,001003	0,001009	0,000919	0,000926	0,000942	0,000952	0,000961
22	0,000751	0,000707	0,000751	0,000696	0,000693	0,000697	0,000759	0,000692	0,000689	0,000744	0,000678	0,000735	0,000707
23	0,001065	0,001065	0,001086	0,001113	0,001023	0,001082	0,001003	0,001000	0,001091	0,001067	0,001022	0,001011	0,001043
24	0,004109	0,004405	0,004150	0,004089	0,004280	0,004302	0,004074	0,003979	0,004214	0,004283	0,004105	0,004065	0,004106
25	0,004801	0,004343	0,004708	0,004686	0,004529	0,004734	0,004532	0,004250	0,004415	0,004356	0,004564	0,004254	0,004299
26	0,000740	0,000710	0,000725	0,000765	0,000725	0,000751	0,000733	0,000695	0,000736	0,000748	0,000710	0,000724	0,000746
27	0,001377	0,001391	0,001405	0,001471	0,001478	0,001386	0,001394	0,001403	0,001413	0,001465	0,001432	0,001390	0,001461
28	0,000923	0,000913	0,000960	0,000955	0,000951	0,000891	0,000905	0,000875	0,000891	0,000915	0,000949	0,000876	0,000922
29	0,001119	0,001129	0,001022	0,001017	0,001066	0,001061	0,001098	0,001042	0,001049	0,001067	0,001074	0,001043	0,001053
30	0,001155	0,001177	0,001131	0,001194	0,001155	0,001071	0,001122	0,001062	0,001059	0,001167	0,001141	0,001152	0,001064
31	0,001042	0,000990	0,000990	0,001058	0,001022	0,001069	0,001002	0,001009	0,001057	0,001003	0,001020	0,001061	0,001020
32	0,000741	0,000671	0,000720	0,000731	0,000713	0,000668	0,000672	0,000725	0,000723	0,000680	0,000698	0,000677	0,000684
33	0,000965	0,000926	0,000975	0,001019	0,000966	0,000913	0,000976	0,000992	0,000903	0,000910	0,000983	0,000936	0,000926

Case 2: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001711	0,001548	0,001545	0,001574	0,001587	0,001552	0,001629	0,001625	0,001589
3	0,000939	0,000939	0,000995	0,000974	0,000991	0,000921	0,000977	0,001014	0,000915
4	0,002034	0,002119	0,002178	0,002004	0,002211	0,002164	0,002096	0,002050	0,002107
5	0,002259	0,002044	0,002233	0,002185	0,002138	0,002091	0,002065	0,002145	0,002076
6	0,000922	0,000958	0,000911	0,000936	0,000889	0,000878	0,000939	0,000883	0,000863
7	0,003129	0,003292	0,003155	0,003278	0,003336	0,003103	0,003128	0,003218	0,003307
8	0,004693	0,004840	0,004782	0,004918	0,004907	0,005091	0,004644	0,004682	0,004960
9	0,005707	0,005818	0,005253	0,005353	0,005286	0,005440	0,005483	0,005470	0,005512
10	0,008135	0,008136	0,007650	0,007557	0,008007	0,007603	0,007740	0,008108	0,007936
11	0,000316	0,000316	0,000316	0,000328	0,000324	0,000320	0,000319	0,000322	0,000305
12	0,000639	0,000684	0,000677	0,000669	0,000635	0,000640	0,000664	0,000618	0,000610
13	0,000703	0,000739	0,000701	0,000721	0,000727	0,000740	0,000695	0,000729	0,000713
14	0,001350	0,001403	0,001400	0,001384	0,001355	0,001339	0,001362	0,001385	0,001329
15	0,001010	0,001010	0,001059	0,001006	0,001054	0,001042	0,000950	0,001017	0,000945
16	0,001152	0,001198	0,001104	0,001125	0,001077	0,001120	0,001084	0,001081	0,001101
17	0,000845	0,000880	0,000834	0,000868	0,000866	0,000855	0,000836	0,000825	0,000901
18	0,001030	0,001021	0,001028	0,001007	0,000985	0,000943	0,000971	0,000998	0,001025
19	0,000965	0,001014	0,000963	0,000990	0,000968	0,000937	0,000935	0,000952	0,000940
20	0,001074	0,001074	0,001062	0,000997	0,001078	0,001024	0,000980	0,001061	0,001058
21	0,000933	0,000942	0,000979	0,000910	0,000927	0,000934	0,000923	0,000987	0,000947
22	0,000721	0,000735	0,000698	0,000690	0,000724	0,000680	0,000713	0,000726	0,000668
23	0,001033	0,001022	0,001072	0,001059	0,001005	0,001024	0,000980	0,001050	0,001079
24	0,004189	0,003902	0,004180	0,004131	0,004285	0,004236	0,004267	0,003851	0,004207
25	0,004300	0,004477	0,004291	0,004370	0,004405	0,004528	0,004518	0,004245	0,004191
26	0,000703	0,000717	0,000751	0,000721	0,000691	0,000747	0,000738	0,000687	0,000678
27	0,001461	0,001405	0,001472	0,001455	0,001466	0,001449	0,001320	0,001415	0,001314
28	0,000940	0,000913	0,000947	0,000927	0,000898	0,000878	0,000903	0,000856	0,000899
29	0,001022	0,001064	0,001093	0,000987	0,001088	0,000993	0,001022	0,001081	0,001038
30	0,001075	0,001075	0,001161	0,001126	0,001101	0,001055	0,001129	0,001116	0,001102
31	0,001020	0,001010	0,001008	0,001036	0,001044	0,001032	0,001050	0,000987	0,000945
32	0,000650	0,000691	0,000697	0,000648	0,000653	0,000658	0,000650	0,000709	0,000640
33	0,000964	0,000974	0,000906	0,000979	0,000902	0,000947	0,000982	0,000942	0,000959

Case 3: Active Load in the Distribution Network used for the Day Ahead Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12
2	0,001493	0,001498	0,001513	0,001539	0,001572	0,001639	0,001682	0,001680	0,001650	0,001629	0,001630	0,001616
3	0,000896	0,000899	0,000908	0,000923	0,000943	0,000983	0,001009	0,001008	0,000990	0,000977	0,000978	0,000970
4	0,001941	0,001948	0,001967	0,002000	0,002044	0,002130	0,002186	0,002184	0,002145	0,002118	0,002119	0,002101
5	0,001075	0,001079	0,001090	0,001108	0,001132	0,001180	0,001211	0,001210	0,001188	0,001173	0,001173	0,001164
6	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
7	0,002986	0,002997	0,003026	0,003077	0,003144	0,003277	0,003363	0,003361	0,003300	0,003258	0,003260	0,003232
8	0,004478	0,004495	0,004540	0,004616	0,004716	0,004916	0,005045	0,005041	0,004949	0,004887	0,004889	0,004849
9	0,005076	0,005094	0,005145	0,005232	0,005345	0,005571	0,005718	0,005713	0,005609	0,005539	0,005541	0,005495
10	0,007165	0,007192	0,007263	0,007386	0,007546	0,007865	0,008072	0,008065	0,007919	0,007820	0,007823	0,007758
11	0,000299	0,000300	0,000303	0,000308	0,000314	0,000328	0,000336	0,000336	0,000330	0,000326	0,000326	0,000323
12	0,000597	0,000599	0,000605	0,000615	0,000629	0,000655	0,000673	0,000672	0,000660	0,000652	0,000652	0,000646
13	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
14	0,001224	0,001229	0,001241	0,001262	0,001289	0,001344	0,001379	0,001378	0,001353	0,001336	0,001336	0,001325
15	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002
16	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
17	0,000806	0,000809	0,000817	0,000831	0,000849	0,000885	0,000908	0,000907	0,000891	0,000880	0,000880	0,000873
18	0,000908	0,000911	0,000920	0,000936	0,000956	0,000996	0,001022	0,001022	0,001003	0,000990	0,000991	0,000983
19	0,000902	0,000905	0,000914	0,000929	0,000950	0,000990	0,001016	0,001015	0,000996	0,000984	0,000984	0,000976
20	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
21	0,000881	0,000884	0,000893	0,000908	0,000928	0,000967	0,000992	0,000991	0,000973	0,000961	0,000962	0,000954
22	0,000773	0,000776	0,000784	0,000797	0,000814	0,000849	0,000871	0,000870	0,000855	0,000844	0,000844	0,000837
23	0,000955	0,000959	0,000968	0,000985	0,001006	0,001049	0,001076	0,001075	0,001056	0,001043	0,001043	0,001034
24	0,004658	0,004675	0,004721	0,004801	0,004905	0,005112	0,005247	0,005243	0,005147	0,005083	0,005085	0,005043
25	0,003284	0,003296	0,003329	0,003385	0,003459	0,003605	0,003700	0,003697	0,003630	0,003584	0,003585	0,003556
26	0,000657	0,000659	0,000666	0,000677	0,000692	0,000721	0,000740	0,000739	0,000726	0,000717	0,000717	0,000711
27	0,001045	0,001049	0,001059	0,001077	0,001101	0,001147	0,001177	0,001176	0,001155	0,001140	0,001141	0,001131
28	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
29	0,002000	0,002008	0,002028	0,002062	0,002107	0,002196	0,002253	0,002252	0,002211	0,002183	0,002184	0,002166
30	0,001314	0,001318	0,001332	0,001354	0,001383	0,001442	0,001480	0,001479	0,001452	0,001434	0,001434	0,001422
31	0,000836	0,000839	0,000847	0,000862	0,000880	0,000918	0,000942	0,000941	0,000924	0,000912	0,000913	0,000905
32	0,000985	0,000989	0,000999	0,001016	0,001038	0,001081	0,001110	0,001109	0,001089	0,001075	0,001076	0,001067
33	0,000926	0,000929	0,000938	0,000954	0,000975	0,001016	0,001043	0,001042	0,001023	0,001010	0,001010	0,001002

Case 3: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0,001508	0,001464	0,001510	0,001512	0,001468	0,001517	0,001506	0,001434	0,001589	0,001520	0,001511	0,001563	0,001600
3	0,000860	0,000923	0,000906	0,000871	0,000917	0,000892	0,000858	0,000860	0,000863	0,000921	0,000925	0,000919	0,000951
4	0,002018	0,001884	0,001944	0,001868	0,001928	0,001914	0,001860	0,001962	0,002007	0,001975	0,001904	0,002072	0,001960
5	0,002010	0,001992	0,002014	0,001897	0,001938	0,002062	0,002087	0,002092	0,002057	0,001966	0,002014	0,001982	0,001950
6	0,000828	0,000812	0,000846	0,000838	0,000814	0,000816	0,000835	0,000820	0,000890	0,000859	0,000846	0,000867	0,000879
7	0,002866	0,003108	0,002991	0,002964	0,003056	0,002884	0,002981	0,002898	0,002936	0,003009	0,002960	0,003095	0,002954
8	0,004254	0,004482	0,004531	0,004715	0,004630	0,004551	0,004517	0,004619	0,004403	0,004376	0,004532	0,004827	0,004524
9	0,005279	0,005283	0,005085	0,005293	0,005298	0,005005	0,005375	0,004927	0,005248	0,004960	0,005136	0,005210	0,005336
10	0,006950	0,006885	0,007466	0,006898	0,006832	0,007354	0,006938	0,007608	0,006973	0,007367	0,007178	0,007355	0,007238
11	0,000308	0,000290	0,000299	0,000308	0,000303	0,000291	0,000298	0,000290	0,000291	0,000295	0,000317	0,000319	0,000323
12	0,000567	0,000622	0,000586	0,000587	0,000623	0,000625	0,000608	0,000598	0,000581	0,000632	0,000580	0,000613	0,000603
13	0,000644	0,000684	0,000684	0,000626	0,000646	0,000681	0,000682	0,000658	0,000659	0,000642	0,000665	0,000694	0,000684
14	0,001175	0,001213	0,001288	0,001240	0,001241	0,001232	0,001235	0,001238	0,001303	0,001184	0,001226	0,001319	0,001236
15	0,000972	0,000889	0,000918	0,000937	0,000957	0,000931	0,000952	0,000964	0,000948	0,000980	0,000918	0,000922	0,000973
16	0,001055	0,001015	0,001057	0,001058	0,001007	0,001041	0,001065	0,001109	0,001059	0,001011	0,001111	0,001040	0,001066
17	0,000822	0,000791	0,000783	0,000816	0,000769	0,000779	0,000772	0,000791	0,000809	0,000837	0,000783	0,000819	0,000864
18	0,000908	0,000899	0,000927	0,000901	0,000911	0,000886	0,000897	0,000964	0,000874	0,000961	0,000891	0,000950	0,000973
19	0,000875	0,000893	0,000867	0,000895	0,000941	0,000953	0,000909	0,000893	0,000868	0,000927	0,000922	0,000972	0,000901
20	0,000984	0,000928	0,000909	0,000929	0,000959	0,000980	0,000993	0,001014	0,000939	0,001011	0,001016	0,001020	0,000995
21	0,000881	0,000864	0,000847	0,000874	0,000849	0,000922	0,000844	0,000908	0,000928	0,000870	0,000909	0,000886	0,000917
22	0,000647	0,000668	0,000662	0,000623	0,000669	0,000638	0,000633	0,000628	0,000676	0,000639	0,000642	0,000678	0,000660
23	0,000917	0,000956	0,000909	0,000929	0,000940	0,000961	0,001012	0,000927	0,000939	0,000953	0,000938	0,000971	0,001004
24	0,003837	0,003916	0,003731	0,003885	0,003927	0,003596	0,003870	0,003652	0,003813	0,003676	0,003768	0,004016	0,003916
25	0,003939	0,004105	0,004109	0,004072	0,003912	0,003922	0,003891	0,003900	0,004075	0,004009	0,004151	0,004126	0,004060
26	0,000650	0,000677	0,000691	0,000652	0,000679	0,000694	0,000649	0,000638	0,000639	0,000682	0,000638	0,000654	0,000697
27	0,001274	0,001327	0,001315	0,001316	0,001266	0,001359	0,001337	0,001275	0,001278	0,001336	0,001276	0,001334	0,001300
28	0,000853	0,000879	0,000796	0,000813	0,000797	0,000858	0,000835	0,000888	0,000805	0,000876	0,000863	0,000892	0,000888
29	0,000955	0,000995	0,000948	0,000996	0,000949	0,000942	0,000964	0,001014	0,000968	0,001021	0,001006	0,001030	0,000985
30	0,000995	0,001036	0,001068	0,000967	0,000968	0,001001	0,001044	0,001006	0,001039	0,001023	0,000996	0,001000	0,001046
31	0,000963	0,000908	0,000964	0,000965	0,000882	0,000885	0,000980	0,000983	0,000901	0,000914	0,000927	0,000912	0,000964
32	0,000608	0,000640	0,000641	0,000654	0,000661	0,000650	0,000651	0,000609	0,000629	0,000657	0,000647	0,000644	0,000633
33	0,000849	0,000867	0,000893	0,000912	0,000869	0,000854	0,000917	0,000832	0,000904	0,000873	0,000841	0,000853	0,000857

Case 3: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	14	15	16	17	18	19	20	21	22	23	24	25	26
2	0,001485	0,001571	0,001642	0,001556	0,001652	0,001525	0,001638	0,001589	0,001616	0,001577	0,001587	0,001699	0,001648
3	0,000928	0,000887	0,000929	0,000962	0,000934	0,000973	0,000954	0,000954	0,000970	0,000996	0,000993	0,000979	0,001019
4	0,002112	0,002022	0,002135	0,002023	0,002024	0,002003	0,002151	0,002024	0,002166	0,002093	0,002107	0,002099	0,002251
5	0,002063	0,001992	0,002002	0,002013	0,002202	0,002161	0,002184	0,002055	0,002155	0,002301	0,002139	0,002109	0,002131
6	0,000875	0,000836	0,000849	0,000845	0,000907	0,000926	0,000863	0,000908	0,000905	0,000920	0,000898	0,000913	0,000951
7	0,003063	0,003111	0,003159	0,003050	0,003082	0,003114	0,003341	0,003441	0,003431	0,003187	0,003175	0,003532	0,003262
8	0,004734	0,004806	0,004551	0,004952	0,004719	0,004960	0,005060	0,004866	0,005146	0,004831	0,005163	0,005196	0,005145
9	0,005470	0,005394	0,005211	0,005185	0,005294	0,005567	0,005404	0,005849	0,005495	0,005362	0,005738	0,005775	0,005659
10	0,007277	0,007093	0,007731	0,007471	0,007397	0,007629	0,007785	0,008258	0,007600	0,008208	0,008181	0,008476	0,007909
11	0,000309	0,000320	0,000325	0,000302	0,000318	0,000327	0,000324	0,000338	0,000340	0,000332	0,000317	0,000330	0,000336
12	0,000600	0,000591	0,000613	0,000635	0,000629	0,000668	0,000616	0,000662	0,000647	0,000677	0,000642	0,000686	0,000699
13	0,000681	0,000712	0,000709	0,000685	0,000734	0,000720	0,000735	0,000728	0,000726	0,000709	0,000765	0,000770	0,000710
14	0,001218	0,001339	0,001308	0,001238	0,001277	0,001277	0,001290	0,001317	0,001379	0,001429	0,001411	0,001379	0,001406
15	0,000930	0,000984	0,000979	0,001014	0,000955	0,000975	0,000996	0,000975	0,001002	0,001019	0,001026	0,001064	0,001084
16	0,001094	0,001045	0,001117	0,001123	0,001057	0,001146	0,001158	0,001204	0,001201	0,001220	0,001158	0,001224	0,001200
17	0,000819	0,000857	0,000853	0,000883	0,000849	0,000824	0,000876	0,000849	0,000855	0,000941	0,000884	0,000935	0,000890
18	0,000988	0,000993	0,000922	0,000937	0,001014	0,000937	0,000957	0,000966	0,001033	0,001060	0,000975	0,001012	0,001022
19	0,000934	0,000911	0,000963	0,000921	0,000988	0,000989	0,000999	0,001039	0,001026	0,001003	0,001050	0,000975	0,000975
20	0,001000	0,001045	0,001001	0,000986	0,001027	0,000986	0,001038	0,001091	0,001087	0,001105	0,001080	0,001055	0,001055
21	0,000904	0,000918	0,000969	0,000900	0,000900	0,000957	0,000909	0,000986	0,000924	0,000960	0,000937	0,000962	0,000962
22	0,000691	0,000661	0,000664	0,000709	0,000731	0,000675	0,000725	0,000732	0,000715	0,000749	0,000695	0,000759	0,000751
23	0,001000	0,000976	0,000951	0,000966	0,001068	0,000976	0,001048	0,001091	0,001045	0,001105	0,001027	0,001044	0,001076
24	0,003821	0,003998	0,004138	0,003962	0,003924	0,003924	0,004292	0,004088	0,004364	0,004058	0,004295	0,004026	0,004279
25	0,004082	0,004315	0,004083	0,004319	0,004149	0,004541	0,004412	0,004278	0,004576	0,004561	0,004409	0,004346	0,004802
26	0,000694	0,000691	0,000667	0,000706	0,000720	0,000692	0,000721	0,000721	0,000733	0,000752	0,000735	0,000703	0,000710
27	0,001267	0,001381	0,001361	0,001315	0,001342	0,001411	0,001454	0,001483	0,001407	0,001359	0,001469	0,001493	0,001493
28	0,000858	0,000915	0,000902	0,000872	0,000899	0,000899	0,000954	0,000927	0,000896	0,000958	0,000936	0,000913	0,000989
29	0,000970	0,001005	0,001041	0,001036	0,001037	0,001007	0,001038	0,001091	0,001003	0,001116	0,001112	0,001022	0,001108
30	0,001041	0,001068	0,001085	0,001069	0,001080	0,001059	0,001103	0,001058	0,001088	0,001129	0,001091	0,001109	0,001132
31	0,000930	0,000984	0,000921	0,000975	0,001005	0,000985	0,000965	0,000996	0,001074	0,001009	0,001077	0,001053	0,001022
32	0,000617	0,000647	0,000663	0,000674	0,000687	0,000701	0,000661	0,000709	0,000720	0,000725	0,000695	0,000678	0,000699
33	0,000942	0,000866	0,000943	0,000939	0,000921	0,000950	0,000988	0,000979	0,000909	0,000934	0,000930	0,000985	0,000985

Case 3: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	27	28	29	30	31	32	33	34	35	36	37	38	39
2	0,001597	0,001731	0,001697	0,001673	0,001665	0,001575	0,001584	0,001710	0,001672	0,001700	0,001580	0,001580	0,001662
3	0,000988	0,001039	0,001038	0,000953	0,000969	0,000955	0,001000	0,001026	0,000984	0,000971	0,000938	0,000987	0,001017
4	0,002251	0,002097	0,002272	0,002174	0,002100	0,002068	0,002188	0,002138	0,002131	0,002018	0,002160	0,002203	0,002203
5	0,002241	0,002241	0,002262	0,002142	0,002242	0,002188	0,002091	0,002127	0,002078	0,002265	0,002107	0,002215	0,002065
6	0,000932	0,000904	0,000979	0,000965	0,000970	0,000956	0,000896	0,000921	0,000909	0,000906	0,000894	0,000903	0,000931
7	0,003530	0,003529	0,003428	0,003379	0,003463	0,003348	0,003465	0,003191	0,003246	0,003269	0,003356	0,003421	0,003161
8	0,005245	0,005244	0,004839	0,004968	0,004745	0,004972	0,004850	0,004835	0,004672	0,005001	0,005132	0,005083	0,004986
9	0,005544	0,005486	0,005599	0,005403	0,005661	0,005410	0,005722	0,005536	0,005741	0,005834	0,005262	0,005706	0,005595
10	0,008230	0,007906	0,008469	0,007788	0,008152	0,008115	0,008236	0,008289	0,007555	0,008080	0,007429	0,008055	0,007743
11	0,000350	0,000333	0,000339	0,000324	0,000333	0,000338	0,000313	0,000326	0,000311	0,000314	0,000339	0,000339	0,000319
12	0,000699	0,000672	0,000672	0,000669	0,000693	0,000676	0,000660	0,000671	0,000643	0,000673	0,000658	0,000632	0,000671
13	0,000710	0,000725	0,000776	0,000751	0,000755	0,000729	0,000748	0,000709	0,000714	0,000755	0,000695	0,000738	0,000731
14	0,001323	0,001433	0,001350	0,001440	0,001434	0,001427	0,001393	0,001335	0,001398	0,001354	0,001269	0,001283	0,001309
15	0,001042	0,001084	0,001094	0,001037	0,001084	0,001028	0,000972	0,000999	0,001027	0,001034	0,001050	0,000960	0,001010
16	0,001212	0,001212	0,001153	0,001147	0,001119	0,001172	0,001143	0,001128	0,001159	0,001144	0,001186	0,001095	0,001163
17	0,000890	0,000953	0,000862	0,000903	0,000899	0,000877	0,000882	0,000844	0,000903	0,000865	0,000845	0,000889	0,000862
18	0,001032	0,001042	0,001032	0,000997	0,001012	0,001048	0,000963	0,000950	0,000977	0,000964	0,001000	0,001040	0,001011
19	0,001025	0,000995	0,001025	0,000970	0,001036	0,001011	0,001046	0,000973	0,001000	0,001007	0,001033	0,000964	0,000955
20	0,001119	0,001065	0,001065	0,001017	0,001034	0,001040	0,001003	0,001042	0,001070	0,001004	0,001001	0,001022	0,001095
21	0,001002	0,000992	0,001001	0,001026	0,000953	0,000988	0,000983	0,000961	0,000958	0,000955	0,000961	0,000952	0,000942
22	0,000736	0,000751	0,000751	0,000718	0,000744	0,000755	0,000730	0,000699	0,000704	0,000723	0,000699	0,000742	0,000742
23	0,001044	0,001043	0,001075	0,001092	0,001066	0,001040	0,001098	0,001074	0,000997	0,001046	0,001063	0,001053	0,001032
24	0,004151	0,004066	0,004192	0,004131	0,004406	0,004010	0,004365	0,004310	0,004173	0,004036	0,004311	0,004229	0,003901
25	0,004755	0,004800	0,004433	0,004322	0,004529	0,004643	0,004622	0,004518	0,004504	0,004667	0,004520	0,004343	0,004388
26	0,000769	0,000754	0,000747	0,000773	0,000740	0,000707	0,000690	0,000716	0,000685	0,000683	0,000688	0,000724	0,000731
27	0,001464	0,001405	0,001492	0,001456	0,001478	0,001443	0,001479	0,001375	0,001399	0,001451	0,001418	0,001418	0,001405
28	0,000951	0,000969	0,000894	0,000890	0,000932	0,000900	0,000887	0,000875	0,000872	0,000943	0,000867	0,000903	0,000958
29	0,001119	0,001022	0,001022	0,001071	0,001098	0,001018	0,001035	0,001095	0,001081	0,001046	0,000990	0,001064	0,001022
30	0,001120	0,001177	0,001120	0,001194	0,001098	0,001127	0,001144	0,001141	0,001126	0,001089	0,001063	0,001152	0,001108
31	0,001073	0,001021	0,001042	0,000985	0,001053	0,001079	0,001064	0,001020	0,001016	0,000963	0,001061	0,001000	0,001020
32	0,000734	0,000734	0,000670	0,000667	0,000678	0,000710	0,000700	0,000663	0,000723	0,000700	0,000684	0,000698	0,000705
33	0,001004	0,000926	0,000965	0,000941	0,000927	0,000952	0,000957	0,000925	0,000979	0,000938	0,000935	0,000983	0,000983

Case 3: Active Load in the Distribution Network used for the Flexibility Market Optimization

Node\Time	40	41	42	43	44	45	46	47	48
2	0,001613	0,001662	0,001675	0,001607	0,001652	0,001616	0,001532	0,001657	0,001525
3	0,000958	0,001017	0,001005	0,001003	0,000991	0,000979	0,000977	0,000956	0,000944
4	0,002161	0,002182	0,002030	0,002068	0,002000	0,001996	0,002054	0,002154	0,001982
5	0,002065	0,002151	0,002147	0,002057	0,002074	0,002112	0,002150	0,002145	0,002161
6	0,000949	0,000922	0,000902	0,000954	0,000889	0,000896	0,000912	0,000928	0,000881
7	0,003227	0,003129	0,003285	0,003311	0,003142	0,003329	0,003064	0,003314	0,003242
8	0,005133	0,004743	0,004977	0,004625	0,005102	0,004752	0,004741	0,004971	0,005056
9	0,005707	0,005430	0,005474	0,005297	0,005231	0,005770	0,005702	0,005196	0,005403
10	0,007431	0,007745	0,007572	0,007712	0,008007	0,007603	0,007817	0,007336	0,008090
11	0,000336	0,000319	0,000316	0,000325	0,000334	0,000326	0,000323	0,000331	0,000321
12	0,000658	0,000658	0,000677	0,000630	0,000674	0,000640	0,000671	0,000656	0,000642
13	0,000703	0,000681	0,000701	0,000714	0,000698	0,000740	0,000688	0,000701	0,000713
14	0,001269	0,001390	0,001307	0,001357	0,001341	0,001365	0,001283	0,001385	0,001329
15	0,001031	0,000960	0,000978	0,001026	0,000964	0,000962	0,000970	0,001047	0,001005
16	0,001141	0,001198	0,001138	0,001182	0,001145	0,001109	0,001185	0,001149	0,001067
17	0,000854	0,000924	0,000878	0,000876	0,000875	0,000873	0,000914	0,000860	0,000832
18	0,000981	0,000971	0,000959	0,001016	0,001014	0,000963	0,001000	0,000978	0,000947
19	0,000984	0,001014	0,000943	0,000961	0,000939	0,000976	0,000964	0,000972	0,000979
20	0,001001	0,001095	0,001062	0,001008	0,000985	0,001034	0,001063	0,001081	0,001058
21	0,000990	0,000971	0,000931	0,000938	0,001003	0,000925	0,000989	0,000902	0,000938
22	0,000742	0,000685	0,000705	0,000697	0,000674	0,000680	0,000692	0,000669	0,000738
23	0,001074	0,001064	0,001020	0,001018	0,001068	0,001086	0,001001	0,001019	0,001027
24	0,004107	0,004148	0,003934	0,003967	0,004000	0,003910	0,004145	0,003892	0,003843
25	0,004521	0,004300	0,004645	0,004503	0,004581	0,004484	0,004254	0,004507	0,004584
26	0,000746	0,000703	0,000744	0,000693	0,000720	0,000718	0,000702	0,000708	0,000727
27	0,001433	0,001461	0,001332	0,001371	0,001340	0,001351	0,001334	0,001359	0,001342
28	0,000958	0,000931	0,000874	0,000936	0,000943	0,000860	0,000876	0,000946	0,000854
29	0,001033	0,001012	0,001062	0,001018	0,001005	0,001086	0,001011	0,000999	0,001027
30	0,001141	0,001086	0,001095	0,001137	0,001145	0,001055	0,001075	0,001072	0,001070
31	0,000970	0,001031	0,001039	0,001036	0,000964	0,001042	0,001040	0,001037	0,001025
32	0,000678	0,000719	0,000690	0,000661	0,000701	0,000658	0,000691	0,000696	0,000694
33	0,000898	0,000907	0,000915	0,000979	0,000968	0,000900	0,000935	0,000886	0,000931

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