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Master in Energy Engineering

FLEXIBILITY SERVICES PROVISION WITH DISTRIBUTED ENERGY RESOURCES (DERs)

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Abbreviations

Along this document, the following abbreviations will be used for convenience:

Abbreviations	Description
FO	Flexibility operator
BRP	Balance responsible parties
DER	Distributed energy resource
DSO	Distribution system operator
EV	Electric vehicle
EMS	Energy Management System
PV	Photovoltaic installation
SOC	State of charge of storages
TSO	Transmission system operator

Executive summary

This study was developed based on the INVADE architecture, and its main objective is to present an algorithm to manage uncertainties of consumption and production in-between the FO instructions, for complying with the required flexible services. In this case the scope is limited to congestion management requirements from the DSO, but the algorithm allows for improvements to add new functionalities. The proposed algorithm works slightly modifying the FO instructions in order to expand the use of flexibility to manage the congestion events.

The study is organized first by introducing the concepts related to flexibility in an electric system and the actors that could need flexibility services. Then an overview is done of the current architecture operation and the information exchanges between the actor that require a service (in this case the DSO) and the FO, presenting this way the main concerns of this study.

Then, this document presents the definitions of the flexible sources that will be used for the development of the algorithm, the methodology that will be carried out and the structure of the input information. In general terms, the study consists of developing the algorithm in python capable of simulating power flows on a network to determine the best way to allocate flexibility.

The algorithm is then described together with the equations and mechanisms used for the flexibility allocation. A simple example has been made to explain the basics of its functioning.

Then the definition of a base scenario is presented, describing the topology of the network, the characteristics of the lines and transformers and of those inflexible and flexible sources that are part of it. The assumptions of the grid behavior (demands, solar radiations for PV panels, and connection status of EV’s) and the FO instructions for the flexible sources are also given.

Finally, the simulation is run and the results are analyzed, also describing the operation of the algorithm in a particular period for a complete understanding.

The algorithm effectively uses the available flexibility to eliminate congestions on the network, limiting the loading percentages of lines and transformers to a predefined value. It also uses the available capacity on lines and transformers to apply downwards regulation and thus minimizing de differences with the FO instructions. The proposed algorithm allows for the reduction of infrastructure expansion costs and provide valuable information for promoting the use of flexible sources in a certain sector of the network.

1 Introduction

In the context of an electricity system, flexibility can be defined as the capacity of the system to maintain the balance between consumption and production of electricity in response to a variation in the current state of the system, expected or not [1]. Flexibility services are traditionally delivered by large electricity producers in response to a variation in demand.

The concept of smart grids allows to take care of flexibility needs, incorporating small producers and even consumers themselves through the control of their appliances (EVs charging points, batteries, flexible loads, generators) which we will call “sources of flexibility". This way, it is important to know the concepts of upward and downward. Upward regulation is defined as an increase in electricity generation or a decrease in demand, while downward regulation is the opposite [2].

Actors requiring flexibility services are Distribution System Operators (DSO), Balance Responsible Parties (BRP), Transmission System Operators (TSO), and Prosumers [3]. Among the main flexibility services that may be required, we can find day-ahead, intraday and self-balancing portfolio optimization (BRP), grid capacity management (TSO), congestion management (DSO and TSO), voltage / reactive power control (DSO / TSO), ToU optimization (prosumer) and kWmax control (prosumer). Flexibility is interesting for DSO and TSO to manage network congestion and thus reduce infrastructure investments. For the BSP, flexibility is important because it allows to manage its resources and lower operating costs. On the other side, prosumers are interested in lowering their electricity billing by using the flexibility of their appliances.

In this context, the INVADE project [4] is developing a platform that acts as an intermediary between the actors that require flexibility services and the consumers and prosumers that can provide them. This relationship is managed by an aggregator that we call the Flexibility Operator (FO). The INVADE project defines the actors, components, and procedures that are required to deliver flexibility services to the network in order to facilitate the incorporation of DERs into the electrical system. Likewise, it describes the layers that make up the platform's architecture, from the Components layer to the Business layer, which represent the interrelationships between the different elements of the system allowing interoperability between them [5]. This study will review some components of the Management layer that still require definition and will try to develop them.

The scope of the present study will be limited to the case of a congestion management flexibility request from a DSO, considering the existence of a single FO responsible for a set of residential and industrial facilities as sources of flexibility. The flexibility needs of the BRP or TSO are outside the scope of this study.

As described by INVADE, at the beginning of a contract between the FO and the DSO, and between the FO and its clients with sources of flexibility that make up their portfolio, the parties agree on a baseline that will serve as a reference to evaluate changes in the pattern of consumption or generation of sources of flexibility. When there is a requirement for flexibility from the DSO, the FO defines a new operating pattern for the sources of flexibility under which it would be possible to deliver the service and then generates a proposal for the DSO. This operation pattern is established for a slot of time defined and agreed in advance between the parties, which is called the “planning horizon”, and at the same time, it is divided into periods for each of which the FO optimizes the volume of energy traded for each source of flexibility. The relationship between the planning horizon and the sub-periods is called “time resolution”.

The proposal is sent to the DSO for review and approval, since it must prevent the new operating state from causing other problems in the system, such as congestion in another sector of the distribution network. When the proposal is feasible under the technical restrictions of the DSO, it responds with an acceptance message to the FO. The FO then has the optimized and approved volumes of electricity to trade between the sources of flexibility and the DSO, but requires the appropriate criteria and algorithms to decide how to apply the instructions to the set of sources of flexibility that make up its portfolio.

For example, if a flexibility proposal states that a set of batteries and EV charging points from different owners must each perform a charging volume within a certain period, it may be necessary to define the charging rates of each element to every moment within each sub-period, taking into account, of course, the external and internal technical constraints. It is then necessary to answer the questions; Should the elements consume or deliver the volume of electricity assigned at a constant power? or perhaps it is convenient to vary the rate to consume or deliver that volume in a non-constant way within the period?. These questions would not make sense if there were no uncertainty in the behavior of the sources of flexibility, but as there is, it is necessary to address this problem.

Thus, this study aims to establish the mechanisms that permit applying convenient instructions to each flexible source under scenarios with uncertainty. This will be exemplified through modeling a scenario composed of some independent residential and industrial facilities, which will have some appliances capable of providing flexibility, such as controllable loads, EVs, batteries, and generators. Likewise, it will be assumed that the facilities have meters both to account for the energy exchanged with the electricity grid and to measure the energy exchanged individually by the flexible elements that comprise them.

2 Justification – Optimization problem

The DSO can request a congestion management flexibility when it presents or predicts congestion problems at some point in the network, for example, in a substation, in a transformer, or one of its feeders. The FO should then look for ways to provide the required flexibility across its client portfolio.

Deliverables D5.3 [6] and D5.4 [7] of the INVADE project define the optimization problem that the FO will solve to establish the optimal way to deliver the flexibility requested by the DSO. This optimization problem has the objective of activating the different sources of flexibility at the lowest overall cost, always complying with a series of technical and operational restrictions. Table 2.1 shows a summary of the constraints for each source of flexibility.

Table 2.1 Technical and Operational constraints for flexibility sources

Flexibility source	Technical constraints	Operational constraints
Batteries	• Charge/discharge efficiency curve • Min/Max. SOC • Charging/discharging power levels • Charging/discharging thresholds • Constant voltage charging • Degradation	• SOC at the end of the planning horizon
Loads	• Type of unit (inflexible, shiftable profile, shiftable volume, curtailable reducible, curtailable disconnectable) • Minimum rest time between two regulations • Min/Max regulation power	• Shift intervals (start, end) • Baseline consumption • Regulation duration • Maximum number of regulations
EVs	• Type of unit (inflexible, shiftable, reducible, disconnectable, V2X) • Charge/discharge efficiency curve • Min/Max. SOC • Charging/discharging power levels • Charging/discharging thresholds	• SOC at a given period • Total and minimum charging demand • Baseline charging schedule • Min/Max charging power • SOC at arrival

	• Constant voltage charging • Degradation	• Control intervals (start, end)
Generators	• Type of unit (inflexible, curtailable reducible, curtailable disconnectable)	• Baseline production

As a result, the optimization algorithm delivers the operation variables that each element must adopt in each period of the planning horizon. These variables are summarized in Table 2.2.

Table 2.2 Results of the optimization problem for the flexibility request

Flexibility source	Optimization Variables
Batteries	• Electricity charged for each period • Electricity discharged for each period
Loads	• Electricity consumed for each period
EVs	• Electricity charged for each period • Electricity discharged for each period
Generators	• Electricity generated for each period

Since the optimization problem takes into account the technical and operational constraints of each source of flexibility, it is certain then that the amounts of electricity delivered by the algorithm as a result are possible to be consumed/generated/charged/discharged by each source of flexibility within the duration of each period. This means, for instance, that it will be feasible for a battery to charge or discharge the assigned volume of electricity respecting its voltage and current limits, or that an EV will achieve the desired SOC before it is disconnected from its charging point, or that a PV generator has the effective capacity to produce the assigned electricity according to its installed power and solar radiation forecasts for each time period.

This algorithm assumes that FO knows the characteristics and limitations of each element connected to the network and optimizes based on this. A case closer to reality would be that a set of elements of a constructive unit, for instance a home, are managed by an energy management system (EMS) and then the FO only has information on these elements in an aggregate form. For the purposes of this study, all the flexible sources are considered to be known by the FO, as this is enough to meet the objective of this work. It the future it would be possible to implement new layers of complexity.

The results obtained from solving the optimization problem correspond, as mentioned, to the amounts of electricity that must be consumed or delivered by each source of flexibility and for each period defined by the time resolution.

This model works as long as there is certainty about the predictions of demand and electricity production of the system, as well as the connection and disconnection behavior of EVs. However, this is not always the case. Solar radiation or wind speeds may decrease compared to forecasts, therefore, reducing the electricity production capacity, or an EV may be disconnected earlier than expected, therefore reducing the available flexibility. Then the available information becomes more uncertain as it moves away from the present time.

The most common way to handle these uncertainties is by applying the results obtained from the algorithm only for the closest period and rerunning the algorithm each time before starting the next period [8] [9], considering all the new information available. This is illustrated in Figure 2.1.

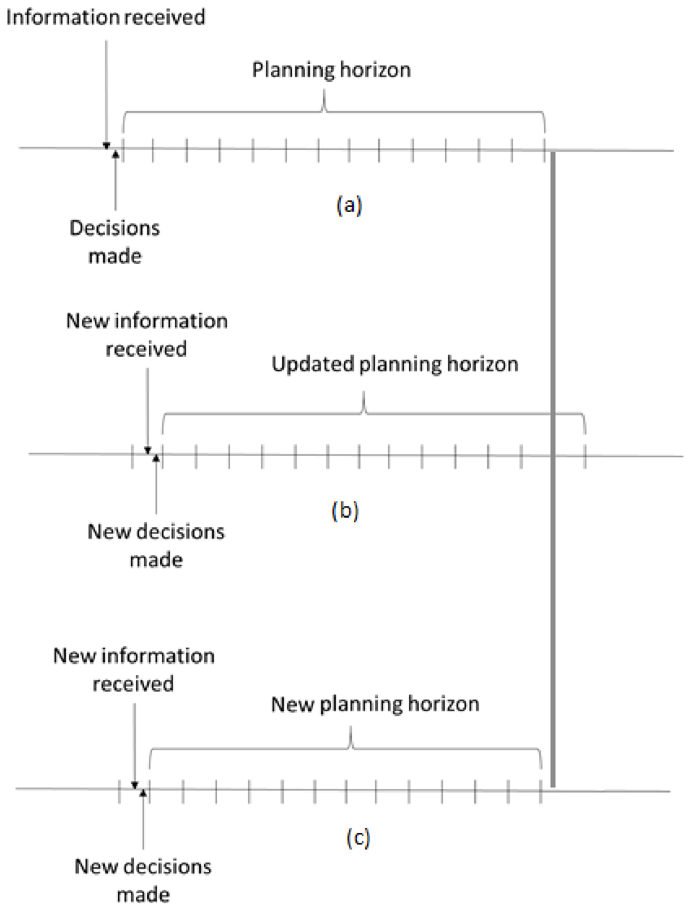

Figure 2.1 Deterministic programming with rolling and receding methods

The planning horizon can be extended or not with each iteration of the optimization algorithm according to Figure 2.1 (b) and Figure 2.1 (c), depending on the content of the updated information. This planning method is called by INVADE the rolling or receding horizon method, whether the planning horizon is extended or not.

Now, regardless of the method used or the time resolution defined for a given system (for instance, 15 minutes or 1 hour), due to the uncertainty about the behavior of the elements that consume or deliver electricity, an undesired situation may occur within a certain period. If a large load is connected, for example, congestion may occur somewhere on the network. This could be solved by running the FO optimization algorithm again with the updated information, however, the complexity and the amount of data that this optimization problem has to handle is such that the time it takes to run is longer that the desired response time. In fact, the time resolution of the planning horizon is defined taking into account the time that the FO takes to execute the optimization algorithm, and must always be greater, and therefore both durations may be similar in order of magnitude.

To avoid executing the FO optimization algorithm for each event in the system, as it is not efficient, a simplified algorithm is needed to react faster, slightly modifying the FO instructions; the electricity consumption and delivery rates of those active flexibility sources that allow for it. It is necessary to make clear that in order to react faster, an optimization problem resolution is not feasible, so whatever the resulting solution, it will deviate slightly from the optimum originally established by the FO algorithm.

To exemplify the above, suppose that the FO has received a network congestion management requirement from the DSO for which it executes its optimization algorithm and defines a flexibility proposal. The FO controller will then generate the instructions to activate the sources of flexibility for the first period within the planning horizon. During the time it takes to run the algorithm, some states on the network can change, such as a new or unanticipated load connection causing congestion at one point in the network. With the information of this new state, the FO begins the second execution of its algorithm, preparing for the next period and modifying its initial proposal to adapt to the new conditions. However, it cannot react to modify the instructions for the current period, so the congestion produced by the load may persist during the whole period.

Thus, the proposed algorithm is supposed to react continually to events during the course of each period and to apply small variations on the original instructions if needed. In this case, for example, it could decrease the rate of charge of the active batteries that are fed through the congested point or activate a greater production of electricity downstream, or any combination for an upwards regulation.

At the same time, the algorithm will search for possibilities of recovery from the small variations performed previously, trying to minimize deviations from the FO instructions at the end of each period. This is achieved through downwards regulation applied to the flexible sources that allow for it.

For the algorithm to react to events, it is assumed that it receives information from meters connected along the electrical network or at least it can read them to take actions.

Events other than congestion may also require a faster response, such as reactive power injection or voltage control, for instance. However, the proposed algorithm will focus on congestion management as the scope of this study.

3 Flexibility sources

Flexibility sources in the context of this study can be any appliance capable of modifying its electricity consumption or delivery pattern to adjust demand to production in the system. For instance, they can be PV panels, wind turbines, batteries, electric vehicles and also loads. However, not all these appliances are flexible sources. Moreover, each type of appliance has sub-categories defining different control possibilities. These sub-categories will serve as the types of elements described later in the system setup.

For the purpose of this study, all flexible sources will be classified into three categories: loads, storage systems and generators.

3.1 Loads

Loads are appliances that consume electricity, for instance TVs, food cooking appliances, washing process or wood cutting machinery. According to INVADE program, they can be classified as inflexible, curtailable or shiftable.

Inflexible loads are those that cannot be controlled by the FO in any way, meaning that they cannot be disconnected nor modified their power consumption freely. These can be for example TVs, lights, or a cooking oven. The electricity consumption of these devices is therefore subject to the user's costumes.

Curtailable loads can be of two types: **disconnectable** or **reducible**. The disconnectable loads can be controlled to reduce their consumption to 0 for a specified interval of time, and then to be reconnected and continue with their usual consumption. This means that cuts must have a maximum duration and be applied only within defined time intervals for each load. Therefore, outside of the time interval, these loads would behave as an inflexible type. Meanwhile, the reducible loads can be controlled to modify their consumption level within a permitted range of power.

In both disconnectable and reducible loads, the reduced consumption is not recovered in the future. Likewise, once consumption is reestablished for disconnectable loads, a minimum rest time must elapse prior to the next disconnection.

Shiftable loads can be controlled to transfer their consumption from one interval of time to another. There are those that allows for a transfer of the exact consumption profile from one interval to another, called **shiftable profile** loads, while also some of these loads allows to be controlled to modify their consumption level within a permitted range of power, always keeping the same volume of energy consumed within the planning horizon. These are called **shiftable volume** loads.

Since the proposed algorithm work slightly modifying the FO instructions, radical variations will not be allowed aiming to maintain the instructions close to the optimal solution obtained by the FO. This means that the temporary instructions will be based only on modifying power levels, thus disconnections or shifts will not be applicable for the proposed algorithm. For this reason, only **reducible** and **shiftable volume** loads types will be treated as “flexible units” by this algorithm.

3.2 Storages

Inside storages category there are the stationary batteries and electric vehicles. Batteries are usually used as a back-up for generators devices and as a way to store the produced energy for its later use. They are fully flexible since they can consume or deliver energy in a settable power level. However, not every installation has the ability of being controlled, as this will depend on the charge controller capabilities. Therefore, their types can be classified as **flexible** or **inflexible**.

Electric vehicles types must reflect the technical characteristics of the charging point as well as those of the car. EVs that can be purely charged and cannot be controlled at all are classified as **inflexible**. Between those that can be controlled, we have to distinguish between the different control options available. Some charging points provide the possibility to delay the whole charging profile to another period and are classified as **shiftable.** Some may have the ability to be interrupted, maintaining its original charging profile but with some periods disconnected. These will be classified as **disconnectable**. If a charging point allows for power level control between a certain range, the type will be **reducible**, while if it also allows the delivery of energy to the grid or to local consumption, its type will be **V2X**.

As with loads, only those storages systems that can be controlled in terms of power level will be treated as “flexible units” by this algorithm. Those are then **flexible** stationary batteries type and **reducible** and **V2X** EVs types.

3.3 Generators

Generators can be PV panels, wind turbines or any kind of electricity producer. They can be inflexible and curtailable.

Inflexible generators cannot be controlled at all by the FO, those providing no flexibility to the system. This means that their power output is defined by the owner and the local characteristics of the resource (i.e. solar radiation, wind).

Curtailable generators can be either **disconnectable** or **reducible**. As with loads, a disconnectable generator's power output level cannot be controlled, but can be turned off. On the other hand, a reducible generator can have its power output modified by the FO within a certain range.

For the purpose of this algorithm, only **reducible** generators type will serve as “flexible units”.

4 Methodology

The following methodology will be used for this study:

1. **Description of the base scenario:** The study will be carried out through the modelling of a base scenario consisting of a medium and low voltage distribution network with several clients connected to it. Clients may be connected to both medium and low voltages and will have associated a set of flexible and/or inflexible appliances.

   In Chapter 8, the topology of the distribution network will be defined and described, as well as the electrical characteristics of its components; lines, transformers, flexible and inflexible sources. The type and distribution of each element will also be defined. The complexity level will allow for power flow simulations using a specialized software, as well as enabling decision making for applying modifications to the FO instructions.

   Also, the planning horizon and time resolution will be defined.

2. **Definition of the initial state:** The initial state is that in which the electrical system is at the moment prior to the application of the instructions established by the FO for the first period. This means defining the levels of active and reactive power of each load, the SOC of each battery and their instantaneous state of charge or discharge, the same for each EV, adding its state of connection to its charging point, and finally the production levels of the generators.

3. **Definition of the appliance's behavior:** The FO generates its flexibility proposals based on an estimation or forecast of the future power levels of the network, currently called a baseline. However, this estimation may differ from reality, producing undesired situations as explained in Chapter 2.

   The behavior of the inflexible loads will be modeled through the definition of their power status along the planning horizon, obtaining this way a power curve. For the flexible loads, it will be assumed that they respect the FO instructions or the temporary instructions set by the proposed algorithm, so no behavior will be defined.

   In the case of EVs, their behavior will be modeled through a connection – disconnection schema. Each time an EV connects to a charging point, its current SOC will be given.

Finally, the generators behavior will be modeled as limitations to their power output, to reflect resource scarcity (wind, solar radiation, etc.).

To simulate the uncertainty of the predictions, these models should differ from the baseline used by the FO. Moreover, to represent most of the possible situations or events that can happen in a power system due to uncertainty, the elements behavior will be adjusted for convenience and may not represent a typical use pattern.

4. **Definition of the flexibility proposal:** The FO proposal will be defined as a set of electricity volumes that are assigned to each source of flexibility and for each period. These volumes of electricity will be measured in MWh and can be assigned for consumption, generation, charging or discharging, depending on the type of flexibility source. This proposal represents the input parameters for the proposed algorithm, and it is assumed that it corresponds to an optimal solution of the FO algorithm, already updated with the new data obtained from the last period events.

5. **Implementation using programming language:** The base scenario will be implemented in its initial state using the PandaPower simulation package for Python [10]. Also, all the operational mechanisms will be defined and implemented. All data for modeling will be stored in Excel sheets and read from them for implementation.

6. **Results analysis:** Simulation will be run for the base scenario and the results will be presented. Differences of both cases with and without the proposed algorithm will be analyzed. A characteristic period will be also analyzed and described. The detailed results for all periods will be annexed to this document.

7. **Conclusions:** Conclusions will be delivered based on the advantages and possible upgrades of the algorithm.

5 Data structure

All data for the model will be stored in Excel sheets and acceded from Python to create the network and simulate the scenario. The data is stored in three different files which contains all information to run the simulation. These files must be modified to run a specific scenario.

Network Data file: This file has all the topological and electrical information required for the initialization of the simulation. It is organized in sheets, each one containing all the information of a type of component and for each one of its units. Table 5.1 shows the data contained in the file.

Table 5.1 Information structure for network creation

Component	Information contained for each unit
External Grid	• Index of the external grid • Bus index it connects to • Voltage reference in per unit • Voltage reference angle
Bus	• Index of the bus • Nominal voltage level • Coordinates X-Y (for plotting)
Lines	• Index of the line • Nominal voltage level • Length of the line • Buses indexes it connects • Type of line
Transformers	• Index of the trafo • Nominal high voltage level • Nominal low voltage level • Buses indexes it connects • Type of trafo
Loads	• Index of the load • Bus index it connects to • Type of load • Minimum and maximum active power levels (only for flexible loads) • Power factor (cos phi)

Generators	• Index of the generator • Bus index it connects to • Type of generator • Minimum and maximum active power levels • Power factor (cos phi)
Storage	• Index of the storage • Bus index it connects to • Type of storage • Minimum and maximum active power levels • Minimum and maximum energy in storage • Charging/discharging efficiency • Initial SOC • Power factor (cos phi)

Grid Behavior file: In the case of inflexible, curtailable disconnectable and shiftable profile loads, the data is structured as arrays of active power levels (MW) for each load unit and for each event in time.

In the case of reducible EVs, V2X EVs, and flexible batteries, the data is structured arrays of 0's or 1's, indicating the disconnected or connected status of each unit respectively and for each event in time. If a storage unit connects, the 1 is replaced by the SOC value of its battery. On the other hand, inflexible EVs, disconnectable EVs, shiftable EVs, and inflexible batteries, data is presented as active power levels (MW) for each unit, each event in time. For storages, in general, a positive power level means charging, while negative means discharging.

Finally, the generators data structure is also arrays containing now the maximum theoretical power output (MW) due to the current amount of resources available (solar radiation, wind, etc.) for each time event. Inflexible generators will operate at the maximum possible power output.

FO Instructions file: The data corresponds to proposal of the FO, which is the amount of energy (MWh) consumed or delivered for each flexible source and for each time period. It is also structured as arrays and must be translated inside the algorithm to be able to apply the instructions in MW, depending on the preestablished duration of each period. If unit is disconnectable then a 0 is indicated in the array for as long as the disconnection instruction lasts. Disconnectable units are guaranteed to continue disconnected as long as the FO instruction lasts.

6 Algorithm description

The main objective of the proposed algorithm is to react faster to congestion events that occur in the network as a consequence of unpredicted power fluctuations. In this way, the proposed algorithm operates over the already defined FO instructions and modifies them slightly for decongestion, while the FO algorithm deals with optimizing the flexibility allocation for the next period, considering all new information from the current period. The proposed algorithm then may feed the FO with the updated information.

The algorithm has been built in a way that it is constantly receiving data of the power levels of each element or a group of them, assuming that meters are available throughout the grid. The power levels fluctuations may come from variations in demand, which may differ from predictions and can happen at any moment during a period, or they can come from the FO instructions, which only occur at the beginning of each period.

The following steps are a detailed description of what it is done inside the algorithm:

1. **Loading data for network and initial state:** At the very start of the simulation and only once, the algorithm loads all the topological and electrical information from the Network Data file for the creation and initialization of the network. Additionally, all data for grid behavior and the FO instructions are loaded for each event and each period of the planning horizon. This data is stored and accessed sequentially during the execution of the algorithm as it will be explained in the following steps.

2. **Setting grid behavior:** The network is configured with all data from the Grid Behavior file for the current event in time. It sets all power levels (active and reactive) for non-flexible units (in the terms defined in Chapter 3). If a disconnectable unit was instructed to be disconnected by the FO, the behavior data is ignored. For storages, if a unit is connected in the current time, its SOC is set.

3. **Setting FO instructions:** The algorithm receives as input data the results of the FO algorithm and applies the instructions at a constant rate of operation for each flexibility source. The instructions are received in MWh, thus the algorithm computes the active and reactive power of each unit depending on its power factor and the period defined duration, using *Equation 1* and *Equation 2*.

Equation 1 $$\mathrm{P[MW]} = \mathrm{FO_{instruction}[MWh]} * \frac{60[\frac{\mathrm{min}}{\mathrm{h}}]}{\mathrm{period\_duration[min]}}$$

Equation 2 $$Q[MVAr] = \tan(\theta) * P[MW]$$

FO instructions overrides the grid behavior set in the previous step. Generators, however, replaces the FO instruction with the maximum power output limited by resources if this is lower.

4. **Resolution of the power flow:** With the instructions applied according to the previous step, the system is solved to obtain the power flows and the congestion levels for each section of line and for each transformer. PandaPower uses method Newton Rapson by default for this task. A line or transformer is congested if its loading percent is above a predefined percentage that is usually around 70%. This limitation is defined inside the algorithm.

   By definition of the INVADE algorithm, if there were no uncertainty in the predictions, this step would not result in cases of network congestion, since DSO and FO originally agreed on the proposal based on a congestion avoidance review. Therefore, it would not be necessary to modify the operating rates, and thus the default constant rate for the instructions defined by the FO would be optimal.

5. **Computation of available flexibility for upwards regulation:** For each flexible source as defined in Chapter 3, the algorithm now computes the individual available flexibility in terms of apparent power (MVA). First, flexibility is computed in terms of active power (MW) and then using the power factor defined in the Network file, apparent power flexibility (S_{flex}) is obtained using Equation 3.

Equation 3 $$S_{flex}[MVA] = \frac{P_{flex}[MW]}{\cos\theta}$$

The calculations will consider several restrictions depending the type of the source:

<u>Loads:</u>

For reducible and shiftable volume **loads**, flexibility for an **upwards regulation** only depends on the minimum active power that each load can handle. Active power flexibility (P_{flex}^{up}) in this case would be the difference between the actual active power value and the minimum defined in the Network file. *Equation 4* is used for this calculation.

Equation 4 $$P_{flex}^{up}[MW] = P_{current}[MW] - P_{min}[MW]$$

Storages:

Flexibility for stationary **batteries** or reducible and V2X **EVs** will depend on the current state of the storage unit; if it is charging or discharging, and if it is connected or disconnected.

Flexibility for an **upwards regulation** in a discharging unit depends on the maximum power output of the storage and the minimum SOC allowed for each unit. The flexibility available from power limitation ($P_{flex\_limit}^{up\_disch}$) will be the difference between the maximum and the current power output, while for SOC limitation, the flexibility ($P_{flex\_soc}^{up\_disch}$) will be the difference between the required power to exhaust battery to its minimum defined SOC during the time left of the current period and the current power output of each unit. On the other hand, if the unit is charging, its flexibility ($P_{flex}^{up\_ch}$) is calculated as the difference between the current and the minimum output power of each unit. See equations *Equation 5*, *Equation 6*, *Equation 7* and *Equation 8*.

Equation 5 $$P_{flex\_limit}^{up\_disch}[MW] = P_{max}[MW] - P_{current}[MW]$$

Equation 6 $$P_{flex\_soc}^{up\_disch}[MW] = (SOC_{current}[\%] - SOC_{min}[\%]) * E_{max}[MWh] * Eff^{disch}[\%] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]} - P_{current}[MW]$$

Equation 7 $$P_{flex}^{up\_disch}[MW] = \min(P_{flex\_limit}^{up\_disch}[MW], P_{flex\_soc}^{up\_disch}[MW])$$

Equation 8 $$P_{flex}^{up\_ch} = P_{current}[MW] - P_{min}[MW]$$

Whichever restriction results in the minimum apparent power is set as the available flexibility for that unit. In any case, if a unit is disconnected, its flexibility is set to zero.

Generators:

For reducible generators, flexibility for an **upwards regulation** actually depends on the maximum power output limited by the resource availability (solar radiation, wind, etc.).

Thus, each unit flexibility ($P_{flex}^{up}[MW]$) will be the difference between maximum power limited by resource and current power output, as it can be seen in *Equation 9*.

Equation 9 $$P_{flex}^{up}[MW] = P_{max\_res}[MW] - P_{current}[MW]$$

As mentioned before, for every type of unit, its flexibility is stored as apparent power, so once the active power flexibility is obtained, the apparent power flexibility will be calculated using *Equation 3.*

6. **Maximum exceeded power calculation:** If step 4 results in congested lines or transformers, the algorithm computes the maximum exceeded apparent power over all elements, identifying the element type (line or trafo) and its index inside the network. The exceeded apparent power is obtained as the difference between the current apparent power in the element and its limited apparent power which depend on the limited loading percent defined inside the algorithm, for instance, 70% of its maximum capacity. Therefore, the following equations are used:

Equation 10 $$S_{current} = \sqrt{{P_{current}}^2 + {Q_{current}}^2}$$

Equation 11 $$S_{limited} = S_{current} * \frac{\text{Limited Loading Percent}}{\text{Current loading percent}}$$

Equation 12 $$S_{exceeded} = S_{current} - S_{limited}$$

If no congestion is found, the algorithm skip steps 7, 8 and 9 and jumps directly to step 10 to look for possibilities of downwards regulation.

7. **Identification of critical sources of flexibility:** In case of congestion in a line or trafo, the algorithm identifies the set of sources of flexibility that could be contributing to the congestion and that can serve to control it. The way the algorithm do this is by applying a temporary power variation to every source of flexibility one at a time, then it runs the power flow simulation and calculates the power variation in the maximum congested line or trafo identified in the previous step. This power variation should be similar to the power variation in those flexible units that are critical to the congestion. If a flexible

source is not fed through the congested element, the power variations will differ greatly. So, by comparing the variations, a set of flexible sources is obtained to work on.

8. **Calculation of available flexibility from critical sources:** From step 5, the individual available flexibility is obtained for all existing flexible sources. In this step, it is computed the total available flexibility of the set of critical flexible sources identified in the previous step. Each individual available flexibility is the apparent power available for reduction, and as so, they can differ in angle between each other. Therefore, the total available flexibility is simply the vector sum of each individual flexibility.

9. **Application of temporary instructions for upwards regulation:** Knowing the flexibility sources that are critical, the algorithm calculates the temporary instructions that must be applied to each of them to avoid or reduce the network congestion (upwards regulation).

   If the exceeded power (S_{exceeded}) from step 6 of the congested element is higher than the total available flexibility ($S_{\text{flex\_total}}$) obtained in the previous step, then each flexibility source will contribute with all its available flexibility ($S_{\text{flex\_unit}}$). In this case, congestion will be reduced but not avoided.

   On the other side, if the exceeded power is lower than the total available flexibility, each unit will contribute with a portion of its available flexibility ($S_{\text{flex\_contribution}}$) equal to a percentage of the exceeded power that its individual available flexibility represents over the total available flexibility. *Equation 13* is used for this case.

   Equation 13 $$S_{\text{flex\_contribution}}[\text{MVA}] = S_{\text{exceeded}}[\text{MVA}] * \frac{S_{\text{flex\_unit}}[\text{MVA}]}{S_{\text{flex\_total}}[\text{MVA}]}$$

   Instructions must be introduced in PandaPower as active and reactive power levels, so once the flexibility contribution is obtained in terms of apparent power, active and reactive power are calculated using *Equation 14* and *Equation 15*.

   Equation 14 $$P_{\text{flex\_contribution}}[\text{MW}] = S_{\text{flex\_contribution}}[\text{MVA}] * \cos\theta$$

   Equation 15 $$Q_{\text{flex\_contribution}}[\text{MVar}] = \tan(\theta) * P_{\text{flex\_contribution}}[\text{MW}]$$

Since decongestion requires an upwards regulation, the flexibility contribution in this step means a decrease of the power consumed by loads and charging storages, while it means an increase in the power delivered by generators and discharging storages.

As a reminder, the temporary instructions will only be applied to sources of flexibility as defined in Chapter 3, leaving out disconnectable and shiftable profile loads, disconnectable and shiftable EVs and disconnectable generators. These are in fact flexible sources for the FO algorithm, but for the proposed algorithm, the use of flexibility from these sources would imply a greater deviation from the optimum obtained by the FO, which is not the objective.

Steps 4, 5, 6, 7, 8 and 9 are repeated until there is no congestion left or until all flexibility from critical units is used. On this last case, congestion is unavoidable.

Since the algorithm solves one congested element at a time, instructions applied for one congested element could produce a further decongestion on a previously solved congested element, and since power demand behavior is constantly changing, there may be room for extra power flow in previously congested lines or transformers. Thus, from now on, the algorithm will try to find possibilities to recover from the FO energy instructions differences, product of the temporary instructions applied for decongestion. Nonetheless, the algorithm avoids applying downwards regulation to a unit to which an upwards regulation has just been applied in the same time event. Therefore, downwards regulation applies only to differences in past events during the current period.

10. **Computation of available flexibility for downwards regulation:** For each flexible source as defined in Chapter 3, individual flexibility for downwards regulation is computed first in terms of active power and then, using *Equation 3*, apparent power is obtained, as described in step 5. As mentioned in Chapter 2, downwards regulation is performed only to try to recover from an existing difference between the FO instructions and the temporary instructions set by the proposed algorithm. If a device has no difference in the instructions for the current period, no downwards regulation will be performed for that unit.

    Again, the calculations of available flexibility will consider several restrictions that differ from an upwards regulation and that will depend on each source type.

Loads:

For reducible and shiftable volume **loads**, flexibility for a **downwards regulation** (P_{flex}^{down}) will depend on both the maximum active power each load can handle and the energy difference with the FO instruction. For the first case, active power flexibility ($P_{flex\_limit}^{down}$) is the difference between the maximum and the current power of each unit. For the second case, the power flexibility ($P_{flex\_e\_diff}^{down}$) will be the difference between the active power value required to consume all energy difference during the time left of the current period and the current power of each unit. If the result is negative, then flexibility will be zero for this case. Whichever results in the lower between both cases is set as the available flexibility for that unit. See *Equation 16, Equation 17* and *Equation 18.*

Equation 16 $$P_{flex\_limit}^{down}[MW] = P_{max}[MW] - P_{current}[MW]$$

Equation 17 $$P_{flex\_e\_diff}^{down}[MW] = E_{diff}[MWh] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]} + FO_{instruction}[MWh] * \frac{60[\frac{min}{h}]}{period\_duration[min]} - P_{current}[MW]$$

Equation 18 $$P_{flex}^{down}[MW] = \min\left(P_{flex\_limit}^{down}[MW], P_{flex\_e\_diff}^{down}[MW]\right)$$

Storages:

Flexibility for stationary **batteries** or reducible and V2X **EVs** will also depend on the current state of the storage unit; if it is charging or discharging, and if it is connected or disconnected.

In the case of a **downwards regulation** in a discharging unit, flexibility will depend on the minimum power output each storage unit can handle and the energy difference with the FO instruction. For the first case ($P_{flex\_limit}^{down\_disch}[MW]$), flexibility is the difference between the current and the minimum power output. For the second case ($P_{flex\_e\_diff}^{down_{disch}}[MW]$), it is computed as the difference between the current power of each unit and its active power value required to reduce its discharging energy an amount equal to the energy difference with the FO during the time left of the current period. If the result is negative, then flexibility will be zero for this case. See *Equation 19, Equation 20* and *Equation 21.*

Equation 19 $$P_{flex\_limit}^{down\_disch}[MW] = P_{current}[MW] - P_{min}[MW]$$

Equation 20 $$P_{flex\_e\_diff}^{down\_disch}[MW] = P_{current}[MW] - (FO_{instruction}[MWh] * \frac{60[\frac{min}{h}]}{period\_duration[min]} - E_{diff}[MWh] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]})$$

Equation 21 $$P_{flex}^{down\_disch}[MW] = \min(P_{flex\_limit}^{down\_disch}[MW], P_{flex\_e\_diff}^{down\_disch}[MW])$$

If it is a charging unit, flexibility will be restricted by its maximum power output, the current energy difference with the FO instruction, and the maximum SOC allowed, usually 100%. Flexibility from limited power output ($P_{flex\_limit}^{down\_ch}[MW]$) is the difference between the maximum and current output power. Flexibility from FO difference ($P_{flex\_e\_diff}^{down\_ch}[MW]$) is the difference between its active power value required to consume all energy difference during the time left of the current period and the current power of each unit. If the result is negative, then flexibility will be zero for this case. Finally, flexibility from SOC is the difference between the power required to charge the battery to the maximum SOC defined (usually 100 %) during the time left of the current period and the current power output. Again, whichever restriction results in the minimum apparent power is set as the available flexibility for that unit. In any case, if a unit is disconnected, its flexibility is set to zero. See equations *Equation 22, Equation 23, Equation 24* and *Equation 25.*

Equation 22 $$P_{flex\_limit}^{down\_ch}[MW] = P_{max}[MW] - P_{current}[MW]$$

Equation 23 $$P_{flex\_e\_diff}^{down\_ch}[MW] = \left(FO_{instruction}[MWh] * \frac{60[\frac{min}{h}]}{period\_duration[min]} + E_{diff}[MWh] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]}\right) - P_{current}[MW]$$

Equation 24 $$P_{flex\_soc}^{down\_ch}[MW] = (SOC_{max}[\%] - SOC_{current}[\%]) * \frac{E_{max}[MWh]}{Eff^{ch}[\%]} * \frac{60[\frac{min}{h}]}{period\_time\_left[min]} - P_{current}[MW]$$

Equation 25 $$P_{flex}^{down\_ch}[MW] = \min(P_{flex\_limit}^{down\_ch}[MW], P_{flex\_e\_diff}^{down\_ch}[MW], P_{flex\_soc}^{down\_ch}[MW])$$

Generators:

For reducible generators, flexibility for a **downwards regulation** will depend on the minimum power output of each unit and the energy difference with the FO instruction. In the first case ($P^{down}_{flex\_limit}[MW]$), flexibility will be the difference between the current and the minimum power output defined in the Network file. For the second case ($P^{down}_{flex\_e\_diff}[MW]$), flexibility will be the difference between the current active power of each unit and the active power value required to reduce its energy production an amount equal to the energy difference with the FO during the time left of the current period. If the result is negative, then flexibility will be zero for this case. As always, whichever restriction results in the minimum apparent power is set as the available flexibility for that unit. See *Equation 26, Equation 27* and *Equation 28*.

Equation 26 $$P^{down}_{flex\_limit}[MW] = P_{current}[MW] - P_{min}[MW]$$

Equation 27 $$P^{down}_{flex\_e\_diff}[MW] = P_{current}[MW] - (FO_{instruction}[MWh] * \frac{60[\frac{min}{h}]}{period\_duration[min]} - E_{diff}[MWh] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]})$$

Equation 28 $$P^{down}_{flex}[MW] = \min\,(P^{down}_{flex\_limit}[MW]\,, P^{down}_{flex\_e\_diff}[MW])$$

As mentioned earlier, for every type of unit, its flexibility is stored as apparent power, so once the active power flexibility is obtained, the apparent power flexibility will be calculated using *Equation 3*.

11. **Identification of feeding lines and transformers:** For each flexible source that has available flexibility as determined in the previous step and that presents a difference with the FO energy assignment (thus, that have the possibility to recover from that difference), the algorithm identifies every line and trafo that is used to fed it with electricity. The way to do this is similar to that of step 7. First, the algorithm applies, one at a time, a temporary power variation to each of these units and runs a power flow simulation. Then, it calculates the power variation in each line and trafo of the network. If the power variation in a line or trafo is similar to the temporary power variation applied to the flexible unit, the line or trafo is feeding it.

    If a flexible source is not fed through a line or trafo, the power variations will differ greatly.

12. **Lower available power capacity calculation:** Out of all the lines and transformers that are feeding a particular flexible unit, the algorithm computes the one with the lower available power capacity, which is limited by the maximum loading percent defined inside the algorithm, for instance, 70% of its maximum capacity. The available power capacity for each element is obtained as the difference between the limited maximum capacity and the current apparent power flowing through the line or trafo. Therefore, the *Equation 10* and *Equation 11* from step 6 are used together with *Equation 29* to get the available power capacity.

Equation 29 $$S_{\text{available}} = S_{\text{limited}} - S_{\text{current}}$$

If a line or trafo have had an unavoidable congestion from previous steps (thus, is still congested), then the available power capacity will be set to 0.

From steps 11 and 12 it is obtained a list of flexible units that have available flexibility and that present a difference with the FO energy assignment, together with their corresponding critical line or trafo, that is to say, the element with the lower available power capacity that feds them.

13. **Identification of next critical line or trafo and flexible sources related:** In the list obtained in steps 11 and 12, it is possible that a single critical line or trafo identified feds more than one flexible source that permits downward regulation. Moreover, the downward regulation should be applied only to those flexible units that are fed through the critical line or trafo with the lower overall available power capacity. Thus, the algorithm first looks for the single line or trafo with the lower available power capacity over all the critical lines and transformers and then identifies the subset of flexible sources that are fed through it. The next steps work over this subset of units. In subsequent iterations this step looks for the critical line or trafo with the next lower available power capacity and returns the list of flexible units to work on, together with the lower available power capacity, until there is no more power capacity available in any element.

14. **Calculation of total available flexibility:** From step 10, the individual available flexibility for downwards regulation is obtained for all existing flexible sources. In this

step, it is computed the total available flexibility of the subset of flexible sources identified in the previous step. This is simply the vector sum of the individual available flexibility of that units.

15. **Application of temporary instructions for downwards regulation:** The algorithm now calculates the temporary instructions that must be applied to each of the flexible sources in the subset to minimize the differences with the FO instructions. If the overall minimum available power capacity ($S_{\text{available}}$) from step 13 is higher than the total available flexibility ($S_{\text{flex\_total}}$) obtained in the previous step, then all the available flexibility ($S_{\text{flex\_unit}}$) for each unit in the subset will be used. In this case, the energy differences that exist will be reduced but not eliminated.

    On the other side, if the overall lower available power capacity is less than the total available flexibility, for each unit in the subset it will contribute with a portion of its available flexibility ($S_{\text{flex\_for\_recovery}}$) equal to the percentage of the available power capacity that its individual available flexibility represents over the total available flexibility. *Equation 30* is used for this case.

    Equation 30 $$S_{\text{flex\_for\_recovery}} = S_{\text{available}} * \frac{S_{\text{flex\_unit}}}{S_{\text{flex\_total}}}$$

    Active and reactive power flexibilities are calculated using *Equation 14* and *Equation 15* in the same way as in step 9 to be able to apply the downwards instructions in PandaPower.

    For downwards regulation, the flexibility contribution in this step means an increase of the power consumed by loads and charging storages, while it means a decrease in the power delivered by generators and discharging storages.

16. **Update of available power capacities:** Since the previous step applies instructions to a subset of flexible sources for downwards regulation, all available power capacities have changed and must be updated for the rest of the lines and transformers in the list obtained in steps 11 and 12. This is done in the same way as in step 12.

The algorithm repeats steps 13, 14, 15 and 16 applying downwards regulation until there is no more available power capacity in any critical line or trafo feeding a flexibility source with differences between the FO assigned energy and its actual consumed or delivered energy.

Finally, from step 2 to step 16, all tasks have been executed for a single event in time. The algorithm then waits for the next event and once it is received it execute step 17 and then starts again from step 2.

17. **Update of storages SOC:** Once a new event in the grid is detected, the algorithm updates all storages SOC, using *Equation 31* for a charging unit and *Equation 32* for a discharging one.

Equation 31 $$\mathrm{SOC}^{\mathrm{ch}}_{\mathrm{updated}}[\%] = \mathrm{SOC}^{\mathrm{ch}}_{\mathrm{current}}[\%] + \mathrm{P}_{\mathrm{current}}[\mathrm{MW}] * \frac{\mathrm{elapsed\_time[min]}}{60[\frac{\mathrm{min}}{\mathrm{h}}]} * \frac{\mathrm{Eff}^{\mathrm{ch}}[\%]}{\mathrm{E}_{\mathrm{max}}[\mathrm{MWh}]}$$

Equation 32 $$\mathrm{SOC}^{\mathrm{disch}}_{\mathrm{updated}}[\%] = \mathrm{SOC}^{\mathrm{disch}}_{\mathrm{current}}[\%] - \mathrm{P}_{\mathrm{current}}[\mathrm{MW}] * \frac{\mathrm{elapsed\_time[min]}}{60[\frac{\mathrm{min}}{\mathrm{h}}]} * \frac{1}{\mathrm{E}_{\mathrm{max}}[\mathrm{MWh}]} * \frac{1}{\mathrm{Eff}^{\mathrm{disch}}[\%]}$$

At the end of a time period as defined by the time resolution (i.e. one hour), it is possible that a flexibility source does not comply with the FO instructions as it will be shown in an example in the next chapter. In this case, the FO needs to update its proposal for the next period to take into account these differences.

7 Simple example

The algorithm proposed will be exemplified in a simplified way using the case of a battery as the only flexible source in a network. The battery system has the following characteristics:

Table 7.1 Simple example battery characteristics

Maximum power rate	5 kW
Minimum power rate	3 kW
Minimum SOC	30%
Current SOC	50%
Maximum Capacity	10 kWh
Charge and discharge efficiency	92% (85% the whole cycle)
Power factor	0.9

Suppose that the battery is instructed by the FO to charge 4 kWh in 1 hour (period duration). The charging power is set to 4 kW so that the energy flow is delivered to the battery at a constant rate according to step 3 of the algorithm description in chapter 8. Figure 7.1 shows the tentative charging power of the battery for the whole period.

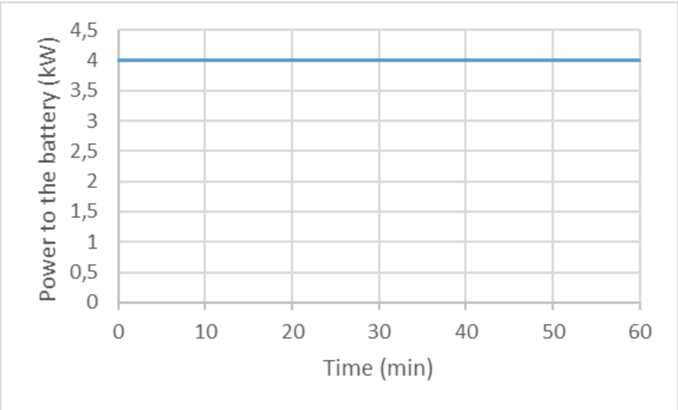

Figure 7.1 Constant charging rate by default

At minute 20 of the current period a congestion with an exceeded power of 0,5 kVA is found in a line of in the network, and the battery can help to avoid it. Then it would be necessary to reduce the charging power an amount equal to the exceeded power. Since the power factor of the battery system (charging controller) is 0,9, from Equation 14 and Equation 15 the active and reactive power flexibility contribution should be:

$$P_{flex\_contribution}[kW] = S_{flex\_contribution}[kVA] * \cos\theta = 0{,}5[kVA] * 0{,}9 = \mathbf{0{,}45\ kW}$$

$$Q_{flex\_contribution}[kVAr] = P_{flex\_contribution}[kW] * \tan\theta = 0{,}45[kW] * 0{,}48 = \mathbf{0{,}22\ kVAr}$$

Therefore, the new charging power rate would be 3,55 kW. Since it is higher than the minimum charging power of the battery (3 kW), the algorithm applies this temporary instruction to the battery. The charging power curve would be that of Figure 7.2 for the rest of the period or until another event occurs or until there is available capacity in the congested line.

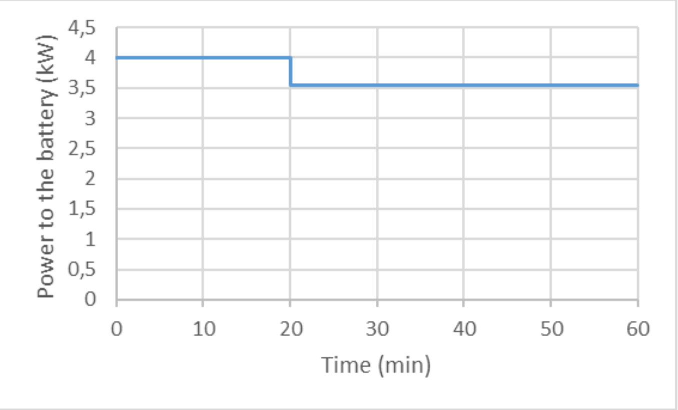

Figure 7.2 Temporary instruction applied at minute 20

Now, suppose that at minute 50 a load disconnects leaving 0,4 kVA of available capacity in the critical line that feds the battery, so that a downward regulation can be applied to recover from the FO instruction difference. At the original constant rate of 4 kW, the expected energy delivered to the battery at minute 50 should be 3,3 kWh, but actually it is only 3,1 kWh. Therefore, in the next 10 minutes it would be desirable that it charges 0,9 kWh to comply with the FO instruction. So, the available flexibility of the battery from this difference with the FO instruction, using Equation 23 should be:

$$P_{flex\_e\_diff}^{down\_ch}[kW] = \left(FO_{instruction}[kWh] * \frac{60[\frac{min}{h}]}{period\_duration[min]} + E_{diff}[kWh] * \frac{60[\frac{min}{h}]}{period\_time\_left[min]} \right) - P_{current}[kW]$$

$$P_{flex\_e\_diff}^{down\_ch}[kW] = \left(4[kWh] * 1[h^{-1}] + (3{,}3 - 3{,}1)[kWh] * \frac{60[\frac{min}{h}]}{10[min]} \right) - 3{,}55[kW] = \mathbf{1{,}8\ kW}$$

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The available flexibility from the maximum power rate restriction, using Equation 22, should be:

$$P_{flex\_limit}^{down\_ch}[kW] = P_{max}[kW] - P_{current}[kW]$$

$$P_{flex\_limit}^{down\_ch}[kW] = 5[kW] - 3.55[kW] = \mathbf{1,45\ kW}$$

Finally, to find the flexibility from SOC restriction, it is necessary to obtain SOC of the battery at minute 50 using *Equation 31*:

$$SOC_{updated}^{ch}[\%] = SOC_{current}^{ch}[\%] + P_{current}[kW] * \frac{elapsed\_time[min]}{60[\frac{min}{h}]} * \frac{Eff^{ch}[\%]}{E_{max}[kWh]}$$

From minute 0 to 20:

$$SOC_{updated}^{ch}[\%] = 50[\%] + 4[kW] * \frac{20[min]}{60\left[\frac{min}{h}\right]} * \frac{92[\%]}{10[kWh]} = \mathbf{62,3}\ \%$$

From minute 20 to 50:

$$SOC_{updated}^{ch}[\%] = 62{,}3[\%] + 3{,}55[kW] * \frac{30[min]}{60\left[\frac{min}{h}\right]} * \frac{92[\%]}{10[kWh]} = \mathbf{78,6}\ \%$$

This way, the flexibility from SOC restriction using Equation 24 results in:

$$P_{flex\_soc}^{down\_ch}[kW] = (SOC_{max}[\%] - SOC_{current}[\%]) * \frac{E_{max}[kWh]}{Eff^{ch}[\%]} * \frac{60[\frac{min}{h}]}{period\_time\_left[min]} - P_{current}[kW]$$

$$P_{flex\_soc}^{down\_ch}[kW] = (100[\%] - 78{,}6[\%]) * \frac{10[kWh]}{92[\%]} * \frac{60\left[\frac{min}{h}\right]}{10[min]} - 3{,}55[kW] = \mathbf{10,4\ kW}$$

The overall flexibility for the downwards regulation will be the minimum flexibility of the above calculated, as stated in Equation 25:

$$P_{flex}^{down\_ch}[MW] = \min(P_{flex\_limit}^{down\_ch}[MW], P_{flex\_e\_diff}^{down\_ch}[MW], P_{flex\_soc}^{down\_ch}[MW])$$

$$P_{flex}^{down\_ch}[MW] = \min(1{,}45[kW], 1{,}8[kW], 10{,}4[kW]) = \mathbf{1,45\ kW}$$

Now, the battery charging power rate can be increased a maximum of 1,45 kW according to its available flexibility, but this clearly violates the available capacity of the line (0,4 kVA). So, the algorithm increases the battery power rate an amount equal to the available capacity. Using Equation 14 and Equation 15, but this time for obtaining flexibility for recovery:

$$P_{flex\_for\_recovery}[kW] = S_{available}[kVA] * \cos\theta = 0{,}4[kVA] * 0{,}9 = \mathbf{0,36\ kW}$$

$$Q_{flex\_for\_recovery}[kVAr] = P_{flex\_for\_recovery}[kW] * \tan\theta = 0{,}45[kW] * 0{,}48 = \mathbf{0,17\ kVAr}$$

Therefore, the new power rate of the battery increases from 3,55 kW to 3,9 kW. If there are no new events in the time left for the period, then the power curve of the battery would be that of Figure 7.3:

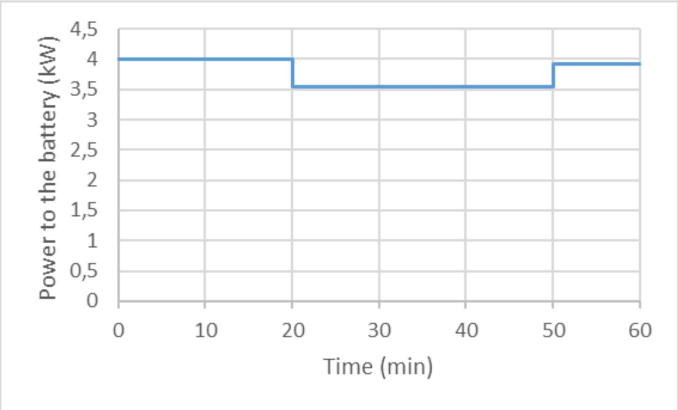

Figure 7.3 Temporary instruction applied at minute 50

At the end of the period, the battery would have charged 3,76 kWh instead of the 4 kWh instructed by the FO, but a congestion has been avoided. The FO is then responsible for adjusting the next period instructions in order to make up for this lack.

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8 Description of the base scenario

8.1 Network topology

The base scenario is built upon a semi-rural town that consists of a radial distribution network that supplies a set of residential and industrial clients and that is fed from a substation that connects it to the transmission network.

The voltage levels are 110 kV for the high side of the substation (transmission), 20 kV for the medium voltage distribution and 400 V for the low voltage distribution. Figure 8.1 shows the topology of the network, while Figure 8.2 shows the network diagram.

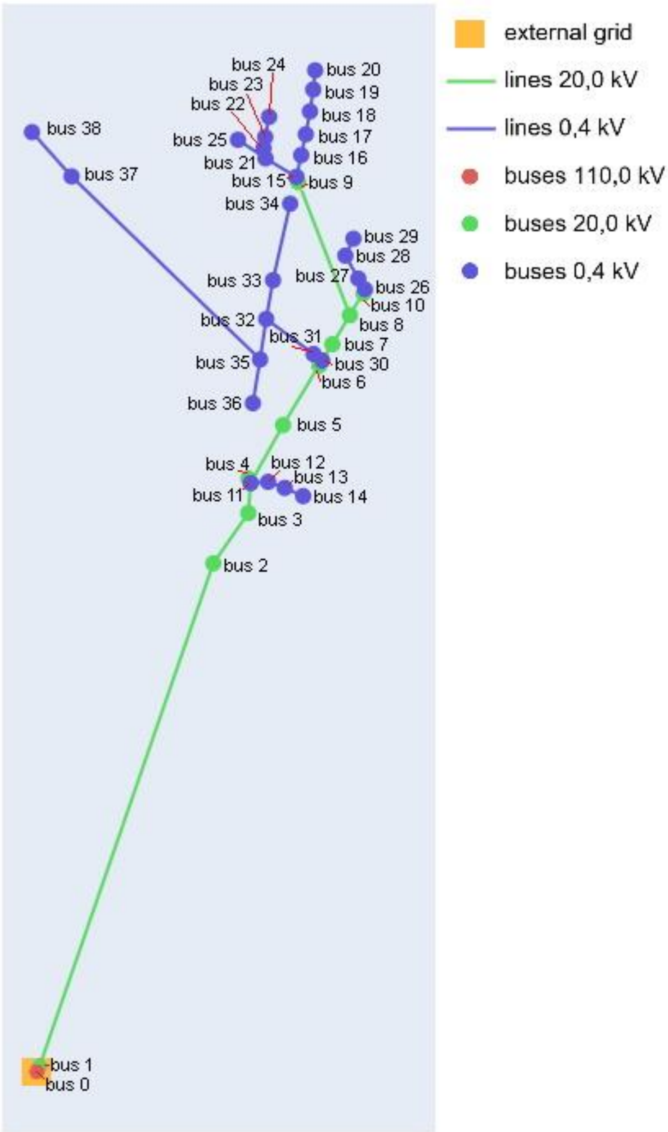

Figure 8.1 Network topology for base scenario

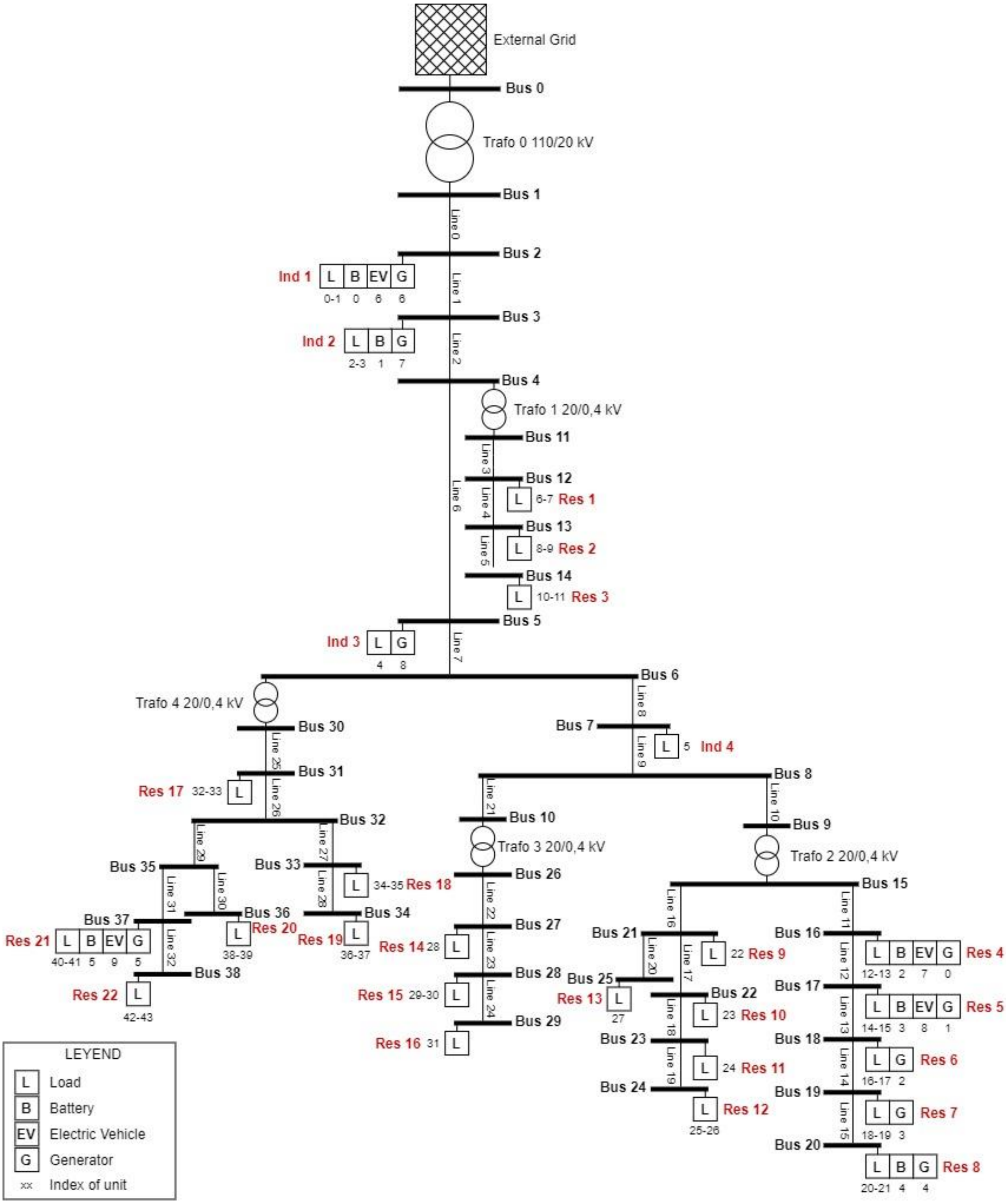

Figure 8.2 Network diagram for base scenario

Loads and sources of flexibility are distributed among 4 small industries and 22 nearby households. The 26 clients have inflexible loads connected, while only a group of them have sources of flexibility too. Table 8.1 shows the distribution summary of these elements.

Table 8.1 Loads and flexibility sources distribution

Client	Voltage Level	Appliances
Industrial 1	20 kV	Loads, PV Panels, Batteries, EVs
Industrial 2	20 kV	Loads, PV Panels, Batteries
Industrial 3	20 kV	Loads, PV Panels
Industrial 4	20 kV	Loads
Residential 1 to 3, 9 to 20 and 22	0,4 kV	Loads
Residential 4, 5 and 21	0,4 kV	Loads, PV Panels, Batteries, EVs
Residential 6 and 7	0,4 kV	Loads, PV Panels
Residential 8	0,4 kV	Loads, PV Panels, Batteries

The detailed description of each component of the network is described below.

8.1.1 Lines

For both medium and low voltage levels (20 kV and 0,4 kV) distribution lines, the conductors used are made of hard aluminum with a galvanized steel core.

For low voltage (0,4 kV), the aluminum wire will have a section 15,9 mm2, while the steel core will have a section of 3 mm2. According to norm UNE-EN 50182, the conductor designation is 15-AL1/3-ST1A.

For medium voltage level (20 kV), the aluminum wire section will be of 34 mm2, while the steel core section is 6 mm2. According to norm UNE-EN 50182, the conductor designation is 34-AL1/6-ST1A.

These are standard type lines included and already defined inside PandaPower. Table 8.2 shows the main characteristics of each line.

Table 8.2 Lines types characteristics for base scenario

Conductor designation (UNE-EN 50182)	Resistance (ohm/km)	Inductance (ohm/km)	Capacitance (nf/km)	Max current (A)	Aluminum section (mm2)	Steel section (mm2)
15-AL1/3-ST1A	1,8769	0,35	11,0	0,105	15,9	3
34-AL1/6-ST1A	0,8342	0,382	9,15	0,17	34	6

There are 32 sections of line connecting the different buses, 9 of which are medium voltage and the rest low voltage. Lengths of each section and their characteristic details are shown in Table 8.3. The measure units for voltage and length were chosen because PandaPower works with these units (kV and km). Index is just used throughout the document to facilitate the reference to an element.

Table 8.3 Lines detail for base scenario

Conductor designation (UNE-EN 50182)	Line index	Voltage level (kV)	Length (km)	From bus	To bus
34-AL1/6-ST1A	0	20	1,39	1	2
34-AL1/6-ST1A	1	20	0,174	2	3
34-AL1/6-ST1A	2	20	0,056	3	4
15-AL1/3-ST1A	3	0,4	0,054	11	12
15-AL1/3-ST1A	4	0,4	0,052	12	13
15-AL1/3-ST1A	5	0,4	0,059	13	14
34-AL1/6-ST1A	6	20	0,153	4	5
34-AL1/6-ST1A	7	20	0,168	5	6
34-AL1/6-ST1A	8	20	0,043	6	7
34-AL1/6-ST1A	9	20	0,076	7	8
34-AL1/6-ST1A	10	20	0,319	8	9
15-AL1/3-ST1A	11	0,4	0,043	15	16
15-AL1/3-ST1A	12	0,4	0,04	16	17
15-AL1/3-ST1A	13	0,4	0,043	17	18
15-AL1/3-ST1A	14	0,4	0,041	18	19
15-AL1/3-ST1A	15	0,4	0,035	19	20
15-AL1/3-ST1A	16	0,4	0,101	15	21
15-AL1/3-ST1A	17	0,4	0,019	21	22
15-AL1/3-ST1A	18	0,4	0,021	22	23
15-AL1/3-ST1A	19	0,4	0,039	23	24
15-AL1/3-ST1A	20	0,4	0,092	21	25
34-AL1/6-ST1A	21	20	0,065	8	10
15-AL1/3-ST1A	22	0,4	0,028	26	27
15-AL1/3-ST1A	23	0,4	0,058	27	28
15-AL1/3-ST1A	24	0,4	0,039	28	29
15-AL1/3-ST1A	25	0,4	0,028	30	31
15-AL1/3-ST1A	26	0,4	0,159	31	32
15-AL1/3-ST1A	27	0,4	0,074	32	33
15-AL1/3-ST1A	28	0,4	0,15	33	34
15-AL1/3-ST1A	29	0,4	0,076	32	35
15-AL1/3-ST1A	30	0,4	0,083	35	36
15-AL1/3-ST1A	31	0,4	0,673	35	37
15-AL1/3-ST1A	32	0,4	0,147	37	38

For every line, if its loading percent is above 70%, it will be considered congested.

8.1.2 Transformers

There are two trafo types in the network going from high to medium and from medium to low voltages, which are standard types included and already defined inside PandaPower. Table 8.4 shows the main characteristics of each trafo.

Table 8.4 Transformers types characteristics for base scenario

Standard type	Nominal power (MVA)	Nominal high voltaje (kV)	Nominal low voltaje (kV)	Relative short circuit voltage (%)	Iron losses (kW)
25 MVA 110/20 kV	25	110	20	12	14
0.25 MVA 20/0,4 kV	0.25	20	0,4	6	0,8

The network has been defined using 5 transformers, one for the connection with the external grid and the rest for the transition between medium and low voltages. Each trafo details is shown in Table 8.5. The measure units for power, voltage levels and losses were chosen because PandaPower works with these units (MVA, kV and kW). Index is just used throughout the document to facilitate the reference to an element.

Table 8.5 Transformers detail for base scenario

Standard type	Trafo index	From bus	To bus
25 MVA 110/20 kV	0	0	1
0.25 MVA 20/0.4 kV	1	4	11
0.25 MVA 20/0.4 kV	2	9	15
0.25 MVA 20/0.4 kV	3	10	26
0.25 MVA 20/0.4 kV	4	6	30

For every trafo, if its loading percent is above 70%, it will be considered congested.

8.1.3 Loads

The 26 clients will have some type of load connected. Additionally, the loads can consume both active and reactive power. Table 8.6 shows the detailed characteristics of the loads and their distribution among clients. Note that minimum and maximum power levels are necessary only for those flexible units in the terms defined in Chapter 3 (reducible and shiftable volume loads). The measure units for power were chosen because PandaPower works with these units (MW). Index is just used throughout the document to facilitate the reference to an element.

Table 8.6 Loads details for base scenario

Client	Source type	Load index	Bus	Min P (MW)	Max P (MW)	Power factor
Industrial 1	reducible	0	2	0,6	1,0	0,90
	inflexible	1	2	-	-	0,85
Industrial 2	reducible	2	3	0,7	2,0	0,90
	inflexible	3	3	-	-	0,80
Industrial 3	inflexible	4	5	-	-	0,90
Industrial 4	inflexible	5	7	-	-	0,95
Residential 1	disconnectable	6	12	-	-	0,95
	inflexible	7	12	-	-	0,90
Residential 2	reducible	8	13	0,002	0,004	0,95
	inflexible	9	13	-	-	0,95
Residential 3	reducible	10	14	0,002	0,004	0,95
	inflexible	11	14	-	-	0,95
Residential 4	reducible	12	16	0,002	0,004	0,95
	inflexible	13	16	-	-	0,90
Residential 5	volume	14	17	0,002	0,004	0,95
	inflexible	15	17	-	-	0,95
Residential 6	volume	16	18	0,002	0,004	0,95
	inflexible	17	18	-	-	0,95
Residential 7	reducible	18	19	0,002	0,004	0,95
	inflexible	19	19	-	-	0,90
Residential 8	reducible	20	20	0,002	0,004	0,95
	inflexible	21	20	-	-	0,95
Residential 9	inflexible	22	21	-	-	0,95
Residential 10	inflexible	23	22	-	-	0,90
Residential 11	inflexible	24	23	-	-	0,95
Residential 12	disconnectable	25	24	-	-	0,95
	inflexible	26	24	-	-	0,95
Residential 13	inflexible	27	25	-	-	0,95
Residential 14	inflexible	28	27	-	-	0,95
Residential 15	disconnectable	29	28	-	-	0,95
	inflexible	30	28	-	-	0,90
Residential 16	inflexible	31	29	-	-	0,95
Residential 17	volume	32	31	0,0025	0,004	0,95
	inflexible	33	31	-	-	0,95
Residential 18	volume	34	33	0,0025	0,004	0,95
	inflexible	35	33	-	-	0,95
Residential 19	disconnectable	36	34	-	-	0,95
	inflexible	37	34	-	-	0,90
Residential 20	reducible	38	36	0,0025	0,004	0,95
	inflexible	39	36	-	-	0,95
Residential 21	disconnectable	40	37	-	-	0,95
	inflexible	41	37	-	-	0,95
Residential 22	disconnectable	42	38	-	-	0,95
	inflexible	43	38	-	-	0,90

8.1.4 Storages

Storages can be either stationary batteries or electric vehicles. Stationary batteries have been put together with a generator, while electric vehicles are randomly distributed among some clients. Storage will consume both active and reactive power because they have a power factor less than one attributable to their charge controller. There are 6 stationary batteries and 4 electric vehicles. Table 8.7 shows the detailed characteristics of the storages and their distribution among clients. Note that minimum and maximum power levels are necessary only for those flexible units in the terms defined in Chapter 3 (flexible batteries and reducible and V2X EVs). The efficiency parameter is defined for one direction: charge or discharge. The complete cycle efficiency is the shown value squared. The measure units for capacity and power were chosen because PandaPower works with these units (MWh and MW). Index is just used throughout the document to facilitate the reference to an element.

Table 8.7 Storages details for base scenario

Client	Storage type	Source type	Storage index	Bus	Min. SOC (%)	Capacity (MWh)	Min P (MW)	Max P (MW)	Eff (%)	Power factor
Industrial 1	Stationary battery	flexible	0	2	30%	0,2	0	0,05	0,9	0,9
Industrial 2	Stationary battery	flexible	1	3	30%	0,2	0	0,05	0,9	0,95
Residential 4	Stationary battery	inflexible	2	16	30%	0,01	-	-	0,92	0,9
Residential 5	Stationary battery	flexible	3	17	30%	0,01	0	0,004	0,9	0,9
Residential 8	Stationary battery	flexible	4	20	30%	0,01	0	0,004	0,92	0,9
Residential 21	Stationary battery	flexible	5	37	30%	0,01	0	0,004	0,9	0,95
Industrial 1	Electric Vehicle	reducible	6	2	70%	0,01	0	0,004	0,9	0,95
Residential 4	Electric Vehicle	reducible	7	16	70%	0,01	0	0,004	0,92	0,9
Residential 5	Electric Vehicle	V2X	8	17	70%	0,01	0	0,004	0,9	0,9
Residential 21	Electric Vehicle	V2X	9	37	70%	0,01	0	0,004	0,92	0,9

8.1.5 Generators

There are 9 generators and all of them are photovoltaic installations. However, it makes no difference to the algorithm and to the aim of the project if generators were of other types. Generators may or may not have an associated stationary battery and are randomly distributed among some clients. Generators can inject both active and reactive power as if their corresponding inverters have the ability to do so. Table 8.8 shows the detailed characteristics of the generators and their distribution among clients. Note that minimum and maximum power levels are necessary only for those flexible units in the terms defined in Chapter 3 (reducible generators). The measure units for power were chosen because PandaPower works with these units (MW). Index is just used throughout the document to facilitate the reference to an element.

Table 8.8 Generators details for base scenario

Client	Generator type	Source type	Generator index	Bus	Min P (MW)	Max P (MW)	Power factor
Residential 4	PV	inflexible	0	16	-	-	0,99
Residential 5	PV	disconnectable	1	17	-	-	0,99
Residential 6	PV	reducible	2	18	0	0,005	0,99
Residential 7	PV	reducible	3	19	0	0,005	0,99
Residential 8	PV	disconnectable	4	20	-	-	0,99
Residential 21	PV	reducible	5	37	0	0,005	0,99
Industrial 1	PV	reducible	6	2	0	0,1	0,99
Industrial 2	PV	inflexible	7	3	-	-	0,99
Industrial 3	PV	reducible	8	5	0	0,023	0,99

8.2 Planning horizon and time resolution

The planning horizon for this study will be set for 12 hours, from 7am to 19pm, to represent the time of the day with most power variations and uncertainty. However, as the grid behavior will be adjusted to convenience, it does not necessarily represent a typical behavior. The time resolution will be 1 hour; thus, the FO instruction file will contain all proposal information for each unit and for every hour of the planning horizon (12 periods). On the other hand, the grid behavior file will contain all information for each unit but for events that can happen in any moment inside the planning horizon.

9 Definition of the initial state

The initial state of the system at 7:00am as well as for each subsequent period is defined mostly together with the appliances behavior, which will be discussed in Chapter 10. However, the network file contains the definition of the initial SOC for each storage unit, which is information not included in the grid behavior file.

Therefore, the initial SOC for each storage unit is presented below in Table 9.1.

Table 9.1 Initial SOC for storages

Storage index	**Initial SOC (%)**
0	50
1	50
2	50
3	50
4	50
5	50
6	90
7	60
8	90
9	60

The SOC for stationary batteries (indexes 0 to 5) has been defined arbitrarily as it is not relevant for the simulation. The same happens with EVs (6 to 9), however, indexes 6 and 8 are supposed to be vehicles associated with a charging point at home, thus their SOC will be almost 100% early in the morning, while indexes 7 and 9 are vehicles associated with a charging point at a working site, thus their SOC should be a little lower at that time.

10 Definition of the appliance's behavior

As mentioned in Chapter 4, the FO generates its flexibility proposals based on an estimation or forecast of the future power levels of the network, currently called the baseline. The actual grid behavior is defined to differ from the baseline in order to simulate uncertainty. This means that demand power levels, resources availability for generators and connection behavior of disconnectable units may not be those expected by the FO. Therefore, the behavior data for non-flexible units is defined below.

Flexible units as defined in Chapter 3 are assumed to be controlled all the time by either the FO or the proposed algorithm, so no behavior data will be set for them.

The detailed behavior data can be found in Annex I, while below it is shown graphically for a better understanding.

Loads:

Inflexible and disconnectable loads will be modeled through the definition of their power level along the planning horizon, obtaining this way the power curves shown in Figure 10.1, Figure 10.2 and Figure 10.3, for high industrial loads, low industrial loads and residential loads respectively.

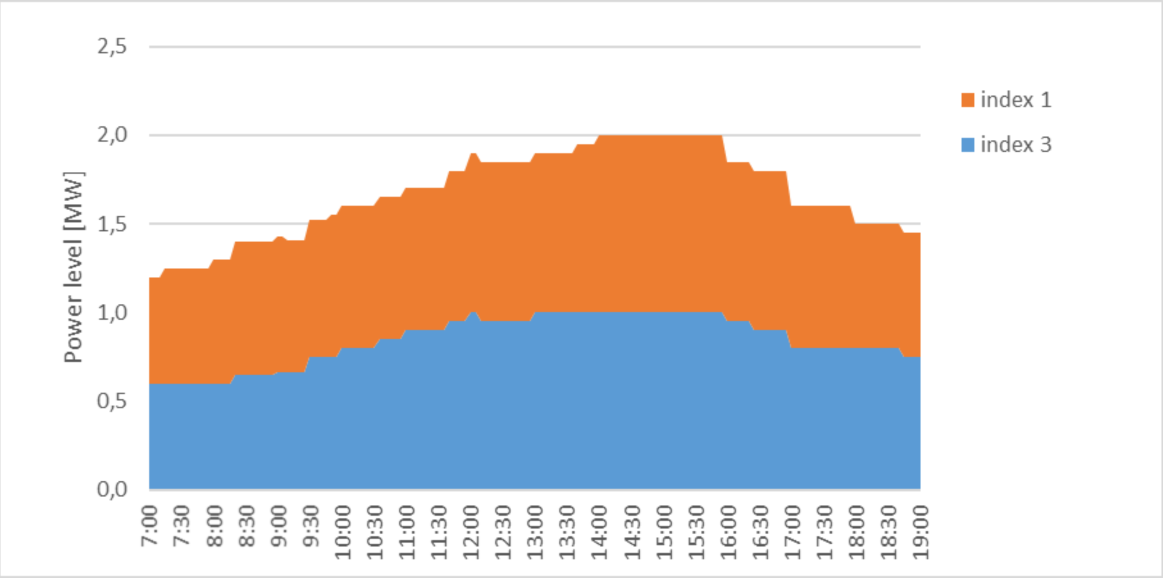

Figure 10.1 Power curve for high industrial loads

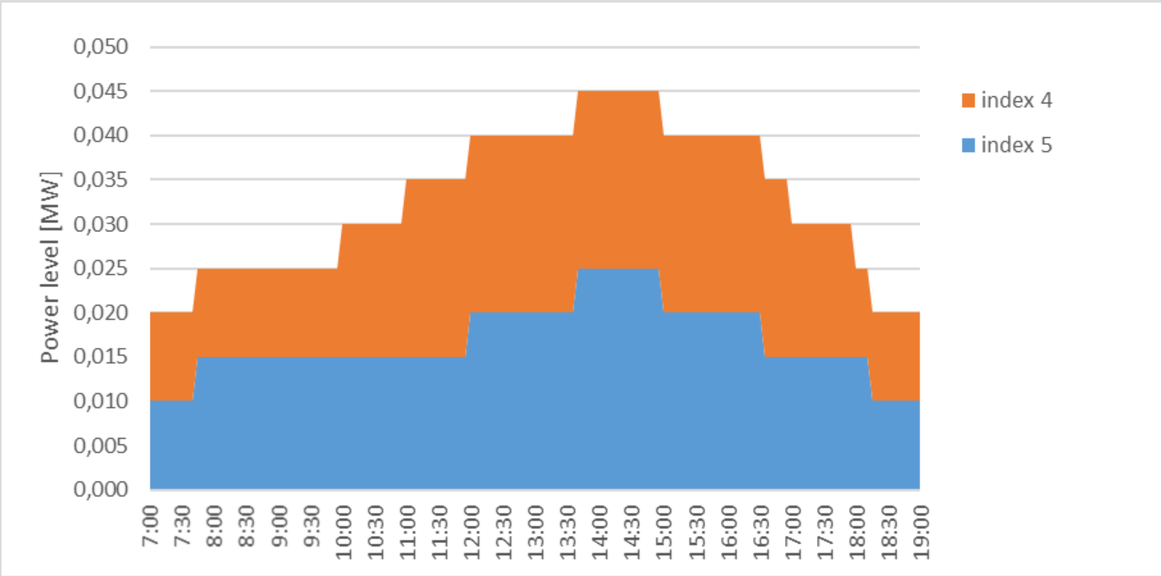

Figure 10.2 Power curve for low industrial loads

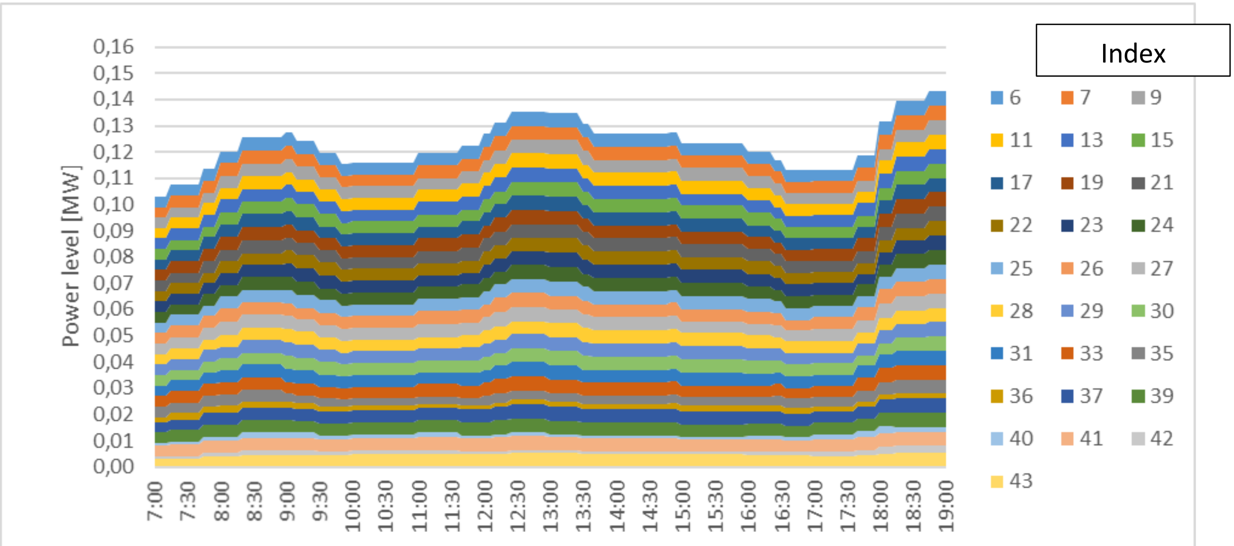

Figure 10.3 Power curve for residential loads

In this base scenario, industrial loads govern the overall loads consumption, because their aggregated power levels are much higher than residential's. A consumption peak will be present from 14:00 hrs. to 15:30 hrs. approximately. Residential loads have their own peak during the last period.

The detailed behavior data can be found in Annex I (a): Inflexible Loads demand along the planning horizon.

Storages:

Index 2 stationary battery is the only one defined inflexible. Its behavior cannot be controlled and for that reason it must be modeled. Figure 10.4 shows its behavior. Positive values mean charging while negative means discharging. The curve was built using the assumption that the battery uses the power produced from the associated generator to charge. In this case, during sun hours. Then the energy of the battery is used during the night and early in the morning.

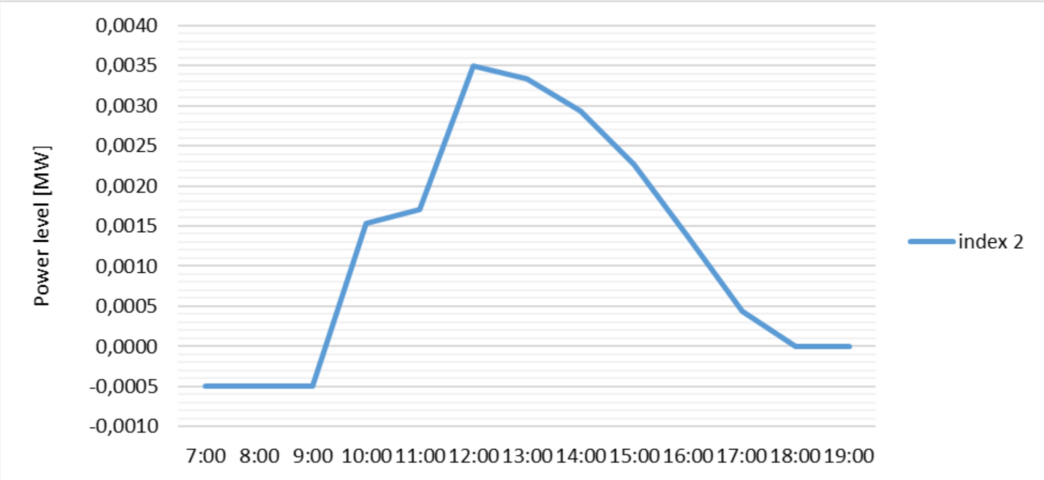

Figure 10.4 Inflexible battery power curve

In the case of EVs, their behavior will be modeled through a connection – disconnection schema. Each time an EV connects to a charging point, its current SOC will be given. Figure 10.5 shows their connection status at each time and whenever a car connects to a charging point, its current SOC is given as the "on" status. Indexes 6 and 8 are supposed to be vehicles associated with a charging point at home, thus they are disconnected during working hours. On the other side, indexes 7 and 9 are vehicles associated with a charging point at a working site, so the opposite happens.

EV index	7:00	8:00	8:40	9:00	9:20	10:00	11:00	12:00	12:30	13:00	14:00	14:30	15:00	16:00	17:00	17:10	18:00
6	on	on	off	off	off	off	off	off	off	off	off	off	off	off	off	60	on
7	off	off	off	off	60	on	on	on	on	on	on	on	on	on	on	on	off
8	on	on	on	off	off	off	off	off	off	off	off	off	off	off	65	on	on
9	off	off	off	60	on	on	on	on	off	80	on	on	on	on	on	on	off

Figure 10.5 Connection status of EVs

The detailed behavior data can be found in Annex I (b): Storages behavior along the planning horizon.

<u>Generators:</u>

Generators are limited in their power output by the availability of resources. Thus, their behavior is modeled as maximum power output at a given time to reflect resource scarcity (wind, solar radiation, etc.).

Limitations to residential generators will be the same for every unit, as all of them are defined to be the same size. Figure 10.6 shows the power limitations of residential generators.

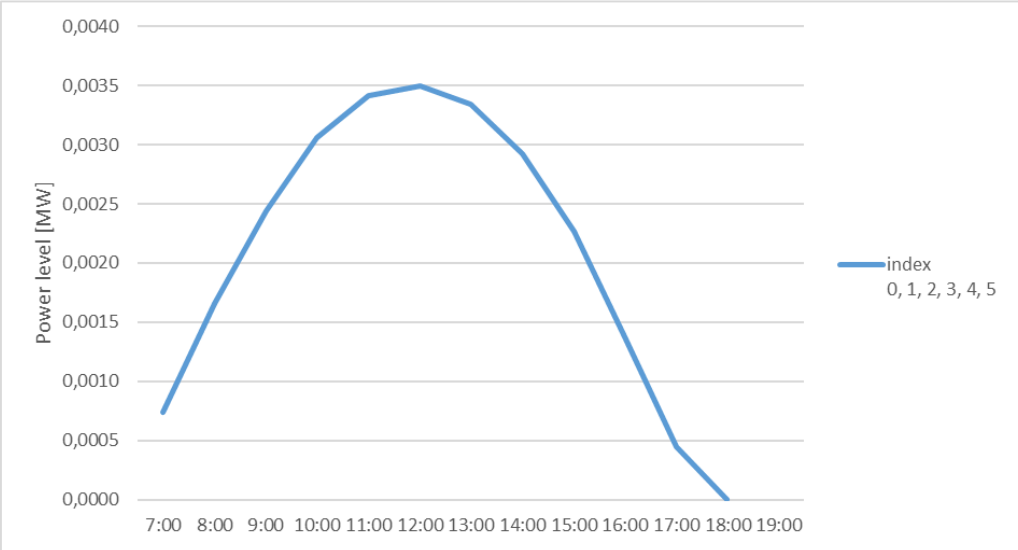

Figure 10.6 Power limitations of residential generators

For inflexible and disconnectable generators, their production is modeled to be the maximum possible from the available resources, as shown in Figure 10.7.

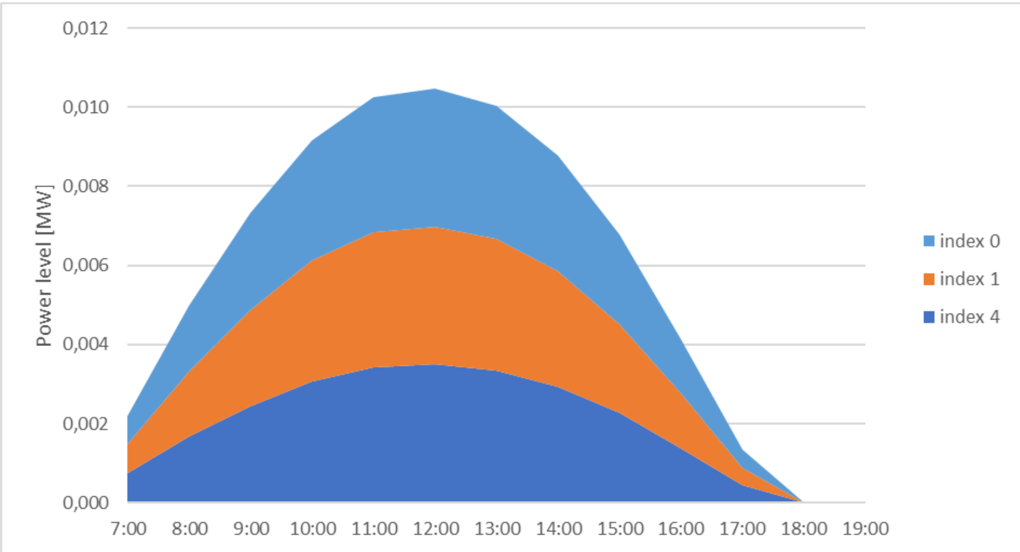

Figure 10.7 Power production of inflexible and disconnectable residential generators

Generators associated to industrial clients are of different sizes, so each one has different limitations as shown in Figure 10.8.

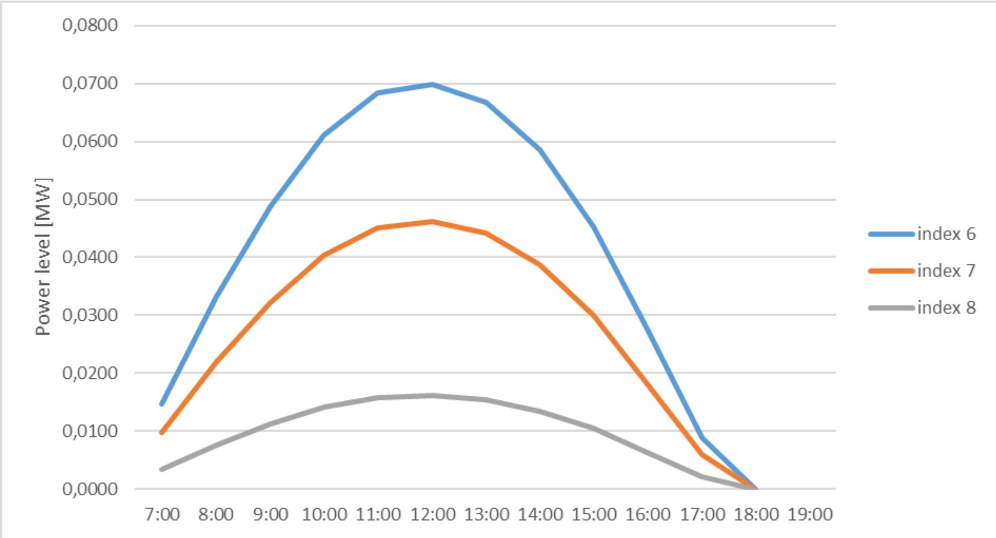

Figure 10.8 Power limitations of industrial generators

Only index 7 is not a flexible source, then its behavior will be the shown in Figure 10.9, which is the same as the limitations presented in Figure 10.8 for that index.

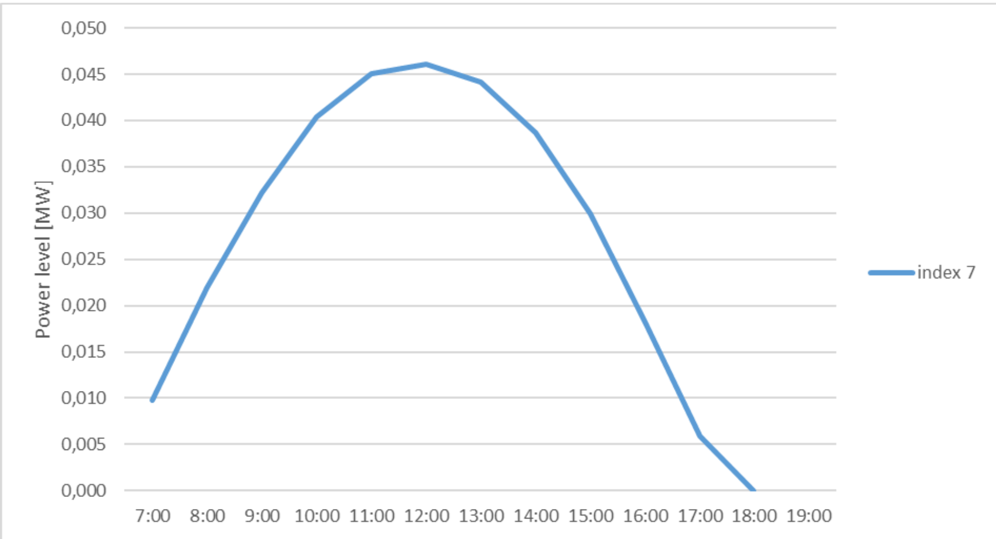

Figure 10.9 Power production of inflexible industrial generator

The detailed behavior data can be found in Annex I (c): Generators limited power output along the planning horizon.

11 Definition of the flexibility proposal

The FO proposal corresponds to the set of electricity volumes that are assigned to each source of flexibility and for each period.

These volumes of electricity will be measured in MWh to facilitate the usage of PandaPower as it works with these units. All instructions are translated into active and reactive power levels, depending on both the individual power factor of each element and the duration of the period (1 hour for the base scenario).

The FO proposal information is given by the FO to the proposed algorithm as input data, thus it represents the optimal solution of the FO algorithm according to the theoretical baseline agreed with the DSO. Also, for each period of time, it is assumed that the instructions are already updated with the new data obtained from the last period events.

All values have been defined in convenient way in order to obtain relevant and interesting results. Also, the instructions respect the restrictions of the FO algorithm, therefore they are in the range from the minimum to the maximum power level of each unit, and for storages, the instructions cannot violate the maximum and minimum SOC restrictions. In the same way, the instructions are compatible with the type of flexible source, for instance, if a load is disconnectable (not reducible), the instruction will be an on/off status and not an energy volume.

More details of the instructions can be found in Annex II, while below they are shown graphically for a better understanding.

Loads:

Loads instructions represent the amount of electricity they should consume during each period of 1 hour defined by the time resolution. Reducible and shiftable volume loads will have the energy instructions (MWh) shown in Figure 11.1 for industrial clients and in Figure 11.2 for residential clients. In both cases, the intention of the FO instruction is to reduce consumption during peak hours according to demand behavior described in Chapter 10.

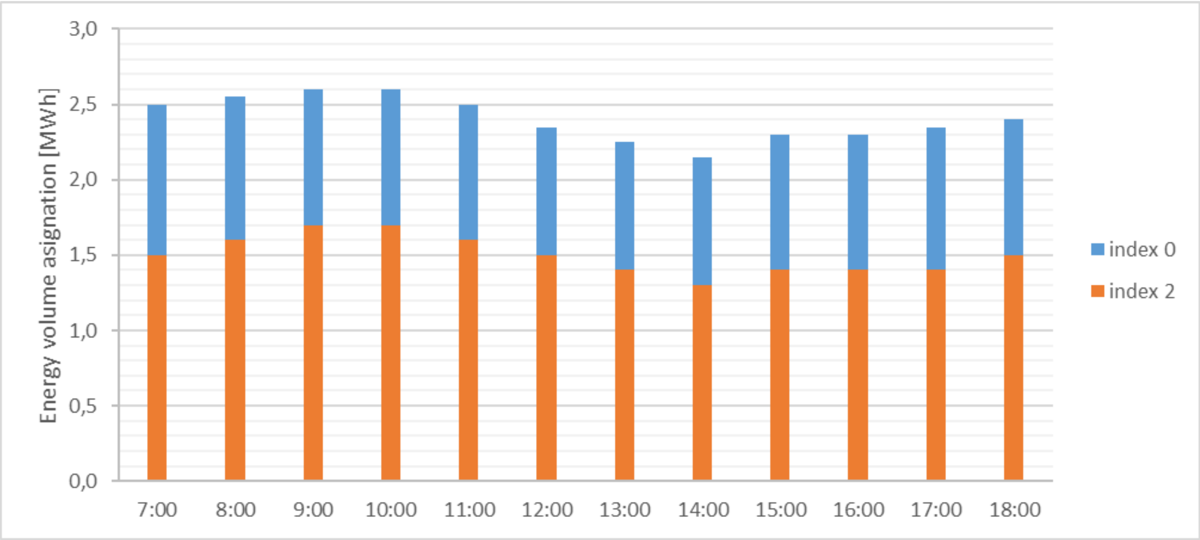

Figure 11.1 FO instructions for industrial loads

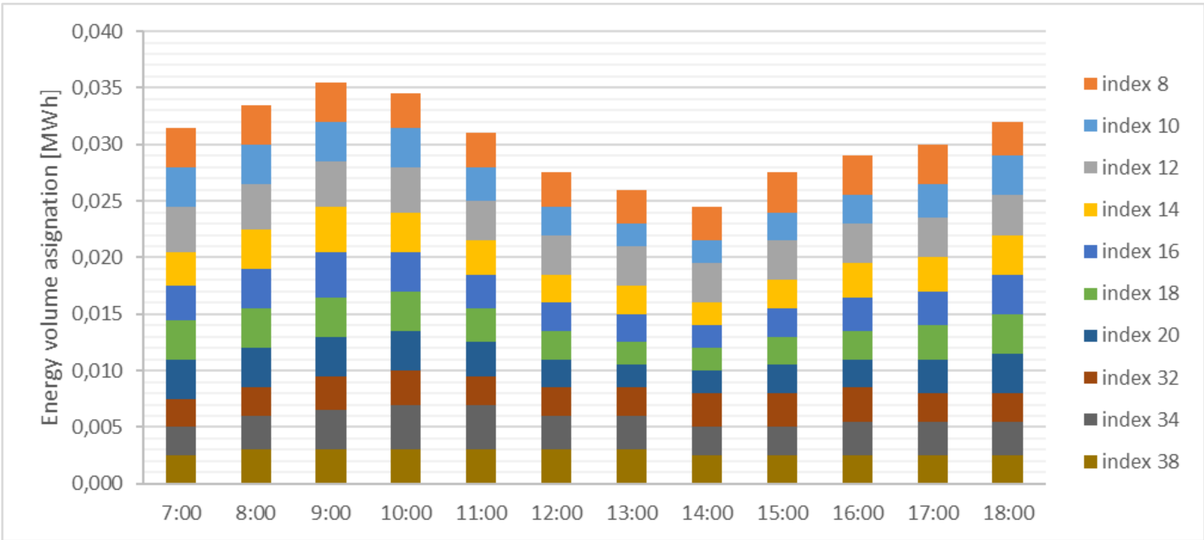

Figure 11.2 FO instructions for residential loads

Disconnectable loads will have the on/off status instructions shown in Figure 11.3. Their status has been defined to be off mainly during peak demand periods.

Load index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
6	on	on	on	on	on	off	off	off	on	on	on	on
25	on	on	on	on	on	on	on	on	on	on	on	off
29	on	on	on	on	off	off	on	on	on	on	on	on
36	on	on	on	on	off	off	off	on	on	on	on	on
40	on	on	on	on	on	off	off	off	on	on	on	on
42	on	on	on	on	on	off	off	off	on	on	on	on

Figure 11.3 FO instructions for disconnectable loads

The detailed instructions data can be found in Annex II (a): FO instructions for flexible loads along the planning horizon.

Storages:

For storages, the instructions represent the amount of electricity (MWh) they should consume during charging (positive value) or deliver by discharging (negative value). Flexible stationary batteries will be instructed to charge or discharge according to Figure 11.4 for industrial clients and to Figure 11.5 for residential clients. In both cases the instructions are mainly to charge using the maximum possible power from generators, sharing sometimes this power with EVs.

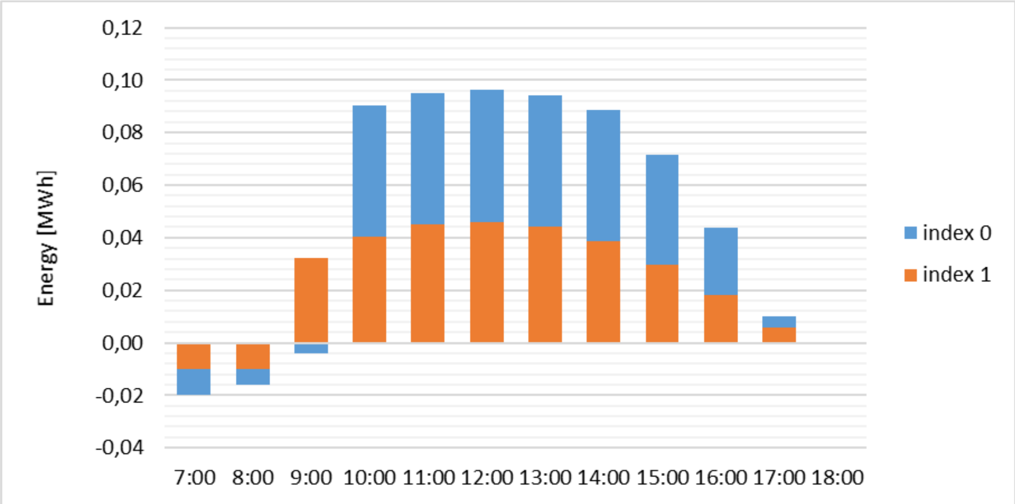

Figure 11.4 FO instructions for stationary batteries in industrial clients

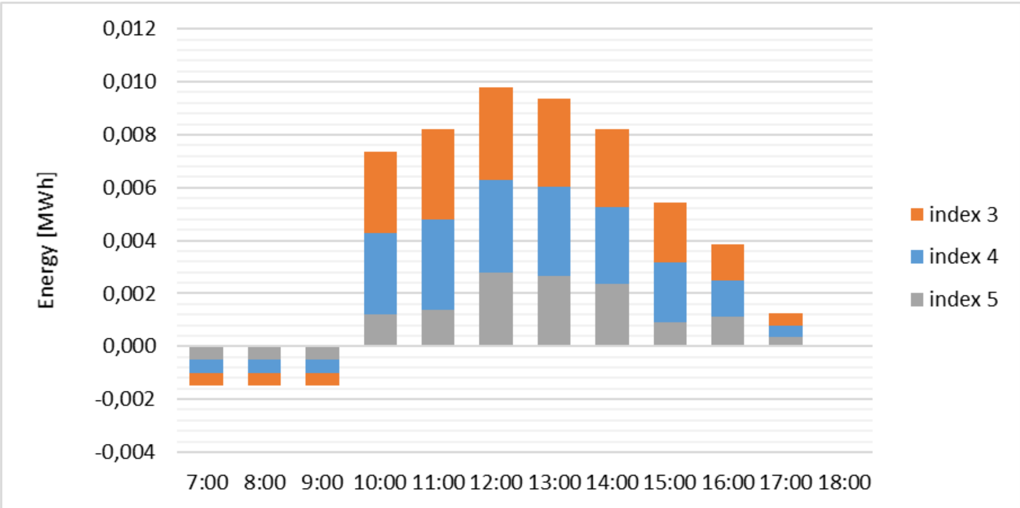

Figure 11.5 FO instructions for stationary batteries in residential clients

Reducible and V2X EVs will be instructed according to Figure 11.6. In both cases, instructions are to charge during the morning and to be off or discharging during peak hours if the vehicle is connected.

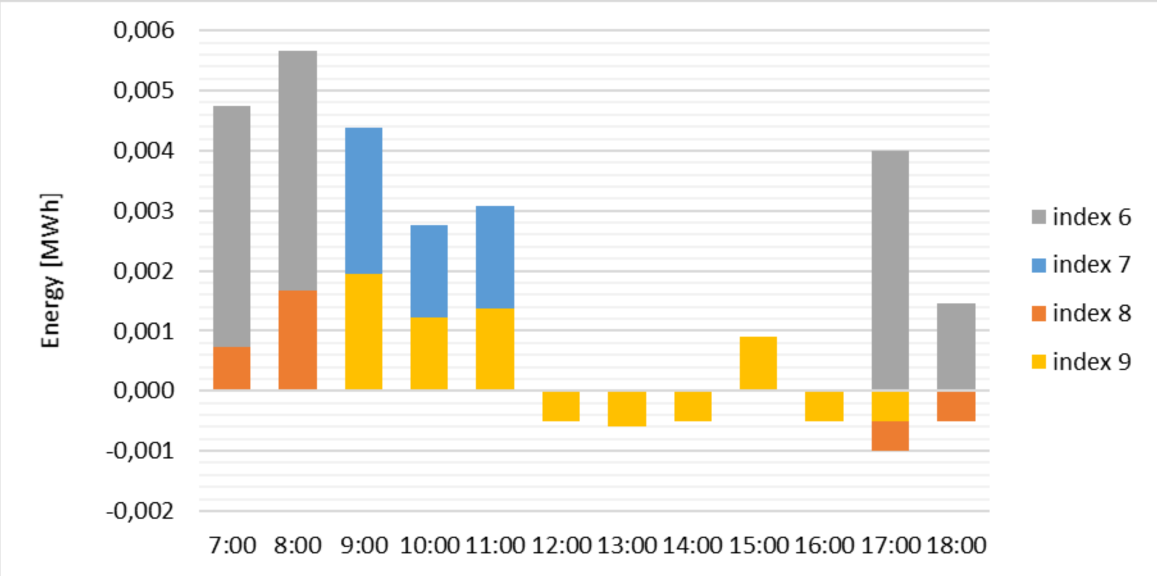

Figure 11.6 FO instructions for EVs

The detailed instructions data can be found in Annex II (b): FO instructions for flexible storages along the planning horizon.

<u>Generators:</u>

Finally, for generators the instructions are the volume of electricity (MWh) that should be injected to the grid. The instruction may be limited by the resource availability (wind, solar radiation, etc.). In this case, the instructions follow the projected available power from sun radiation as can be seen in Figure 11.7 for industrial clients and Figure 11.8 for residential clients.

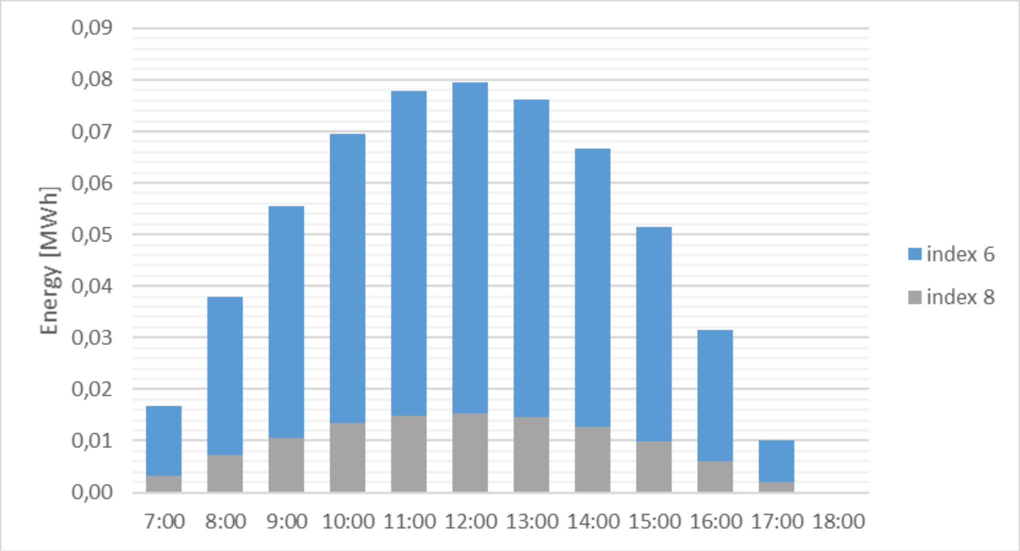

Figure 11.7 FO instructions for generators in industrial clients

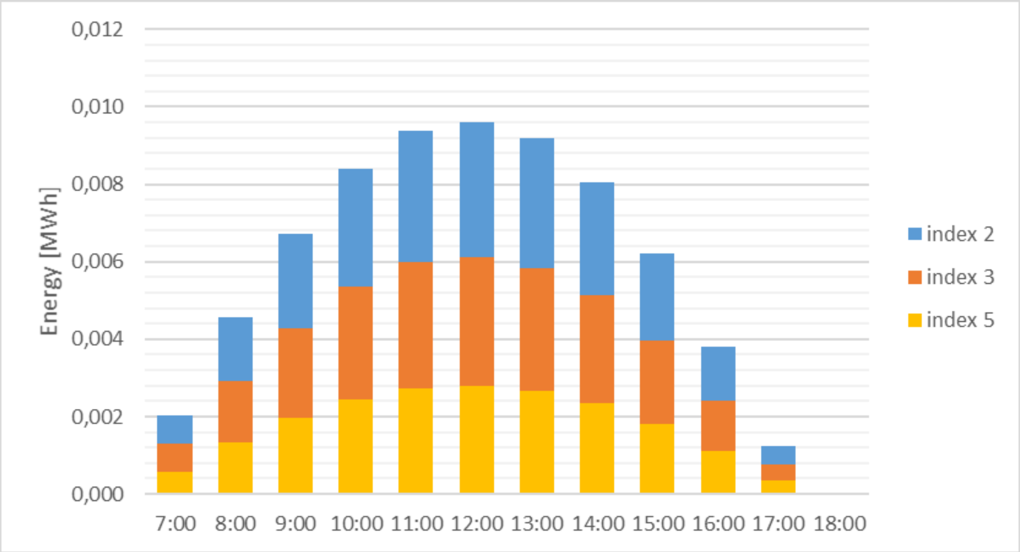

Figure 11.8 FO instructions for generators in residential clients

The detailed instructions data can be found in Annex II (c): FO instructions for generators along the planning horizon.

12 Results analysis

To illustrate the contribution of the proposed algorithm, first the simulation is run only applying the behavior data and the FO instructions, leaving aside the proposed algorithm aid. To be able to compare both cases (with and without the proposed algorithm), the data from grid behavior and FO instructions will not be modified through simulations. However, in a real case, FO instructions should differ as they are updated before each period using the data from the recent status of the network. Yet, events within a period may still be producing unavoidable congestions. Figure 12.1 shows the loading percent throughout the planning horizon of the 4 more congested lines. Figure 12.2 shows the same for the 5 transformers that are part of the network. All time events within each period are included.

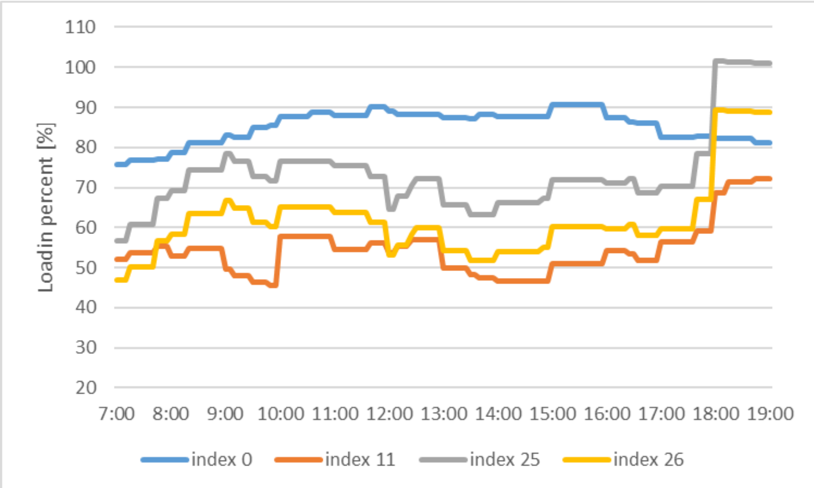

Figure 12.1 Lines loading percent without proposed algorithm aid

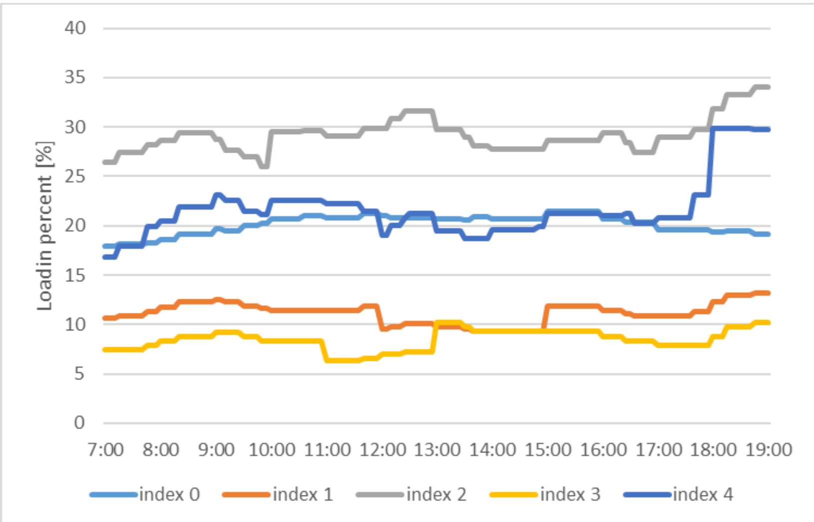

Figure 12.2 Transformers loading percent without proposed algorithm aid

Line 0 appears over the established limit of 70% throughout all the planning horizon. Line 25 is near critical state almost always, reaching congestions over 100% to the end of the planning horizon while lines 11 and 26 only presents overloading in the last period. This is expected, since line 0 in feeding all the system from the external grid and lines 11, 25 and 26 are the three low voltage lines with the most loads connected.

On the case of the transformers, even without the proposed algorithm aid, the loading percent is always in acceptable levels as their capacity is much higher than the line types chosen.

Now if we apply the proposed algorithm to the simulation, the results obtained are shown in Figure 12.3 for lines and Figure 12.4 for the transformers.

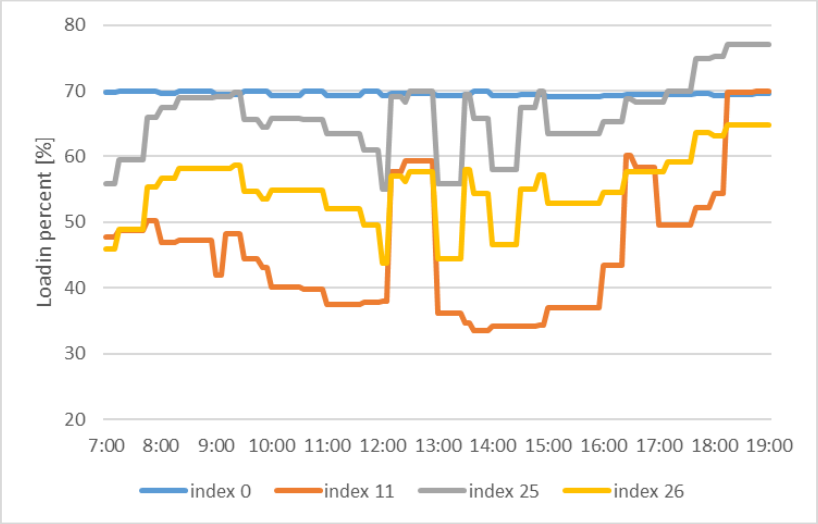

Figure 12.3 Lines loading percent with proposed algorithm aid

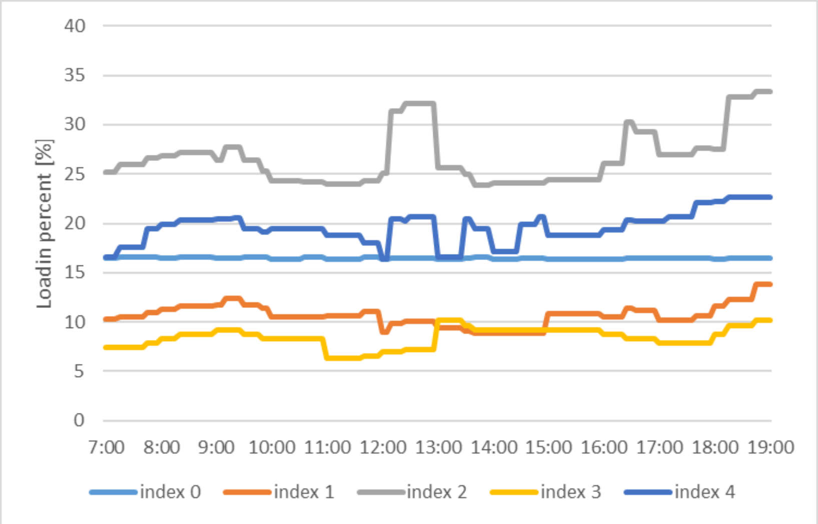

Figure 12.4 Transformers loading percent with proposed algorithm aid

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As can be seen, almost all the congestions in the lines could be controlled and avoided with the help of the proposed algorithm and the flexible sources. In fact, most of the loading percentages have been reduced in all time events, both for lines and transformers. Only line 25 remains with congestion during the last period. It could not be eliminated because the flexible sources fed through that line run out of flexibility. However, it is remarkable that its loading percent was reduced significantly from 101% - 102% to 75% - 77%.

The importance of this result is that through controlling flexible sources for decongestion of a network, a lot of investments in capacity expansion can be avoided. For instance, in the base case studied, only line 25 could need an upgrade. The low voltage line type used for this simulation, as described in Chapter 8, is the 15-AL1/3-ST1A with a section of 15,9 mm2. If we upgrade line 25 to a 24 mm2 section type, 24-AL1/4-ST1A, the congestion of that line can be further reduced to the range 59% - 62% in the last period with the proposed algorithm aid as shown in Figure 12.5.

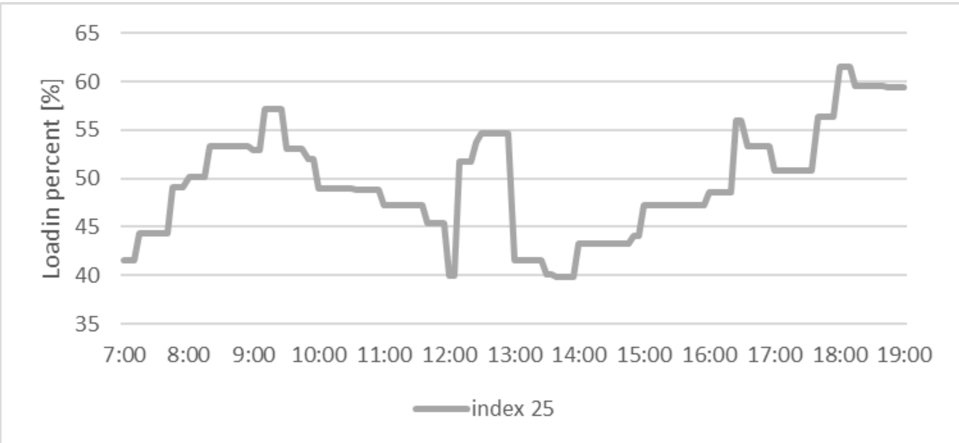

Figure 12.5 Line 25 loading percent with proposed algorithm aid and upgraded line type

Now let us take a look at the used flexibility and the differences between the temporary instructions and those of the FO. From Figure 12.6 to Figure 12.13 we can see the partial and the accumulated energy differences between the FO and the temporary instructions applied by the proposed algorithm. The blue bars show the expected total energy consumed / delivered by the group of flexible units according to the FO instructions by the time given, while orange bars show the actual energy consumed / delivered. Each figure shows the percentage that the temporary instructions represents over the FO instructions.

Figure 12.6 (a) Reducible and shiftable volume loads partial energy difference between FO and Temporary instructions

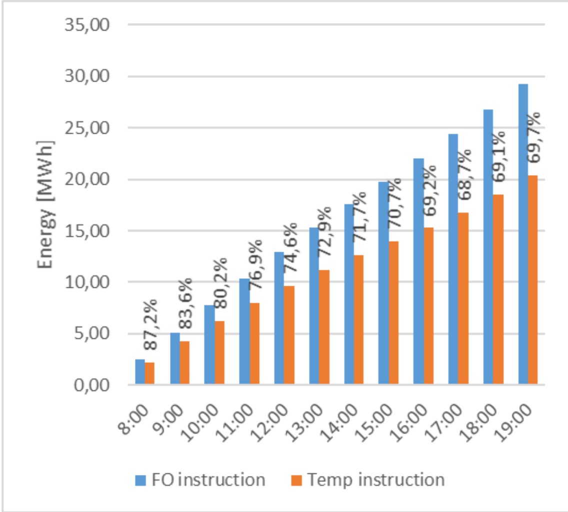

Figure 12.7 Reducible and shiftable volume loads accumulated energy difference between FO and Temporary instructions

Figure 12.8 Charging flexible stationary batteries and reducible-V2X EVs partial energy difference between FO and Temporary instructions

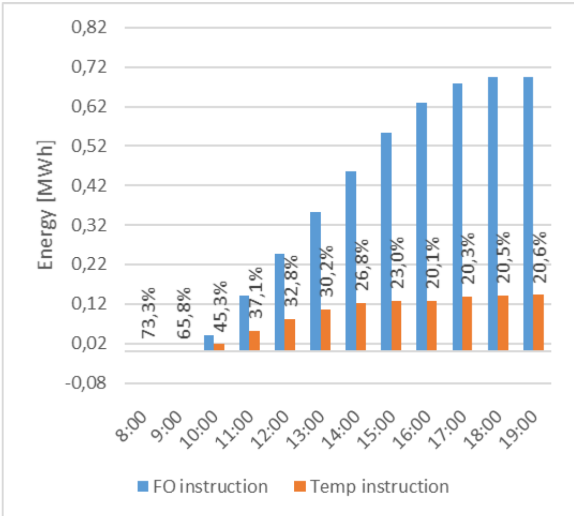

Figure 12.9 Charging flexible stationary batteries and reducible-V2X EVs accumulated energy difference between FO and Temporary instructions

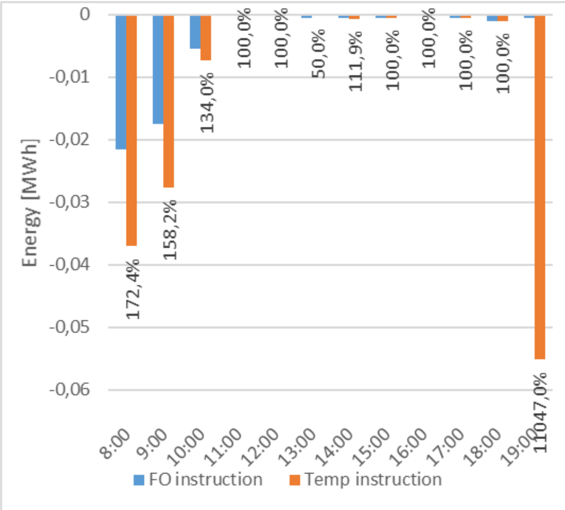

Figure 12.10 Discharging flexible stationary batteries and reducible-V2X EVs partial energy difference between FO and Temporary instructions

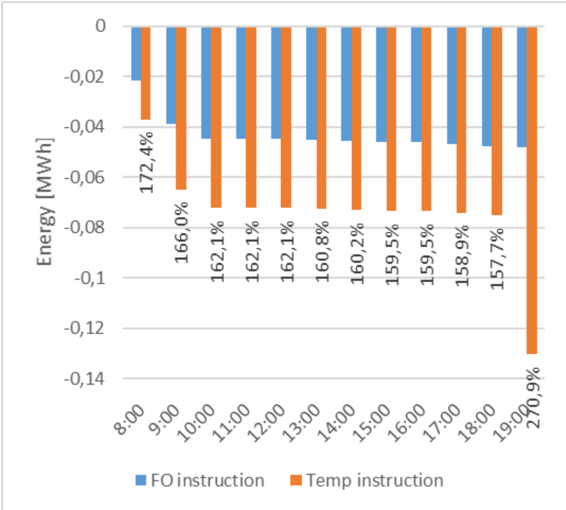

Figure 12.11 Discharging flexible stationary batteries and reducible-V2X EVs accumulated energy difference between FO and Temporary instructions

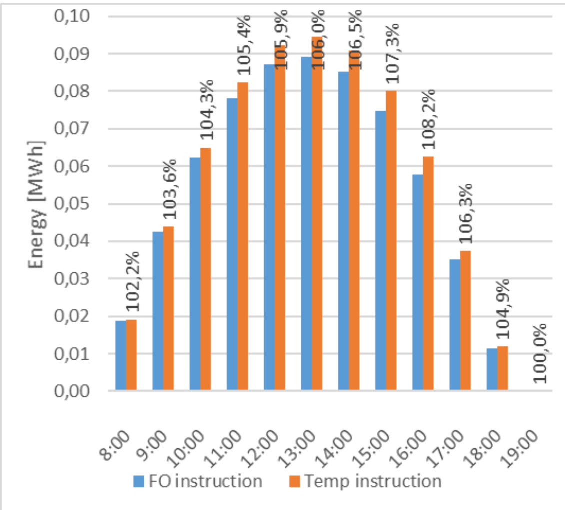

Figure 12.12 Reducible generators partial energy difference between FO and Temporary instructions

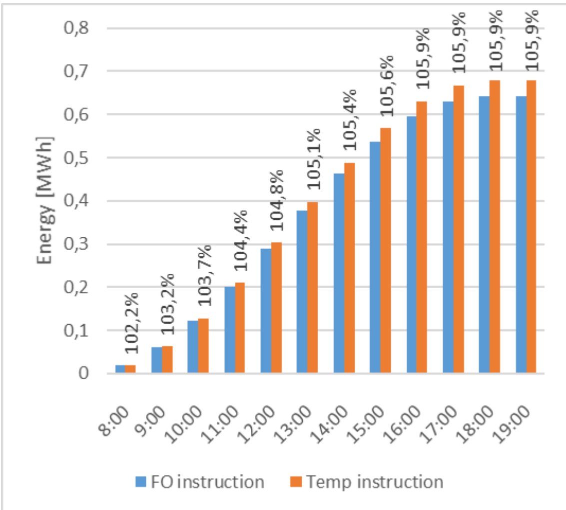

Figure 12.13 Reducible generators accumulated energy difference between FO and Temporary instructions

We can see that most of the flexibility in MWh comes from the control of flexible loads. This is mainly due to the volume of flexibility coming from loads (an average of 0,74 MWh per hour) compared to that coming from storages and generators (0,026 MWh and 0,0036 MWh per hour respectively). Note that industrial loads alone have more flexibility available that storages and generators together in this scenario. This can be confirmed just by looking at their maximum and minimum power as defined in Chapter 8.

In terms of individual percentage, however, storages contribute more than the other flexible sources, since their minimum defined power is 0 MW. If we look at the charging storages charts, the accumulated energy consumed at the end of the planning horizon equals 21% of the energy instructed by the FO to be charged, while in loads it equals 70%. If we move up the minimum power parameter for storages, their consumed energy will increase accordingly. This is important to consider for ensuring a SOC percent at the end of a period or the planning horizon.

In the case of discharging, from 11:00hrs to 18:00hrs, almost the same energy assigned by the FO is discharged, but this is because only V2X vehicles are discharging during some periods in that time slot. Note that V2X vehicles have defined a minimum SOC of 70%, thus their flexibility for extra discharging is extremely limited. Outside that time slot, stationary batteries are providing most of the flexibility for discharging, since they are programmed to charge during sun hours only and discharge out of that time range. This explains the huge difference of the delivered energy in the last hour. From 18:00 hrs., batteries cease to charge and are instructed by the FO to be at 0 MW. Also, the proposed algorithm considers an idle battery as available for discharging. Therefore, since the demand reaches a new peak during this period, mostly due to residential loads demand, recently charged batteries start to discharge to contribute with the required flexibility.

Generators in terms of decongestion have little flexibility to offer, since they are maximizing their production all the time. Of course, this would not be the case if the installed capacity were big enough compared to the demand. In the scenario studied, the installed capacity of the flexible units is around 138 kWp, while the loads demand alone is over 2 MW in peak hours. However, some flexibility is provided. This flexibility comes from the assumption that solar radiation happens to be slightly higher than the predicted by the FO. Therefore, the PV panels may produce more energy than that instructed by the FO.

Now, it is interesting to see which is the contribution of the downwards regulation functionality of the proposed algorithm. Let us first review the aggregated differences when the functionality is off. From Figure 12.14 to Figure 12.17 it is shown the accumulated energy difference between the FO and the temporary instructions as before, for loads, charging storages, discharging storages and generators, but this time adding a third column for the temporary instruction without the downwards functionality. Figures show in blue bars the FO instructions, in orange bars the temporary instructions with the downwards functionality and in grey bars those without downwards functionality. Percentages indicate the variation of the instructions without functionality from those with the functionality, in terms of volume of energy over that instructed by the FO. This means for example that if at the end of the planning horizon, loads consumed energy is 69,7% of the FO instructed energy with the downwards functionality, without it the consumed energy would be 0,4% less, that is to say 69,3%.

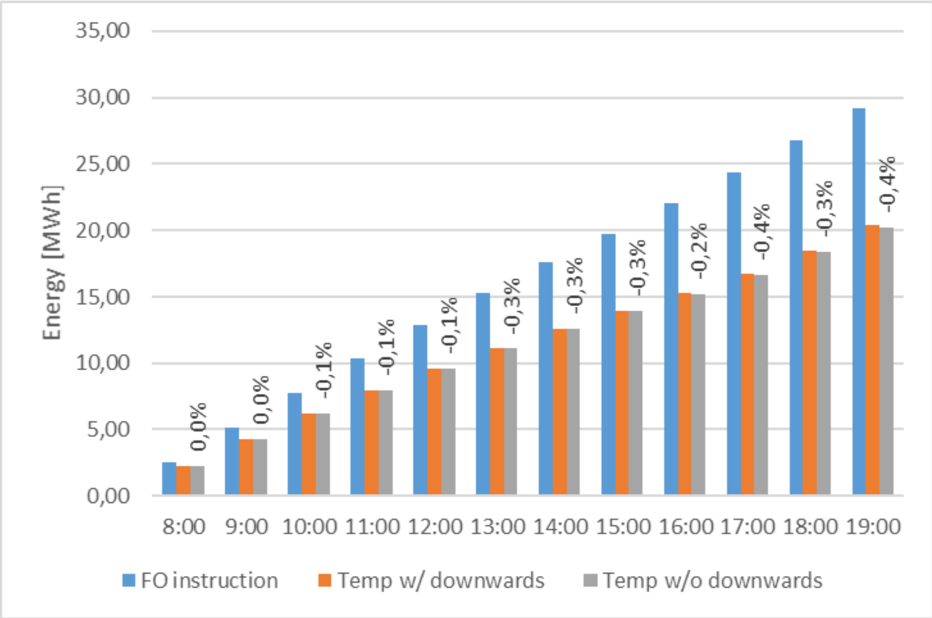

Figure 12.14 Reducible and shiftable volume loads accumulated energy difference between FO and Temporary instructions w/ and w/o downwards functionality

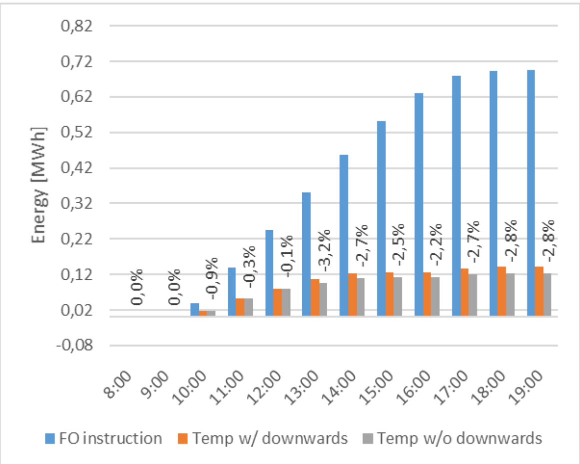

Figure 12.15 Charging flexible stationary batteries and reducible-V2X EVs accumulated energy difference between FO and Temporary instructions w/ and w/o downwards functionality

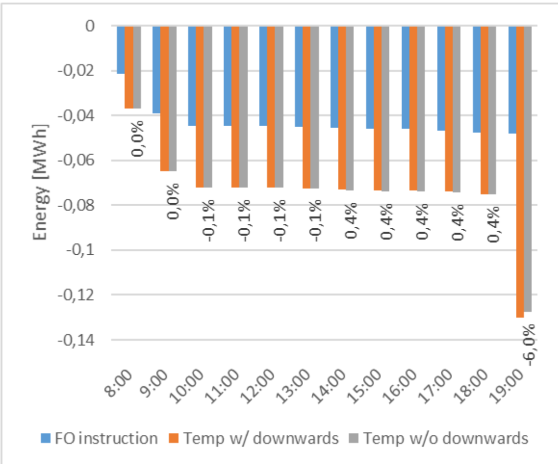

Figure 12.16 Discharging flexible stationary batteries and reducible-V2X EVs accumulated energy difference between FO and Temporary instructions w/ and w/o downwards functionality

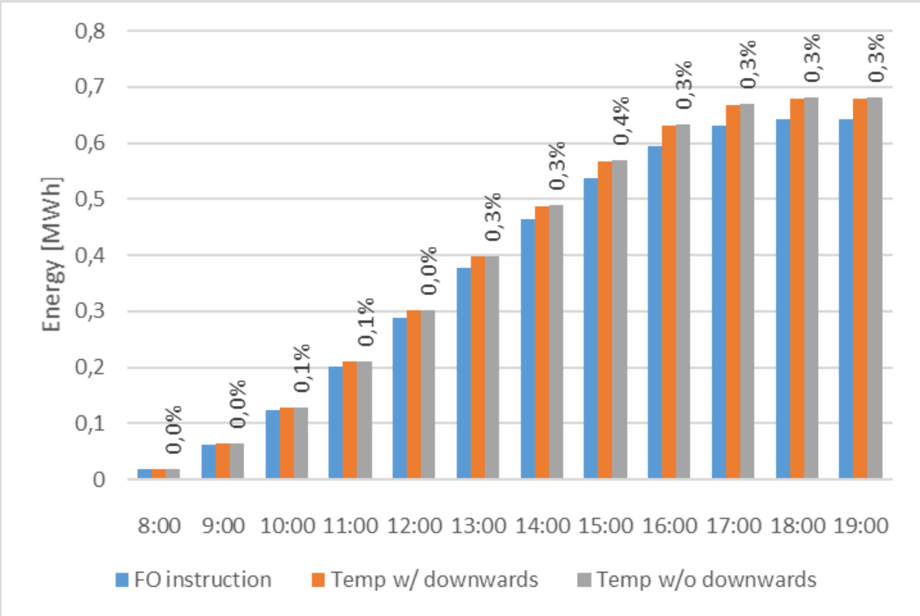

Figure 12.17 Reducible generators accumulated energy difference between FO and Temporary instructions w/ and w/o downwards functionality

First thing to notice is that in an aggregated form, there is not much difference when adding the downwards funtionality. Assigned energy for consumption / delivery for loads go from 69,3% to 69,7% of that instructed by the FO. Charging storages go from 17,8% to 20,6%, discharging storages go from 264,9% to 270,9% and generators go from 106,2% to 105,9%.

From the above, the second thing to notice is that the intuition that downwards regulation would reduce the energy differences with that instructed by the FO is not always correct. That's the case of discharging storages where the energy discharged increases, moving away from the FO instruction. However, this is one of the most important benefits of the downward regulation, and can be exemplified looking at one example:

Storage 5 is instructed by the FO to charge at 0,0028 MW at 12:00 hrs., but since there is a congestion detected in line 0, it is set to a temporary power of 0,0004 MWh. Without the downwards functionality, this unit would remain charging at 0,0004 MWh until the next FO intructions ocurrs, one hour later, or until another need for flexibility happens during the period, in which only a further reduction would be possible. The downwards functionality allows for a recovery at 12:10, where there are detected some changes in the network meters, but no congestion is found. At that time, the new temporary instruction to storage 5 is to charge at 0,0033 MW, recovering from the previous dramatic decrease. Figure 12.18 shows the power curves of each case. As can be seen, the charge obtained thanks to the downwards regulation from 12:00 hrs. to 15:00 hrs. permits a future discharge during the last period, this way avoiding a congestion on line 26 with a loading percent of 84% - 85% which otherwise would have ocurred. Also, the unavoidable congestion of line 25 mentioned earlier would have been much bigger without the downwards functionality, reaching a loading percent of 97%.

This results in a difference between the energy discharged and the FO instruction greater than in the case where there is no downwards regulation, but the congestion of the lines 25 and 26 in the last period was reduced significantly.

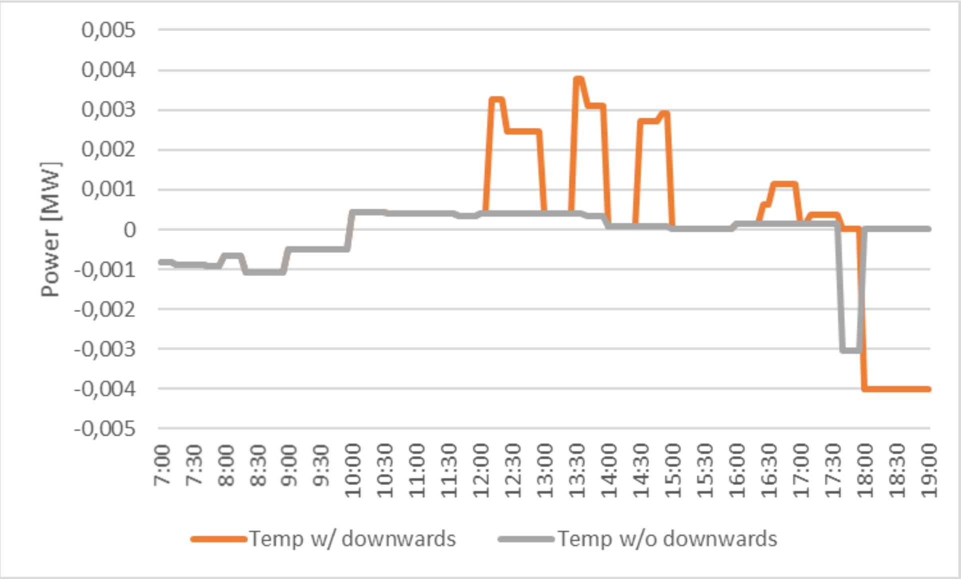

Figure 12.18 Power level of storage 5 in both cases with and without the downwards functionality

Apart for the congestion avoidance, some information can be extracted from the simulation. For instance, if it is desirable to promote the use of some kind of flexible source and in which sectors of the network they would be useful. For the base scenario it can be concluded that the installation of more generators and storages in buses 31 to 38 would have been a solution for the unavoidable congestion in line 25 during the last period.

We will see now how the algorithm works during a characteristic period of the base scenario. The results obtained from running the algorithm will be analyzed first by presenting the status of the network before each relevant step, and then by explaining the algorithm execution and results obtained when temporary instructions are applied.

Finally, a quick review of the execution time of the algorithm will be presented.

The detailed results for all periods can be found in Annex III.

12.1 Results for a characteristic period

The period chosen is from 9:00 hrs. to 10:00 hrs., because during this slot of time both upwards and downwards regulations are required and special situations are present. At the beginning of this period, the FO instructions are applied to all flexible sources. Then, running the power flow gives us the network status that is shown in Figure 12.19.

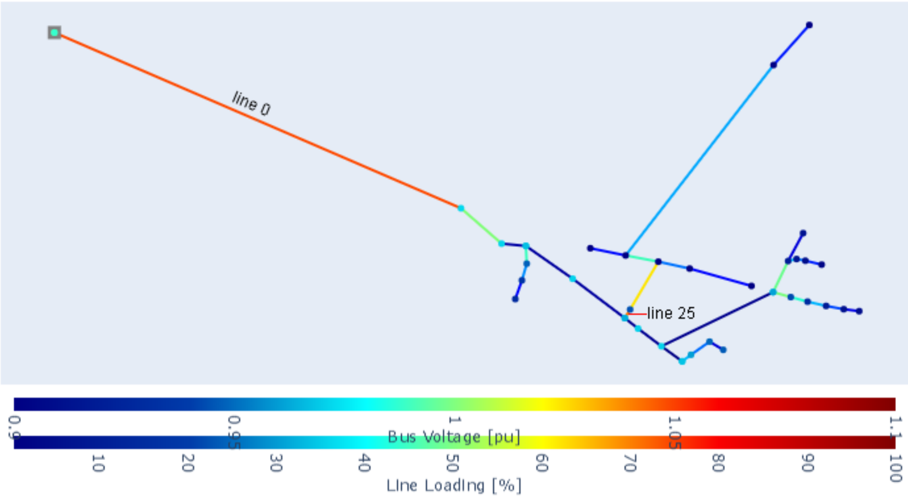

Figure 12.19 Network status at 9:00 hrs. before applying flexibility

Line 0 appears with a loading percent of 83,1%, meaning it is congested by 13,1% over the limitation of 70% established in Chapter 8. Line 25 is also congested with a loading percent of 78,3%. The exceeded powers are 0,7631 MVA and 0,0058 MVA respectively. Since the maximum exceeded power is that of line 0, the algorithm starts looking for critical flexible sources with available flexibility to apply temporary instructions for decongestion of this line first. Table 12.1 shows the critical flexible sources found for line 0 with their respective available flexibility and the flexibility used for decongestion. In this case, as the available flexibility is higher that the exceeded power, only 51% of it is used, matching the exceeded power.

Table 12.1 Upwards flexibility at 9:00 hrs. from critical flexible sources associated with line 0

Event time: 9:00hrs Congested Element: Line 0				
Critical Flexible source	**Indexes**	**Total Flexibility [MVA]**	**Used Flexibility [MVA]**	**Used Flexibility [%]**
Loads	0 - 2 - 8 - 10 - 12 - 14 - 16 - 18 - 20 - 32 - 34 - 38	1,4591	0,7406	51%
Storages	0 - 1 - 9	0,0396	0,0201	51%
Generators	3 - 5 - 6 - 8	0,0051	0,0026	51%
Total		1,5033	0,7630	51%

With these instructions, congestion is eliminated for line 0 as shown in Figure 12.20, where flexible sources are indicated with an “L” for loads, “S” for storages and “G” for generators. The new loading percent obtained for this line is 69,4%. Line 25 loading percent is also reduced to 71,2% because some flexible units affecting line 0 are also affecting line 25, however, it is still congested with an exceeded power of 0,8284 kVA.

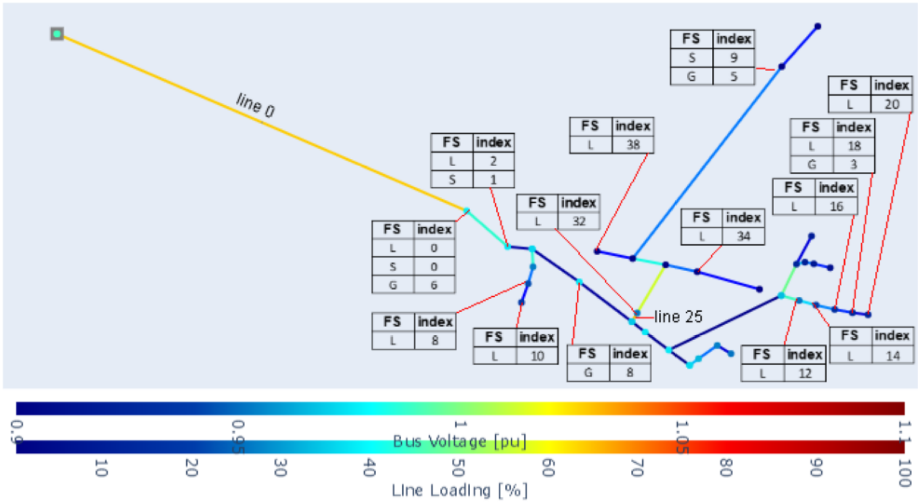

Figure 12.20 Network status at 9:00 hrs. after applying flexibility for line 0

The algorithm then starts to look for flexible sources for the decongestion of line 25. Once identified, available flexibility is computed, and the temporary instructions are applied according to Table 12.2. This time, 35% of the available flexibility is used for the reduction of line 25 loading percent to 69,1%.

Table 12.2 Upwards flexibility at 9:00 hrs. from critical flexible sources associated with line 25

Event time: 9:00hrs Congested Element: Line 25				
Critical Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	32 - 34 - 38	1,0377	0,3676	35%
Storages	9	1,0678	0,3787	35%
Generators	5	0,2427	0,0861	35%
Total		2,3360	0,8284	35%

Figure 12.21 shows the network status after applying instructions for decongestion of line 25.

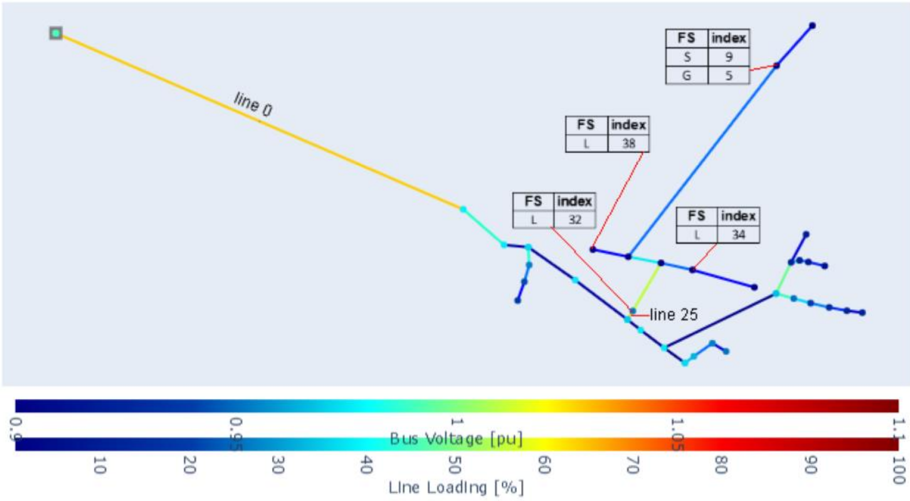

Figure 12.21 Network status at 9:00 hrs. after applying flexibility for line 25

Both congestions were eliminated, so now the algorithm begins to look for possibilities for recovery from FO instructions, but since the period is just beginning no possibilities are found. The program then waits for another event to happen.

Notice that since there were two congested lines at 9:00 hrs., the instructions applied for line 25 further reduced the loading percent of line 0. In this case is almost imperceptible because the flexibility used for line 25 is small compared to line 0 capacity, but in any case, this may lead to extra room for downwards regulation during the next time event.

Notice too that after applying the temporary instructions, loading percentages are reduced slightly below the maximum of 70%. This is because transmission losses are not considered in the calculation of temporary instructions. So, every time an upwards regulation is applied, there will be less transmission losses upstream of the regulation point, meaning an extra decongestion aid.

At 9:10 hrs. some changes in the network are detected, but no congestion is found. Therefore, the algorithm jumps directly to search for recovery opportunities.

At this time, the flexible sources used at 9:00 hrs. for decongestion have accumulated some energy difference with the FO, so, if there is room in the lines and transformers feeding them, the algorithm will apply downwards regulation. Then, for each one of these flexible sources, the algorithm looks for every line and trafo feeding them, and among these, it finds the line or trafo with the lowest available power capacity. In this case, line 25 appears to be the one with the lowest available capacity, 1,4819 kVA, and a loading percent of 67,4%. The flexible sources this line is feeding, their current flexibility for downwards regulation and the finally used flexibility are displayed in Table 12.3.

Table 12.3 Downwards flexibility at 9:10 hrs. from flexible sources associated with line 25

Event time: 9:10hrs Minimum available power: Line 25				
Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	32 - 34 - 38	1,7235	0,6576	38%
Storages	9	1,7753	0,6774	38%
Generators	5	0,4035	0,1539	38%
Total		3,8837	1,4819	38%

After applying the instructions, all lines and transformers available capacity are updated. Then, the next element with the new lowest available capacity is analyzed as before. This time it is line 11 with 0,0206 MVA of available capacity. Table 12.4 shows the summary of flexibility found and used for this line. Available flexibility is lower than the available capacity of line 11, so all of the flexibility is used.

Table 12.4 Downwards flexibility at 9:10 hrs. from flexible sources associated with line 11

Event time: 9:10hrs Minimum available power: Line 11				
Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	12 - 14 - 16 - 18 - 20	5,1293	5,1293	100%
Storages	-	0,0000	0,0000	-
Generators	3	0,0751	0,0751	100%
Total		5,2032	0,0052	5,2032

Next element with available capacity is line 3 with 0,0219 MVA. Table 12.5 shows the flexible sources and flexibility used.

Table 12.5 Downwards flexibility at 9:10 hrs. from flexible sources associated with line 3

Event time: 9:10hrs Minimum available power: Line 3				
Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	8 - 10	1,9235	1,9235	100%
Storages	-	0,0000	0,0000	-
Generators	-	0,0000	0,0000	-
Total		1,9235	0,0019	1,9235

Finally, the last element with available capacity is line 0 with 0,0240 MVA after updating the power flow. Then, downwards regulation is applied according to Table 12.6.

Table 12.6 Downwards flexibility at 9:10 hrs. from flexible sources associated with line 0

Event time: 9:10hrs Minimum available power: Line 0				
Flexible source	**Indexes**	**Total Flexibility [MVA]**	**Used Flexibility [MVA]**	**Used Flexibility [%]**
Loads	0 - 2	0,8798	0,0233	3%
Storages	0 - 1	0,0228	0,0006	3%
Generators	6 - 8	0,0027	0,0001	3%
Total		0,9051	0,0240	3%

Downwards regulation has ended, but since transmission losses are not considered in the calculations of temporary instructions, the algorithm does a last revision of congestions. This time, downwards regulation done has increased loading percent of line 25 to 71,1% with an exceeded power of 0,7583 kVA, so again this congestion must be solved. The same flexible sources to which the downwards regulations were applied are now available for decongestion. Table 12.7 shows the results. The final loading percent of line 25 is 69,2%.

Table 12.7 Upwards flexibility at 9:10 hrs. from critical flexible sources associated with line 25

Event time: 9:10hrs Congested Element: Line 25				
Critical Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	32 - 34 - 38	1,3266	0,3365	25%
Storages	9	1,3665	0,3466	25%
Generators	5	0,3106	0,0788	25%
Total		2,9895	0,7583	25%

No more congestions are found, so the algorithm waits for the next event.

At 9:20 hrs., no congestion is found, but there are possibilities for recovery at lines 0 and 25. Line 25 has the lowest available power; 0,2290 kVA.

Table *12.8* shows the applied flexibility.

Table 12.8 Downwards flexibility at 9:20 hrs. from flexible sources associated with line 25

Event time: 9:20hrs Minimum available power: Line 25				
Flexible source	**Indexes**	**Total Flexibility [kVA]**	**Used Flexibility [kVA]**	**Used Flexibility [%]**
Loads	32 - 34 - 38	1,7530	0,1016	6%
Storages	9	1,8057	0,1047	6%
Generators	5	0,4104	0,0238	6%
Total		3,9503	0,2290	6%

Then the updated available capacity of line 0 is 0,0854 kVA, so downwards regulation is applied but it is almost insignificant. The final loading percent obtained are 69,5% for line 0 and 69,7% for line 25.

At 9:30 hrs., another congestion is detected at line 0. Its current loading percent is 71,8% with an exceeded power of 0,1053 MVA. Again, upwards regulation is applied to reduce loading percent to 69,9%. See Table 12.9.

Table 12.9 Upwards flexibility at 9:30 hrs. from critical flexible sources associated with line 0

Event time: 9:30hrs Congested Element: Line 0				
Critical Flexible source	**Indexes**	**Total Flexibility [MVA]**	**Used Flexibility [MVA]**	**Used Flexibility [%]**
Loads	0 - 2 - 8 - 10 - 12 - 14 - 16 - 18 - 20 - 32 - 34 - 38	0,7489	0,1020	14%
Storages	0 - 1 - 9	0,0220	0,0030	14%
Generators	3 - 5 - 6 - 8	0,0027	0,0004	14%
Total		0,7733	0,1053	14%

After applying the instructions, no possibilities for recovery are found.

At 9:50 hrs., line 0 is again congested with 0,0276 MVA over its limit. Flexibility used is shown in Table 12.10. Loading percent is reduced from 70,5% to 70,0%.

Table 12.10 Upwards flexibility at 9:50 hrs. from critical flexible sources associated with line 0

Event time: 9:50hrs Congested Element: Line 0				
Critical Flexible source	**Indexes**	**Total Flexibility [MVA]**	**Used Flexibility [MVA]**	**Used Flexibility [%]**
Loads	0 - 2 - 8 - 10 - 12 - 14 - 16 - 18 - 20 - 32 - 34 - 38	0,6469	0,0264	4%
Storages	0 - 1 - 9	0,0252	0,0010	4%
Generators	3 - 5 - 6 - 8	0,0023	0,0001	4%
Total		0,6742	0,0276	4%

Finally, no possibilities for recovery are found and neither another event happens during the time left for the period. This way the algorithm successfully managed the congestion events, minimizing at the same time the differences with the FO instructions through. Downwards regulation wherever was possible.

At 10:00 hrs. another period starts and all FO instructions are set again for flexible sources. The FO is responsible for making up for the energy differences from the last period through updated instructions. The proposed algorithm just restarts its cycle and resets all energy differences for the flexible sources.

12.2 Execution time of the proposed algorithm

The algorithm was developed in Tablet PC with processor x64 Intel Core i3-4012Y, 1,5 GHz and 4 GB of RAM, using PyCharm for Windows 10. The execution time depends greatly on the current CPU usage of the computer, so different times where obtained in each run. The best results obtained were about 60 to 70 seconds for the base scenario and for 12 periods. This means that each period took about 6 seconds to conclude. However, since the characteristics of the CPU used are far from the optimum, these times are expected to decrease dramatically with the proper equipment.

13 Conclusions and recommendations

The presented algorithm was built to exemplify the benefits of implementing an interface between the FO and the flexible sources that can react to the network events fast and in-between the periods defined for the FO. The algorithm works very well limiting the congestion of the network with the help of flexible sources; however, the conditions of the network have been defined conveniently to facilitate the visualization of its operation. In this way, flexible sources defined are able to provide more flexibility than they probably could in a real system. For instance, storages minimum power would have been updated by the FO together with its instructions to ensure a minimum SOC at the end of the planning horizon. If this were the case, some congestions would not be avoided in the base scenario. To sum up, the FO should also control the operating range of the proposed algorithm, limiting its attributions.

From the above unavoidable congestions, the proposed algorithm provides valuable information with the aim of detecting the sectors of the network where flexible units are required, and in this way developing programs to promote the installation of these. If not, at least information is obtained about where an infrastructure expansion would be desirable.

Although the algorithm works well for the base scenario and fulfills the purpose for which it was built, further improvements can be achieved, making it more precise and faster. For instance, transmission losses can be incorporated to the model, therefore the temporary instructions for upwards or downwards regulations would be more accurate. In an upwards regulation, it would be possible to reduce the flexibility used for decongestion, while in a downwards regulation, unexpected congestions can be avoided with less iterations.

Also, the proposed algorithm works using an iterative method to reach close to the desired values of loading percentages. In this way, when there are 2 or more congested elements in a single time event, congestion is solved sequentially for each element through each iteration. This leads to a non-optimal result since instructions to solve a congestion in one element further reduce the congestion on previously solved elements if both share some flexible sources. It is desirable to improve the method to prevent this, therefore using as little as possible the available flexibility.

The scope of this project was to manage congestion events, however, it could also be improved to manage other type of flexibility services, for instance grid capacity management (TSO), voltage / reactive power control (DSO / TSO), ToU optimization (prosumer) and kWmax control (prosumer). This way this solution would be a great aid for the FO to manage uncertainties.

14 References

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15 Annex I: Grid behavior data

15.1 Annex I (a): Inflexible Loads demand along the planning horizon

Table 15.1 Inflexible loads demand [MW]

index	7:00	7:15	7:45	8:00	8:20	9:00	9:10	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10
1	0,6000	0,6500	0,6500	0,7000	0,7500	0,7700	0,7500	0,7700	0,8000	0,8000	0,8000	0,8000	0,8500	0,9000	0,9000
3	0,6000	0,6000	0,6000	0,6000	0,6500	0,6600	0,6600	0,7500	0,7500	0,8000	0,8500	0,9000	0,9500	1,0000	0,9500
4	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0150	0,0150	0,0200	0,0200	0,0200	0,0200
5	0,0100	0,0100	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0200	0,0200
6	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
7	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
9	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
11	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
13	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
15	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
17	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
19	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
21	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
22	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
23	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
24	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
25	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
26	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
27	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
28	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
29	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
30	0,0040	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050
31	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
33	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
35	0,0040	0,0040	0,0040	0,0045	0,0045	0,0030	0,0030	0,0030	0,0025	0,0025	0,0025	0,0025	0,0025	0,0035	0,0035
36	0,0020	0,0025	0,0025	0,0025	0,0025	0,0025	0,0020	0,0020	0,0020	0,0020	0,0020	0,0015	0,0015	0,0015	0,0015
37	0,0040	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
39	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
40	0,0010	0,0010	0,0015	0,0015	0,0020	0,0020	0,0020	0,0015	0,0015	0,0015	0,0015	0,0015	0,0010	0,0010	0,0010
41	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
42	0,0010	0,0010	0,0015	0,0015	0,0020	0,0020	0,0020	0,0015	0,0015	0,0015	0,0015	0,0015	0,0010	0,0010	0,0010
43	0,0030	0,0030	0,0040	0,0040	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050

(continuation) Table 15.1 Inflexible loads demand [MW]

index	12:25	13:00	13:30	13:40	14:00	14:50	15:00	16:00	16:25	16:35	17:00	17:40	18:00	18:15	18:45
1	0,9000	0,9000	0,9000	0,9500	1,0000	1,0000	1,0000	0,9000	0,9000	0,9000	0,8000	0,8000	0,7000	0,7000	0,7000
3	0,9500	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	0,9500	0,9000	0,9000	0,8000	0,8000	0,8000	0,8000	0,7500
4	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0150	0,0150	0,0100	0,0100	0,0100
5	0,0200	0,0200	0,0200	0,0250	0,0250	0,0250	0,0200	0,0200	0,0200	0,0150	0,0150	0,0150	0,0150	0,0100	0,0100
6	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
7	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
9	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
11	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
13	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
15	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
17	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
19	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
21	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
22	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
23	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
24	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
25	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
26	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
27	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
28	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
29	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
30	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055
31	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
33	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
35	0,0035	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0035	0,0035	0,0035	0,0040	0,0045	0,0050	0,0050
36	0,0015	0,0020	0,0020	0,0020	0,0020	0,0025	0,0025	0,0025	0,0025	0,0025	0,0020	0,0020	0,0020	0,0020	0,0020
37	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
39	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0050	0,0053	0,0053
40	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0015	0,0015	0,0015	0,0020	0,0020	0,0030	0,0020	0,0020
41	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0050	0,0053	0,0053
42	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0015	0,0015	0,0015	0,0020	0,0020	0,0027	0,0025	0,0025
43	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055

15.2 Annex I (b): Storages behavior along the planning horizon

Table 15.2 Inflexible battery index 2 operation rates [MW]

index	7:00	8:00	8:40	9:00	9:20	10:00	11:00	12:00	12:30	13:00	14:00	14:30	15:00	16:00
2	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0015	0,0017	0,0035	0,0035	0,0005	0,0000	0,0000	0,0000	0,0000

Table 15.3 Connection status of EV's (0 is off, 1 is on, other is SOC[%])

index	7:00	8:00	8:40	9:00	9:20	10:00	11:00	12:00	12:30	13:00	14:00	14:30	15:00	16:00
6	1	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	60	1	1	1	1	1	1	1	1	1
8	1	1	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	60	1	1	1	1	0	80	1	1	1	1

15.3 Annex I (c): Generators limited power output along the planning horizon

Table 15.4 Generators limited power output due to solar radiation [MW]

index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
1	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
2	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
3	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
4	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
5	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
6	0,0147	0,0332	0,0488	0,0612	0,0683	0,0699	0,0668	0,0586	0,0453	0,0276	0,0089	0,0000
7	0,0097	0,0219	0,0322	0,0404	0,0451	0,0461	0,0441	0,0386	0,0299	0,0182	0,0059	0,0000
8	0,0034	0,0076	0,0112	0,0141	0,0157	0,0161	0,0154	0,0135	0,0104	0,0063	0,0020	0,0000

16 Annex II: FO instructions data

16.1 Annex II (a): FO instructions for flexible loads along the planning horizon

Table 16.1 FO instructions for flexible loads [MWh]

index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0	1,0000	0,9500	0,9000	0,9000	0,9000	0,8500	0,8500	0,8500	0,9000	0,9000	0,9500	0,9000
2	1,5000	1,6000	1,7000	1,7000	1,6000	1,5000	1,4000	1,3000	1,4000	1,4000	1,4000	1,5000
8	0,0035	0,0035	0,0035	0,0030	0,0030	0,0030	0,0030	0,0030	0,0035	0,0035	0,0035	0,0030
10	0,0035	0,0035	0,0035	0,0035	0,0030	0,0025	0,0020	0,0020	0,0025	0,0025	0,0030	0,0035
12	0,0040	0,0040	0,0040	0,0040	0,0035	0,0035	0,0035	0,0035	0,0035	0,0035	0,0035	0,0035
14	0,0030	0,0035	0,0040	0,0035	0,0030	0,0025	0,0025	0,0020	0,0025	0,0030	0,0030	0,0035
16	0,0030	0,0035	0,0040	0,0035	0,0030	0,0025	0,0025	0,0020	0,0025	0,0030	0,0030	0,0035
18	0,0035	0,0035	0,0035	0,0035	0,0030	0,0025	0,0020	0,0020	0,0025	0,0025	0,0030	0,0035
20	0,0035	0,0035	0,0035	0,0035	0,0030	0,0025	0,0020	0,0020	0,0025	0,0025	0,0030	0,0035
32	0,0025	0,0025	0,0030	0,0030	0,0025	0,0025	0,0025	0,0030	0,0030	0,0030	0,0025	0,0025
34	0,0025	0,0030	0,0035	0,0040	0,0040	0,0030	0,0030	0,0025	0,0025	0,0030	0,0030	0,0030
38	0,0025	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0025	0,0025	0,0025	0,0025	0,0025

Table 16.2 FO instructions for status of disconnectable loads (0 is off, 1 is on)

index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
6	1	1	1	1	1	0	0	0	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	0
29	1	1	1	1	0	0	1	1	1	1	1	1
36	1	1	1	1	0	0	0	1	1	1	1	1
40	1	1	1	1	1	0	0	0	1	1	1	1
42	1	1	1	1	1	0	0	0	1	1	1	1

16.2 Annex II (b): FO instructions for flexible storages along the planning horizon

Table 16.3 FO instructions for flexible storages [MWh]

index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0	-0,0100	-0,0060	-0,0040	0,0500	0,0500	0,0500	0,0500	0,0500	0,0417	0,0254	0,0042	0,0000
1	-0,0100	-0,0100	0,0322	0,0404	0,0451	0,0461	0,0441	0,0386	0,0299	0,0182	0,0059	0,0000
3	-0,0005	-0,0005	-0,0005	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
4	-0,0005	-0,0005	-0,0005	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
5	-0,0005	-0,0005	-0,0005	0,0012	0,0014	0,0028	0,0027	0,0023	0,0009	0,0011	0,0004	0,0000
6	0,0011	0,0003	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0040	0,0014
7	0,0000	0,0000	0,0024	0,0015	0,0017	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
8	0,0007	0,0009	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0005	-0,0005
9	0,0000	0,0000	0,0020	0,0012	0,0014	-0,0005	-0,0006	-0,0005	0,0009	-0,0005	-0,0005	0,0000

16.3 Annex II (c): FO instructions for generators along the planning horizon

Table 16.4 FO instructions for flexible generators [MWh]

index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
2	0,0007	0,0017	0,0024	0,0031	0,0034	0,0035	0,0033	0,0029	0,0023	0,0014	0,0004	0,0000
3	0,0007	0,0016	0,0023	0,0029	0,0032	0,0033	0,0032	0,0028	0,0022	0,0013	0,0004	0,0000
5	0,0006	0,0013	0,0020	0,0024	0,0027	0,0028	0,0027	0,0023	0,0018	0,0011	0,0004	0,0000
6	0,0135	0,0306	0,0449	0,0563	0,0629	0,0643	0,0615	0,0539	0,0417	0,0254	0,0082	0,0000
8	0,0032	0,0073	0,0107	0,0134	0,0149	0,0153	0,0146	0,0128	0,0099	0,0060	0,0019	0,0000

17 Annex III: Results

17.1 Annex III (a): Results for lines and transformers

Table 17.1 Loading percent of lines at the beginning of each time event [%]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	69,8	70,0	70,0	69,6	69,9	69,9	69,4	69,5	69,5	69,9	70,0	69,2	70,0	69,2	69,9	69,2	69,5	69,6
1	40,6	40,1	40,2	40,1	39,9	39,9	40,1	40,5	40,5	41,0	40,5	39,9	40,8	40,4	40,5	39,5	39,6	39,7
2	2,8	2,9	3,2	3,1	3,2	3,2	3,1	3,2	3,2	3,1	3,0	3,0	3,0	2,9	2,9	2,9	3,4	3,4
3	34,3	34,9	36,5	37,7	38,9	38,9	39,4	41,5	41,5	39,2	38,2	35,2	35,2	35,6	37,0	29,6	32,9	33,7
4	21,9	21,7	22,5	22,9	23,4	23,4	23,8	26,7	26,7	25,2	24,2	21,3	21,2	20,8	21,5	21,7	24,2	25,0
5	11,0	10,9	11,7	11,5	12,1	12,1	12,0	13,4	13,4	12,3	12,2	10,8	10,8	10,4	11,1	10,8	11,7	12,5
6	2,4	2,5	2,7	2,7	2,7	2,7	2,7	2,7	2,7	2,6	2,5	2,5	2,5	2,5	2,5	2,5	3,0	3,0
7	2,3	2,3	2,6	2,6	2,7	2,7	2,6	2,7	2,7	2,6	2,5	2,5	2,5	2,4	2,3	2,4	2,9	2,9
8	1,6	1,6	1,7	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,7	1,7	1,7	1,6	1,6	1,7	2,0	2,0
9	1,4	1,4	1,5	1,5	1,5	1,5	1,5	1,6	1,6	1,5	1,4	1,4	1,4	1,3	1,3	1,4	1,6	1,7
10	1,1	1,1	1,1	1,1	1,2	1,2	1,1	1,2	1,2	1,1	1,1	1,0	1,0	1,0	1,0	1,1	1,3	1,4
11	47,7	48,7	50,2	46,9	47,3	47,3	41,9	48,2	48,2	44,5	43,1	40,1	39,8	37,4	37,7	37,9	57,7	59,4
12	37,8	38,1	39,6	37,0	37,6	37,6	33,6	39,1	39,1	35,8	34,6	29,7	29,5	26,9	27,5	25,8	42,3	44,0
13	28,8	29,3	30,9	28,0	29,0	29,0	25,7	29,6	29,6	26,7	26,4	21,7	21,5	19,8	20,8	19,1	29,0	30,6
14	19,3	19,9	20,6	18,8	19,1	19,1	16,8	19,1	19,1	17,5	17,3	15,2	15,1	14,2	14,5	13,2	22,2	23,0
15	8,8	8,6	9,4	8,2	8,7	8,7	7,7	9,2	9,2	8,0	7,9	8,2	8,1	7,2	7,6	6,7	13,6	14,5
16	37,7	39,4	40,2	44,4	45,2	45,2	47,7	46,1	46,1	45,3	42,7	42,7	42,7	44,4	45,2	47,8	49,6	50,4
17	25,3	26,2	27,0	29,5	30,3	30,3	32,1	31,2	31,2	30,4	28,7	28,7	28,7	29,5	30,3	32,1	33,0	33,9
18	18,8	19,6	20,4	22,1	22,9	22,9	23,8	23,0	23,0	22,2	21,3	21,3	21,3	22,1	22,9	23,8	24,7	25,6
19	12,5	13,4	13,4	15,0	15,1	15,1	15,9	15,1	15,1	15,1	14,2	14,2	14,2	15,0	15,1	15,9	16,8	16,8
20	6,2	7,0	7,0	7,9	7,9	7,9	7,9	7,1	7,1	7,1	7,0	7,0	7,0	7,8	7,9	7,9	8,7	8,7
21	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,3	0,3	0,3	0,3	0,3
22	24,4	24,4	26,0	27,5	29,1	29,1	30,6	30,6	30,6	29,1	27,5	27,5	27,5	20,6	21,4	22,9	23,0	23,7
23	18,4	18,4	20,0	20,8	22,3	22,3	23,2	23,2	23,2	21,6	20,8	20,8	20,8	13,9	14,7	15,5	15,5	16,2
24	6,1	6,1	6,8	6,8	7,6	7,6	7,6	7,6	7,6	6,8	6,8	6,8	6,8	6,8	7,6	7,6	7,6	8,3
25	55,8	59,6	65,9	67,4	69,0	69,0	69,1	69,2	69,7	65,7	64,5	65,8	65,7	63,4	61,0	55,1	69,2	68,3
26	46,0	49,0	55,3	56,6	58,2	58,2	58,1	58,2	58,7	54,7	53,6	54,9	54,8	52,1	49,6	43,7	57,0	56,2
27	21,0	22,0	23,2	24,7	24,4	24,4	22,4	21,8	21,9	21,4	20,5	20,7	20,6	17,0	17,6	18,6	20,0	20,6
28	10,4	11,3	12,4	12,4	12,6	12,6	12,6	11,7	11,7	11,5	11,4	11,5	11,5	8,0	8,8	8,7	9,0	9,9
29	25,0	26,9	32,1	31,9	33,8	33,8	35,7	36,4	36,8	33,3	33,1	34,3	34,2	35,1	32,0	25,1	37,0	35,5
30	10,8	11,7	11,9	12,7	12,2	12,2	12,5	12,5	12,5	12,3	12,3	12,2	12,2	13,0	12,9	12,6	14,8	14,5
31	14,2	15,2	20,1	19,2	21,6	21,6	23,2	24,0	24,3	21,0	20,9	22,0	22,0	22,2	19,1	12,6	22,2	21,1
32	7,6	7,8	11,4	11,3	13,7	13,7	13,9	14,0	14,1	12,5	12,5	13,7	13,7	13,7	12,2	9,6	10,8	11,7

(continuation) Table 17.1 Loading percent of lines at the beginning of each time event [%]

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	69,6	69,3	69,5	70,0	69,3	69,4	69,5	69,1	69,3	69,5	69,5	69,5	69,5	69,6	69,2	69,5	69,5	69,5
1	39,7	39,6	39,7	39,3	38,0	38,2	38,2	37,9	38,9	38,9	38,8	39,1	39,1	39,2	41,0	41,3	41,1	41,1
2	3,4	3,1	3,2	3,2	3,1	3,2	3,3	3,3	3,4	3,6	3,5	3,3	3,3	3,4	3,4	3,7	3,8	3,8
3	33,7	31,1	30,3	29,5	29,4	29,4	29,4	36,2	35,1	38,3	37,5	33,8	33,8	35,4	38,9	41,3	46,6	46,6
4	25,0	23,2	22,4	21,6	21,5	21,5	21,5	21,5	21,1	24,3	24,3	20,6	20,6	20,6	22,6	24,2	29,5	29,5
5	12,5	11,5	10,7	10,7	10,7	10,7	10,7	10,8	10,1	11,3	11,3	9,8	9,8	10,6	11,9	12,7	14,8	14,8
6	3,0	2,7	2,8	2,8	2,8	2,9	2,9	2,8	2,9	3,1	3,0	2,9	2,9	3,0	2,9	3,1	3,2	3,2
7	2,9	2,6	2,7	2,7	2,6	2,7	2,7	2,6	2,7	2,9	2,7	2,6	2,6	2,7	2,8	2,9	3,0	3,0
8	2,0	1,9	1,8	1,9	1,9	1,9	1,9	1,8	1,8	2,0	1,9	1,7	1,7	1,8	1,8	2,0	2,0	2,0
9	1,7	1,5	1,5	1,4	1,4	1,4	1,4	1,4	1,5	1,6	1,6	1,5	1,5	1,5	1,5	1,8	1,8	1,8
10	1,4	1,1	1,1	1,0	1,0	1,0	1,0	1,0	1,1	1,3	1,2	1,1	1,1	1,2	1,2	1,4	1,4	1,4
11	59,4	36,2	34,7	33,5	34,2	34,2	34,3	36,9	43,4	60,1	58,4	49,6	49,6	52,2	54,3	69,8	69,9	69,9
12	44,0	28,7	27,2	26,0	27,2	27,2	27,2	29,9	34,8	48,7	47,8	39,1	39,1	40,8	41,4	55,5	55,6	55,6
13	30,6	21,1	19,5	19,4	20,5	20,5	20,5	22,4	25,5	34,4	33,5	29,6	29,6	32,1	34,4	43,6	43,2	43,2
14	23,0	14,2	13,5	13,3	13,9	13,9	13,9	14,8	17,3	23,6	22,7	20,3	20,3	22,0	22,2	29,1	28,8	28,8
15	14,5	7,6	6,8	6,7	6,8	6,8	6,8	7,6	8,6	13,4	13,4	9,7	9,7	10,6	8,8	14,0	13,7	13,7
16	50,4	51,2	50,3	47,7	47,7	47,7	47,7	46,1	45,2	42,8	41,1	41,9	41,9	41,9	39,4	41,9	43,6	43,6
17	33,9	34,6	33,8	32,1	32,0	32,0	32,0	31,2	30,4	28,7	27,9	27,9	27,9	27,8	23,8	25,5	26,4	26,4
18	25,6	25,5	24,7	23,8	23,8	23,8	23,8	23,0	22,1	21,3	20,5	20,5	20,5	21,3	16,4	17,3	17,3	17,3
19	16,8	16,8	16,8	15,9	15,9	15,9	15,9	15,1	15,1	14,2	13,4	14,2	14,2	14,2	8,6	8,7	8,7	8,7
20	8,7	7,9	7,9	7,9	7,9	7,9	7,9	7,1	7,1	7,1	6,3	7,0	7,0	7,8	8,6	8,6	8,7	8,7
21	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,3	0,3	0,3	0,4	0,4	0,4	0,4
22	23,7	33,8	32,2	30,7	30,7	30,7	30,7	30,7	29,1	27,5	27,5	26,0	26,0	26,0	29,1	32,2	33,8	33,8
23	16,2	25,5	24,0	23,2	23,2	23,2	23,2	23,2	21,6	20,8	20,8	19,2	19,2	20,0	22,3	24,7	25,5	25,5
24	8,3	8,4	7,6	7,6	7,6	7,6	7,6	7,6	6,8	6,8	6,8	6,1	6,1	6,8	7,6	8,4	8,4	8,4
25	69,9	55,8	69,4	65,7	58,0	67,5	69,9	63,5	65,3	68,8	68,3	68,3	69,9	75,0	75,3	77,0	77,0	77,0
26	57,7	44,5	58,0	54,3	46,7	55,1	57,2	52,9	54,6	57,7	57,6	57,7	59,2	63,6	63,1	64,8	64,8	64,8
27	20,7	18,7	19,7	19,3	21,2	21,6	22,6	22,4	21,6	23,0	23,4	21,0	21,6	22,7	24,5	26,5	26,5	26,5
28	9,9	9,6	9,0	8,9	12,2	12,4	13,3	13,2	12,3	12,4	12,4	10,6	10,6	11,7	12,6	13,6	13,6	13,6
29	37,0	25,7	38,3	35,1	25,5	33,5	34,6	30,6	33,0	34,7	34,3	36,7	37,6	40,8	38,6	38,4	38,4	38,4
30	14,6	12,6	14,5	14,1	12,5	12,8	12,9	11,9	11,9	12,0	11,2	12,0	12,1	13,1	13,1	13,7	13,7	13,7
31	22,5	13,2	23,9	21,0	13,0	20,7	21,8	18,7	21,1	22,7	23,1	24,7	25,6	27,7	25,5	24,7	24,7	24,7
32	11,9	10,6	10,9	10,6	9,7	10,5	10,7	12,3	12,5	12,8	12,9	13,0	13,2	14,8	17,2	17,9	17,9	17,9

Table 17.2 Loading percent of transformers at the beginning of each time event [%]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	16,5	16,5	16,6	16,5	16,5	16,5	16,4	16,4	16,4	16,5	16,6	16,4	16,6	16,4	16,5	16,4	16,4	16,5
1	10,3	10,5	10,9	11,3	11,6	11,6	11,7	12,4	12,4	11,7	11,4	10,5	10,5	10,6	11,1	8,9	9,9	10,1
2	25,2	25,9	26,6	26,8	27,2	27,2	26,4	27,7	27,7	26,4	25,2	24,3	24,2	24,0	24,3	25,1	31,4	32,2
3	7,4	7,4	7,8	8,3	8,8	8,8	9,2	9,2	9,2	8,8	8,3	8,3	8,3	6,3	6,5	7,0	7,0	7,2
4	16,5	17,6	19,5	19,9	20,4	20,4	20,4	20,4	20,6	19,4	19,1	19,4	19,4	18,8	18,0	16,3	20,4	20,2

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	16,5	16,4	16,4	16,5	16,4	16,4	16,4	16,3	16,4	16,4	16,4	16,4	16,4	16,5	16,4	16,4	16,4	16,4
1	10,1	9,3	9,1	8,9	8,8	8,8	8,8	10,8	10,5	11,4	11,2	10,1	10,1	10,6	11,6	12,3	13,9	13,9
2	32,2	25,6	24,9	23,8	24,1	24,1	24,1	24,4	26,1	30,2	29,2	26,9	26,9	27,7	27,6	32,8	33,3	33,3
3	7,2	10,1	9,7	9,2	9,2	9,2	9,2	9,2	8,8	8,3	8,3	7,9	7,9	7,8	8,8	9,7	10,1	10,1
4	20,6	16,5	20,5	19,4	17,2	19,9	20,6	18,8	19,3	20,3	20,2	20,2	20,6	22,1	22,2	22,7	22,7	22,7

17.2 Annex III (b): Results for loads

Table 17.3 Loads power rate at the beginning of each time event after congestion management [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	0,9052	0,8902	0,8869	0,8251	0,7979	0,7979	0,7477	0,7526	0,7526	0,7318	0,7264	0,7030	0,6994	0,6874	0,6706	0,6350	0,6458	0,6458
1	0,6000	0,6500	0,6500	0,7000	0,7500	0,7500	0,7700	0,7500	0,7500	0,7700	0,8000	0,8000	0,8000	0,8000	0,8500	0,9000	0,9000	0,9000
2	1,3103	1,2803	1,2738	1,2789	1,2089	1,2089	1,1924	1,2085	1,2086	1,1393	1,1214	1,0432	1,0314	0,9621	0,9118	0,8122	0,8466	0,8466
3	0,6000	0,6000	0,6000	0,6000	0,6500	0,6500	0,6600	0,6600	0,6600	0,7500	0,7500	0,8000	0,8500	0,9000	0,9500	1,0000	0,9500	0,9500
4	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0100	0,0150	0,0150	0,0200	0,0200	0,0200	0,0200	0,0200
5	0,0100	0,0100	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0150	0,0200	0,0200	0,0200
6	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0000	0,0000	0,0000
7	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
8	0,0031	0,0031	0,0031	0,0030	0,0028	0,0028	0,0027	0,0037	0,0037	0,0034	0,0034	0,0023	0,0023	0,0023	0,0022	0,0021	0,0032	0,0032
9	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
10	0,0031	0,0031	0,0031	0,0030	0,0028	0,0028	0,0027	0,0037	0,0037	0,0034	0,0034	0,0025	0,0025	0,0023	0,0022	0,0021	0,0026	0,0026
11	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
12	0,0035	0,0035	0,0034	0,0033	0,0031	0,0031	0,0030	0,0040	0,0040	0,0037	0,0037	0,0027	0,0027	0,0024	0,0024	0,0022	0,0038	0,0038
13	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
14	0,0028	0,0027	0,0027	0,0030	0,0028	0,0028	0,0030	0,0040	0,0040	0,0037	0,0037	0,0025	0,0025	0,0023	0,0022	0,0021	0,0026	0,0026
15	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
16	0,0028	0,0027	0,0027	0,0030	0,0028	0,0028	0,0030	0,0040	0,0040	0,0037	0,0037	0,0025	0,0025	0,0023	0,0022	0,0021	0,0026	0,0026
17	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
18	0,0031	0,0031	0,0031	0,0030	0,0028	0,0028	0,0027	0,0037	0,0037	0,0034	0,0034	0,0025	0,0025	0,0023	0,0022	0,0021	0,0026	0,0026
19	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
20	0,0031	0,0031	0,0031	0,0030	0,0028	0,0028	0,0027	0,0037	0,0037	0,0034	0,0034	0,0025	0,0025	0,0023	0,0022	0,0021	0,0026	0,0026
21	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
22	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
23	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
24	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
25	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
26	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
27	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
28	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
29	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0000	0,0000	0,0000	0,0000	0,0000
30	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050
31	0,0040	0,0040	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
32	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0027	0,0027	0,0028	0,0027	0,0027	0,0027	0,0027	0,0025	0,0025	0,0025	0,0025	0,0025
33	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
34	0,0025	0,0025	0,0025	0,0028	0,0025	0,0025	0,0028	0,0030	0,0030	0,0029	0,0029	0,0030	0,0030	0,0029	0,0029	0,0026	0,0031	0,0029
35	0,0040	0,0040	0,0040	0,0045	0,0045	0,0045	0,0030	0,0030	0,0030	0,0030	0,0025	0,0025	0,0025	0,0025	0,0025	0,0035	0,0035	0,0035
36	0,0020	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0000	0,0000	0,0000	0,0000	0,0000
37	0,0040	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055
38	0,0025	0,0025	0,0025	0,0028	0,0025	0,0025	0,0027	0,0027	0,0028	0,0027	0,0027	0,0027	0,0027	0,0026	0,0026	0,0026	0,0031	0,0029
39	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
40	0,0010	0,0010	0,0015	0,0015	0,0020	0,0020	0,0020	0,0020	0,0020	0,0015	0,0015	0,0015	0,0015	0,0015	0,0010	0,0000	0,0000	0,0000
41	0,0040	0,0045	0,0045	0,0046	0,0046	0,0046	0,0046	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0055	0,0055
42	0,0010	0,0010	0,0015	0,0015	0,0020	0,0020	0,0020	0,0020	0,0020	0,0015	0,0015	0,0015	0,0015	0,0015	0,0010	0,0000	0,0000	0,0000
43	0,0030	0,0030	0,0040	0,0040	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0045	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0055

(continuation) Table 17.3 Loads power rate at the beginning of each time event after congestion management [MW]

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	0,6458	0,6360	0,6373	0,6307	0,6086	0,6091	0,6094	0,6000	0,6399	0,6536	0,6548	0,7333	0,7333	0,7333	0,7429	0,7433	0,7545	0,7545
1	0,9000	0,9000	0,9000	0,9500	1,0000	1,0000	1,0000	1,0000	0,9000	0,9000	0,9000	0,8000	0,8000	0,8000	0,7000	0,7000	0,7000	0,7000
2	0,8466	0,8009	0,8050	0,7863	0,7206	0,7221	0,7232	0,7000	0,7930	0,8328	0,8366	0,9666	0,9666	0,9666	1,0811	1,0822	1,1222	1,1222
3	0,9500	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	0,9500	0,9000	0,9000	0,8000	0,8000	0,8000	0,8000	0,8000	0,7500	0,7500
4	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0200	0,0150	0,0150	0,0150	0,0100	0,0100	0,0100	0,0100
5	0,0200	0,0200	0,0200	0,0250	0,0250	0,0250	0,0250	0,0200	0,0200	0,0200	0,0150	0,0150	0,0150	0,0150	0,0150	0,0100	0,0100	0,0100
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
7	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
8	0,0032	0,0021	0,0021	0,0021	0,0020	0,0020	0,0020	0,0020	0,0022	0,0040	0,0040	0,0026	0,0026	0,0026	0,0025	0,0025	0,0040	0,0040
9	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
10	0,0026	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0021	0,0028	0,0028	0,0024	0,0024	0,0024	0,0027	0,0027	0,0040	0,0040
11	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
12	0,0038	0,0022	0,0022	0,0022	0,0021	0,0021	0,0021	0,0020	0,0022	0,0040	0,0040	0,0026	0,0026	0,0026	0,0027	0,0036	0,0035	0,0035
13	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
14	0,0026	0,0021	0,0021	0,0021	0,0020	0,0020	0,0020	0,0020	0,0021	0,0036	0,0036	0,0024	0,0024	0,0024	0,0027	0,0036	0,0035	0,0035
15	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
16	0,0026	0,0021	0,0021	0,0021	0,0020	0,0020	0,0020	0,0020	0,0021	0,0036	0,0036	0,0024	0,0024	0,0024	0,0027	0,0036	0,0035	0,0035
17	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
18	0,0026	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0021	0,0028	0,0028	0,0024	0,0024	0,0024	0,0027	0,0036	0,0035	0,0035
19	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
20	0,0026	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0021	0,0028	0,0028	0,0024	0,0024	0,0024	0,0027	0,0036	0,0035	0,0035
21	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
22	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
23	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
24	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
25	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0000	0,0000	0,0000	0,0000
26	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
27	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
28	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
29	0,0000	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
30	0,0050	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0045	0,0040	0,0045	0,0050	0,0055	0,0055
31	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
32	0,0025	0,0025	0,0025	0,0025	0,0025	0,0032	0,0033	0,0025	0,0026	0,0028	0,0030	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025
33	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0055	0,0055	0,0055	0,0055
34	0,0029	0,0026	0,0034	0,0032	0,0025	0,0025	0,0025	0,0025	0,0026	0,0028	0,0030	0,0027	0,0030	0,0025	0,0025	0,0025	0,0025	0,0025
35	0,0035	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0030	0,0035	0,0035	0,0035	0,0035	0,0040	0,0045	0,0050	0,0050	0,0050
36	0,0000	0,0000	0,0000	0,0000	0,0020	0,0020	0,0025	0,0025	0,0025	0,0025	0,0025	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020
37	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055
38	0,0029	0,0026	0,0034	0,0032	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025	0,0025
39	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0050	0,0053	0,0053	0,0053
40	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0010	0,0015	0,0015	0,0015	0,0020	0,0020	0,0020	0,0030	0,0020	0,0020	0,0020
41	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0045	0,0045	0,0050	0,0050	0,0053	0,0053	0,0053
42	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0010	0,0015	0,0015	0,0015	0,0020	0,0020	0,0020	0,0027	0,0025	0,0025	0,0025
43	0,0055	0,0055	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0045	0,0045	0,0045	0,0040	0,0040	0,0045	0,0050	0,0055	0,0055	0,0055

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Table 17.4 Flexible loads power rate difference between FO and temporary instructions for each time event [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	-0,0948	-0,1098	-0,1131	-0,1249	-0,1521	-0,1521	-0,1523	-0,1474	-0,1474	-0,1682	-0,1736	-0,1970	-0,2006	-0,2126	-0,2294	-0,2150	-0,2042	-0,2042
2	-0,1897	-0,2197	-0,2262	-0,3211	-0,3911	-0,3911	-0,5076	-0,4915	-0,4914	-0,5607	-0,5786	-0,6568	-0,6686	-0,6379	-0,6882	-0,6878	-0,6534	-0,6534
8	-0,0004	-0,0004	-0,0004	-0,0005	-0,0007	-0,0007	-0,0008	0,0002	0,0002	-0,0001	-0,0001	-0,0007	-0,0007	-0,0007	-0,0008	-0,0009	0,0002	0,0002
10	-0,0004	-0,0004	-0,0004	-0,0005	-0,0007	-0,0007	-0,0008	0,0002	0,0002	-0,0001	-0,0001	-0,0010	-0,0010	-0,0007	-0,0008	-0,0004	0,0001	0,0001
12	-0,0005	-0,0005	-0,0006	-0,0007	-0,0009	-0,0009	-0,0010	0,0000	0,0000	-0,0003	-0,0003	-0,0013	-0,0013	-0,0011	-0,0011	-0,0013	0,0003	0,0003
14	-0,0002	-0,0003	-0,0003	-0,0005	-0,0007	-0,0007	-0,0010	0,0000	0,0000	-0,0003	-0,0003	-0,0010	-0,0010	-0,0007	-0,0008	-0,0004	0,0001	0,0001
16	-0,0002	-0,0003	-0,0003	-0,0005	-0,0007	-0,0007	-0,0010	0,0000	0,0000	-0,0003	-0,0003	-0,0010	-0,0010	-0,0007	-0,0008	-0,0004	0,0001	0,0001
18	-0,0004	-0,0004	-0,0004	-0,0005	-0,0007	-0,0007	-0,0008	0,0002	0,0002	-0,0001	-0,0001	-0,0010	-0,0010	-0,0007	-0,0008	-0,0004	0,0001	0,0001
20	-0,0004	-0,0004	-0,0004	-0,0005	-0,0007	-0,0007	-0,0008	0,0002	0,0002	-0,0001	-0,0001	-0,0010	-0,0010	-0,0007	-0,0008	-0,0004	0,0001	0,0001
32	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0003	-0,0003	-0,0002	-0,0003	-0,0003	-0,0003	-0,0003	0,0000	0,0000	0,0000	0,0000	0,0000
34	0,0000	0,0000	0,0000	-0,0002	-0,0005	-0,0005	-0,0007	-0,0005	-0,0005	-0,0006	-0,0006	-0,0010	-0,0010	-0,0011	-0,0011	-0,0004	0,0001	-0,0001
38	0,0000	0,0000	0,0000	-0,0002	-0,0005	-0,0005	-0,0003	-0,0003	-0,0002	-0,0003	-0,0003	-0,0003	-0,0003	-0,0004	-0,0004	-0,0004	0,0001	-0,0001

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	-0,2042	-0,2140	-0,2127	-0,2193	-0,2414	-0,2409	-0,2406	-0,3000	-0,2601	-0,2464	-0,2452	-0,2167	-0,2167	-0,2167	-0,1571	-0,1567	-0,1455	-0,1455
2	-0,6534	-0,5991	-0,5950	-0,6137	-0,5794	-0,5779	-0,5768	-0,7000	-0,6070	-0,5672	-0,5634	-0,4334	-0,4334	-0,4334	-0,4189	-0,4178	-0,3778	-0,3778
8	0,0002	-0,0009	-0,0009	-0,0009	-0,0010	-0,0010	-0,0010	-0,0015	-0,0013	0,0005	0,0005	-0,0009	-0,0009	-0,0009	-0,0005	-0,0005	0,0010	0,0010
10	0,0001	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0005	-0,0004	0,0003	0,0003	-0,0006	-0,0006	-0,0006	-0,0008	-0,0008	0,0005	0,0005
12	0,0003	-0,0013	-0,0013	-0,0013	-0,0014	-0,0014	-0,0014	-0,0015	-0,0013	0,0005	0,0005	-0,0009	-0,0009	-0,0009	-0,0008	0,0001	0,0000	0,0000
14	0,0001	-0,0004	-0,0004	-0,0004	0,0000	0,0000	0,0000	-0,0005	-0,0009	0,0006	0,0006	-0,0006	-0,0006	-0,0006	-0,0008	0,0001	0,0000	0,0000
16	0,0001	-0,0004	-0,0004	-0,0004	0,0000	0,0000	0,0000	-0,0005	-0,0009	0,0006	0,0006	-0,0006	-0,0006	-0,0006	-0,0008	0,0001	0,0000	0,0000
18	0,0001	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0005	-0,0004	0,0003	0,0003	-0,0006	-0,0006	-0,0006	-0,0008	0,0001	0,0000	0,0000
20	0,0001	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0005	-0,0004	0,0003	0,0003	-0,0006	-0,0006	-0,0006	-0,0008	0,0001	0,0000	0,0000
32	0,0000	0,0000	0,0000	0,0000	-0,0005	0,0002	0,0003	-0,0005	-0,0004	-0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
34	-0,0001	-0,0004	0,0004	0,0002	0,0000	0,0000	0,0000	0,0000	-0,0004	-0,0002	0,0000	-0,0003	0,0000	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005
38	-0,0001	-0,0004	0,0004	0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 17.5 Flexible loads energy difference between FO and temporary instructions at the end of each time period [MWh]

Index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0	-0,1069	-0,1430	-0,1595	-0,1985	-0,2182	-0,2060	-0,2155	-0,2411	-0,3000	-0,2516	-0,2167	-0,1540
2	-0,2138	-0,3678	-0,5317	-0,6617	-0,6547	-0,6592	-0,6033	-0,5785	-0,7000	-0,5822	-0,4334	-0,4081
8	-0,0004	-0,0006	-0,0001	-0,0007	-0,0007	0,0000	-0,0009	-0,0010	-0,0015	-0,0003	-0,0009	-0,0001
10	-0,0004	-0,0006	-0,0001	-0,0010	-0,0007	0,0000	0,0000	0,0000	-0,0005	0,0000	-0,0006	-0,0005
12	-0,0005	-0,0008	-0,0003	-0,0013	-0,0011	0,0000	-0,0013	-0,0014	-0,0015	-0,0003	-0,0009	-0,0002
14	-0,0003	-0,0006	-0,0003	-0,0010	-0,0007	0,0000	-0,0004	0,0000	-0,0005	0,0000	-0,0006	-0,0002
16	-0,0003	-0,0006	-0,0003	-0,0010	-0,0007	0,0000	-0,0004	0,0000	-0,0005	0,0000	-0,0006	-0,0002
18	-0,0004	-0,0006	-0,0001	-0,0010	-0,0007	0,0000	0,0000	0,0000	-0,0005	0,0000	-0,0006	-0,0002
20	-0,0004	-0,0006	-0,0001	-0,0010	-0,0007	0,0000	0,0000	0,0000	-0,0005	0,0000	-0,0006	-0,0002
32	0,0000	0,0000	-0,0003	-0,0003	0,0000	0,0000	0,0000	-0,0001	-0,0005	-0,0002	0,0000	0,0000
34	0,0000	-0,0004	-0,0006	-0,0010	-0,0011	-0,0001	-0,0001	0,0000	0,0000	-0,0002	-0,0002	-0,0005
38	0,0000	-0,0004	-0,0003	-0,0003	-0,0004	-0,0001	-0,0001	0,0000	0,0000	0,0000	0,0000	0,0000

17.3 Annex III (c): Results for storages

Table 17.6 Storages power rate at the beginning of each time event after congestion management [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	-0,0162	-0,0175	-0,0178	-0,0106	-0,0120	-0,0120	-0,0056	-0,0056	-0,0056	-0,0060	-0,0064	0,0172	0,0166	0,0146	0,0118	0,0070	0,0088	0,0088
1	-0,0162	-0,0175	-0,0178	-0,0131	-0,0142	-0,0142	0,0159	0,0164	0,0164	0,0141	0,0136	0,0139	0,0134	0,0131	0,0106	0,0065	0,0083	0,0083
2	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0015	0,0015	0,0017	0,0017	0,0035	0,0035	0,0035
3	-0,0008	-0,0009	-0,0009	-0,0007	-0,0007	-0,0007	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0010	0,0010	0,0010	0,0008	0,0005	0,0040	0,0040
4	-0,0008	-0,0009	-0,0009	-0,0007	-0,0007	-0,0007	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0010	0,0010	0,0010	0,0008	0,0005	0,0040	0,0040
5	-0,0008	-0,0009	-0,0009	-0,0007	-0,0011	-0,0011	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0004	0,0004	0,0004	0,0003	0,0004	0,0033	0,0025
6	0,0008	0,0008	0,0008	0,0002	0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0005	0,0005	0,0005	0,0004	0,0000	0,0000	0,0000
8	0,0006	0,0005	0,0005	0,0006	0,0005	0,0005	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
9	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0006	0,0009	0,0010	0,0009	0,0008	0,0004	0,0004	0,0004	0,0003	-0,0005	-0,0005	-0,0005

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	0,0088	0,0072	0,0074	0,0060	0,0017	0,0018	0,0018	0,0000	0,0034	0,0048	0,0050	0,0016	0,0016	0,0016	-0,0234	-0,0234	-0,0223	-0,0223
1	0,0083	0,0064	0,0065	0,0054	0,0013	0,0014	0,0014	0,0000	0,0024	0,0035	0,0036	0,0022	0,0022	0,0022	-0,0262	-0,0261	-0,0250	-0,0250
2	0,0035	0,0005	0,0005	0,0005	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	0,0040	0,0005	0,0005	0,0004	0,0001	0,0001	0,0001	0,0000	0,0002	0,0022	0,0022	0,0002	0,0002	0,0002	-0,0021	-0,0004	-0,0005	-0,0005
4	0,0040	0,0005	0,0005	0,0004	0,0001	0,0001	0,0001	0,0000	0,0002	0,0022	0,0022	0,0002	0,0002	0,0002	-0,0021	-0,0004	-0,0005	-0,0005
5	0,0025	0,0004	0,0038	0,0031	0,0001	0,0027	0,0029	0,0000	0,0001	0,0006	0,0012	0,0001	0,0004	0,0000	-0,0040	-0,0040	-0,0040	-0,0040
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0007	0,0007	0,0008	0,0008
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
8	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005
9	0,0000	-0,0009	-0,0004	-0,0005	-0,0005	-0,0005	-0,0005	0,0000	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	-0,0005	0,0000	0,0000	0,0000	0,0000

Table 17.7 Flexible storages power rate difference between FO and temporary instructions for each time event [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	-0,0062	-0,0075	-0,0078	-0,0046	-0,0060	-0,0060	-0,0016	-0,0016	-0,0016	-0,0020	-0,0024	-0,0328	-0,0334	-0,0354	-0,0382	-0,0430	-0,0412	-0,0412
1	-0,0062	-0,0075	-0,0078	-0,0031	-0,0042	-0,0042	-0,0163	-0,0158	-0,0158	-0,0181	-0,0186	-0,0265	-0,0270	-0,0320	-0,0345	-0,0397	-0,0378	-0,0378
3	-0,0003	-0,0004	-0,0004	-0,0002	-0,0002	-0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0020	-0,0020	-0,0024	-0,0026	-0,0030	0,0005	0,0005
4	-0,0003	-0,0004	-0,0004	-0,0002	-0,0002	-0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0020	-0,0020	-0,0024	-0,0026	-0,0030	0,0005	0,0005
5	-0,0003	-0,0004	-0,0004	-0,0002	-0,0006	-0,0006	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0008	-0,0008	-0,0010	-0,0010	-0,0024	0,0005	-0,0003
6	-0,0003	-0,0003	-0,0003	-0,0001	-0,0001	-0,0003	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0024	-0,0024	-0,0024	-0,0024	-0,0024	-0,0010	-0,0010	-0,0012	-0,0013	0,0000	0,0000	0,0000
8	-0,0002	-0,0002	-0,0002	-0,0003	-0,0004	-0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
9	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0013	-0,0010	-0,0009	-0,0011	-0,0011	-0,0008	-0,0008	-0,0010	-0,0010	0,0000	0,0000	0,0000

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	-0,0412	-0,0428	-0,0426	-0,0440	-0,0483	-0,0482	-0,0482	-0,0417	-0,0220	-0,0206	-0,0204	-0,0026	-0,0026	-0,0026	-0,0234	-0,0234	-0,0223	-0,0223
1	-0,0378	-0,0377	-0,0376	-0,0387	-0,0373	-0,0373	-0,0372	-0,0299	-0,0158	-0,0147	-0,0146	-0,0036	-0,0036	-0,0036	-0,0262	-0,0261	-0,0250	-0,0250
3	0,0005	-0,0029	-0,0028	-0,0029	-0,0028	-0,0028	-0,0028	-0,0023	-0,0012	0,0009	0,0009	-0,0003	-0,0003	-0,0003	-0,0021	-0,0004	-0,0005	-0,0005
4	0,0005	-0,0029	-0,0028	-0,0029	-0,0028	-0,0028	-0,0028	-0,0023	-0,0012	0,0009	0,0009	-0,0003	-0,0003	-0,0003	-0,0021	-0,0004	-0,0005	-0,0005
5	-0,0003	-0,0023	0,0011	0,0004	-0,0023	0,0004	0,0006	-0,0009	-0,0010	-0,0005	0,0001	-0,0002	0,0000	-0,0004	-0,0040	-0,0040	-0,0040	-0,0040
6	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0040	-0,0040	-0,0040	-0,0008	-0,0008	-0,0006	-0,0006
7	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
8	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
9	0,0005	-0,0003	0,0002	0,0001	0,0000	0,0000	0,0000	-0,0009	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 17.8 Flexible storages energy difference between FO and temporary instructions at the end of each time period [MWh]

Index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
0	-0,0072	-0,0055	-0,0019	-0,0331	-0,0364	-0,0415	-0,0432	-0,0482	-0,0417	-0,0211	-0,0026	-0,0231
1	-0,0072	-0,0038	-0,0171	-0,0267	-0,0328	-0,0381	-0,0380	-0,0373	-0,0299	-0,0151	-0,0036	-0,0259
3	-0,0004	-0,0002	0,0000	-0,0020	-0,0025	-0,0001	-0,0029	-0,0028	-0,0023	0,0000	-0,0003	-0,0009
4	-0,0004	-0,0002	0,0000	-0,0020	-0,0025	-0,0001	-0,0029	-0,0028	-0,0023	0,0000	-0,0003	-0,0009
5	-0,0004	-0,0004	0,0000	-0,0008	-0,0010	-0,0005	-0,0008	-0,0009	-0,0009	-0,0005	-0,0002	-0,0040
6	-0,0003	-0,0002	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0040	-0,0007
7	0,0000	0,0000	-0,0024	-0,0010	-0,0012	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
8	-0,0002	-0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
9	0,0000	0,0000	-0,0011	-0,0008	-0,0010	0,0003	-0,0001	0,0000	-0,0009	0,0000	0,0000	0,0000

Table 17.9 Storages SOC at the beginning of each time event [%]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	50,0	47,8	42,9	40,4	38,5	36,2	34,0	33,5	33,0	32,5	31,3	30,7	35,3	38,4	42,7	44,5	45,0	46,0
1	50,0	47,8	42,9	40,4	38,0	35,4	32,8	33,9	35,2	36,4	38,5	39,5	43,2	45,7	49,6	51,2	51,7	52,6
2	50,0	48,6	45,9	44,6	42,8	40,9	39,1	38,2	37,3	36,4	34,6	33,7	41,9	47,8	58,2	63,5	68,8	76,9
3	50,0	47,8	42,9	40,4	38,0	35,3	32,7	31,8	30,9	29,9	28,1	27,2	32,7	36,5	42,5	44,9	45,6	54,6
4	50,0	47,8	43,0	40,5	38,1	35,5	32,8	31,9	31,0	30,1	28,3	27,4	33,0	36,9	43,0	45,5	46,2	55,4
5	50,0	47,8	42,9	40,4	38,0	34,0	30,0	29,1	28,1	27,2	25,4	24,4	26,6	28,2	30,6	31,5	32,1	39,5
6	90,0	91,9	95,5	97,3	97,9	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4
7	60,0	60,0	60,0	60,0	60,0	60,0	60,0	60,0	60,0	60,0	60,0	60,0	62,8	64,8	67,8	69,0	69,0	69,0
8	90,0	91,3	93,7	94,8	96,7	98,3	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9
9	60,0	60,0	60,0	60,0	60,0	60,0	60,0	61,0	62,4	63,9	66,6	67,9	70,1	71,7	74,1	75,1	74,2	72,8

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	46,3	48,3	49,9	50,5	51,4	51,8	52,1	52,2	52,2	52,8	53,2	54,1	54,2	54,6	54,8	51,6	45,1	42,0
1	52,9	54,8	56,2	56,7	57,5	57,8	58,0	58,1	58,1	58,6	58,9	59,5	59,7	60,2	60,5	56,9	49,6	46,2
2	79,5	95,6	97,8	98,5	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
3	57,6	75,6	77,8	78,5	79,7	80,2	80,5	80,7	80,7	81,3	84,7	93,1	93,3	94,1	94,6	88,8	86,3	84,8
4	58,5	76,9	79,1	79,9	81,1	81,6	81,9	82,1	82,1	82,8	86,2	94,8	95,0	95,8	96,3	90,6	88,2	86,8
5	41,3	52,4	54,2	59,8	69,2	69,5	77,7	82,1	82,1	82,6	83,6	87,9	88,1	89,7	89,7	78,6	56,4	45,3
6	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	98,4	60,0	60,0	60,0	61,6	64,7	66,5
7	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0	69,0
8	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	99,9	65,0	64,1	61,3	59,4	58,1	55,3	53,9
9	72,4	80,0	75,3	74,6	72,7	70,0	68,2	67,3	67,3	65,0	64,1	61,8	60,9	58,2	56,4	56,4	56,4	56,4

17.4 Annex III (d): Results for generators

Table 17.10 Generators power rate at the beginning of each time event after congestion management [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
0	0,0007	0,0007	0,0007	0,0017	0,0017	0,0017	0,0024	0,0024	0,0024	0,0024	0,0024	0,0031	0,0031	0,0034	0,0034	0,0035	0,0035	0,0035
1	0,0007	0,0007	0,0007	0,0017	0,0017	0,0017	0,0024	0,0024	0,0024	0,0024	0,0024	0,0031	0,0031	0,0034	0,0034	0,0035	0,0035	0,0035
2	0,0007	0,0007	0,0007	0,0017	0,0017	0,0017	0,0024	0,0024	0,0024	0,0024	0,0024	0,0031	0,0031	0,0034	0,0034	0,0035	0,0035	0,0035
3	0,0007	0,0007	0,0007	0,0016	0,0016	0,0016	0,0024	0,0023	0,0023	0,0023	0,0023	0,0030	0,0030	0,0034	0,0034	0,0035	0,0033	0,0033
4	0,0007	0,0007	0,0007	0,0017	0,0017	0,0017	0,0024	0,0024	0,0024	0,0024	0,0024	0,0031	0,0031	0,0034	0,0034	0,0035	0,0035	0,0035
5	0,0006	0,0006	0,0006	0,0014	0,0017	0,0017	0,0023	0,0022	0,0022	0,0022	0,0022	0,0028	0,0029	0,0032	0,0033	0,0034	0,0027	0,0029
6	0,0138	0,0139	0,0139	0,0315	0,0317	0,0317	0,0469	0,0468	0,0468	0,0471	0,0471	0,0595	0,0595	0,0667	0,0670	0,0691	0,0688	0,0688
7	0,0097	0,0097	0,0097	0,0219	0,0219	0,0219	0,0322	0,0322	0,0322	0,0322	0,0322	0,0404	0,0404	0,0451	0,0451	0,0461	0,0461	0,0461
8	0,0033	0,0033	0,0033	0,0074	0,0074	0,0074	0,0109	0,0109	0,0109	0,0110	0,0110	0,0138	0,0138	0,0155	0,0155	0,0160	0,0159	0,0159

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
0	0,0035	0,0033	0,0033	0,0033	0,0029	0,0029	0,0029	0,0023	0,0014	0,0014	0,0014	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
1	0,0035	0,0033	0,0033	0,0033	0,0029	0,0029	0,0029	0,0023	0,0014	0,0014	0,0014	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
2	0,0035	0,0033	0,0033	0,0033	0,0029	0,0029	0,0029	0,0023	0,0014	0,0014	0,0014	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
3	0,0033	0,0033	0,0033	0,0033	0,0029	0,0029	0,0029	0,0023	0,0014	0,0013	0,0013	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
4	0,0035	0,0033	0,0033	0,0033	0,0029	0,0029	0,0029	0,0023	0,0014	0,0014	0,0014	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
5	0,0029	0,0032	0,0022	0,0024	0,0029	0,0021	0,0019	0,0023	0,0013	0,0012	0,0011	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
6	0,0688	0,0660	0,0660	0,0662	0,0584	0,0584	0,0584	0,0453	0,0273	0,0272	0,0271	0,0086	0,0086	0,0086	0,0000	0,0000	0,0000	0,0000
7	0,0461	0,0441	0,0441	0,0441	0,0386	0,0386	0,0386	0,0299	0,0182	0,0182	0,0182	0,0059	0,0059	0,0059	0,0000	0,0000	0,0000	0,0000
8	0,0159	0,0153	0,0153	0,0153	0,0134	0,0134	0,0134	0,0104	0,0063	0,0063	0,0063	0,0020	0,0020	0,0020	0,0000	0,0000	0,0000	0,0000

Table 17.11 Flexible generators power rate difference between FO and temporary instructions for each time event [MW]

Index	7:00	7:15	7:45	8:00	8:20	8:40	9:00	9:10	9:20	9:30	9:50	10:00	10:35	11:00	11:40	12:00	12:10	12:25
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0001	0,0000	0,0000	0,0000	0,0000	0,0001	0,0001	0,0001	0,0001	0,0002	0,0000	0,0000
5	0,0000	0,0000	0,0000	0,0001	0,0003	0,0003	0,0003	0,0003	0,0002	0,0003	0,0003	0,0004	0,0004	0,0005	0,0005	0,0006	-0,0001	0,0001
6	0,0003	0,0003	0,0003	0,0009	0,0012	0,0012	0,0020	0,0019	0,0019	0,0022	0,0023	0,0032	0,0033	0,0039	0,0042	0,0048	0,0046	0,0046
8	0,0000	0,0000	0,0000	0,0001	0,0002	0,0002	0,0003	0,0003	0,0003	0,0003	0,0003	0,0005	0,0005	0,0006	0,0006	0,0007	0,0007	0,0007

Index	12:30	13:00	13:30	13:40	14:00	14:30	14:50	15:00	16:00	16:25	16:35	17:00	17:10	17:40	18:00	18:15	18:45	19:00
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	0,0000	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
5	0,0001	0,0006	-0,0005	-0,0003	0,0006	-0,0002	-0,0004	0,0005	0,0002	0,0001	0,0000	0,0001	0,0000	0,0001	0,0000	0,0000	0,0000	0,0000
6	0,0046	0,0046	0,0045	0,0047	0,0045	0,0045	0,0045	0,0036	0,0019	0,0018	0,0018	0,0004	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000
8	0,0007	0,0007	0,0007	0,0007	0,0007	0,0006	0,0006	0,0005	0,0003	0,0003	0,0003	0,0001	0,0001	0,0001	0,0000	0,0000	0,0000	0,0000

Table 17.12 Flexible generators energy difference between FO and temporary instructions at the end of each time period [MWh]

Index	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
3	0,0000	0,0000	0,0000	0,0001	0,0001	0,0000	0,0001	0,0001	0,0001	0,0000	0,0000	0,0000
5	0,0000	0,0003	0,0003	0,0004	0,0005	0,0001	0,0001	0,0001	0,0005	0,0001	0,0000	0,0000
6	0,0003	0,0011	0,0021	0,0032	0,0040	0,0046	0,0046	0,0045	0,0036	0,0018	0,0004	0,0000
8	0,0000	0,0002	0,0003	0,0005	0,0006	0,0007	0,0007	0,0006	0,0005	0,0003	0,0001	0,0000