Project Milestone Report

Microgrid Positioning

www.ugrip.eu

MILESTONE M2.1.

Baseline Microgrid Simulation Model

Project Acronym	uGRIP
Project Number	77229
Funding Scheme	ERA – NET Smart Grid Plus
Project Start Date	April 1, 2016
Project End Date	March 31, 2019
Work Package	2
Task	2.1
Date of delivery	
Version:	Final ☐ Final draft ☐ Draft ☒
Type of document	Milestone Report
Deliverable participants	FER-UNIZG, DTU, OFFIS
Authors (Partners)	Hrvoje Pandžić, Mateo Beus, Ivan Pavić, Frederik Banis
Contact person	Hrvoje Pandžić (hrvoje.pandzic@fer.hr)
Keyword List	Microgrid, operation, simulation

History of Changes

Version	Author, Institution	Changes
01	Hrvoje Pandžić, FER-UNIZG	Final draft

Table of Contents

List of Figures

List of Tables

Nomenclature

The nomenclature used in this report is listed here for quick reference.

Sets

Ω^M	Set of parts of a piecewise thermal generator cost curve indexed by m.
Ω^T	Set of time periods indexed by t.

Variables

c_t	Cost of operating a thermal generator during time period t, $€/MWh$.
dr_t^f	Reduced part of the flexible demand during time period t, MWh.
drr_t^f	Retrieved amount of the reduced demand of the flexible demand during time period t, MWh.
g_t^{pv}	Output of photovoltaics during time period t, MW.
$g_t^{pv,curt}$	Curtailed part of the available photovoltaic output during time period t, MW.
g_t^{th}	Output of thermal generator during time period t, MW.
$g_{m,t}^{th}$	Output of the m-th segment of thermal generator during time period t, MW.
g_t^w	Output of wind generator during time period t, MW.
$g_t^{w,curt}$	Curtailed part of the available wind generator output during time period t, MW.
h_t	Binary variable equal to 1 if storage is charged during time period t, and 0 otherwise.
q_t^p	Electricity purchased in the market at time period t, MWh.
q_t^s	Electricity sold in the market at time t, MWh.
s_t^{ch}	Charging power of storage during time period t, MW.
s_t^{dis}	Discharging power of storage during time period t, MW.
soc_t	Storage state of charge at the end of time period t, MWh.
x_t	Binary variable equal to 1 if thermal generator is online during time period t, and 0 otherwise.
y_t	Binary variable equal to 1 if thermal generator is started during time period t, and 0 otherwise.

z_t	Binary variable equal to 1 if thermal generator is shut down during time period t, and 0 otherwise.

Parameters

A	Fixed generation cost of thermal generator, €.
B_m	Slope of the m-th segment of the thermal generator piecewise cost curve, €/MW.
D_t^f	Flexible demand during time period t, MWh.
D_t^{nf}	Non-flexible demand during time period t, MWh.
DUR^{dr}	Duration of demand response in time periods.
DUR^{drr}	Duration of demand response recovery in time periods.
K^f	Load retrieval coefficient.
P^{max}	Maximum output of thermal generator, MW.
P_m^{max}	Maximum output of m-th segment of the piecewise cost curve of thermal generator, MW.
P^{min}	Minimum output of thermal generator, MW.
P_t^{pv}	Available photovoltaic output during time period t, MW.
P_t^w	Available wind turbine output during t, MW.
RD^{th}	Ramp down limit of thermal generator, MW/h.
RU^{th}	Ramp up limit of thermal generator, MW/h.
$S^{ch,max}$	Maximum charging power of storage, MW.
$S^{dis,max}$	Maximum discharging power of storage, MW.
S^{th}	Start-up cost of thermal generator, €.
SOC^{max}	Maximum storage of charge, MWh.
SOC^{min}	Minimum storage of charge, MWh.
η^{ch}	Storage charging efficiency.
η^{dis}	Storage discharging efficiency.
λ_t	Cost of electricity in the market at time period, €/MWh.

1. Introduction

In order to ensure optimal economic performance of a microgrid, its operation needs to be realized through two layers. The first layer is the optimization layer that aims to minimize the long-term operating cost, while the second layer is the control layer whose goal is to follow the operating trajectory imposed by the optimization layer.

The basic functionality of the control layer is to ensure that microgrid is operated in a safe way by regulating the physical variables, such as common bus bar voltage (both ac and dc microgrids) and frequency (only ac microgrids), as well as current contributions of interfacing converters to suitable levels during steady-state and transient conditions. It is also important to emphasize the importance of integrating a coordinated control layer on top of the basic regulation. The purpose of coordinated control layer is to optimize real-time performance of the microgrid. From practical point of view, coordinated control layer can be realized either through centralized, decentralized or distributed implementation.

One of the ultimate goals of this project (WP2) is to develop an optimization layer that derives the long-term operational schedule based on forecasted values of the uncertain parameters: output of local renewable energy sources, e.g. wind turbines and photovoltaics, local load curve, and electricity prices (in case of dynamic pricing). Since this layer looks at least 24 hours ahead and considers uncertain parameters, it usually uses simple, i.e. linear, models of the microgrid elements and produces microgrid trajectory for the following 24 hours. The optimal trajectory is a set of variable values in time. For instance, if the optimization is performed in 15-minute discreet intervals, the trajectory is consisted of the values of variables at each discreet time step. This trajectory is then passed on to the control layer that uses a detailed representation of the microgrid elements. The control layer runs continuously in a closed loop and tries to match the imposed trajectory set points making the necessary adjustments in real time.

In this report, deterministic baseline simulation model is introduced. Using this baseline model, a dedicated microgrid operating model containing predictable and unpredictable (stochastic) energy consumers, producers or prosumers will be developed in tasks 2.2-2.4 of WP2. The developed microgrid operating model that includes uncertain parameters will subsequently be used in optimization layer.
Figure 1 shows the basic operating principle and coordination of optimization and control layers.

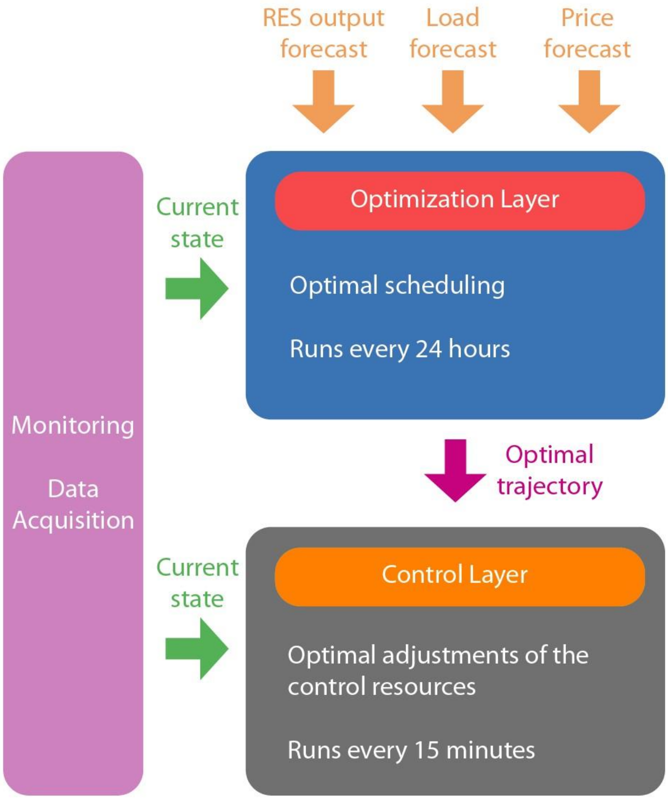

Figure 1 Microgrid operation scheme using optimization and control layer

2. Microgrid Optimization Model

The long-term goal of microgrid operation is the minimization of operating costs or maximization of profit, which are equivalent in this case. In other words, the goal is to satisfy all the local energy needs and maximize market performance by exercising arbitrage (selling electricity at high price and purchasing electricity at low price). Arbitrage can be exercised on time-of-use tariffs, which is common in today's retail. In this project, we are interested in the case when the price is transferred from the wholesale market (volatile thought day). If the price on a distribution-level market is volatile, small scale energy sources, or an aggregator in their name, can better utilize their flexibility. The point is to transfer wholesale dynamics to end-customers and use their aggregated flexibility to further lower total system costs. In the rest of this section, we consider a microgrid under dynamic pricing, and refer to this price as market price.

We consider a general case in which a microgrid consists of the following generic elements:

- inflexible demand,
- flexible demand (capable of providing demand response),
- thermal generator, e.g. Diesel generator,
- photovoltaic plant,
- wind turbine,
- energy storage, e.g. batteries

The objective of the microgrid operation is the maximization of its profit:

$$Maximize\left[\sum_{t\in\Omega^T}\lambda_t\left(q_t^s-q_t^p\right)-c_t\right] \qquad (1)$$

The revenue is made by selling electricity q_t^s at price P_t, while expenses include electricity purchased in the market q_t^p at priceP_t and cost of the local generation c_t. Objective function 1 is subject to the constraints that will be explained in the following subsections.

2.1. Power balance constraint

$$g_t^{th}+g_t^{w}+g_t^{pv}+s_t^{dis}+dr_t^f+q_t^p=D_t^{nf}+D_t^f+drr_t^f+s_t^{ch}+q_t^s, \qquad \forall t\in\Omega^T \qquad (2)$$

On the left-hand side are the terms that inject electricity (thermal generator, wind turbine, photovoltaics, discharging of storage, reduced part of the flexible demand, and electricity purchased from the distribution network), while on the right-hand side the terms that withdraw electricity (non-flexible load, flexible load, retrieved part of the reduced demand, charging of storage, and electricity sold into the local distribution network).

2.2. Thermal generator model

$$g_t^{th}\le P^{max}*x_t, \qquad \forall t\in\Omega^T \qquad (3)$$

$$g_t^{th}\ge P^{min}*x_t, \qquad \forall t\in\Omega^T \qquad (4)$$

Thermal generators might have minimum stable output, i.e. level of minimum sustainable output which a generator unit is capable of producing. This means that the thermal unit is either off or its output is higher than its minimum stable output.

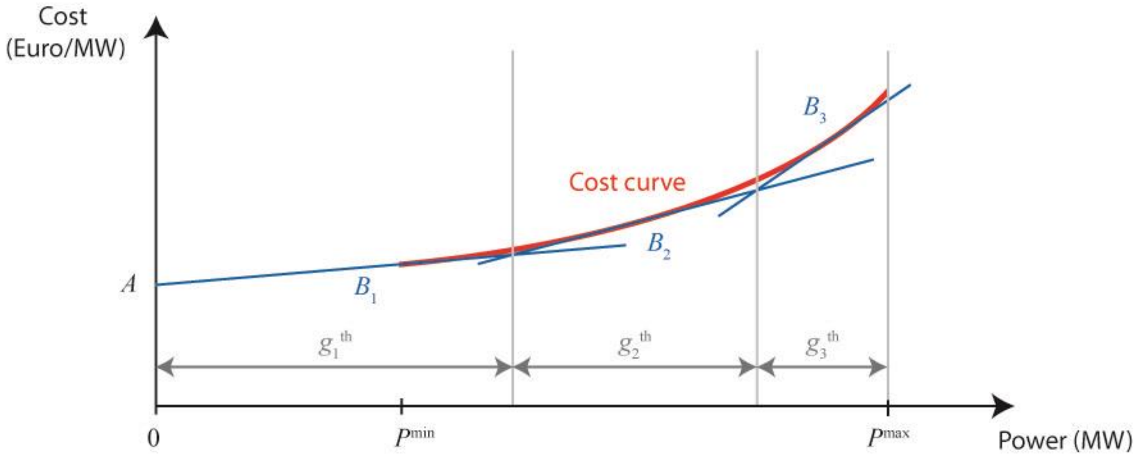

Figure 2 Piecewise linear cost curve of a thermal generator

To model this, we need to introduce binary variable x_t. Constraints 3 and 4 work in the following way: if x_t takes value 0, g_t^{th} is forced to zero and the unit is off; if x_t equals 1, 3 limits g_t^{th} from above g_t^{-th} and from below to g_t^{th}?.

$$y_t - z_t = x_t - x_{t-1}, \qquad \forall t \in \Omega^T \tag{5}$$

$$y_t + z_t \leq 1, \qquad \forall t \in \Omega^T \tag{6}$$

In order to model start-up cost and minimum on and off times of thermal generator, we need to know in which time period the thermal generator was started and in which it was shut down. This is modelled through binary variables y_t (value 1 if thermal generator is started during time period t and zero otherwise) and z_t (value 1 if thermal generator is shut down during time period t and zero otherwise). Constraint 5 determines if thermal generator is started up or shut down during time period t based on the change of its on/off status, i.e. binary variable x_t , between time periods t and $t-1$. Constraint 6 ensures that thermal generator cannot be started up and shut down during the same time period.

$$c_t = S^{th} * y_t + A * x_t + \sum_{m \in \Omega^M} B_m * g_m^{th}, \qquad \forall t \in \Omega^T \tag{7}$$

$$g^{th} = \sum_{m \in \Omega^M} g_{m,t}^{th}, \qquad \forall t \in \Omega^T \tag{8}$$

$$g_{m,t}^{th} \leq P_m^{max}, \qquad \forall t \in \Omega^T, m \in \Omega^M \tag{9}$$

A general thermal generator cost curve is non-linear (red curve in figure 2). In order to preserve the linearity of the optimization model, this curve is linearized by pieces (blue lines in figure 2). On top of this, if a thermal generator is started during time period t, it induces start-up cost S^{th}. Thermal generator output cost is thus modelled in constraint 7 as the sum of the start-up cost, no-load cost and variable cost that depends on the generator output. Since the start-up cost should be only considered

in the first time period a thermal unit went on-line, constraint 5 sets appropriate value to the binary value y_t indicating that the thermal unit went on-line during time period t. Finally, constraint 8 sets the thermal generator output to the sum of its piecewise segments, which are limited in 9. Since the output curve is concave, variables $g_{m,t}^{th}$ will start assigning output to the first piece of the linearized cost curve, then the second, and so on, resembling the real-life operation of a thermal generator. This is because the slope of the cost curve B_m is lowest for the first part of the curve and then monotonically increases until the last piece of the cost curve.

$$x_t = x_0, \qquad \forall t \in [0, L^{up} + L^{dn}] \tag{10}$$

$$\sum_{tt=t-UT-1}^{t} y_{tt} \leq x_t, \qquad \forall t \in [L^{up}, T] \tag{11}$$

$$\sum_{tt=t-DT-1}^{t} z_{tt} \leq 1 - x_t, \qquad \forall t \in [L^{dn}, T] \tag{12}$$

Constraint 10 sets the on/off status for the first part of the optimization horizon based on the initial status of the generator. For example, if the generator must stay on for three hours, L^{up} will be 3, and L^{dn} will be 0. If no minimum up or down time constraints are active at the beginning of the scheduling horizon, both and will be 0. Constraints 11 and 12 enforce minimum up and down time for the remaining time intervals.

$$g_t^{th} - g_{t-1}^{th} \leq RU^{th}, \qquad \forall t \in \Omega^T \tag{13}$$

$$g_{t-1}^{th} - g_t^{th} \leq RD^{th}, \qquad \forall t \in \Omega^T \tag{14}$$

Since thermal generators cannot instantaneously change their power output, constraints 13 and 14 are used to limit the amount of output a thermal generator can change in between each two consecutive time periods. Constraint 13 limits the up-ramping capability of thermal generator to RU^{th}, while 14 limits the down-ramping capability to RD^{th}. Generally, the higher $RU^{th}$and RD^{th}, the more flexible the thermal generator, which helps counteract the intermittency of renewable generation.

2.3. Wind turbine output

$$g_t^{w} = P_t^{w} - g_t^{w,curt}, \qquad \forall t \in \Omega^T \tag{15}$$

Available wind turbine output P_t^w is mostly used to supply the microgrid, which is modelled through variable g_t^w , but in some cases, can be curtailed, which is captured by variable $g_t^{w,curt}$.

2.4. Photovoltaic output

$$g_t^{pv} = P_t^{pv} - g_t^{pv,curt}, \qquad \forall t \in \Omega^T \tag{16}$$

Similar to the wind turbine output, the photovoltaics output P_t^{pv} comes at no operating cost. Variable g_t^{pv} represents the portion of available photovoltaics output used to supply the microgrid, while $g_t^{pv,curt}$ is the curtailed portion.

2.5. Storage model

Energy storage is characterized by its state of charge, which is changing over time, and operates within the minimum and maximum state of charge. On top of this, storage device is limited by its charging and discharging ratings and efficiencies. Microgrids can contain different types of energy storage, e.g. flywheels, fuels cells or any of the battery technologies. Here, we present a generic energy storage model independent on the storage technology itself.

$$soc_t = soc_{t-1} + s_t^{ch} * \eta^{ch} - \frac{s_t^{dis}}{\eta^{dis}}, \qquad \forall t \in \Omega^T \tag{17}$$

$$SOC^{min} \leq soc_t \leq SOC^{max}, \qquad \forall t \in \Omega^T \tag{18}$$

$$s_t^{ch} \leq S_t^{ch,max} * h_t, \qquad \forall t \in \Omega^T \tag{19}$$

$$s_t^{dis} \leq S_t^{dis,max} * (1 - h_t), \qquad \forall t \in \Omega^T \tag{20}$$

Energy storage state of charge is calculated using equation 17. State of charge in the current time period is equal to the state of charge in the previous time period plus the energy charged minus the energy discharged. Both charging and discharging processes are imperfect and their respective efficiencies are considered. Constraints 18-20 limit the energy storage state of charge, charging power and discharging power, respectively. In order to avoid simultaneous charging and discharging, binary variable h_t is introduced. This variable takes value 1 if the storage is charged and 0 if it is discharged during a time period.

2.6. Demand response model

Demand response presents a portion of flexible demand that is reduced at a certain time period. This means that the load is increased at other time periods in order to satisfy the comfort within the building that is a part of the microgrid, the constraints of an electricity consuming process within the microgrid, or the requirements of any other flexible load. Depending on the load, more or less load than reduced will be retrieved at other time periods. For instance, if the flexible load in question is lighting, the retrieved load at other time periods will be close to zero, because if the light in a room is dimmed due to demand response action, it will not result in brighter light at other time periods. On the other hand, devices from the heat-ventilation-air conditioning group will yield higher demand retrieval, thus resulting in higher overall demand. An example of the load whose demand response actions do not change the overall demand are pool pumps. A generic flexible load is modelled using the following constraints.

$$dr_t^f \leq DR_t^{f,max} * \alpha_t^f, \qquad \forall t \in \Omega^T \tag{21}$$

$$drr_t^f \leq DRR_t^{f,max} * \beta_t^f, \qquad \forall t \in \Omega^T \tag{22}$$

$$\alpha_t^f + \beta_t^f \leq 1, \qquad \forall t \in \Omega^T \tag{23}$$

Constraint 21 limits the amount of flexible load that can take part in demand response at each time period to dr_t^f, while constraint 22 limits the amount of flexible load that can be recovered at each time

period to drr_t^f. The role of binary variables α_t and β_t is to prevent simultaneous reduction and recovery of the flexible demand within the same time period. Note that this would happen in case of flexible demand whose return ratio is below 100%.

$$K^f * \sum_{t \in \Omega^T} dr_t^f = \sum_{t \in \Omega^T} drr_t^f, \qquad \forall t \in \Omega^T \tag{24}$$

In order to enforce the retrieval of the reduced flexible demand within the optimization horizon, constraint 24 uses the load retrieval coefficient K^f. This coefficient depends on the type of deferred load and ranges from 0 for lights to 1.2 and beyond for heating and cooling devices.

Depending on the flexible load type and the desired operating paradigm, some of the following constraints can be added.

If demand recovery has to start as soon as the demand response is over:

$$\beta_t \geq \alpha_t - \alpha_{t-1}, \qquad \forall t \in \Omega^T \tag{25}$$

Demand response duration limit is imposed using the following constraint:

$$\sum_{tt=t-1}^{t+DUR^{dr}} \alpha_{tt} \leq DUR^{dr}, \qquad \forall t \in \Omega^T \tag{26}$$

Demand response recovery duration limit is imposed using the following constraint:

$$\sum_{tt=t-1}^{t+DUR^{drr}} \alpha_{tt} \leq DUR^{drr}, \qquad \forall t \in \Omega^T \tag{27}$$

If demand can be recovered only after it had been reduced, i.e. no pre-cooling or pre-heating, the following constraint should be used:

$$\sum_{t \in \Omega^T} dr_t^f \geq K^f * \sum_{t \in \Omega^T} drr_t^f, \qquad \forall t \in \Omega^T \tag{28}$$

3. Modelling Example

As an illustrative example, we model a microgrid that consists of a non-flexible load, two flexible loads, two thermal generators, a wind turbine, a battery storage, and photovoltaics. We optimize the microgrid operation for the 24-hour time horizon with a 1-hour time step. Load, available wind output, available photovoltaic output and electricity prices throughout the day are given in Table 1. Non-flexible load represents aggregated fixed loads. The first flexible load represents an industry--grade heating or cooling device whose load does not change much during the day. Only 20% of the load can be reduced at any time period and hourly load can be increased by up to 40% when returning the reduced load. Load return factor for flexible load 1 is 1.2, meaning that 20% more energy that was reduced needs to be returned. Additionally, the load reduction cannot occur in two consecutive hours.

The second flexible load represents a constant load in a two-shift operated industry process where machines start operating at 7 am and operate for 16 hours until 10 pm. Therefore, all the increase and decrease in demand can only occur during those 16 working hours. Hourly load can be reduced by up to 20% and up to 30% of the hourly demand can be retrieved at each hour. The load return factor is 1.1.

Thermal generator data are provided in Table 2. The microgrid contains two thermal generators rated at 3.3 and 4.2 MW. The first generator has lower minimum output, 0.4 MW, but needs two hours to reach its full capacity after being offline. The second generator has high minimum stable output, 1.5 MW, but high ramp rates (it can start up and reach its rated output within one hour). Minimum up and down times of generators 1 and 2 are two and three hours, respectively. Generator 1 has slightly higher start-up cost, but lower fixed generation cost and lower piecewise generation costs. Generation cost curve of both generators is divided into three equal parts (three times 1.1 MW for generator 1 and three times 1.4 MW for generator 2). Both generators had been off for three hours before the optimization horizon, i.e. both can be started up at any point during the day.

Battery storage energy capacity is 3 MWh, while charging and discharging rates are 2 MW. Minimum state of charge is 20% of the energy capacity and both charging and discharging efficiencies are 92%. Prior to the optimization horizon, the storage state of charge was at 50% of its capacity and it needs to end the day at the same level.

3.1. Results of the deterministic simulation

The overall profit in the deterministic case is $-€3795.1$, which is the sum of the local thermal generation cost, $€4264.2$, and market profit, $€469.1$. Generator actions are shown in Figure 3. Generator 1 starts operating at 5 am, in order to support the increased load and compensate for the reduced wind output. Due to the up-ramp limit, its output reaches only 2.5 MW at hour 5. From hour 6 onward, it operates at its full capacity. On the other hand, generator 2 starts up at hour 8 and reaches its maximum output within this hour because its up-ramp constraint is not binding. This generator stays in operation at its capacity until the end of the day as well.

Table 1 Load (MW), available wind output (MW), available photovoltaic output (MW) and electricity prices (€/MW) throughout the day

Hour	Non-flex. load	Flex. load 1	Flex. load 2	Wind	PV	Prices
1	1.5	0.3	0	1.3	0	16
2	1.5	0.3	0	1.2	0	17
3	2	0.4	0	1.4	0	18
4	2	0.3	0	0.8	0	16
5	2.5	0.5	0	0.7	0	19
6	4.5	0.5	0	1.1	0	18
7	5	0.6	1	0.8	0.05	22
8	7	0.6	1	0.5	0.1	28
9	7	0.7	1	0.4	0.2	27
10	6.5	0.6	1	0.7	0.25	34
11	6.5	0.6	1	0.9	0.2	30
12	7.5	0.8	1	0.5	0.4	28
13	6	0.6	1	0.6	0.4	26
14	5.5	0.7	1	1	0.6	33
15	5.5	0.7	1	1.1	0.45	39
16	5	0.6	1	0.8	0.4	29
17	4.5	0.5	1	0.7	0.3	31
18	6	0.6	1	0.3	0.15	38
19	7	0.4	1	0.5	0	44
20	7.5	0.6	1	0.2	0	48
21	7	0.5	1	0.4	0	38
22	5	0.4	1	0.4	0	31
23	3	0.3	0	0.5	0	28
24	2.5	0.3	0	0.6	0	27

Table 2 Thermal generator data

	Generator 1	Generator 2
Capacity, MW	3.3	4.2
Min. output, MW	0.4	1.5
Up ramp, MW/h	2.5	6
Down ramp, MW/h	2.5	6
Min. up time, h	2	3
Min. down time, h	2	3
Start-up cost, €	750	600
Fixed generation cost, €	11	17
Cost curve capacity (segment 1), MW	1.1	1.4
Cost curve slope (segment 1), €/MW	14	19
Cost curve capacity (segment 2), MW	1.1	1.4
Cost curve slope (segment 2), €/MW	15	20
Cost curve capacity (segment 3), MW	1.1	1.4
Cost curve slope (segment 3), €/MW	16	21

Demand response actions are shown in Figure 4. Flexible load 1, which is a cooling/heating device, performs precooling/preheating during the night hours to take advantage of the high wind turbine output and low market prices. The demand is reduced during the high net load hours (net load is defined as the actual load minus the output of the non-controllable resources such as wind and solar) respecting the constraint that forbids demand reduction during two consecutive hours. Overall, 0.86 MW of flexible load 1 was curtailed and 1.032 MW was retrieved. Flexible load 2 operated in a way that reduces the net demand in the high-price hours (hours 15 and 18-21 are the ones with the highest market prices). Overall, 1.5 MW of the flexible demand 2 was reduced and 1.65 MW was returned.

Energy storage operation throughout the day is shown in Figure 5. The storage is charged from 50% to 100% state of charge in the first hour and stays fully charged until the end of hour 9. Discharge at the maximum rate in hour 10 is the result of the high price spike (34 €/MW) in the market. The afternoon minimum market price in hour 13 is used to fully charge the storage. Afternoon spike price at hour 15 (39 €/MW) causes storage to discharge at the maximum rate and again charge in the following hours at lower prices. Storage is again discharged to the minimum state of charge during hour 20, i.e. the time period with the highest market price 48 €/MW. Finally, the storage is charged back to the initial capacity in the last hour at a low price.

Interaction of the microgrid and the market is shown in Figure 6. During the low-price hours 1-9, 12 and 13, the electricity is purchased from the market. During the high-price hours 10, 14 and 15, the electricity is sold in the market. However, during the evening high-peak hours 18-21, not much electricity is sold in the market to make profit. This is the result of the high local load in the evening hours, as visualized in Figure 6. The positive stacked bars sum the resources that supply the demand (thermal generators, storage discharge, demand response, wind turbine output, photovoltaic output, and electricity purchased in the market), while the negative stacked bars combine the resources being added on top of the base demand (non-flexible and base flexible demand), such as storage charge, returned demand response and electricity sold in the market. The return of the reduced demand appears as small negative bars in hours 1 through 7 (DRR 1) and hours 7-9, 11-13 and 15 (DRR 2). The

excess electricity is used either for charging the storage (in hours with low market prices) or selling in the market (in hours with high market prices). The demand in hour 19 is barely satisfied with the available generation and low storage discharge, while the storage is discharged at the maximum rate in hour 20, in order to maximize the sold electricity in this peak-price hour. Insufficient local capacity in hour 21 is supplemented with purchased electricity from the market. Since the generation cost of thermal generators is lower than the market prices in hours 22-24, their excess output is sold in the market. Throughout the day, the microgrid sells 13.7 MWh and purchases 23.3 MWh from the market.

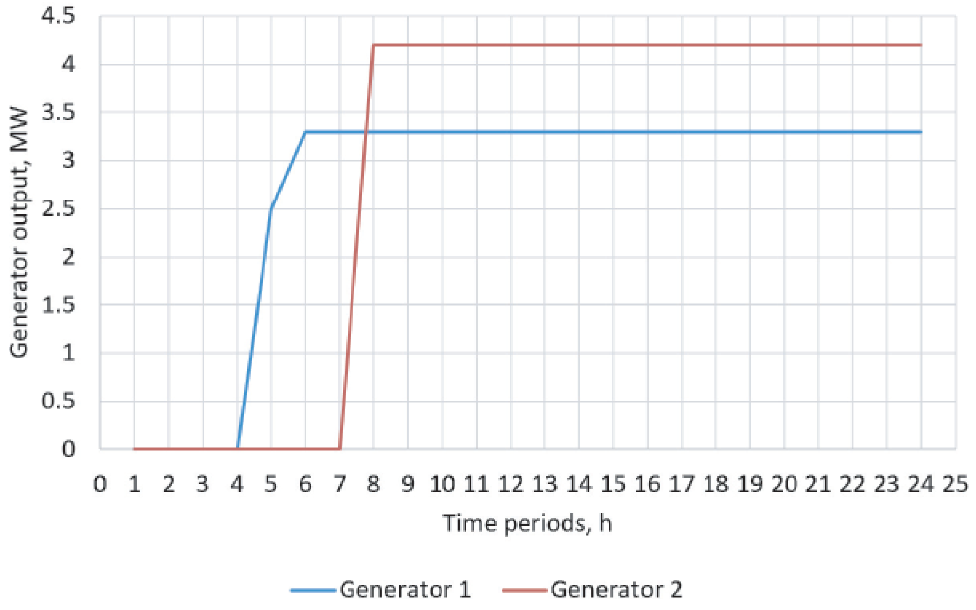

Figure 3 Generator operation throughout the day

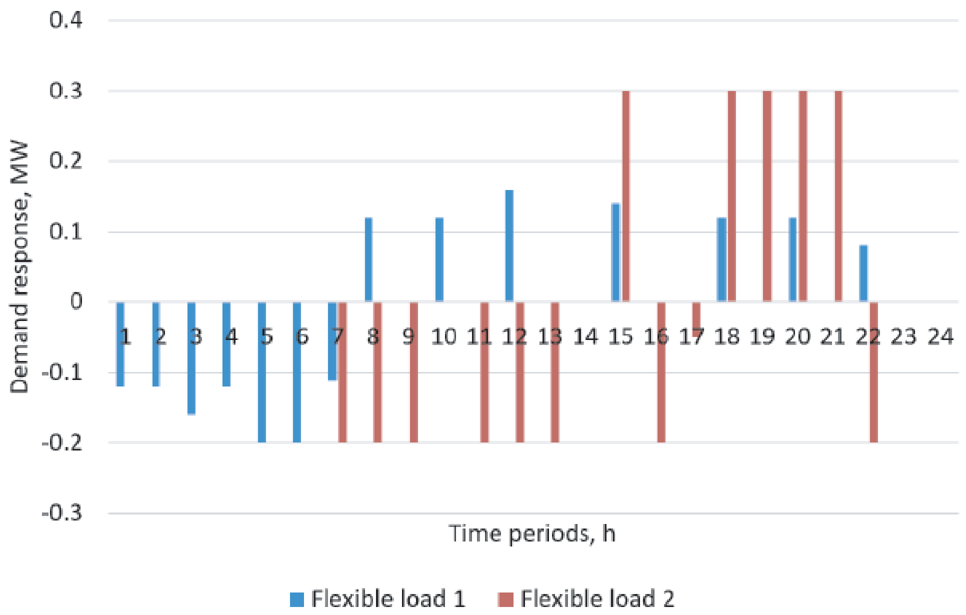

Figure 4 Demand response actions throughout the day for the deterministic case

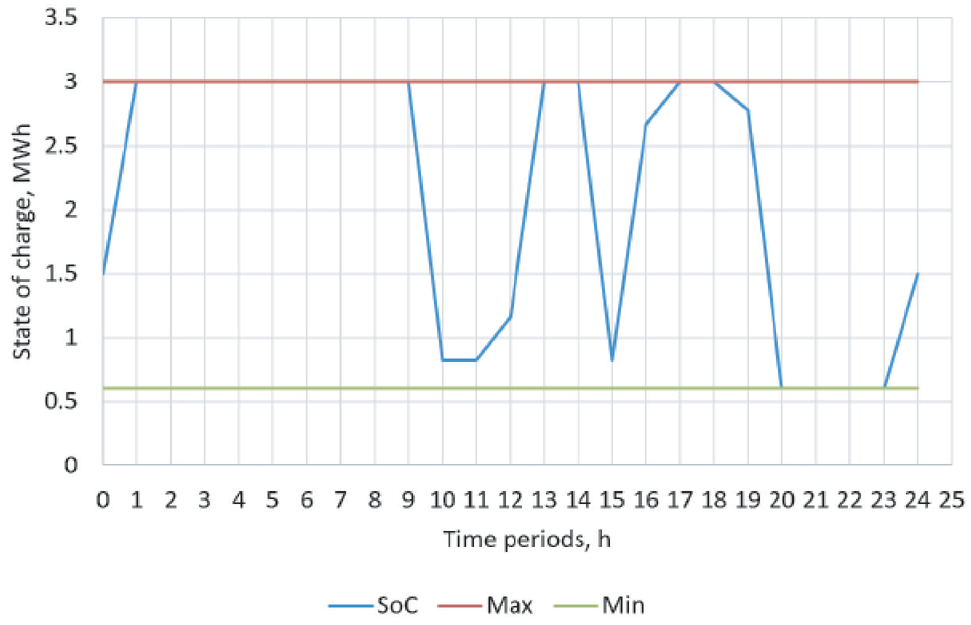

Figure 5 Storage state of charge throughout the day

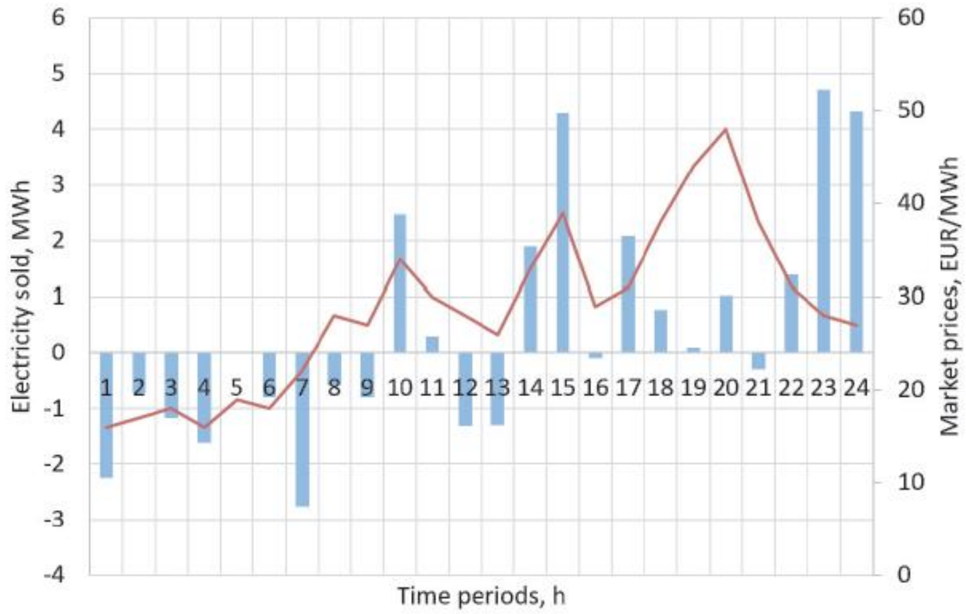

Figure 6 Microgrid - market interaction throughout the day

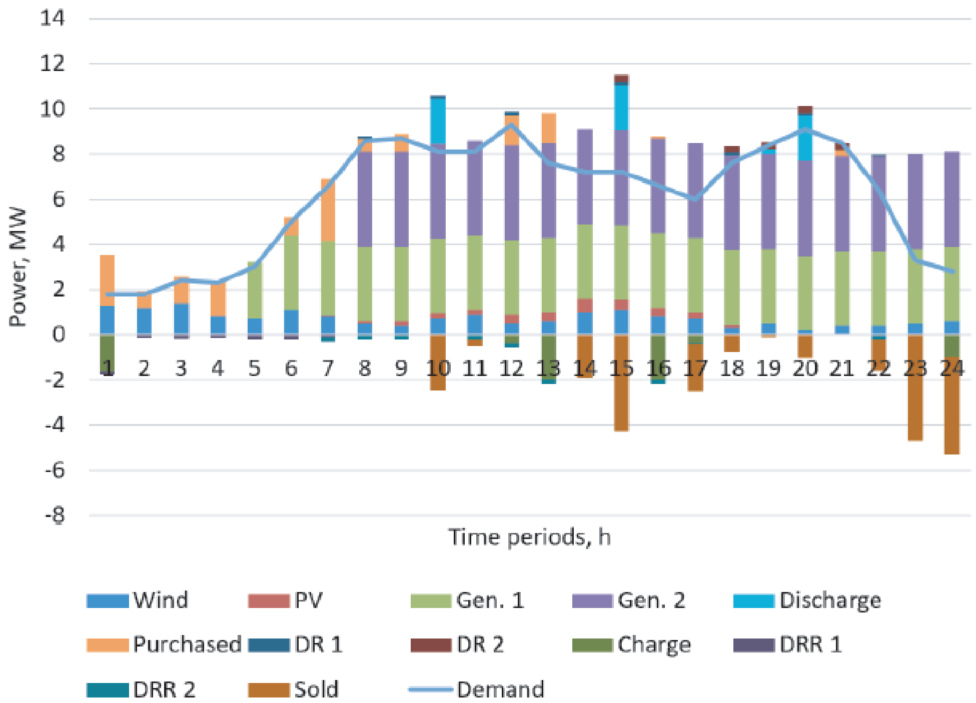

Figure 7 Power balance throughout the day

4. Conclusion

Deterministic baseline microgrid model introduced in this report will serve as a basis for the development of stochastic microgrid model that will include uncertain parameters. The following uncertain parameters will be included: output of local renewable energy sources (wind turbines and photovoltaics), local load curve, and electricity prices. The main goal of stochastic model will be to outperform deterministic baseline model.