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Full-scope simulation of grid-connected microgrids

dr. Attila KOVÁCS, Róbert GAÁL
Astron Informatics Ltd.
Hungary

SUMMARY

In the near future, with the spread of renewable distributed energy generation and storage technology, microgrids will become increasingly relevant components of power systems. In the analysis of their operation and interaction with the adjacent network, the application of simulation is indispensable.

A microgrid can be considered as a mini power system having its own effective power – frequency and voltage control, but it can be decoupled from the network only in special cases. However, using its generating capacities and intelligent consumers, it is able to follow transaction schedules. In addition, in the main operational states (i.e. islanding, parallel operation) the microgrid control system is able to follow different policies and controlling objectives (minimizing the energy infeeding from the adjacent grid, optimizing the usage of storage- and renewal generation units etc.).

The Liveable Future Park in Fót, Hungary, sponsored by the local electricity supplier, has a low-voltage microgrid connected to the medium voltage utility network, comprising renewable generating units, consumers and a SCADA-/microgrid controlling system. As part of the project, a Full-scope Microgrid Simulator was created (FMS), allowing researchers to study various controlling schemas in different weather conditions, without disturbing the everyday running of the park. An attractive simulation user interface was also developed to demonstrate microgrid operations for visitors.

The current paper presents the features and operational experiences of FMS, putting a special emphasis on the extension of distribution network modelling with renewal generation and microgrid controlling. Due to its modelling principles, FMS may effectively support the design and future operation of microgrids.

KEYWORDS

simulation, microgrids, network modelling, renewal power generation

1 Microgrid modelling principles

A microgrid can be defined simply as a physically separable part of the distribution network, comprising generation, consumption, and network controlling equipment. It is able to operate either connected to the adjacent network (parallel, or coupled mode), or separately (islanding, decoupled mode). When simulating microgrids - besides describing (medium or low voltage) distribution network components (lines, cables, switching equipment) - a special emphasis must be put on modelling:

- *Renewable generation units* (solar cells, wind- and water turbines) including the simulation of weather conditions.
- *Consuming units*. Due to the small amount of these, major loads must be modelled not statistically but uniquely (e.g. a heat pump of a large building).
- *Storage unit* (large-capacity accumulator) that can both generate or consume energy.
- *Microgrid control system* monitoring internal generating-, storage- and consuming units. It can optimize the energy purchase from the adjacent network, set up islanding operational state etc.

It is a further modelling aspect that in the decoupled operation mode system-level controlling issues (effective power-frequency balance, voltage regulation) arise at a low level, inside the microgrid. Full-scope simulation of microgrids is therefore a complex task as both detailed, equipment level models of the distribution network and system level models (load-flow, P-f) must be applied.

The main objective of the simulation is to gain operational experience with microgrids (e.g. studying different operational modes, controlling schemas). Thus a quasi-stationary modelling of the changing of time-continuous network and equipment parameters, completed with a detailed simulation of discrete state changes provides satisfactory results. Similarly to training simulators, modelling electrical transients is not a requirement here.

FMS was realised with a further development of an existing Network Training Simulator (NTS) specially developed for the modelling of distribution networks ([3]). Models of microgrids and the necessary user interface components were added to NTS features.

2 Network and equipment models applied

2.1 Model of the electrical network

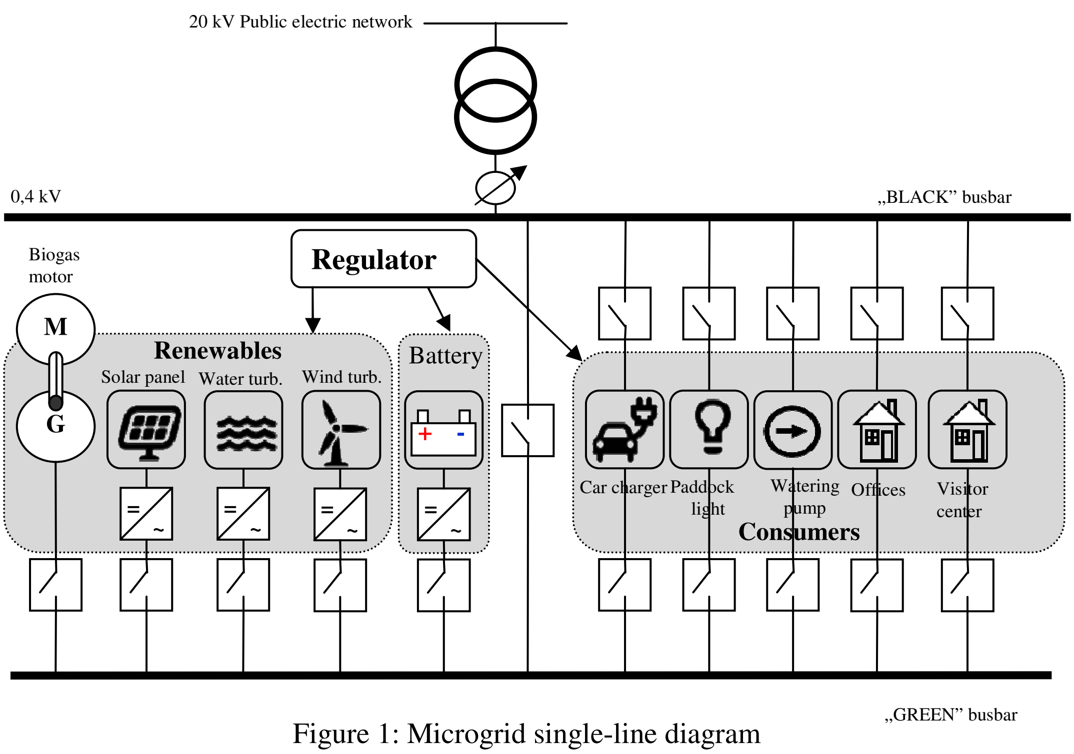

Figure 1: Microgrid single-line diagram

The overall single-line diagram of the network modelled in the FMS can be seen in Figure 1. It comprises two main parts:

a) The 20/0,4 kV infeeding transformer of the local electricity supplier is connected to the "black" busbar. The rated power is 160 kVA, being appropriate for the safe supply of all consumers of the Future Park.
b) Renewable generating units are connected to the "green" busbar via circuit breakers. Inverter and rectifier units are simulated in a simplified way, transparently.

Black and green busbars can be connected with a busbar coupler, so the parallel operation of the renewables with medium voltage infeeding and islanding can be simulated too.

Major consumers are modelled individually, minor ones are grouped together, based on their electrical behaviour and location (e.g. offices, visitor center). Consuming units can be connected either to black or green busbars. An interlocking mechanism prevents them from being connected to both busbars at the same time. If the busbar coupler is switched off, the switch-over of a consumer can only be executed if its circuit breakers are not switched on simultaneously (dark switch-over).

Feeders of the generating units and consumers are equipped with measuring transformers for indicating current and power values.

2.2 Load-flow calculation

The power flows and voltages are calculated by an iterative load-flow (LF) algorithm. However the LF used in microgrids differs significantly from one used in the meshed networks of transmission and distribution systems ([1]). The reasons are the following:

- The R/X ratio of microgrids is much higher than that of transmission and distribution networks, so decoupled fast LF algorithms cannot be applied. In addition, the large impedances may cause divergent calculation.
- Microgrid topology is often radial, so potential-based, simplified computing methods ([2]) can be used, combined with iterative LF algorithms.
- Usually there are no voltage regulating nodes, and the devices for the voltage-reactive power regulation generally used in high- or medium voltage networks are missing too.
- Asymmetric voltage-/loading states may occur easily, so load-flow calculation per phase must be used. The network calculation model here is impacted by zero sequence parameters, and the handling of the starpoint of the supplier transformer and consumers. Unfortunately, running LF algorithm per phase triples the calculation efforts.

2.3 Effective power – frequency modelling

The simulator uses the so called single node power-frequency (P-f) model. It means that the connected network (island) is considered as one node, where every network element operates on the same current frequency and the power-swings on the branches of the network are not modelled. Each consumer has its own P(f) characteristics. The simulator algorithm separately calculates the resulting P-f characteristic of the island for consumers and generators. The current operating point will be the intersection point of these two curves in the P-f coordinate system.

The simulator identifies the current operating frequency of the island and calculates the power of each generator and consumer via their P(f) characteristics and the current common island frequency. The P-f calculation is executed whenever the production or consumption changes.

2.4 Modelling of renewable generating units

In FMS the following generating units are modelled: solar, wind turbine, water turbine. All of these are simulated with the pairing of a general generating equipment (GGE) model, and a primary energy conversion (PEC) model. The different characteristics of renewable units are modelled with the suitable parameterization of the GGE and the approppriate selection of PEC method.

2.4.1 General generation equipment model

GGE has the following parameters and characteriscics:

- Switching status (ON/OFF). In switched off state its output power is zero.
- Limitation of the output effective power (P_{min}, P_{max}).
- Reference input (setpoint) for the desired effective power (P_{setp}). It can be provided by the controlling unit, the PEC model, the power profile, or it can be set up manually in the user interface. If P_{setp} is out of the range determined by P_{min} and P_{max}, then the limit values act, as setpoints (see Chapter 3.2).
- Associated ramp up/-down curves (see 2.7.2). These specify how the generating unit output power will follow the sudden changes of P_{setp}. Using of ramping up/-down feature may be prohibited, in this case output power will follow the setpoint changes without any delay.
- P-f diagram of the unit. Actual frequency dependency of a unit is modelled with a linear function, later on several linear sections of different gradients may be used for describing the frequency behaviour of the unit in a major range around the nominal frequency.
- Controlling parameters can be set up if the actual unit is involved in microgrid regulation, or not. Also the priority (i.e. sequence) of the utilization of the unit for controlling purposes can be parameterized.

2.4.2 Model of primary energy conversion

Converting the power of primary energy sources described by windspeed [m/s], water runoff [m^3/s], sunlight intensity [W/m^2] into electrical effective power is simulated by respective conversion curves (see Figure 2).

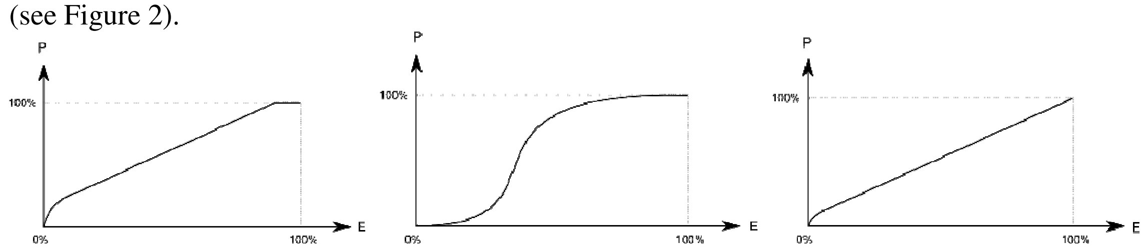

Figure 2: Typical sunlight intensity, windspeed, water runoff conversion curves

Calculation of sunlight intensity conversion is also affected by the following factors:

- Period of the day: in FMS the daily change of sunlight intensity (daily profile in relative units) can be defined for both winter- and summertime. When the user sets up the simulation date and time, the system will automatically adjust the proper conversion for all generating units, based on the conversion curves in relative units, the daily profiles in relative units, and the numerical ranges of the related quantities.
- Cloud coverage: Daily profiles of sunlight intensity refer to a completely clear, sunny weather. Cloud coverage value (0..100%) can be adjusted by the user, and the actual profile value will be reduced proportionally.
- Air temperature: The efficiency of photovoltaic cells decreases with the increase in temperature. FMS simulates this phenomenon with a simple linear coefficient $K*(\tau_{ext\_act} - \tau_{ext\_start})$, where K is a practical proportional factor, τ_{ext_act} and τ_{ext_start} are the initial and the actual environmental temperature values respectively. Effective power calculated according to daily profile and cloud coverage will be modified based on this temperature factor.

Sunlight intensity can be adjusted in the user interface as well. This value will be applied by the simulator without any of the modifications described above.

2.5 Battery model

The battery can be used both as an energy producer and a consumer unit playing an important role in regulation of the microgrid. In FMS the battery is modelled by electrical energy storage and charge-discharge controller equipment. These contain parameters and processes, which are relevant in the simulation of microgrid behaviour.

The battery has the following parameters:

- Maximum nominal capacity of the battery (C_{nommax}, in [Wh]).
- Minimum level of charge (C_{minlev}). Under this charge level electricity cannot be gained from the battery. This cannot be higher than C_{nommax}.
- Maximum level of charge (C_{maxlev}). On reaching this level of charge, the charger does not continue charging the battery, in other words it does not consume electric energy from the network. It cannot be lower than zero.
- Actual level of the electric charge (C_{act}). This increases if the battery is charged and decreases if it is discharged. The simulator calculates this variable cyclically with Δt period time. The change of the charging level is $\Delta C = P*\Delta t$, where P is the average of the charging or discharging power during the last Δt time. The actual level of capacity is calculated with the following formula: $C_{act} = C_{pre} + \Delta C = C_{pre} + P \cdot \Delta t$, where C_{pre} is the level of charge at the beginning of the calculation cycle. The sign of the charging power is positive, that of the discharging power is negative.
- The ratio of charging level is $C_{ratlev} = C_{act}/C_{nommax} *100$ [%] This can be varied between 0 and 100%.

The battery cooperates closely with the charge-discharge controller equipment with the following parameters:

- In switched off state its output power (P_{out}) is zero.
- In charging mode it consumes energy from the network, and it behaves like a consumer.
- In discharging mode it feeds energy into the network, behaving like a generator.
- The output power depends on the prescribed set point power (P_{sp_ch} or P_{sp_dc}) which is limited by the maximum charging (P_{max_ch}) and discharging (P_{max_dc}) power.
- The output power follows the change of set point power according to an associated ramping curve. The model can handle different ramping curves for charging and discharging modes. This feature can be disabled. In this case the P_{out} follows the value of the set point without any delay.

2.6 Model of the public electric network feeder

The microgrid is connected to the medium voltage public distribution network through a 20/0,4 kV feeder transformer. In comparison with the microgrid, the public network can be regarded as infinite. In parallel mode the power difference of production and consumption flows through the feeder transformer. The electrical power consumed or generated by the microgrid is concentrated at the connection point to the public network.

The load-flow calculation of distribution network handles the concentrated microgrid power the same as other consumers, and calculates the voltage at the medium voltage connection point. This will be an input value for voltage potential calculation of the microgrid. The voltage potential calculation identifies the internal voltages of the microgrid (voltage drops) considering the electrical parameters of the feeder transformer.

2.7 Modelling of generation and consumption in time domain

2.7.1 Daily profiles and schedules

The changes of analogue values in time are modelled with the help of profile curves in the simulator, describing the changes in a 0-100 % range with relative units. These profiles can be assigned to different devices, like generators or consumers. The relative units are rescaled according to the maximum power of a given device. The resulting schedules contain absolute values considered to be the prescribed power of the devices. At the renewables the profiles can be assigned not only to electric power but also to primary energy resources like wind-force, solar radiation or water runoff. By using schedules the life of the microgrid can be modelled realistically.

In the microgrid of Fót Liveable Future Park a SCADA system is applied collecting various technological data, among others the changes of generation and consumption. These measured schedules can be imported into the simulator and with their help a real day of the microgrid can be studied.

2.7.2 Ramping up and down of effective power during the simulation

During the operation of the microgrid the power demand or the generated power will not change continuously. For example, a consumer may suddenly be switched on or a generator may suddenly be disconnected from the network. It means that the required output power (setpoint) of energy producers suddenly changes in order to keep the power balance of the microgrid. This transient process has significant influence on microgrid operation since these small networks do not contain a meaningful amount of rotating mass to support stability. In reality the output power of generating devices can only change continuously. By modelling ramping up and down the effective power microgrid behaviour can be exactly simulated. This is especially important in islanding operation mode when a microgrid behaves similarly to a large energy system.

The algorithm of the generator model is run cyclically by the simulator engine. The time length of a calculation cycle can be parameterized by the user. The output power of the generator tries to follow the desired input power (setpoint). If the setpoint value is greater than the actual output power of the generator, the algorithm calculates the next value of the output power to the end of the next cycle ahead according to the ramping up factor. In the reverse case the calculation is made with the ramping down factor. The ramping process is continued until the actual output power reaches the setpoint value. The ramping process is shown in Figure 3.

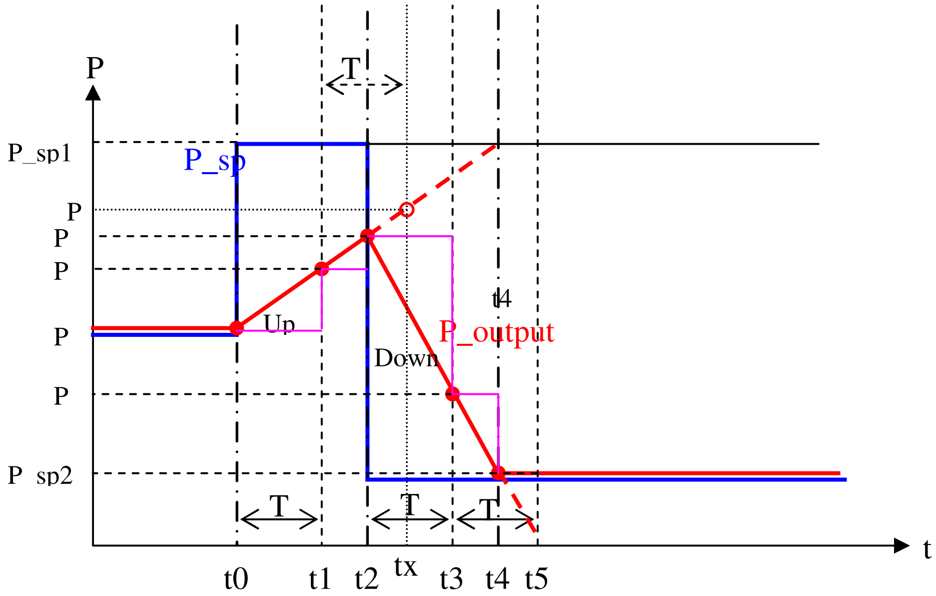

Figure 3: Ramping up and down

Legend:

P_sp:	Setpoint (input) for generator.
P_ output:	Actual out power of the generator.
Up:	Ramping up factor.
Down:	Ramping down factor.
T:	Length of the calculation time cycle.
P0:	Initial value of the setpoint and the output power until t0 time.
t0 :	Time of first change of setpoint value.
t1:	Absolute time of the first calculation.
P_sp1:	Increased setpoint value.
P1:	The first calculated output power in ramping up direction.
P_sp2:	Decreased setpoint value.

t2:	Time of the second change of the setpoint value.
P2:	Current value of the output power calculated at the time t2.
tx:	The absolute time of the next calculation cycle if the setpoint value has not changed again.
px:	The next output power value at the time tx if the ramping up process has continued.
t3:	The time of the next calculation following change time of setpoint.
P3:	The output power value calculated at time t3 during the ramping down process.
t4:	Time when the output power reaches the current valid setpoint value (P_sp2).
t5:	The next calculation time, if the output power has not already reached the setpoint value earlier.

3 Simulation environment, simulator functions

3.1 The simulator engine

FMS is based on the simulation models and discrete simulation engine of NTS (Network Training Simulator ([3], [4])). NTS is mainly used for network operator training purposes, so besides the calculation of analogue values (load-flow and frequency model) it has advanced functionality for the simulation of processes represented by various discrete technological events, like protection and automation operations. The processes are simulated as a snapshot-series of stationary states of the electrical network. Transient and subtransient status changes are not emphasized.

NTS models the devices as a synchronous sequential network. For all types of devices a general device model can be applied. Its outputs depend only on its inputs and internal status variables. Inputs and outputs are connected by the internal algorithm (i.e. logic) describing the logical operation of the given real device. Devices can be connected via their ports. The simulator engine (Discrete Time Simulation Module) runs the internal algorithms of devices and distributes values of the device ports in the synchronous sequential network. In this way any complex system can be simulated.

This simulation method provides a uniform framework for the simulation both of devices operating in discerete manner (such as protections and automations) and devices characterised by analogous electrical quantities (like generators, consumers or energy storages).

3.2 Handling of different set-point sources

Setpoint values of the generator equipment may come from several sources. These are the next ones in order of increasing priority:

- Default value, which is set in base parameterisation.
- Schedule handler
- Regulator of active power
- Conditional event handler
- User interface

If nothing is set, the generator continuously provides the permanent active power parameterized in simulator database. If a schedule is assigned to the generator, it will follow the changes of the setpoint considering its ramping ability. The regulator function can overwrite the schedule according to the regulation strategy. If a conditional event (see Chapter 3.3) parameterized by the user has an impact on the setpoint input port of the generator and the condition is met, then the current valid setpoint will be the value set in the conditional event. The setpoint value set by the user has the highest priority. In other words the user can manually control the generation in the graphical user interface.

The setpoint handling function can run in two different operation modes. In manual setpoint operation mode the user can fix the source of the setpoint. In this case the simulator ignores the other setpoint sources. In automatic operation mode it is always the source of the highest priority that is in use.

3.3 Conditional events

During the operation of the electric power system one or several events can imply other events, forming a series of events, for example a sequence of protection operation initiated by a short circuit. In the simulator such causal relationships are usually modelled by equipment algorithms. However sometimes these causal relations are incidental and very unique, so their modelling with a special device algorithm would not be an economical solution. Such relations can be effectively modelled by conditional events.

The conditional event is composed of a condition and a command. Operand of the condition can be any equipment port, for example a switching element status or an analogue value of a measure transformer. The simple conditions can be combined to more complex conditions applying logical operators.

The command part of the conditional event can change any equipment port. For example, it can change a setpoint value or send a control command to a circuit breaker. The command will be executed if the condition is met (becomes true).

The conditional events can be organized into event groups. The simulator checks each condition when any equipment port was changed and executes those which become true. This way simple automations or regulators can be built up by composing conditional events quickly, which is very useful when studying microgrid behaviour.

3.4 Scenario management

The scenario is a special case of conditional events, where the condition is the time. Scenario management is one of the basic simulator functions. With the help of scenarios the user can program events with one second time resolution in advance. Scenarios can be saved, loaded and joined with each other.

4 Microgrid operational modes

A microgrid basically differs from a medium or low-voltage public network since the microgrid is able to consciously regulate its own electrical consumption. It can be achieved with the help of regulable consumers or energy producers, more often renewables (solar panels, small wind- or water turbines). The microgrid has its own power control system and is able to follow a schedule for taking energy from the public network or optimizing its own consumption and power generation. In extreme situations, for example when the public network is out of operation (black out), the microgrid can operate in standalone mode, supplying its own consumers with its own internal energy producers. In this operation mode the microgrid behaves similarly to the electric power system. However, the time constants of a microgrid are incomparably smaller ones, and network stability is also more vulnerable.

The regulator plays a key role in life of the microgrid. There can be various regulation purposes, but the most important thing is that the consumers are continuously provided with electrical energy as economically as possible. The more renewable energy is consumed, the more economical the operation of the microgrid will be. Almost all kinds of regulation purposes can be served with two basic regulation modes:

- Islanding operational mode
- Maximal utilization of renewable energy

These regulation modes will be outlined below.

4.1 Islanding operational mode, P-f controlling

In islanding operation mode the circuit breaker of the feeder MV/LV transformer is switched off. The consumers are fed by renewable generators.

The output power of the renewable generators is closely dependent on the availability and change of the primary energy sources (wind speed, sun radiation etc). The availability of primary energy is very varying, so planning and regulation of green energy production is often difficult. In addition, the main purpose is to maximize the use of this variable energy.

The number of consumers in the microgrid is relatively low and the consumed power of a consumer can be relatively high compared to the total consumption of the microgrid. In addition, the behaviour of the relatively few consumers cannot be described statistically as well as in large networks. Due to these facts it is not easy to plan the total consumption of the island, and sometimes it may change drastically (for example, when a large consumer is turned off or on).

However, the regulator has to ensure the balance between production and consumption of the island and it has to keep the proper island-frequency. This task cannot be solved without a fast-regulating power generator or consumer, which is able to eliminate the difference between production and consumption. An ideal solution could be a battery of properly high capacity and power that can be either a producer or a consumer. In addition, it does not require any external source of energy, and it can feed consumers during energy-shortages with energy accumulated in the over-production period.

Controlling actions by the regulator of the microgrid may be:

- determining the setpoint value of the renewable power generators,
- switching the consumers on or off,
- charging or discharging the battery.

The regulator changes the power of the units according to their priority order. The priority can be set per consumer or generator unit. The are two categories of consumers:

- Non-critical consumers, which can be switched off any time.
- Critical consumers. These can be switched off only in last case.

The regulation process uses and observes a few special charging levels of battery:

- If during the discharging process the charge of battery decreases to the so called *Consumer shifting level,* the regulator starts to switch off the non-critical consumers (e.g. electric water boilers) which can be rescheduled.
- If the discharging process is continued, and the charging level reaches the *Consumer critical level*, the regulator switches off the critical consumers according to their priorities.
- In the opposite direction, when the battery is being charged, the regulator switches on the critical consumers if the charging level exceeds the *Consumer critical level*, and also switches on the other consumers if the battery charge reaches the *Consumer shifting level*.

The reason why switching consumers on or off depends on the battery charging level is that a consumption switched on could turn the power balance of the island back in the opposite (shortage of energy) direction, so that the regulator would need to switch off this consumer again. In this way the battery operates as an energy puffer, ensuring the hysteresis of the regulation.

4.2 Maximal utilization of renewable energy

In parallel operation mode the transformer connected to the public network is switched on and the "green" and the "black" busbars are coupled via the busbar coupler (see Figure 1). The strategy of the regulation is that the consumers be supplied with as much "green" energy as possible, and consumption from public network be reduced to the lowest level. This strategy can be realised by the consumers and the charging of the battery following the schedule of the renewable electrical power generators dictated by the availability of primary energy sources.

For this purpose, the regulator switches the consumers on or off according to their priority order. The critical consumers will not be switched off, since they are supplied by the public network. The battery plays a balancing role. It stores the surplus of green energy and feeds this stored energy back in case of energy shortages.

If the power demand of consumers is greater than the generated green power, the shortage has to be eliminated by discharging the battery. It is feasible only if the charging level of the battery is above the minimal level. If the difference between the consumed and generated power is greater than the maximum discharging power of the battery, some consumers have to be switched off. The same will be done if the battery is discharged, and it cannot manage the power shortage. If these actions are not effective enough, the shortage will be covered by the public network.

In the event of the power shortage exceeding the maximum power of the feeding transformer, the microgrid should be decoupled from the public network, and the regulator should switch over to the islanding mode. In this operation mode the critical consumers can be curtailed too.

If the renewable power generators produce more power than the consumers demand, then the first step is that the regulator switches on the consumers limited earlier, provided that the charging level of battery is above the *Consumer shifting level*. The regulator gradually switches back consumers according to their priority order. If all consumers are already switched on, the battery is charged with the maximum power or if is fully-charged and there is still a green energy surplus, then this can be fed back to the public network.

If the power fed back to the public network exceeds the maximum power of the feeding transformer (transformer overloading), then the microgrid has to be decoupled from the public network and the regulator should be switched over to islanding mode. In this operation mode the curtailment of green generators is possible.

4.3 Changing between operation modes

4.3.1 Switching over from parallel mode to islanding

Pre-requisites:

- The green and the black busbars must be disconnected (busbar coupler is switched off).
- The charging level of the battery has to reach at least the minimum level. Otherwise, the battery must be charged from the public network to a given level.

The whole process is started by a command sent to the circuit breaker of the feeding transformer. The regulator supervises the charging of the battery. The switch off command will be executed when the charging level of the battery reaches the given limit. From this time the islanding regulation mode will be valid.

4.3.2 Switching over from islanding to parallel mode

The operating island can be connected back to the public network only with a synchronisation procedure. If the conditions of synchronised switching are not fulfilled, then there are two ways to avoid undesired network disturbances caused by asynchronous switching:

a) Each generator has to be shut down (island is in black-out) and then the whole microgrid can be connected to the public network by switching on the circuit breaker of the feeder transformer.

b) Consumers can be switched over from green busbar to black busbar one by one. In this case the busbar coupler will be switched off.

5 Experiences, future development objectives

In the simulator the real, actual characteristics of the existing Future Park were examined first. The Park is under continuous development. In its present state it is not suitable for permanent islanding due to the followings:

- There is no AC voltage source inside the grid to maintain sinusoidal voltage during islanding, and provide drive voltage for the inverters. However it is planned to invest in a major inverter unit being capable of producing AC voltage also in decoupled mode.
- There is no built-in synchronising equipment to reconnect the grid to the utility network.
- The built-in renewal generation capacity is insufficient. As the full power of the consumption is about 150 kW, the built-in 40 kW renewal generation power and the 40 kW battery power allows the supply only the most important consumers in islanding mode, temporarily.
- The network topology of the real Future Park is not as clear, as in the FMS model (see Figure 1). The majority of the consumers can not be connected to either the green or the black busbar, so the consuming units can not be switched over to islanding mode one by one.

In second phase the problems described above were eliminated by adding to FMS models a diesel generation unit of 70 kVA with synchronising capability. As well, islanding with partial involvement of different consumers was studied. As the main focus was put on FMS operational aspects, quantitative analysis of these studies is out of the scope of present paper.

As a future development objective, with combination of the models of NTS and FMS, an integrated simulation environment can be created for comprehensive simulation of the distribution network and several connected microgrids. Thus the following aspects can be investigated:

- Effects of distributed generation/microgrids to the power flows in the distribution network, determining optimal distribution network topology.

- Utilization of microgrids in system disturbance mitigation, load curtailment policies realized via centralized controlling of microgrids.
- Energy trading aspects, following commercial transaction schedules with microgrids.
- Participation of microgrids in system balancing.

6 Conclusion

Presented modelling approach allows to study the actual and various future configurations of the Future Park, supporting the decisions concerning further investments. Also it is an effective research tool to investigate the internal phenomena of microgrids and their reaction to the utility network, and to gain operational experiences in a virtual environment. As a future perspective, common simulation of several microgrids and the distribution network supports the analysis of the involvement of renewables into power system control.

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