SIMULATION OF ISLANDING IN DISTRIBUTION NETWORKS

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ABSTRACT

By spreading the renewable distributed energy resources (DERs) the operation of distribution networks during outages must be re-considered. Actual network operation regulations do not support the utilization of autonomous capabilities of microgrids and DERs under disturbances, as in the case of voltage problems and short circuits of MV lines distributed generation units must be switched off until the clearing of the fault. Thus, supplying local consumers during outages of the distribution network by islanding is not possible. However, by maintaining the service in a part of the MV/LV network critical consumers should not be interrupted, and SAIDI indices also could be decreased. Actual paper describes simulation studies investigating different operational modes, including islanding in a large scale Network Training Simulator (NTS), modelling a MV network with connected microgrids, storage units and renewable generating units. The main objective of the simulation is to define the technical requirements of islanding, the necessary co-ordination between MV restoration and distributed generation, the needed control system actions performed by Distribution Management System (DMS), Active Network Management (ANM) and microgrid regulators in order to develop new restoration strategies.

INTRODUCTION

Studies were performed with a further development of an existing Network Training Simulator (NTS) especially developed for the modelling of distribution networks ([1]). Models of microgrid components (including batteries, renewable generating units, microgrid regulator), batteries and generating units connected directly to MV busbars, and also ANM functions were added to NTS features.

In the NTS, both traditional consuming areas and self-regulating microgrids can be coupled to the radial distribution network (see Figure 1). Thus several operational modes, islanding situations shall be studied, such as:

- Different microgrid controlling policies (e.g. maximizing the utilization of renewable energy)
- Decoupling of a microgrid from the MV network
- Outage of a MV line
- Outage of HV lines, HV/MV substations

Concerning islanding operation mode, the following tasks and requirements will arise:

- Detection or creation of viable islands by adequate load shedding policies
- Load-frequency and voltage regulation of the islands
- Fulfilling quality requirements during islanding (voltage, frequency)
- Protection system reconfiguration for islanding
- Network loss impacts of islanding
- Labour safety of MV restoration works in the neighbourhood of active islands
- Necessary ANM actions and ANM co-operation with microgrid regulators

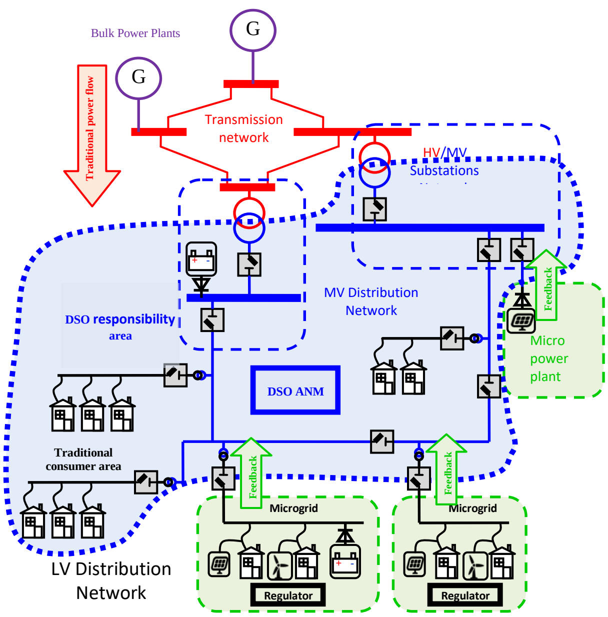

Figure 1

These aspects will be further discussed when describing case studies (see also Chapter 'Special aspects of islanding').

SIMULATION ENVIRONMENT

The main objective of the simulation is to gain operational experience with extended MV networks completed with DERs and microgrids. We use a quasi-stationary modelling for the time dependent behaviour of the network- and equipment parameters, completed with a detailed simulation of discrete state changes. This approach provides satisfactory results. Similarly to training simulators, modelling of electrical/electromechanical transients is not a requirement here.

NTS is mainly used for network operator training purposes, thus – besides the calculation of analogue values (current, voltage, frequency) – it has an advanced functionality for the simulation of discrete technological events, like protection, automation and switching equipment operations. NTS models these 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, DTSM) runs the internal algorithms of devices and distributes values of the device ports in the synchronous sequential network. In this way any complex discrete system can be simulated.

The following main simulation models are described in [2] in detail:

- Special load flow for MV networks (de-coupled, per-phase calculation [3], [4])
- Single node power-frequency model for the islands
- Discrete time simulation modelling (DTSM)
- Renewable generating unit models (wind and solar units with the appropriate primary energy conversion, biogas motor/generator)
- Battery and inverter modelling
- Daily changes of consumption and generation (daily profiles)

Further discussion of the models and other simulator functions (e.g. scenario management) are out of the scope of this paper.

SIMULATION RESULTS

Case Study 1: Maximizing the utilization of renewable energy in a microgrid

This study focuses on a single microgrid, beeing connected to the MV network (non-islanding case, see Figure 2.) The controlling strategy comprises the utilization of the maximum possible green energy, and minimizing the energy exchange between the public MV network and the microgrid.

Case Study description

In a sunny and windy day the photovoltaic power plant and the wind turbine produces electric energy almost with their maximal power. The biogas motor-generating unit is switched on only for supplying the power demand of watering (between 4:30 and 7:00 hours). The battery is at a low charge state in the morning, since consumers discharged it during the night. The required power of consumers is less than generated by the renewables, thus the battery is charged by the surplus energy.

Early in the morning and late afternoon, the grass is watered by a high power water pump. Since the battery charge level in the morning is still low and the solar panels, as well as the wind turbines cannot generate enough power for the water pump, the microgrid regulator starts the biogas motor-generating unit. The generator produces so much energy that even the battery can be charged during the watering process.

Until noon, renewables fully charge the battery. Late afternoon, the battery can cover the power demand of the watering pump, so the biogas generating unit does not have to be started.

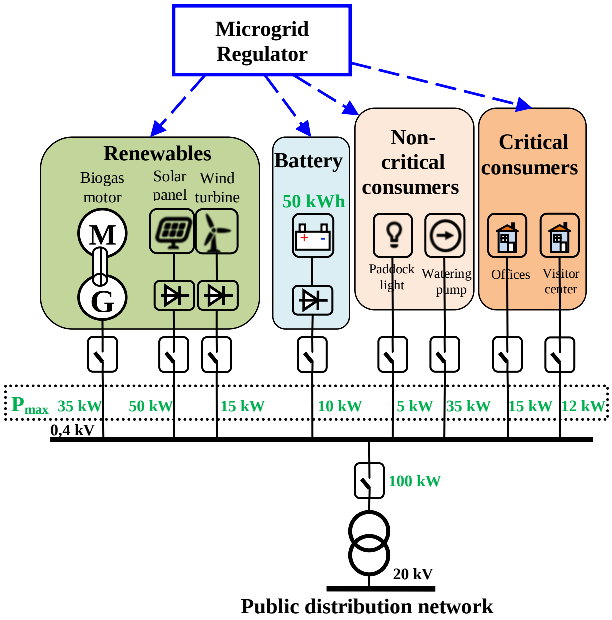

Figure 2

Case Study 1 assessment

Daily power profiles of the generating units, battery, feeding from the MV network can be seen in Figure 3.

It can be seen, that according to the controlling strategy, power from the public MV network is necessary only for a short period of watering time. Otherwise, the microgrid is covering its own power need. This means that it could be operated in islanded mode during the most of the day. But power balance is not the only aspect, in islanding operation mode several other problems would arise that should be managed properly (see Chapter 'Special aspects of islanding').

There was some generation curtailment during afternoon, too, as Microgrid Regulator followed the decreasing of consumption, instead feeding back the surplus green energy to the public MV network (see curve 'Sum green power').

Case Study 2: Microgrid decreases the not-supplied energy in a faulty MV line

Case Study description

Base case

The studied network is according to Figure 4.

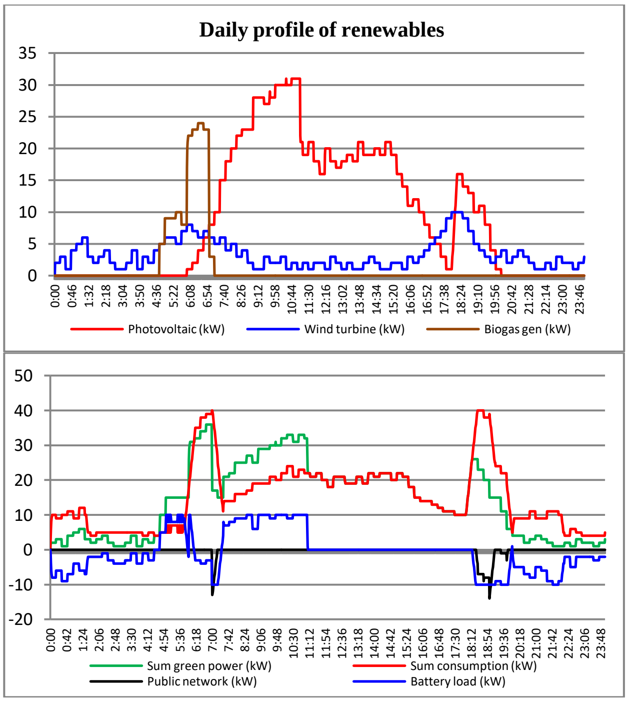

Figure 3

The weather is sunny and windy so the solar panels and the wind turbine of microgrid can produce electric energy. Initially, the battery is almost fully charged. Consumers 1-5, Microgrid, Village as well as Farm 1 and 2 are supplied from Substation 1. All pole mounted switches are closed except 'E' which is the normal disconnecting point during normal operation state.

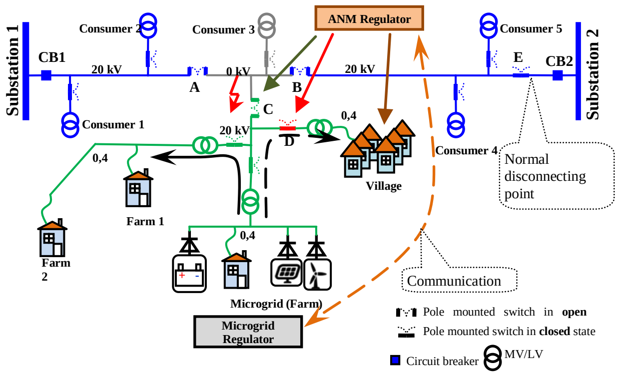

Figure 4

Event

A permanent short circuit appears on the section between A and B pole mounted switches.

Network restoration

The dispatcher has found and separated the faulty network section. Consumer 1 and 2 has been switched back to Substation 1. Consumer 4 and 5 has been switched over to Substation 2 via switching ON pole mounted switch 'E'. Village, Microgrid and Farm 1-2, as well as Consumer 3, are not supplied.

Options for saving the consumers from a longer black-out

Microgrid is in an advantageous situation, because it has enough generation capacity and electrical energy reserve. It could supply itself with energy for a long time.

Consumer 3 is in the worst situation, because the fault is located in its own network section. There is no chance to energize it before the fixing of the faulty network section.

Fortunately Farms, Microgrid and Village can be disconnected from the faulty network part by switching OFF disconnector 'C'. The ANM communicates with Microgrid regulator, and it learns that Microgrid has enough energy reserve and production for supplying other consumers too. (See further considerations in Chapter 'Special aspects of islanding'.)

At first, ANM regulator switches OFF the non-critical consumers (e.g. boilers and heating devices) in Village and perhaps in Farms and only the critical consumers stay switched ON. The ANM (or the dispatcher) disconnects a part of the network via switching OFF pole mounted switch 'C'. Microgrid can supply Farms and Village via the public MV distribution network (see Figure 4). The consumption of Village is much larger than Microgrid's generation capacity, so the charging level of battery is decreasing quickly. The owner of Microgrid originally invested money in battery and renewable generators in order to cover self consumption. But in an advantageous situation it can offer its surplus for other consumers. However, if the charging level of the battery is decreasing under a predefined limit, then the cooperating mode has to be ended. Microgrid regulator sends a warning signal to the ANM Regulator when the charging level approaches this limit. The measurements of consumptions are at ANM's disposal, so it can calculate how it has to reduce the external consumption. Since the consumption of Village cannot be further reduced, the ANM decides to switch OFF pole mounted switch 'D'.

In our example, the consumption of Farms are much smaller than Microgrid's production so they can be supplied with green power and, at the same time, the battery can be charged.

When the sun sets and the wind also subsides, the energy production of Microgrid decreases and the energy demand will be supplied by the battery. Approaching to 'cooperation' charge limit Microgrid is disconnected from the public network and Farms stay without power supply. Microgrid further operates in islanding mode. In a lucky situation, Microgrid can maintain the service through the whole restoration time.

Case Study 2 assessment

Figure 5 shows such a situation when a network fault causes 4 hour long outage (9.00-13.00). Fortunately, the battery is almost fully charged at the beginning. The transfer power of public transformer and inverter is big enough for supplying external consumers.

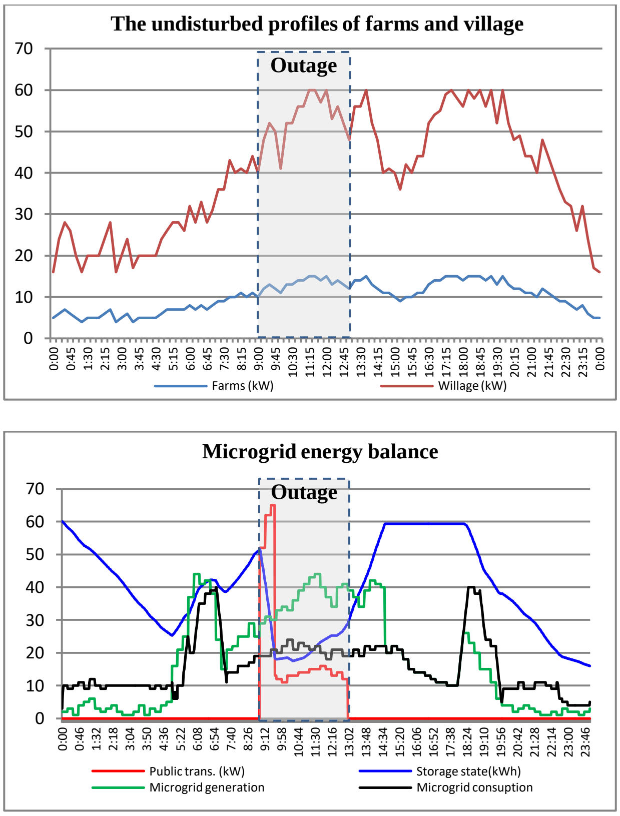

Figure 5

However, the consumption of Village is relatively large compared to Microgrid's battery capacity so its charging level decreases drastically. This operation mode can be kept only for 40 minutes. When the battery charge level decreases below the critical value, ANM Regulator will switch OFF Village. After that, renewables can supply Farms and internal consumers, and slowly recharge the battery.

This situation can be improved if during the outage biogas motor is switched ON. In this case, the battery level can be held high enough for cooperation mode.

The experiences of simulation showed that close to the critical battery level Village cannot be supplied, even if a relatively large battery charging hysteresis is applied, as ANM Regulator switches it ON and OFF too frequently, causing more disturbance to the consumers than a permanent outage.

Future Study: Outage of HV lines, HV/MV substations

As a further development, an extended outage of the HV system will be investigated according to Figure 6.

Future Study description

The outage in 120 kV voltage level impacts Substation 1 and Substation 2, so these supplying points of distribution network will be deenergized. The MV switching equipment in Substation 1 is equipped with a large battery and a major PV power plant is also connected to it. Their capacity are big enough for supplying the customers connecting to Substation 2, too (Consumer 2). However, it should be supplied through a long MV coupler line causing a meaningful voltage drop, so the voltage at the connection point of Consumer 2 will be too low. Microgrid connecting at the end of Customer 2's line could compensate this low voltage with feeding reactive power into the network. In this way, Consumer 2 can be supplied until Microgrid is able to provide reactive power.

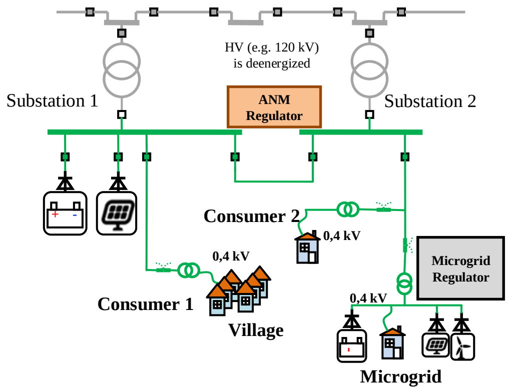

Figure 6

SPECIAL ASPECTS OF ISLANDING

Several islanding aspects were pointed out by the simulations. Some of them is presented below.

During islanding all of the power flows, its directions, the point of supply, the short circuit current will change, thus protection equipment must be prepared for this. The low voltage ride-through capability, the direction, the timing, etc. should be adequate to the new situation. Sometimes even coordination between different protections and knowledge of islanding situation could be required. It will be an ANM task to re-organize the protection system in real-time for islanding. Often new protections must be built in (e.g. at the feeding points of microgrids) or protection zones must be formed to keep selectivity and clear short-circuits appearing within the island.

One other important aspect is the stability of the system. During islanding it is decreased drastically, due to the small number of consumers and generators. Moreover, some equipment's power consumption does not directly depend on the frequency. Therefore, the power balance could only be kept either by using direct communication between consumers, generating units and controllers, or by frequency/voltage dependent characteristic of the equipment (for applying simple droop control or something else), or the mixture of the two methods.

The different levels of regulation must be connected with each other, e.g. the regulation of microgrids depends on external signals from the ANM and the ANM also depends on the current state of microgrids. This includes many parameters and timing is crucial. Moreover, an ANM system must be aware of other loads, generation and storage systems outside the microgrid and regulate them. ANM should always evaluate the possibilities and create viable islands through e.g. load shedding, network sectionalizing, considering the limitations of the system. Here forecasting function of the possible operational states could be an effective support.

However, fulfilling the above requirements has an advantage: the system will be more controllable, more flexible. This increased flexibility could also be exploited during normal operation, e.g. by offering services to the power system: balancing capacity reserve, voltage regulation, restoration enhancing.

Labour safety aspects also should be re-considered, because in islanding the supply point is not only the HV/MV transformer. Live line maintenance, training of personnel should be utilized as much as possible to prevent accidents. The working area must be separated from all possible infeeding directions (see Figure 4, pole mounted switches A, B, and C), not only from upstream, as in "traditional" networks (switches A and B).

All of the above aspects require new standards and regulations to pave the way for these new possibilities. These are twofold. First, the general requirements and allowed behaviour of the system should be extended: e.g. offering balance reserve, islanding with public grid. Secondly, the applied indicators should also be re-evaluated. E.g. SAIDI and SAIFI for those customers who are supplied partially during an outage, the power quality requirements in emergency islands, the effect of islanding on network losses. In a simulation it could be only a matter of switch status, but in an actual power system the law/regulation/standard is binding what can and cannot be done.

The core of all these possibilities is the communication between the systems. Therefore technical requirements are important and need proper specification. At least the following information must be shared between the systems during the simulations:

- ANM → microgrid:
  - Required power balance
  - Need for "extended" islanding
- Microgrid → ANM:
  - Level of charge
  - Current power of the storage
- Microgrid → internal equipment:
  - Power setpoint
  - Power of the storage
- Internal equipment → microgrid:
  - Power capability/need
  - Level of charge
- ANM → internal equipment outside of microgrids:
  - Power setpoint
  - Power of the storage
- Internal equipment outside of microgrids → ANM:
  - Power capability/need
  - Level of charge

The currents and voltages are calculated within the microgrid and ANM controller in order to reduce the communication burden. Some other parameters were also embedded into the controllers, e.g. power ramping up/down properties, maximum capability of equipment.

The communication can involve methods using the power system itself (e.g. BPL, or voltage/frequency characteristics), or a separate IT infrastructure (e.g. GSM, ZIGBEE, fibre optics). One important key aspect is the timing of these signals: it should not affect the system's stability, which is meaningfully decreased during islanding.

CONCLUSION

From the case studies it can be seen, that utilizing DERs to maintain service in islands during disturbances is a promising conception, however it has several pre-requisites. ANM must be able to detect/create viable islands by load-shedding, network sectioning. Protection system must be further developed to clear short-circuits even during the islanding, when the direction of power flow is inversed. As well, voltage problems may occur in extended islands, that should be managed by ANM, via appopriate reactiv power regulation. Beyond technical aspects operational rules, quality and availability indices (SAIFI, SAIDI) should be re-considered.

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