CASE STUDY ON COMMERCIAL SIZED MW-LEVEL MICROGRID

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ABSTRACT

The paper will give an overview of the MW-level microgrid case in Marjamäki in which all the production units and battery energy storage are connected to grid through an inverter. The focus on the paper is on modelling and simulation of transient dynamics at the time of islanding while there are no rotating AC machines for frequency nor voltage references. The industrial-type microgrid operates on medium voltage level. Based on the results, it is evident that with the chosen control method the energy storage is capable of supplying the needed active and reactive power while adjusting only its output voltage magnitude and thus, makes islanding possible. With the adopted method in this paper, the master and all the slave units can operate independently just monitoring their output values so that the communication between the units are not needed. The simulations were carried out by using PSCAD transient simulation software package.

INTRODUCTION

One novel entity in the future electrical energy system is the microgrid. A generic definition treats microgrid as a cluster of locally available or distributed generation (DG) resources, other renewable energy resources and local loads connected to the utility grid (Fu et al. 2013). Microgrid can be a fairly small entity, e.g. formed by the resources of an individual customer, a large one consisting of several customers, or even a larger area having MW-size energy resources on a medium voltage network. Microgrid can operate in parallel with the supplying grid and may have also capability to be operated as an island. It can also be a self-sustaining off-grid solution without any connections to other grids. More precisely, as suggested by the work of the CIGRÉ C6.22 Working Group, Microgrid Evolution Roadmap (Marnay et al. 2015), microgrids are "electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, co-ordinated way either while connected to the main power network or while islanded". In practice, the realization of microgrids varies depending, for example, on available resources, market area, regulations and technology.

Microgrid-related studies have gained more attention on recent years. Several types of stability studies, including various types of generating units and control methods, have been conducted. They prove that microgrids can withstand severe grid conditions in stand-alone mode if the numbers and types of generating units are properly dimensioned and appropriate control methods are selected. For example, two combinations of generating units: i) generation with static electronic converter and synchronous generator and ii) static converter connected generation, survived a severe load imbalance following two very different control strategies (Negri et al. 2017). Further, the successful control and operation of a microgrid in islanded mode consisting of several different generating units is feasible. For example, uninterrupted power supply to local loads can be provided with the combination of a diesel unit, PV plant and battery energy storage (Koohi-Kamali & Abd Rahim 2016).

In microgrids centralized control methods, which are typical for a large-scale power systems, can be used but because of the small size of the system decentralized methods can be exploited equally well. In general, two types of power sharing methods between generating units are frequent. In a droop-control method, each production unit adjusts its output power based on the measured quantities of the microgrid, such as voltage and frequency. In a master and slave control method, one master unit dictates the voltage and frequency in the microgrid and other units operate on the basis of commands received from the master unit (Caldognetto & Tenti 2014).

The microgrid of Marjamäki area

A microgrid of a remarkable size is under construction in Marjamäki Lempäälä, near the city of Tampere in Finland. Marjamäki will be a local microgrid consisting of, e.g., 4 MW solar power plant, total of 8.4 MW gas turbines, two 65 kW fuel cells, 2.4 MW/1.6 MWh electrical energy storage system, heat and cooling storages, smart buildings, each with their own resources for demand response functionalities, and intelligent grid automation and management systems. The industrial-type microgrid has a medium voltage connection to the grid of the local DSO and its own gas and district heating networks. An overview of the microgrid region is shown in Figure 1.

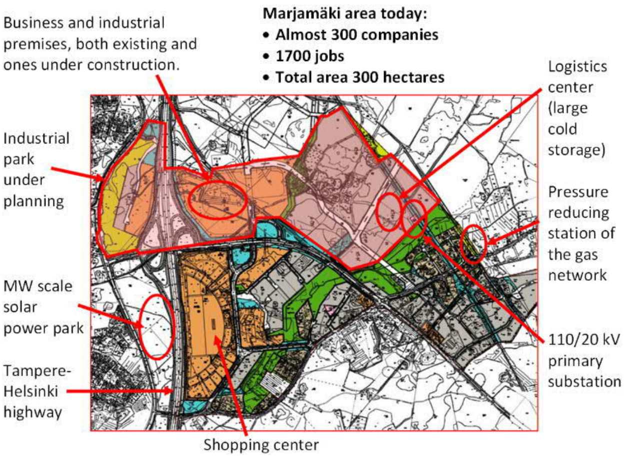

Figure 1. Microgrid region of Marjamäki area.

In this paper transient simulation model based on main characteristics of Marjamäki is developed. The simulation models cover in detail the various control loops and protection circuits and switching instants of the semiconductor devices forming the power electronic interfaces. Main energy resources consists of both DC and AC but all the production units are connected to the grid through an inverter. The paper presents transient response and the post-fault dynamics of each of the production unit in the microgrid in a case of islanding transition due to a fault on external grid. Based on the results, a detailed analysis covering the response of the main units is given. At the end, it is discussed the future needs for the dynamic simulations of microgrids as a part of power systems.

PROBLEM FORMULATION

Because several types of microgrids can be developed, different combinations of grid architectures, production units and control methods are applicable. Each combination has its own case-specific features, in particular regarding frequency, voltage stability and control, as well as power sharing methods between generation units. The normal operation and fault response of microgrids varies greatly depending on whether generation units are directly grid-connected (e.g. diesel-generation set) or connected to the grid via a power electronics (e.g. PV plant). In the latter case, due to fast switching actions of power electronics the overall response speed can be considered faster than the former one. However, if no other energy sources with adjustability are used, the nature of primary source can drastically reduce the controllability. Also, the control methods which are not using communication between production units, is generally thought to be more robust and preferable than the ones using it.

While operating on medium voltage level, resistances and inductances of the cables are roughly equal in magnitude. Therefore, the assumptions made on high voltage power systems are not applicable on medium voltage levels. As a consequence, strong cross-coupling between the active and reactive power control methods can exists if traditional control methods are used. Also, the frequency loses its traditional meaning in a microgrid which has no directly connected rotating machines. This can lead to situations in which traditional control methods are obsolete and novel rethinking must be adapted. With the adopted method in this paper, the master and all the slave units can operate independently just monitoring their output values so that the communication between the units are not needed.

Much of empirical tests on microgrids under severe grid conditions are done in rather moderate power levels on laboratory environment. Typically power levels had started from tens of watts reaching to some thousands of watts depending on the case. Very often the results of MW-scale dynamic simulations are verified by the tests done with kW-level on laboratory setups. However, with still partly new and emerging technology, it might be unclear and challenging to assess the validation value of laboratory test results on MW-scale real units. All this has led to situation in which no benchmark model, or models exists for variety of microgrid simulation studies. Also, it is likely that several benchmark models are needed in order to cover wide variety of microgrid solutions.

There are very few, if any, MW-sized microgrid solutions available for research purposes. The Marjamäki microgrid area is still under construction but it already render opportunity of doing dynamic simulations with the retrieved data. Also the collection of versatile filed measurements on the existing grid is under work.

SIMULATION MODEL AND CHAIN OF THE EVENTS

Simulation model

The schematic overview of the simulation model is illustrated in Figure 2. The main parameters of the microgrid, i.e. voltage levels, feeder lengths, capacity ratings and machine data of production units, have been retrieved from Lempäälän Energia. In Figure 2 the main events and the control actions are also illustrated.

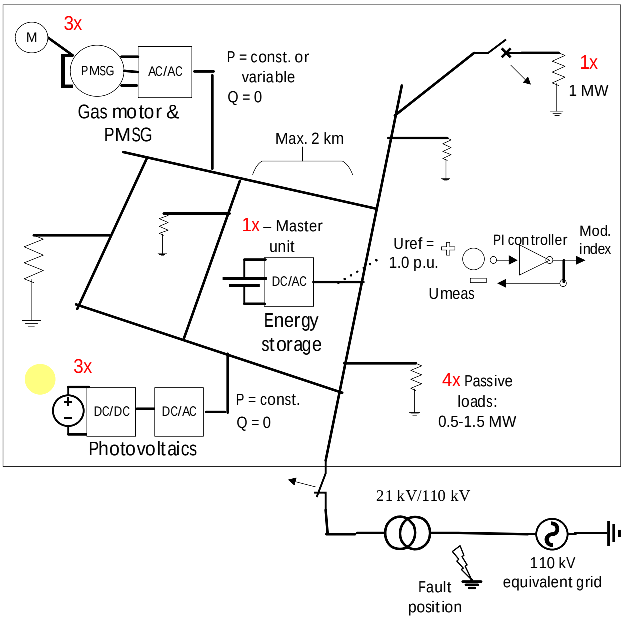

Figure 2. Schematic overview of the simulation model.

The most relevant data of the each production unit and related power electronics are presented in Table 1.

Table 1. Production units –related data.

Unit	QTY	Power electronics	Nominal power	DC-link voltage	DC-link protection	Grid side voltage	Control method	Grid side filter
Energy storage	1	Inverter	2.4 MVA	1.75 kV	No	1 kV	SPWM	LCL
Photovoltaic	3	Boost chopper & inverter	1.2 MW	2.25 kV	Yes, resistor	1.2 kV	SVPWM	LCL
PMSG & Gas motor	3	Back-to-back inverter	1.5 MVA	1.05 kV	Yes, resistor	0.7 kV	SPWM & SVPMW	LCL

Apart of the space vector modulator, all the components are found on PSCAD master library.

Chain of the events

Figure 3 illustrates the chain of the events in the simulation case study.

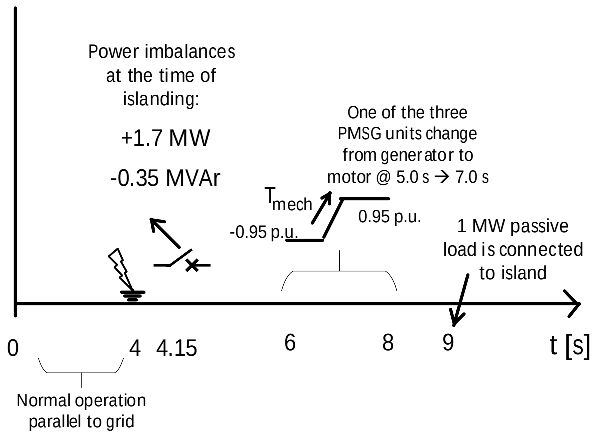

Figure 3. Chain of the events.

The first four seconds the microgrid is operating parallel to grid. Within this period all the production units are on grid-feeding mode and are synchronized on grid voltages with each of its own phase-locked loop (PLL).While grid-feeding mode, the active and reactive power references for energy storage are set to zero. At the time of four second, a low resistance three-phase short circuit is applied on PCC (Point of Common Coupling). When the value lower than 0.4 p.u. RMS voltage is detected, the circuit breaker opens and the energy storage change its mode from grid-feeding to grid-forming with the internal PLL.With the internal signal generator the energy storage keeps the frequency at 50 Hz because there are no directly grid-connected rotating machines for a frequency nor voltage reference. The energy storage adjust modulation index on SPWM (Sinusoidal Pulse Width Modulation) to control its output voltage at 1.0. p.u.. The parameters of the PI-controller dictates the response speed of the energy storage. The other production units keep their grid-feeding mode with the same PLL-detection method and thus, are now synchronized on voltages provided by energy storage. While on island mode, torque of one of the PMSG (Permanent Magnet Synchronous Generator) change its sign (i.e. generating mode to motoring mode). Also, one passive load is connected in order to emphasize the highly variable, and severe, grid conditions.

THE RESULTS

Figure 4 illustrates the voltage at PCC, active and reactive power of energy storage, the modulation index and the frequency at PCC. Right after the energy storage changes its state to grid-forming, both active and reactive power shoot rapidly. The response of the active and reactive power are in opposite directions due to power imbalances shown Figure 3. Just after the islanding, a very high reactive power injection can be seen which is a result of the fact that the energy storage is the only grid-forming unit. Grid voltage overshoot slightly but settles down within 300 ms.

Figure 5 illustrates active and reactive power injected to grid of the two PMSG-units. Also, DC-link voltages and rotational speed of the machines are shown. During the fault, the ability of an inverter to feed active power to the grid is reduced. Due to that, DC-link voltage rises up sharply. The brake resistor switch is triggered when the voltage level of 1.15 kV is reached. The rise of DC-link voltage is reflected on the machine terminals, which increase the counter electrical torque and hence the machines will slow down. The rise of the DC-link voltage leads also to high reactive power injection to the grid. The responses of all the three PMSG-units are almost identical. The power oscillations of the energy storage in Figure 4. are mostly due to heavy power fluctuations of PMSG-units rather than the control actions of the storage itself.

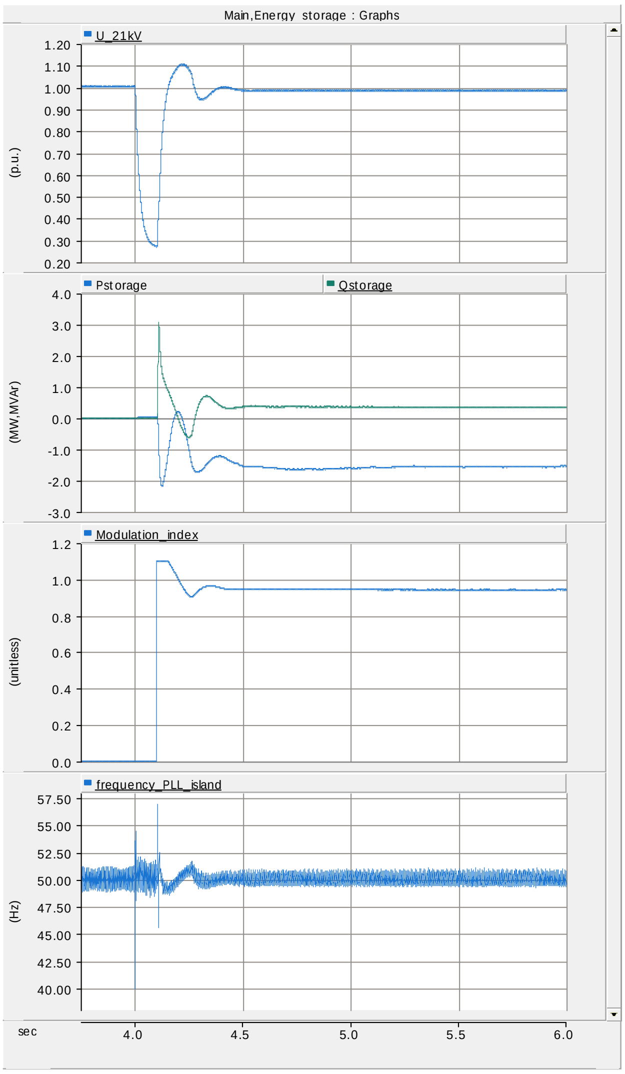

Figure 4. Voltage at PCC, active and reactive power of energy storage, the modulation index and the frequency at PCC

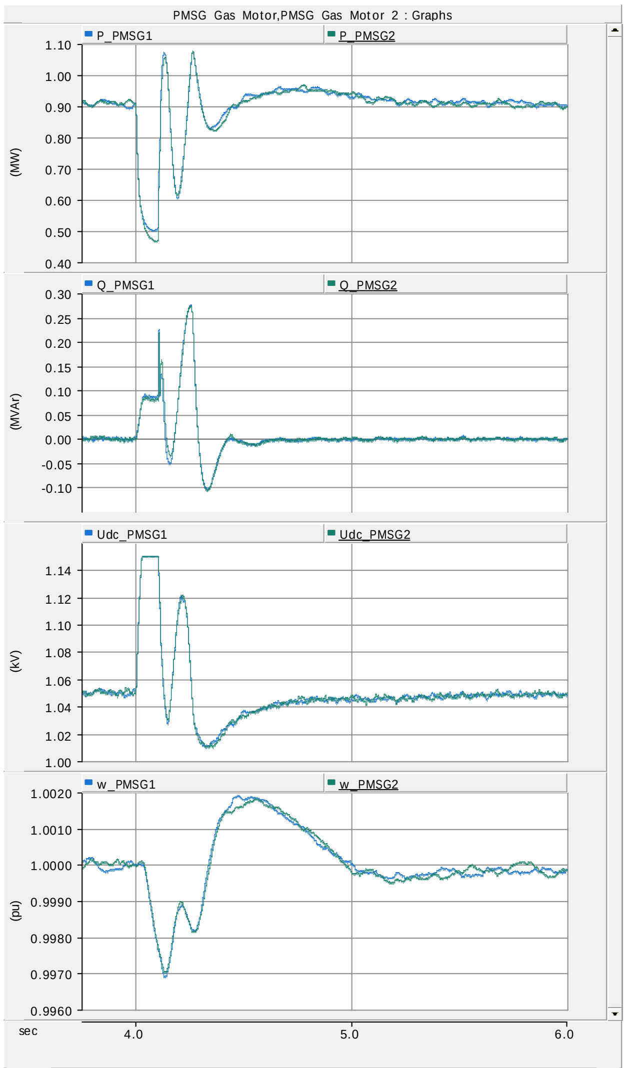

Figure 5. Active and reactive power injected to grid of the two PMSG-units, DC-link voltages and rotational speeds of the machines.

Figure 6 illustrates active and reactive power injected to grid of one of the PV-units. Also, DC-link voltage and boost-chopper reference signal are shown. As no rotating machines are involved, the fault and especially post-fault responses are reduced compared to PMSG-units in Figure 5. The differencies are also due to different controller parameter values of the grid-side inverters on these two production unit types. The tuning of PMSG-unit grid-side inverter is largely dependent on the dynamic requirements on the machine-side inverter (i.e. allowed speed deviation, expected torque variations etc.) which might result in faster dynamic response requirements for the grid-side inverter also.

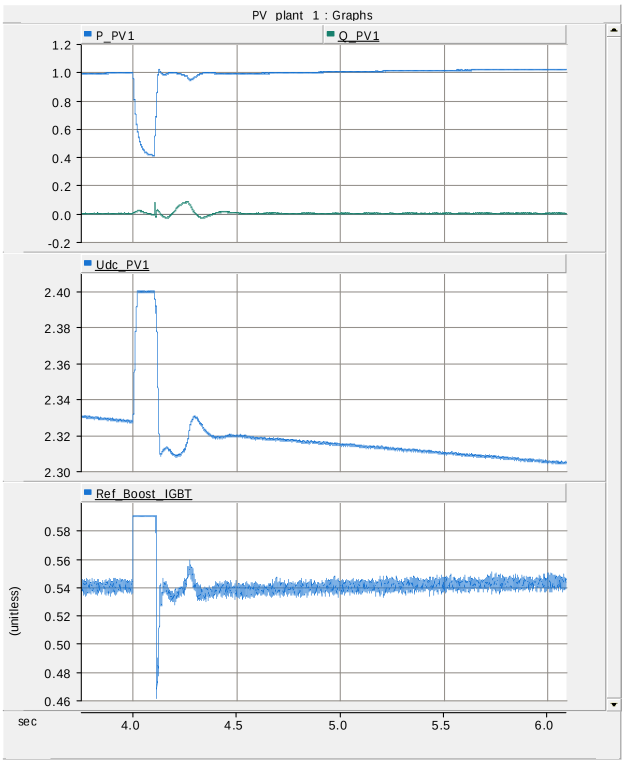

Figure 6. Injected active and reactive power of one of the PV-units, DC-link voltage and chopper reference signal.

Figure 7 illustrates of how the energy storage feed the active power to grid when one of the PMSG-units shift on motoring mode. The transition is very smooth. Only when the 1 MW load is connected at the time of eight second, a small voltage dip can be seen.

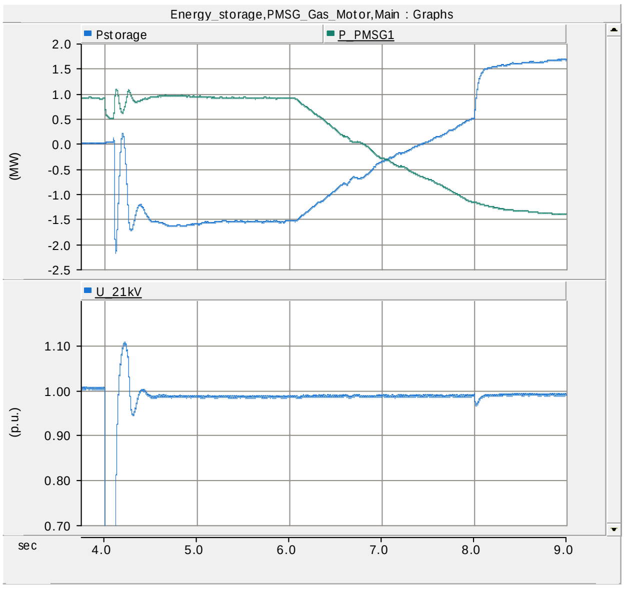

Figure 7. Active powers of the energy storage and one PMSG-unit together with the grid voltage.

CONCLUSION AND DISCUSSION

The simulation results show the dynamic response of different production units typically adhered to microgrids. It can be seen that with the chosen control method the energy storage is capable of balancing the needed active and reactive power and thus, makes the islanding possible. Also, the master and all the slave units can operate independently just monitoring their output values so that communication between the units are not needed. In the medium voltage level the resistance and inductance of the cables are close in magnitude. Also, the frequency loses its traditional meaning in an island in which all production units, and rotating motors if any, are connected to grid through an inverter. This might lead in to situations in which traditional control methods are obsolete and novel rethinking must be adapted.

Publications done so far have concentrated mostly on the transmission or the distribution grid level regarding stability studies. In the future, as the number of microgrids will increase, they role cannot be neglected while evaluating on power system stability issues.

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