Control Strategies for MicroGrids Emergency Operation

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I. INTRODUCTION

THECNOLOGICAL developments in the last few years are bringing up new forms of electricity production – the MicroSources (MS). The interconnection of small modular generation sources to low voltage distribution systems can form a new type of power system, the MicroGrid (MG). MG can be connected to the main power network or be operated autonomously, if they are isolated from the power grid in face of a planned or unplanned event. In addition, fast system recovery (Black Start capabilities) after major fault conditions can be provided. This concept is being developed within the framework of the European R&D project MicroGrids, involving several research institutions and companies.

A MG comprises also an hierarchical control and management system: in an upper level, the MiocroGrid Central Controller (MGCC) provides the technical and economical management of the MG; in a lower level, Load Controllers (LC) can be used for load control, making use of an interruptibility concept; also MicroSource Controllers (MS) are used to locally control the active and reactive power production levels.

The MS are small units of less than 100 kWe, most of them with power electronic interface, using either renewable energy sources (wind and solar energy) or fossil fuel in high efficiency local co-generation mode (microturbines or fuel cells). The successful design and operation of a MicroGrid requires the solution of a number of demanding technical and non-technical issues, in particular related to their operation and control. The presence of power electronic interfaces in fuel cells, photovoltaic panels, microturbines or storage devices brings up a new situation when compared with conventional power systems using synchronous generators. Fuel cells and photovoltaic panels (PV) has no moving parts; microturbines has light weight moving parts but are connected to the LV grid through power electronic interfaces. The dynamic behavior of such an inertialess system and the slow response of some MS to the control systems is quit different from the one observed in conventional power systems. Furthermore, conventional power systems have energy storage on the rotating masses of synchronous generators, which provides energy balance in the moments subsequent to a load connection. A MG requires some form of energy storage (batteries or flywheels) to face transients during islanded operation.

Up to now, functionalities for operation restoration are available only for conventional power systems, where system restoration is based on a top-down approach, beginning with the start-up of conventional generation units and ending with the connection of loads and dispersed generation units. With the dissemination of the MG concept, new techniques must be derived, since MG can be used for service restoration in their area of influence. A sequence of actions for MG service restoration is proposed and tested through simulations.

II. MICROGRID CONTROL FOR AUTONOMOUS OPERATION

The work described in this paper corresponds to the approaches followed by different partners involved in MicroGrids project to deal with MG control under islanded conditions.

A. MicroGrid Operation Regarding Inverters Control Modes

The first approach corresponds to the establishment of the MG control modes regarding the usual schemes to control a power electronic interface. As there is not expectable to have fully controllable synchronous generators in a MG, inverters are responsible for frequency and voltage control during islanded operation. The usual control approaches control an inverter can be defined as [4]:

- PQ control – the inverter is controlled to inject a given active and reactive power
- Voltage Source Inverter (VSI) Control – the inverter acts as a voltage source with controlled magnitude and frequency.

The VSI is to be coupled with a storage device and to balance load and generation during islanded operation. Its control is preformed using droop concepts [5-7]. One important feature of the VSI is its capability to react to power systems disturbances during islanded operation based only on information available at its terminals [5]. In this way, a seamless transition between interconnected and autonomous operation mode can occur, since it is supported by the VSI in the first moments.

Combining inverter control modes, two global operation strategies can be defined for MG operation:

- Single Master Operation: A VSI can be used as the reference voltage when the main power supply is lost (balance of local load and generation); all the other inverters can then be operated in the PQ mode;
- Multi Master Operation: More than one inverter is operated as a VSI. However, other PQ controlled

inverters may coexist.

During islanded operation, the power injected by storage devices is proportional to MG frequency deviation. Therefore, correcting permanent frequency deviation during islanded operation should be a key objective in any control strategies in order to avid storage devices to keep injecting (or absorbing) active power whenever MG frequency deviation differ form zero. Combining the primary frequency regulation provided by the storage device with load shedding of less important loads and secondary load frequency control prove to be the key features for successful MG islanded operation.

B. MicroGrid Operation Regarding Primary Energy Source Control

The possible control strategies of the MS and the storage device may be: (a) PQ control (fixed power control), (b) Droop control and (c) Frequency/Voltage control. PQ control is adopted so that the MS and the storage run on constant power output. In addition, the power output of the storage may be fixed at zero when the MG is operated in grid-connected mode. However, as PQ control delivers a fixed power output, it makes no contribution to local frequency control of the MG. Therefore, the control scheme of the storage has to be changed from PQ control to droop control with frequency control during islanded operation.

III. MICROGRID SIMULATION PLATFORMS

Several MS technologies were considered to coexist in the MG and the corresponding dynamic models were derived [2-3]. A simulation platform under the *Matlab/Simulink* environment was developed to study the dynamic behavior of several MS operating together in a LV network and controlled according to what was described in section *II.A*. The fast transients associated with the initial moments of the MG restoration procedure were studied in another simulation platform developed in *EMTP-RV*, where the switching details of the power electronic interfaces were included. The longer term dynamic behavior of the MG during the restoration procedure was also evaluated using the *Matlab/Simulink* platform. As an illustrative example, the *Matlab/Simulink* simulation platform is shown in Fig. 1. An important feature that can be evaluated with the simulation tool is the inverters behavior during short circuits and the value of providing sufficiently high fault currents for fast and efficient fault detection during islanded operation mode (by considering a convenient oversizing).

Another simulation tool was also developed in PSCAD/EMTDC to evaluate MG control functionalities described in section *II.B*. It was assumed two situations: firstly, the MS and the storage device by the synchronous generators; in a second approach, MS and storage are represented by and the STATCOM-BES.

IV. MICROGRID BLACK START

The MicroGrid Black Start (BS) functionalities were developed using the control strategy described in section *II.A*. Two types BS functions are needed: local BS of the MG after as general system blackout and grid reconnection during BS. The strategies to be followed uses the hierarchical control system of the MG, namely LC, MC and the MGCC. The electrical problems to be dealt with include building the LV network, connecting micro-generators, controlling voltage, controlling frequency and connecting controllable loads. During the restoration of the LV network, load-tracking problems will arise, since some microgenerators (fuel-cells, microturbines) have slow response and are inertia-less. Such a system requires some form of storage to ensure a fast energy balance between local generation and consumption. Also, MS require local energy storage to launch generation and fed local auxiliary control systems. In this way, a Multi Master operation is used in the initial stages of the MG restoration procedure.

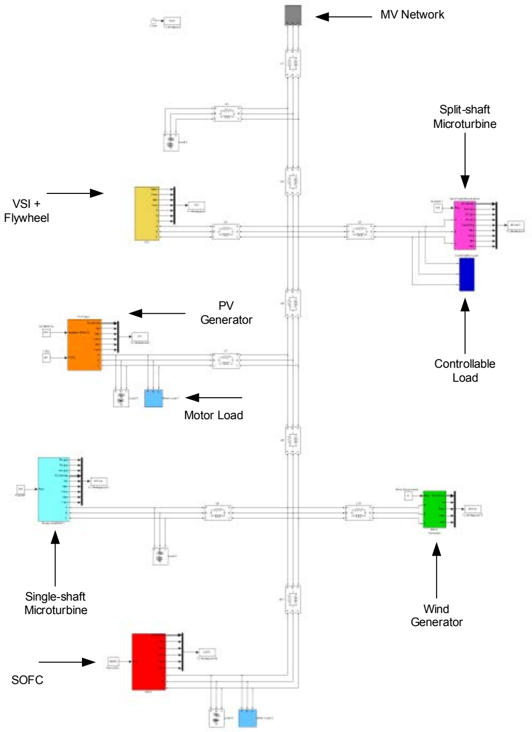

Fig. 1. LV test network in *Matlab/Simulink* simulation platform

The MGCC periodically gets information from LC and MC about consumption and electric production respectively and stores this information in a database. It also has information about black start capability of each MS and its technical characteristics like active and reactive power limits. After a blackout, the MGCC will try to restore the last MG load scenario, starting with the connection of most critical loads. The BS procedure is in this case a sequence of events controlled by a set of rules stored in the MGCC software and activated by local information about voltage and frequency.

V. RESULTS AND DISCUSSIUONS

When using the control approach described in section II.A, A short-circuit in the MV network was simulated at t=10 seconds and was eliminated after 100 milliseconds with the islanding of the MG.

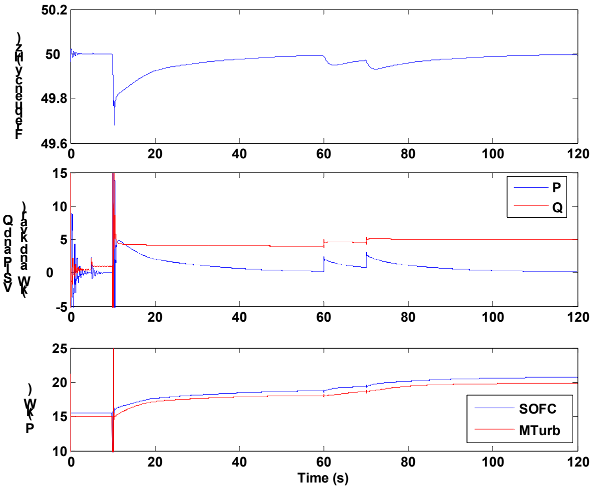

Fig. 2. MG Frequency, VSI active and reactive power and SOFC and single-shaft microturbine active power

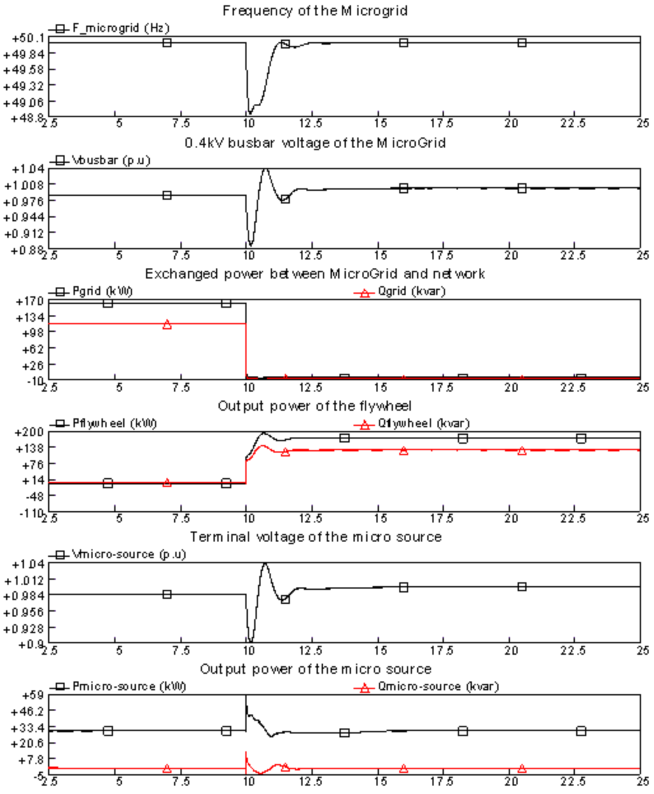

Fig. 2. Dynamic behaviour of the MG when using Frequency/Voltage control

The initial total load of the MG was around 70 kW and the MS generation, prior to the islanding, was around 45 kW. In face of the large initial frequency deviation an amount of load was automatically shedded in order to aid frequency restoration. This load was reconnected later in small load steps allowing also the evaluation of the MG behaviour in load-following conditions.

Fig. 3 shows the dynamic performance of the MG when the flywheel uses Frequency/Voltage control during islanded mode (strategy described in section *II.B*). The control of MS is still PQ control. The control of the flywheel is switched from PQ control to Droop control after islanding. During islanded mode of the MicroGrid, the output of the micro source is maintained at a constant value. After islanding the frequency and voltage of the MicroGrid are both brought back to the normal values (50Hz and 1.0p.u).

The sequence of actions defined for MG black start, is being tested in the simulation platforms. As an illustrative example, Fig. 4 shows the output power of several MS while performing the first steps of the proposed sequence of actions.

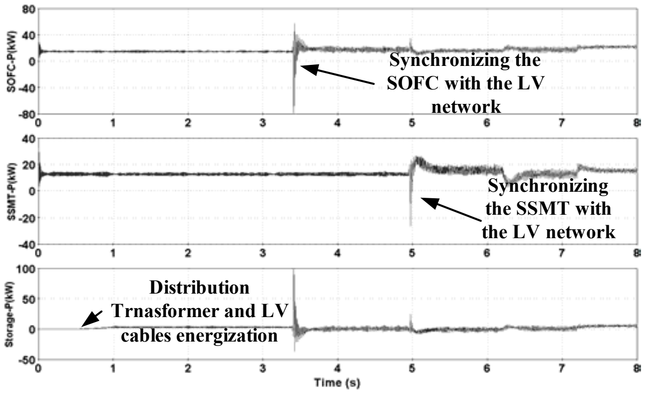

Fig. 4. MS active power in the first moments of the BS procedure

VI. CONCLUSIONS

Simulation results indicate that the islanding of the MG, can be performed safely under several different power importing and exporting conditions. Storage devices are absolutely essential to implement successful control strategies for MG operation in islanded mode with the load-shedding procedure assuming also very high importance to avoid fast and long frequency deviations.

Rules and conditions to be checked during the restoration stage by the MG components were derived and evaluated through numerical simulation, proving the feasibility of such procedures.

VII. REFERENCES

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