IMPLEMENTATION OF A TEST MICROGRID IN BARCELONA

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ABSTRACT

The aim of this paper is to present a real implementation of a microgrid in IREC's Laboratory in Barcelona. The described microgrid aggregates generation, storage and controllable load units operating in a single system. The communications architecture is composed by a hierarchical layer embodied by an iNode developing a global management of the microgrid, and iSockets, located in the lower hierarchy layer. One main advantage of having a microgrid with emulated power systems is that it can analyse phenomena that depends on uncontrolled manner, such as weather fluctuations, in a rapid and easy way.

INTRODUCTION

Future grids will change its centralised configuration due to the need of including renewable energies with distributed energy generation (DER), new storage elements and the introduction of electric vehicles (EV's). In that sense, microgrid technologies are gaining widespread attention. Yet there is much research to be performed in order to test different strategies of microgrid implementation, control algorithms, communications, protection, power electronics, and measurement. In that sense, this platform will allow to test and monitor real microgrids in a real and fast way, with the power electronics, algorithms or communications described.

Microgrids, can operate in islanded mode, and may enable local control of DER and thereby reduce the need for central dispatch [1]. Also microgrids can operate connected to the grid, where DER can be injected to the main grid.

Islanding operating mode is not allowed at this time by local regulation, but power electronics elements and control must be considered. This microgrid is the sum of the collaborative project DER IREC 22@ Microgrid, and other projects sponsored or promoted by the utility Endesa [3] as Smarcity, Verde, Charge & Ride or V2M. It is a living laboratory with capabilities to investigate different microgrid configurations, and apply technologies related to energy flux transfer, power control, communications, electric vehicle, power systems and other technologies.

MICROGRID COMPONENTS

Components

The Catalonia Institute for Energy Research (IREC) microgrid is located in Barcelona, Spain. It is a 40 kW low voltage microgrid connected to the grid [2]. The power system of the microgrid consists of different emulated and real power units as shown below (Fig. 1 and Fig. 2):

The emulated systems include:

- Generation unit (4kVA): can be programmed to emulate different kinds of renewable energy resources such as wind or photovoltaic. The dependence on weather conditions of these sources is reflected in their curve response and, therefore, real behaviour can be reproduced.

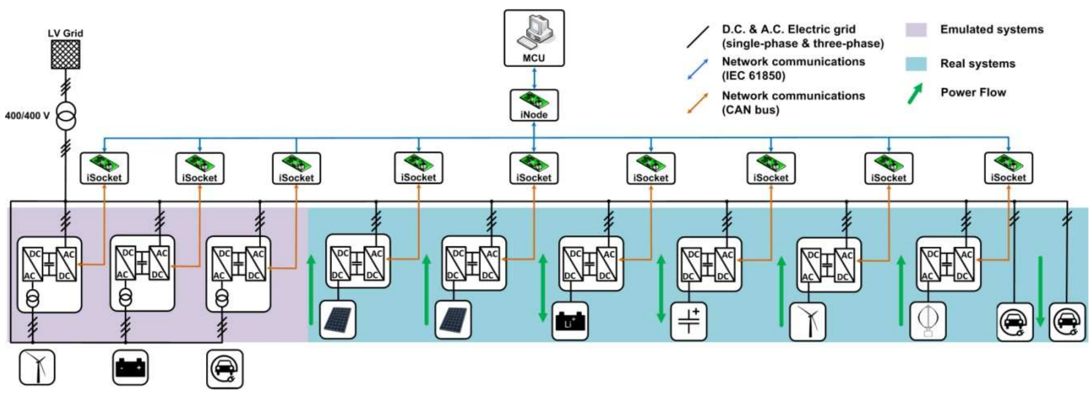

Fig. 1 IREC's microgrid functional schematic.

Fig. 2 Four cabinets of the microgrid.

- Energy storage unit (4kVA): this unit can be programmed with the charging profile of different battery technologies.
- Load unit (4kVA): this last unit can emulate the real behaviour of different types of consumptions: sensitive-loads and/or non sensitive-loads, as well as the charging of an electric vehicle.

The real systems include:

- Urban wind turbine power generator (2 x 1 kVA). In order to study the performance of different technologies, both a horizontal and vertical axis microwindmills are installed.
- Photovoltaic generator (2 x 2.5 kW). As with wind power, two different kind of photovoltaic panels are installed; monocrystalline and polycrystalline.
- Lithium-ion battery storage (5 kW). The energy supplied by the battery should be enough to support critical loads for at least two hours.
- Ultracapacitors storage (5 kW). These elements are suited for discharging large amounts of energy during short periods of time to cover peaks in demand and, furthermore, they can go through up to hundreds charge/discharge cycles.
- PEV slow charger (2 x 3.6 kW). Commercial chargers for plug-in electric vehicles.

Emulated generators and consumptions

The emulation is performed via hardware. Each three phase hardware emulated unit is composed of two line-frequency phase-controlled AC/DC converters in back-to-back configuration. The converters may behave as active inverters or as active rectifiers.

Emulation is performed in terms of active power injected to the grid or consumed from it. It has been considered that a node behaves as a generator (Fig 4.a) when active power flows from the AC side to the DC bus of the lower converter (from now referred as “Emulator”), then from the DC bus to the AC side of the upper converter (from

Fig. 3 Converters used in back-to-back configuration.

now referred as “Active Front End”, AFE) and finally it returns to the grid. On the other hand, it behaves as a consumption when active power flows from the AFE to the Emulator, and then it returns to the grid (Fig 4.b).

The Emulator controls the maximum active power across the DC at any time. This maximum value is time variable and depends on what it is being emulated. For example, if it emulates a fully discharged storage unit, the converter does not supply power to the bus, but it may “accept” power from it (which is the equivalent to charging the storage unit). The AFE is only visible to a management system. It recieves start/stop messages, active power and reactive power reference values, and it is requested information about status and measurements. The AFE converter tries to deliver the power that it is commanded to. It continuously measures the DC bus voltage. If this voltage drops, the AFE understands that it must extract less power from the bus. On the other hand, if the voltage rapidly increases, it understands that it must inject less power to the bus [3].

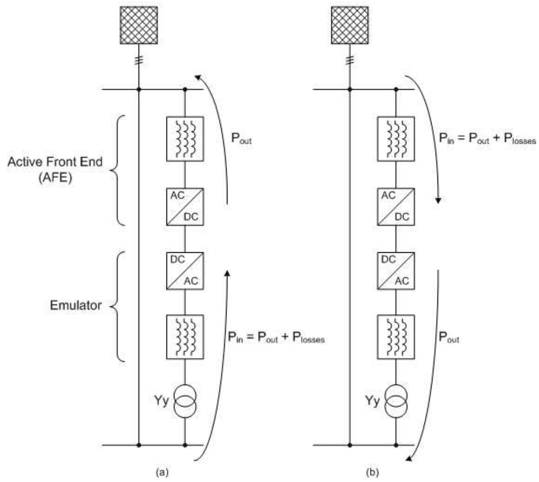

Fig. 4 (a) Generation emulation. (b) Consumption emulation.

Management and control units

Basic microgrid control units are the iSocket (Intelligent Socket) located inside the power converter unit (emulator) and the iNode (Intelligent Node) located close to the Microgrid Control Unit (MCU). The microgrid is externally managed by an automation system, guaranteeing electric security and stability, reliable power supply with optimal quality, self-healing behavior (automated maintenance and outage prevention) and some cybernetic security.

This management system is hierarchical and 3-layered. At the top layer, the Microgrid Control Unit (MCU) (see Fig. 1) manages the overall microgrid. The iNode and iSockets, which represent middle and bottom layer respectively, perform time critical tasks: power control, emergency management and logging, etc. For the time being, it has been considered that there is an iSocket for every microgrid's unit, and one single iNode (Fig. 1). The MCU is a PC running on Windows XP. The iNode and iSockets are embedded boards based on the Freescale i.MX25 processor (ARM9 family) running on Windows CE 6.0. It has also been fully tested embedded boards with Digi's UNC90 module, which is based on Atmel's T91RM9200 ARM9 microcontroller and runs on an embedded Linux (Linux kernel v2.6 for ARM9 processors).

Communications among the iNode and iSockets are according to IEC 61850 standard. Every iSocket communicates with the respective AFE via CAN.

IEC 61850

In order to ease the engineering and integration effort in the design of the microgrid, IEC 61850 standard has been chosen for iNode-iSockets communications [4]. A license of SISCO's **MMS-EASE *Lite*** has been acquired, which is a source code product for embedding the IEC 61850 protocols in IEDs.

For each unit it has been identified the Logical Nodes (LNs) that represent measurements, status and other features, such as: MMXU, MMDC, ZAT, ZBTC… The main purpose of this project is not the standard exclusively, but commissioning a set of technologies. From the very start, some simplifications were considered:

1) Only mandatory Data elements and Data Attributes would be included.
2) For each unit, Logical Nodes would be grouped in one single Logical Device (LD).
3) Regarding IEC 61850, the iNode would behave only as client, and iSockets would behave only as servers.
4) The iNode "would know" each unit's Logical Nodes.
5) Only "Read" and "Write" MMS services would be used.

MMS-EASE *Lite* libraries are prepared to be compiled and then run on Windows, Linux and QNX. It has been necessary to make some few changes, so they can run on Windows CE as well.

CONTROL ALGORITHM

The control algorithm implemented in IREC's microgrid is based on the independent control of active and reactive power [5].

Two different types of control have been implemented: centralised and distributed. In the centralised mode the iNode is in charge of the decisions and the power of one unit depends on the other's power. On the other hand in the distributed mode the iNode is a bridge between IEC 61850 and CAN and the iSocket is the element responsible for taking the decisions, in addition, the power delivered by each unit is independent of the others.

The iNode, in the centralised control, receives the information of the total active/reactive power from all the iSockets and receives the reference value (P^* Q^*) from the MCU. With these parameters it calculates F_p and F_q, dimensionless parameters whose values range from -100 to +100. These are sent to the iSockets, who with these values, calculate the set value (P^*_i Q^*_j) to send to each converter (Fig. 5).

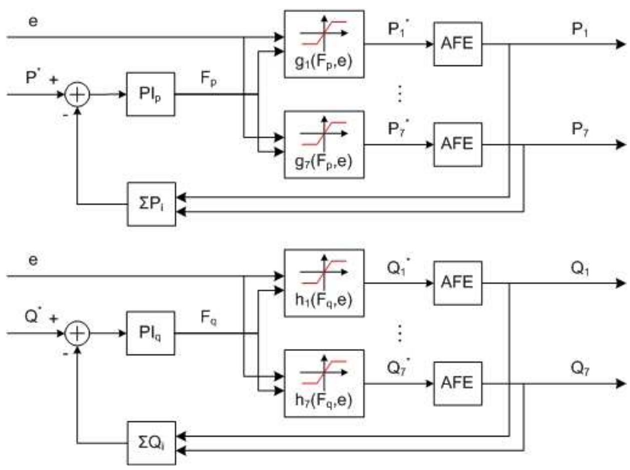

Fig. 5 Active and Reactive power closed-loop control.

Another input of the system is the energy price (e), which will be passed over from the iNode to the iSockets.

The iNode uses two independent PI controls to achieve its goal. Meanwhile every iSocket applies a piecewise function to obtain P^*_i and Q^*_j as follows (1) and (2):

$$P_i^* = \begin{cases} P_{i\text{-}max} & \beta_{Pi} < F_P \\ P_{i\text{-}min} + \frac{P_{i\text{-}max} - P_{i\text{-}min}}{\beta_{Pi} - \alpha_{Pi}} (F_P - \alpha_{Pi}) & \beta_{Pi} \geq F_P \geq \alpha_{Pi} \\ P_{i\text{-}min} & F_P < \alpha_{Pi} \end{cases} \quad (1)$$

$$Q_i^* = \begin{cases} Q_{i\text{-}max} & \beta_{Qi} < F_Q \\ Q_{i\text{-}min} + \frac{Q_{i\text{-}max} - Q_{i\text{-}min}}{\beta_{Qi} - \alpha_{Qi}} (F_Q - \alpha_{Qi}) & \beta_{Qi} \geq F_Q \geq \alpha_{Qi} \\ Q_{i\text{-}min} & F_Q < \alpha_{Qi} \end{cases} \quad (2)$$

Where $\beta_{Pi} \geq \alpha_{Pi}$ and $\beta_{Qi} \geq \alpha_{Qi}$. These parameters are dynamic values that are recalculated depending on the behaviour of each microgrid unit (storage, consumption or generation), energy price and the current state. They can be interpreted as the participation priority of each microgrid unit. For example, as the state of charge of a battery increases, it will become more reluctant to charge and this effect can be mathematically represented as an increase in the value of the parameters α and β.

In the distributed mode both F_p and F_q are set to zero and no feedback is needed. In this case the only input of the iSockets is the energy price (e).

MEASUREMENTS AND RESULTS

Measurement equipment

To measure the behaviour of the emulated and real power units of the microgrid, a commercially available three-phase power analyzer is mounted in each unit. These power analysers can measure, calculate and display the main electrical parameters under balanced or unbalanced conditions. All the measurements are taken in true rms value using the three voltage inputs and the three current inputs. It is important to note that some of the power units can inject, store or consume energy from or to the grid emulator; or what is the same, the microgrid is a bidirectional power flow system. This fact requires these power analysers to be able to measure in one direction or two quadrants (power consumption), and in both directions or four quadrants (power consumption and generation).

The IREC's microgrid is hardware independent; because of the use of a standard communication protocol like Modbus/RTU or Modbus/TCP protocols (through a generic UDP or TCP connection).

SCADA

The use of a Supervisory Control And Data Acquisition (SCADA) software makes configuration and supervision of microgrids easier. Total knowledge of the operating of every Distributed Generation unit (DG), Distributed Storage (DS) unit or Distributed Generation/Storage unit (DG/DS) of the microgrid allows the user to supervise the system at all times and therefore to resolve unforeseen situations quickly.

The SCADA used in IREC's microgrid uses a real-time system to calculate energy production (generation and storage) and consumption of each unit. Using this software any electrical or physical parameter can be requested in real time, integrating many different electrical or physical parameters in one or various systems installed in the same grid, even accessible from external grids (decentralised energy control systems). The communication between software is via LAN or the Internet. This SCADA also acts as a centralising and information management unit. The objective of this software is to process data and prepare reports. Fig. 6 shows the current SCADA used in the IREC's microgrid.

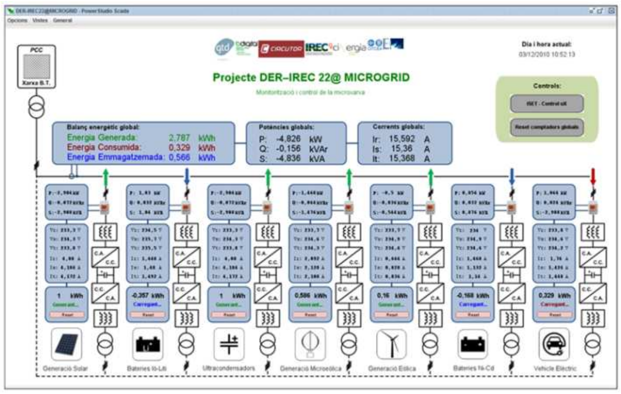

Fig. 6 Microgrid SCADA.

CONCLUSIONS

IREC's microgrid is a flexible hybrid microgrid, incorporating real and emulated power units, emulating real generation, storage and load. By proper communication interfaces, the units are managed and controlled by energy efficient algorithms, and measurement systems provide real time supervision and regulation.

Acknowledgments

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