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i-Sare. The Future Grid.

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Abstract. This paper presents a real implementation of hierarchical control scheme for a smart grid equipped with voltage source converters, attached to renewable and conventional energy generators and storage systems based on ultracapacitors, flywheel and batteries, which is able to assume the demand of domestic, commercial, industrial and electric vehicle demanding current loads up to 400 kw in islanded mode or connected to the main grid.

The hierarchical control used is implemented in the central control system and in each of the converters connected to the intelligent grid, in order to distribute the control over all the elements involved in the generation of energy. For this purpose it is used a distributed communication architecture based on EPICS to manage all the information generated.

This micro grid, called i-Sare, was developed during the 2012 and beginning of 2013, and will be operational in Donostia (Gipuzkoa) at the end of 2013.

In this paper real test results are presented to demonstrate the effectiveness of the control and the communication architecture used in iSare.

Key words

Smart grid, renewable energy source integration, electric vehicle, harmonic compensation.

1. Introduction

The current requirements relative to the energy efficiency and integration of new elements in the grid, such as electric vehicles and renewable energy sources, require the development of a new kind of power grid, different to the one we have nowadays.
Global energy sector is largely dependent on combustion energy sources like fuel-oil and natural gas, which are becoming scarce. This fact together with the climate change and the sociological and economic challenges of the 21 century, supposes for the electric network the need of growing the transportation infrastructure, and this has an impossible cost to assume nowadays. So it is clear that it is necessary a new concept of electric network: intelligent network or Smart Grid.

The European industrial politics has as an objective to establish the bases that will do possible the networks of next generation (Smart Grid), promoting the development of the smart meters, the integration of the renewable energies and electric vehicle (EV) chargers. The integration of the electric vehicle will lead the implementation of the smart grid concept due the assumption of the electro mobility in our culture.

But the intelligent grid needs the active participation of the client on the network, not only as a consumer but also as a producer or as an energy storer, which it is not the case currently. This objective requires a new control system more efficient, that takes in consideration the power quality of the grid, harmonic compensation and P/Q regulation among other subjects.

This new grid must have innovative technologies and services in energy control and data communication in order to get more efficient grid, and intelligent power.

This new Smart Grid should integrate different sources of energy with generation and storage options. It is necessary to include environmentally friendly sources, such wind and solar generation, playing an important role the electric vehicle, as a consumer and as a generator.

Regarding the integration of electric vehicles in the network, up till now it is not possible to charge millions of electric cars at the same time without causing an increase of the tension of network or a failure of supply. The introduction of the concept of electro mobility in the cities is changing the energy supply systems requirements, for

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which the infrastructure of the city by itself should be capable of supporting the new demand.

Among these agents it is necessary to include electric vehicles and bidirectional charger that can be consider as small power plants capable of absorbing energy when charged or inject energy at discharging. This dual load / generator has introduced the concept "Vehicle to Grid" (V2G) or G2V, so the electric vehicle can be used, as an example, as storage from diurnal solar plants.

Furthermore the intelligent grid will provide better power quality, improving load factor and it will answer to system disturbances.

2. i-Sare project. 400kW Smart Micro Grid

i-Sare is a smart grid project, whose objective is to develop a power grid more efficient and reliable, improving safety and quality of supply in accordance with the requirements of the digital age. This micro intelligent network serves as a test plant to develop and validate the status of different generation and storage technologies and control strategies.

This project attempts to place regional companies at the forefront of intelligent networks.

The benefits of this smart grid can be resumed in six points:

1. Fighting climate change by replacing fossil fuels with renewable energy and successfully integrate into the network.
2. Develop the called “islanding phenomenon”, the capacity of an area to work perfectly, in case of failure, isolated from the main network (“island mode”).
3. Increase control and visibility of all network parts to anticipate demand and to correct deficiencies in the shortest possible time.
4. Turning consumers into active participants, allowing them to plan their consumption
5. Reduce costs by avoiding the construction of new infrastructure (WiFi and Power Line Communication will be used).
6. Prepare the network for large-scale deployment of electric vehicles (V2G & G2V).

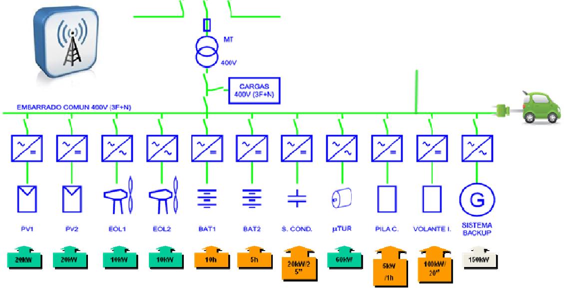

Fig. 1. Elements in i-Sare smart grid

i-Sare is equipped with power transformers, protection of medium and low voltage, storage systems (batteries, flywheels and supercapacitors), distributed generation systems (wind, solar, cogeneration group, diesel generator and fuel cell), and points for electric vehicle recharging. The main characteristics of i-Sare, are:

- A bidirectional power generation system of 60 kW nominal power and peak power of near 400 kW. The system uses digital technology and facilitates the integration of sources of generation from renewable sources. This system can operate in island or connected to the network. In this case it can operate at maximum generation capacity to deliver all the energy possible to the distributor, based on a specific demand of the distributor at a high price (see Figure 1).
- Open control architecture for data transfer and real-time control, for managing energy in the micro-grid, consisting of interoperable communications infrastructure between the control center the smart meters and the converters. This architecture integrates techniques for load management, systems monitoring, control of power flow, and techniques for preventive maintenance procedures.
- The communications in the grid is based on EPICS (Experimental Physics and Industrial Control System), which is a set of open source tools focused on the development of distributed control systems in real time using the Ethernet to communicate the different EPICS devices [12] .
- The communication architecture allows remote access to the facility through an IP network with high security [13], facilitating the operation and system diagnostics. The fundamental data of the installation can be viewed in real time through a website; and locally, using the EPICS tools like CSS [14]
- It is a good test bench to develop new controls in order to assess the effects of new elements that may come to introduce in the future.

The i-Sare micro grid is only possible if it is seen as an intelligent communications infrastructure that provides, at all times, precise information and control of all the elements in the network. For this purpose the system requires an architecture to collect information of the smart grid, measuring devices across the net and in addition to connect the control centers of the energy suppliers, which can be hundreds of miles away to the control center of the smart grid.

In Fig. 2. it is shown an overview of the installation of i-Sare.

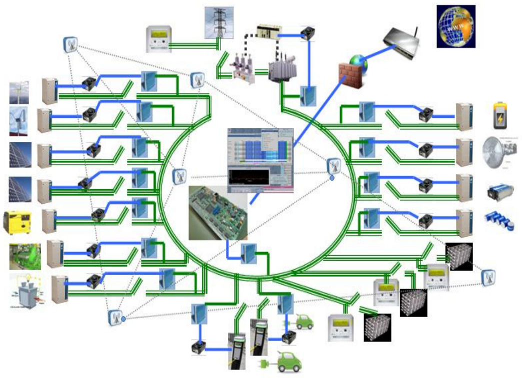

Fig. 2. i-Sare elements distribution

The green lines represent the distribution of electricity, either from a pole medium voltage 30 kV connection or from the secondary of a transformer 400 V.

The blue lines represent a bus Ethernet cable on which EPICS is based to distribute the communication.

The dashed black line refers to discrete signals, both digital and analog equipment from buses without communication.

A. Hierarchical Control

The control system is a hierarchical control in which the primary and part of the secondary control are implemented in local control, in each micro inverter connected to the grid.

The other controls are performed in a central control, [1].

As mentioned before the control of i-Sare is hierarchical and it is composed by four levels:

1) *Primary control.* The power electronics converters have to adjust the active and reactive power flow wich can be achieved through the frequency and voltage droop control, i.e. the micro sources can emulate the parallel synchronous generators in a traditional power system and automatically share the total load demand. Thus, consumers are able to manage their demand actively. The Droop Control allows the sharing of power with no communication between the inverters connected to the grid
2) *Secondary control:* regulates the voltage and frequency inside the micro grid by using a central controller with communications to each primary control. This control permits harmonic compensation and compensate voltage unbalances. It sends the output of its regulation through a communication system that is not critical, to each inverter. Furthermore, the secondary control takes care of synchronization with the main network.

   Applying different control strategies, for eliminating the voltage harmonics and generating a balanced current, even when there are unbalanced loads, the system contributes to the micro network robustness, increasing the energy efficiency and reliability and improving the quality of wave provided the final consumer.
3) *Tertiary control*: optimizes the microgrid according to economic optimization and is responsible for the exchange of energy between the microgrid and the main grid or other microgrids, forming microgrids clusters.
4) *Fourth control*: is aimed at economic Management system and would be implemented in the central control [3].

B. Distributed Control: Communications infrastructure

The distributed control system in i-Sare is based on EPICS. In the terminology EPICS Process Variables are named variable (PV). EPICS implements a client / server architecture that enables this communication as long as all elements are part of the same local network built on implementing Ethernet TCP / IP to exchange data and UDP / IP for connection management [16].

The essential component of this collaboration is the Channel Access (CA), a protocol that provides transparent communication between clients who need information or require actions to perform and servers that process the requests, called I / O servers. This protocol allows a client need only know the name of PV which is looking to access the information there. When you receive a message requiring a particular PV, it looks and establishes a TCP connection between client and server.

Moreover, the so-called Input / Output Controller (IOC) are collections of EPICS routines and databases necessary to define the PV-s and what actions should be performed. In other words, are the drivers, which act as both clients and servers in the system. The IOCs implemented in i-Sare are a embedded computers [17] running a series of routines EPICS PVs used to define and implement control algorithms in real time.

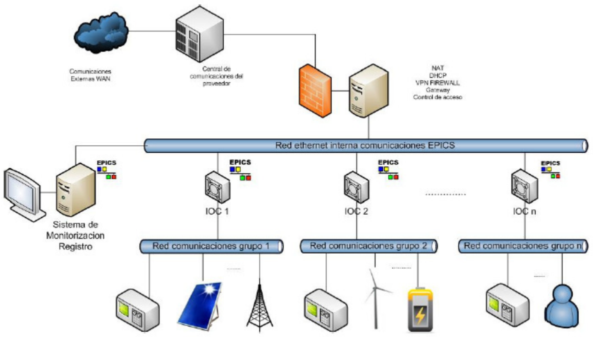

Fig. 3. Communication architecture

C. Central Control

The central control of the intelligent network has the capacity to reason, make independent decisions and take actions over the elements that constitute the network, sending the working setpoints to each of the active elements. Every element will adjust its behavior to this setpoint.

The control system acts as a bridge between the smart grid and the conventional electricity grid, the element that provides the necessary orders for the smart grid to exchange with the electrical grid the energy required for operation.

In addition, the central control needs local controllers for each of the elements that generate, store or consume energy within the smart grid. Protections and smart sensors play a role in this effort and allow identification of each of the groups that produce or consume energy at all times. Moreover they send this information to central control and from here to the distribution network operator, that it is connected, in real time. Thus, it may take the most appropriate actions every time.

So, the whole system of micro grid control is centralized in a central processing unit. As it is mentioned, this control center is responsible for collecting all the necessary information from all components of the network (active loads, generators available in the micro grid, energy that is able to provide each system and at what cost) and hourly rates of consumption and generation set by the energy distributor that will fit the micro grid. With this information the control center decides which generators have to be implemented and how operating conditions in order to meet the power requirements of active loads. Moreover, it must handle the energy plus to return energy to the grid whenever profitable or desirable.

D. Experimental Results

Part of the smart grid is tested in order to verify the smart control and the communications. This tested smart grid is formed by two 20kW solar inverters, loads, central control and the devices for communications: two IOCs, two BPL, Ethernet switches, wireless antenna and a data server.
Control algorithms are implemented in a control card based on TMS320335 Texas Instrument floating point DSP.

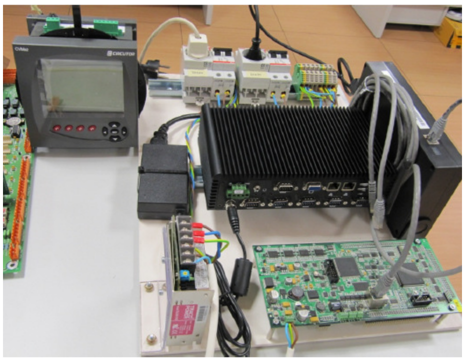

Fig. 4. Central control hardware

Every data and the grid status are shown and can manage from a CSS screen based on EPICS, where it is possible to configure the smart grid in islanding mode or grid connected mode, send setpoints and orders.

Fig. 5 CSS screen of monitoring system

The control architecture is tested step by step. First of all, the implementation of secondary and primary control in one inverter connected to a controlled load is verified in islanding mode. After that, the two inverters are connected generating the micro grid. Finally, the micro grid is connected to a supplier main grid, including also the tertiary and fourth control.
Following figures show some of the results of the tests carried out. The voltage and current responses both in islanded mode and grid connected mode are measured.

Fig. 6 Oscilloscope results showing voltage and current responses to load changes

4. Conclusion

This paper has presented the advantages of a smart grid instead of a conventional power grid; in particular, the benefits of i-Sare.
The experimental results show that the control is implementable in a real scenario. It has been shown that the micro grid can operate properly with the hierarchical control and the proposed communications architecture.
Although these experimental results seem to be good enough, the control and communication system has to be tested in a real micro grid i-Sare.

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