# THE APPLICATION OF COMMUNICATION ARCHITECTURES FOR THE MANAGEMENT OF AN EXPERIMENTAL MICROGRID

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## ABSTRACT

*An extreme flexibility of a microgrid operation requires general, integrated and hierarchical proper management and control systems. A wide variety of communication technologies from communication medias, communication protocols to sensors and algorithms are available for microgrid applications. The requirements of communication capabilities differ with the varying microgrid architectures, physical scales, control strategies, functions. In this paper, typical communication protocols are applied to the layout of an experimental microgrid (MG). A hierarchical control is then implemented in order to allow primary and secondary generation unit regulation of the MG.*

## INTRODUCTION

For the efficient integration of distributed energy resources (DERs) to the grid, the concept of microgrids has attracted significant interest. A microgrid is a small grid in which distributed generations and electric loads are placed together and controlled efficiently in an integrated manner [1]. It contributes to utility grid's load levelling by controlling power flow between utility grid and microgrid according to a predetermined power flow pattern. It contributes to an efficient operation of distributed generation by operation planning considering grid economics and energy efficiency. A microgrid should be able to either operate integrated with the utility grid or disconnected (i.e., islanded) from the distribution system. This also implies that a microgrid should have its own management system to support the control functions needed to autonomously regulate power flows [2], as well as to participate into the energy market for electricity trading [3].

In order to guarantee an extreme flexibility of the microgrid operation, general, integrated and hierarchical proper management and control systems have to be developed. There are different concepts on microgrid controller architecture, from decentralized peer-to-peer to centralized master-slave topology. With regard to peer-to-peer configuration, fast and highly reliable local frequency and voltage controls are provided. However, the peer-to-peer decentralized microgrid topology has limitations on achieving high system performance and advanced applications because of the lack of communications. On the other hand, although the control is highly dependent on communications, the centralized microgrid control architecture is able to achieve better coordination among the controllable elements and hence provide valuable performance and more advanced applications.

In the long run, the need for close system monitoring and higher performance along with the development of the smart grid communication technology will promote the integration of communication with microgrid.

A wide variety of communication technologies from communication medias, communication protocols to sensors and algorithms are available for microgrid applications [4]. The requirements of communication capabilities differ with the varying microgrid architectures, physical scales, control strategies, functions. For instance, real time voltage and frequency control requires more reliable, more frequent and faster information exchange than the economical dispatch. The problem is how to choose the reliable, performance-satisfying, yet cost-effective solutions to meet all the functions requirements in a microgrid. The engineers from both communications and power systems backgrounds are trying to provide solutions. With the emphasis on communications setup, a Wi-Fi network is tested for small scale microgrids energy management in a laboratory environment in [5], whereas RS485 lines and LabVIEW interface are considered in [6].

The aim of this paper is to develop standardized control strategy for realistic microgrid system. The adopted control architecture will be able to maintain three phase voltages and frequency in the grid precisely and provide power sharing between the units according to unit rating, meteorological parameters, economical dispatch perspective and user settings. To this purpose, the application of typical communication protocols to the layout of an experimental microgrid (MG) are compared. In particular, different network configurations are considered, supported by Profibus or Modbus remote terminal unit (RTU) systems, and including connections realized by copper-wire Ethernet or optic fiber Ethernet. This preliminary study will point out advantages and disadvantages of these communication technologies and provide the optimal network configuration able to support the MG under investigation.

Simulations will be then carried out in order to implement a hierarchical control, where at level 1 the droop control of a unit, generator or storage, that corresponds to the control logic of a conventional generating unit primary regulation is applied. A follow-up monitoring of the levels 2 and 3 (secondary and tertiary) goes back to, respectively, the voltage and frequency values pre-disturbance, and change the set point of active and reactive power in relation to the programming load resulting from a problem optimization.

## COMMUNICATION AND CONTROL SYSTEMS FOR SMART MICROGRIDS

To operate an integrated system as the MG, an Energy Management System (EMS) supported by a communication infrastructure has to be built to monitor and support other functions such as unit commitment, load forecasting, and to control all DERs and loads. A challenge to the realization of the above is the selection of a suitable communication infrastructure [5].
In the definition of the communication protocol architecture, following the general reference model ISO-OSI [7], industrial communication protocols involve physical, data link and application layer. The choice generally falls into field bus solutions (such as Profibus, Modbus) as well as Ethernet technology using TCP/IP protocols [4][8]. Since Ethernet offers higher speed and longer connection distance, more and more power system devices in the market incorporate a suitable port besides the traditional serial port. This situation has created a vast development space for Ethernet technology to be adopted in power system communications. Moreover, the development of Common Interface Models (CIM) allows different applications modelling aspects of the microgrid (from protection status to economic properties) to exchange information about the status of electric grid components [4][9].
The presence of a suitable communication architecture allows the construction of a centralized EMS, where the controller is provided with the relevant information of distributed energy devices in order to determine an optimal coordinated exploitation of the resources according to the selected objective functions [10].
At the same time, decentralized EMS for microgrid entrusts control functions to each device, based on local variables, in order to perform specific control actions. These are mainly realized by means of droop control of inverter-equipped distributed resources regulating active, and reactive power depending from bus frequency and voltage.
Distributed control implements primary control actions, with little cost on communication infrastructure, fast response and high reliability, though involving limitations on achieving high system performance. On the other hand, the centralized microgrid control architecture is able to achieve secondary control goals, aiming at a better coordination among the controllable elements, with a further cost for realizing the communication infrastructure [11][12].

## EXPERIMENTAL MICROGRID

The considered MG is developed at low-voltage level of 400 V and consists of different distributed generation units, storage devices and loads, as sketched in Fig. 1.

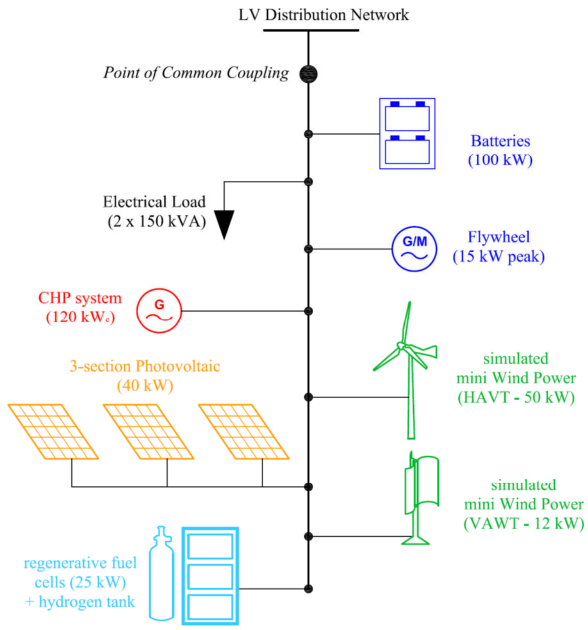


Figure 1. Experimental MG layout.

Generation facilities include 2 horizontal axis wind turbines with 25 kW size, 2 vertical axis wind turbines with 6 kW size, and photovoltaic system, with rated power of 40 kW roughly, equipped with different technologies and suitable power converters. Moreover, a gas-fuelled CHP system is considered, with a maximum capacity of 120 kW. Two storage devices with different technical characteristic are considered: a set of batteries (100 kW peak / 1 h) and a flywheel (15 kW / 20 min). These technologies are meant to feed programmable load banks, up to 300 kVA, and the whole microgrid is also able to exchange power with the local distribution network, interfaced with a back-to-back converter.
In order to match performance requirements and cost issues, different communication architectures for the experimental microgrid applications have been examined. Taking into account the range of distance of the facilities from the central control room (from some meters to 100 m), as well as the heterogeneity of interface solutions of each device, the communication network layout that mainly fits the experimental MG is reported in Figure 2. In this Figure, purple, green and red lines indicate connections via Profibus or Modbus RTU, copper-cable Ethernet and fiber optic Ethernet, respectively.
In particular, in the Profibus network shielded double-conductors wires according to IEC 61158 standard are exploited, with a RS485 connector. Local controllers

(RTU) are connected to PLC of each device through pre-wired cable with RS485 or M12PB connector.
The Ethernet network is composed of copper cables with 4x2 IE TP Cord RJ45 wires, able to reach 100 to 1000 Mbit/s. The fiber optic Ethernet connections involve multimodal fiber with LWL cable in glass 50/125 µm and SC connectors.
The switches and gateways are able to support at least Modbus/TCP and Ethernet/IP protocols, and have Ethernet and optic ports.

The communication system layout includes an RTU for each device, except the general switchboard. The adoption of a common industrial protocol based on TCP/IP involves the installation of converters in the case proprietary protocols are provided. The RTU is able to perform local control actions on the local actuator (e.g. a PLC) as well as to accept continuous regulation and control signals elaborated in the EMS.

Moreover, RTUs are provided with Ethernet connection for all devices. The communication system includes two field switches, each dealing with a group of devices, connected through a fiber optic ring, able to keep the communication, in the case of a fault in one side, exploiting the opposite direction. The fiber optic ring extends up to the control room, where two further switches in redundant configuration allow a reliable connection to the server level. Two twin servers are considered, both equipped with the EMS functions, although one of them is the master and the other is kept updated although in stand-by, in order to provide a prompt backup in the case of failure. The human interface (HMI) is realized by means of local workstations, connected via Ethernet as well. Switches in the control room allow for connection of different operator places connected to SCADA and EMS. Training activities could be carried out on off-line workstation, accessing the database only in reading mode.

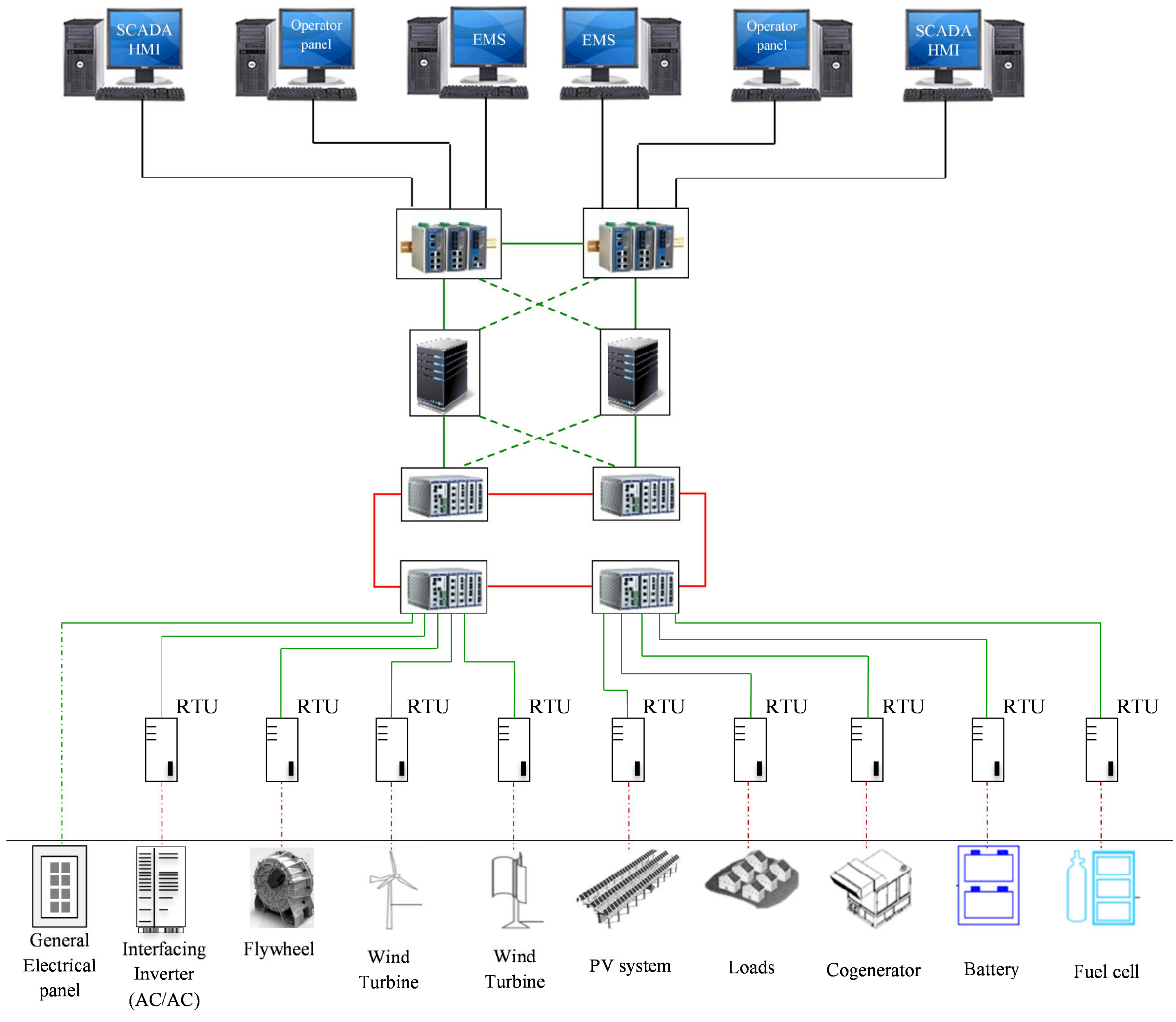


Figure 2. Communication architecture for the experimental MG

## MICROGRID CENTRAL CONTROL FUNCTION IMPLEMETATION

In order to assess the functionality of control actions that could be implemented in the centralized EMS and the effectiveness of the principles on which the communication layout is based, simulations are carried out on a basic test system, as depicted in Figure 3. The configuration for these simulations includes two twin three-phase low-voltage devices equipped with power converters, connected in islanded mode to a variable electric load. Each device is able to perform primary frequency and voltage regulation according to P-f and Q-V droop characteristics as reported in [13]. Moreover, a secondary controller is placed over the whole system, according to [14], in order to restore original values of voltage and frequency at the load connection busbar.

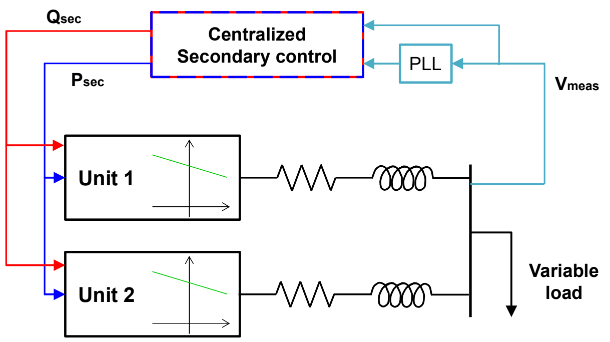


Figure 3. Test system control framework

It is worth to remark that the exchange of signals between microgrid devices and the centralized secondary controller is subject to the performance of communication system. However, the total delay in sending and receiving on Ethernet-based microgrid is proved to be in the range of milliseconds [15], therefore it can be neglected in the proposed transient stability simulations, with a time step of 0.01 s and a total interval of 3 s. In this time window, the action of tertiary control can be neglected as well, since its effects typically occur every 5-15 minutes.

Simulations start with a total load of 1000 W at unitary power factor, and the two units are called to feed 600 W and 400 W, respectively. At 0.4 s, a step increase of load by 100 W is imposed, and at 0.7 s load reactive power reaches 200 VAr. Finally, at 1 s, the secondary control is activated.

Simulation results are shown in Figures 4-5, where frequency and voltage magnitude at load bus are shown. Moreover, in Figures 6-7 active and reactive power generated by the two units are reported.

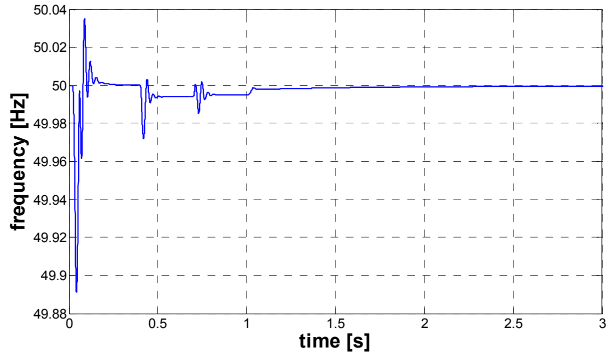


Figure 4. Frequency behavior at load bus

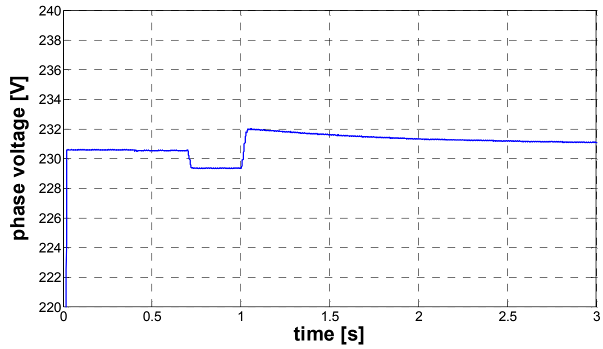


Figure 5. Voltage magnitude at load bus

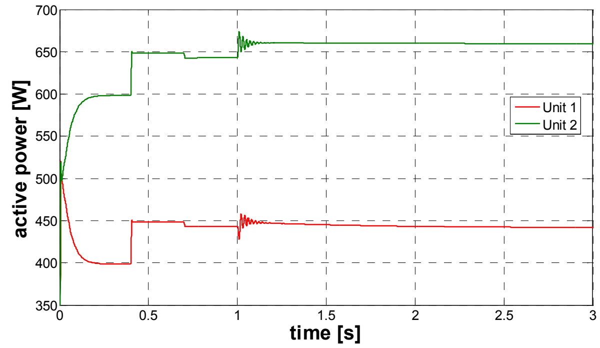


Figure 6. Generated active power

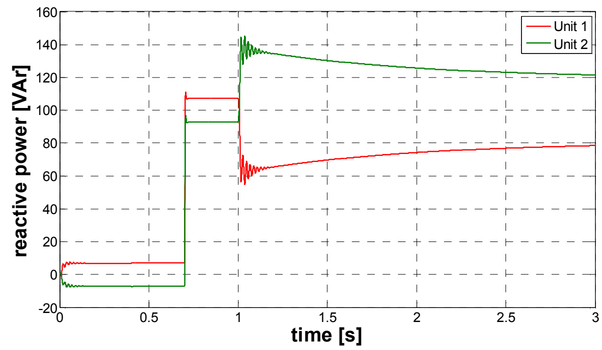


Figure 7. Generated reactive power

It can be observed that in the first time interval, after a short oscillation starting from 500 W, the units are able to reach the imposed set-points of active power, achieving frequency and voltage nominal values. The step increase of load active power at 0.4 s is equally shared between the two units, leading to a frequency decrease of 0.006 Hz. The step increase of load reactive power at 0.7 s is satisfied analogously, leading to a voltage drop of 0.54%. It is worth to remark that each variation induces oscillations in frequency and voltage, due to the R-L nature of electrical connections.

The secondary control starting from 1 s allows the microgrid to reach nominal values of voltage and frequency by the end. This happens with some voltage and frequency oscillations just after the secondary control connection, and leads the two units to generate 660 W and 440 W, respectively. Reactive power is shared between the two units according to the same ratio (120 VAr and 80 VAr, respectively).

The action of secondary controller is therefore able to restore voltage and frequency, and it is of vital importance in the case of islanded microgrid. This condition could be realized in the MG previously described by controlling the power exchange with the distribution network.

## CONCLUSIONS

The setup of microgrids involves the definition of specific control actions of the energy management system. Although decentralized control is able to perform important regulation tasks, centralized EMS is required to achieve a better coordination of the devices taking part to the system. The work has shown possible solution for implementing a communication infrastructure on a MG under construction, and an optimal layout is reached by means of Ethernet connection. The functionality of centralized secondary control has therefore been tested on a plain isolated system. Further work will deal with the realization of the full dynamic model of the microgrid and the definition of complete EMS function for centralized real-time control.

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