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Proposal of a Communication Layer for a Renewable Energy Microgrid Testbed

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Abstract. Microgrids (MG) are becoming a definitive solution for the integration of renewable energies sources in the energy matrix. As it becomes an independent cluster of energy apart from the main grid, it needs a specialized control called Microgrid Central Controller (MGCC) and consequently a robust communication layer with the primary controllers in order to prevent failure and disturbances to the grid. In Brazil, an effort has been made to build a laboratory structure to simulate a microgrid environment, but with a field approach. This paper proposes a solution to the communication layer, physical and logical, that meet the requirements of a real field application allowing interconnection of real physical equipment to the testbed. The results indicate that the communication should use a physical interconnection with an Ethernet Based Protocol, considering time synchronization and redundancy.

Key words. Protocols, Reliability, Power Systems, Simulation

1. Introduction

The microgrid concept is a worldwide trend that can significantly change the planning and operation of the Electric Power Systems, mainly at the distribution level [1]. Through this concept, it is proposed an information layer above the electrical system in order to be able to perform tasks such as control, protection, and optimization of the system itself [1].

To achieve those objectives, microgrids are composed of complex electrical, control and communication systems, which operate in a parallel and coordinated manner [2]. These features raise important questions about the infrastructure of the electrical system, especially in the communication layer that interconnects the device controls of the microgrid.

Based on this context, several efforts have been made at a worldwide level in the sense of building flexible testbeds to perform microgrids analyses. This work is a part of a process of planning and deploying a Microgrid Analyses Laboratory in Brazil, as mentioned by [2].

The objective of this paper is listing the technologies and protocols used nowadays in the energy sector and it proposes a flexible communication scheme to laboratory testbed. The flexibility cited above allows this platform to emulate a microgrid environment, with several topologies and communication protocols, in order to perform analyses in the communication system under aspects like delay, latency, and accuracy of each one the evaluated scenarios.

2. Microgrid Control

The microgrid concept assumes a cluster of micro-sources, loads and energy storage systems, all operating in a coordinated and intelligent manner to supply electricity to the costumers, in both grid-connected and islanded mode [3]. The key components that can be found in a microgrid are illustrated in Figure 1.

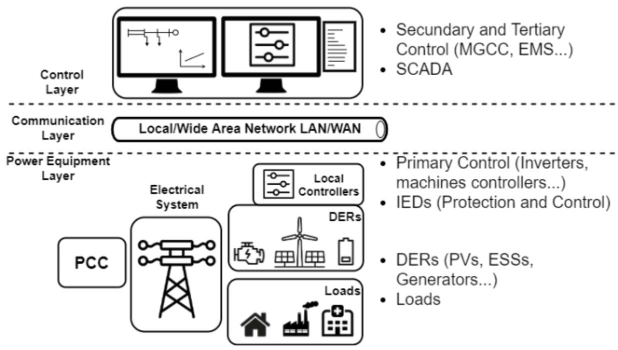

Fig. 1. General microgrid topology [4]

The first layer is composed of several power equipment connected to the electric system and its respective controllers. Distributed Energy Resources (DERs) such as Photovoltaic Generators, Synchronous Generators, and Energy Storage Systems represent the controllable sources. In this layer, the Primary Control is responsible for control output and power sharing (balance) of the DERs.

The Primary Control is composed of the local controllers, which is based just on local measurements and therefore no communication system is required [3]. However, recent research indicates a trend in the usage of a communication link among local controllers, i.e. decentralized, and also between local controllers and the central controller [3], [5].

The Tertiary Control operates in the high-level layer, Control Layer in Figure 1. This layer is constituted by a high-level control system, like an optimal operation point and provide a remote supervisory of the whole system.

Thus, it is a geographically distributed system, a robust communication layer, or the middle layer, must provide reliability to the control equipment in order to prevent that any failure or disturbance affects the controllers to act accordingly to its programmable logic [6]. This layer is responsible to interconnect the first and third layer, Power Equipment Layer and Control Layer, respectively.

The focus of this paper is the communication layer of the microgrid. In general, the communication infrastructure employed in these systems is based on Ethernet, which introduces an issue in the control and protection system, which is the inherent delay and latency in data communication [5].

Furthermore, the integration of different proprietary communication protocols also affects the performance of the control strategy, mainly in the interoperability and free allocation of functions features, which become essential for harnesses the full benefits of the microgrids.

3. Communications: Logical and Physical Layer

The communication layer is divided into two main parts: a logical layer and a physical layer. To comprehend these inner layers, the requirements must be known in order to determine the suitable components. In Figure 2, these components are generally described and further explained in the next sections.

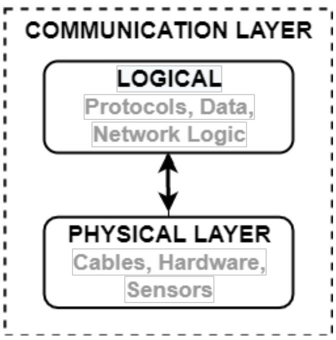

Fig. 2. Communication layer and its main components

A. Logical Layer

As observed in the earlier section, so all the benefits of the microgrid concept are harnessed, it is necessary a robust and efficient communication system that interconnects all device controls. Communication interfaces must establish a bi-directional between the different controllers, both in the same layer (horizontal communication) and different layers (vertical communication).

1) Industrial Protocols

A protocol defines the rules that the sender, recipients, and all intermediate devices must follow in order to be able to effectively communicate [7].

Industrial automation applications use a set of protocols for control, locomotion, synchronization and safety. The number of protocols is large, but these three most widely adopted are Ethernet/IP, Profinet and Modbus/TCP [8].

Modbus is an application layer protocol for client / server communication between devices connected on different buses or networks. Modbus is currently transported using [9]

- RS232, RS422, RS485;
- TCP/IP;

2) DNP3 Protocol

The Distributed Network Protocol version 3 (DNP3) is an event-oriented protocol for the transmission of data from point A to B using serial and IP communication. This protocol was first used by electricity and water companies and later used by other areas and is commonly used in SCADA-type systems for communicating control commands and process data [10].

Similarly as the Modbus protocol, DNP3 can also be transported using serial communication (RS485) or TCP/IP.

3) IEC 61850 Standard

The IEC 61850 Standard defines some protocols for communication between equipment in different layers, using MMS, GOOSE or Sample Values.

This standard became one of the most preferred standard used to define protocols in substation utilities and generally in electrical sector [11], [12].

4) Time Synchronization Protocols

The IEEE 1588 Standard specifies the PTP (Precision Time Protocol) enabling high accurate clock synchronization in packed based Networks. The PTP is a master-slave synchronization protocol defining mechanisms to find the best master in the network.

With the adoption of the TSN (Timing Synchronization Network), which is a profile of PTP, the precision of PTP based networks increased to the nanoseconds level [13].

In this context, there has been implementation of this protocol in microgrid with satisfactory results [14][15].

B. Physical Layer

The logical layer must use a physical medium to transmit the data. Usually defined as a physical layer, this layer comprises the involved hardware, cables and sensors, which can be interconnected.

The interconnection of a set of devices capable of communicating is called network [7].

1) Twisted Pairs

It is the cheapest and most used wired medium. The wires are braided to reduce electrical interference from similar pairs that are close. The transmission speed can reach up to 10 Gb/s with the new technologies [16].

2) Fiber Optics

Although twisted pairs can be cheaper and more accessible, in some fields fiber optics are preferable in electrical sector, mainly due to its immunity from noise.

A fiber optic cable is constructed from a glass or plastic structure and transmits signals in the form of light [15]. Fiber optic communication is widely used for two reasons [16]:

• Immune to electrical noise and;
• Optical isolation of surges and transients.

3) Redundancy

The IEC 62439 standard defines two redundancy protocols for automation networks based on the Ethernet Technology. The Parallel Redundancy Protocol (PRP) is a network protocol standard for Ethernet that provides seamless failover against failure of any network component [17].

This usage of this standard for redundancy was already proposed to be used with the IEC 61850 protocols in substations, increasing reliability, availability and security of this network [18].

4. Communication Definition: Microgrid Testbed

A. Description of the Microgrid Testbed

In response to the increased complexity of operation and control due to the microgrid theme, an effort is being made to build a hybrid laboratory in Brazil involving both real and emulated devices [2]. A brief explanation of the infrastructure of the laboratory is described below.

The main advantage of this testbed is the capability of representing several topologies of microgrids. For this, the key component of the testbed is the Real-Time Simulator (RTS), which will be an operating trough of the Control and Power Hardware-in-the-loop (CHIL and PHIL) concepts.

The RTS employed in the testbed is the Real-Time Digital Simulator (RTDS™), which contains several and consolated library in the power system equipment [19]. A piece of the microgrid could be represented digitally in the RTDS, and the interface with another device will be made through the power amplifiers (PHIL) and a communication link (CHIL).

Concerning the communication interface, the RTDS supports the followings protocols, GSE/Goose, Sampled Values, PMU, DNP3, MODBUS, IEC 60870-5-104, and user-selected protocols by socket communication [19].

Besides the RTS platform, the testbed will be composed by a set of real-physical devices, like synchronous generator, PV, Battery Energy Storage System (BESS), and a set of the emulated device, which will be possible, represents the behavior of different sources [2].

The interface with the commercial controllers, such as inverters and governors, will be made through protocols like MODBUS and DNP3, according to the controller specific requirements.

The infrastructure of the laboratory will also be able to perform tests in a user-developed controller, like the MGCC and the primary controller. Strategies for protection and coordinated control may also be possible.

Furthermore, the testbed might be used to evaluate different communication protocols in the microgrid operation, and the effects of the parameters like latency, jitter, and loss of packets over the network.

B. Communication Requirements

The communication layer must be defined according to the control strategy used [6]:

- Direct link (without internet): network to send and receive commands of various protocols such as PROFIBUS, MODBUS, CAN or DNP3, based on master-slave topology.
- Internet link: traffic information using the benefits of TCP, including other information such as timestamp. Problems with the master-slave topology. There may be serious failures in the absence of connection to the master.

Geographically distributed systems have issues such as different latencies and bandwidth, therefore a time synchronization to ensure that all microgrid components agree on the timestamp [6].

For this reason, some of the requirements for the chosen communication layer must consider:

- latency, bandwidth, packet loss.
- Inclusion of QoS for packet priority.

The network also needs to be prepared for device insertion or removal. When this device is connected to this network, security concerns (cyber-attacks) are also required [6].

C. Proposed Communication Layer

Considering the requirements raised in the previous section and the available technologies in the laboratory, Figure 3 illustrates the overall proposition of a communication layer for the microgrid testbed.

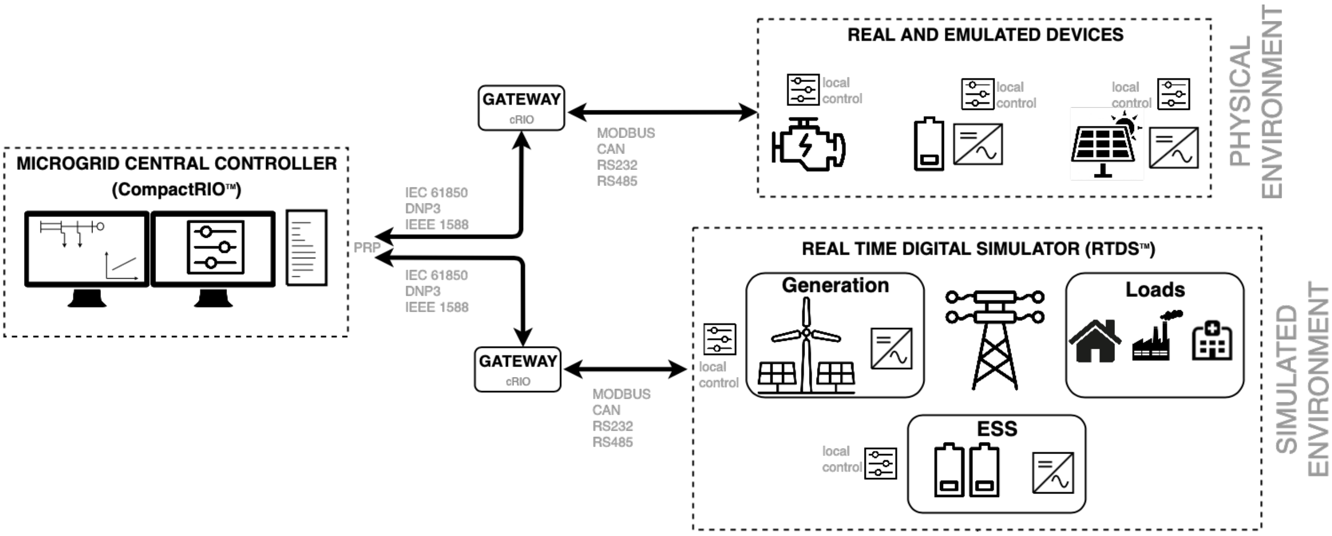

Fig. 3. Proposed communication system

In MGCC, for controlling the system, it will be used a CompactRIO™ (cRIO) Controller from National Instruments®. This type of embedded controller provides real-time operational system control and supports Field-Programmable Gate Array (FPGA). These two features allow monitoring and controlling with a single device [20].

The control of isolated microgrids is more critical than the traditional connected to the main grid. It is required a high level of coordination, and the usage of a centralized control is chosen rather than distributed one [3].

For time synchronization, the IEEE 1588 protocol was chosen. Results of the implementation of this protocol in microgrids show that accuracy can be achieve within 200 ns [15].

Furthermore, the integration of this protocol with IEC 61850 has shown feasibility as described by [14]. In this implementation of the IEEE 1588 protocol results were within jitter and latency requirements of the IEC 61850 Standard. The latency including backbone was below 600 ns.

In the gateway, another cRIO Controller is used. This embedded controller has the function of a protocol converter. Due to the programming language, this equipment allows flexibility in using and changing protocols according to the test needs.

LabVIEW is the programming language used for programming this controller. This language allows programming a real time application for monitoring and a FPGA module for both monitoring and controlling. Additionally, the LabVIEW allows interfacing with the user through a Human-Machine Interface (HMI) [21].

In the physical layer, the interconnection among the equipment is performed through optical fiber and IEC 62439 compatible media converters, which provide the conversion from optical fiber to twisted pair and redundancy in the optical fiber link.

With the current configuration, the testbed enables the use of traffic control and network emulation, even allowing to verify the Quality of Service (QoS) conditions of the communication layer [22].

5. Conclusion

The microgrid concept is nowadays a reality that could change substantially the conception of the distribution system. Recent research has shown that methodology and appropriate tools are required to subside the project and operation of these systems.

Based on this context, this paper proposed a communication layer that will be used in a laboratory for microgrid analyses. In addition, to interconnect different devices in the testbed, the communication layer will be able to perform control algorithms and evaluate the performance tests on the communication system, both in the logical and physical layer.

The usage of Ethernet networks is a growing in the electric power system, the proposed infrastructure of the communication is projected to be compatible with several proprietary protocols and real physical system. Requirements as real-time software, time synchronization, redundancy, and scalability were observed in the proposed topology.

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