Smart Grid Integration Hubs

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***Abstract* — The integration of decentralized generation units and the application of demand response programs brings changes to the power systems. Microgrids are emerging with relevant advantages for the power system operation. For this reason, several research projects are currently studding and finding methods to improve microgrids management. The development of adequate management systems, taking into account relevant retrofitting levels is of upmost importance. This paper presents and describes a gateway to be used in existing buildings in order to enable their integration in systems that are capable of managing microgrids. The gateway can monitor and control loads, generators and other equipment. For the case study the gateways will be installed in three buildings and integrated in SOICAM system able to manage microgrids. The results show the data retrieved by the gateways and sent to the central operation room.**

***Index Terms* — Demand response, load monitoring, microgrid, gateway for monitoring and control.**

I. Introduction

The power system paradigm has been changing over the last years. The massive integration of distributed generation and energy storage units brings significant advantages for the grid, but also increases the management complexity [1] [2]. A distributed approach, contrarily to the current centralized approach, can improve the grid management and achieve the desired benefits of massive integration of distributed generation [3]. The decentralization of the grid can be achieved using microgrids [4].

The implementation of microgrids brings advantages for several players in the scope of smart grids [5]. A microgrid can involve several distinct players that share the same location. The continuous communication between the players and the microgrid operator is essential to allow an effective energy management [6]. The use of gateways can solve this problem. However, they should be well chosen in order to meet the requirements of the microgrid.

The use of microgrids is supported by the scientific and the technical community. However, the efficient implementation of microgrids is still uncommon. The implementation and study of microgrids regarding their management and efficiency is essential to overcome this situation.

ne of the most important aspects of a microgrid is their gateways. These gateways can be smart meters or other equipment that enables the monitoring, control and communication of each player. The existing gateways are expensive and closed, not allowing the researchers to explore new possibilities.

This paper proposes a gateway for microgrids. The proposed gateway is modular and can work with several wireless communication protocols. The proposed solution provides an easy to build/use gateway that can communicate with the energy analyzers available in the market. The proposed gateway uses a microcontroller (PIC18F25J11) to build a bridge between the energy analysers and one of three types of wireless protocols: TCP/IP, Dash7, and Zigbee. In the case study presented in the paper, the microgrid uses the ZigBee protocol, enabling the use of a mesh network. The use of Mesh Networks suits the microgrid scenarios and can be very useful for isolated microgrids or microgrids within a wide area [7].

The main contribution of this work is the dissemination of a gateway that can be used for research microgrids. The paper presents a case study that integrates the proposed gateways in three real buildings. SCADA Office Intelligent Context Awareness Management (SOICAM) system is also presented and used in the case study in order to read and display the data.

This paper is organized as follows. Section I gives a brief introduction to the developed work. Section II describes the proposed gateway, regarding the infrastructure and used protocols. Section III describes SOICAM system and its functionalities used for this paper. Section IV describes all the installations of the case study. Section V presents the obtained results. Finally, Section VI presents the main conclusions of the work.

II. Proposed Gateway

For consumption measuring, two different types of systems were developed: electromechanical and electronic meter. Electromechanical meters are somehow limited since they can only read the power consumption but nothing more. Nevertheless electronic meter can read a big range of parameters such as power consumption, power generation, frequency, voltage, current, and more. In addition, typically with electronic systems, it is possible to see the measured values on a screen or read the energy parameters using a communication interface.

The authirs developed an electronic board that can read analog input signals, communicate by RS-485 transceiver as a

master in network and control loads remotely. This electronic board can communicate with energy analyzers and other devices (such as, actuators and sensors) using RS-485 transceiver and transmit/receive data by a wireless transceiver. These transceivers can use on of the following protocols: TCP/IP (Wi-Fi), Dash7 or Zigbee.

The use of RS-485 communication enables the interaction with the majority of energy analyzers on the market as well as much invertors on the market (AC/DC and DC/AC). These interactions provide the gateway with the required data. The gateways developed allow the monitoring and control of devices connected and like a smart meter they communicate to a communication central. In this case, SOICAM is used system as the communication central (Section III). Figure 1 shows the block diagram used in the proposed gateways.

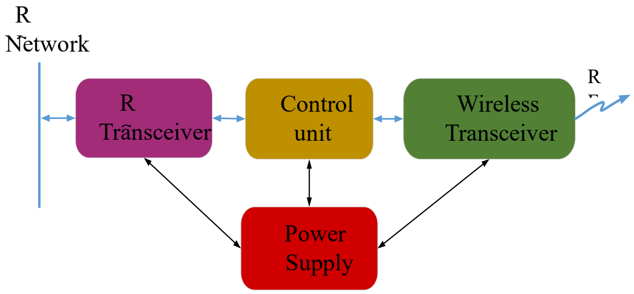

Figure 1. Gateway - block diagram

In this diagram, the black arrows correspond to power supplies and blue arrows regard the interaction between blocks. The diagram has three main blocks regarding the gateway communication protocols: RS-485 Transceiver block (pink); Control Unit block (brown); and Wireless Transceiver block (green).

RS-485 Transceiver (pink block) operates as an intermediate between the Control Unit (microcontroller) and RS-485 network. The left arrow in the pink block is the RS485 communication, the right side arrow is the serial communication between Control Unit and RS-485 transceiver. Besides that another connection is performed between the Control Unit and the RS-485 Transceiver; this connection enables the RS-485 control to write and read data.

The Control unit (brown block) corresponds to the microcontroller. This is the brain of the system; it control every process. For this block was chosen the microcontroller PIC18F25J11; the decision factor was the maximum frequency, two serial communications, type of package, number of pins and size of program memory. The PIC18F25J11 microcontroller can operate in 48 MHz (12MIPS) and it has two serial ports, PDIP package, 28 pins and 32 Kbytes of program memory.

The Wireless Transceiver (green block) is a wireless transceiver that supports multiple protocols. This block supports the modules: RV-XV; WizziMote; and Xbee. These modules, used as transceivers, use three types of protocols: TCP/IP; Dash7; and Zigbee.

A. RS-485 interface

In energy systems RS-485 is widely used in energy analysers, Programmable Logic Controllers (PLC), invertors, motor drivers and much more. This communication protocol is used in the microgrid works, such as [8], [9] and [10]. The proposed gateway uses RS-485 communication in order to interact with those devices.

The RS-485 communication uses 2-wires or 4-wire to produce a differential communication bus. The RS-485 network can manage long distances, until 1,200 meters. However, this distance can only be achieved using RS-485 nodes across the network. A single network can have 32 devices, but only one master per network. The master can ask and send data to the slaves. The slaves can only respond to the master. The messages passing on the network are public and can be read by every node in the network. Each slave has its own ID and can only reply to messages sent with that ID.

The protocol used in this communication is Modbus/RTU. This master and slave protocol is simple and easy to use, being available in the majority of devices that implement RS-485 communication. The proposed gateway can use this protocol as a master or as a sniffer; these operation models are described in Section IV (part *A* and *B*).

B. TCP/IP Protocol by IEEE 802.11 Standard

The IEEE 802.11 standard regards wireless communication using TCP/IP protocol, being a standard in Wi-Fi communications [11]. For the proposed gateways this protocol is used for buildings with wireless internet communication that use IEEE 802.11.

The RV-XV is a module by Roving Networks and it is a certified Wi-Fi solution. Currently this module shall belong to the microchip. It is intended to implement TCP/IP stack using the RN-171 Wi-Fi module and incorporates 802.11 b/g radio, 32 bit processor and real-time clock. The communication interface is UART, so it is only need 4 wires to communicate. The baudrate is selectable by software with maximum of 464 Kbps over UART. In addition, the maximum power to transmission is 12 dBm, and it incorporates 8 GPIO and 3 analog input sensors.

C. Dash7 protocol

Dash7 protocol was create in order to overcome the limitation of other wireless communications [12]. The main features and advantages of this protocol are the very low consumption and the capability of penetration in heavy material, such as, concrete walls and metallic objects. The operational frequency of Dash7 is 433 MHz.

In Dash7 protocol are specified four types of classes: blinker; endpoint; gateway; and subcontroller. Each device, using this protocol, must be in one of the classes but can change the class during their execution. The topologies allowed are similar to Zigbee topologies, allowing: start topology; tree topology; and mesh topology.

The WizziMote is a device developed by Wizzilab that was intended to implement the Dash7 protocol. It integrates a TI CC430F5137 and an antenna matching circuit for the 433MHz band in a compact form-factor. It can operate as a

microcontroller, has a dedicated UART interface, 8 configurable GPIOs, 6 configurable ADIO, three leds to debug and three buttons to teste. With a partial Dash7 protocol UART can operate in 9600 bits/s, 57600 bits/s and 115200 bits/s. Besides that, it can operate as bridge between UART port and radio communication, in other words, every data sent by UART is automatically sent by wireless. This system implements a partial Dash7 protocol because it isn't complete, implementing some layers.

D. Zigbee protocol

The zigbee is a wireless communication protocol to be used in sensors and machines and was created as a low-power communication protocol and low cost, operating on 2.4 GHz in most countries of the world [13]. This technology allows the communication point-to-point and point-multipoint, enabling the formation of three types of networks natively, star network, tree and mesh. In the Figure 2. Zigbee topologies is possible to see the different topologies that can be employed.

Participants in the Zigbee network can be end-devices, routers or coordinator, see Figure 2. Zigbee topologies. In one network can only be a coordinator because it has responsibility for creating the network, control its parameters and basic maintenance. In turn, the number of routers and enddevices may not exceed 65535 for the reason that 16-bit addressing is used. Routers are continuously active and were created with the purpose of extending the network range, and, finally, the end-devices are devices with cyclical periods of sleep, decreasing power consumption.

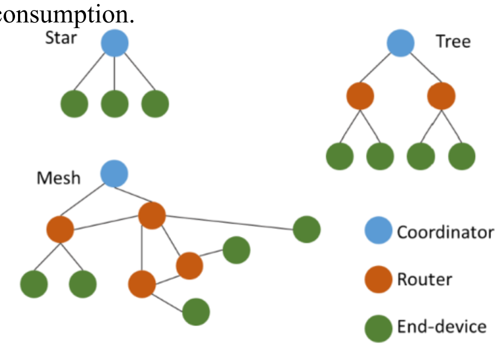

Figure 2. Zigbee topologies

Xbee is a device developed by digi international which implements the Zigbee stack and two variants that are Xbee ZB, Xbee ZB pro. The main difference between this equipment is the communication range which in indoor environment for Xbee ZB and ZB Xbee Pro are, respectively, 30 meters and 90 meters and in outdoor ranges (open field) are 90 meters and 1,600 meters, respectively. These ranges are different to the transmit power which are respectively 1 mW and 60 mW. In addition, the Xbee allows a maximum rate of 250 Kbits/s and uses a serial communications interface (UART) with a baud rate ranging from 1200 bits/s up to 250 Kbits/s. Finally, it allows two modes of operation: AT mode and API mode. In the AT or transparent mode modules act as a serial port and any data sent over the serial port will be sent by RF. In turn, the API mode presupposes the construction of frames for performing different operations, in other words allows greater control of all operation. The API mode also enables mesh networks.

III. SOICAM

The integration of gateways in buildings enables the monitoring and control of equipment. However, the application of gateways is not enough to achieved a microgrid scenario. Beside the gateways it is necessary the integration of a system able to interact with the gateways, reading the monitoring data and send order for the control. It is also recommended that this system possesses some intelligent for the microgrid management. SCADA Office Intelligent Context Awareness Management (SOICAM) system was initially developed for the management of one building [14]. The main advantage of the system is the capability of execution demand response programs in the managed building.

In the last year, SOICAM was evolved in order to manage several buildings using a multi-agent system. Each computational agent has their own SOICAM version. For the microgrid operator the system has an agent that aggregates the information of all the other agents present in the multi-agent system.

SOICAM system manage all the data gathered and sent by the gateways. The data will them be put available for user visualization and stored in a database. The lack of energy data is one of the main problems in the research centres. The application of the proposed gateways with a support system for data storage can help and improve the quality and quantity of studies regarding microgrids, using real data and real buildings.

IV. Infrastructure

The integration of the proposed gateways with SOICAM system uses three real buildings in Institute of Engineering Polytechnic of Porto (ISEP/IPP). The footprint of the buildings is shown in Figure 3, the used buildings are:

- Building N: composed by 7 offices, 1 server room, 1 meeting room, 1 kitchen and 1common area; this building is used by 20 researchers daily;
- Building I: composed by 1 classroom, 1 server room, 4 offices, 1 meeting room and 2 common areas; this building is used by 15 researchers and near 40 students daily;
- Building F: only has distributed generation; 1.2 kW wind turbine and a total of 2.4 kW photovoltaic generation;

The used buildings are not physically connected, in order to have a microgrid it was necessary to build communication channels between them. The blue dashed lines in Figure 3 represents the desired connections in order to connect all the buildings together. Building N has an operation room for microgrid management.

The measures of consumption and generation are done using energy analysers. Each building has multiple energy analysers in order to separate and individualize the measurements. For this scenario the buildings were equipped with one gateway for each on of them. The proposed gateway was connected to the energy analysers already installed. In this scenario it was used Zigbee protocol. This decision was made regarding the distances.

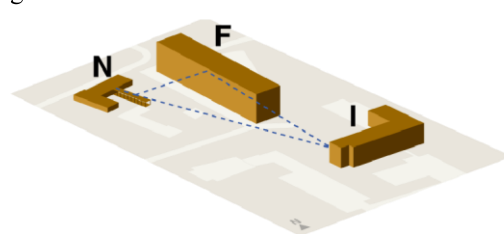

Figure 3. Buildings footprint

Building N and building F have their own PLC for monitoring and control the buildings. These PLCs use RS-485 communication in order to change information with the energy analysers. The PLCs work as masters in the RS-485 network and cannot be stopped. For this reason, the proposed gateway can operate as a master or a sniffer in the RS-485 network. Building N and building F will use the gateway in sniffer mode, while building I will use the gateway in master mode.

A. Sniffer mode

In this configuration the proposed gateway operates as sniffer in the RS-485 networks, sniffing all the data passing in the network. The sniffer mode can be used in RS-485 networks that already have a master requesting the necessary data from the analysers. For networks where the master does not request the required data the proposed gateway cannot operate because of the missing data. The flow chart that describes the process is presented in Figure 4.

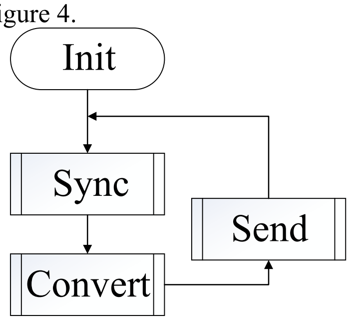

Figure 4. Sniffer mode flowchart

First off all, some variables are initialized such as the address register of first analyser, code for Modbus/RTU operation, number of analysers, size of matrix to store data, etc. Then, a sync function is called and microcontroller start trying to sync data on RS-485 network with the initialized variables. After synchronization, the received data is stored in the microcontroller memory. The data is stored as an array of characters. Them, the data is pre-processed using the function Convert. This function, represents different kinds of conversions. It can be used to convert received data to IEEE 754 floating Point or integer with 4 or 8 bytes. After the conversion the gateways sends the data to the operation point.

In our scenario the send function implements the mode API of Zigbee, so in the first step the frame is filled, then the total of characters is calculated and in the end is calculated the checksum. After that, the data is sent through serial communication.

B. Master mode

The gateway installed in building I use the master mode. This mode enables the gateway to actuate as master in the RS485 network. In this case the gateway should ask each energy analyser, or any other RS-485 equipment, for the values than want to read. Because this mode acts as master, it is possible to have control of the equipment placed on the RS-485 network. Not all the equipment allow control, and not all the equipment allow the same kind of control. Meaning that the control can be studied and analysed by the user, in order to answer their needs. Figure 5 shows the flowchart of the RS485 communication block used in the gateway when it acts as master.

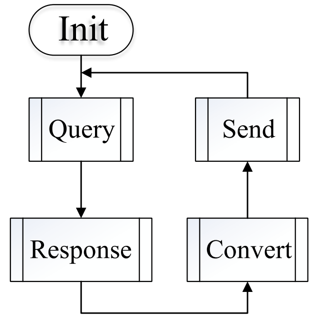

Figure 5. Master mode flowchart

In Init some variables are initialized such as queries, memory to store data converted, etc. Then, the first function called is Query. This function is accountable to send a message to RS-485 network. This message can be used to control loads or ask some power parameters from the energy analysers. Once the main goal of this system is monitor the power parameters the query to read parameters is commonly used. After send a query the Response function is called. This function allows the reading of the frame sent by energy analysers as a response by previous query. In the next step Convert function is called. Depending of register type in energy analyser, this function can convert IEEE754 floating point or Integer values. Finally, the Send function is called. This function implements the mode API of Xbee module, so in the first step the frame is filled, then the total of characters is calculated and in the end is calculated the checksum. After that, the data is sent through serial communication.

C. Installation of the Gateways

Two configuration types were used for the gateways installation. The first used two gateways (PLC and proposed gateway) and the second used just the proposed gateway. ZigBee protocol was used in both configurations.

In building N and building F it was used the sniffer mode (section IV.*A*), enabling the use of two gateways at the same time. The PLC gateway is used by other system in order to store de energy data regarding the buildings. The proposed gateway will also monitor the building but will integrate a system developed to test demand response programs in real facilities. The installation schema of the gateway in building N and building F can be seem in Figure 6.

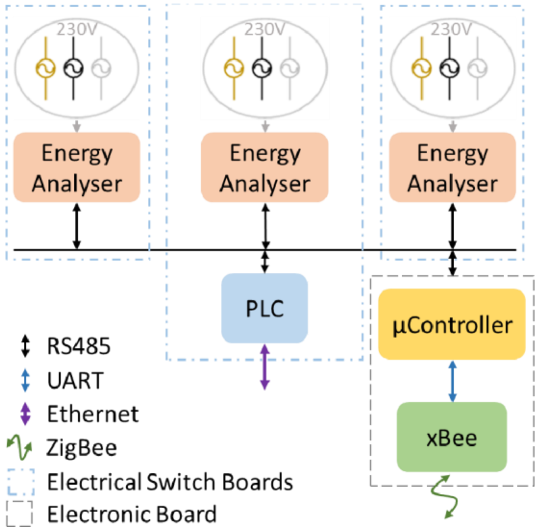

Figure 6. Building N and building F installation schema

The installation in building I is different from the building N. In building I there were no gateway already working. The building only had two energy analysers without and PLC. For the installation on this building it was used the gateway working as a master in RS-485 communication with the energy analysers. Figure 7 shows the installation schema used for building I.

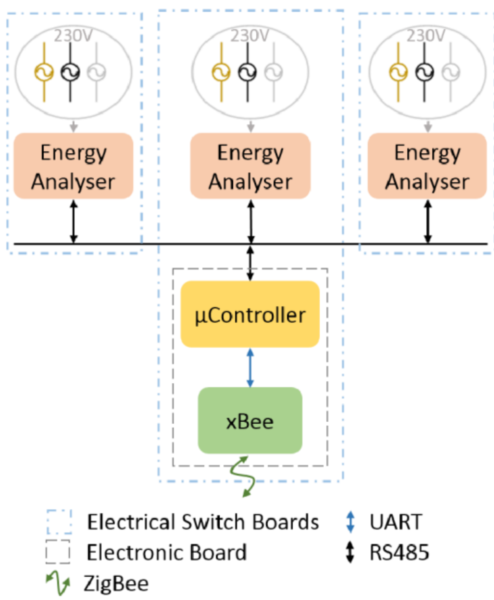

Figure 7. Building I installation schema

The proposed gateways will monitor the buildings using 10 seconds periods. The data is send to a central operation room located in building N. Figure 8 shows the location of the gateways, the central operation room and the Zigbee routers necessary to propagate the signal. The use of routers allows the repetition of the signal coming from the gateways.

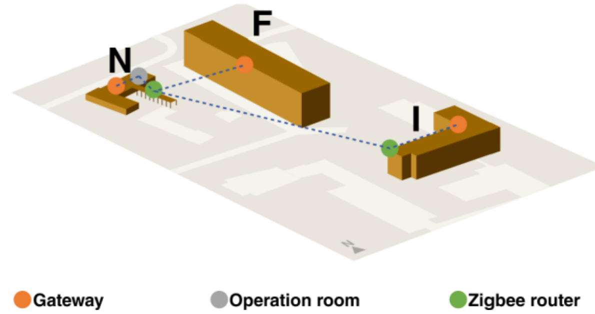

Figure 8. Gateways and repeaters location

The integration of the buildings with SOICAM system using the proposed gateways allows us to build a microgrid to test demand response programs and to monitor all the data on the players. The gateways work as an integrator between real facilities and management software systems.

V. RESULTS

In this paper the focus is the use of the proposed gateway in order to monitor and connect every player in the microgrid. The results regard the monitoring of building N (consumption) and building F (generation).

The charts were built within a two hour period with a data acquisition of 10 seconds. The data is sent using Zigbee protocol for communication between gateways. The use of two routers installed in the microgrid enables the signal propagation. In the central operation room the data is received by a Zigbee coordinator that is integrated in SOICAM. This integration enables the interpretation and storage of the data.

For the consumption data the energy analysers separate the consumption by the type of loads, in our microgrid we have three types of loads: HVAC systems; celling lights; and electrical sockets. This separation allows a better analyses and observation of the consumptions. Figure 9 shows the real-time consumption (10 second periods) of building N received in the central operation room. The shown consumption are separated regarding load type.

Is also possible to see the individual generation of building F. The real-time energy generation of building F can be seen in Figure 10. The data is separated by the generation type: wind generation; and photovoltaic generation.

The central operation room have access to individual player consumption and generation, as seen in Figure 9 (consumption) and Figure 10 (generation), and provide the global consumption and generation. The data is received in the Zigbee network coordinator and sent to a computer, using a xBee USB shield. The data is them received, analysed and processed by SOICAM that can use the data for demand respond programs. In this paper SOICAM will read all the data and present charts for individual consumption, individual generation and microgrid consumption and generation. In this paper no demand response program will be executed in the microgrid.

The application of the gateways enables the acquisition of real-time data that can be used in microgrid management systems, solving the lack of data problem. This way is possible to implement a microgrid for research proposes.

VI. CONCLUSION

In this paper is described and shown a cheaper gateway that can be integrated in real buildings, enabling the integration of the buildings in energy management systems. There is a present-day need to test and analyse algorithms developed for microgrids. The proposed gateways enable the test of these algorithms in real facilities. Currently the construction of a microgrid is not clear and is not easy for research centres that want to improve their infrastructure and apply their algorithms in real facilities. The proposed gateway is able to meet the current research centres groups in the energy field that work with microgrid management. The main contribution of these paper is the presentation of a gateway that can be used in research centres.

The obtained results are promising and point this work to good future. The microgrid is working in GECAD without this gateways for a year, but using this type of gateways is possible to test new methodologies and communications for microgrids.

VII. References

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