Chapter 14

# Development and Implementation of Wireless Sensor Network for the Electricity Substation Monitoring

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/50489

## 1. Introduction

The requirements for process instrumentation, combined with the advances in wireless communications and electronics allowed the design of wireless sensor networks (WSNs). The technology applied to these sensors and communication networks has enabled the evolution of these systems has been called a smart sensor networks. In this case, not only collect sensor data, but also perform local processing, and may also act in the system, and subsequently, if necessary perform transmission. These smart sensor networks allows a more effective monitoring system, fault detection, and others, thus improving the reliability and system maintenance [2, 3, 6].

Among the challenges of design, development and installation ofsmart sensor networks, we can highlight environments where electromagnetic interference can reduce your performance or make it inoperable. In such cases, hybrid networks, that combine wireless systems with wired structures may be more appropriate [8]. These hybrid structures also allow better power management of these networks, since in some the cases the sensor node can be installed in places with difficult or no access. In these cases, the physical connection can even be used as a redundancy of the communication system.

In cases where the substation has been installed and is running without the provision of a monitoring system, it is not possible with commercial solutions available to monitor the system without performing some kind of reform of infrastructure. In this particular case, the structure reforms to allow passage of communication cables bring numerous disorders. Currently these power substations do not have any type of on-line monitoring. In cases where there a fault, after some consumers inform the concessionaire, a team must move to the place to search for the substation where the fault occurred.

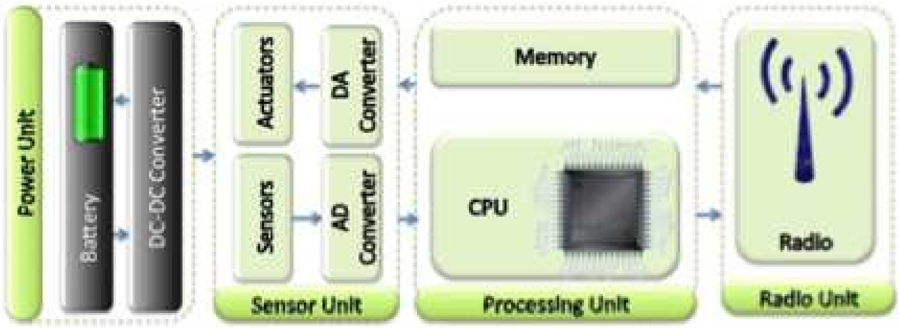


**Figure 1.** Sensor Node Basic Structure

The objective of this chapter is to develop a integrating system considering a set of smart sensors and communication systems for use in a underground power distribution substation. The underground power distribution substation chosen, owned to the network grid system in the city of Porto Alegre in Brazil. The depth of these substations is 4-5 meters, under layers of asphalt and concrete. Therefore another challenge of this work was to establish the communication with the system installed in the interior of substation and the outside, since this is not possible through radio systems and are not available physical bus installed for this purpose.

## 2. Wireless sensor networks

A Wireless Sensor Network can contain hundreds or thousands of small autonomous elements called sensor nodes, and each sensor can feature a large variety of sensors (e.g., temperature, speed, acoustic, seismic). In many cases, nodes are randomly spread over remote areas, making it difficult to perform any maintenance to the nodes. Hence, a node remains live while it has enough battery capacity for its normal operation, and the network lifetime strongly depends on the remaining capacity of the nodes in the network.A sensor node has a few basic components (see Figure 1) as follows [1, 7]:

- *Power Unit*, usually a battery, which acts as the power source for all node's components;
- *Sensor Unit* that contains a group of sensors and actuators;
- *Processing Unit* which includes a microprocessor or a micro-controller;
- *Communication Unit* which consists of a short range radio for wireless communication.

## 3. Network grid underground distribution system

The underground distribution systems represent an attractive alternative for applications in distribution systems in large urban centers, which are characterized by large concentrations of load and require high levels of quality, continuity and reliability of electricity supply.

There are two most common forms of connecting underground distribution systems, the radial system or the network grid system. The network system, is a low voltage distribution system having a set of transformers which the secondary side are connected in parallel,

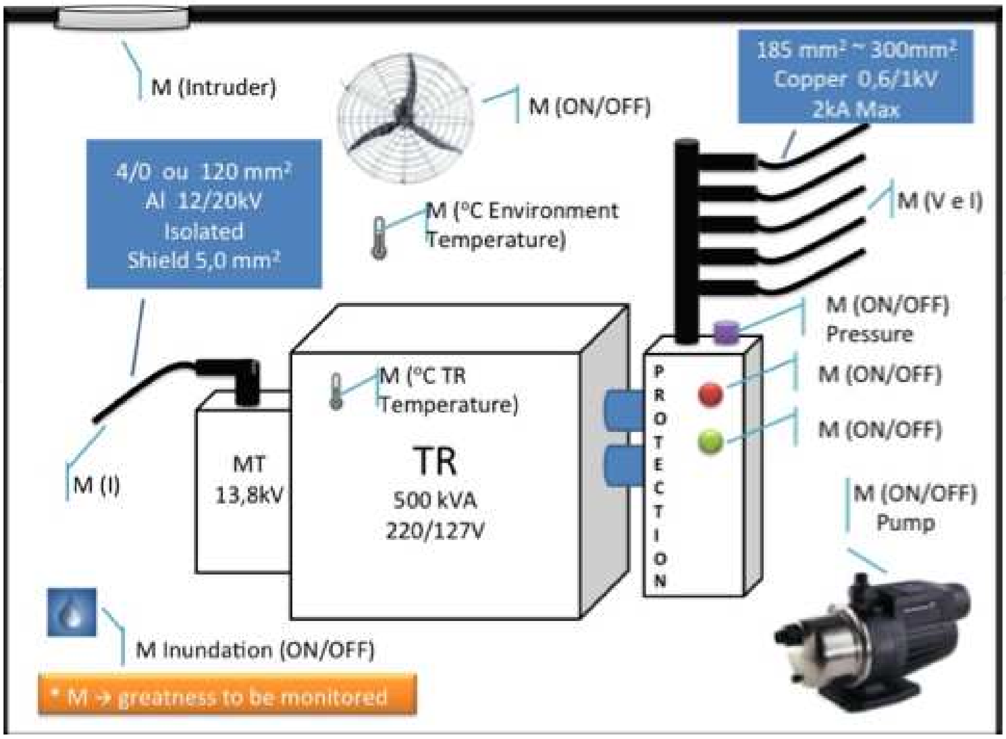


**Figure 2.** The Greatness Monitored by the Developed Systems

supplying the load. This topology allows the supply of electricity is maintained even if one or more transformers to leave the provided service, as long as the total power of the remaining transformers is equal to or higher than load demands, furthermore allows to improve the voltage characteristic of secondary.

The network grid system is installed at the central region of Porto Alegre is fed with a primary voltage of 13.8 kV and secondary voltages of 127/220V, being composed of a 500 kVA transformers, submersible, hosted in subterranean chambers, which are accommodated under of the central city streets. The biggest risks in this type of system are inundation, overheating, faults in the protection system, alterations in the pressure of the protection system. In the Figure 2 can be observed the greatness monitored by the developed system.

## 4. Developed architecture for monitoring system

The system developed (see Figure 3) is based on the concept of intelligent sensors. The Smart Sensors Modules (SSM's) can take a reading of up to four greatness, two analog and two digital, communicating through a wireless network and/or a physical network [4, 5].

A second module is designed for use with the acquisition of the greatness, this has a quickly dynamics and need to read more than four channels such as: voltages and currents in the three fase system in the secondary of the transformer. This device is called as remote data acquisition unit (RDAU). The data of these two systems are concentrated by the developed Gateway. The Gateway establishes communication with the exterior. As stated before, this communication is not possible through a radio link or a wired conventional structure since the characteristics of the substation does not allow the deployment of these systems. Therefore

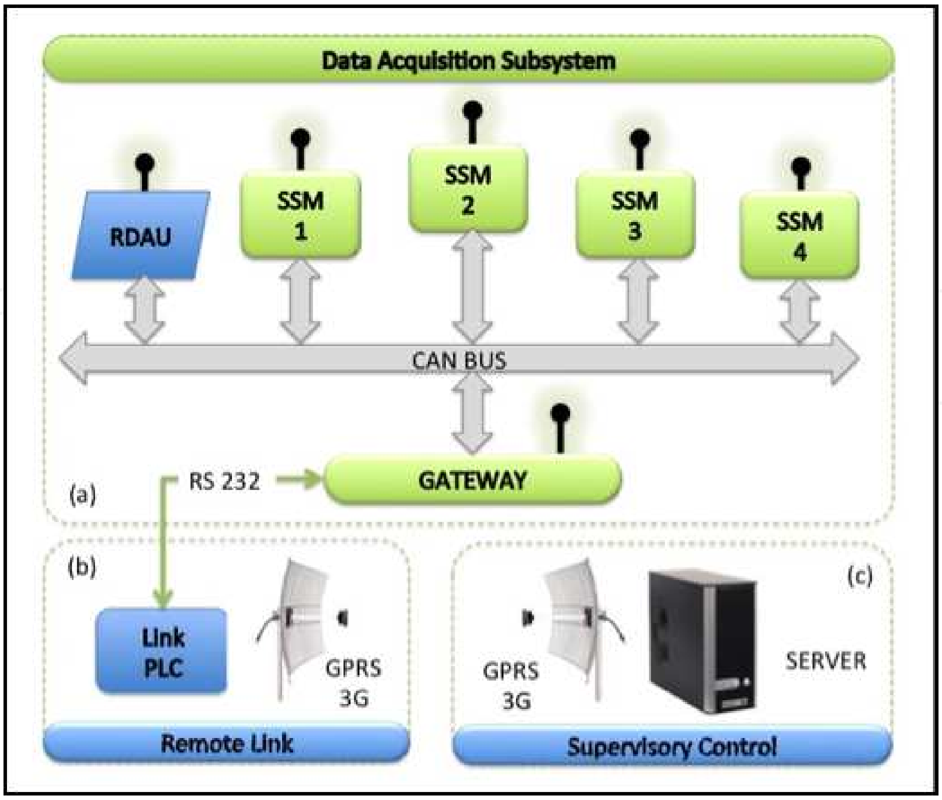


**Figure 3.** The Monitoring System Developed.

it has been used a PLC (Power Line Communication), allowing extraction of data from that environment (i.e., Underground Substation).

In the outside area the received data is retransmitted by a system GPRS/3G to a server. The monitoring system presents with the following subsystems (see Figure 3):

- Data Acquisition Subsystem;
- Remote Link; and
- Control Subsystem.

## 5. Intelligent sensor module - SSM's

The SSM's devices (See Figure 4) are capable of performing functions of sensoring, processing and transmitting/receiving data. Its architecture (See Figure 5) consists of a power subsystem, a sensor subsystem and communication subsystem.

The sensor subsystem and communication subsystem are managed by a PIC18F2580 microcontroller. This was chosen because of project requirements and also have by the same have be a built hardware dedicated to the CAN bus communication. In addition, adds support to various peripherals, such as analog-digital converter (A / D) 10-bit, four timers, USART serial interface (UNI-sectional sSynchronous Asynchronous Receiver Trans-Mitter), among others. The power subsystem is responsible for maintaining the supplied for the SSM, being the primary source of energy from the CAN bus and / or battery pack. When needed, the

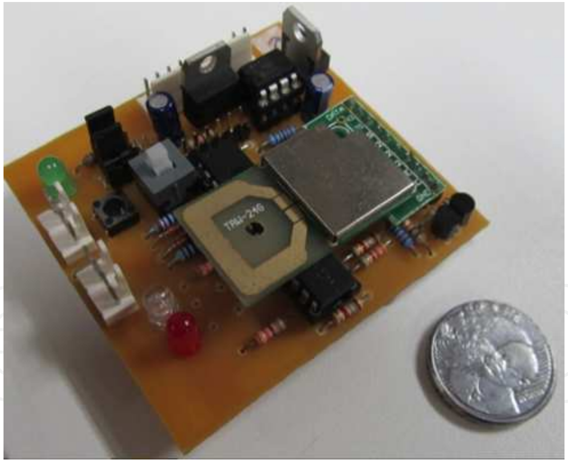


**Figure 4.** Intelligent Sensor Module - SSM.

CAN bus also feeds the recharging batteries system. This system consists in a battery pack with a capacity of 900 mAh and 7.2 V.

The SSM is equipped with four sensor inputs, 2 digital and 2 analog. The analog inputs are pre-conditioned to receive signals in the range 0-5 V or 4-20 mA, depending on the characteristics of the sensor connected. If the sensor connected to the SSM need power supply, it is provided together with the signal connector.

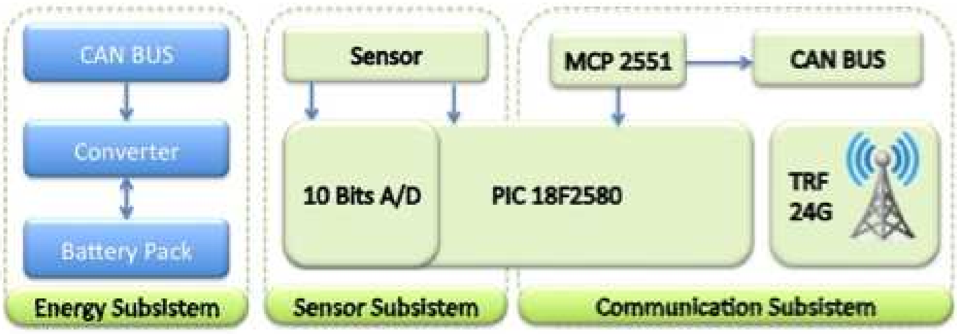


**Figure 5.** SSM Architecture.

The SSM using the communication subsystem to send / receive data in two different ways: via wireless network or via the physical network. The physical network is primarily intended for the redundancy, the wireless network being the primary means of exchanging information. As a communication device by radio frequency module was used TRF-24G, which employs the transceiver nRF2401A. This device performs the modulation GFSK (Gaussian Frequency Shift Keying) in data transmission at a rate of a maximum 1Mbps. It features integrated antenna and the transmission power can be set in the range -20 to 0 dBm, enabling a range of 250 m (without obstacles).

The physical bus meets the norm ISO11898-2 international standard intended for the CAN communication [3]. It specifies patterns relating to the physical layer of the CAN protocol, one being the use of a transceiver device that makes the interface between the sensor and CAN bus node, making certain electrical conditions provided in the standard are met.

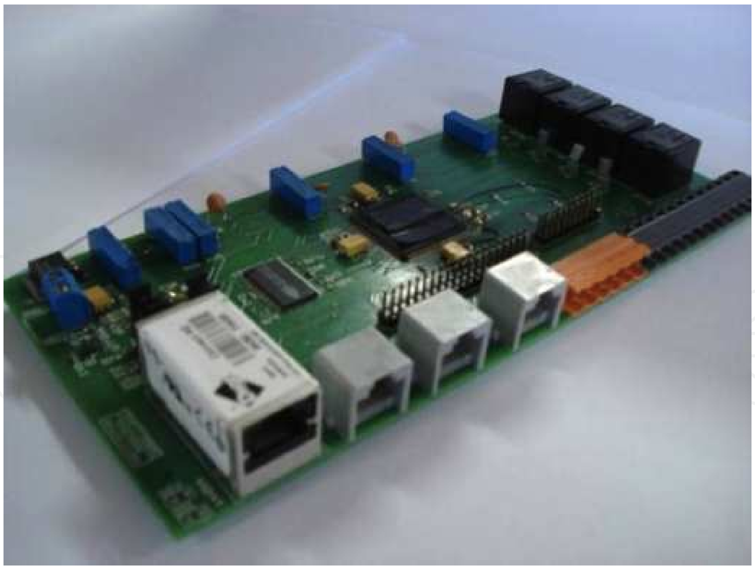

**Figure 6.** Remote Data Acquisition Unit - RDAU.

Among these conditions include the protection against short circuits, voltage levels, among others. Therefore, the SSM's are connected to the bus via the CAN transceiver MCP2551 manufactured by Microchip Technology. A prototype of SSM was developed to experimental validation. Every SSM has an address assigned by the Gateway during installation the network, organizing themselves independently (plug and play).

## 6. Remote Data Acquisition Unit - RDAU

Differently from ISM topology the RDAU (see Figure 6) is a static projected acquisition unit for monitored system, with three voltage and three currents acquisition, transmission to RS, besides incorporate four digital inputs.

**Voltage and current transducers**

For voltage and current signals acquisition the transducers LV20-P and LA25-NP (LEMTM) are used respectively (hall- effect sensor). The voltage and current RMS phase values in the secondary of the measurement transformer are, respectively, 65V and 5A. Considering 50% overvoltage and 150% overcurrent, the system is able to measure until 100V (voltage) and 12,5A (current). To prevent aliasing problems, it was added a anti-aliasing, Butterworth filter is the 2nd order low-pass.

**The Digital Signal Processor - DSP**

The TMS320F2812 DSP uses Harvard architecture, with: 64kB of program memory, 64kB of data memory, 18kB of RAM memory and 1MB external interface memory. The operate frequency is 150MHz (6.67ns/instruction).

**DSP software**

The TMS320F2812 software was developed in C++ language, using Code Composer PlatinumTM platform (Texas Instruments TM). The program was divided in sub-routines, facilitating the agreement, maintenance and posterior update.

**Main routine**

This routine configures peripherals like GPIO, interruptions and external components configuration, as transceiver. The pins had been configured as inputs and outputs, except for the SPI pins and external interruption pins. A/D Control Routine The A/D converter is started by Adc.h library. The AD conversion routines had been configured with auto conversion of six samples in simultaneous sampling cascaded sequencer mode. It becomes simultaneous acquisition of one voltage phase and one current phase, 80ns dephasing phase/phase. The clock frequency is 25MHz. Communication Routines The communication can be carried out by two modules: asynchronous (RS-232), using SCI port; or, synchronous (wireless), using SPI port. At radio transmission, are sent 68 samples/cycle, while in serial transmission RS 232 are sent 10 samples/cycle. In asynchronous communication (serial RS-232), the transmission routine was configured with 1 stop bit, none parity, 8 data bits and speed transmission of 115200bps. The samples are grouped in a package forming a synchronism protocol, indicating for the receiver the beginning of the package and permitting to verify if the received data are correct. The package is formed by 4 heading words, 1 checksum data word, 1 checksum heading word and 60 data words. In the synchronous communication routine (to transceiver), SPI port is configured as a master, sending 16 data bits, with 1MHz transmission tax. This routine also defines the clock polarity, data transitions are during the rising edge, but delayed by half clock cycle, in agreement with the requirements of the transceiver. Besides configuring the reception interruption. The transmission routine is qualified each two conversions carried out by A/D converter. In this routine the data package are grouped to be sent to transceiver (transmitting mode). The first byte is preamble, the second address, followed for 14 bytes of data and finishing with CRC16, that transceiver (receiver) uses to verify if the received data are correct. The reception interruption is generated each time that the receive buffer (FIFO) will have 14 data bytes and the DR1 will be enabled.

**Transceiver module**

In the same way that ISM, the RDAU uses TRF-2.4GTM transceiver module for radio communication. The communication between the microprocessed unit and the transceiver is carried out through synchronous serial interface. The bits are sent to radio or received from a defined tax of clock. The TRW-24G configuration was carried out separately, one as receiving and other as transmitting. The receiver was configured as ShockBurst operation mode, with 24bits address, one reception canal, 14 data words and 16bits CRC. The transmitter was configured as direct mode, because in the ShockBurst mode the transceiver must be disabled each final data package, besides there is 50ns delay to each time that this is active again. In the direct way, always active, the data are only sent if there is a clock together the data. After the configurations the main routine begins an infinite loop, waits the interruptions and to each 2 A/D conversion begins the sending package routine.

## 7. Gateway

It was also developed a Gateway which is responsible for interconnecting all sensors (SSM and RDAU) and the transmission system PLC. The essential difference of the Gateway to the SSM is that there are an additional RS232 serial communications port used to perform the interconnection with the PLC. The physical aspect of the Gateway is shown in Figure 7.

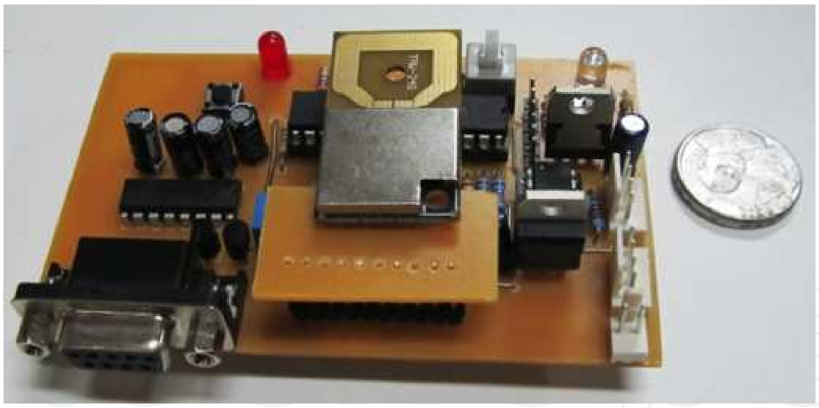

**Figure 7.** Gateway.

The exchange of information between the Gateway and SSM's is done over the MODBUS communication protocol. This protocol is characterized essentially by being the master-slave. Defines a structure of communication messages used to transfer data between analog and discrete devices with microprocessor detection and information transmission errors. The MODBUS protocol is located at 7th level of the OSI Reference Model (Open Systems Interconnection), which corresponds to the application layer that provides communication such as "client / server" between devices connected to different types of buses or network topologies [4]. The MODBUS also allows easy integration with SCADA systems although not the main focus of this work.

The management and addressing SSM's is performed by the Gateway, which in turn, updates and constantly checks the presence of new SSM's that are connected to the bus.

## 8. PLC modem

The PLC system installed in the the central area of Porto Alegre city, in low voltage cabling, underground network, consists of a pair of transmitter / receiver PLC, developed from a PLC MODEM PL-3120 manufacturing ECHELON. MODEM connected to the PL-3120 is a microcontroller whose functions are:

- Transmitter / Receiver PLC installed on the transformer;
- Data collection and ambient temperature of the transformer housing;
- Generation of data packet to send to the MODEM PL-3120 through the serial interface (UART); and
- Management control messages sent via the mains, supplied by MODEM PL-3120.

Transmitter / Receiver PLC installed in the former tender:

- Receipt of data packets sent via the mains, supplied by MODEM PL-3120;
- Check validity of data received;
- Configuring the Modem GSM / GPRS;
- Generation of data packet to send to the GSM MODEM / GPRS through UART serial interface; and

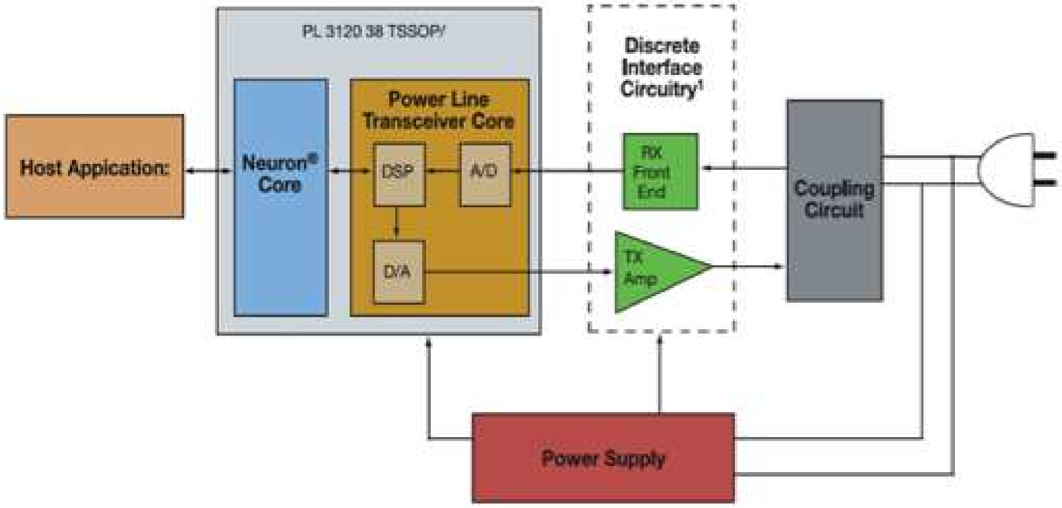


**Figure 8.** PLC Node based in PL-3120.

- Management control messages sent over the cellular network, delivered by the GSM MODEM / GPRS.

The PLC MODEM PL-3120 incorporates a NEURON processor, 4Kbytes of application memory and 2Kbytes RAM. The processor performs the NEURON routines protocol interconnecting the nodes of a network PLC, ISI - Interoperable Self Installation, and communication protocols, with an option to activate or not the protocol CENELEC. All these protocols are proprietary and has been recorded in ROM on the device. Figure 8 presents a block diagram of the constituents with a PLC node based on the PL-3120.

The MODEM PL-3120 can operate in bands A and C defined in CENELEC standards, which are selected from the crystal used to trigger the MODEM. The selection of the band CENELEC also defines the rate of data transmission on the electrical system. By selecting the band, the communication will occur at a rate of 3.6Kbps.

As shown in block diagram in Figure 8, there is the need for integration of an interface between the PL-3120 and the circuit will make the coupling of the modulated carrier to the grid. The interface circuit is composed mainly of an amplifier that can apply a signal to the power supply in one of the frequencies of operation of the PL-3120, with up to 1A peak-to-peak. Figure 9 shows the circuit diagram of the amplifier output, which forms part of the interface circuit. It is a discrete transistor circuit in a modified push-pull configuration.

The Figure 10 presents an analysis of frequency response of the power amplifier of the PLC transceiver. It can be seen a response practically flat in the frequency range of 1kHz to 20kHz. In the frequency range corresponding to the band The CENELEC standart there is a peak in the curve of the amplifier gain, the maximum occurs at a frequency of 100kHz, falling abruptly after this frequency.

The tested system was installed in the network system of CEEE-D (Companhia Estadual de Distribuição de Energia Elétrica) in the metropolitan area of Porto Alegre city (See Figure 11). The monitoring system (RDAU and SSMs) was installed in the northeast network grid system (RNE), the transformer station T-103-7A (code CEEE-D), which is the feeder 2RNE as supplier

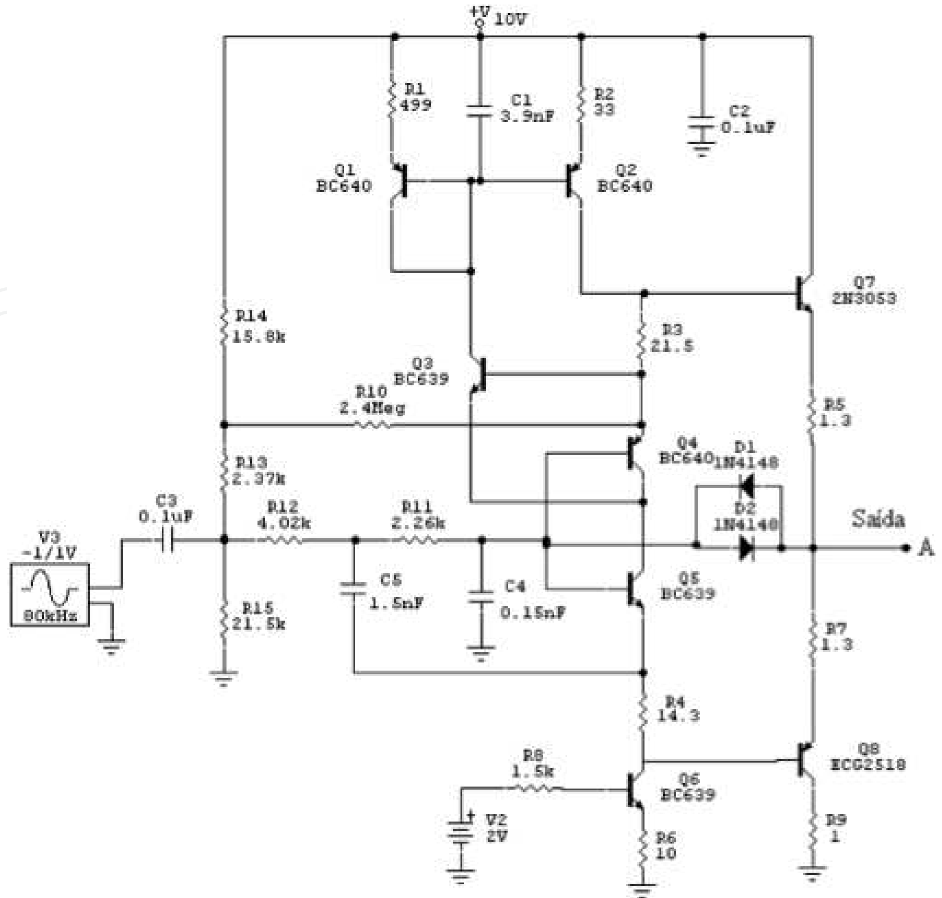


**Figure 9.** TX Amplifier.

of energy. The gateway developed manages the receipt of the data system and is connected to the PLC signal transmitter, the output low voltage transformer. The approximate distance between the transmitter and receiver is about 250 meters, since there is no direct path and the cables contour the square

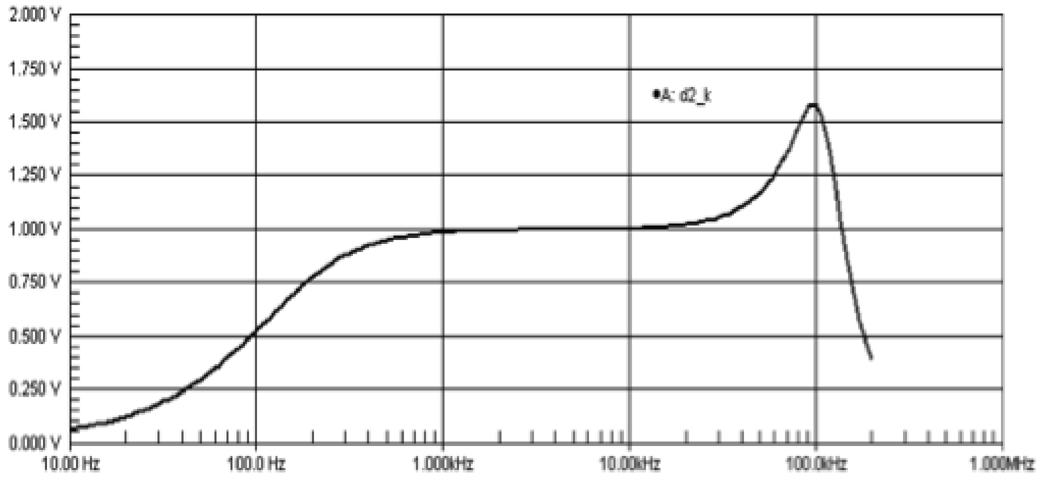


**Figure 10.** Frequency response of the TX amplifier.

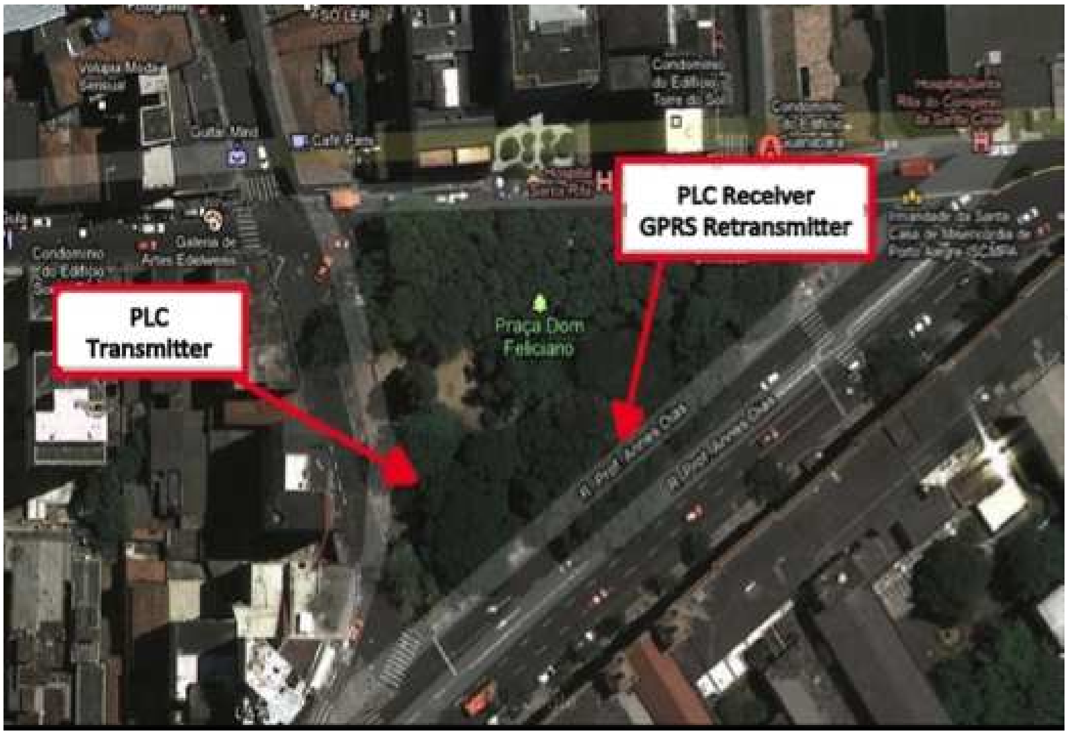


**Figure 11.** PLC Receptor and Transmitter localization.

Due to the robustness provided mainly by the adoption of structure hybrid in Smart Sensors Modules and Remote Data Acquisition Unit, there are no packet losses in communication between them, since the most critical data such as voltage and current traveling through the system CAN when they are not received appropriately by the tranceivers. The battery system of the sensor nodes acts as backup in cases where redundancy happens. In these cases, the worst possible condition, occurs when the sensor node is continuously processing and transmitting data and energy consumption reaches 57mA peak. Just as a tested set of batteries used in these extreme conditions that could be evaluated for its durability. The figure below shows these results.

The interval between samples is 1 second and therefore can be estimated operating time critical state in 4 hours and 15 minutes on average. After collecting the data on the server, they can be viewed in real time on supervisory controller.

The Supervisory Controller (SC) Subsystem was developed in order to emphasize data presentation versatility. It runs on standard PC architecture originally using a web browser and mobile devices with Android and a IOS respectively . The Application was developed to support on-line data presentation through reading of the received data files. Users may be able to explore, navigate and visualize all the data they are interested in. Since the main function of the SC subsystem is receive and store the data derived from the ISM?s and the RDAU?s, it can process and present them to operators through: i) SCADA (proprietors systems); or, ii) Man Machine Interface (HMI) specially designed for this purpose. Several possible operation scenarios can be considered for the SC subsystem. First, lets consider a scenario where the monitored data are distant from the SC and a wired infrastructure is available (Ethernet TCP/IP). Then, the acquired data for the RDAU and the ISM?s will be transmitted through the wired network communicating through the Remote Server (RS) . Another situation, where


**Figure 12.** Web based real timer viewer for the supervisory system.

the monitored data is distant but wired network does not exist. Then, the SR-SC connection can be made over Wi-Fi. In a third scenario, where the data monitored is close to the SC the transmission can be directly made - gateway to SC. The connection between gateway - SC is accomplished through serial communication, using either USB or RS-232 ports of the computer.

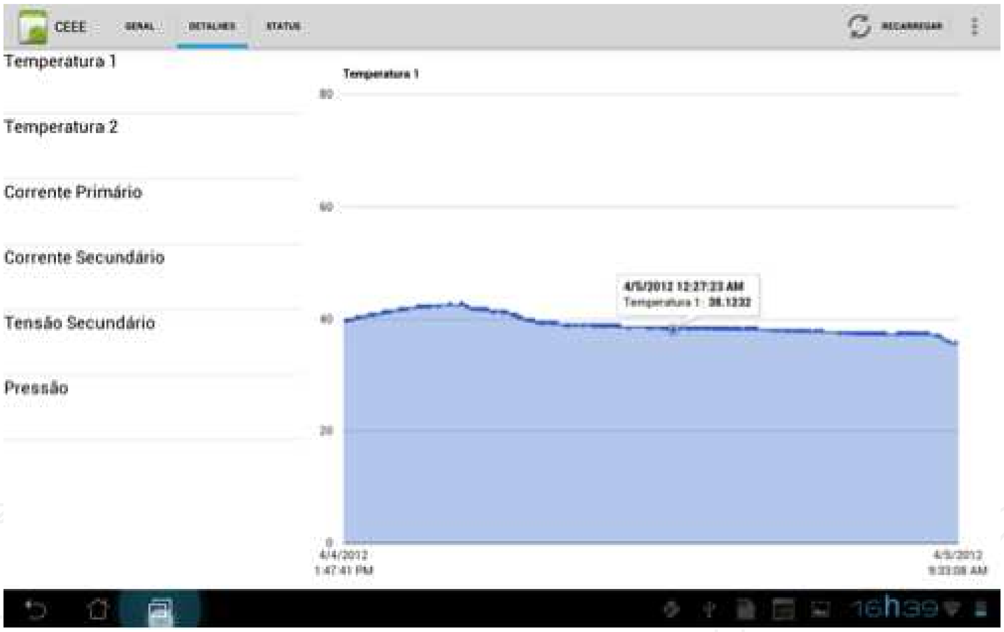


**Figure 13.** ANDROID real timer viewer for the supervisory system.

Figure 12 show the Human Machine Interface (HMI) is used in the SC was developed in PHP Language (Hypertext Preprocessor). Initially it was developed for the voltage and currents monitoring; temperature monitoring; pressure monitoring; and fifteen digital inputs for determination of state operation system. The HMI was extended to the smartphone platform aiming at facilitating access information from any mobile phone. In this context two applications have been developed (see Figure 14 and Figure 13) for the two platforms most used: Android Platform and Platform IOS.


**Figure 14.** IOS real timer viewer for the supervisory system.

## 9. Conclusions

This chapter has presented a monitoring system that is applied to underground power electrical substation. The advances in wireless communication, microelectronics, digital electronics, and highly integrated electronics, in addition to the increasing need for more efficient controlled electric systems, make the development of monitoring and supervisory control tools the object of study of many researchers. The system presented in this chapter allows choosing the desired communication transmission mode: wired, wireless, or both. Performance results show that our system could well be applied for monitoring and fault detection in electrical underground network grid systems.

The main advantages of this system are numerous. Firstly it allows the automation and monitoring of a substation without the need for any change infrastructure or other civil works. Second, because it is characterized as a non-invasive system, any device has to be drilled (one should remember that all equipment in the substation, they have IP68 protection - against floods). Finally, the redundancy possible by the choice of hybrid architecture allows the system proposed has high fault tolerance in the monitoring. The disadvantages of the proposed system is the fact that even using the 3G or 4G infrastructure as a means of long distance communication. In order to reduce the possibility of flaws in this system, two different cell phone carriers are used redundantly.

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