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A Hybrid Network Architecture Applied to Smart Grid

F. Salvadori[1], C.S. Gehrke[2], M.de Campos[3], P. S. Sausen[3], A. C. Oliveira[2]

[1]*Electrical Engineering Department – Federal University of Paraiba DEE/UFPB, João Pessoa, PB, Brazil*
Email Address: salvadori.fabiano@cear.ufpb.br
[2]*Electrical Engineering Department – Federal University of Campina Grande DEE/UFCG, Campina Grande, PB, Brazil*
[3]*Technology Department - Regional University of the Northwestern State, Ijuí, RS, Brazil*

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Abstract: The smart grid can be defined as a modern electric power grid infrastructure for improved efficiency, reliability and safety, with smooth integration of renewable and alternative energy sources, through automated control and modern communications technologies. The increased need for more effective control of power electrical systems, turned the development of smart grids the main object of study for many researchers. This paper proposes a digital system for condition monitoring, diagnosis and supervisory control applied to smart grids. The system is based on hybrid network architecture, consisting of a Wired Infrastructure, a Wireless Sensor Network (WSN) and a Power Line Communications (PLC). The system is based on three hardware topologies responsible for the signal acquisition, processing, and transmission: Remote Data Acquisition Units (RDAU's), Intelligent Sensors Modules (ISM's) and a PLC's Modem. The basic characteristics of the presented integrated system are: (a) easy and low cost implementation, (b) easy to set up by user, (c) easy implementation of redundant routines (security), (d) easy expandability, (e) portability/versatility, (f) extended network lifetime, and (g) open system.

Keywords: component —Control, Hybrid network, Monitoring, Smart Grids.

I. Introduction

Industrial, commercial and residential power users are rap-idly becoming aware of electronic monitoring and control systems capable of delivering tangible benefits and significant return on investment. Benefits can generally be classified in terms of energy cost savings, better equipment utilization, and increased system reliability. Electric utilities objective include a high degree of security and adequacy of bulk power supply systems, together with effective and economic operation and maintenance.

Electric utilities applications have ranged from Supervisory Control and Data Acquisition (SCADA) systems primarily concerned with remote operations to distribution automation, which focuses on operation efficiency. The smart grid is a modern electric power grid infrastructure for improved efficiency, reliability and safety, with smooth integration of renewable and alternative energy sources, through automated control and modern communications technologies. In the smart grid, reliable and real-time information becomes the key factor for reliable delivery of power from the generating units to the end-users [1].

Nowadays, systems designed specifically for industrial, commercial and residential customers of electric utilities pro-vide similar functions but are tailored to meet the specific requirements of an industrial, commercial or residential power system. Embedded systems can be found everywhere in daily life, from electrical commodities and appliances, to nonlinear compensation mechanism, complex automation systems and adaptive control systems [2,3].

In addition, increasing complexity of power grids, growing demand, and requirement for greater reliability, security and efficiency as well as environmental and energy sustainability concerns continue to highlight the need for a quantum leap in harnessing communication and information technologies.

According with [4], there are a variety of researches which show that more active participation in the market by the demand side could have significant benefits for the whole market. In particular:

o Reduction in the energy cost for consumers who shift their demand from periods of high prices to periods of lower prices;

o Reduction in the overall generation cost of the system because this demand shifting will flatten the overall demand profile;

o Even consumers who do not adjust their demand will make a profit if this reduction in cost translates into a reduction in prices;

o Avoiding price spikes (i.e. very large increases in price over short periods of time);

o Reduction in the ability of generating companies to exert market power.

Integrated systems let us avoid severe economic losses resulting from unexpected failures, and improving system reliability and maintainability [5].There are several hardware and software solutions for implementing smart grids for the most varied scenarios [1,6,7]. Integrated systems can consist of a number of devices connected to a computer through a Local Area Network (LAN), usually consists of a shields twisted pair of wires [8].

According to [9], the PLC application in smart grid power consumption field, demonstrate the favorable prospect. In [10] the authors investigates the effects of load impedance, line length, and branches on such systems, with special emphasis on powerline networks.

There is an increasing interest in applying technology to protect and control to electric utilities. At present many power utilities are being faced with the reality of conventional centralized control systems limitations, as they can greatly degrade due to the complexity of dealing with network events that would require enormous amount of data to properly manage them. Today's Intelligent Electronic Devices (IED’s) and robust communications processors contain large amounts of valuable data that have been available for years but largely overlooked. Initial integration efforts by most vendors focused solely on providing data access and control of supervisory control and data acquisition [6,7,11,12,13].

Wireless Sensor Networks (WSN’s) will play a key role in the extension of the smart grid towards residential premises, and enable various demand and energy management applications. Efficient demand-supply balance and reducing electricity expenses and carbon emissions will be the immediate benefits of these applications [1,6].

This paper presents hybrid network architecture applied to smart grids in industrial, commercial and residential power systems automation. The proposed systems is subdivided in three subsystems (see Fig. 1): i) Data Acquisition Subsystem; ii) Communication Subsystem; and, iii) Supervisory Controller Subsystem.

The data acquisition subsystem is composed of Remote Da-ta Acquisition Units (RDAU’s), for rapid dynamic data as voltage and current, and Intelligent Sensor Modules (ISM’s), for slow data acquisition such as temperature. RDAU also has actuation capability. Data communication is based on hybrid network communication architecture: (1) Wireless - Radio Frequency (RF); (2) Wired – Ethernet based; and (3) Power Line Communication. The supervisory controller subsystem presents an open source implementation for the Human-Machine Interface (HMI).

Importantly, smart grid enabling new network management strategies provide their effective grid integration in Distributed Generation (DG) for Demand Side Management and energy storage for DG load balancing [14].

The proposed system provides flexibility, fault tolerance, high sensing fidelity, low cost, rapidly response, and interoperability, making the system an ideal platform for power usage evaluation and condition monitoring altogether, and allowing the construction of high level intelligent power management system in smart grids.

II. DATA ACQUISITION SUBSYSTEM

Automation processes are extremely associated to Instrumentation and Control. The concept normally used for data acquisition in process control is usually accomplished by placing sensors close to the actual phenomenon [11]. Data gathered by the sensors are then transmitted through a wired communication infra-structure to the processing place.

The evolution of sensor technology and communication networks has allowed, to employ, intelligent sensors for improving the processing control. In this case, sensors not only collect data but they also perform some local processing and transmitting their results through: wireless communication (i.e., radio transmission), or for wired communication infra-structure avoiding data redundancy [15].

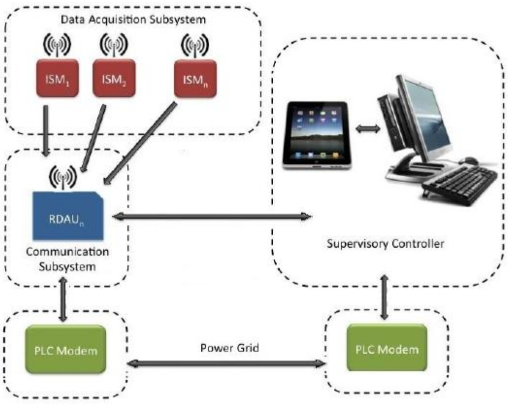

Fig. 1: The proposed system.

Concerning to this idea, the system is using two platforms to data acquisition: Remote Data Acquisition Units (RDAU’s) and Intelligent Sensor Modules (ISM’s).

A. Remote Data Acquisition Unit (RDAU)

Different RDAU’s are responsible monitoring rapid dynamic data and fault detection. For this purpose, the RDAU provides six analog inputs and four digital inputs, transmitting the data to a supervisory controller, and if required the platform can operate based on digital outputs. RDAU system is illustrated in Fig. 2.

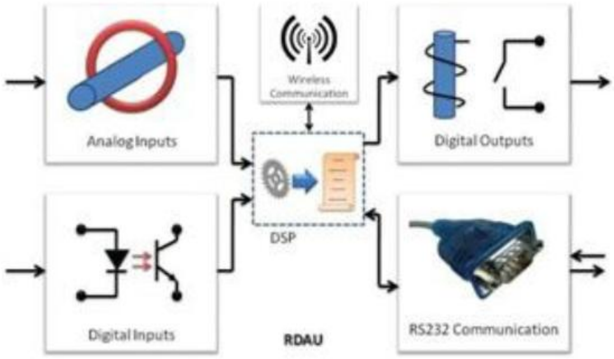

Fig. 2: RDAU block diagram.

Analog inputs

Transformers are used for the voltages measurements with a 11:1 relation, and HAIS100 (LEM™) for measuring the cur-rents. The RMS voltage value in the primary supervision trans-former is 75V. Considering 50% over-voltage, the system is able to measure up to 110V. The current sensor have 100A of nominal primary current. The same can measure currents up to 300A. To achieve better resolution for the current measure, two conditions were developed, one for maximum current of 5A (low power circuits) and another for 100A (high power circuits). The transition is implemented via software.

Digital input and outputs

Besides the common analog voltage and current inputs, the RDAU has also the capability to analyze four digital inputs: low level, ranging from 0V to 75V, and high level, ranging from 95V to 127V. For the actuation in power systems, the RDAU provides four digital outputs that can be used whenever necessary.

TMS320F2812

The TMS320F2812 microprocessor operating at 150MHz clock frequency (i.e., 6.67ns/instruction). The memory architecture is organized as follows: 64kB program memory, 64kB data memory, 18kB RAM, one external memory interface with 1MB, and 128kB Flash ROM. The system also provides an AD converter, PWM, and timers.

Software

The software was developed based on the C++ language, using the Code Composer Platinum™ platform (Texas Instruments ™). The main routine configures peripherals and interruptions, enabling data acquisition, data processing and data transmission.

The data acquisition subroutine uses the internal AD converter of the DSP. The DSP has two parallel sample-and-hold channels, that connect at one analog/digital converter with a 12-bit resolution, working with maximum conversion rates of 25 MHz/channel. The sampling is takes places simultaneously for each pair of inputs.

The sampling time was adjusted for 7680 samples/second, representing 128 samples/cycle for each voltage and current of the phases R, S and T. Aiming at improving the system's performance, some data processing is performed locally to reduce the number of data packet transmissions.

The RDAU processing data subroutine performs the computation of the RMS values for the voltage and current phases, active, reactive and complex three-phase power and power factor, in addition to the computation of Fast Fourier Trans-former (FFT).

From the RMS values, the operator can analyze the power system behavior (i.e. fault analysis), allowing to cover all rules and international standards. Given that the system has some processing power, it allows running several control algorithms and the implementation of fault detection techniques.
All the results obtained from the data processing unit are transmitted through a “transmission data subroutine” to the Supervisory Controller (SC). This subroutine configures the RS232 communication with two stop bits, no parity, eight data bits, and 115,200 bps data rate, based on the MODBUS proto-col.

The connection between the RDAU and the SC is performed through serial communication, RS232 (for short distance), or Ethernet.
In the next item the possible communication scenarios will be explained. Concerning to the protocol, transmission rate and that data process occurs in the TMS320F2812, the using of the transmission channel is 15%.
The Prototype was implemented and can be seen in Fig. 3 and Fig. 4.


Fig. 3: RDAU Prototype


Fig. 4: RDAU Hardware

B. Intelligent Sensor Module (ISM)

Unlike the RDAU subsystem that has continuous processing and transmission data besides actuation capability, the Intelligent Sensor Module (ISM), Fig. 5, is less powerful, transmitting data throw longer intervals, and like this has less processing time and save battery power. ISM module performs data acquisition metrics which has slow dynamic (e.g. tempera-ture).

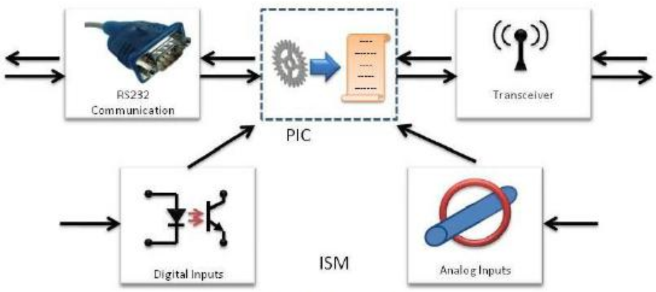

Fig. 5: ISM block diagram.

Considering that the ISM can be located anywhere, the sys-tem can be battery powered or powered by an external source. In case it is battery powered, four AAA 1.2 V rechargeable batteries are employed. The external source has input voltage of 127V, and output of 5.6V. Besides providing the required voltage, it can also be used to recharge the AAA batteries. The Prototype was implemented and can be seen in Fig. 6.
To provide wireless communication, addressing ISM mobility issues, a transceiver TRF-2.4G was chosen as the RF communication module.

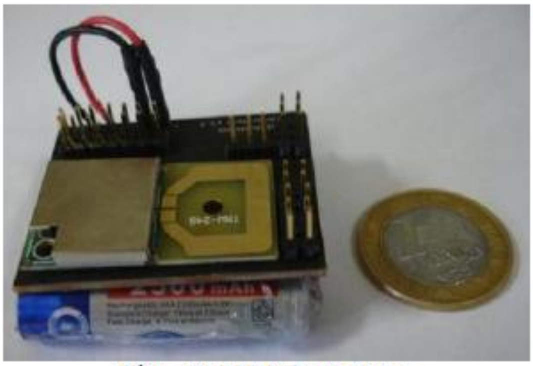

Fig. 6: ISM Prototype.

III. COMMUNICATION SUBSYSTEM

Nowadays, there is a lack of communication ability in electric power systems. In smart grid concept, intelligent sensors should communicate to each other, local processing and advanced large computing power. For data transmission between smart meters and electrical utilities different communication technologies can be used in infrastructure-based wired or wire-less.

Recent developments in communication technologies have enabled cost effective remote control systems which have the capability of monitoring the real time operating conditions and performances of electric power systems. Each communication technology has its own advantages and disadvantages that must be evaluated to determine the best communication technology for automation system. In order to avoid possible disruptions in power systems due to unexpected failures, a highly reliable, scalable, secure, robust and cost effective hybrid communication network between system under analysis and a remote control center is paramount. This high performance hybrid communication network should also guarantee very strict Quality of Service (QoS) requirements to prevent possible power disturbances and outages. This paper presents a hybrid communication network architecture, including wireless (RF), and wired possibilities, to enable minimum cost and very highly reliable communication for several possible operation scenarios of automation applications.

A. RS232

The serial interface (i.e., RS232) is employed when the RDAU is nearby the SC. This way, communication between the two modules takes places without the need of any other communication module.
The serial communication is based on MODBUS. This protocol has two transmission modes: ASCII and binary. The binary mode (RTU) is the one used in our system. The end of a message is identified after there is no transmission for a minimum period of 1.5 times a data word transmission.
The packet structure (see Fig. 7) includes:

- Network address;
- Packet type;
- Packet data;
- Error detection mechanism (i.e., CRC, to check the message integrity).

Fig. 7: MODBUS RTU framing.

The communication follows a master-slave approach, where only one device (the master) can query the other devices (slaves). The slaves reply back sending the data required by the master. The master can address one slave at a time or all the network devices through diffusion messages (i.e., broadcasting).

B. Radio Frequency (RF)

In a second scenario where the monitored data is distant and there is not wired communication infrastructure, data gathered from the monitoring devices can be transmitted via a wire-less interface, which is easy to implement and a way cheaper compared to standard wire communication (e.g., via fiber op-tic).

The TRF-2.4G transceiver developed by LAIPAC™ uses an nRF2401 component (NORDIC Semiconductors™). It uses GFSK modulation with a data transmission rate of up to 1 Mbps. The transceiver unit is includes an antenna, a frequency synthesizer, an amplifier, a crystal oscillator, and a modulator/demodulator.

The transmission power can be configured ranging from -20 dBm to 0 dBm, reaching distances up to 250 m (without obstacles). The advantages of wireless communication include their commercial acceptance and their application in environments with physical barriers.

Some aspects affect the energy consumption of the radio, including type of modulation, data transfer rate and transmission energy. A usual approach in the applications of wireless sensors is that their duty cycle is very short (i.e., around 1%). Nodes can schedule their events and remain in sleep mode while there is no need to be active, saving battery power and extending the network lifetime.

Many micro-controllers have an asynchronous oscillator circuit, which remains running while the core and the peripherals are inactive. This capability makes it possible to return from a sleeping state in just a few microseconds.

The radio has four operation modes: Transmission (TX), Reception (RX), IDLE and SLEEP. The choice among different transceivers was based on two aspects: the frequency clock and the energy consumption for the different operation modes.

The transceivers that operate in 2.4 GHz are easily available and are less prone to noise. Due to their high data rate the energy consumption for a single bit transmission is very low. However the same speed is also required from the micro-controller. This problem is addressed in the nRF2401 transceiver through the application of a data buffer that adapts a low performance microcontroller (e.g., 10 Kbps) with the data rate transmission of the radio (i.e., 1 Mbps) [6]. The main characteristics of the transceivers analyzed in our research are presented in Table 1.

TABLE I
A COMPARATIVE BOARD OF ENERGY CONSUMPTION FOR SOME COMMERCIAL TRANSCEIVERS

Model	Tx rate (kbps)	Freq. (MHz)	Sleep (uA)	Idle (mA)	Rx (mA)	Tx (mA)
NordicVLSI/nRF2401	1000	2400	1	0.5	15	6.5
Conexant/CX72303	1000	2400	1	0.02	24	11
Conexant/RF109	1200	2400	5	25	89	31
Ericsson/PBA31301	1000	2400	65	21	40	32
Ericsson/PBA31305	1000	2400	70	35	50	60

C. Ethernet (TCP/IP)

Third scenarios, where the monitored data are distant from the SC and a wired infrastructure is available. Between all the advantages of Ethernet communication two useful situations can be described: places where wired networks has already been installed; or places where wifi communication is hard (e.g. due to interferences and difficulties to install antennas).

In this scenario the DE311™ from B&B Electronics™ module is being used. This module provides a data communication solution for connecting Windows and Unix/Linux hosts to asynchronous serial devices over a TCP/IP based Ethernet. As the input data is from asynchronous serial, and RDAU provides RS232, the communication between DE311 to RDAU is directly.
The protocol is based on sockets interface. Such technology, improved by the University of California, in Berkeley, from 80s on, made possible a UNIX implementation of the sockets package to TCP/IP protocols. Nowadays, it is the most usable method to access a TCP/IP network and Internet

Originally the sockets were developed as the BSD (Berkeley Software Distribution) UNIX Operational System intrinsic parts. As a consequence, they use lots of concepts found in other Kernel routines. Particularly, sockets are integrated to the I/O routines.
This integrated system main advantage lies in its flexibility: can be written a unique applicative that transfers data to an arbitrary localization. A socket is, primarily, a transparent data connection between two computers linked on a net. It is identified by the computers network address as well as by a door localized in each computer.

Socket represents a TCP/IP network connection point. When two computers want to maintain a conversation, each one of them uses one socket. In this procedure a computer named server opens a socket, here specifically the Supervisory Controller, and makes a connection check. The RDAU, sends a signal to the server socket aiming to start a connection. In order to establish a connection just the destiny address and the port number are necessary. In the TCP/IP specific door numbers are reserved to specific protocols, for instance, 25 to SMTP (Simple Mail Transmission Protocol) and 80 to HTTP (Hyper Text Transfer Protocol).
Sockets present two main operation modes: the connection based mode and the without connection mode. The based con-nection modes work as a telephone; they have to establish a connection while interrupting the call. Everything that flows between these two events arrives in the same order as it was transmitted. On the other hand, the mode without connection does not guarantee the deliver, and the mail different items can arrive in a different order from that they were transmitted.

D. Power Line Communication (PLC)

Power Line Communication (PLC) is a technique that uses the existing power line to transmit high-speed (2-3 Mb/s) data signals from one device to the other.
The PLC system installed in low voltage cabling, the underground network, consists of a transmitter/receiver pair PLC, developed from a PLC MODEM PL-3120 (ECHELON TM). Connected to the modem is a PL-3120 microcontroller, whose functions are:
PLC transmitter/receiver (installed in the power transformer):
a. Transformer temperature data acquisition;
b. Data packet generation to send to the modemviaPL-3120serial interface (UART);
c. Management of control messages sent through the electric grid, delivered by thePL-3120 modem;

PLC transmitter/receiver (installed in switches):
a. Receiving data packets, sent through the electric grid, delivered by thePL-3120Modem;
b. Check validity of the data received;
c. Modem GSM/GPRS configuration;
d. Generation of the data packet to send to the GSM/GPRS mode mvia UART serial interface;

e. Management of control messages sent through the cellular network, delivered by the GSM/GPRS modem.

The PLC modem PL-3120 incorporates a NEURONTM processor, 4KBytes of application memory and 2KBytes of RAM. The NEURONTM processor, performs the interconnecting protocol routines the nodes of a network PLC, ISI –Interoperable Self Installation, and communication protocols, with an option to activate or not the CENELEC protocol. All these protocols are proprietary and were recorded in the device ROM. Fig. 8 is shown a block diagram with the component parts of a PLC node based on PL-3120.

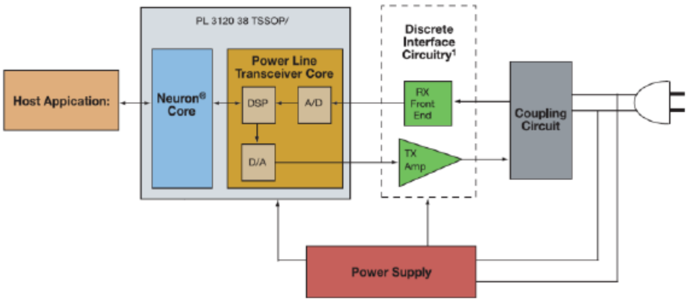

Fig. 8: PLC node based in PL-3120.

The PL-3120 Modem can operate in A and C bands as de-fined in CENELEC standards, which are selected from the crystal used to power the modem. Using a 6.5536 MHz crystal, the modem operates in the frequency bands to generate carrier frequencies of 86 KHz (primary carrier) and 75 KHz (secondary carrier). If powered by a 10 MHz crystal, it will operate in C band, generating carrier frequencies of 132 KHz (primary carrier) and 115 KHz (secondary carrier). The ability to generate two carriers, separated in frequency, is a strategy to improve the efficiency of communication through the electric grid.

As the grid represents a noisy channel and variable attenuation characteristic in time and frequency in a given instant of sending data, the channel may be too corrupted by noise and high attenuation or present in a primary carrier frequency, in this situation the use of secondary carrier may allow the realization of sending data through the electric grid.

The selection of the CENELEC band also defines the data transmission rate on the grid. When you select band A, the communication will occur at a 3.6Kbps rate. In the C band, the rate increase to 5.4 Kbps. In the system installed for testing, PLC transmitters/receivers are configured to operate in C band. Following, the equipment must be reconfigured to operate in the A band. This reconfiguration is to change the crystal and change the value of some passive components (resistors and capacitors) of the interface circuit.

As shown in block diagram (Fig. 8), an interface is necessary for making integration between the PL-3120 and the circuit will make the coupling of the modulated carrier to the grid. The interface circuit is mainly composed of an amplifier that can apply a signal to the electric grid in one of the operation frequencies of the PL-3120, with up to 1A peak-to- peak.

IV. SUPERVISORY CONTROLLER SUBSYSTEM (SC)

Nowadays different equipment's have an integration technique for each vendor, which does not communicate to equipment from other vendors. Like this, once an organization commits to a vendor's proprietary integration solution, it is difficult to change or extend capabilities without the vendor's involvement [16].

The Supervisory Controller Subsystem was developed in order to emphasize data presentation versatility. It runs on standard PC architecture using Linux or Windows Operational System, once the interface was developed using JAVA language, and IBM-DB2 Express-C and MySQL to database.

The application was developed to support on-line data presentation through reading of the received data files, including as well as a Database system, which stores the data [17]. Since the main function of the SC subsystem is receive and store the data derived from the RDAU's, it can process and present them to operators through: i) SCADA (proprietors systems); or, ii) Human Machine Interface (HMI) specially designed for this purpose.

A. Human Machine Interface (HMI)

The HMI, Fig. 9, used in the SC as mentioned before, was developed in JAVA language and is divided in four parts de-scribed follow:

Part 1 – Monitoring

Allow the user to show the graphical representation of all the variable of the platform, with real time values of voltage and current as well as powers values, Fig. 9.

Fig. 9: HMI Main Interface.

Part 2 - Alarms

Include a sequential listing of alarms and changes of state. This list allows to the operator to notice of any disturbance of the power system, as sag, swell, overcurrent and overload. The list of alarms can be seen in Fig. 9, however, the meters issue alerts in real time, shown in Fig. 10.

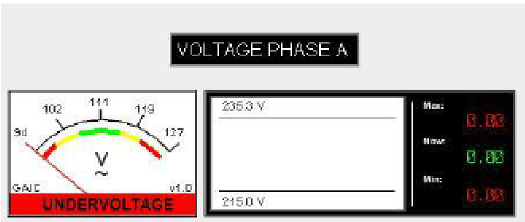

Fig. 10: Alarm warning of a meter.

Part 3 – Database

The measurement of voltage and current are stored in a hard disk (HD) permitting after analyzes anytime that is necessary.

Part 4 – Historic graphics and reports

This function was developed for the user can observe the evolution of the current, voltage, and power values in a deter-mined time (see Fig. 11 and Fig. 12).

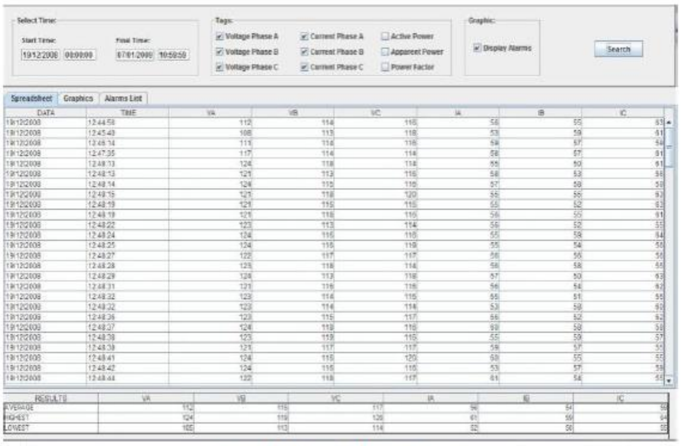

Fig. 11: Spreadsheet Report.

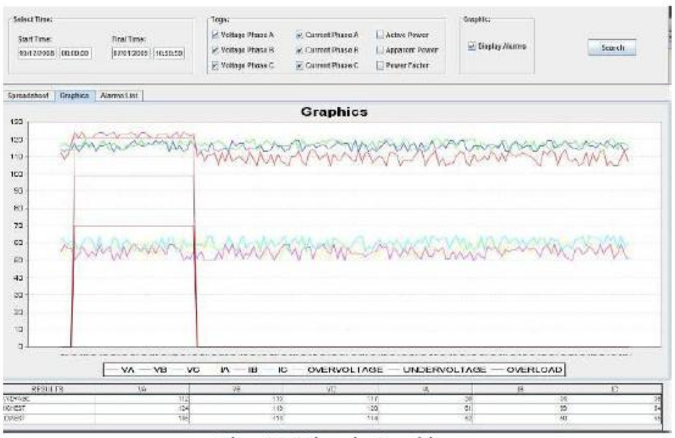

Fig. 12: Historic Graphics.

Part 5 – Parameters

To a better versatility the parameter of sag and swell can be configured by the user. In this form the nominal values and alarm enabling will run under the usual norms. The configurable parameters are: nominal voltage, maximum swell, mini-mum sag and overcurrent. (See Fig. 13).

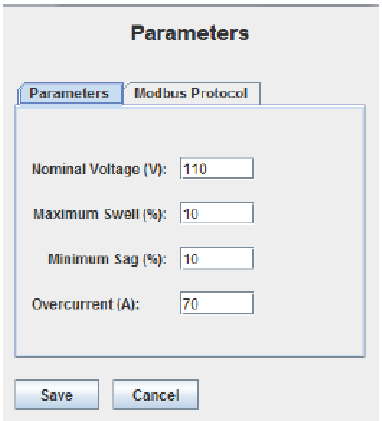

Fig. 13: Parameters.

EXPERIMENTAL RESULTS

To evaluate our system's performance, we have defined a set of experiments for analyzing:

- Remote Data Acquisition Unit (RDAU) – maximum practicable data acquisition and obstacles susceptibility;
- Intelligent Sensor Module (ISM) - maximum practicable data acquisition, obstacles susceptibility and maximum lifetime batteries;
- Communication (Ethernet (TCP/IP) and Wifi) – transmission rate;
- Power Line Communication (PLC) – Behavior of the data transmission for different days and different day's times;
- Human-Machine Interface (HMI) - easy of understanding information and time response;

The RDAU/ISM systems were evaluated for different scenarios monitoring an under ground electric distribution grid.

A. RDAU – Maximum practicable data acquisition

The RDAU improved the sampling rate, because it employs a DSP (TMS320F2812). In this case, the RDAU could achieve 128-samples/cycle, translating to 7680-samples/s. These results allow analyzing up to the 64th harmonic. Considering that the RDAU is used for the signals acquisition with fundamental frequency of a 60Hz, and as performs an A / D conversion for each 260ns, comes to a sampling frequency of 7.68kHz, resulting in a maximum bandwidth, or the Nyquist frequency of 3.84kHz. These values fully attend the technical standards for the monitoring of electrical power substations.

ISM – maximum achievable data acquisition

The Intelligent Sensor Modules are used only for the acquisition of signals with large constant times, and therefore do not need a high processing capacity (e.g. temperature). The maxi-mum capacity of acquisition of ISM was 12-samples/cycle.

RDAU/ISM - Transmission Rate

Both, the RDAU and the ISM, using the same transceiver for communication (TRF 2.4G). Radio Frequency (RF) communication is well suited for environments with physical barriers. However, it is prone to interference.

RDAU/ISM - obstacles susceptibility

The ISM/RDAU systems were evaluated for two different scenarios (with and without obstacles). Preliminary results for the first scenario show that the sensor node is able to transmit without any packet losses up to a distance of 80m, regardless of the antenna orientation. At a distance of 90m, and with the antennas directed at each other, we notice around 10%packet losses. Distances larger than 100m showed an unacceptable number of packet losses. As for the second scenario, we noticed that obstacles such as a 30cm concrete wall allows trans-mitting to distances only up to 60m without any significant packet losses.
RDAU/ISM - maximum lifetime batteries

Considering that a WSN is energy constrained, it is paramount to reduce the consumption of energy due to modulation, filtering, and demodulation. The energy consumed by the radio depends on the type of modulation, data transfer rate, and transmission energy.
To extend the network lifetime, we have adopted the Dynamic Power Management with Scheduled Switching Mode (DPM-SSM) protocol for wireless sensor nodes [6].

DPM-SSM is a power management technique that schedules state transitions to a sleeping state based on the current node's battery capacity. As the battery capacity degrades, upon reaching some predefined energy levels, the scheduling takes place more often to improve the battery capacity recovery.

When a node subsystem is switched to a sleep state, there is a huge reduction on the current drawn from the battery by that component. Hence, it allows us to take advantage of the battery recovery effect. In a sensor node, the radio is the subsystem that, in average, draws more energy from the battery. Thus, DPM-SSM adopts switching to the sleep state from a transmission state. By doing that, it is possible to take more advantage of the battery capacity recovery effect, because the gap be-tween the current drawn from the battery between a transmission state and the sleep state is larger than considering the other state (i.e., between Rx and Sleep).

Unlike the original DPM-SSM protocol that provides three operating modes, which are triggered depending on the current battery capacity, we have chosen just one operating mode that is activated starting from the very moment that the sensor node is activated. This way, a node is always put to sleep after a transmission, regardless of the current battery capacity.

B. PLC - Data Transmission Behavior

The data transmission behavior can be verified by Fig. 14, which presents the sum total of data received by time of day in the period from 28/08/2011 to 11/11/2011. It can be seen, in Fig. 14, that the loss of data communication occurs in the period of greater load consumption, proving the influence of the power flow on the performance of the PLC modem.

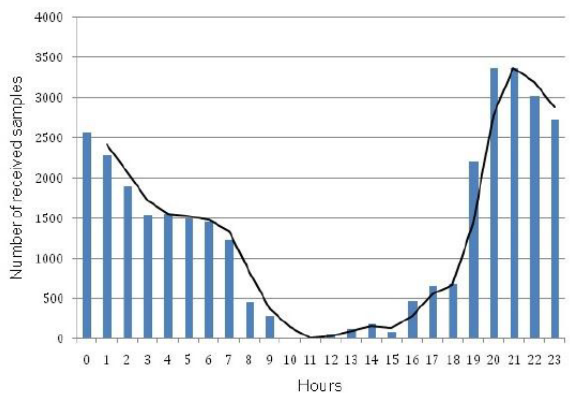

Fig. 14: Total data receivedby timeof the dayin the period August 29, 2011 to November 11, 2011.

V. CONCLUSIONS

This paper presents a system applied to smart grid for automated, industrial, commercial and residential power systems based on the concept of hybrid architecture involving the use of with infrastructure network, WSN and PLC acting together or separately. This paper demonstrating that it is feasible to bring together several communications technologies to get a high level of fault tolerant system.

Several scenarios were analyzed considering the infrastructure network, WSN or PLC connection. The tests aimed to analyze the behavior of the three subsystems that make up the automation system for an underground electric distribution grid.
For data acquisition subsystem the tests were conducted aiming to verify the signals bandwidth acquired by RDAU. This analysis was performed from the Nyquist Theorem and Fourier Series. Concomitant use of these methods has the ability to verify analysis of harmonics of the unit.

The analysis of the RDAU bandwidth presented results consistent with the established standards [13,17]. Where as the RDAU bandwidth is 3.84kHz. It was found that the RDAU to identify until the 64th harmonic.

The ISM tests were performed in this case: the distance that the module is capable of transmitting and the number of packets sent X time. Preliminary results show that the sensor node is able to transmit without any packet losses up to a distance of 80m. At a distance of 90m, and with the antennas directed at each other, we notice around 10% packet losses. Distances larger than 100m showed an unacceptable number of packet losses. With obstacles such as a 30cm concrete wall allows transmitting to distances only up to 60m without any significant packet losses.

The use of PLC technology has proved to bean interesting alternativeconsidering that theelectrical grid is available for use not requiring new wired structure. But showed problems in moments of greater power flow. These problems should be solved in short time.

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