Integration of a Smart Meter with the Brazilian Broadband PLC System

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Abstract—This work outlines the integration of a smart metering device with the novel Brazilian broadband power line communication (PLC) system, which was recently developed to fulfill the needs and demands related to smart grid communication and digital divide. With this regards, we discuss the developed hardware for interfacing with the smart metering device as well as the programs designed to collect the data which was transmitted by the smart meter using a PLC modem. A field trial was carried out in a low-income gated community and the attained results show that this integration can effectively fulfill throughput demands related to smart metering.

Keywords—Smart Metering, Power Line Communication, Electric Power Grids.

I. INTRODUCTION

Currently, R&D efforts to the use of Power Line Communication (PLC) systems in order to provide telecommunication infrastructure for smart metering application is one subject of great interest to electric utilities [1]. The reason for that relies on the fact that they can use their own infrastructures for delivering both energy and data. Regarding smart metering application, the meter manufacturer and the electric utilities have agreed that the average daily data demanded from an individual power meter is roughly 500 bytes. The use of narrowband PLC technologies seem to be appropriate for this application because this kind of technologies can offer datarate as high as 250 kbps and data can be transmitted through the medium-to-low voltage transformer and reach distances surpassing one kilometer because the frequency band between 10 kHz and 500 kHz is used for data communication. As a result, the narrowband PLC systems was standardized by the IEEE and ITU-T, see IEEE P1901.2 [2] and G.hnem (from ITU-T) standards [3].

Despite of that, two Germany companies, named PPC [4] and Devolo [5] have products for smart metering applications based on broadband PLC technologies that make use of chipset based on the IEEE P1901 standard. These companies have found out that the use of broadband PLC technologies can be much more reliable than the narrowband because they can use very wide frequency band to exchange the data of metering devices. Due to the fact each metering device demands low data-rate compared with the data-rate in broadband PLC technologies, which is over 200 Mbps, then it can

easily circumvent noise and unreliable subchannels because multicarrier modulation is also adopted.

Regarding broadband PLC technologies, we can point out that, besides smart metering applications, it can have a potential use to deal with digital divide problem in developing countries. In fact, the cost for deploying a telecommunication infrastructure in those kind of countries may be prohibitive due to the low-income of the population. As a result, the use of broadband PLC technologies to address both network access demands of costumers and electric utilities application is an important subject to be investigated.

Grounded on these drivers, the Brazilian broadband PLC system was recently developed as the output of a research and development program started in 2010 for one of the largest electric energy utilities in Brazil. This novel PLC system implements a so-called Brazilian PLC standard, which was developed to fulfill the characteristics of the Brazilian electric power grids [6]. This novel PLC system is capable of providing data rate as high as 450 Mbps at the physical layer and makes use of clustered-orthogonal frequency division multiplexing scheme [7] to limit the data-rate of each PLC modem in 90 Mbps. As a result, the costs of PLC modem as well as the whole PLC system can be considerably reduced.

Aiming to show that the Brazilian broadband PLC systems can be used to provide a telecommunication infrastructure for smart metering applications, this work outlines the integration of a smart metering device with the novel Brazilian broadband PLC system. Basically, we discuss the developed hardware for interfacing with the smart metering device, indicating the standard protocols applied in each part of the communication system. We also indicate that such integration can be applied to other meter vendors with no big effort. Additionally an overview of the communication path is then described, as well as the results of a field trial implemented.

The rest of this paper is organized as follows: Section II briefly describes the Brazilian broadband PLC System; Section III describes the developed hardware to allow the interface between smart metering device and a PLC modem, which is part of the novel PLC system; Section IV outlines the integration of broadband PLC system together with smart metering device; Section V addresses the laboratory and field tests and attained results; finally, conclusions are presented in Section VI.

II. THE BRAZILIAN BROADBAND PLC SYSTEM

The specifications of the Brazilian broadband PLC System, named novel PLC system, are based on electric power grids

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of a typical developing country; it makes use of the clustered orthogonal frequency division multiplexing (clustered-OFDM) scheme [7] for reducing the cost associated with PLC modems; and it takes into account the Brazilian telecommunication regulation for Broadband PLC [Anatel].

Figure 1 shows the use of the novel PLC system in a typical low-voltage electric power grids. As we can see, there are one PLC base station (BS) and several PLC modems that communicate with each other through the BS. In this system, the BS works as a bridge by providing 10/100/1000 Mbps Ethernet interface for connecting the modems belonging to the PLC access network with another data network (optic, wireless, or wired connection) for internet access. The PLC BS and PLC modems have a coupling interface that injects and extracts signals from power cables.



Fig. 1. Typical scenario to deploy the novel PLC system.

The PLC BS is responsible for managing the operation of PLC access network by controlling the connection and disconnection of PLC modems as well as their dynamic resource allocations and transmission scheduling. Also, the BS can be installed on a pole sharing or not the medium-tolow voltage transformer and support up to 180 PLC modems. Figure 2 shows the prototype of the PLC BS together with personal computer and a robust power supply in a typical field test in Juiz de Fora city, Minas Gerais, Brazil.



Fig. 2. The prototype of the PLC BS.

On the other hand, the PLC modem has a serial interface for connecting the smart metering device and a 10/100 Mbps Ethernet interface that can be used to establish a wireless local area network. Also, the PLC modem can only operate in one pre-allocated subchannel (cluster) and due to the specification of the novel PLC system it can achieve data-rate up to 93 Mbps in the physical layer. Based on the fact that the number of clusters is equal to five, the PLC BS delivers a data-rate up to 465 Mbps at its physical layer.

Each one of the 5 clusters occupies a bandwidth equal to 10 MHz and makes use of an independent Hermitian Symmetric-OFDM (HS-OFDM) scheme for data communication [7]. The clusters #1 to #5 have a 0 to 10 MHz, 10 to 20 MHz, 20 to 30 MHz, 30 to 40 MHz and 40 to 50 MHz frequency bands, respectively. In practice, the cluster #1 occupies frequency band between 1.7 and 10 MHz due to regulatory constraints.

Considering the application layer, Table I presents the achieved data-rate per user when the novel PLC system operated in an outdoor and low voltage electric power grid of a gated community composed of 1215 houses in the city of Juiz de Fora, Minas Gerais, Brazil.

TABLE I Data-rates (MBPS) at the application level when all sub-carriers modulates 4096-QAM symbols

	Cluster					
Data rate	#1	#2	#3	#4	#5	Total
Downlink	17.71	17.74	17.77	17.78	16,53	87.53
Uplink	7.10	7.09	7.11	7.07	0.91	29.28
Total	24.81	24.83	24.88	24.85	17.44	116.81

III. METERING INTEGRATION

A block diagram of the adopted metering system data communication topology is showed in Figure 3, where Subscriber Stations (SS) connected to the same low-voltage and outdoor distribution grids can communicate via PLC network with BS, allowing data to flow from smart metering devices up to Smart Metering Center.



Fig. 3. Block diagram of a smart metering system communication topology.

The SS is the equipment for the utility customers and it is installed at the entrance premise close to the electricity smart metering device. As indicated before, the management of the PLC network traffic is in charge of the BS. The BS also can be considered as the gateway of the novel PLC system, as it provides communication interface between PLC network and TCP/IP network. It is important to notice there is no meter data storage in the BS. In a regular situation, the metering data management is carried out at the Smart Metering Center.

Each smart metering device receive requests, answering demanded information and this means, for the most common

meter information and basic quantities, an exchange of few hundred of bytes. This type of communication is enough to deal with such amount of data as we also have information being collected and recorded by each individual smart metering device. That is a great advantage from the metering side. The data is recorded primarily in each meter and the set of the useful information of all meters are collected by Smart Metering Center in a daily basis.

The smart metering devices are capable of not only to accumulate the basic data, such as kWh and kVarh in all four quadrants, but they can also inform outages, current, voltage and power factor. The smart metering devices have configurable load profile and internal relay for disconnecting the load. The smart metering device is connected to the novel PLC system using PLC modem and as already indicated it uses serial communication to send and receive data. The data exchanged between smart metering device and PLC modem occurs through a serial interface device that crosses Transmitter (Tx) and Receiver (Rx) connections, together with a Serial-to-Ethernet converter.

In a first stage the serial 2-way communication available in the smart metering device is converted to Ethernet protocol, which makes the network and device address management easier. The second stage will convert the resolved Ethernet to PLC (and vice versa). Similar converter device exists also in the BS, translating the PLC to Ethernet. It is important to point out another advantage to use Ethernet as a pattern at the edges of the PLC network: as the BS is connected to a Transmission Control Protocol/Internet Protocol (TCP/IP) backhaul for transferring data to the Smart Metering Center, the Ethernet link layer is very appropriate for this situation.

The communication program at the Smart Metering Center retrieves data collected by the smart metering devices. After identified the IP address of each device within the Network Address Translation (NAT), the program is able to establish direct communication with the smart metering devices via a specific protocol.

The most direct topology model, which can be seen in Figure 3 is to establish a data connection between a smart metering device and a PLC modem located at the home of a registered consumer on the novel PLC system. On the opposite edge of the network, next to BS, NAT server IP address grants access to all measurement modules connected to the PLC network. The destination of the smart metering device data after passing the PLC network depends on how it is implemented and can be taken on the pole itself or via Internet or also establishing a Virtual Private Network (VPN) with the Smart Metering Center. By means of a communication tool via User Datagram Protocol (UDP) socket, one can assign IP address for each of the converters coupled to smart metering devices. To perform such task, this tool is installed at the Smart Metering Center, which connects to the NAT network via VPN or on a device that performs the official on-site measurements connected to the NAT network via an available data communication technology.

Finally we point out that the novel PLC system acts as a hub, without interfering or identifying data collected, since they are encapsulated and transmitted via the communication module as common Ethernet data type. The data security is guaranteed by authentication methods in each connection stage [6].

IV. INTERFACE BETWEEN SMART METERING DEVICE AND NOVEL PLC SYSTEM

The smart metering device provides 2-way communication via a serial port available at its block of connections. In order to satisfy the communication conversion needs, two hardware were developed to provide the interface between smart metering device and PLC modem. It is important to notice that these developed hardware are not restricted to the smart metering device used in this integration.

The first hardware is wired directly to the serial smart meter interface and is responsible for swapping the Tx and Rx connections by means of a set of logic inverters. This hardware has also a voltage regulator for stepping down the 24VDC received from smart metering device to a stable 5VDC. Such hardware is named "Meter Interface" and its prototype is showed in Figure 4.

The integrated smart meter serial interface talks a proprietary protocol and this is the part of the development that must be adjusted to each new smart meter that would be integrated. The way to communicate with the smart meter depends on its design. Another possible communication channel is via optical port, but it is still a serial communication.



Fig. 4. The developed smart meter interface.

The other hardware is the Serial-to-Ethernet Converter that is powered up using the regulated 5VDC received from "Meter Interface" hardware. Such converter uses a TCP/IP network module that allows it to be IP configurable. This feature makes possible to identify each smart metering device inside the network. The implemented chipset is responsible for treating the exchanged data between serial bus and 10/100 Mbps Ethernet port in a proper way. The Serial-to-Ethernet Converter is the bridge between the smart meter 2-way serial communication and the PLC modem. The prototype of this converter is showed in Figure 5.

The hardware "Meter Interface" and Serial-to-Ethernet Converter together with the smart meter constitute the SS, as shown in Figure 6.

At the other side of this communication path, which began with the smart metering device, there is the Communication Terminal located at the Smart Metering Center. Basically there are two programs that should be used: Zuchi UTP Config and ELOComm. The first one identifies the SS IP addresses via



Fig. 5. The developed Serial-to-Ethernet converter.



Fig. 6. Block diagram for the SS.

UDP broadcast messages. The second one is used to collect data from the smart meters. The Figure 3 exemplifies this topology.

The program Zuchi UTP is responsible for the smart meter identification in the PLC network and it is capable of reconfiguring the Serial-to-Ethernet Converter, enabling Dynamic Host Configuration Protocol (DHCP) or assign a fixed IP and also indicating the type of socket connection (server or client). ELOComm program is responsible to establish the communication with the smart meters in the PLC network and it performs the requests to access their data, i.e. cumulative registers (kWh, KVArh), instantaneous values (power, current, voltage, frequency and power factor). Figures 7 and 8 show the main screen of the programs Zuchi UTP and ELOComm.



Fig. 7. Main screen of the program Zuchi UTP Config.

V. RESULTS

The field tests for this integration were performed at "Neo Residencial" gated community in Juiz de Fora city, Brazil. The BS and SS equipment arrangement is in accordance with the figures 9 and 10 (BS is mounted on the pole while the SS is fixed at the consumer entrance premise).

Latency tends not to be a big problem to smart meter data measurement if real time pricing is not a played role. But even

Tipo de interface C Secial		· Ethernet		
		200000		
Endereço IP remoto: 192.168.000.101	Porta TCP remota 2051		Abri Eechar	
	1			
Intervalo de pooling (s)	MAR: 32 30 31 34 63 34 33 33 64 38 34 36 6	i6 37 34 31	Inisiar Parar	
Descrição		Valor		
Fwd Active W L1L2L3				
Rev Active W L1L2L3				
Import Reactive VAr L1L2L3				
Export Reactive VAr L1L2L3				
RMS Current (mA) L1				
RMS Current (mA) L2				
RMS Current (mA)L3				
RMS Voltage (n//) L1				
RMS Voltage (wi/) L2				
RMS Voltage (wi/) L3				
Power Factor L1 (1/1000)				
Frequency (mHz)				
VA L1L2L3				
Power Factor L2 (1/1000)				
Power Factor L3 (1/1000)				
Sir(PA) L1 (1/1000)				
Sin(PA) L2 (1/1000)				
Sir(PA) L3 (1/1000)				
Find Active W L1L2L3 multiple	ied by CT/VT ratio if enabled			
Rev Active W L1L2L3 multpl	ied byCT/VT ratio if enabled			
Import Reactive VAr L1L2L3	nullplied by CTAVT ratio if enabled			
Export Reactive VAr L1L2L3	multiplied by CTAVT ratio if enabled			
Q1 Reactive Var L1L2L3				
02 Reactive Var L1L2L3				
Q3 Reactive Var L1L2L3				
Q4 Reactive Var L1L2L3				
		lan		

Fig. 8. Main screen of the ELOComm PLC program.



Fig. 9. The BS installation on the field.



Fig. 10. The SS Installation on the Field.

in this situation the communication delay must comply with agreed limits for the novel PLC system in order to keep the reliability and data quality delivered. The measured latency for the PLC communication link was 16.66 ms, which guarantees a good performance as such indicator should be as low as 100 ms [8].

Figure 11 shows an example of smart metering device data traffic exchange that can be observed through a messages monitor window that is part of Communication Terminal. The quantities reported by the smart meter using the complete novel PLC system topology installed on field is showed in Figure 12.

Selected quantities can be visualized in a display window also provided by Communication Terminal as showed in Figure 13. It is important to point out that the visualized quantities can be customized, i.e., the user can define the most relevant and critical quantities to be showed as needed.



Fig. 11. Messages monitor window.

😭 ELO Comm PLC - Faculdade de Engenharia Elétrica,	UFJF - Versão 0.0.0.1	
Arquivo Monitor Ajuda Display		
C Serial	6 Ethernet	
Endereço IP remoto: Porta TCP remota:		Abrir Eechar
Intervalo de pooling (s) MAK: 1 32 30 31 34 63 34 33 33 64 38 34 3	6 65 37 34 31	Iniciar Parar
Descrição	Valor	
Find Active W L1L2L3	938	
Rev Active W L1L2L3	0	
Import Reactive VAr L1L2L3	10	
Export Reactive VAr L1L2L3	0	
RMS Current (mA) L1	0	
RMS Current (mA) L2	0	
RMS Current (mA) L3	4274	
RMS Vokage (mV) L1	0	
RMS Voltage (mV) L2	0	
RMS Voltage (mV) L3	220401	
Power Factor L1 (1/1000)	0	
Frequency (mHz)	59950	
VA L1L2L3	941	
Power Factor L2 (1/1000)	0	
Power Factor L3 (1/1000)	996	
Sin(PA) L1 (1/1000)	0	
Sin(PA) L2 (1/1000)	0	
Sin(PA) L3 (1/1000)	11	
Fwd Active W L1L2L3 mulitplied by CT /VT ratio if enabled	938	
Rev Active W L1L2L3 multiplied by CT /VT ratio if enabled	0	
Import Reactive VAr L1L2L3 multiplied by CT /VT ratio if enabled	10	
Export Reactive VAr L1L2L3 multiplied by CT/VT ratio if enabled	0	
Q1 Reactive Var L1L2L3	10	
Q2 Reactive Var L1L2L3	0	
Q3 Reactive Var L1L2L3	0	
04 Reactive Var L1L2L3	0	

Fig. 12. Messages monitor window.

Considering [6], the novel PLC system has effective data rates of 3.05 Mbps at the uplink and 8.62 Mbps at the downlink, however as the smart meter has a demand of 500 bytes of data to be downloaded, it would be possible to allocate, considering a 10 minute interval, more than 1 thousand devices in the novel PLC system. Nevertheless the BS has an user allocation capacity of 180 SSs [6], number that meets the vast majority of low voltage and outdoor electrical distribution grids in Brazil and Latin America.

VI. CONCLUSION

The results presented in this paper demonstrated how suitable is the integration of a smart meter with the Brazilian

🖶 Display	
Potencia	Instantânea
938W	
Corrente 4274mA	Instantânea
Tensão I	nstantânea
220401n	١V

Fig. 13. Selected quantities in a display window.

Broadband PLC System. The devices developed for such integration were carefully designed so they can be used also with other existing smart meters in the market, being an agnostic equipment in terms of meter vendor.

The collected data from each smart meter is dependent on the smart meter design, capabilities and metering functions and this way it naturally varies, but the developed ELOComm PLC program can be adapted for each smart meter model so it can request advanced and basic information or also selected and relevant quantities, fulfilling the utilities needs.

In a big picture, the integration of a smart meter with the novel PLC system using the developed hardware described in this paper is very adaptative and it takes advantage of addressed-market standard layers and recognized protocols for solving its own connection stages.

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