A Proposed Broadband Power Line Communication System for Smart Grid Applications in a Typical Egyptian Network

Fahd Hashiesh, *Member, IEEE,* and Pavel Soukal

Abstract — **Broadband over Power Line (BPL) has evolved since its advent in the United States in 2001. Whereas then the focus was on commercial services, such as high-speed Internet access and VoIP, now there is probably as much or more interest in using BPL for so-called smart-grid applications. This paper proposed a BPL system for smart grid application and it is implementation over a typical power system in a newly developed residential area in Egypt. The results of the field test with the effect of using noise filters are also evaluated.**

Keywords — **Broadband Power Line (BPL), Noise Filtering, Smart Grid.**

I. INTRODUCTION

THE deployment of Broadband Power Line (BPL) for smart-grid is a win-win for broadband subscribers as well as electric customers. That's because BPL networks are usually designed to support commercial broadband services, as well as smart-grid applications. Moreover, utilities will tend to deploy BPL for smart-grid across their entire service territory, including areas that may not otherwise be considered economic for broadband services alone. Finally, utilities are willing wholesalers, creating an opportunity for third parties to provide broadband services to their customers by piggy-backing on the BPL network [1 - 3].

II. BROADBAND POWER LINE COMMUNICATION

Broadband Power Line Communication is a kind of communication technology, which uses Medium Voltage (MV) & Low Voltage (LV) distribution network as the communication media to implement transmission of data, voice and real time image. Nowadays, many low voltage broadband PLC access and meter-reading sites have been available, coming to commercialization. Meanwhile, medium voltage broadband PLC technology is continuously developing, and devices of MV & LV PLC with 200Mbps or above have come out. Thus, after advanced technologies are applied to the monitoring system of distribution running, it will not only overcome the shortcomings of the above communication manners, but will transmit general data information effectively as well as video image data on the key monitoring sites

according to the requirements depending on its advantages of bandwidth. On the basis of no extra investment, it adds an important function to the system to monitoring the vital monitoring points more visually and obviously [4, 5].

All BPL systems operate by impressing a modulated carrier (like orthogonal frequency division multiplexing - OFDM) signal on the wiring system. Different types of power line communications use different frequency bands, depending on signal transmission characteristics of the power wire. BPL high-speed modems usually use frequencies from units to tens of MHz. The connection to the power wire is secured by inductive or capacitive couplers.

This technology has come with specific terminology of the units that are deployed in the field:

BPL injector is used to inject the PLC signal into the power wire. It can be situated on the MV transformer or on the electrical pole typically in a place, where is connection into the Internet.

BPL repeater works as Time or Frequency Division Repeater to amplify or stabilize the attenuated carried data signal. It is often installed in periodic distances on MV/LV lines.

BPL extractor is used to bypass PLC signal from MV to LV line. This devices is usually situated near MV/LV transformer, where is the power supply for the customer premise. It is used for connection to the Customer Premises Equipment (CPE) modems.
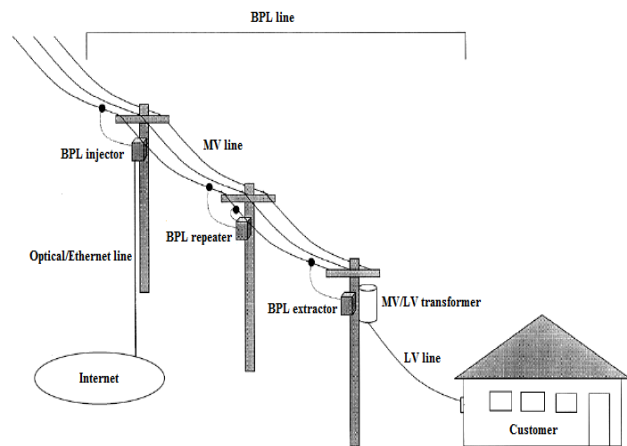

Fig. 1. BPL network components

Fahd Hashiesh is now with SABA Electric, Cairo, Egypt; (e-mail: fahd.hashiesh@ieee.org).

Pavel Soukal., is now with Corinex Communications, Bratislava, Slovak Republic; (e-mail: pavel.soukal@corinex.com).

III. SMART GRID APPLICATIONS

The fundamental components to a Smart Grid are real time monitoring and reaction of events on the Grid, anticipation of upcoming events, and problem isolation. In order to realize the Smart Grid, data are gathered from large numbers of intelligent sensors and processors installed on the power lines and equipment of the distribution grid (e.g. switches, circuit breakers, transformers, bus bars, etc.) and then providing such information to central information processing systems which both present the information to operators and use the information to send back control settings. The foundation for this "closed loop control" is a reliable, two way communication network, such as BPL. This allows for outage detection, automated fault isolation and load management which can improve the efficiency of power use and distribution.

The Smart Grid strategy also includes the real time metering of electric power (commercial and residential) and smart sensors on the network, such as, Smart Thermostat's and relay's in a home, that reduce or shift that use to off peak periods to better manage a utility's fixed capacity to generate and transmit power. A modernized Smart Grid becomes a digital energy distribution system.

BPL based Smart Grid networks are unique in providing a full suite of applications and management tools including AMI, Outage Management, Distribution Automation, Demand Response Management, and Security and Surveillance.

A. Automated Meter Infrastructure (AMI)

AMI refers to systems that measure, collect and analyze energy usage, from advanced devices such as electricity meters, gas meters, and/or water meters, through various communication media on request or on a pre-defined schedule. This infrastructure includes hardware, software, communications, customer associated systems and meter data management software.

The network between the measurement devices and business systems allows collection and distribution of information to customers, suppliers, utility companies and service providers. This enables these businesses to either participate in, or provide, demand response solutions, products and services. By providing information to customers, the system assists a change in energy usage from their normal consumption patterns, either in response to changes in price or as incentives designed to encourage lower energy usage use at times of peak-demand periods or higher wholesale prices or during periods of low operational systems reliability [6].

B. Outage Management

Outage Management is really two operating functions that are created and enabled through the system wide deployment of Smart Grid architectures; Proactive Outage Detection and Notification. With Smart Grid, almost every electric grid element becomes part of a private, secure digital communications network. As such, substation,

feeders, cap banks, switches, transformers and other elements can be viewed in their natural operating state. Baseline metrics are established, and performance deterioration identified and prioritized "way before the point of failure". This can be used to determine a faulty insulator or a pending transformer failure.

A new ability to aggregate loads, view power quality, operating temperatures, and demand response program participation is available through new Network Management Systems. Utilities begin pro-active distribution and load management on enhanced scales and feeder efficiencies.

Once this digital network and sensor points are established, immediate outage detection, or even proactive outage detection and notification becomes the norm. The utility's Network operating center (NOC) can now see outage alarms, or pre-outage alarms. Crew notification via email, SMS, phone, work ticket, etc are all immediately triggered. In addition, through a unique database management process, utilities can also choose to notify "affected" customers around the failing network element. Utilities will even have the ability to automatically notify customers immediately after service restoration. Immediate response, proactive customer notification, and prioritized maintenance efforts now become the norm, and provide a tremendous customer service improvement that is both perception and actual process improvements. coverage of a BPL network.

C. Distribution Automation

With all grid elements linked, monitored and controlled, utility's have the view and processes to measure real time power quality across each feeder and neighborhood. The controlled equipment consists of substation transformers, capacitors, breakers, reclosers and distribution transformers, even aggregated meter loads.

Specific load control programs can be established that provide real time capacitor bank and breaker/switch control; enhancing and balancing actual consumer demand with distribution load. A new level of power quality and load balancing combine to help a utility lower their line losses, and improve their operating efficiency and costs. Separate management programs around transformer overloading, meter/retail theft, Auto connect/disconnect, voltage/current/phase monitoring and adjustments all combine to dramatically improve the customer experience, and the utility operating efficiency [7, 8].

D. Street Lighting Control

Most street lighting system just controls the street lamps by switching on or off the AC power that supply all lamps on the street with simple street lamp controllers according to the time of sunrise and sundown. But, with the technology of power line carrier remote control and monitor of the street lamps in an area can be designed. With the use of BPL the lighting control system can monitor the status of the street lamps and gives real-time alarm information to supervision center when an error occurs. Furthermore, more power energy will be saved and lesser workers will be needed for maintaining the street lamps [9 - 11].

E. Security & Surveillance

Surveillance is very useful to governments and law enforcement to maintain social control, recognize and monitor threats, and prevent/investigate criminal activity. Surveillance cameras are video cameras used for the purpose of observing an area. They are often connected to a recording device, IP network, and/or remotely watched by a security guard/law enforcement officer.

IV. PROPOSED SMART GRID ARCHITECTURES

The proposed smart grid system architecture is given in Fig. 1. The system architecture is composed of four levels, starting from consumer level (home level) passing through street level (district or zone level) and MV substation level (residential compound level) up to supervision or control level (MV supply or generation level). The BPL is used as the communication infrastructure to connect all application levels using the existing MV & LV power cables.
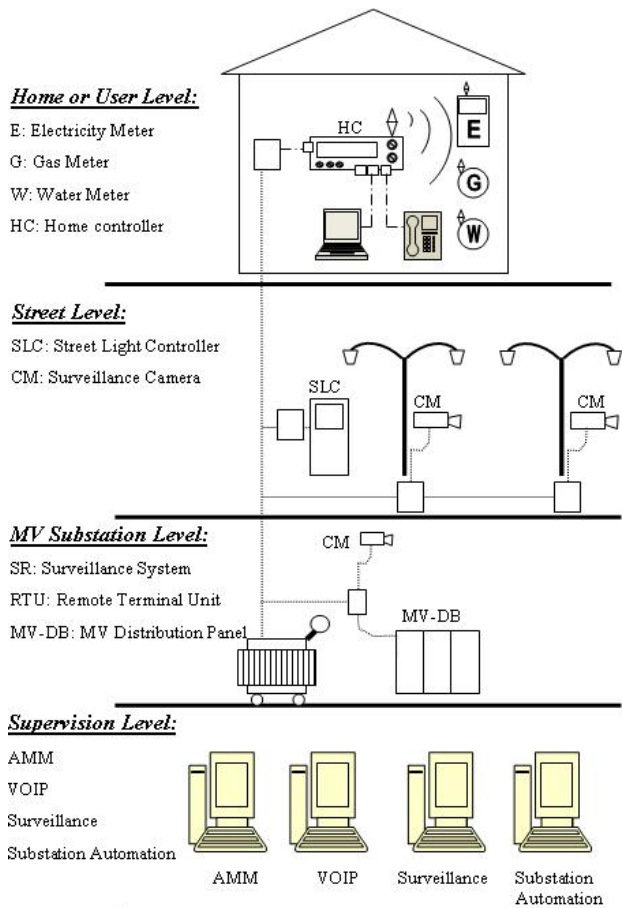

Fig. 2. Different application levels of the proposed Smart Grid network.

A. Consumer applications level

Electric, Water & Gas Smart meters are meters that have built in intelligence that allow them to store and communicate data to other sources on the network. In our proposal they use the Zigbee technology to communicate with the home controller. The home controller is an IP enabled device and connected directly to BPL infrastructure. To make use of maximum capabilities of the BPL technology such as internet sharing, other IP enabled devices such as personal computers and VOIP devices can also connected through the home controller.

B. Street applications level

In this level the street lighting controller is connected through the BPL network. As another application IP surveillance cameras are used to monitor street traffic and security guarding.

C. MV Substation applications level

In this level most applications & benefits of smart grid are activated. The BPL are connected the Remote Terminal Units (RTU) to the NOC. The RTU collect the data from various power devices and switchgears. Then sending these data to the NOC in order to monitor and control the power flow. The IP surveillance cameras are used to monitor and guard the substation.

D. Control & Supervision Level

This is what we are calling the network operation center or NOC. It contains a number of servers, workstations, monitors & printers. They are all gathering the data transmitted using the BPL to start analyzing according to the application associated.

V. IMPLEMENTATION OF THE PROPOSED SYSTEM

In order to evaluate the effectiveness of the proposed system a typical Egyptian MV & LV network is chosen to carry out the field tests. The network chosen is located at newly developed residential district. Fig. 3 shows a part from the single line diagram of this network.
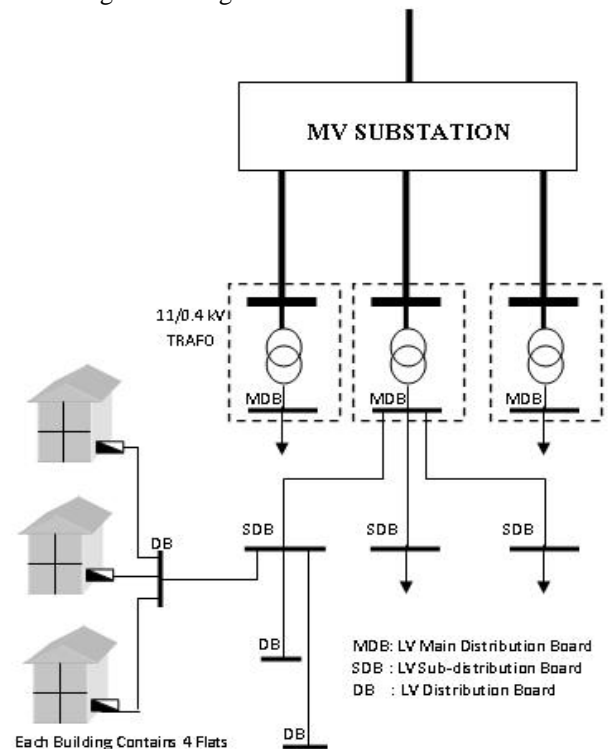

Fig. 3. Power network topology

Test procedures are as follows: Choosing and installing the BPL hardware in different location in the network. Recording the throughout speed at consumer electrical outlets is the next step. Then testing the effect of filtering high frequency noise generated by different consumer appliances is the last step.

A. Step one

The main characteristics of the chosen BPL hardware [12] are described in the following sections. Typical installation for theses hardware is clear in Fig. 4.

Medium Voltage Access Gateway

The Corinex Medium Voltage Access Gateway is chosen for our application. The chosen device intergarates three separated powerline modules which can support advanced BPL structures with MAC filtering, VLANs and Optimized VLANs (OVLAN) support and prioritization. The bandwidth can be configured in the range from 2 to 34 MHz with power mask control and SNMP management. Its transfer rate is up to 200 Mbps, where regenerators can be used to repeat the transmitted signals up to 300 meters.

Low Voltage Access Gateway

These BPL modem devices are designed for low voltage power line access networks in either single phase, threewire or threephase fourwire system. This Gateway is ideal for use as a Head End unit to control a last mile lowvoltage access network as well as a large in building distribution network. With using with Time Division Repeater units, it can extend the coverage of a BPL network.

Customer Premises Equipment (CPE)

The last last devices in the BPL chain network are the CPE. The Corinex AV 200 Powerline/ Ethernet Wall Mount Adapter CPE is chosen for our application. These devices allow end users to connect their ethernet enabled devices such as PC's, VoIP phones and Media Centers to any electrical socket in a premise to create a data transfer link. This CPE has 200Mbps throughput speed and support multicast for video and audio distribution.

Filters

The power supplies of some home appliances (especially those with a transformer or a coil built-in) normally generate excessive high frequency noise. These unwanted electrical signals can pass from the power supply through the input power connections into the power lines. The power-line devices connected to these same power lines may pick up this noise, which may disrupt the power-line communications or make them completely unintelligible.

Filter is carefully designed to eliminate and block all noisy signals from entering the electrical power line grid. The Corinex Powerline Filter does not create phase delays,

amplitude errors, DC shifts or waveform distortion. It eliminates 50/60 Hz noise and harmonics without altering the frequency characteristics of the input signal, even when these frequencies overlap with noise components.
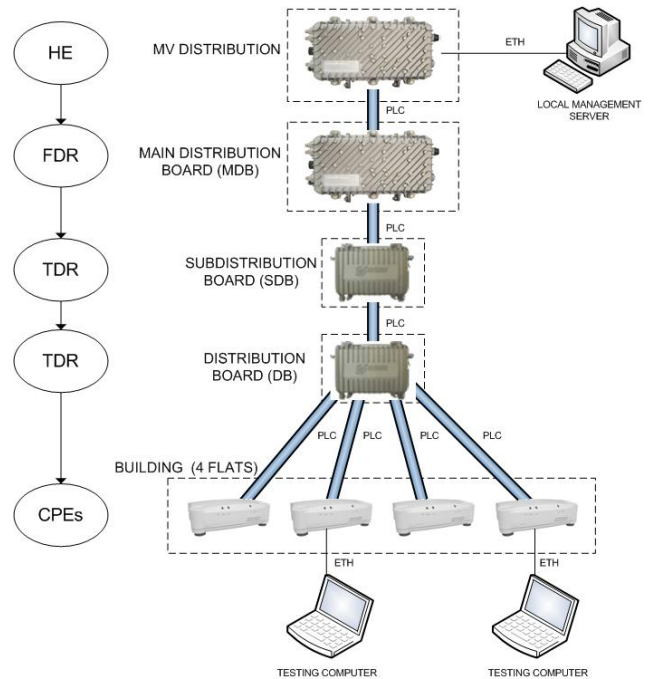

Fig. 4. BPL hardware test set arrangement

B. Step two

Testing the throughput between head end (HE) and CPE gives a record shown in first row of Table 1.

C. Step three

Our goal in this step is to determine what home appliances are crucial for the correct high speed PLC communication. The Television (TV), Personal Computer (PC) and Refrigerator were used as typical home appliances. From table 1 gives the results from the physical throughput speed test between two modems in the real deployment with usage of the Corinex Powerline Filters on the selected appliances.

TABLE 1: EFFECT OF USING FILTERS.

Test Type	Tx[Mbps]	Rx[Mbps]
Without Filters	12	10
With Filters	26	10
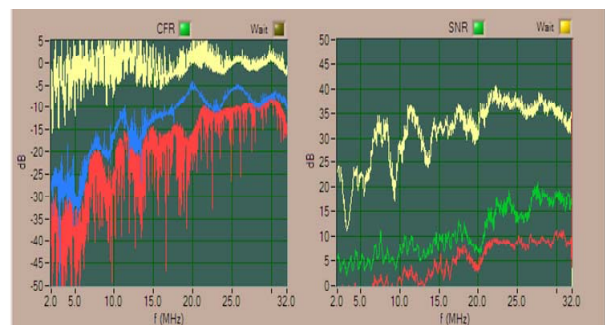
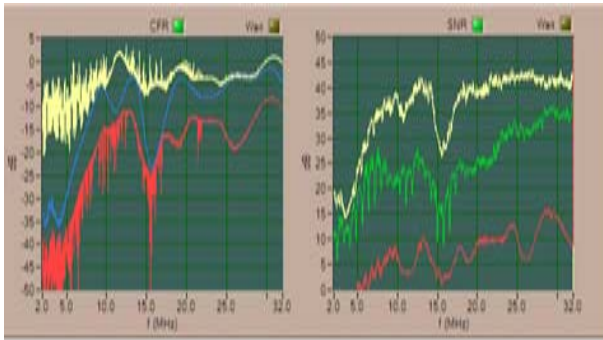
Fig. 5. SNR - without using filters.

Fig. 6. SNR - with using filters

In the first test, all three appliances were filtered. On the Fig. 5 and 6 can be seen the minimum, average and maximum Channel Frequency Response (CFR) on the left side of the figures and the Signal to Noise Ratio (SNR) on the right side.

With the Corinex Power line Filter, there are great improvements in CFR regards noise on lower frequencies (no flapping on the average curve) and even SNR has better values. In Table 1 can be seen physical throughput speeds with and without filters. The transmission and receive speeds with the filters is more than twice higher.

The second test designates what appliance is doing most power line noise and helps decide what should be filtered in the first place. Results in Table 2 shows physical throughput speeds when the filter on selected appliance is used. The highest speed improvement is when the refrigerator is filtered. The second appliance, which should be filtered, is TV and third with minor speed improvement is PC. In any case, for higher PLC throughput speeds, it is recommended to filter all of noisy appliances in the home.

TABLE 2: USING FILTERS WITH DIFFERENT HOME APPLIANCES.

Appliance	Tx[Mbps]	Rx[Mbps]
Filter on the PC	4	7
Filter on the TV	16	12
Filter on the Refrigerator	24	12

VI. CONCLUSION

A proposed broadband power line communication system for implementing smart grid application is presented in this paper. The proposed system is evaluated through the implementation on a typical MV & LV network in Egypt. A proposal for installing BPL hardware in the system is also highlighted. Effect of using noise filters is tested and gives sufficient results. The noise filters used to block harmful signals from Pc, TV & refrigerator. Tuning between different frequencies in the range from 2 to 34 MHz is recommended for future works.

VII. REFERENCES

[1] Pimentel, P.R.S. Baldissin, A. Cesar, L.S. Framil, R.R. Pascalicch, A., "Revolution in the distribution (use of the technology power line communication in the transmission of data, voice and images)," IEEE/PES Transmission and Distribution Conference and Exposition: Latin America, 8-11 Nov. 2004.

[2] A. Papaioannou, F.N. Pavlidou, "Evaluation of Power Line Communication Equipment in Home Networks," IEEE Systems Journal, Volume 3, Issue 3, Sept. 2009 Page(s):288 – 294.

[3] R.E. Brown, "Impact of Smart Grid on distribution system design," IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 20-24 July 2008.

[4] A. Skrzypczak, P. Siohan, J. Javaudin, "Application of the OFDM/OQAM Modulation to Power Line Communications," IEEE International Symposium on Power Line Communications and Its Applications, ISPLC 2007, 26-28 March 2007 Page(s):71 – 76.

[5] Florio A., Murillo F., W.K. Chen, "BPL O&M Applications in C.A. La Electricidad de Caracas," IEEE/PES Transmission and Distribution Conference and Exposition: Latin America, Aug 2006.

[6] D.G. Hart, " Using AMI to realize the Smart Grid," IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 20-24 July 2008.

[7] Jai Belagur and Rick Schmidt, "IP Communication for Substation Automation, Distribution Automation, and Other Utility Applications – A Business Case," IEEE/PES Transmission and Distribution Conference and Exposition, April 2008.

[8] Xu Zeng, Ming Liang, Huaizhi Liu, Yan Renand Rui Yang, "Monitoring System of Distribution Running States Based on Broadband Power Line Communication, " IEEE International Conference on Power System Technology, PowerCon 2006.

[9] J. D. Lee, K.Y. Nam, S.H. Jeong, S.B. Choi, H.S. Ryoo, D.K. Kim, "Development of Zigbee based Street Light Control System," IEEE Power Systems Conference and Exposition, PSCE '06, Nov. 2006.

[10] Cho SungKwan, V. Dhingra, "Street lighting control based on LonWorks power line communication," IEEE International Symposium on Power Line Communications and Its Applications, ISPLC 2008, 2-4 April 2008 Page(s):396 - 398

[11] C. Wang, D.L Zhang, H.L. Qin, Y.Y. Yao, Y. Sun, Y. Shen, "HPS Street Lighting Lamp Networking over Power-lines," IEEE International Conference on Power System Technology, PowerCon 2006.

[12] http://www.corinex.com