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Role of Narrow-Band Low Data Rate Power Line Communication in Smart Grids and Noise Reduction Strategy

[1]Bilal Masood, [2]Fareed Ud Din and [1]Sobia Baig

[1]Department of Electrical Engineering,
COMSATS Institute of Information Technology Lahore, Pakistan
[2]Department of Computer Science and Information Technology,
Superior University Lahore, Pakistan

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Abstract: An effective design of Smart Grid (SG) must include robust combined sensing, efficient Communication and elegant control system, so a vigorous network is the core requirement of a Smart Grid keeping in view the concepts of sensor networks and electrical and topological properties of distribution system. Two-way communication is the most effective way of transceiving the data on both sides; towards Low Voltage (LV) side and towards Medium Voltage (MV) side, which is the basic property of a Smart Grid and has gained higher attraction of the utility companies. The paper enlightens the service of a SG as a communication infrastructure, linking smart meters through the Power Line Communication (PLC) network. PLC's are evolving as an appropriate medium for signal and information communication within Smart Grid application, especially for Advance Metering Infrastructure (AMI) and Home Area Network (HAN). Smart Meters and PLC's increase the strength of a Smart Grid as by providing robust two-way communication. For noise reduction this paper elaborates the clipping strategy and the use of equalizer which can reduce the effect of noise and attenuation in the channel signals in PLC's. Clipping is cutting of the amplitude of the received signal up till a predefined threshold value without changing the phase in order to reduce noise effects.

Key words: Smart Grid (SG) · Power Line Communication (PLC) · Low Voltage (LV) · Medium Voltage (MV) · Advance Metering Infrastructure (AMI)

INTRODUCTION

Utility companies around the world have been using PLCs for remote metering and load control applications [1]. Single carrier narrowband (NB) solutions which operate in the kHz data region at rates up to few kbps and broadband (BB) systems which operate in the High Frequency (HF) band (2-30 MHz) where data rates up to 200 Mbps can be achieved by commercially available products [1]. In [2] a qualitative attempt has been made to fortify the use of PLC's in the smart grid and how a smart grid becomes a physical infrastructure when PLC's are used. The debate on the type of PLC's in Smart Grids is still open. Basically there are two types of PLC's: (1) Broad Band PLC's (BB-PLC's) and (2) Narrow Band PLC's (NB-PLC's). NB-PLC's are further divided into two categories. The one is Low Data Rate Narrow Band PLC's (LDR-NB-PLC's) which are capable of carrying some Kbps of data and the other is High Data Rate Narrow Band PLC's (HDR-NB-PLC's) which are multi-carrier based technology capable of carrying data from some kbps to 500 kbps. NB-PLC's and BB-PLCs provide a bi-directional communications platform capable of delivering real-time data to a variety of utility applications. Smart and ahead of time two-way communication is helpful to identify and even predict equipment failures in grid. Greatest suitability for PLCs is for the distribution side of the grid, which is also the part of the grid to support micro-grids (ìGrids), distributed generation (DG) and consumer participation [1]. Within the distribution network, there is today considerable evidences are openly found that PLCs can provide on the MV side connectivity

Corresponding Author: Bilal Masood, Department of Electrical Engineering,
COMSATS Institute of Information Technology Lahore, Pakistan.

to transformer substations in point-to-point configurations and on the LV side connectivity between transformers and meters in point-to-multipoint configurations [2]. In the case of problem identification, problem location, problem isolation and service restoration then substation must communicate with external entities such as switches, reclosers or sectionalizers. All these communications require low-speed connectivity that is well provided within PLC capabilities as PLC support all the data transfer within this range.

NB-PLCs are certainly well suited for AMI. There is a vast amount of field data about the performance of PLC-based Smart Meters as over 100 million LDR NB-PLC devices have been deployed around the world [2]. In many cases, if NB-PLC are deployed, they avoid the capital expense of installing couplers at the MV/LV transformer as Low Frequency signals can penetrate the transformer - although with a substantial (Signal to Noise Ratio) SNR effect but this noise and attenuation can be handled and reduced through some strategies elaborated in this paper.

NB-PLC: The Best Suited Technology for SG Applications: For data transmission, network topologies are based upon two main communication media: the wireless such as WLAN/WiMAX [3,4] or ZigBee [5], optical communications [6] and the wired such as DSL or power line carrier [7]. Wireless media do have some advantages over wired communication solutions e.g. cost effective infrastructure and ease of availability to connect distant and areas [7]. Flip side of the coin is that wired communication media is more beneficial as it has less signal attenuation as compared to wireless infrastructure because the path for the signal flow is dedicated to a particular signal. The most important feature of wired media is that they do not rely on batteries like wireless infrastructure does. The data flow in smart grids can be categorized into two categories: (1) from sensors of electrical appliances to the smart meters (2) from the smart meters to the utility data centre [8].

For the first flow we can have technologies like Power line communication and wireless communication which includes ZigBee, z-waves and others. For second flow we have cellular technologies and internet. The selection of technologies may vary with place as well as with environment. PLC's not only support on LV side but they are preferable on the MV side too. The use of LDR-NB-PLC was tested in [3] for successfully transmitting a signal on MV side through PLC and this test transmission appeared as less expensive than other communication technological methods based on telephone line signals [3, 10].

PLC is better than wireless infrastructure, because in emergency situations very often conventional networking technologies encounter congestion due to a spiking the collision rate, i.e. when all meters tend to access the channel at the same time (black-out, restoration, etc.) or when multiple signals requires immediate actions [2, 11]. In these challenging scenarios, traditional networking approaches including unconscious-incompetent wireless sensor networks ail due to the network congestion and competitive channel access mechanism. Unlike wireless solutions based on ZigBee or WiFi, PLC-based AMI have a proven track record of being able to avoid network congestion when cooperative schemes are employed [2], [12]. For example, the Real-time Energy Management via Power Lines and Internet (REMPLI) project has experimentally demonstrated the possibility of using HDR NB-PLCs in transforming channel contention into channel cooperation by using a Single Frequency Network with ?ooding based routing [13]. These approaches are immensely employed in order to improve the delivery of the information that can be predicted much more accurately, timely and with more power efficient transmission.

This study focuses on the preferred use of NB-PLC over BB-PLC as a transmission medium in SG information communication. NB-PLC technology offers reliability in going through the transformer; keeping in view that this reliability depends upon the transformer itself, because on the architectural upshot of going through the transformer is handled by many more smart meters, controlled by a single Data Concentrator Unit (DCU) located on the MV side (pictorially elaborated in Figure-1). Then again DCU send the aggregated data from many meters associated with that particular DCU, back to the Sub-Station by using PLC. Hence NB-PLC here gets preference on BB-PLC as, a BB-PLC deployment require the couplers since BB signals cannot pass through the transformer. This competence also heavily influence the business where there customers per transformer are variant: good to use coupler installation with BB-PLC deployment when customers are more and with less customers it is economical advantageous to avoid coupler installation.

NB-PLC's are also adequately beneficial in the implementation of Demand Response Applications which requires establishing a link between the utility side and consumer side appliances. Due to the higher attenuation that signals experience over the LV side, BB-PLC

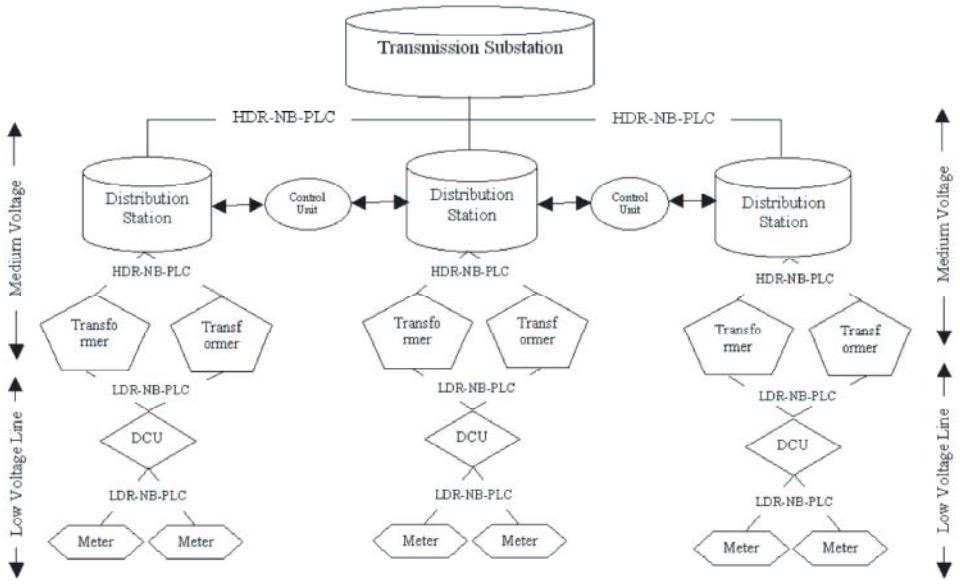

Fig. 1: Proposed PLC Network Topology

deployment is not always the ideal solution for such kind of applications when direct load control is implemented because most of the time distance between appliances and the utility signal injection point (the smart meter, the MV/LV transformer) gets too large. Due to the lower path loss at lower frequencies, NB-PLC solutions are good candidates for both direct and indirect load control [2].

Prposed PLC Network Topology: The proposed PLC Network Topology consists of different main components, which are categorized in different sub-modules depending upon the two different voltage ranges Medium Voltage on the transformers side and Low Voltage on the consumer side. Overall the topology consists on Transmission Substation (TS) for initial ignition of the power, Distribution Station (DS) for delivering the power to the lower sections, Control Unit (CU) for balancing the loan controls on the consumer side, Data Concentrator Unit (DCU) for collecting the information for the consumer meters, Smart Meters for measuring the power consumption efficiently and the NB-PLC's, as transmission medium, both Low Data Rate and High Data Rate. On the MV side the TS transmit power through HDR-NB-PLC with the help of DS which has been controlled by the CU's as sometimes there are different appliances working on the consumer end, needs a lot of power so the load can be increased on a single side other than others under single DS's, hence the load is controlled by the CU attached to them. DS's again using HDR-NB-PLC communicates with the Transformers and they, on the down side using LDR-NB-PLC, transceive the information with DCU. DCU's are the aggregating devices attached to the smart meters on the consumer side; they also use NB-PLC with Low Data Rate Capabilities. Figure-1 clarifies the structure of the proposed network topology.

Hence the proposed network includes all the transmission with the NB-PLC but with the fact that this topology may include noises and attenuation as mentioned by different authors in [15, 17, 19, 20]. These noises and attenuations and data loss can be handled through different strategies mention in this study.

Noise in NB-PLC's: PLC's provide robustness thus can be implemented anywhere by using already existing electricity network infrastructure. It offers low installation cost as it uses existing power lines as a communication route. By implementing PLC Network Solution the cost is being reduced to at least 50% in investment in developing a new network infrastructure [12].

PLC's do have various limitations, as they are designed for power transmission not that of data, so there are a lot of troubles to face while transmitting the data: a number of uninvited and unwanted noises, high frequency attenuation and varying impedance in a power line channel, due to which issues like interference and signal attenuation arise [13, 14]. The power line channel varies abruptly when the network topology changes, i.e. when devices are plugged in or out and switched on or

off. However, even when no such event occurs, still short-term variations are exhibited as because of the periodic fluctuation of the high-frequency parameters of electrical devices plugged in. In addition, the noise injected into the channel by appliances is also dependent on the instantaneous amplitude of the mains voltage.

Noises in Power Line Can Be Classified Several Types: Permanent Background & External Noise: Power line supplementary equipments produce background noise which always remains there within the communication line i.e. permanent partial discharges of insulators and apparatus. This background noise is not a specific one and can never be ignored as it can be caused by any of the surrounding machinery. As consumer sites are becoming full of equipment that implies parallel capacitors as a filter which is commonly placed at various consumer sites [13]. This capacitor acts as a sink or short-circuits to all high frequency signals. Increasing penetration of new devices both disturbs and filter worsens the case for PLC. Noises generated from such kind of problems are known as external noises. This paper implied a technique named as zero forcing technique which can easily handle the noise introduced in the information transmission through PLC specifically.

Synchronous & Asynchronous Periodic-impulsive Noise: The impulse noises generate by the apparatus and the other background factors produces impulses with respect to the sample interval of time can be categorized as the synchronous but impulsive noise. Synchronous can cause the degradation the transmission thorough the PLC. Asynchronous noise are varying noises which can be inducted within the main stream of the transmission by the varying parameters i.e. load demands and the voltages differences. Both of the noises can be dominated by the clipping noise reduction technique as mentioned in this paper.

Narrow Band& Switching Operation Noise: A background noise introduced at the NB vicinity especially stationary at its minimal values over the period of time which vary for seconds to minutes and sometimes for hours as mentioned in the simulation presented by the [15]. Switching Operation Noise: This type of noise is produced due to the switching operations performed by control room, switching of circuit breakers, isolators and various faults in transmission line. Switching operation noises are critical and can create the malfunctioning of equipments or interrupt the communication services.

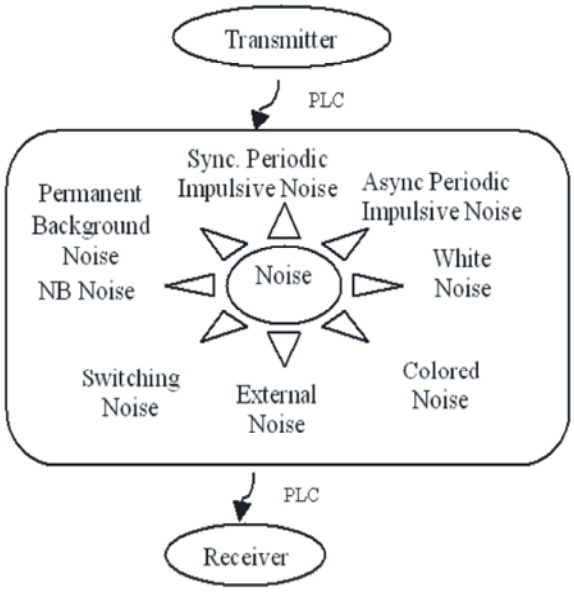

Fig. 2: Expected Noise in the transmission for SG

Colored Noise: Sometimes the transmission signals emit the noise effect as the result of the stochastic processes and ultimately the signals show different colors because of correlation and Gaussian effects as mention in the older algorithm designed for simulation of exponential correlated colored noise [16]. White Noise: As PLC's are not designed for signal transmission so there are some risks in the transmission of the critical information regarding disruptions or the feedback from the working modules in the PLC topology. That is why there is always a thermal noise exists while communicating the information thermal noise is also called the white noise as Power Spectral Density (PSD) of the thermal noise is approximately equal to that of spectral to overall the spectral frequency.

All the noises introduced in this paper are pictorially represented in the Fig. 2.

Noise Reduction Strategies in Proposed Network: As the there have been a lot of studies in the domain for the noise free transmission of the signals so as there have been several good algorithms and noise reduction strategies have been designed and implemented for the noise reduction and removal. Some techniques i.e. Zero Forcing, Minimum Mean Square Error and Clipping techniques, have been discussed in this paper and uplift the need for the upbringing research domain for more robust and elegant noise reduction and removal strategies.

Zero Forcing: Zero Forcing technique is having good impact for rejecting the interference and it does have the value as linear detector which satisfies the condition for the linearity and identity of the forcing matrix [16].

$$D_{ZF}\sum_{n=1}^{\infty}C = I \tag{1}$$

where D_{ZF} is the decoding matrix, C is the Channel Matrix for channel strength from 1 to infinity and 'I' is identity matrix. Edge of the Zero Forcing Techniques is that other noise reduction strategies leave some impact in the channel when they are implied but ZF techniques is the ideal one when there is no noise in the channel.

Mnimum Mean Square Error: Minimum Mean Square Error scheme is well reputed technique for the diminution of the power of noise component. This noise reduction schemes uses the SNR and decoding matrix with respect to SNR, as in this way the interference can be easily rejected in accordance in these two values. This technique can be represented by the equation:

$$D_{\mathrm{MMSE}}\sum_{n=1}^{\infty}\left(c+\frac{1}{\gamma}\mathrm{I}\right) \tag{2}$$

Where D_{MMSE} is the decoding matrix for minimum mean square error strategy and γ denotes the signal to noise ratio. This scheme is useful for avoiding the noise effects before they get amplified that is why the earlier implementations show the huge involvement of MMSE as noise reduction strategy in power lines for information and signal transmission..

Clipping Techniques: Impulsive noise is most trouble creating category in the LV networks as its impact can cause a lot of data loss in the communication trajectory so in order to avoid the worst case thus must be any memory-less nonlinear strategies to mitigate the effects as mentioned by Mehdi in [19]. Clipping technique is an important methodology to provide an efficient reduction in generated impulsive noise by using orthogonal frequency division multiplexing (OFDM) technique. Clipping can be categorized into two dimensions as it can be implemented with fixed threshold or with the probabilistic and optimized limits.

Static Clipping: OFDM is a good approach as mentioned in [17] for providing a shelter for the impulsive noise. Clipping techniques as implied by Y. Kim and Jang Nam Bae in [15] and by Khalifa Mawali and Zahir in [18]. The following is the designed mathematical equation which gives the clipping with the two limits the upper limit and the bottom:

$$\mathrm{Y_{(n)}} = \sum_{n=0}^{n-1}\begin{pmatrix} r_n & |r_n| \le \mathrm{T}(c) \\ T(c)e^{j\arg(r_n)} & |r_n| > \mathrm{T}(c) \end{pmatrix} \tag{3}$$

where n = 0,1,2 .... .n – 1

The most efficient and robust feature of the clipping technique is that is does not change the phase but focus on the amplitude which is modified and corrected over the specific threshold value with a combined effect as mentioned the equation above mentioned. Clipping with fixed threshold is a good noise reduction technique in wireless and in wired especially in NBPLC [19, 20].

Dynamic Clipping: Static Clipping can be criticized on the basis of the selection of the threshold values; there must be cautious selection for optimized clipping thresholds (T(c)) in order to achieve minimum Bit Error Rate (BER) in signals transmission. If T(c) has been selected too short, most of the OFDM signals can be clipped which eventually increase the BER. Similarly on the other side, for very large values of T(c), Clipping would not hamper the impulsive noise in the signal. So leaves the reason for implementing Clipping technique will remain an absurd. Same goes for the upper limit of the threshold either the noise is not detected with accuracy and precision or not detected at all in the cases of large and small thresholds respectively.

Hence the selection of threshold is still an open question with optimization as an optimal and dynamic Clipping technique in which the threshold limits are selected with respect to minimum BER for different SNR values. These optimal values can be achieved and simulated in any Integrated Simulation and Development Editors (ISDE's).

CONCLUSION

This paper focuses and analyzes the NB-PLCs as the best suit for the transmission and information communication and for that purpose PLC is considered to

be an efficient communication technology in the SG applications more due to its feature of already existing infrastructure of power lines as far. Although today's technologies are getting more mature and field proven, so there are two aspects that can hinder the success of PLC as compared to other technological media mentioned in this study. One is the data rate for high and medium voltages in SG applications networks and the second is noises which hinder the timely and accurate transmission of data. The paper elaborates the noise along with its various types and their reduction techniques. Also, NB-PLCs provide flip benefits as it offers both peak data rates i.e; from several kbps (LDR) up to 500 kbps (HDR). Long term higher throughput would be required to fulfill the growing needs of SG applications that can be provided by power line communications. The noise reduction techniques mentioned in this paper can help a lot for complete and sound transmission of data and critical information.

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