Channel Modelling and Channel Selection for Broadband PLC on Medium Voltage Overhead and Underground Lines

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Abstract

The use of the Broadband Power Line Communication (BPL) on Medium Voltage (MV) overhead and underground lines is considered. It is found that there are two technical prerequisites in order to aid in the deployment of a BPL network on a MV grid. The first is the channel model which is a transfer function in order to estimate the channel characteristics and the second is the selection of channels which are frequency bands used for the communication. This paper gives an overview of these prerequisites in order to deploy BPL on a MV grid consisting of both overhead and underground lines.

Index Terms

Channel modeling, channel selection, BPL, MV.

I. INTRODUCTION

IT is commonly accepted that information and communication technologies are a critical part to the concept of a Smart Grid. In order to achieve the concept of a Smart Grid, bi-directional communications networks must be overlaid onto the electrical infrastructure at all levels. Bidirectional communication between primary substations (PSs) is nothing new and has been available for close to a century now. At the low voltage level, advances in Automated Metering Infrastructure (AMI) and smart homes (automation within and around the home) has now become more common. However, comparatively little automation is available at the distribution or Medium Voltage (MV) network level which is surprising as it is at the very center of the overall grid. However, this is now changing due to two factors:

- All the data from low voltage level such as AMI data may be accumulated further at the MV level before being transmitted to the control center. The MV grid essentially acts as a Wide Area Network (WAN).
- Remote monitoring and control of MV transformer stations becomes necessary in order to provide better power quality and reliability against fault conditions.

One interesting communications technology for use within the MV network is Broadband Power Line Communications (BPL). A critical aspect in the large-scale deployment and thereby the scalability of a BPL network is defining a set of suitable guidelines for the cell planning. As in cellular wireless networks, the communication nodes in a large-scale BPL network must be allocated to different cells and channels must be assigned to these cells. Therefore channel selection and assignment become important tasks which can only be enabled through a sufficient understanding of the communications channel. As the MV electric grid is part of the critical infrastructure of a utility, access to such networks for research and development work with BPL is typically restricted. Therefore, in order to develop a BPL solution for MV smart grid applications Model Based Design (MBD) within simulation environments becomes an important tool. However, MBD requires that suitable models may be defined for certain aspects of the BPL and MV electrical networks. Some academic work has been performed in modeling MV-BPL networks, however, the work is mainly concentrated on investigating link characteristics in a relatively small section of the overall network. Furthermore, some of the work was done on only short link lengths and extrapolated to longer link lengths which is not an optimistic estimation.[4] So, there is a need of further work to be done. One other commonly accepted fact is that the electric grid especially at the distribution level (MV and LV) may vary from region to region. When considering the general geographic topology of Switzerland it consists of collection of small urban cities with large rural areas in-between. An analysis of a typical MV grid in Switzerland shows that this topography also carries over into the grid topology. The analysis has also shown that the grid consists of a mixture of both underground cable and overhead wire links. Many links between SSs will contain a mixture of both underground cable and overhead wires with transitions existing in between. Therefore, in order to deploy BPL on a typical

Swiss MV network, considering this mixture of different link types between SSs is crucial. This can be considered as an extension of Ormazabal's MV-BPL solution which is being deployed extensively by Iberdrola for urban/sub-urban networks (see e.g. **Error! Reference source not found.**) to support more rural networks. This paper will focus on modeling a channel (transfer function) and selecting different channels (frequency bands) to use; with special consideration given for networks consisting of a mixture of overhead wires and underground cables.

II. BPL CHANNEL MODELING

It is very important to know the attenuation and noise caused by the channel in order to estimate the performance of a system over a channel which will be dependent upon the Signal-to-Noise-Ratio (SNR). A channel model is helpful to estimate this attenuation and noise. It is necessary to have two separate channel models for underground and overhead MV lines because transmission via overhead MV wires differs considerably from transmission via MV underground cables. For underground cable the attenuation increases rapidly with increasing frequency and is dominated by dielectric material loss. On overhead wires the attenuation increases more slowly versus frequency and can be mainly attributed to the multi-path fading effect. It is also necessary to have a channel model for the attenuation over the transition from overhead to underground or vice versa due to the impedance mismatch which may be present. Finally, in addition to the attenuation of the channel, a model of the background noise on both underground cable and overhead wires is required.

A. Measurements

In order to define the channel model, a series of field measurements have been performed. Such measurements can be considered to be in-situ measurements or measurements which are made directly within the targeted system. Due to the nature of the BPL channel which is highly dependent upon the actual impedance conditions in the network, in-situ measurements are the preferred means for measuring the channel.

B. Channel model characteristics

The channel model consists of an attenuation model and a noise model. It is well known, the attenuation depends on both the distance and frequency. Consequently, the attenuation model can be defined in three dimensional space formed by the attenuation, distance and frequency. Whereas noise model depends on only the frequency which results in two dimensional space formed by the noise and frequency.

C. Findings from the channel modeling and measurements

The measurements and the resulting channel model shows that an acceptable SNR is provided on overhead wire links up to at least 2km. Unlike overhead wires, underground cables suffer more from more severe attenuation and it is only possible to achieve several hundreds of meters connection range with an acceptable SNR. It is also important to consider the cable type for the underground connections as the new cables which are made of polyethylene (PE) perform better than older Paper Insulated Lead Covered (PILC) cables. These models have also been verified through measurements with BPL modems.

III. BPL CHANNEL SELECTION

A. BPL Network structure

In order to provide a scalable solution which can provide BPL coverage of a large MV network, the network is typically divided into several clusters, called cells. This work focuses on the use of BPL technology based on Open PLC Research Alliance (OPERA) technology. According to the OPERA specification, each cell consists of one Head End (HE) node which connects the cell to the backbone infrastructure, one or more repeaters used for extending the coverage and one or more slaves. Application endpoints may be attached to any BPL node within the network and the BPL network acts as a layer 2 switched Ethernet network. The HE is the central node that controls and assigns resources to all the nodes based on a TDMA with hybrid resource sharing mechanism [2].

B. Necessity for multiple channels

All nodes within a single cell must be configured to operate on the same channel. As no dynamic channel allocation is supported, channels must be manually allocated to cells such that neighbouring cells operating on the same channel will not interfere with each other. Due to the TDMA protocol interference would lead to an unacceptable degradation of the communications channel. Interference can be avoided by using a guard distance between the cells which are using the same channels. Because of this guard distance, gaps or regions which cannot be covered by BPL may exist in the network. To increase the amount of channel reuse within the network and minimize the gaps in coverage, multiple channels are used similar to the channel assignment problem known from mobile wireless networks. Therefore, the definition of suitable channels becomes an important network parameter. Multiple channels must be defined which are able to provide sufficient throughput in order to meet the application requirements. Given the frequency selectivity of the BPL channel this is a non-trivial task. It is also important to note here that the selected channels should also have guard band (separation between adjacent channels). The guard band is necessary in order to allow for analogue filtering of adjacent channels which could negatively influence the performance of the BPL transmission.

C. Electro Magnetic Compatibility (EMC)

Whether justified or not, PLC is traditionally seen in a very negative regard with respect to EMC. As electrical wiring has not been specially designed for the suppression of radiated High Frequency (HF) or Very High Frequency (VHF) emissions, there is the potential that PLC may generate unwanted emissions which can interfere with other primary or secondary services which may share the same frequency band as the BPL network. Since underground cables are shielded and buried, EMC emissions caused by underground MV=BPL transmission is not severe in contrast to overhead MV=BPL transmission [1]. Recognizing the potential EMC problem for BPL, different standard bodies have reacted by introducing two concepts for limiting this interference: [5]

- Notching of certain narrow bands which are used by different broadcast radio services
- Limiting of the allowed Power Spectral Density (PSD) of the PLC signal by defining a Limit PSD Mask (LPM)

D. Channel selection considerations

In order to select the appropriate operational channels for the BPL network, it is important to consider the following influential factors:

- The connection type that is dominant in the MV grid (underground/overhead).
- The number of active sub-carriers in a selected channel.
- The minimum SNR that can be achieved in a cell with the selected channel

As the MV electric grid within Switzerland is dominant with both underground and overhead connections, it is important that the selected channels should perform well on a cell with both underground and overhead connections. The possible number of active sub-carriers in a frequency band is influenced by EMC standards which define the range of sub-carriers to be deactivated if they lie within frequency bands which are used by other broadcast radio users in order to reduce interference. The minimum SNR that can be achieved in a cell is dependent on several factors, namely: link length distribution between the modems, type of connection (underground, overhead, mixed) and underground cable type.

E. Channel selection procedure

Based on the channel selection requirements explained earlier, the total frequency band potentially supported by the OPERA BPL technology (2-30MHz) has been divided into smaller frequency bands, so-called channels, which will be assigned to different BPL cells. The various frequency sub-bands which have been selected for further analysis are:

- (2MHz-7MHz, 8MHz-18MHz, 20MHz-30MHz)
- (2MHz-8MHz, 9MHz-19MHz, 20MHz-30MHz)
- (2MHz-10MHz, 10MHz-19MHz, 20MHz-30MHz)
- (2MHz-11MHz, 12MHz-19MHz, 20MHz-30MHz)
- (2MHz-12MHz, 13MHz-19MHz, 20MHz-30MHz)

In order to find the suitable channels for the whole MV network which is dominated by mixed connections (underground and overhead lines), each channel is applied on all of the connections in the network. If a connection does not satisfy the minimum required physical layer data rate (given by the individual applications), nor the minimum number of active sub-carriers after notching the narrow bands defined in [5] [6], the connection has been disabled. Because of these disabled connections, parts of the network get disconnected and the network is divided into several segments. Given these segments, we can calculate the coverage of the MV grid network for each of the channels, and finally determine the frequency bands that provide the best coverage.

F. Findings from the analysis

From the analysis, it is found that the 2MHz-10MHz, 10MHz-19MHz and 20MHz-30MHz frequency bands are the most suitable channels for the MV network of a Swiss utility. However, underground cables suffer a lot from attenuation in the 20MHz-30MHz frequency band. Hence, this frequency band is allocated to a cell with only overhead connections and small underground connections. It is also found from the analysis that the best channel gives up to 80% coverage of the MV network of the Swiss utility using BPL after notching the narrow bands. It is important to note that there is no standard communication technology that could promise full coverage of an electric grid [7]. Hence the results show that BPL is a very promising solution in order to deploy a communications network on a MV grid.

IV. SIMULATIONS

Even though the above channel selection analysis was conducted by considering the application characteristics, it is still necessary to verify whether the end-to-end bandwidth and latency requirements of the applications can be fulfilled for the selected channels within a more integrated environment. In order to verify this, a network simulation platform has been developed using the OMNeT++ event-based simulation platform.

Based on the OPERA standard, several modules are created in OMNeT++ which reflect the functionalities of the OPERA protocol stack. The protocol stack includes PHY, MAC, LLC and convergence layers. Connections between different BPL nodes and the supported throughput of those connections is determined based on models for the MV network topology as well as the channel models. Application layer models for the previously mentioned applications among others are also modelled. Simulations are used to then investigate the end-to-end performance considering different MV network topologies, cell sizes, different applications, different channel configurations, etc. The simulation results also showed that the above selected channels are providing sufficient results.

V. CONCLUSION

A brief overview of channel modeling and channel selection is provided in order to deploy BPL on MV overhead and underground connections. These topics were investigated in a Swiss federally funded research project by the Lucerne University of Applied Science and Arts together with Ormazabal and a Swiss utility. The goal of this project is to check the feasibility of BPL on a Swiss electric grid and find the percentage of MV grid that can be covered with BPL.

REFERENCES

[1] Lazaropoulos, Athanasios G., and Panayiotis G. Cottis. ”Broadband transmission via underground medium-voltage power linespart II: capacity.” Power Delivery, IEEE Transactions on 25.4 (2010): 2425-2434.

[2] Specification-Part, Opera. ”1: Technology.” Open PLC European Research Alliance 198.

[3] Dominiak, Stephen, et al. ”Challenges of Broadband PLC for Medium Voltage Smart Grid Applications.” Proceedings of the 6th WorkShop on Power Line Communications, Rome, Italy. 2012.

[4] Navarro, Monica, and Jose Antonio Moreno. "Field channel measurements in a medium voltage overhead power line." Power Line Communications and Its Applications (ISPLC), 2011 IEEE International Symposium on. IEEE, 2011.

[5] CENELEC, Final Draft FprEN. "50561-1,“." Powerline communication apparatus used in low voltage installations-Radio disturbance characteristics-Limits and methods of measurement-Part 1: Apparatus for in-home use 6 (2011).

[6] ITU-T Recommendation G.9664, Unified high-speed wireline-based home networking transceivers - Power spectral Density Specification, pp. 8-9, December 2011.

[7] Jingcheng Gao, Yang Xiao, Jing Liu, Wei Liang, and CL Philip Chen. A survey of communication/networking in smart grids. Future Generation Computer Systems, 28(2):391-404,2012.

[8] Marta Solaz, Javier Simón, Alberto Sendín, Lars Andersson, Mikko Maurer and Aitor Amezua. “MVBPL – RELIABLE, FUTURE PROOF AND COST EFFICIENT.” 23rd International Conference on Electricity Distribution, Lyon, France. 2015.