A NEW APPROACH FOR ONLINE MONITORING OF POWER CABLE CONDITION IN DISTRIBUTION NETWORKS USING BROADBAND POWERLINE COMMUNICATION AND SIMPLE SENSOR SOLUTIONS

Hamed REZAEI, Nexans Power Accessories, Germany
Nikolai HOPFER, University of Wuppertal, Germany
Markus ZDRALLEK, University of Wuppertal, Germany
Christoph RAQUET, Power Plus Communications AG, Germany
Ulrik DIETZLER, Energieversorgung Leverkusen GmbH & Co. KG, Germany
Markus KRAMPF, Energieversorgung Leverkusen GmbH & Co. KG, Germany

SUMMARY

With the increasing number of renewable resources in today's distribution networks the need for monitoring the condition of power grids and cablesare becoming more imperative to ensure a reliable power supply. The existing diagnostic techniques for cables are mostly cost-intensive and not extensively used. Hence the need for a cost-effective and practical monitoring/diagnostic tool isof great importance.A novel method to achieve this goal was aimed in the course of a research project in Germany to define and approve a new solution concept for online monitoring of grid condition with a specific focus on power cables by using the secondary effect of broadband powerline communication technology (BPL), which has the primary task of data transmission over power cables in power networks. This paper articulates how BPL technology creates new insights into power cable conditions using data transmission characteristics and how the concept and theoretical background was approved through laboratory tests as well as real field tests.Furthermore the condition assessment functionality of powerline communication was supported by the selective installation of simple sensor solutions to better scope network parameters with the possible objective of integrating them into network management as well as asset management.

Key words:power cable, condition monitoring, broadband powerline communication, medium voltage sensor

Contact: hamed.rezaei@nexans.com

INTRODUCTION

Application - Medium voltage underground cables are a vital component in power distribution system for ensuring a reliable energy supply. Therefore appropriate condition monitoring technologies for cables play an important role in achieving this goal and targeting the cables that pose the most urgent reliability concerns by providing required information for safe and reliable operation and replacement strategy. As the number of renewable resources and decentralized generations increases, demands for reliable power cause a growing tendency to apply different strategies, most preferably in the form of online based condition monitoring. The power utilities tend to prefer having a constant and permanent overlook over their networks and specifically cables not only to be able to detect the faulty condition, when they occur but also be able to monitor cable conditions in real time for trend analyzing purposes and accordingly defining appropriate replacement actions as part of a preventive maintenance strategy.

New solution concept/Project idea - A new approach targeting this issue is using broadband powerline communication technology (BPL) as an assessment tool for power cables. As a widely used communication and data transmission tool in smart grid applications BPL is primarily used as an information and communication technology (ICT), using the existing power electrical infrastructure of power grids and power cables in particular. Hence BPL provides an additional use case besides its primary job of data communication, which is cable condition assessment by using the existing BPL infrastructure in power network.
BPL records permanently the channel characteristicsof each individual BPL-Links during its operation and utilizes them primarily to optimize the communication. The experiences from several projects verified that these channel characteristics and their dynamic in operation make a secondary utilization possible: There is a strong correlation between cable condition, the load and faulty events and the local channel characteristics of BPL-

Communication in grid.That means in a BPL-infrastructure and without any supplementary detection technique there is already so much information about the grid condition, which couldprovide conclusive statement about cable condition and faults in power grid. However this effect was not systematicallyanalyzed and its usage was not verified to generate reliable information in network operation.

Objectives and milestones - The aforementioned effects were the starting point of a research project in Germany, aiming at presenting a new approach foronline cable condition assessment and fault detection through the secondary effect of BPL-Infrastructure.The premier objective of the project washence developing a concept for systematic usage of already existing channel characteristics of a BPL power grid to detect the critical grid states in low and medium voltage level, detectingthe foreseeable faults in the grid and also a path to utilization of the collected data from the grid in network operation management and expansion planning. To achieve this purpose the Installation of simple and inexpensive sensor solutions in both low and medium voltage was foreseen to integrate network parameters (voltage and current) in BPL-system and to have as comprehensive data as possible in order to support the network management function.
The work started by investigating the theoretical background, followed by appropriate laboratory testsat the high voltage Institute of the University of Wuppertal and eventually a field test under the real condition of a distribution network in the city of Leverkusen in an urban area in west of Germany.

CRITICAL CABLE CONDITIONS

Since the project has two main source of information, namely sensors and BPL-modems, the first step was determining the main critical cable conditions and assigning them to the relevant detection source to find out which parameters could be detected by using and analyzing the BPL-data (BPL channel characteristics) and which one require additional sensors to be detected. This work was initiated by listing up the main critical cable conditions and then was narrowed down in the course of the project to the conditions, whose detection was proven to be possible by means of the intended approach. These parameters were categorized into the limit violation of diagnostic parameters e.g. partial discharge, dissipation factor, cable sheath fault as well as defected components in grid and also the limit violation of the operating parameters e.g. frequency (50 Hz ± 0,5 Hz), voltage (U_N ± 10%), current (overload, short-circuit or ground fault current), switch positions and power quality.
A main aspect of the project, which this paper is focusing on, was the critical parameters, related to cable condition.

DETECTION METHODS

The identified cable conditions were basically divided in two categories: the ones which could be identified by analyzing the BPL characteristics and could have a correlation with the characteristics of BPL-signals and the ones which require additional sensor to be detected, inter alia, voltage and current.A distinction was also made between the parameters which are typically detected locally in the network (e.g. in transformer stations or substations) and parameters which are detected or measured globally.

RESULTS

Theoretical background

BPL transmission is based upon OFDM multi-carrier modulation scheme, in which signals are transmitted using 917 independent carriers in the frequency range from 1.8 to 30 MHz [1]. A significant parameter describing quality of incoming signals at receiving BPL modems is the signal to noise ratio (SNR), which is determined for all 917 carriers automatically and on a regular basis. The SNR includes information about signal attenuation between sender and receiver and the noise power at receiver as described in [2]. High attenuation and also high noise power both lead to a low SNR. It was assumed that high frequency characteristics of power cables are dependent on their condition, e.g. ageing of dielectric as also described in [3].

Laboratory testings

Laboratory testings were performed to investigate the influence of ageing of XLPE and PILC cables on their attenuation. The attenuation per unit length was measured using time domain reflectometry. This measurement technique is described in [4].

The ageing dependency of the attenuation of XLPE medium voltage cables was investigated for influence of thermal ageing in a climate air oven. Figure 1 shows the attenuation per unit length of a 10 kV XLPE cable for several cycles of thermal ageing. Each cycle consists of 350 h heating at 90 °C and cool down to 20 °C for measurements.

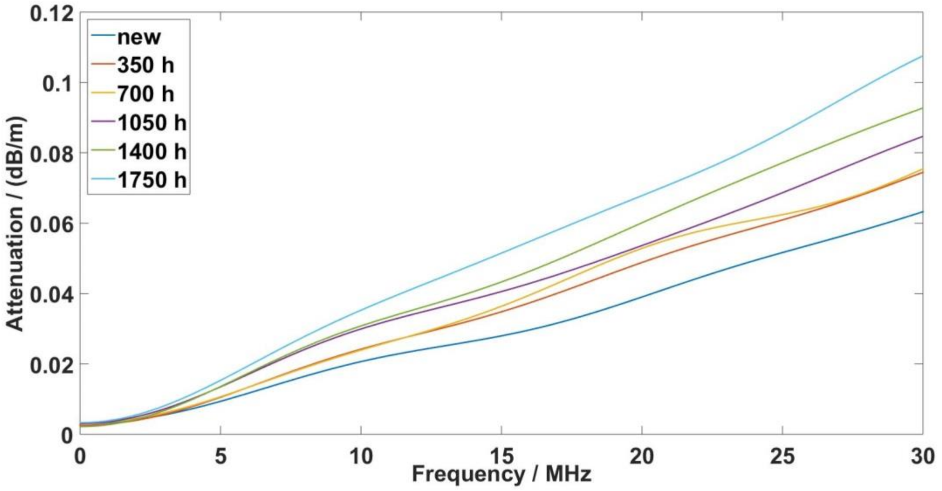

FIGURE 1 – ATTENUATION CONSTANT OF THERMALLY AGED XLPE MEDIUM VOLTAGE CABLE AS A FUNCTION OF FREQUENCY AND AGEING.

The results of attenuation measurements show that the typical low pass characteristic in XLPE cables is intensified due to increasing duration of thermal ageing. The attenuation especially at high BPL frequencies is sensitive to ageing, so investigated ageing conditions can be determined using BPL. Thermal ageing of 1750 h leads to a significant increase of attenuation at 30 MHz. Since this Figure shows attenuation per unit length, the effect is very significant especially for long cables [3].

In another test setup regarding cable ageing, a PILC cable was heated several hours to cause impregnation loss through its open ends. Cable's attenuation per unit length was measured after cooldown. After 80 hours of heating impregnation stopped to leak out. In total approximately 2 liters of impregnation leaked out. Figure 2 shows the result of the attenuation measurements.

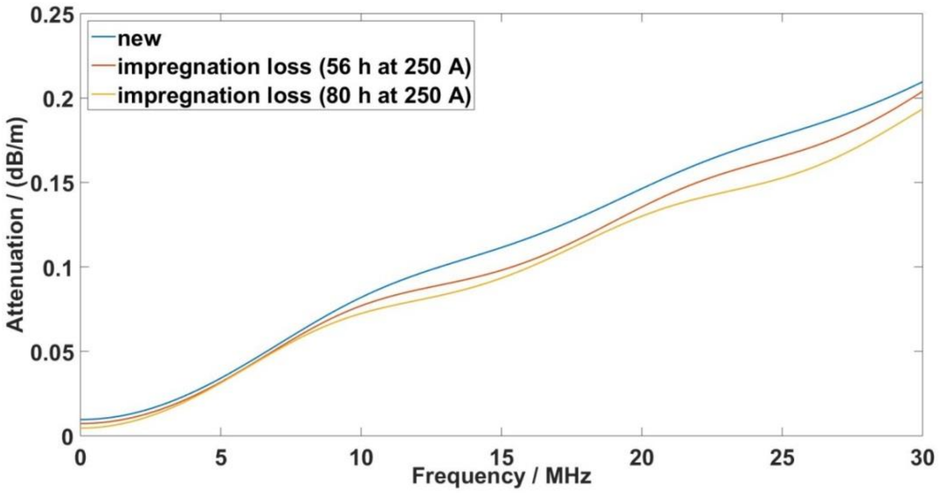

FIGURE 2 – ATTENUATION CONSTANT OF PILC MEDIUM VOLTAGE CABLE WITHIMPREGNATION LOSS AS A FUNCTION OF FREQUENCY AND AGEING [3].

Even new PILC cables can have much higher attenuation per unit length than XLPE cables. Due to impregnation loss attenuation especially at higher frequencies decreases. This impregnation loss caused changes of dielectric parameters of the insulation system, that improve BPL transmission, but impair dielectric withstanding voltage.
The results of laboratory tests prove that the attenuation, in particular of upper BPL frequencies, depends on different ageing mechanisms. A comparision of attenuation trends due to impreganation loss of a PILC cable with thermal ageing of an XLPE cable shows up opposite directions. Since attenuation constants are per unit length parameters, changed attenuation due to ageing becomes more significant the longer the aged cables are. Thus, the attenuation as well as the SNR are important parameters to support condition assessment of power cables.

Practical field test

After laboratory testing investigated effects were analyzed in a field test environment in a part of the distribution grid of Leverkusen, Germany. For this purpose, 38 BPL modems were installed there, that perform SNR measurements every 15 minutes for every carrier frequency resulting in a kind of monitoring of cables in distribution grids [5]. Figure 3 shows the results of SNR measurements as a time series exemplary. There, high SNR is marked by blue and low SNR by red zones. It can be seen that SNR measurements are time dependent, although the overall view is relatively constant.

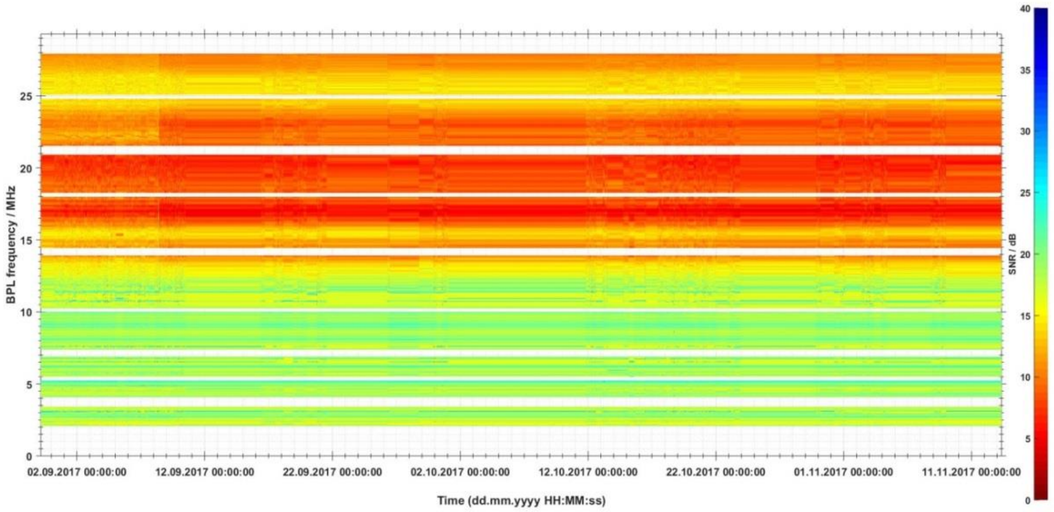

FIGURE 3 – SNR MEASUREMENTS OF A XLPE MEDIUM VOLTAGE CABLE SYSTEM OVER APERIOD OF 75 DAYS

A linear trend analysis showed up a decreasing SNR for upper BPL frequencies over time in case of some XLPE cables in service. This is the expected trend in consideration of laboratory testings of XLPE cables. Since SNR measurements were performed for a few months, these results are not statistically significant and further measurements and investigations have to be done to confirm the results of trend analysis or to find new finger prints to determine cable conditions.
Beside cable conditions and long trends due to ageing, short-term changes were also detected that can be used to detect other phenomenon. Figure 4 visualizes heavy gradients of the SNR caused by defect NH fuses in a three phase low voltage grid. NH fuses are part of transmission paths for communications in low voltage grids. Figure 4 shows the effect of intact NH fuses on four (three to zero) phases.

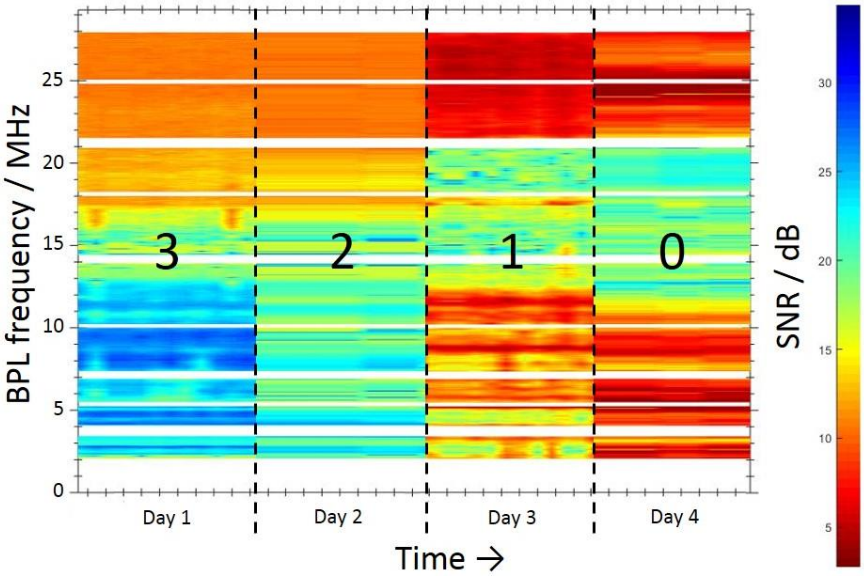

FIGURE 4 – SNR MEASUREMENTS OF A LOW VOLTAGE CABLE SYSTEM INFLUENCED BY DEFECT NH FUSES ON SEVERAL PHASES

It can be shown that a failure of the NH fuse on one phase leads to an immediate and permanent decrease of the SNR on many BPL frequencies.

Using different sensors voltages and currents were measuered. Measurements of currents in the medium voltage showed up that cables are loaded less than 20 %. Hence, temperature increase was low and not detectable using BPL signals. Figure 5 shows voltage and current measurement in the medium voltage grid (L1), which were performed every 15 seconds.

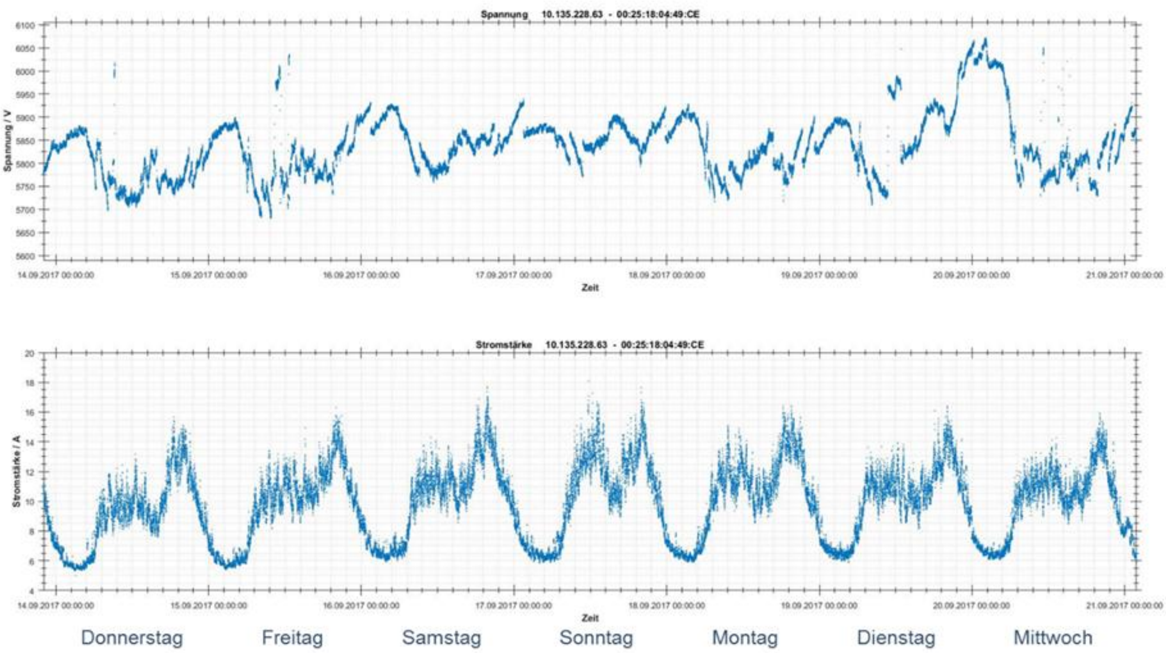

FIGURE 5 – VOLTAGE AND CURRENT MEASUREMENTS IN A MEDIUM VOLTAGE GRID (L1) OVER A PERIOD OF ONE WEEK

Another aspect of investigation are asymmetries and limit violation of the the phase voltage system in the low voltage grids, which become more important in future smart grids that include decentral producer. Figure 6 shows a three phase measurement in the low voltage grid. Measurements in the low voltage grid were performed every 10 seconds.

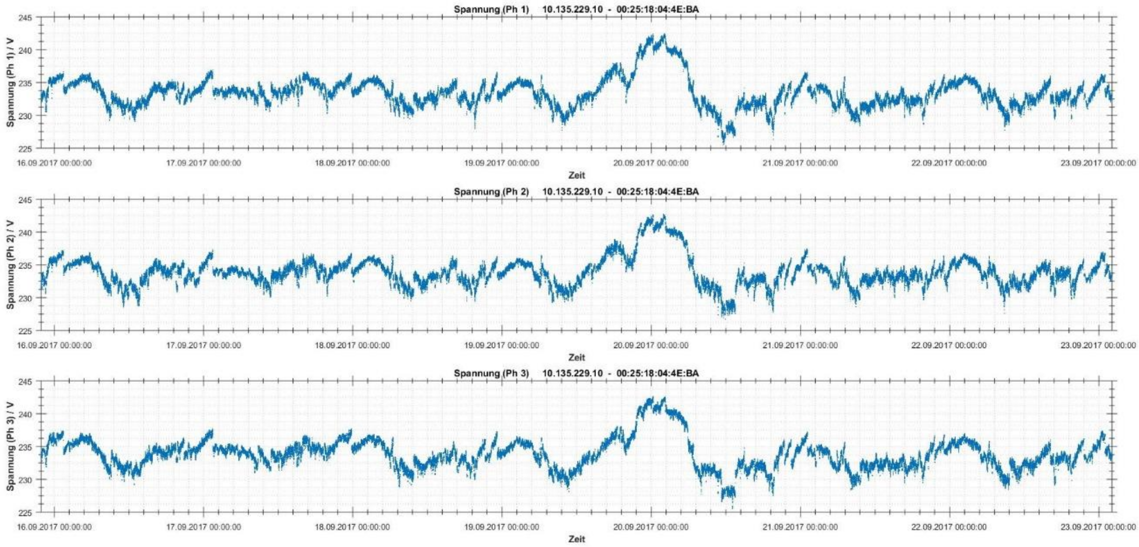

FIGURE 6 – VOLTAGE MEASUREMENTS IN A THREE PHASE LOW VOLTAGE GRID OVER A PERIOD OF ONE WEEK

The voltage and current measurements did not illustrate any limit violations during field testing, however they can be used to gather information for grid operators. In addition to this they can support an implementation into a decentralized network automation system by increasing transparency in the network.

CONCLUSION

The paper gives a picture of the work done with the intention of establishing a condition assessment method using BPL communication and simple sensor technology in distribution networks. The approach is analyzing data transmission characteristics of BPL technology based on three basic signal characteristics: reflections at weak points, attenuation due to ageing and temperature as a further influencing parameter and noise influence of partial discharges.

The results prove clear influence on the captured BPL signals. Thermal ageing and increasing temperature of medium voltage cables show a significant increase of the attenuation. Ageing and temperature affect attenuation constants of power cables, especially in the range of upper BPL frequencies which means the original low pass characteristic of power cable is intensified.

The project proves that using SNR measurements as an indicator for assessing cable condition can be traced in the corresponding frequency ranges. Hence, it is proved that BPL communication has the potential to determine different kinds of cable conditions and support both network management as well as asset management in operating distribution networks,especially in the future smart grids, where BPL is the chosen ICT tool for data transmission.

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