Monitoring of Distribution Grids Using B-PLC Infrastructure

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Abstract

The presented Broadband PLC Infrastructure, with integrated low-cost voltage sensors, offers a solution to German grid operators' most urgent challenges, namely extending grid monitoring to the low voltage level, state detection of grid operating material and establishing a communications infrastructure for the imminent smart meter rollout. The proposed B-PLC system has been tested in urban and rural grid areas.

Index Terms

B-PLC, Grid Monitoring, Low Voltage, Medium Voltage, Grid Operation

I. INTRODUCTION

ACCORDING to German legislation, only around 10 % of all meters need to be equipped with a communications device (i.e. smart meter gateway). In order to provide a viable B-PLC communications infrastructure, it is therefore necessary to install a repeater in each street cabinet. This potential disadvantage turns into an advantage, when you equip the repeaters in the street cabinets with low-cost voltage sensors that can provide continuous and grid-wide monitoring. With the B-PLC system, the measurement data can be sent to the backend in real-time, where grid surveillance systems can use it as input data.

II. MEASURING VOLTAGE AND EVALUATING THE B-PLC SPECTRUM

The B-PLC modems used for voltage measurements are equipped internally with an energy metering IC that is typically used in metering devices. Although for communications, a connection to any of the phases and the neutral conductor would be sufficient, the modem is connected to all three phases and the neutral conductor in order to measure all three phases continuously. Having a connection to all three phases, it is also possible to calculate the phase angle between the voltages. The measured data is then sent to the backend using the light-weight IoT protocol MQTT, which guarantees high scalability. The minimum interval of sending data is once per second.

The results of the voltage measurements in low voltage grids are displayed in Figure 1, Figure 2 and Figure 3.

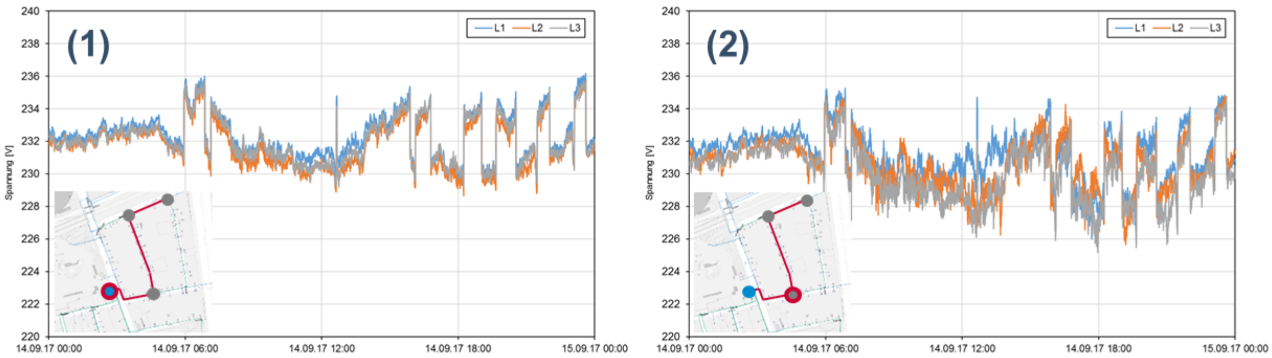


Figure 1: Results from the Voltage Measurements in an urban Low Voltage Grid (part 1)

With the help of the sensor data, grid operators can easily…

(1) determine when a voltage step takes place and what effect it has on the local voltage level
(2) check if all measured values are within the allowed voltage range of 230 V ± 10 %

(3) recognize if there are asymmetries between the three phases (e.g. due to 1-phase feed-in or load)
(4) identify phase rotation along a low voltage power line
(5) verify how a large amount of PV feed-in lifts the voltage level during the daytime.

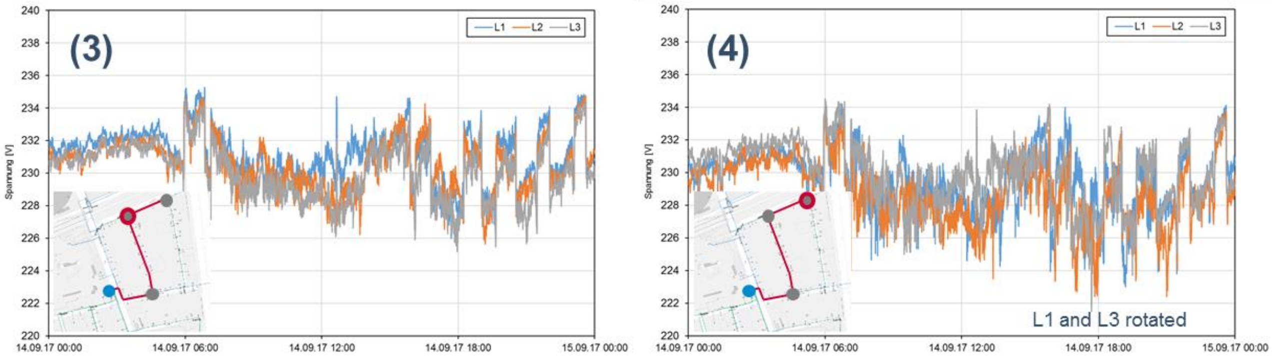


Figure 2: Results from the Voltage Measurements in an urban Low Voltage Grid (part 2)

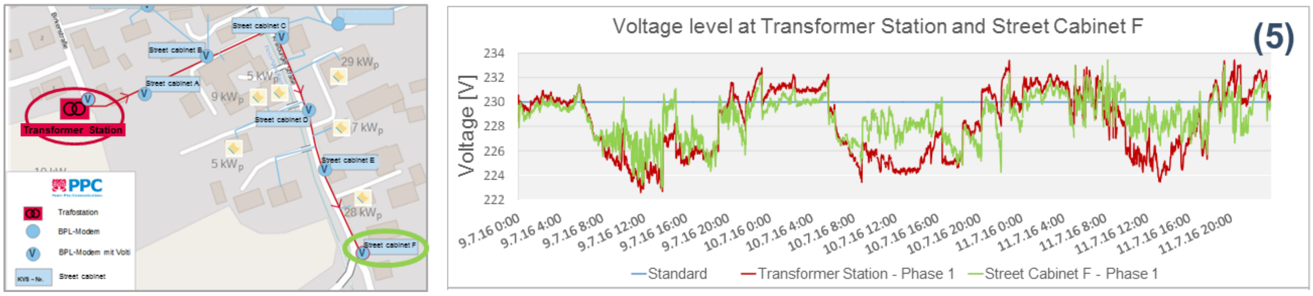
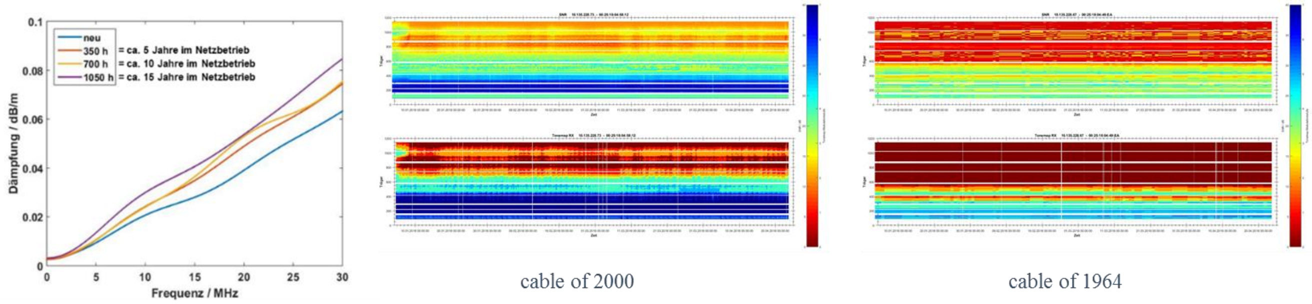


Figure 3:Results from the Voltage Measurement in a rural Low Voltage Grid

In addition to the results derived from voltage sensors that only use the B-PLC system as a communications infrastructure, the B-PLC system itself can provide information about grid operating materials – especially the cables used for data transmission. By analyzing the signal-to-noise ratio (SNR) of the 917 subcarriers used for data modulation, it is possible to determine the "real" cable age, which consists of a cable's nominal age plus the load that was on this cable during its lifetime.

The B-PLC chip in the modem normally collects the SNR data to evaluate how good the signal quality between itself and a neighboring modem is. On the basis of this value it then decides which modulation step to choose for each of the 917 subcarriers between around 2 and 28 MHz. Usually this data is immediately deleted after its main purpose. By accessing the chip and retrieving the SNR values from it, one is able to use it for different purposes as well. Evaluating the SNR means getting a detailed insight into the cable between the modem and its neighbor in the frequency range of high-price measuring devices sometimes used in transformer stations.

When a cable is aging, the signal attenuation increases, especially in the upper frequency range. This correlation could be found in laboratory testing with artificial cable aging (i.e. heating up a cable to 90 °C for several hundreds of hours simulating many years of high load operation), as is displayed in Figure 4 on the left. An increased signal attenuation results in a lower SNR value. The correlation could also be found in field tests that were performed during the "Fühler im Netz" research project, as is displayed in the following graph on the right. The diagrams show the SNR (above) and the Tonemap (below) over time (around 4 months). The y-axis indicates the frequency (from 2 to 28 MHz). Blue color stands for high SNR values (dark blue = 40 dB), red color stands for low SNR values (dark red = 0 dB or below). The comparison of the two cables shows that the SNR values of the older cable are significantly lower than the ones of the younger cable, especially in the higher frequency range – just as the laboratory results predict.



cable of 2000

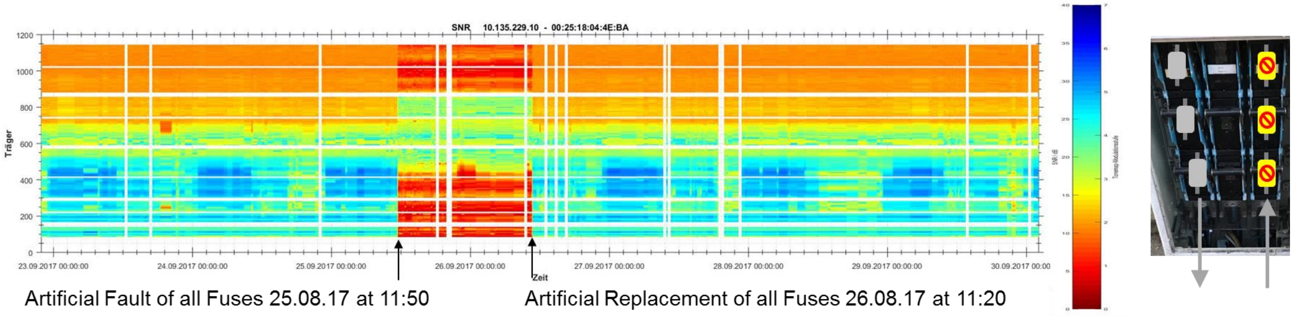
cable of 1964

Figure 4: Results from Evaluating the B-PLC Spectrum – Detection of Cable Aging

While this method of determining the “real” age of a cable can generally be applied to cables of all voltage levels, it is especially effective when used on medium voltage cables. The two examples displayed in Figure 4 are derived from medium voltage cables (U_N = 12 kV).

On low voltage cables, the evaluation of the B-PLC Spectrum, namely of the SNR, can provide another very interesting advantage for grid operators. In Figure 5 the SNR over time is displayed (the graph covers one week in Sep 2017). On 25.08.17 at 11:50 an artificial fault of all three fuses was created. 24 hours later the fuses were artificially replaced. Artificial replacement stands for the use of coupling condensators which act as high pass filters with a threshold frequency of 1 MHz. Artificial fault stands for installing faulty fuses instead of coupling condensators.

The SNR of the communication across faulty fuses is very different compared to the one across working fuses / coupling condensators. When a fuse breaks, the galvanic contact is interrupted. The open cut-off point acts like a high pass filter with a threshold value somewhere in the frequency range of B-PLC. That is the reason why the lower frequencies tend to have a significantly lower SNR when the fuse is broken. Grid operators can make use of that effect as they are now able to determine whether or not a fuse has broken. For meshed grids this is particularly useful.



Artificial Fault of all Fuses 25.08.17 at 11:50

Artificial Replacement of all Fuses 26.08.17 at 11:20

Figure 5: Results from Evaluation the B-PLC Spectrum – Detection of Fuse Faults

III. CONCLUSION

Putting all results together, it becomes clear that the proposed Broadband Powerline Communications system, with integrated voltage sensors, can provide a huge benefit for grid operators seeking cost-efficient grid monitoring solutions. With the results from this system, grid operators are in a better position to deal with the imminent challenges of integrating larger shares of renewables into the low voltage grids and for erecting a charging infrastructure, suitable for the growing success of electric vehicles.

ACKNOWLEDGMENT

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