EXPERIMENTAL INVESTIGATIONS OF ELECTRICAL INFLUENCES ON POWER LINE COMMUNICATION PERFORMANCE IN DISTRIBUTION GRID APPLICATIONS

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ABSTRACT

Powerline communication (PLC) offers the chance for distribution grid operators to use the existing energy cable grid simultaneously as an infrastructure for communication purpose. In this paper practical examinations under realistic conditions are performed in the distribution grid laboratory of the Center for Grid Integration and Storage Technologies of RWTH Aachen University. Measurements with different photovoltaic (PV) inverters demonstrate the robustness of state of the art G3-PLC modems against additional attenuation and emission of noise of PV inverters in operation. Furthermore the adaptive reconnection ability of these modems is pointed out for smart grid application.

INTRODUCTION

The successful implementation of future smart grids relies on the availability of a reliable and cost efficient communication infrastructure. Powerline communication (PLC) offers the chance to use the existing low voltage (LV) cable grid for data transmission instead of using external networks or building an extra infrastructure. PLC as a possible backbone for future information and communication (ICT) infrastructure has to guarantee a reliable and sufficient performance even in the occurrence of electrical disturbances or in combination with increased decentralized power generation. But due to the fact that the operation of PLC leads to cable networks used as a shared medium of power supply and communication, the communication channel undergoes continuous changes [1].

Today’s and future distribution grids are characterised by a potential partial high density of decentralized power generation units, for instance solar power systems. For the transformation of the direct current (DC) at the output of the solar panels into alternating current (AC) for power grid connection, power inverters are needed. These power inverters use e.g. pulse-width modulation PWM as a control algorithm and semiconductor devices for switching actions. As a consequence of switching, harmonics above 50 Hz can be produced and emitted into the power grid. Therefore photovoltaic (PV) inverters can act as an additional noise source leading to further disturbances on the powerline channel [2]. To comply with grid integration standards [3], output filters with inductances (L) and capacitances (C) in the form of L, LC or LCL filters are used to damp the outgoing frequencies [4]. In contrast to the risk of additional channel noise, PV inverters could have a damping effect on high frequency signal distribution because of its output filters connected to the power grid. For this reason, practical examinations on PV inverters under load conditions in a realistic testbed are performed in this paper.

A further issue relating to distribution grid applications is a change of the energy cable grid topology in operation. In case of electrical faults or due to operational needs, for instance maintenance works, the cable topology can vary and thus the powerline network has to be flexible and adaptive to build up new communication routes to ensure a reliable reconstruction of the communication line. Powerline networks consist of a central personal area network (PAN) coordinator modem acting as a point of data concentration and PAN end devices installed e.g. in households for smart metering applications, acting as clients.

The central PAN coordinator modem for PLC can be installed at the LV side of the substation transformer. After a disconnection of the transformer at the LV side by an open circuit breaker or tripped LV fuse, the communication path to the underlying PAN clients are also disconnected and the implemented reconnection ability of the PAN clients has to take place. Depending on the switching cause and fault scenario, another substation with a PAN coordinator is able to supply the underlying distribution grid. In this case, all PAN clients have to set up a new robust connection to the PAN coordinator in the other substation. The reconnection ability of state of the art PLC modems is investigated and results are presented and discussed in this paper.

TESTBED FOR PLC INVESTIGATIONS

To investigate the applicability of PLC in various scenarios, experimental tests are carried out in the distribution grid laboratory of the Center for Grid Integration and Storage Technologies of RWTH Aachen University [5]. The laboratory grid for PLC testing consists of a LV-cable grid (35 to 240 mm² type NAYY) of more than 3,000 m length in total. The individual cable lines range from 20 to 500 m in length and can be interconnected flexibly by inserting LV fuses of type NH2 into fuse-switch-disconnectors in distribution cabinets (1-6, A and B in Figure 1). Furthermore the LV cable grid can be connected to different medium voltage substations with power ratings from 400 to 1250 kVA.

To each of the distribution cabinets 1-6, a G3-PLC modem is installed as a PAN client. The G3-PLC standard is part
of the narrow band PLC technology (NB-PLC) and uses frequencies below 500 kHz for signal modulation. The PLC modes used in this examination operate in the frequency band of 150 kHz to 500 kHz, which is not part of the CENELEC band (3 kHz to 148.5 kHz) and allowing data rates up to 240 kBit/s on the physical layer [6][7]. G3-PLC PAN coordinators (in figures only ‘PAN’), running on the same hardware platform as the PAN clients (in figures only ‘PLC’), are installed in two medium voltage substations in series to a medium voltage cable lines, fuses and current transducer with two (see Figure 1). The measurement devices are connected on the network side to the PAN coordinator to measure the power level of the signal reaching the PAN coordinator. The difference between $P_{in}$ [dBm] and $P_{out}$ [dBm] is defined as the signal attenuation $\Delta P$ [dB] of the channel, which is also frequency dependent. Noise measurements with the spectrum analyser detect the mean power level $P_{noise}$ [dBm] of emitted noise signals in a time span of 2 minutes. Both, the frequency generator and the spectrum analyser, are connected by a capacitive coupling unit with the LV grid to uncouple the grid voltage from the measurement devices.

In order to demonstrate the adaptive reconnection ability of PLC technology a test setup in Figure 3 is used.

**DESCRIPTION OF THE METHODOLOGY**

Measurements on the physical as well as on application layer are performed. The measurements with focus on PV inverters are done with the testing setup in Figure 2. Different PV inverters (see Table 1 for specification) are connected by short cable lines, fuses and current transducer with two distribution cabinets in series to a medium voltage substation in the Testing Center. A PAN client is installed right behind the AC/DC inverter, to verify the robustness even in electrically close installation. On the LV side of the substation, behind the voltage fuses, the corresponding PAN coordinator for the communication link is installed.

**Table 1 Specifications of the photovoltaic inverter.**

<table>
<thead>
<tr>
<th>Inverter</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Quantity</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>AC Phases [#]</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>AC Power [kVA]</td>
<td>36</td>
<td>33,3</td>
<td>4,4</td>
</tr>
</tbody>
</table>

**Figure 2 Experimental setup for inverter tests on PLC.**

In this test setup the channel qualification is done by a signal attenuation and noise measurement. For this purpose a frequency generator is placed close to the PAN client. The feed in power of the frequency generator is set to $P_{in} = +13$ dBm, similar to the output power of the PLC modems for the modulation of the signal on the 50 Hz grid frequency. A spectrum analyser of the type Tektronix RSA306 is installed close to the PAN coordinator to measure the power level $P_{out}$ of the signal reaching the PAN coordinator. The difference between $P_{in}$ [dBm] and $P_{out}$ [dBm] is defined as the signal attenuation $\Delta P$ [dB] of the channel, which is also frequency dependent. Noise measurements with the spectrum analyser detect the mean power level $P_{noise}$ [dBm] of emitted noise signals in a time span of 2 minutes. Both, the frequency generator and the spectrum analyser, are connected by a capacitive coupling unit with the LV grid to uncouple the grid voltage from the measurement devices.
common switch. In the initial state, both circuit breakers are closed, but all PAN clients (PLC1-6) have a defined and stable network connection only with PAN1 coordinator. When the switch of PAN1 coordinator opens, for instance due to a fault scenario, the PAN client PLC1 is forced by the enduring TCP data stream to seek for another PAN coordinator. The other PAN clients (PLC2 to PLC6) are not used for data transmission. In this test setup a third computer is used to force a spontaneous and simultaneous reconnection of these end devices to rebuild a connection to the new PAN coordinator right after the disconnection. Thus the influence of concurrent connecting PAN clients on the reconnection sequence can be observed.

ROBUSTNESS OF G3-PLC MODEMS IN INTERACTION WITH PV INVERTERS

Results of damping measurements with different PV inverters and disconnected PLC devices are given in Figure 4.

The chain of damping elements, consisting of cables, distribution cabinets and installation equipment leads to a damping of the signal to a minimum of $P_{\text{out}}^\text{min} = -4 \text{ dBm}$ at a frequency of $f = 150 \text{ kHz}$. Additional installation of a parallel inverter increases the damping effect of the power signal in total. The subtraction of the cable damping characteristic from the inverter attenuation measurement leads to the net inverter attenuation in Figure 5.

The graph shows, that there is no dependence of the operation state and output power on the attenuation characteristic, because of the static output filters. Furthermore it is observable that the filter design differs between manufacturer A and B significantly in damping characteristic. The power inverters B and C of manufacturer B effect a maximum attenuation of $\Delta P = -25 \text{ dB}$ at $f = 200 \text{ kHz}$. Maximum attenuation of inverter A is measured at $f = 150 \text{ kHz}$ of $\Delta P = -7 \text{ dB}$. Beside the attenuation characteristic, the noise emission of these inverters under load is measured with disconnected PLC devices and plotted in Figure 6.

![Figure 4 Damping measurements on test grid.](image)

![Figure 5 Attenuation of PV inverter in operation.](image)

![Figure 6 Noise emission of PV inverter in operation.](image)
AVAILABILITY AFTER GRID TOPOLOGY CHANGES

Exemplary results of the reconnection ability tests for PLC modems are plotted in Figure 7.

Figure 7 Exemplary result of a PLC reconnection tests.

The graph of Figure 7 shows the time resolved TCP data rate in kBit/s, when PLC1 as PAN client is connected to a PAN coordinator and an interruption process to the PAN coordinator is started at $t = 30$ s. After a mean time of approximately 45 s, the reboot of the PLC system is done and a successful commutation of the communication path to the other PAN coordinator leads to a robust return of the data rate.

The same test procedure is done with 6 concurrent PAN clients. However Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism is typically used for medium access control on the shared medium by the PLC modems [9], no significant increase in connection time compared to single modem tests is measured. Thus, reconnection ability could be successfully demonstrated.

CONCLUSION

Practical examinations on different PV inverters show, that an additive signal attenuation of the output filter and noise emission in operation are strongly dependent on the design of the inverter by the manufacturer. Noise emission of the PV inverters is measured above $P_{\text{noise}}^{\text{max}} > 0$ dBm in CENELEC frequency range, which may lead due to a noticeably reduced SNR to a decrease of PLC performance. An influence on the transmission rate of the tested G3-PLC modems by parallel PV inverter operation was not observable in any test setup. Further tests should be performed with multiple power inverters in common operation to examine the possibility of additive noise or damping effects.

The reconnection ability after an interruption of the communication link in case of e.g. switching actions in the grid is demonstrated by a test in this paper. By a time-resolved data rate measurement, mean reconnection times of 45 s through man made interruptions in the test setup can be observed and after that a stable communication link is established again.

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REFERENCES


