ELECTROMAGNETIC COMPATIBILITY BETWEEN ELECTRONIC LOADS AND AUTOMATED METER READING SYSTEMS USING PLC

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ABSTRACT

According to Finnish legislation, at least 80 % of the energy meters in Finland have to be remotely readable and provide hourly based energy data by the end of 2013. Based on a questionnaire made to Finnish DSOs, a conservative estimate can be made that approx. 30…50 % of these meters will use PLC communication in LV network. In a sample of 110 647alredy installed meters approx. 3.6 % of the meters using PLC had experienced communication problems either in commissioning stage or during operation. On-site measurements to study common customer apparatus disturbing the PLC were conducted in the networks of a few DSOs. Most common disturbance sources were frequency converters and switch-mode power supplies. A method based on HF current measurements was developed to facilitate the location of the disturbance source. The measurements indicate that in addition to insufficient emission limit standardization below 150 kHz the aging of customer equipment is a relevant cause of interference problems.

INTRODUCTION

Acquisition and installation of automated meter reading (AMR) systems is going on in many European countries and some have already completed the first round of installations. One of the decisions the DSOs are facing is the choice of the communication medium used by the meters. There are several communication methods available such as those based on wireless mobile communication networks (GSM/GPRS, 3G), low power radio and power line communication (PLC). One of the popular communication methods is PLC in the 3…95 kHz frequency range, because the medium is available at all places, where electrical energy has to be metered and there are no direct fees for the communication. For example, in Sweden it is approximated that half of the meters communicate via PLC [1]. According to Finnish legislation, at least 80 % of the energy meters in Finland have to be remotely readable and provide hourly based energy data by the end of 2013. Finnish legislation requires reading of the energy data once per day, which sets higher demands for the reliability of the communication than the monthly reading required, for example, in Sweden so far. PLC is regulated by the CENELEC standard EN 50065-1, which states, among others, the frequencies and signalling levels allowed in the low voltage (LV) network. For most customer equipment, however there are no emission or immunity limits specified in standards in the frequency range 3…150 kHz. This is one of the reasons why PLC may be disturbed by the emissions of customer equipment and vice versa. To get a general view of the extent of EMC problems in this frequency range, a questionnaire was made to Finnish DNOs. This paper presents the main results of the questionnaire and some practical examples of on-site measurements and methods for locating the disturbance sources and solving the EMC problems.

QUESTIONNAIRE TO FINNISH DNOS

In April 2011 Tampere University of Technology (TUT) in co-operation with Finnish Energy Industry conducted a questionnaire to Finnish DSOs concerning AMR meters. The goal was, among others, to get a view of the communication technologies selected by DSOs, experiences acquired of the AMR systems and the interference problems related to, especially, PLC systems. A total of 18 Finnish DSOs having a total of 1 935 275 energy meters answered the questionnaire. Thus, the questionnaire covers approximately 2/3 of the meters in Finland. At the time of the questionnaire 847 071 meters were remotely readable.

Shares of different Communication Technologies

A total of 10…13 DSOs answered the detailed questions concerning the selected communication technologies and disturbance problems experienced with meters using PLC communication in LV network. Fig. 1 presents the distribution of communication technologies in case of each DSO separately and in all DSOs (in total).

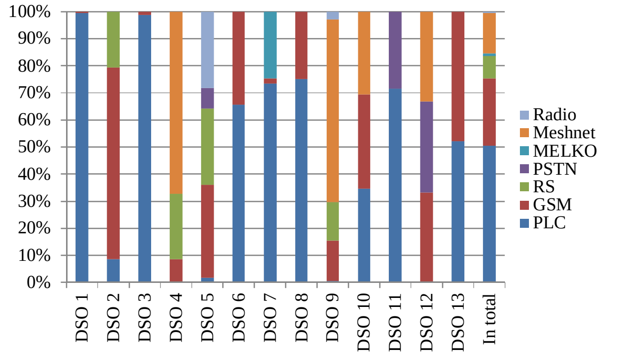

Fig. 1. Shares of communication methods used in meters of Finnish DSOs by the end of 2013 (sample: 1 696 532 meters).

Based on the number of meters covered by Fig. 1 and the total number of meters in Finland (approximately 3 million) a conservative estimate can be made that by the end of 2013 approx. 30…50 % of the energy meters in Finland will use PLC communication in LV network. A more detailed analysis of the questionnaire results is presented in [2].

Reported cases where PLC has been disturbed by Customer Equipment

According to the results of the questionnaire, the percentage of energy meters having suffered from communication problems varied between DSOs from 1 % to 26 %, on average it was approximately 3.6 % in a sample of 110 647 meters managed by 8 DSOs. Communication problems were 3-4 times more common in the commissioning stage than later during operation. On the other hand, successful operation in commissioning stage does not guarantee trouble-free operation in the future, because the disturbance level in the network is neither constant nor regulated by standards. According to the questionnaire frequency converters have been the most common cause of communication problems. Other problematic apparatus have been energy saving lamps and single phase devices (such as antenna amplifiers, teleoperator devices, digital set top boxes) having switch-mode power supplies [2].

Reported cases where Customer Equipment have been disturbed by PLC Signal

A total of 23 cases where PLC had caused malfunctions of customer apparatus were reported by the DSOs. The low number of cases reported indicates, that the disturbance problems caused by PLC signal to customer apparatus are not as common as disturbance problems caused by customer apparatus to PLC. The reported cases were:

a. 15 pcs of touch dimmer lamps (TDLs)
b. Other lighting control equipment
c. 1 pc of intercom system using PLC
d. 1 pc of Homeplug-ethernet link
e. 1 pc of aerial amplifier
f. 1 pc of heating control system of a detached house
g. Traffic light control
h. 2 pcs of DSOs older PLC systems (MELKO) at 3…5 kHz frequency range

In reality the number of interference cases is likely to be larger since in many cases the customers do not complain about the problem to the DSO (they do not recognize the problem as being related to mains supply and PLC).
Two different TDLs were studied by TUT in laboratory with two different PLC communication systems and the malfunction (unintentional on/off switching and stepping through the different dimming states) of the TDLs was proved to be caused by the PLC signal. Tests were also made with discontinuous sinusoidal signals of different frequencies to determine the sensitivity of TDLs to disturbance signals reminiscent of the PLC signal. The test results are reported in detail in [3].

ON-SITE MEASUREMENTS OF SWITCH-MODE POWER SUPPLIES

During 2012 TUT conducted on-site measurements in the LV networks of a few Finnish DSOs to study common causes of PLC problems. The conducted disturbance measurements reported in this paper were made with a Rohde & Schwarz ESPI-3 spectrum analyzer and ESH2-Z3 passive voltage probe and EZ-17 current probe.
Two DSOs reported a total of tens of cases where single phase plug-in power supplies of communal aerial or cable TV systems have caused malfunction of PLC. One of the cases was studied on-site. The switch-mode power supply (SMPS) of a communal aerial receiver was on phase L2 in the main distribution room of a terrace house, while the meters in the same room communicated with the concentrator on phase L1. The conducted disturbance voltages measured at each phase at the main distribution board of the terrace house are presented in Fig. 2. As the figure indicates, the power supply causes wideband disturbances in L2 with voltage greater than 100 dBµV even above 150 kHz, where the voltage should be less than 56…66 dBµV to conform with the existing EMC standards. In phases L1 and L3 the disturbance voltage was approximately 10 dB lower (approx. 1/3 of voltage), but still high enough to block the communication. In this case the reason for the high interference level was the aging (drying) of the electrolytic smoothing capacitor between the rectifier and DC/DC-converter of the power supply [2].

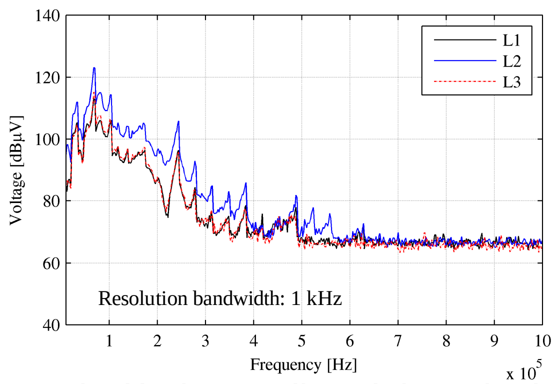

Fig. 2. Conducted disturbances caused by a single phase switch-mode power supply of a communal aerial system in three phases.

In another case studied a SMPS of a new 4G/LTE mobile phone base station disturbed the PLC. The switching frequency of the power supply was approximately 44.5 kHz with the second harmonic at 89 kHz (Fig. 3.). In this case the power supply was intact, but the voltage of the second harmonic between the PLC frequencies used by the DSO is high enough to block the PLC. Several similar cases have been found after this one. In places where the base station was located in the same building with the DSO's PLC data concentrator the power supply typically blocked the communication in most of the meters assigned to the concentrator. According to the 4G/LTE base station operator the supply is tested and fulfills the existing EMC requirements. The problem is that below 150 kHz there are currently no emission limits for this kind of equipment. So far the DSO has installed additional EMC filters into the feeder of the supply to get the PLC working. In most cases this has solved the communication problem.

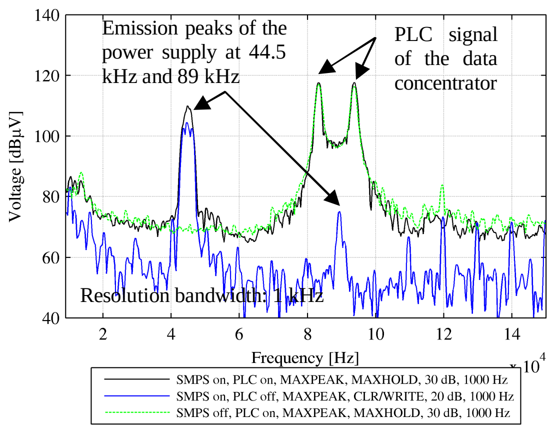

Fig. 3. Conducted disturbances caused by SMPS of a 4G/LTE base station.

ON-SITE MEASUREMENTS OF VSDS

Variable speed drives (VSD) are nowadays very common, for example, in ventilation systems of blocks of flats and other large buildings and in water and waste water pumping stations. The switching impulses of the IGBT transistors forming the pulse width modulated voltage to the fan motor cause wideband disturbances which, if not handled properly, are a potential problem source to PLC.

One interference case studied with on-site measurements is presented below. In this case, the reason for the PLC problems of the energy meters was the disturbances caused by five small frequency converters (FCs, nominal power 0.75 kW each) used to control the ventilation system of the block of flats. According to the type codes of the FCs they were equipped with EN 55011 Class B filters. The conducted interference voltages presented in Fig. 4 were measured at the L1 terminal of one of the disturbed meters.

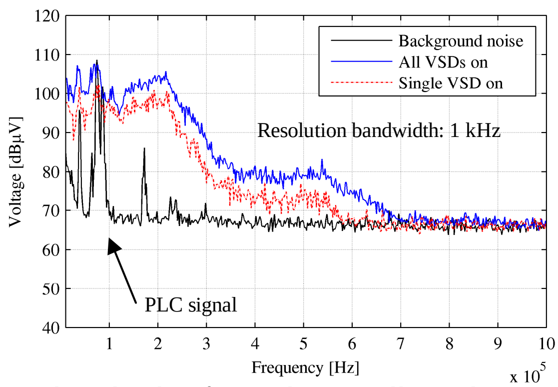

Fig. 4. The conducted interference voltages caused by a single VSD and all 5 VSDs in operation and all VSDs switched off.

At frequencies below 230 kHz the disturbance voltage of a single VSD is mainly above 95 dBµV (measured with 1 kHz bandwidth), which is more than 30 times higher than what could be expected based on the filter class. Potential reasons contributing to the high disturbance level may be:

- Unshielded or too long motor cables
- Installation flaws (e.g. incorrect grounding of the shield of the motor cables)
- Aging of the frequency converter component(s)
- The converter has not fulfilled the EMC requirements in the first place

Based on [4] the manufacturer's declaration of conformity to EMC standards does not always guarantee that a frequency converter fulfills the EMC requirements.

LOCATION OF DISTURBANCE SOURCES

Especially, in cases where a large amount of meters suffer from communication problems, it is often difficult to locate the disturbance source. High frequency (HF) current measurements proved to be a useful tool in such cases. As an example, Fig. 5 presents a network diagram of a case where a faulty antenna amplifier disturbing the PLC system was located by HF current measurements. In this case a total of approx. 330 meters supplied by the same transformer station could not communicate with the concentrator.

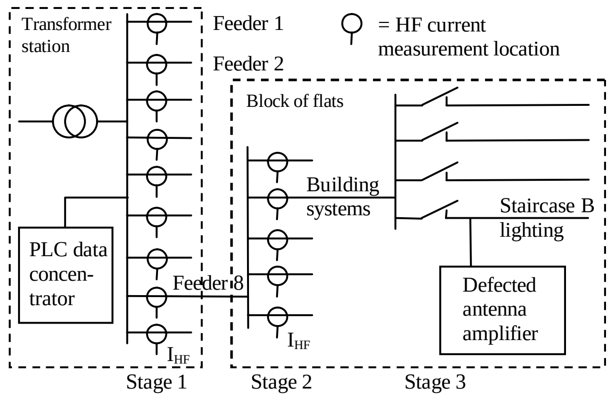

Fig. 5. Network diagram of a case where a defected antenna amplifier disturbing PLC of energy meters was located by HF current measurements.

The location process was started from the transformer station (stage 1) with HF current measurements of all feeders. The feeder with the highest disturbance current was no. 8 feeding a block of flats (Fig. 6). In stage 2 the HF current measurements at the main distribution board of the block of flats indicated that the highest disturbance current flows at the building systems branch (Fig. 7). Because in this branch circuit most of the loads were non-critical from the viewpoint of interruptions, it was easier to switch off the loads (staircase and other lightings, ventilation etc.) one by one using the miniature circuit breakers. By measuring simultaneously the HF disturbance voltage it was possible to determine which switch-off caused the disturbance voltage to drop (Fig. 8). The disturbance source was localised to staircase B lighting circuit, where the source was not the lighting, but a defected antenna amplifier powered from the lighting circuit. The problem was solved by replacing the amplifier with a new one. In case of loads switching on and off intermittently power frequency current measurement can also be used as an additional method to help in recognizing the size and type of load if the branch circuits for some reason cannot be measured separately with the HF method.

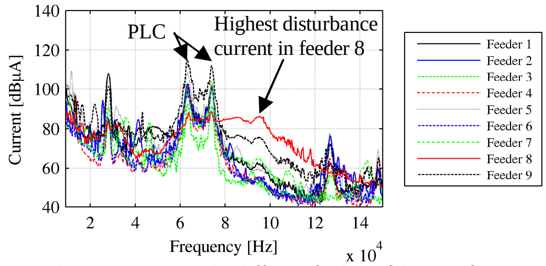

Fig. 6. The HF currents in the different feeders of the transformer station.

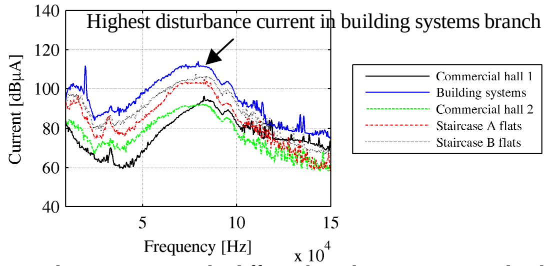

Fig. 7. The HF currents in the different branch circuits measured at the main distribution board of the block of flats.

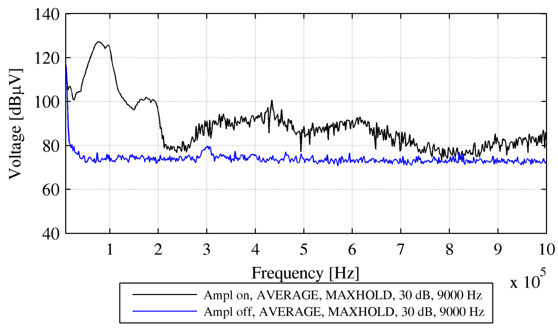

Fig. 8. The HF disturbance voltage at the main distribution board of the block of flats with the antenna amplifier switched on and off.

SOLUTIONS TO PLC RELATED EMC PROBLEMS

The potential solutions to the PLC related EMC problems depend on the cause of the problem. In all interference cases it should be verified that the apparatus involved (PLC and customer apparatus) are intact and correctly installed. Installation flaws are a relevant cause of problems especially in case of frequency converters. Aged or defected apparatus should naturally be changed into new intact ones. If the problem is not aging or installation flaws, a suitable EMC filter may be installed between the disturbing (or disturbed) apparatus and the network. Although the currently available filters are mainly designed for frequencies above 150 kHz, their attenuation at the higher end of CENELEC A band (60…95 kHz) used by most modern PLC systems is usually high enough to solve the EMC problem. In case of single phase apparatus in three phase systems changing the apparatus to a different phase may also be an option (three phase meters usually use only one phase to communicate). In the long run, standardization should be developed in the frequency range 3…150 kHz so that reliable operation of both electronic loads and PLC in the power network would be possible.

CONCLUSIONS

Based on the questionnaire made to the Finnish DSOs it seems that by the end of 2013 approximately 30…50 % of the approximately 3 million energy meters in Finland will use PLC communication in LV network. In a sample of 110 647 already installed PLC meters of 8 DSOs approximately 3.6 % of the meters had experienced communication problems either in commissioning stage or during operation. Common causes of communication problems in the PLC systems have been frequency converters, energy saving lamps and single phase devices equipped with switch-mode power supplies. Based on the interference cases studied by on-site measurements and literature studies four different root causes for PLC problems may be distinguished:

- aging of customer apparatus (or their components)
- installation flaws (especially in case of VSDs)
- in spite of the manufacturer's declaration of conformity to EMC standards the apparatus does not fulfill the EMC requirements
- lack of emission limits between 3…150 kHz

HF current measurement proved to be a valuable tool in locating the disturbance sources in such networks where power interruptions cannot be easily arranged. Although not optimized for PLC frequencies, EMC filters offer a usable solution to the disturbance problems.

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