ATTENUATION AND NOISE LEVEL - POTENTIAL PROBLEMS WITH COMMUNICATION VIA THE POWER GRID

Sarah RÖNNBERG
LTU - Sweden
sarah.ronnberg@ltu.se

Martin LUNDMARK
LTU - Sweden
martin.lundmark@ltu.se

Mats WAHLBERG
Skellefteå Kraft - Sweden
mats.wahlberg@skekraft.se

Marcus ANDERSSON
LTU – Sweden
mac.andersson@gmail.com

Anders LARSSON
LTU – Sweden
anders.1.larsson@ltu.se

Math BOLLEN
STRI and LTU - Sweden
math.bollen@stri.se

ABSTRACT

This paper will give examples of the potential problems associated with remote-meter reading via the power grid and describe some of the technologies available. Examples will be given of practical cases in which the communication channel does not function in the intended way. Three potential problems with communication via the power grid are identified in the paper:

- *The noise level is too high for the information to reach the receiver*
- *The attenuation at the frequencies used for communication is too high. Several cases have been identified where this made communication impossible. Certain types of end-user equipment cause a large attenuation of the communication signal, so that a too small amount of the signal reaches the receiver*
- *Interference with other equipment. A flicker problem was found due to a modulated 100-Hz signal used for communication*

INTRODUCTION

In Sweden, the change from manual meter reading at irregular intervals, to automatic remote meter reading at pre-defined instants is planned to be finished in July 2009. It seems feasible that at least half of the remote meter communication devices will use the power grid the first distance from the power meter. The main reason is simple: this communication medium is available at all places where electricity has to be metered. However, the power grid is not designed as a communication channel. It is constructed to deliver electrical power with low losses at the power-system frequency (50Hz in Sweden), and the communication has to share this channel. The frequency range used for automated meter reading is 9 to 95 kHz (with some exceptions); the same range is often used by switch mode power supplies. The characteristics of the power line as a communication channel vary with time, because loads are constantly connected and disconnected. Impedance mismatches occur due to different cables and channel splits. Crosstalk between phases is also very common and therefore, if communication is present on one phase it will affect the other two. Each load connected has a different effect on the characteristics of the power line, and there is no way to predict what kind of load will be present at a specific moment in time [1] [2].

POTENTIAL PROBLEMS

Interfering signals

A multitude of signals are present on the power network: power electronics and other loads generate some of them; and others are generated for communication. For communication, all other signals but the intended ones are considered as interfering signals or noise. Power electronic devices are a common source of such noise. These devices meet the requirements of the product standards according to conductive emission by EMC filter. Those standards place limits to the emission levels above 150 kHz and below 2 kHz. In Cenelec's A-band (9-95 kHz), commonly used for power-line communication, there are no restrictions for conductive emission generated by connected equipment. If a signal, e.g. from a switch mode power supply like in Figure 1, coincides with a communication signal, deciphering such a mixed signal would be difficult.

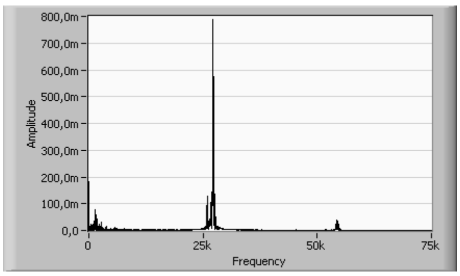

Figure 1, a signal originating from an UPS, amplitude in volts.

Attenuation

Experience from measurements at a significant number of locations, show that attenuation will probably be the most serious challenge to signaling on the power grid in the future. Attenuation is defined as a decrease in signal amplitude, or the difference between the signal level at the output and the input of the communications channel.
The communication signal will always experience attenuation due to losses in the cables, and this attenuation is well known. The solution to this kind of attenuation is to keep the distance between the sender and receiver short or if the distance is too long, to use a repeater. The big challenge for power-line communication is a different kind of attenuation: attenuation by shunting. This is caused by end-user equipment connected to the grid. Every piece of equipment affects the characteristic of the communication channel. The earlier-mentioned EMC filters often have a capacitor connected between phase and neutral. The power cord and other cables in the power grid, add inductance and capacitance to the circuit. The capacitance of the filter creates a resonance circuit with the inductance of the power grid. At the resonance frequency the impedance of the filter will be substantially lower than the impedance of the rest of the channel. If the resonance frequency and the communication frequency are close the majority of the communication signal will run through the load, leaving only a small signal to reach the receiver at the other end of the communication channel. The filter or the electrical equipment responsible for the resonance circuit will effectively shunt the communication signal and basically block any attempt of signaling using at or near this resonance frequency.
A filter makes no distinction between interfering signals and communication signals. The increasing number of EMC filters is therefore, by itself, a threat to the communication via the power grid, mainly by absorbing the communication signal and thereby attenuating the signal. When the signal is attenuated, the communication also becomes less resilient to noise. Therefore it is often incorrectly concluded that it is the noise emitted by the equipment that causes interference with the communication channel. However it is not that noise, but the attenuation caused by the low impedance of the EMC filter as seen from the site of the transmitting equipment.

MEASUREMENTS

A number of measurements have been conducted to examine how connected loads affect the communication and how the communication affects the loads. In many cases attenuation and not interfering signals, have been the reason for communication failures.

Attenuation measurements on site

In this section an example of a communication failure due to attenuation, at a school is further explained. The communication system uses frequencies ranging from 9 to 95 kHz [3], [4].

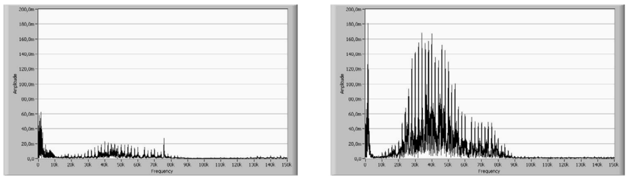

Figure 2, left, communication with the server connected, right, communication when the server was disconnected.

The investigation showed that a server used by the school caused severe attenuation to the communication signal as shown in Figure 2. When the server was disconnected, the received communication signal was substantially greater. In combination with high-frequency fluorescent lamps, that also caused slight attenuation, the communication failed. The lighting was turned off during the nights, but the server was normally connected at all times.
The server was moved to a different phase and this reduced the attenuation enough for the communication to be successful. It is not feasible in the long run to dedicate a phase to power line communication, since the power grid is designed for power delivery.

Attenuation measurements in the laboratory

The theory that the capacitor and the inductance of the cables caused resonance was tested in a lab. By varying the cable lengths, and thereby varying the inductance, the resonance frequency will change, [5].

Cable length (m)	Minimum |Z| (Ω)	Resonance Frequency (kHz)
0	0.30	78.6
1.8	0.35	73.4
3.6	0.44	68.0
7.2	0.58	61.4
25.8	0.90	45.8
45.8	1.27	38.0

Table 1, minimum impedance for the resonance frequency with different cable lengths.

Table 1 shows the measured impedance for a standard laser printer with varying lengths of cable. The presented data shows that the resonance frequency decreases with increasing cable length. They also show both the EMC filter and the cable length impact resonance frequency and minimum impedance. This also indicates that the same

equipment would give a different response when connected at different locations, i.e. with difference cable lengths to the location of the transmitter.
Measurements on other equipment with different cable lengths show different types of response. The total attenuation for the communication channel is a combination of the attenuation of the power grid and the attenuation caused by connected equipment shunting the signal.
Multimedia equipment, together with energy-saving equipment, will increase in numbers in our homes in the future. This may seriously obstruct the chance of successful communication.

Another important aspect concerns the impact of the communication signals on the equipment. The EMC filter involved in the resonance will be repeatedly exposed to high-frequency signals of rather high power. The filter is likely not designed for this and may be damaged. The damaged filter would in turn result in more high-frequency noise being generated by the end-user equipment.

A test setup was built in a laboratory to show how different loads affect power line communication. The source was a power line transceiver; a concentrator was used as receiver and the lamp was connected in a neighboring building. Figure 3 shows the current received by the concentrator to the left, the current absorbed by the load in the middle and the current emitted by the transceiver to the right. The loads are two identical 4W energy-saving lamps, with the only difference being the manufacturing dates.

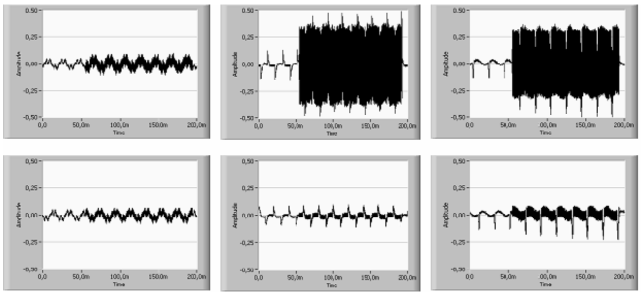

Figure 3, Currents during power line communication. Upper row of figures is the lamp with an earlier manufacturing date. From left to right, Concentrator, 4W energy saving lamp and Power Meter Transceiver.

In the upper case, the lamp forms a low-impedance path. The transceiver aims at maintaining the voltage amplitude at the communication frequency by injecting more current. The lamp absorbs the major part of this current and only a small part reaches the receiver.
It is unknown whether or not the load will survive regular exposure to currents of such magnitudes in this frequency range. Since only the manufacturing date differs between the lamps, it is hard to explain the results, but there has to be a difference in the construction. Because of this, judging which equipment is hindering the communication is complicated.
This kind of lamp is recommended as energy-saving equipment, and therefore is assumed to exist in large volumes. Note that the switching frequency of the lamp, which normally would be seen as an interfering signal, can be neglected in comparison to the current it absorbs from the communication. The current through the energy-saving lamp is approximately $600mA_{pp}$. Five or ten identical lamps connected close to the receiver/transmitter, can easily absorbs all the communication current.

COMMUNICATION AS AN INTERFERING SIGNAL

For some equipment the communication itself can be experienced as an interfering signal. There have been cases when power line communication has been a contributing factor of light flicker [6], as well as clocks running too fast. At one measurement site, halogen lights were supplied through a light dimmer. Measurements showed that light flicker occurred when the dimmer missed a half-cycle, and thus a voltage drop over the lamp occurred. The produced light flicker was intense and had a stroboscope-like characteristic. However, the measure voltage fluctuations (“voltage flicker”) were far below the limit of what is seen as unacceptable in the flicker standard [7] [8] (Pst=1). The communication signal produced a precipitous edge, which led to an oscillation that was moving along the voltage waveform. This oscillation, when reaching the zero-crossing, disturbed the light dimmer thus causing the light flicker to occur.

If the communication channel faces attenuation and the solution is an increasing amount of repeaters, the level of current at the communication frequencies increases. The signal strength is however restricted and cannot exceed 134 dBμV [9]. This corresponds to a voltage limit of $7V_p$, there are however no limits to the current level. When the impedance level is lowered by a connected load the emitted current will increase, as discussed earlier. Home care medical equipment and multimedia are examples of sensitive equipment that may be adversely affected by these types of current.

CONCLUSION

Three types of interference between end-user equipment and power-line communication have been identified. The emission by end-user equipment may directly interfere with the communication signal. This has traditionally been viewed as the main potential problem. However, the experience from measurements is that this is in practice rarely a concern. The attention paid to this problem by manufacturers of communication equipment may have prevented this problem from occurring at a wide scale. The future growth of the amount of emission and changes in the character of emission may cause problems in the future with equipment installed today and designed for today's emission.

The second type of interference occurs due to low impedance of an end-user device as seen from the transmitter. As a consequence of this low impedance the major part of the current signal generated by the transmitter passes through the end-user device whereas only a small part reaches the receiver. The transmitter will compensate for this by injecting more current, but current limits or voltage limits may be reached preventing successful communication. The experience from a significant number of measurements is that this attenuation is the major concern for the success of power-line communication. Severe attenuation has also been reproduced in a laboratory environment where it was shown that seemingly identical equipment could impact communication in a completely different way. This makes it very difficult to predict the performance of the power-line communication even for an existing situation. It is likely that the amount of electronic equipment will further increase in future, so that also this type of interference is likely to increase.

The third type of interference occurs when the communication signal adversely impacts the performance of end-user equipment. A case is explained in the paper in which a communication signal leads to light flicker without the voltage fluctuations exceeding any limit. A potential problem associated with the before-mentioned second type of interference is the thermal overloading of EMC filters due to communication signals. The transmitter will compensate for the attenuation by increasing the amount of current injected into the system. The majority of this current will however be absorbed by the EMC filter. The repeated exposure of the filter to high-frequency currents of high amplitude may significantly reduce its lifetime. This problem has not been observed yet, but it should be noted that premature failure of equipment is often difficult to link to a specific cause. The high-amplitude high-frequency currents may also, through inductive coupling, cause interference signals in the electronic circuits resulting in equipment mal-operation. With increasing numbers of sensitive devices the risk of such type of interference will only increase.

It is clear from the study presented in this paper that a number of interference problems already are apparent and that more potential problems have been identified. It is very important that these potential problems are addressed at an early stage and certainly before the widespread implementation of power-line communication for remote-meter reading. One way of addressing this problem is by an open exchange of information between the different stakeholders, including distribution operators, manufacturers of end-user equipment and manufacturers of telecommunication equipment.

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