INTERFERING SIGNALS AND ATTENUATION – POTENTIAL PROBLEMS WITH COMMUNICATION VIA THE POWER GRID

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A fast shift is taking place in Sweden and in other countries from manual meter reading at irregular intervals, to automatic remote meter reading at pre-defined instants. Remote meter reading is an essential part of a well-functioning electricity market, but the transmission of large numbers of readings (millions for some network operators) poses serious technical challenges. Different communication channels have been tried, but the power grid is the one that is in any case always available at places where electricity has to be metered.

The power grid is however not designed as a communication channel; high disturbance levels and attenuation may occur. The main concern is the as yet unpredictable character of both disturbance and attenuation. The widespread use of the power grid as a communication channel (as will likely be the case with remote meter reading) may also lead to interference with other equipment.

This paper will give a general overview of the potential problems associated with remote-meter reading via the power grid and describe some of the technologies available. A comparison will be made between the power grid as a communication channel and other, dedicated and shared, channels. 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. Although cases with high noise level have been identified, no problems have been reported. The communication protocols used appear to be sufficiently resilient against existing noise levels
- 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

1 THE POWER GRID AS A COMMUNICATION CHANNEL

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. In December 2005 approximately 670,000, 13 percent, of the 5,200,000 systems had been changed [1]. In the beginning of 2006 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

1.1 Shared vs. dedicated communication channel

The power grid is one of the most electronically contaminated environments. The frequency range dedicated for automated meter reading is 9 to 95 kHz, the range often used by switch mode power supplies. The power grid is a shared communication channel, and there are almost no restrictions to what kind of signals are allowed from connected equipment. To limit the conducted emission above 150 kHz and according to product standards, equipment includes an EMC filter constructed without any consideration to the shared communication channel. Sometimes the EMC filter in combination with the power grid causes resonance, and together they act like a notch filter to the communication channel (further discussed in section 2.2). Signals coinciding with the resonance frequencies are attenuated, thus communication at these frequencies is impaired.

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 without impedance adaptation. These mismatches are very common in the power grid and produces signal reflections that can lead to signal cancellation. 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 time [2] [3].

A traditional computer network illustrates a dedicated channel, no other types of equipment than the expected one is allowed. There is only one transmitter and one receiver, a split is made using hubs, switches or routers. All cables and connected equipment have regulated characteristic impedance, and there are restrictions to cable lengths, attenuation etc.

1.2 Communication interference

Interference when the power grid is used as a communication channel could be divided into two parts:

- Interfering signals (noise)
- Attenuation

Distinguishing between these two types of communication failures is important, mainly because they must be treated differently. While interfering signals could be solved using software (frequency changes and retransmissions or adjustments in the communication protocols), the attenuation is more complex [4] [5]. In a worst-case scenario the problem has to be solved by replacing the communication hardware (repeaters, boosters) or even loads connected to the power grid. Finding a solution without really knowing what was wrong is no problem in the beginning, in test installations, but this “trial and error” is not economical in the long run.

In a shared communication channel normally the communication user does not have control over the channel. This makes it even more important to distinguish between interfering signals and attenuation. Unfortunately, it seems that the knowledge about the communication interference by attenuation is fairly unknown nowadays.

1.3 Equivalent circuit for the power line

It is possible to represent the power line as a distributed RLC network [3] as shown in Figure 5:

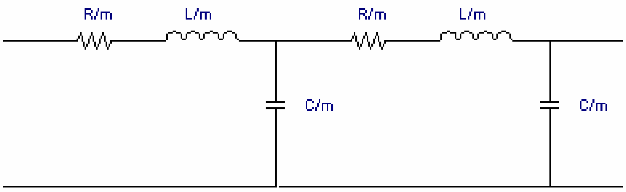

Figure 1, The power line as a distributed RLC network

The distributed impedance has a characteristic value:

$$Z_C = \sqrt{\frac{L}{C}} \qquad (1)$$

Calculations on different types of wires show characteristic impedance varying from 20 Ω to 100 Ω, depending on the physical dimensions of the wire. The impedance of the power grid, including wires, distribution transformer and the connected loads is lower. Measurements on power system impedance made by Malack et Al. [6] and Tanaka [7] shows values from 2 Ω to 30 Ω, for frequencies below 1 MHz, which is lower than the characteristic impedance of the wires.

At power system frequencies up to tens of kilohertz the power line source impedance is low and increases with the frequency. The source impedance is primarily related to the ability to deliver high current and a minimum voltage distortion. At frequencies higher than 1 kHz, the connected equipment, and especially equipment including an EMC-filter will often decrease the impedance.

1.4 Communication channel model

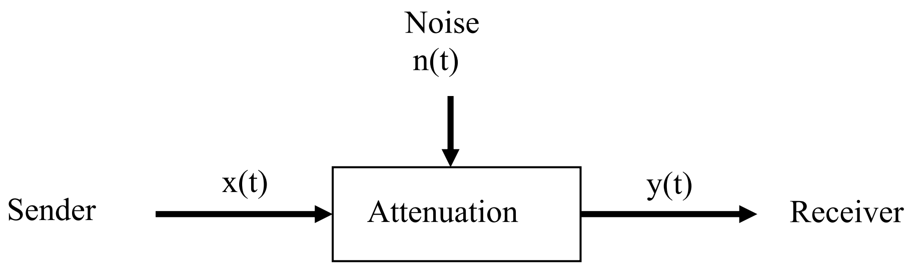

Figure 2, Communication model

Fig. 2 shows a schematic model of a typical communication channel. The model applies to all communication media, including twisted-pair copper wires and power line communication. An input signal $x(t)$ into the channel will experience attenuation and noise (or interfering signals). The signal will be attenuated by a factor k, and exposed to noise, resulting in an output signal $y(t)$. This can be expressed in eq. 2:

$$y(t) = k \cdot x(t) + n(t) \qquad (2)$$

2 POTENTIAL PROBLEMS

2.1 Interfering signals

There exists a multitude of signals on the power line network, power electronics and other loads generate some of them, and others are generated for e.g. communication. For the communication, all other signals but the expected ones are considered as interfering signals or noise. Noise-generating loads connected to the power grid vary with time, making prediction of the amount of noise virtually impossible.

If the information never reaches the receiver, the noise level may be too high. To correctly interpret the information, it is important that the communication protocols are sufficiently resilient to noise. This can be done in many different ways in software, i.e. alternate communication frequencies, frequency hopping or redundant information.

Power electronics meet the product standards requirements according to conductive emission by EMC filter, limiting the emission levels above 150 kHz. Below 150 kHz, normally there is no emission attenuation. It is possible to change the product standards requirements to also include frequencies below 150 kHz. Besides the increasing cost to the products and the delay until the new standard has full impact, the used filter also has to leave the impedance level in the communication channel high. This requirement should be fulfilled independent of the number of devices using EMC filters.

If a signal, e.g. from switch mode power supply like in fig. 3, coincides with a communication signal, deciphering such a mixed signal would be difficult. The measurement is done using a HP filter.

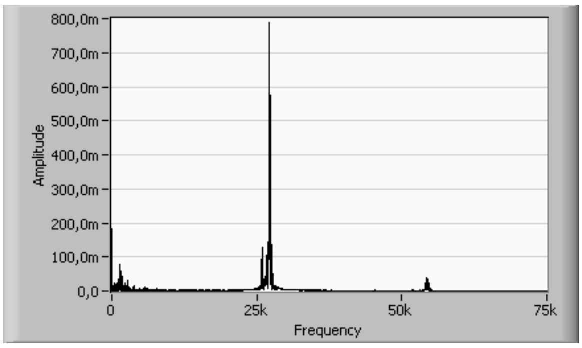

Figure 3, A possible interfering signal originating from an UPS, amplitude in volts

2.2 Attenuation

Attenuation will probably be the most serious challenge to signaling on the power grid in the future. It 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:

$$\text{Attenuation (dB)} = 20 \cdot \log \frac{V_{output}}{V_{input}} \qquad (3)$$

The attenuation of the communication channel depends mainly on the impedance level. The impedance level could be divided in three parts:

- Feeding transformer
- Impedance of the power grid, including all cable splits
- The loads connected to the power grid, and mainly their EMC filters

The feeding transformer and the power grid have steady state behavior, while the loads connected to the power grid change all the time. The number of power electronic loads increases fast, accelerated by the fast changes in multimedia and the interest of energy-saving. An EMC filter makes no distinction between interfering signals and communication signals. The increasing number of EMC filter is therefore, by itself, a threat to the communication in the power grid, mainly by lowering the impedance level in the communication channel ranging from 9 to 95 kHz.

In the case of interfering signals, the problem can sometimes be solved using software, but solving attenuation in this way is virtually impossible.

2.3 Communication as an interfering signal

For other equipment the communication itself can sometimes be experienced as an interfering signal. There have been cases when power line communication has been a contributing factor of light flicker [8], as well as clocks running too fast. If the communication channel faces attenuation and the solution is an increasing amount of repeaters and boosters, the level of current at the communication frequencies increase. The voltage is however limited to 7 V_{pp}. Home care medical equipment and multimedia are examples of sensitive equipment that can be exposed to these types of signals. No reports of this have yet been reported, but a possible conflict of interest rises between an interference-free environment and power line communication.

3 MEASUREMENTS

Measurements have been conducted to examine how connected loads affect the communication. In many cases attenuation and not interfering signals, have been the reason for communication failures, perhaps depending on the use of good communication protocols. In fact, very few cases are known where interfering signals alone have been the cause of the communication failure.

3.1 Attenuation measurements on site

In this section an example of a communication failure, due to attenuation, at a school is explained further. The communication used was Enermet's wideband communication system, PLT-30 [9], [10]. This system uses frequencies ranging from 9 to 95 kHz. The communication was coupled to phase A.

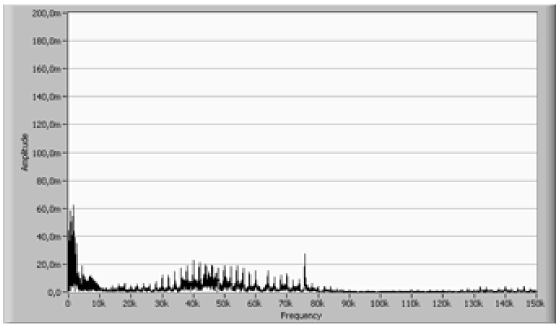

Figure 4, Enermet's wideband communication system, PLT-30, with server connected

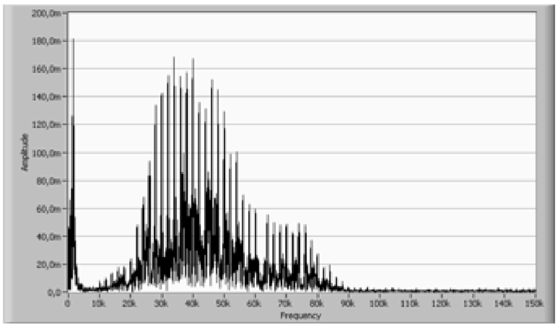

Figure 5, The non-attenuated signal from Enermet's wideband communication system, PLT-30

Investigation showed that a server used by the school, when connected, caused severe attenuation to the communication signal as shown in fig. 4. When disconnected, the communication signal was substantially greater (fig. 5). 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 expected to run at all times.
Measurements show that crosstalk of the communication signal is present on all three phases, but is seen the least on phase C. Because of this the server was connected to phase C instead of the original phase B. 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.

3.2 Attenuation measurements in lab

Some loads, such as PCs, utilize EMC filters to fulfill the requirements set by EMC standards. These EMC filters, when connected, causes resonance due to the properties of the power line and other appliances. If resonance occurs the filter will become a notch filter and basically block any attempt of signaling using the resonance frequency.

The attenuation increases with the frequency, reaching fairly high levels at the frequencies of interest. Another contributing factor is impedance mismatches as discussed earlier. A simple communication circuit is shown in fig. 6. Z_S is the source impedance; Z_R is the receiving impedance, and the impedance Z represents the equipment connected to the power grid, working like a shunt on the communication signals. By varying the frequency of the source, the attenuation as a function of frequency is produced.

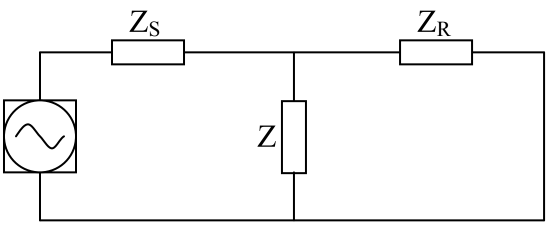

Figure 6, The characteristic impedance of any signaling circuit

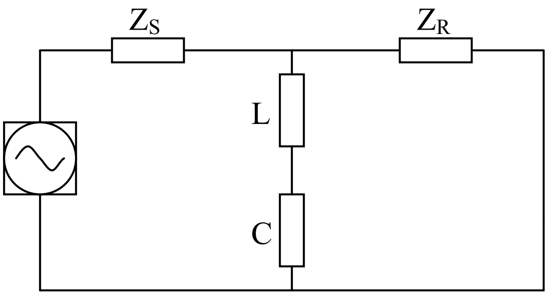

Figure 7, Measuring the filter effect of equipment

Equipment including an EMC filter often has a capacitor, C in fig. 7, connected between phase and neutral. The power cord and other cables in the power grid, adds inductance, L, to the circuit. These two are assumed to create a resonance frequency that sometimes coincides with the frequency range of the communication channel. By varying the cable lengths, the resonance frequency will change.

A measurement of a printer manufactured in the 90’s is shown in fig. 8. The presented measurement show that the resonance frequency decreases with increasing cable length. They also show that the assumption of a resonance circuit with EMC filters and cable lengths is reasonable. The impedance at the resonance frequency can be read from table 1. For cable lengths less than 30 meters the minimum impedance is below 1 Ω, which is most likely close the output impedance of a PLC transmitter. PLA-21 power line amplifier [11] used in “high attenuation power circuits” has maximum output impedance of 0.5 Ω and than guaranteed delivering $2A_{pp}$. In this case, a significant part of the signal would travel through the single EMC filter, and there could be lots of EMC filters in a power grid.

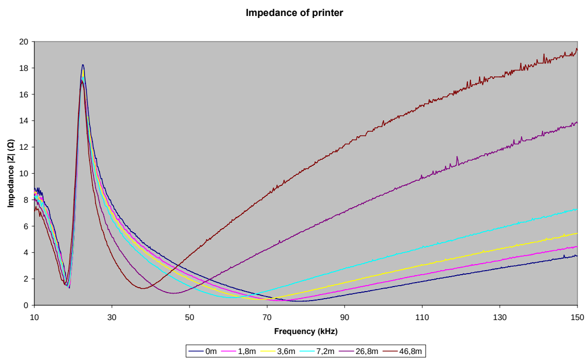

Figure 8, Shunt impedance of the printer with different cable lengths

Cable length (m)	Minimum |Z| (Ω)	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 higher resonance frequency with different cable lengths in printer

Similar measurements were made on a computer bought in 2006, fig. 9, showing the same type of resonance but in different frequencies. Measurements on other equipment with different cable lengths show different types of response. In this way notch filters are created when equipment is connected at different places in the power grid. The total attenuation for the communication channel is then a combination of the properties of the power grid and the connected equipment. Figure 9 shows a computer and fig. 10 shows the computer from fig. 9 together in parallel with the printer from fig. 8.

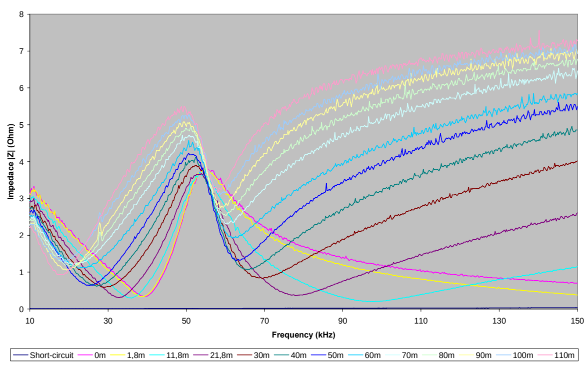

Figure 9, Shunt impedance of the computer with different cable lengths

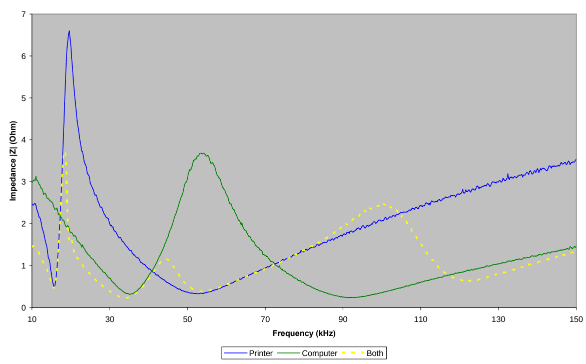

Figure 10, Shunt impedance of printer, computer connected simultaneously

The dotted line from fig. 10 shows the total shunt impedance, with both computer and printer connected, under 3 Ω almost throughout the frequency range of the communication channel. It stands to reason that multimedia equipment, together with energy-saving equipment, will increase in numbers in our homes in the future. This can seriously obstruct any chance of successful communication.

Another important aspect is that of the EMC filter specification, if they are adapted for such repeated currents, at high frequencies, such as 75 kHz. This could result in broken filters, which in turn results in the emission of even more noise.

3.3 Communication measurements on PLT-30

A test setup using the same principles as in fig. 6 was done in a laboratory to show how different loads affect the power line communication. The source was replaced by a power line transceiver, a concentrator was used as receiver and the lamp in the middle as the Z from fig. 6. Figure 11 shows the currents of the concentrator to the left, the load in the middle and the power meter to the right. The loads are two identical 4W energy-saving lamps, with the only difference being the manufacturing dates.

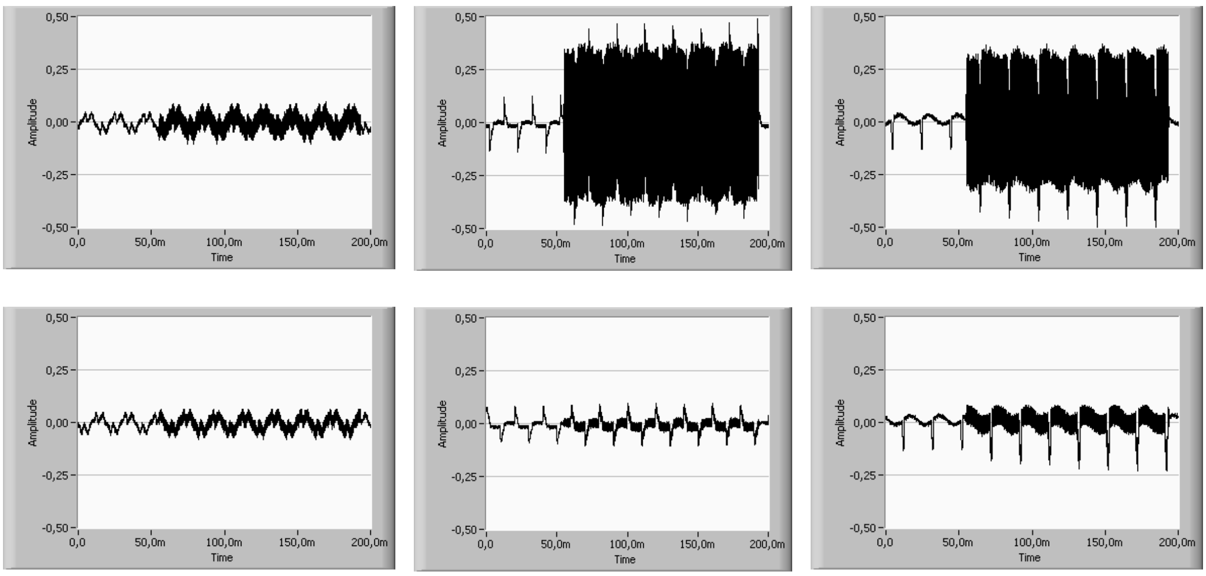

Figure 11, Currents during power line communication using PLT-30. Upper row of figures is the lamp with an earlier manufacturing date. From left to right, Concentrator, 4W energy saving lamp and Power Meter Transceiver.

The measurement shows that a load can absorb a part of the communication signal and the result is a current much higher than the one needed for regular operation. It is unknown whether or not the load is dimensioned for 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 what 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 switch 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 $600mA_{pp}$, which corresponds to about 1/3rd of the maximum peak-to-peak current for a PLA-21 power line amplifier ($2A_{pp}$) [11]. What a PLT-30 system delivers is unknown. Five or ten identical lamps connected close to the receiver/transmitter, probably absorbs all the communication current.

3.4 Communication as an interfering signal

In some cases, the combination of slow power line communication and a light dimmer has produced light flicker. Only a few cases of light flicker have been reported so far, implicating that a third contributing factor appears to be needed for the phenomenon to occur.

Measurements in the field

At one site of measurement, halogen lights were operating directly on 230V 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 flicker was intense and had a stroboscope-like characteristic. However, this type of flicker, when measured, is far below the limit of what is accepted in the flicker standard [12] [13]. Connecting a 5µF capacitor between the phase and neutral solved the problem in some, but not all cases.

Reproducing the flicker

Using the Pehr Högström Laboratory, located at EMC on SITE in Skellefteå, the light flicker was successfully reproduced using slow power line communication, a light dimmer and a variable inductance to simulate the third, unknown factor. Measurements in the laboratory produce the same kind of light flicker as seen in measurements done in the field. Disconnecting the PLC unit caused the flicker to cease, as well as connecting the capacitor.

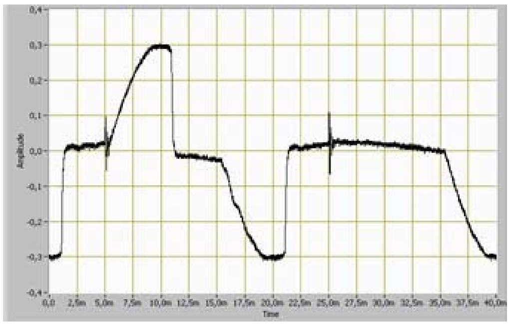

Figure 12, High frequency, high amplitude oscillation causing the missing half-cycle

As can be seen from fig. 12, an apparent oscillation exists around the zero crossing. The oscillation was moving along the waveform, and resulted in a missing half-cycle when striking the zero crossing [8].

4 CONCLUSION

The way the problems with interfering signals are treated today, meaning that the focus has shifted from interfering signals to attenuation. The awareness of this is limited, because it is hard to distinguish between the two. The attenuation is a bigger problem than first expected in the area of power line communication, which seems to be unclear. Attenuation is the kind of disturbance to a signal that can not be forbidden. Measurements show that single appliances can cause an attenuation too great for communication signals to be interpreted correctly.

The fast changes in multimedia and the interest of saving energy increases the number of power electronic loads using switched power electronics. According to product standards the equipment includes an EMC filter reducing conducted emission above 150 kHz. The communication channel in the power grid is below 150 kHz, 9-95 kHz for automated meter reading. This EMC filter makes no distinction between interfering signals and communication signals, and resonance phenomena occur between the EMC filter and the power grid. The increasing number of EMC filters is therefore, by itself, a threat to the communication in the power grid, mainly by lowering the impedance level, causing attenuation, in the communication channel ranging from 9 to 95 kHz.

Measurements have shown how the EMC filter in the power inlet to a printer and a computer together with the power cord, caused attenuation to the power grid communication channel. The attenuation is affected by the length of the power cord and this attenuation on the communication channel increases as the amount of connected equipment with EMC filters increases.

A distinction between communication failures caused by interfering signals or attenuation is important, mainly because they have to be treated differently. While interfering signals could be solved using software, the attenuation however is more complicated. In a worst-case scenario the problem has to be solved by replacing the communication hardware or loads connected to the power grid. Finding a solution without really knowing what was wrong is no problem in the beginning, but this “trial and error” is not economical in the long run.

How the communication signal can act as an interfering signal to other equipment has been shown in this paper. Power line communication below 9 kHz and a light dimmer has produced light flicker. Only a few cases of light flicker have been reported so far, implicating that a third contributing factor appears to be needed for the phenomenon to occur. The flicker produced has a different type of characteristic than the flicker defined in the standard.

5 DISCUSSION

The example of light flicker caused by power line communication in combination with light dimmers shows the problem of having up-to-date standards when new technologies are introduced. It also shows the complex combination of, separately functioning, new technologies, which does not work as intended when connected to the power grid.

It is unknown whether or not power line communication will work in the future. To date it is known how well the communication works, how much work is needed for troubleshooting and the number of meters unreachable.

New technologies like multimedia, medical equipment and energy-saving equipment with a potential problem of interfering and being interfered will increase in our homes. This new equipment is sensitive, and thus requiring a noiseless environment. At the same time, we want to use the power line as a communication channel, and consequently adding noise to the power line, which seems like an impossible equation.

Increasing the EMC filters bandwidth down to 9 kHz is a way to decrease the interfering signals, but they still cause attenuation in the communication channel, unless making a special design of the EMC filters. This design is complicated when the communication channel is a shared channel. A filter has to be constructed to a specified impedance level and on the power grid the impedance level is changing, mostly depending on the loads.

Independently of how the problems of interfering signals and attenuation are solved, they have to be solved now, or the consequences will be great. The longer the wait, the more other solutions than power line communication has to be considered.

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