Some consequences for the power grid of high densities of electronic equipment

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Abstract

During the last few years, the amount of electronic equipment has increased rapidly in our homes and at our work. The availability of cheap electronic equipment has enabled a chance in our lifestyle. Today the technology has made it possible to watch movies with surround music, play computer games, home care technology etc. and we tend to spend more and more time using electronic equipment. Whereas this has overall resulted in an increase in energy consumption the same technology also enables more energy-efficient equipment.

Almost all electronic equipment is connected to the electric mains (either continuously or during charging) via regulated power supplies. The continuous development in power electronic and in digital electronics has resulted in reduced weight, energy loss, size and price for these power supplies. Especially so-called switch mode power supplies (SMPS) are becoming more popular because of these benefits. However they generate harmonics and high-frequency disturbances, which can create electromagnetic compatibility (EMC) problems for the power grid as well as for neighboring equipment.

This paper will highlight some problems that can arise when many different power supplies are densely connected to the electric mains. Measurements have been made on sites were numerous electronic devices are connected. The results of these measurements are presented and some of the consequences are discussed.

The result shows that a high density of regulated power supplies might lead to a high level of neutral current which can lead to overloaded wires, with fire as a result as well as increased levels of magnetic fields. The high-frequency components can further lead to damage or mal-function of other equipment.

Keywords: Electromagnetic compatibility, power quality, harmonics, switch-mode power supplies.

Introduction

All around the world there are a continuous development of electronic equipment. It is among others our desire for new and better products that drives the development. One can also see how new equipment changes our lifestyle. Today we tend to spend more and more time using electronic equipment at our homes and at our works. A private home, 30 years ago, typically held a TV, radio and a stereo. Today the same home contains much more electronic equipment such as computers, DVD-players, surround equipment etc. For example, our wish to be able to watch our favourite movie with surrounding sound at our homes is today a reality. The trend to surround us with more electronic equipment brings a variety of different equipment connected to the power grid with a non-negligible impact on the grid and indirectly on our own life. Some examples of such impact will be given in this paper, concentrating on the non-sinusoidal character of the current taken by electronic equipment.

Electronic Equipment and Waveform Distortion

Electronic equipment is often served by a regulated power supply. The aim of these power supplies is to deliver the right voltage and current level to the equipment. The development of regulated power supplies has moved from the use of 50/60Hz transformers to the use of high frequency transformers. The transformers used in the past were mostly linear load for which the current was nearly sinusoidal. The modern power supplies often use techniques were the current drawn by the power supply is not sinusoidal. The benefit of electronic power supplies are the reduce of weight, energy loss, size and cost but the drawback is the waveform distortion.

Figure 1 shows examples of the current drawn by some common devices with regulated power supplies. Since the current is distorted and not sinusoidal the waveform contains other frequencies besides the fundamental frequency at 50 or 60 Hz. There are two reasons for obtaining information on these frequency components: the frequency spectrum is used to quantify the severity of the waveform distortion and the propagation of the distortion through the grid can be studied and understood much more easier when the frequency components are known. With the help of a discrete Fourier transform (DFT) a digital (discrete) measured time signal be analysed to obtain this frequency spectrum. The harmonics are defined as signal components at multiples of the fundamental frequency. For a fundamental frequency at 50Hz the 2nd harmonic is at 100Hz, the 3rd harmonic at 150Hz, and so on. Electronic power supplies usually generates only harmonic components (i.e. at multiple integers of the fundamental frequency) but there are other loads that can create subharmonics (at frequencies below the fundamental frequency) and interharmonics (in between the harmonics). An example of a frequency spectrum will be shown below.

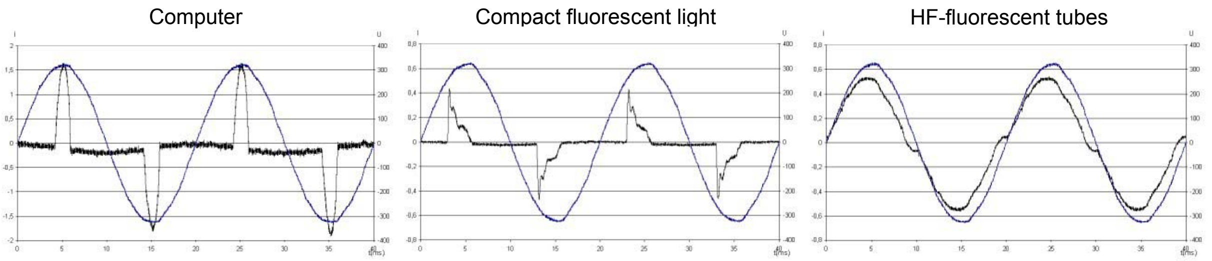

Figure 1 shows a few different electronic loads.

A SMPS often rectifies the main current and then uses a fast switching transistor to cut up the dc current to ac current at high frequency, typical about 20 to 100kHz. The current from the SMPS to the grid contains in that case a switching frequency at e.g. 20kHz and at its multiple integers (40 kHz, 60 kHz, etc). Most existing SMPS does not produce significant amounts of these "high-frequency harmonics", but there is a trend towards more use of equipment that produces these. Some of the consequences of this will be discussed in the next section.

Conducted and radiated emissions generated from electronic equipment have been known for a long time and regulations are in place to limit electromagnetic interference (EMI). Both the low frequency harmonics and the high frequency harmonics are regulated by standards. According to the EMC-directive equipment has to comply with the standards before it can be put into the European market. Regulated power supplies have to comply with IEC 61000-3-2, which limits the low frequency harmonics (i.e. up to about 2 kHz). The distortion per device is limited in this way, but with an increasing number of devices, the total distortion still increases. Also are there seldom any limits for frequency components between 2 kHz and 150kHz.

Consequences of Harmonic Distortion

The non-sinusoidal wave shape of the current has a number of serious consequences for the performance of the power system and directly or indirectly for the customer. Here we will give an incomplete list of the most important consequences. For a complete list, the reader is referred to the literature on this subject (e.g. Arrillaga and Whatson, 2003).

- A sinusoidal current makes the most efficient use of the transport capacity of the power grid. For the same amount of transported energy, a non-sinusoidal current requires more transport capacity than a sinusoidal current. The result is that the power system becomes more expensive which indirectly results in a higher electricity price.
- Non-sinusoidal currents lead to non-sinusoidal voltages. Certain types of end-user equipment, especially electrical motors, will no longer function correctly or even be damaged when the voltage waveform deviates too much from its sinusoidal shape. As this would not be acceptable, electricity companies have to invest in equipment to reduce the distortion of the voltage waveform. This in turns leads to a further increase in the electricity price.
- The harmonic distortion taken by small (single-phase) electronic equipment causes a large so-called zero-sequence current in the neutral conductor. This has resulted in dangerous overheating situations in the past, but the problem is currently well understood by most power engineers. However it again leads to higher costs for the power supply system.
- Non-sinusoidal currents lead to additional losses in the network. They are thus responsible for an increase in total energy consumption. Measurements have shown that the non-sinusoidal character of the current taken by a television leads to additional losses in the system equal to 1.5 to 2% of its total energy consumption (Lundquist, 2001). The percentage loss increases with increasing amount of distorting equipment.
- An indirect effect of the presence of this zero-sequence current is an increase in the level of low-frequency magnetic fields in domestic and office environments if the system is designed with a common neutral and protective earth wire.
- Higher frequency components in the current and in the voltage lead to a deterioration of the performance of electronic equipment, to audible noise with telecommunication and audio equipment; and to accelerated ageing of, for example, fluorescent lamps. Especially the before-mentioned frequency components associated with the switching frequency are a concern here.
- An indirect consequence of the negative impact of these high-frequency harmonics is that it can place a barrier to the introduction of certain types of equipment e.g. medical, safety and communication equipments. If we realize that two important sources of high-frequency harmonics are energy-saving lamps and renewable-energy generators, this has even environmental consequences.

Neutral currents

The power grid was once designed for linear loads. The three-phase system had the advantages of the availability of two voltage levels and that the current would sum up at the neutral point so the neutral-current never could be higher than the highest phase-current. If the phase currents had the same amplitude and a 120 degree phase shift it resulted in zero neutral current and therefore it was possible to build a three-phase system, with three wires, that could transport the same amount of power as three separate one-phase systems with 6 wires. But if the load currents are the same as the computer current in figure 1 there will be no longer a cancellation of the currents at the neutral point as shown in figure 2.

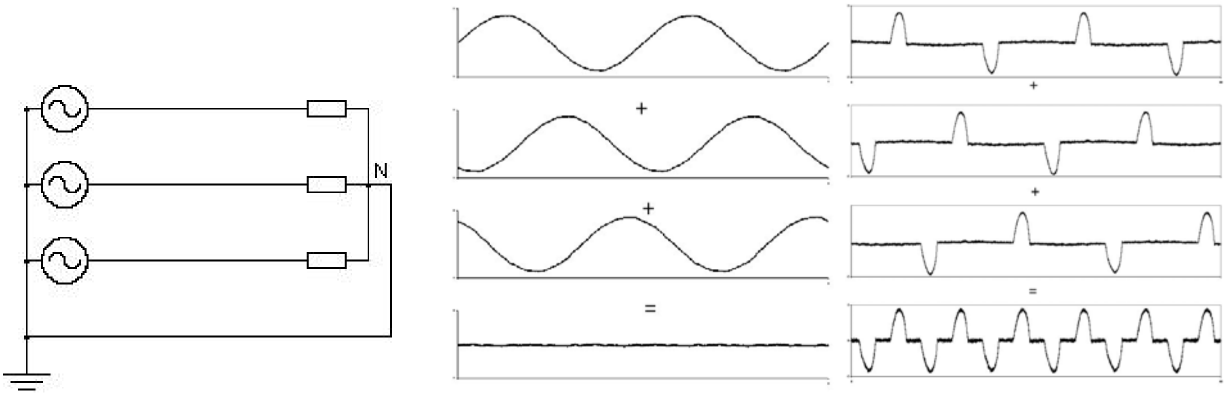

Figure 2 The current summation in the neutral point (left) for linear load (center) and non-linear load (right).

Non-linear loads will cause neutral-currents that can be much higher than the phase-currents. In terms of harmonic components the explanation that the harmonics with odd multiples of three, i.e. 3rd, 9th, 15th and so on, have the same phase angle in the three phases so that these currents will add in the neutral point.

Measurement at a Lan-Party

A measurement was made at a “Lan-Party” were about 140 young people had gathered to play computer games together. The participators brought their own computers and monitors and they hooked their computers to a local area network. The measurements were made at the point of common coupling and figure 3 shows how the current varied during the weekend. The neutral-current was about 1.7 times higher than the average phase current but due to that the load wasn’t symmetrical in all three phases, which resulted in a small amount of fundamental current in the neutral wire.

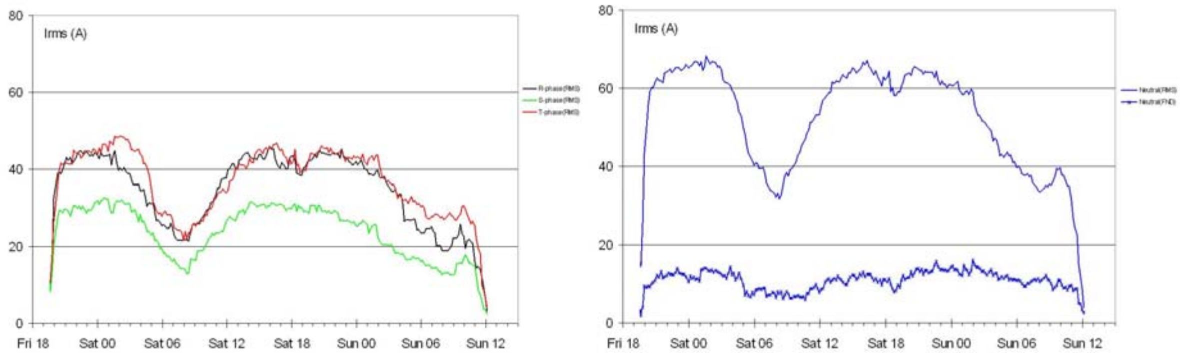

Figure 3 Variation of the phase-current (left) and neutral-current (right) during the weekend. The left-hand figure shows the rms current in the three phase conductors. The right-hand figure shows the rms value (top curve) and the fundamental value (bottom curve) of the neutral current.

Figure 4 shows the measured phase and neutral current and their harmonic spectra. The time-window is about 20 ms. Note that the neutral-current has 3 cycles during 20 ms, which shows that the current contains mainly a 150 kHz component, which also follows from the harmonic analyses.

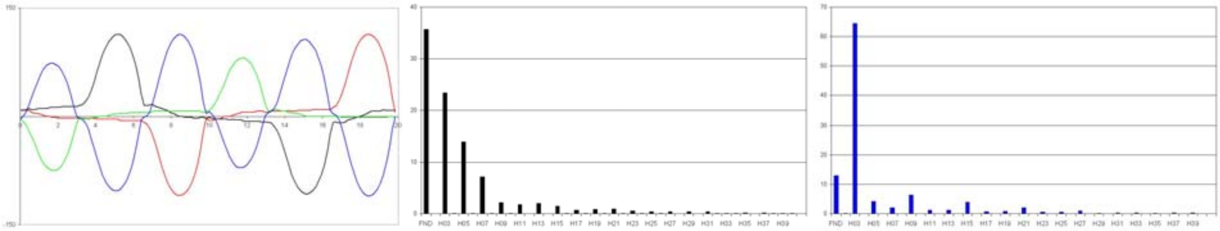

Figure 4 shows the measured currents and phase A harmonics and neutral harmonics.

The “Lan-party” is a very computer dense example but compared with a school, office or even an apartment building it is not that extreme. Computers need to comply with the standard IEC 61000-3-2 and according to this standard is e.g. the third harmonic limited to 3.4mA/W or a maximum of 2.3A. During the lanparty was the total maximal 3-phase power about 21kW and according to the standard can then the third harmonic current be up to 71.4A in the neutral wire for this type of load. The maximal measured third harmonic current, shown in figure 4 was about 66A, which is slightly under the limit given by the standard. This shows that the contributions from individual devices will simply add. A doubling of the amount of power consumed by electronic equipment will thus lead to about a doubling of the harmonic distortion.

Conclusion

We tend to use more and more electronics equipments today and in our desire to reduce the energy consumption we are developing more energy efficient power supplies but as shown has this technique a drawback in drawing non-sinusoidal currents which will affect the power system that was not design fore that type of load. Measurements at a Lan-party show some of the effects of a high concentration of computers on the low voltage system. Depending on how the low voltage system is designed and the density of electronic equipment the result can be high levels of magnetic fields and/or overloaded cables with fire as a consequence. Further can the HF-signals generated by the electronic power supplies cause problems to e.g. home care technology, communication and safety systems.

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