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Power quality issues in the electric power system of the future

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ABSTRACT

With the advent of new electricity production modes, power electronics, LED lamps and underground cables, new types of disturbances will appear, including an increase in distortion between 2 kHz and 150 kHz that is referred to as 'supraharmonics.' A shift of resonances to lower frequencies may partly compensate for the increased emissions at higher frequencies, but the transfer of disturbances will become less predictable. Equipment immunity also is likely to become less predictable.

1. Changes in society and in the grid

The electric power system (the "grid") is exposed to similar types of changes as the rest of society. For a development in society to impact the grid it has to have impact on electricity production, electricity consumption, or the grid itself. Some of the most important changes that have such an impact are:

- Changes in production
  - Change from large production units under control of a network operator to small units connected to the distribution network and/or to renewable sources whose availability and production is controlled by the weather.
- Changes in consumption
  - New types of consumption, with electric cars the example most often discussed in research and related forums. However the transition from gas heating to electric heating (most likely in the form of heat pumps) will be another such change that could have a huge impact on the grid.
  - New versions of existing consumption; many direct-driven electric motors are replaced by adjustable-speed drives where higher efficiency is the driving force. The replacement of incandescent lamps by compact fluorescent and LED lamps is another example.
  - Large numbers of small devices, where device chargers are the main part.
- Changes in the grid
  - The replacement of overhead lines by cables. At low and medium voltage levels, many countries have already close to 100% of the grid underground. Examples are Germany and The Netherlands, with 75% and 90% of medium-voltage networks underground, respectively. Other countries, like Sweden, are quickly undergrounding even their more remote rural networks. But even at a higher voltage level, including transmission, there is a clear trend towards more underground cables.
  - The number of HVDC links connecting to the transmission system is increasing, with some countries or areas having many such links within a relatively short distance. Other types of power electronics in the grid are also showing an increasing trend. For example, the Scandinavian grid is connected to the grid of continental Europe by 10 HVDC links.
  - Power line communication is being increasingly used to communicate with energy meters.
  - Finally, there is a whole spectrum of developments that go under the name "smart grids."

2. Power quality

Many of these changes have unintended consequences for the performance of equipment connected to the grid. The ultimate aim of the electric power system is to deliver energy to this equipment. Those unintended consequences therefore require serious attention. Those same changes could also have unintended consequences for the grid, including component overload, instability, and

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supply interruptions. The consequences for the grid will not be addressed in this article.

The study of the performance of equipment connected to the grid is part of the field of "power quality." The ultimate aim of all work within power quality is to ensure a low probability of interference between the grid and equipment connected to it ("ensure a high probability of electromagnetic compatibility," to use the terminology in the IEC standards on EMC). Unintended consequences for equipment connected to the grid translate into unintended changes in probability of interference. Such changes are due to:

- Changes in emission levels;
- Changes in immunity levels;
- Changes in transfer through the grid.

This article provides an overview of the unintended changes in emission, immunity, and transfer for four specific developments:

- Replacement of incandescent lamps by LED and compact fluorescent lamps; (This will be discussed in detail in Section 3.)
- The shift to renewable electricity production (Section 4);
- Increasing amount of equipment with an active power-electronic interface (Section 5);
- Replacement of overhead lines by cables (Section 6).

The overview will consider 11 different power-quality disturbances, as listed in Fig. 1. Most of the terms are standard power-quality terms. The term "supraharmonics" is new and refers to waveform distortion roughly in the frequency range 2 kHz to 150 kHz. Supraharmonics will be discussed in detail in Section 7.

3. New types of lighting

The replacement of incandescent lamps by compact fluorescent and LED lamps has accelerated significantly in many countries (Fig. 2) because of a number of political decisions followed by faster-than-expected technical developments.

3.1. Changes in emission

Many types of compact fluorescent and LED lamps show a highly distorted current. Concern has been expressed that the mass introduction of those lamps will result in large increases in voltage and current distortion. A number of studies have been carried out to investigate this concern (Blanco et al., 2013; Rönnberg et al., 2010, 2012), among others, with the main conclusion being that the increase is minor even in the worst case and in some cases the aggregation effects introduced by the lamps has led to a decrease in harmonic levels. After replacing 576 incandescent lamps with a combination of compact fluorescent and LED lamps in a hotel in Sweden, a slight increase could be observed for some individual harmonics in some phases while there was a decrease in other phases (Rönnberg et al., 2010). Similar observations were made when incandescent lamps were replaced at 12 semidetached houses (Rönnberg et al., 2012). The impact from other devices cannot be ignored and even though the lamps add harmonics, the effect will, due to aggregation, not result in an overall increase in harmonic magnitude for the installation.

An overview of both simulations and measurements is presented in (USAID, 2010) where it is concluded that the simulations generally predict a higher increase in distortion due to replacement of incandescent lamps by CFL than shown by measurements.

Measurements have, on the other hand, shown that most high-efficiency fluorescent lamps and many types of LED lamps are a source of supraharmonics (Blanco et al., 2013; Larsson et al., 2010; Martínez and Pavas, 2015). The measured magnitudes are in most cases low but this is a type of device, using a diversity of technologies, which will likely be connected in large numbers.

3.2. Changes in immunity

Compact fluorescent and LED lamps are less sensitive than incandescent lamps to steady-state overvoltages. The impact of other disturbances on life length of modern lamps is not very well studied. An additional temperature rise of components in lamps has been observed during high levels of supraharmonic voltage

	Emission	Immunity	Transfer
Voltage dips			
Voltage swells			
Harmonics			
Supraharmonics			
Interharmonics			
Slow voltage variations			
Fast voltage variations			
Voltage unbalance			
Transients			
Frequency variations			
DC components			

Fig. 1. Template for evaluation the impact of different changes on emission, immunity and transfer for 11 different types of voltage disturbances.