POWER QUALITY

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Preface

Electrical power is becoming one of the most dominant factors in our society. Power generation, transmission, distribution and usage are undergoing significant changes that will affect the electrical quality and performance needs of our 21st century industry. One major aspect of electrical power is its quality and stability – or so called Power Quality.

The view on Power Quality did change over the past few years. It seems that Power Quality is becoming a more important term in the academic world dealing with electrical power, and it is becoming more visible in all areas of commerce and industry, because of the ever increasing industry automation using sensitive electrical equipment on one hand and due to the dramatic change of our global electrical infrastructure on the other.

For the past century, grid stability was maintained with a limited amount of major generators that have a large amount of rotational inertia. And the rate of change of phase angle is slow. Unfortunately, this does not work anymore with renewable energy sources adding their share to the grid like wind turbines or PV modules. Although the basic idea to use renewable energies is great and will be our path into the next century, it comes with a curse for the power grid as power flow stability will suffer.

It is not only the source side that is about to change. We have also seen significant changes on the load side as well. Industry is using machines and electrical products such as AC drives or PLCs that are sensitive to the slightest change of power quality, and we at home use more and more electrical products with switching power supplies or starting to plug in our electric cars to charge batteries. In addition, many of us have begun installing our own distributed generation systems on our rooftops using the latest solar panels. So we did look for a way to address this severe impact on our distribution network. To match supply and demand, we are about to create a new, intelligent and self-healing electric power infrastructure. The Smart Grid. The basic idea is to maintain the necessary balance between generators and loads on a grid. In other words, to make sure we have a good grid balance at all times. But the key question that you should ask yourself is: Does it also improve Power Quality? Probably not!

Further on, the way how Power Quality is measured is going to be changed. Traditionally, each country had its own Power Quality standards and defined its own power quality instrument requirements. But more and more international harmonization efforts can be seen. Such as IEC 61000-4-30, which is an excellent standard that ensures that all compliant power quality instruments, regardless of manufacturer, will produce the same results when connected to the same signal. This helps reduce the cost and size of measurement instruments so that they can also be used in volume applications and even directly embedded into sensitive loads. But work still has to be done. We still use Power Quality standards that have been written decades ago and don't match today's technology any more, such as flicker standards that use parameters that have been defined by the behavior of 60-watt incandescent light bulbs, which are becoming extinct.

Almost all experts are in agreement - although we will see an improvement in metering and control of the power flow, Power Quality will suffer. This book will give an overview of how power quality might impact our lives today and tomorrow, introduce new ways to monitor power quality and inform us about interesting possibilities to mitigate power quality problems.

Regardless of any enhancements of the power grid, "Power Quality is just compatibility" like my good old friend and teacher Alex McEachern used to say.
Power Quality will always remain an economic compromise between supply and load. The power available on the grid must be sufficiently clean for the loads to operate correctly, and the loads must be sufficiently strong to tolerate normal disturbances on the grid.

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Part 1

Power Quality Today and Tomorrow

1

Consequences of Poor Power Quality – An Overview

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1. Introduction

Modern customers use large number of sensitive devices comprising of power electronics that are quite sensitive to power quality (PQ) disturbances in the supply network. From worldwide customer surveys, it is found that complaints on PQ related disturbances (for example: harmonics, voltage dips, flicker, etc.) are increasing every year. In Europe, the quality of electricity that is provided by a grid operator has to comply with reference parameters set in the European standard EN 50160 and other specific standards or the national grid codes. In contrast, it was observed that the customer's polluting loads often interact adversely with the network components and distort the network's voltage. When the supply voltage is distorted, the customer's device draws non-sinusoidal current from the network that might be different than the sinusoidal voltage condition. This can cause many technical problems (such as extra heating, misoperation, early aging of the devices etc.) to the customer's devices at his installation. The non-sinusoidal current also causes extra losses and other problems to various network components (as example: cables and transformers). Moreover, poor PQ often has large financial consequences to the affected customers (mainly to the industries with process plants). In extreme cases, poor PQ of the electric supply can cause financial losses to the network operators and the equipment manufacturers too. All these factors led to the discussion about the responsibility sharing of PQ problems in the network. In this chapter the impacts of poor PQ will be analyzed from the perspectives of the customers, the network operators and the equipment manufacturers.

2. PQ related complaints in different countries

Every year the network operators in different countries around the world receive many complaints about PQ problems from different groups of customers. A customer complains when the operation of devices at his installation is interrupted leading to techno-economic inconveniences. It is observed that almost 70% of the PQ disturbances are originated at the customer's premises while 30% are in the network side [Emanuel & McNeil, 1997]. The Electric Power Research Institute (EPRI) conducted a five year (1990-1995) monitoring program for distribution power quality (DPQ-I) among 24 utilities throughout the United States of America. Another program DPQ-II was conducted in 2001-2002. These study results [Melhorn et al., 2005], [McNulty et al., 2002] concluded that voltage sags (dips) and swells, transient over-voltages (due to capacitor switching), harmonics and grounding related problems are the most common PQ complaints among the American customer as presented in Fig. 1.

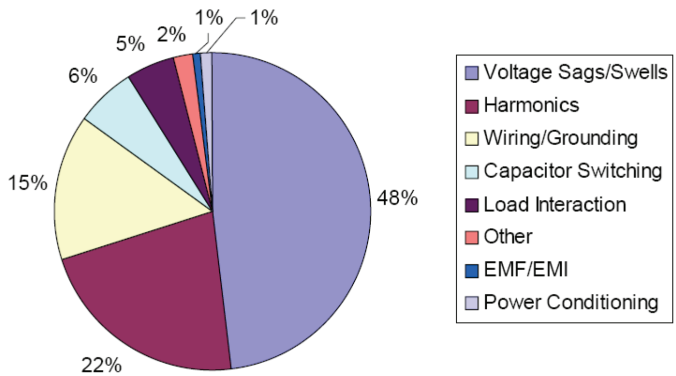

Fig. 1. PQ problems experienced by the American customers

In 2001, the European Copper Institute has done a PQ survey covering 1,400 sites in 8 countries of Europe. It is found that harmonic distortions, power supply reliability, voltage dips and electromagnetic compatibility are the most important issues for the countries of the European Union (EU) [Keulenaer, 2003]. Another PQ campaign was conducted by the Leonardo Power Quality Initiative (LPQI) among various customers in the EU-25 countries in 2004. It was concluded that on average the absolute share of impacts of power quality and reliability related problems are due to voltage dips (23.6%), short interruptions (18.8%), long interruptions (12.5%), harmonics (5.4%), transients and surges (29%) and other PQ related problems (10.7%) [Manson & Targosz, 2008]. In the United Kingdom, the customers mainly complain because of the disputed accounts and the supply standard related to the restoration time after fault interruptions. Some complaints are also about the supply quality issues such as voltage dips, harmonics and flicker [Wharmby, 1998]. In South Africa, voltage dips and transients have been identified as major PQ problem. This is because of the fact that a large part of the electricity infrastructure consists of overhead lines [Johnson & Coney, 1997].

3. Technical impacts of poor PQ

Now-a-days the customers use large number of devices at their installations that consist of power electronics. The residential customers use different domestic appliances such as televisions (TV), video cassette recorders (VCR), microwave ovens, personal computers (PC), heating-ventilation-air conditioning equipments (HVAC), dishwashers, dryers etc. The business and office equipments include workstations, PCs, copiers, printers, lighting etc. On the other hand, the industrial customers use programmable logic controllers (PLC), automation and data processors, variable speed drives (VSD), soft starters, inverters, computerized numerical control (CNC) tools and so on. Presently, many customers use compact fluorescent lamps (CFL) for lighting their installations. Many of these devices are quite sensitive to PQ disturbances. Case studies and surveys in different countries around the world have been done to estimate the impacts of poor PQ to the customers. However, until now, only few cases are surveyed to analyze the technical and non-technical inconveniences of poor PQ to the network operators. Nevertheless, a theoretical estimation of technical losses on different network components because of various PQ disturbances can be done to get an indication of possible impacts of poor PQ in the network.

3.1 For customers

From various surveys, it was generally noticed that industries are vulnerable to long and short interruptions (that are considered as 'reliability issues' in the power system analysis). Voltage dip is the main PQ problem for the semiconductor and continuous manufacturing industries, and also to the hotels and telecom sectors. Harmonic problems are perceived mainly by the commercial organizations and service sectors such as banks, retail, telecom etc. Another PQ problem that draws high attention is the presence of transients and surges at the customer's installation. In 2001, the Leonardo Power Quality Initiative (LPQI) surveyed in eight countries of the European Union (EU) [Keulenaer, 2003] and declared that the customers report a complaint to the network operators when they suffer one of the inconveniences as shown in Table 1 at their sites due to poor PQ of the electric supply.

Perceived inconvenience	*Affected devices*	*Reported PQ problem*
Computer lock-ups and data loss	IT equipments (that are sensitive to change in voltage signal)	Presence of earth leakage current causing small voltage drops in earth conductors
Loss of synchronization in processing equipment	Sensitive measurements of process control equipment	Severe harmonic distortion creating additional zero-crossings within a cycle of the sine wave.
Computer, electronics equipments damage	Electronic devices like computer, DVD player etc.	Lightning or a switching surge
Lights flicker, blink or dimming	Flickering, blinking or dimming of lighting devices, and other visual screens	Fast voltage changes leading to visible light flicker
Malfunctioning of motors and process devices. Extra heating, decreased operational efficiency and premature aging of the equipments	Motors and process devices	Presence of voltage and current harmonics in the power supply
Nuisance tripping of protective devices	Relays, circuit breakers and contactors	Distorted voltage waveform because of voltage dip
Noise interference to telecommunication lines	Telecommunication system	Electrical noise causing interference signals

Table 1. Customer's reported complaints in EU-8 as per LPQI survey