Understanding Power Quality Problems

Voltage Sags and Interruptions

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Chapter One

Overview of Power Quality and Power Quality Standards

Everybody does not agree with the use of the term *power quality*, but they do agree that it has become a very important aspect of power delivery especially in the second half of the 1990s. There is a lot of disagreement about what *power quality* actually incorporates; it looks as if everyone has her or his own interpretation. In this chapter various ideas will be summarized to clear up some of the confusion. However, the author himself is part of the power quality world; thus part of the confusion. After reading this book the reader might want to go to the library and form his own picture. The number of books on *power quality* is still rather limited. The book "Electric Power Systems Quality" by Dugan et al. [75] gives a useful overview of the various power quality phenomena and the recent developments in this field. There are two more books with the term power quality in the title: "Electric Power Quality Control Techniques" [76] and "Electric Power Quality" [77]. But despite the general title, reference [76] mainly concentrates on transient overvoltage and [77] mainly on harmonic distortion. But both books do contain some introductory chapters on power quality. Also many recent books on electric power systems contain one or more general chapters on power quality, for example, [114], [115], and [116]. Information on power quality cannot be found only in books; a large number of papers have been written on the subject; overview papers as well as technical papers about small details of power quality. The main journals to look for technical papers are the IEEE Transactions on Industry Applications, the IEEE Transactions on Power Delivery and IEE Proceedings-Generation, Transmission, Distribution. Other technical journals in the power engineering field also contain papers of relevance. A journal specially dedicated to power quality is Power Quality Assurance. Overview articles can be found in many different journals; two early ones are [104] and [105]. Various sources use the term "power quality" with different meanings. Other sources use similar but slightly different terminology like "quality of power supply" or "voltage quality." What all these terms have in common is that they treat the interaction between the utility and the customer, or in technical terms between the power system and the load. Treatment of this interaction is in itself not new. The aim of the power system has always been to supply electrical energy to the customers. What is new is the emphasis that is placed on this interaction, and the treatment of it as a separate area of power engineering. In Section 1.2 the various terms and interpretations will be discussed in more detail. From the discussion we will conclude that "power quality" is still the most suitable term. The various power quality phenomena will be discussed and grouped in Section 1.3. Electromagnetic compatibility and power quality standards will be treated in detail in Section 1.4. But first Section 1.1 will give some explanations for the increased interest in power quality.

1.1 INTEREST IN POWER QUALITY

The fact that power quality has become an issue recently, does not mean that it was not important in the past. Utilities all over the world have for decades worked on the improvement of what is now known as power quality. And actually, even the term has been in use for a rather long time already. The oldest mentioning of the term "power quality" known to the author was in a paper published in 1968 [95]. The paper detailed a study by the U.S. Navy after specifications for the power required by electronic equipment. That paper gives a remarkably good overview of the power quality field, including the use of monitoring equipment and even the suggested use of a static transfer switch. Several publications appeared soon after, which used the term power quality in relation to airborne power systems [96], [97], [98]. Already in 1970 "high power quality" is being mentioned as one of the aims of industrial power system design, together with "safety," "reliable service," and "low initial and operating costs" [99]. At about the same time the term "voltage quality" was used in the Scandinavian countries [100], [101] and in the Soviet Union [102], mainly with reference to slow variations in the voltage magnitude.

The recent increased interest in power quality can be explained in a number of ways. The main explanations given are summarized below. Of course it is hard to say which of these came first; some explanations for the interest in power quality given below, will by others be classified as consequences of the increased interest in power quality. To show the increased interest on power quality a comparison was made for the number of publications in the INSPEC database [118] using the terms "voltage quality" or "power quality." For the period 1969-1984 the INSPEC database contains 91 records containing the term "power quality" and 64 containing the term "voltage quality." The period 1985-1996 resulted in 2051 and 210 records, respectively. We see thus a large increase in number of publications on this subjects and also a shift away from the term "voltage quality" toward the term "power quality."

Equipment has become more sensitive to voltage disturbances. Electronic and power electronic equipment has especially become much more sensitive than its counterparts 10 or 20 years ago. The paper often cited as having introduced the term power quality (by Thomas Key in 1978 [1]) treated this increased sensitivity to voltage disturbances. Not only has equipment become more sensitive, companies have also become more sensitive to loss of production time due to their reduced profit margins. On the domestic market, electricity is more and more considered a basic right, which should simply always be present. The consequence is that an interruption of the supply will much more than before lead to complaints, even if there are no damages or costs related to it. An important paper triggering the interest in power quality appeared in the journal Business Week in 1991 [103]. The article cited Jane Clemmensen of EPRI as estimating that *"power-related problems cost U.S. companies $26 billion a year in lost time and revenue."* This value has been cited over and over again even though it was most likely only a rough estimate. **Equipment causes voltage disturbances.** Tripping of equipment due to disturbances in the supply voltage is often described by customers as "bad power quality." Utilities on the other side, often view disturbances due to end-user equipment as the main power quality problem. Modern (power) electronic equipment is not only sensitive to voltage disturbances, it also causes disturbances for other customers. The increased use of converter-driven equipment (from consumer electronics and computers, up to adjustable-speed drives) has led to a large growth of voltage disturbances, although fortunately not yet to a level where equipment becomes sensitive. The main issue here is the nonsinusoidal current of rectifiers and inverters. The input current not only contains a power frequency component (50 Hz or 60 Hz) but also so-called harmonic components with frequencies equal to a multiple of the power frequency. The harmonic distortion of the current leads to harmonic components in the supply voltage. Equipment has already produced harmonic distortion for a number of decades. But only recently has the amount of load fed via power electronic converters increased enormously: not only large adjustable-speed drives but also small consumer electronics equipment. The latter cause a large part of the harmonic voltage distortion: each individual device does not generate much harmonic currents but all of them together cause a serious distortion of the supply voltage. **A growing need for standardization and performance criteria.** The consumer of electrical energy used to be viewed by most utitilies simply as a "load." Interruptions and other voltage disturbances were part of the deal, and the utility decided what was reasonable. Any customer who was not satisfied with the offered reliability and quality had to pay the utility for improving the supply. Today the utilities have to treat the consumers as "customers." Even if the utility does not need to reduce the number of voltage disturbances, it does have to quantify them one way or the other. Electricity is viewed as a product with certain characteristics, which have to be measured, predicted, guaranteed, improved, etc. This is further triggered by the drive towards privatization and deregulation of the electricity industry. Open competition can make the situation even more complicated. In the past a consumer would have a contract with the local supplier who would deliver the electrical energy with a given reliability and quality. Nowadays the customer can buy electrical energy somewhere, the transport capacity somewhere else and pay the local utility, for the actual connection to the system. It is no longer clear who is responsible for reliability and power quality. As long as the customer still has a connection agreement with the local utility, one can argue that the latter is responsible for the actual delivery and thus for reliability and quality. But what about voltage sags due to transmission system faults? In some cases the consumer only has a contract with a supplier who only generates the electricity and subcontracts transport and distribution. One could state that any responsibility should be defined by contract, so that the generation company with which the customer has a contractual agreement would be responsible for reliability and quality. The responsibility of the local distribution would only be towards the generation companies with whom they have a contract to deliver to given customers. No matter what the legal construction is, reliability and quality will need to be well defined. **Utilities want to deliver a good product.** Something that is often forgotten in the heat of the discussion is that many power quality developments are driven by the utilities. Most utilities simply want to deliver a good product, and have been committed to that for many decades. Designing a system with a high reliability of supply, for a limited cost, is a technical challenge which appealed to many in the power industry, and hopefully still does in the future. **The power supply has become too good.** Part of the interest in phenomena like voltage sags and harmonic distortion is due to the high quality of the supply voltage. Long interruptions have become rare in most industrialized countries (Europe, North America, East Asia), and the consumer has, wrongly, gotten the impression that electricity is something that is always available and always of high quality, or at least something that should always be. The fact that there are some imperfections in the supply which are very hard or even impossible to eliminate is easily forgotten. In countries where the electricity supply has a high unavailability, like 2 hours per day, power quality does not appear to be such a big issue as in countries with availabilities well over 99.9%. **The power quality can be measured.**

The availability of electronic devices to measure and show waveforms has certainly contributed to the interest in power quality. Harmonic currents and voltage sags were simply hard to measure on a large scale in the past. Measurements were restricted to rms voltage, frequency, and long interruptions; phenomena which are now considered part of power quality, but were simply part of power system operation in the past.

1.2 POWER QUALITY, VOLTAGE QUALITY

There have been (and will be) a lot of arguments about which term to use for the utility-customer (system-load) interactions. Most people use the term "power quality" although this term is still prone to criticism. The main objection against the use of the term is that one cannot talk about the quality of a physical quantity like power. Despite the objections we will use the term power quality here, even though it does not give a perfect description of the phenomenon. But it has become a widely used term and it is the best term available at the moment. Within the IEEE, the term power quality has gained some official status already, e.g., through the name of SCC 22 (Standards Coordinating Committee): "Power Quality" [140]. But the international standards setting organization in electrical engineering (the IEC) does not yet use the term power quality in any of its standard documents. Instead it uses the term *electromagnetic compatibility*, which is not the same as power quality but there is a strong overlap between the two terms. Below, a number of different terms will be discussed. As each term has its limitations the author feels that power quality remains the more general term which covers all the other terms. But, before that, it is worth to give the following IEEE and IEC definitions.

The definition of power quality given in the IEEE dictionary [119] originates in IEEE Std 1100 (better known as the Emerald Book) [78]: *Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment.* Despite this definition the term power quality is clearly used in a more general way within the IEEE: e.g., SCC 22 also covers standards on harmonic pollution caused by loads.

The following definition is given in IEC 61000-1-1: *Electromagnetic compatibility is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment* [79].

Recently the IEC has also started a project group on power quality [106] which should initially result in a standard on measurement of power quality. The following definition of power quality was adopted for describing the scope of the project group: *Set of parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform).*

Obviously, this definition will not stop the discussion about what power quality is. The author's impression is that it will only increase the confusion, e.g., because power quality is now suddenly limited to "normal operating conditions."

From the many publications on this subject and the various terms used, the following terminology has been extracted. The reader should realize that there is no general consensus on the use of these terms.

Voltage quality (the French *Qualité de la tension*) is concerned with deviations of the voltage from the ideal. The ideal voltage is a single-frequency sine wave of constant frequency and constant magnitude. The limitation of this term is that it only covers technical aspects, and that even within those technical aspects it neglects the current distortions. The term voltage quality is regularly used, especially in European publications. It can be interpreted as the quality of the product delivered by the utility to the customers.

A complementary definition would be **current quality**. Current quality is concerned with deviations of the current from the ideal. The ideal current is again a single-frequency sine wave of constant frequency and magnitude. An additional requirement is that this sine wave is in phase with the supply voltage. Thus where voltage quality has to do with what the utility delivers to the consumer, current quality is concerned with what the consumer takes from the utility. Of course voltage and current are strongly related and if either voltage or current deviates from the ideal it is hard for the other to be ideal.

Power quality is the combination of voltage quality and current quality. Thus power quality is concerned with deviations of voltage and/or current from the ideal. Note that power quality has nothing to do with deviations of the product of voltage and current (the power) from any ideal shape.

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