POWER QUALITY AND QUALITY OF SUPPLY

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ABSTRACT

This paper deals with term Power Quality and its reference to terms Voltage Quality, Continuity of supply, and Quality of Supply. There are described the main voltage disturbances and voltage characteristics given by the standard EN 50160. In final part of the paper power quality monitoring is mentioned.

1. INTRODUCTION

For long time the main concern of consumers of electricity was the continuity of the supply, i.e. the reliability. Nowadays consumers want not only reliability, but quality too. Power quality is determined by ability of customer equipment to perform properly. The reason to explain the current interest in power quality is growing economic impacts on the network operators (i.e. the utilities) and their customers. The costs associated with "lack of quality" can be large, especially for industrial customers. If for example a production line trips, it may take several hours to restart with severe financial consequences.

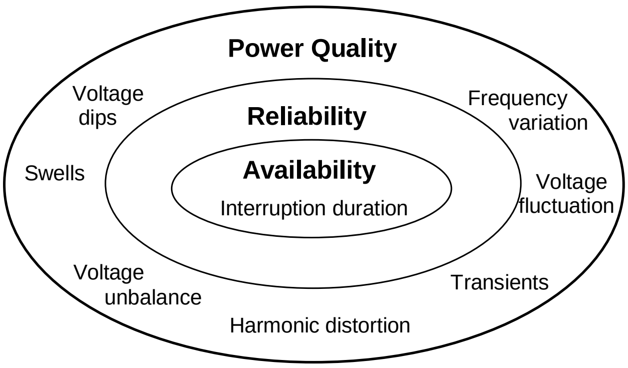


Figure 1 – Relationship between availability, reliability and power quality

The devices and equipment being applied in industrial and commercial facilities are more sensitive to power quality disturbances than equipment applied in the past. Equipment containing microprocessor-based controls and power electronic devices, computers, control automation systems, adjustable-speed drives, contactors can be sensitive to many types of disturbances besides actual interruptions (see Table 1). These devices and equipment can be parts of advanced production or information processes. Processes and equipment have become more interconnected and interrelated which can make them more vulnerable to failure of one component. The whole system is as sensitive as the most sensitive equipment. Malfunction of equipment or misoperation of an important process can affect production continuity resulting in material damages (e.g. in industry), pecuniary losses (e.g. in banking systems) or other losses (e.g. in dispatching centres, hospitals, laboratories).

Table 1 – Equipment sensitivity to voltage disturbances

Equipment	Voltage disturbances								
	Oscillatory transients	Impulsive transients	Dips and undervoltage	Swells and overvoltage	Interruptions	Harmonics	Notching	Noise	Voltage fluctuations
CNC machine	•	•	•	•	•		•	•	
Adjustable speed drives	•	•	•		•	•	•		
Personal computers	•	•	•		•			•	
Programmable logic controllers	•	•	•		•	•	•	•	
Relays, contactors, motor starters		•	•		•				
Fax machine		•	•		•			•	
Metal-halide and high-pressure sodium lighting		•	•		•				•
Telecom switching equipment	•	•	•		•	•	•	•	
Electronic ballast fluorescent lighting		•			•			•	•

The power quality problems don’t always come from the utility system either. The same equipment which is sensitive to voltage disturbances, itself often causes voltage disturbances for other customers. Power electronics equipment, such as adjustable speed drives, results in a continuous string of transients (notching) as well as steady state harmonic distortion. On the other hand, these voltage disturbances affect significantly function of power electronics equipment.

2. DEFINITION OF POWER QUALITY

The quality of delivered electricity, like quality of other goods and services, is difficult to define and quantify. There is not one accepted definition of quality electricity. The quality is mainly determined by the quality of the voltage waveform, as it is impossible to control the currents drawn by customer loads. Voltage quality is not only the responsibility of the network operator but also, in certain respects, depends on producers and customers.

Power quality is the combination of current quality and voltage quality, involving the interaction between the system and the load. ***Voltage quality*** concerns the deviation of the voltage waveform from the ideal sinusoidal voltage of constant magnitude and constant frequency. *Current quality* is a complementary term and it concerns the deviation of the current waveform from the ideal sinusoidal current of constant magnitude and constant frequency. Voltage quality involves the performance of the power system towards the load, while current quality involves behaviour of the load towards the power system.

There is always close relationship between voltage and current in any practical power system. Although the generators may provide a near-perfect sinusoidal voltage, the current passing trough the impedance of the system can cause a variety of disturbances to the voltage. To understand the basis of many power quality problems is necessary to deal with the interaction between the load and the power system. The power system can only control the quality of the supply voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits.

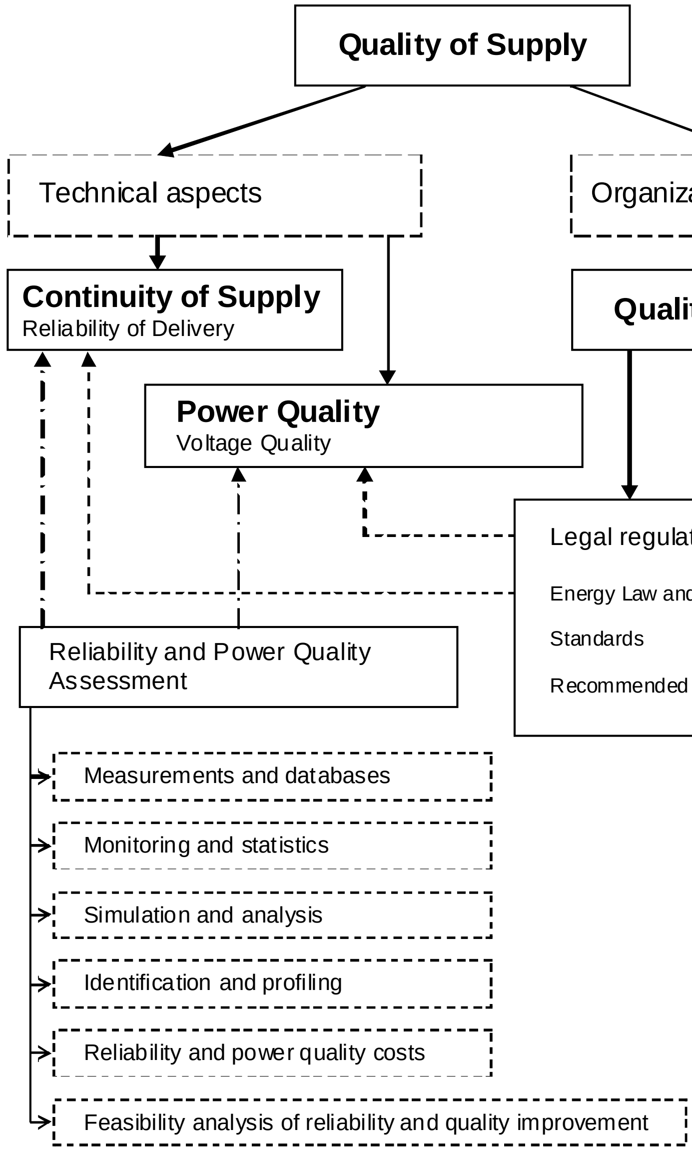
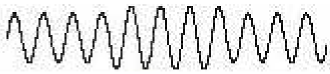
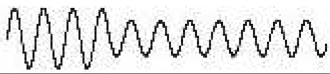
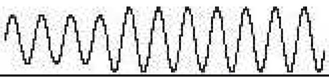
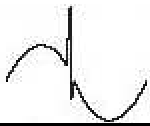
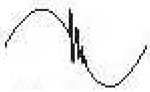
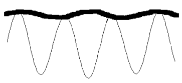
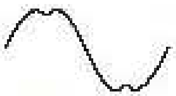
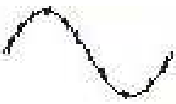
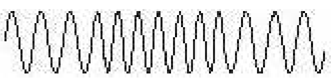


Figure 2 – Dimensions of the Quality of Supply

Quality of supply is a combination of voltage quality and the non-technical aspects of the interaction between the utility and its customers. Quality of service in electricity supply has a number of different dimensions, which can be grouped under three general headings: commercial relationships between a supplier and an end-user, continuity of supply, and voltage quality.

- ***Continuity of supply*** (also referred to as *Reliability of delivery*) is characterized by the number and duration of interruptions. Several indicators are used to evaluate the continuity of supply in transmission and distribution systems (e.g. SAIDI, SAIFI).
- ***Voltage quality*** 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. Voltage quality is described according to the European standard EN 50160 by the characteristics of the supply voltage concerning: frequency, magnitude, waveform and symmetry of the phases.
- ***Quality of service*** *(*also referred to as *Commercial quality)* concerns the quality of relationships between a supplier and a customer. It covers many aspects of the relationship (e.g. transparency of the tariff structure, information supply, responses on customers’ complaints, metering, reading and billing), but only some of them can be measured and regulated through standards or other instruments.

Table 2 – Summary of power quality disturbances

	PQ Disturbance	Frequency / Rise Time	Duration	Magnitude
Amplitude	INTERRUPTION 	collapse	10 ms to 3 min	0
	VOLTAGE DIP 	power frequency	10 ms to 1 min	0.1 to 0.9 pu
	VOLTAGE SWELL 	power frequency	10 ms to 1 min	1.1 to 1.8 pu
	UNDERVOLTAGE 	power frequency	> 1 min	0.8 to 0.9 pu
	OVERVOLTAGE 	power frequency	> 1 min	1.1 to 1.2 pu
	TRANSIENT OVERVOLTAGE (Impulsive Transients) 	rise time: ns to ms	50 ns to 1 ms	0 to 10 pu
	TRANSIENT OVERVOLTAGE (Oscillatory Transients) 	1 kHz to 10 MHz	1 µs to 50 ms	0 to 6 pu
Waveform distortion	VOLTAGE FLUCTUATIONS (FLICKER) 	modulation frequency < 50 Hz	steady-state variation	+/- 0.1 pu
	HARMONICS 	harmonic orders: 0 to 50	steady-state variation	< 0.1 pu
	NOTCHING 	broad-band	steady-state variation	< 0.1 pu
Balanc e	VOLTAGE UNBALANCE 	power frequency	steady-state variation	---
Frequency	FREQUENCY VARIATION 	49.5 to 50.5 Hz (47 to 52 Hz) for synchonous systems	< 10 s	---

3. VOLTAGE CHARACTERISTICS (EN 50160)

The European Committee for Electrotechnical Standardisation (CENELEC) issued the standard EN 50160 “Voltage characteristics of electricity supplied by public distribution systems”. The standard EN 50160 is one of the first documents quantifying the voltage quality experienced by customers. It gives the main characteristics of the voltage at the customers supply terminals in public LV (to 1 kV), MV (between 1 kV and 35 kV) and HV networks under normal operating conditions. “Supply terminals” is defined as the point of connection of the customer’s installation to the public system, so called the point of common coupling (PCC).

Voltage quality is determined by the voltage characteristics. Because some incidents affecting the supply voltage are random in time and location, some of the characteristics are described with statistical parameters instead of specific limits, e.g. voltage magnitude. For some characteristics, e.g. voltage dips, interruptions and overvoltages, only indicative values are given.

• **Voltage magnitude** – 95% of the 10-minute averages during one week shall be within ±10% of the nominal voltage. It indicates that the range of variation of the 10 minutes rms values of the supply voltage is U_n±10% for 95% of a week. In short, this means that for more than 8 hours a week there are no limits for the supply voltage value.

• **Frequency variation** - 95% of the 10-second averages shall not be outside the range 49.5 to 50.5 Hz.

• **Voltage fluctuation** - 95% of the 2-hour long-term flicker severity values obtained during one week shall not exceed 1.

Short-term severity P_{st} is measured with a specified equipment over a period of 10 minutes and P_{lt} is calculated from a sequence of twelve P_{st} values over a two-hour interval, according to the expression

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{P_{sti}^3}{12}} .$$

• **Harmonic distortion** – Harmonic voltages are evaluated individually or globally. Individually by their relative amplitude u_h related to the fundamental voltage U_1, where h is the order of the harmonic. For harmonic voltage components up to order 25, values are given which shall not be exceeded during 95% of the 10-minute averages obtained in one week (see Table 4.3). Globally by the total harmonic distortion factor THD that is calculated as follows: $THD = \sqrt{\sum_{h=2}^{40} (u_h)^2}$

The THD shall not exceed 8% during 95% of the week.

Table 3 – Values of individual harmonic voltages at the supply terminals for orders up to 25, given in percent of the fundamental voltage U_1

Odd harmonics		Odd harmonics triplen harmonics		Even harmonics	
order h	relative voltage u_h [%]	order h	relative voltage u_h [%]	order h	relative voltage u_h [%]
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,5	6 … 24	0,5
13	3	21	0,5		
17	2				
19, 23, 25	1,5				

• **Voltage unbalance** – the ratio of negative-sequence $U_{(2)}$ and positive sequence voltage $U_{(1)}$ shall be obtained as 10-minute averages, 95% of those shall not exceed 2% during one week. The unbalance ratio is defined:

$$\rho_U = U_{(2)} / U_{(1)} * 100 \quad [\%]$$

• **Signaling voltages -** 95% of the 3-second averages during one day shall not exceed 9% U_n for frequencies up to 500 Hz, 5% U_n for frequencies between 1 and 10 kHz, and threshold decaying to 1% U_n for higher frequencies.
• **Voltage magnitude steps –** these normally do not exceed ±5% of the nominal voltage, but changes up to ±10% can occur a number of times per a day.
• **Voltage dips -** frequency of occurrence is between a few tens and one thousand events per a year. Duration is mostly less than 1 second, and voltage rarely drops below 40% U_n.
• **Short interruptions** – occur between a few tens and several hundred times events per a year. The duration is in about 70% cases less than 1 second.
• **Long interruptions -** frequency of occurrence may be less than 10 or up to 50 per a year.
• **Transient overvoltages** – will generally not exceed 6 kV in a 230 V system.
• **Temporary (power frequency) overvoltages –** will generally not exceed 1.5 kV in a 230 V system.

3.1. Power quality monitoring

In most countries the potential impact of “lack of quality” is growing. It is therefore likely that more measuring equipment will be placed in the network and at customer connection points.

Measurement of voltage characteristics can be divided into three categories according to the purpose of the measurement:

- permanent monitoring, e.g. for verifying contractual obligations – in transmission delivery points, connection points of HV end-users, substations 110 kV/MV
- temporary surveying, e.g. to check the performance of the supply system, or to check user complaints – in connection points of MV and LV end-users
- general investigations.

Measurements and assessment of voltage characteristics have to be made according to standards, e.g. [2], [3]. These standards also define requirements for power quality measurement instruments warranting measurement comparability and repeatability.

To verify power quality level, the utilities have to archive results of measurements and assessment of voltage characteristics together with information on power system conditions and parameters in time of measurement. Power quality data are also used on purpose of the power quality benchmarking in European countries.

4. CONCLUSIONS

The EN 50160 gives only general limits, which are technically and economically possible for the supplier to maintain in public distribution systems and which provide a minimum, a barely adequate quality supply. Most suppliers routinely exceed these limits by a large margin. If the customer has higher requirements for supply quality, a separate agreement between the supply utility and the customer must be made. The part or whole standard EN 50160 can be replaced by this contract. The utility can namely guarantee higher power quality to the important industrial and commercial customers. On basis of contacts the utility could also supply low quality power to some customers at advantageous, i.e. lower, price.

There are typical areas that will be addressed in power quality contracts:

- Reliability/power quality concerns to be evaluated
- Power system performance indices to be used
- Expected level of power system performance (baseline)
- Penalty for performance outside the expected level and/or incentives for performance better than the expected level (financial penalties, performance-based rates, shared savings, etc.)
- Measurement/calculation methods to verify and accurately assess system performance, means of evaluating compliance
- Responsibilities for each party in achieving the desired performance
- Responsibilities of the parties for resolving problems

To meet customer demands on higher power quality the utilities often have to install mitigation devices or to make changes in structure of the power system. Costs associated with changes in structure of the system are generally very high and can influence electricity price. There is a need to make decision what mitigation technique is most cost-effective. Most customers prefer solution of power quality problems on the supply system side. Question is whether the customers are willing to accept the higher price of electricity.

With the introduction of competition between utilities power quality becomes an issue for the regulator, because power quality problems can affect the economic position of the utilities on market. The regulator may use economic incentives to guarantee minimum power quality levels.

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