# Towards Voltage Quality Regulation In Europe

# An ERGEG Public Consultation Paper

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This ERGEG public consultation paper sets out ERGEG's views on the issue of voltage quality. The paper raises a number of questions upon which comments by stakeholders are requested (in particular on the issues for consultation pointed out in chapter 7).

Comments should be sent to **voltagequality@ergeg.org** and should be received by **22nd February, 2007**.

## Executive summary

Electricity has several characteristics which demonstrate its quality, which means its availability and usefulness. The usefulness of electricity when there are no interruptions is described by the level of the voltage quality. Voltage quality is becoming an important issue in many countries, because of the sensitivity of end-use equipment and the increasing concern of both distributors and customers. Voltage quality is a complex issue as it is composed of several parameters, each of them with its own characteristics. The voltage quality parameters are listed and defined in, among other international standards, the European standard EN 50160 (1999). A new version is now under approval but amendments do not change the nature of the standard. This norm was born as a response to 85/374/EEC (product liability directive) and does not describe the typical or average situation of voltage quality levels in Europe. It gives the maximum (worst) values of variations of the voltage characteristics under normal operating conditions in any low[1] or medium[2] voltage supply point in Europe. The voltage characteristics in EN 50160 are not intended to be used as electromagnetic compatibility (EMC) levels or user emission limits for conducted disturbances in public distribution systems.

EN 50160 (1999) applies in all EU member countries for the referred voltage levels. In some countries voltage quality limits given in EN 50160 are used for voltage levels higher than 35 kV.
Voltage quality is still a new issue for regulators. In some, but very few ERGEG member countries is a body other than the regulator responsible for voltage quality. In most countries, the regulator is interested in monitoring actual voltage quality levels, and a significant number of the countries have installed or will soon install a monitoring system. A good knowledge of the real situation is a preliminary step towards any kind of regulatory intervention. Monitoring systems will show in the near future more about the actual levels and will help in explaining differences (for instance in relation to the network structure).

EN 50160 sets binding limits of compliance for only a few voltage quality parameters. Binding limits are intended only under normal operating conditions and generally they refer to 95 % of the time (leaving no limits for approx. 8 hours every week). Only indicative values are given for the rest of the voltage quality parameters, especially for events like rapid voltage changes and voltage dips, which however are disturbances generally perceived as most annoying by the largest share of (business) customers.

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[1] In EN 50160 low voltage (LV) is used for the supply of electricity, whose upper limit of nominal RMS value is 1 kV.

[2] In EN 50160 medium voltage (MV) is used for the supply of electricity, whose nominal RMS value lies between 1 kV and 35 kV.

European regulators are concerned about the voltage quality standards indicated by EN 50160 (1999). Following that norm, many disturbances are not constrained at all. The EN 50160 limits and values are too loose and do not constitute a good reference for voltage quality in most European networks. Generally, network performance in Europe is already better than EN 50160 limits. In coming years, therefore, we can expect regulators to pay increasing attention to voltage quality issues. For instance, many regulators think that stricter voltage quality standards are required; some of them have already introduced or are engaged to prepare more constraining standards. More constraining standards may be necessary to uphold today's quality, e.g. to counteract a deterioration of the power quality with time. Minimum voltage quality requirements are needed for customer protection, and are necessary in order to solve disputes between different stakeholders. Regulators have to take into account both private and public interests. Given the nature of electricity, every party connected the power system influences voltage quality, which means that every party also should meet requirements.

The 3rd CEER Benchmarking Report on Quality of Electricity Supply - C05-QOS-01-03 (December 2005)[3] stated three final recommendations for future work on voltage quality:

- EN 50160 should be revised by CENELEC in cooperation with ERGEG and other stakeholders, taking into account both the actual levels of voltage quality in European transmission and distribution networks and the evolution of customers' needs.
- It is strongly recommended that at least the most critical voltage quality parameters be monitored and that results be published, in order to determine, in a first stage, the actual performance of networks.
- It is highly advisable to undertake further research on power quality contracts and information on this market-like tool, which can result in an efficient way to satisfy special quality needs without increasing general tariffs.

Within the above described context, this ERGEG consultation paper develops some proposal to CENELEC for revising EN 50160. The main issues listed in a priority order are the following:

1. <u>There are some voltage quality parameters whose measurement rules and definitions should be better defined, searching for the widest international consensus as possible</u>. Unique definitions are necessary in order to calculate or measure different parameters in a uniformly way. Definitions should be improved especially for rapid voltage changes, supply voltage dips and swells (temporary power frequency overvoltages). The threshold between rapid voltage changes, voltage dips and interruptions should be equally defined internationally, which is not the case today. Also a further harmonization in operational rules for calculating main continuity indices (SAIDI, SAIFI, MAIFI) is openly recommended.[4]

2. <u>Limits for voltage variations – Avoid "95%-of-time" clause and avoid long time intervals for averaging measured values:</u> We suggest that different provisions should apply only for the

[3] The document is available at the CEER website from the following address: http://www.ceer-eu.org/portal/page/portal/CEER_HOME/CEER_PUBLICATIONS/CEER_DOCUMENTS/2005/CEER_3RDBR-QOES_2005-12-06.PDF

[4] Some continuity indices are defined in the American standard IEEE1366 Guide for Electric Power Distribution Reliability Indices. Continuity indices are widely used among European countries, but not always in the exact same way. It is therefore considered that there is a need to define continuity indices at European level. Some of the uncertainties are present especially as regards counting sequences of interruptions and defining Major Event Day.

consequences of exceptional events – that should be better defined – and for taking into account some special conditions of network management (as for instance back-feeding in case of faults). Further, a change of the 10-minute RMS average value, used for supply voltage variations, should be taken for consideration. A too-wide averaging may hide some important slow supply voltage variations.

3. Limits are needed for every voltage level: high voltage and extra-high voltage levels should be considered in the renewed standard. HV and EHV networks are by nature meshed whilst MV and LV networks are radial or radially operated; this difference must be taken into account, as well as the contribution of HV and EHV to disturbances in MV and LV networks.

4. Indicative values given in EN 50160 for voltage events (especially dips and swells) are often too vague and no longer acceptable. As a preliminary step, dips and swells could be classified by severity, in order to distinguish events according to the typical causes that provoke them and the consequences they may lead to. Especially for dips and interruptions the rather vague ranges given for informative purposes (e.g. “up to several hundreds”) are not useful for customers, neither for claiming damages when these occur nor even for designing their own protection systems in an economically sound manner or for taking appropriate countermeasures.

5. Duties and rights of all the parties should be taken into account; a general framework is proposed to share the responsibility between network companies, equipment manufacturers and final customers. In this field, a sound coordination among technical standards (both system-related and product-related) is of paramount importance. Further, characteristics of withdrawal (e.g. harmonic currents) should be explored, as well as minimum level of short-circuit power provided by operators, in order to clearly identify responsibilities for voltage quality disturbances. Measurement procedures and tools as well should be considered in order to simply obtain a non controversial measure of disturbances, and as far as possible, a meaningful one for detecting responsibilities.

6. Realistic and even differentiated voltage quality levels should be defined according to network characteristics, taking into account different factors (overhead/underground, operational earthing, etc.). Both the classification according to severity and the availability of field data from the recently monitoring systems installed in some countries could be extremely helpful for this purpose. The costs borne by customers for poor voltage quality require a new technical answer about reference levels applicable in the specific situation; the approach cannot be the encompassment of all the worse levels throughout Europe any longer. .

7. The concept of “power quality contracts” should be developed in order to clarify in which situations it’s applicable, as in many cases the improvement of quality of service requires interventions in the network that are to be made by the network operator. In those situations, a group of customers could benefit from the improvement and the power quality contracts might not be adequate for all.

Setting more restrictive standards than those stated in EN 50160 may entail higher costs for network investments. But whether more restrictive standards than those stated in EN 50160 will entail higher costs or not, depends on the today's level of quality within each country. On the one side, improving voltage quality levels can lead to a benefit for the economy and the whole society. Reviewing the limits stated in EN 50160 according to ERGEG recommendations can drive this improvement especially for worst-served customers. On the other side, regulators should not allow to deteriorate the actual level of voltage quality if these – as often happens – are better than those stated in EN 50160. When introducing national voltage quality requirements, regulators should however take into account international emission and immunity standards.

As next steps, ERGEG will promote the development of monitoring systems throughout the EU and EEA countries in order to collect data on actual levels of voltage quality. On the other hand, ERGEG invites CENELEC and academic electrical researchers to assess costs and benefits related to the balance between new technical requirements and their economical consequences. ERGEG offers its cooperation to the work necessary for revising the technical standard EN 50160.
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# 1 Introduction

## 1.1 Voltage quality – Variations and events[5]

Service quality is an important issue in the electricity sector. Consumers are highly sensitive to all aspects of service quality. They value the timeliness with which their requests are dealt with (commercial quality), the reliability of electricity supply (continuity of supply), and also the characteristics of the supply voltage (voltage quality). Continuity of supply (understood as the availability of electricity) and voltage quality (understood as the usefulness of electricity) are often referred to as power quality. In addition the quality of the current is normally included in the term power quality.

Voltage quality (VQ) covers a wide range of factors. Voltage quality (VQ) parameters are listed and defined in the European standard EN 50160 (1999, Corrigendum Sept. 2004; hereinafter "EN 50160"), which is applicable in all EU member states for low and medium voltage networks (i.e. up to 35 kV). For the purpose of this work, we refer to the following VQ parameters:

- Supply voltage variations;
- Rapid voltage changes;
- Flicker severity;
- Supply voltage dips;
- Supply voltage swells (temporary power frequency overvoltages)[6]
- Transient overvoltages;
- Supply voltage unbalance;
- Harmonic voltages;
- Interharmonic voltages;
- Mains signalling voltage on the supply voltage.

Voltage quality includes frequency variation limits as well, but we do not draw attention on these as they are monitored and managed by the interconnected European power system operators. Frequency variations are of concern for isolated networks, typically on islands not synchronously connected to the main grid.

Voltage quality disturbances can be grouped in two types:

- *Voltage variations*, i.e. small deviations from the nominal or desired value that occur continuously over time. Voltage variations are mainly due to load pattern, changes of load or nonlinear loads. Supply voltage variations, voltage fluctuations leading to flicker, voltage unbalance, harmonic and interharmonic voltages are all examples of voltage variations.

[5] The distinction between voltage variations and voltage events has been drawn from the major textbook on voltage quality (Math H. J. Bollen, Understanding Power Quality Problems. Voltage Sags and Interruptions, IEEE Press Series on Power Engineering, 2000)

[6] EN 50160 deals with power frequency overvoltages only between live conductors and earth. Swell is an international common term for power frequency overvoltages both between live conductors and between live conductors and earth, c.f. among others IEC 61000-4-30. The term supply voltage swell is used through this position paper.

- *Voltage events*, i.e. sudden and significant deviations from normal or desired wave shape. Rapid voltage changes, supply voltage dips, swells and transient overvoltages are among the most important voltage events, a part from interruptions that are the best-known example of a voltage event. Opposite of voltage variations that occur continuously over time, voltage events only happen every once in a while. They have to be identified through continuous monitoring. Monitoring of events takes place by using a “trigger” that starts when voltage exceeds a given threshold. For instance, voltage dips are identified when the voltage (RMS value) goes below the “dip threshold” that is currently set at –10% of nominal or declared voltage level.

The distinction between voltage variations and voltage events is very important from the regulatory viewpoint:

- Voltage variations are the “*physiology*” of network functioning, as it is impossible that a given voltage characteristics (e.g. magnitude or angles between phases) keeps always and continuously the exact nominal value. Hence, because electrical equipment is designed to work optimally at the nominal value and with an ideal sine wave, voltage variations have to be kept as small as possible. Network operators can do many things in order to keep voltage variations as small as possible, which eventually lead to a more efficient network management. For instance, keeping voltage magnitude close to nominal value with power factor close to unity is strictly related with having less electricity losses. Voltage variations outside predefined limits may lead to severe problems for customers.

- Voltage events represent the “*pathology*” of the network functioning and are of large concern for end-use equipment. Voltage events can lead to interruption of the final productive process that uses electricity – even if there is no interruption of the supply. Voltage events are to be treated with stochastic approaches, as they are by nature occasional – and fortunately rather rare – events. Operators can adopt some kind of actions to prevent and mitigate voltage events, but voltage events can not disappear totally. Therefore, customers using equipments particularly sensitive to voltage events should consider to take their own countermeasures through technical solutions that can override some kind of voltage events with no or little problems for the end-use equipment.

## 1.2 Influence on the voltage quality

Voltage quality is a complex and multi-dimensional issue, affected by several factors. In fact, the levels of the above described parameters result from the inherent reliability and robustness of the network, as well as from the interaction between the network and the customers.

Interruptions, voltage dips, temporary and transient overvoltages are mainly caused by incidents that occur in the network. Supply voltage variations, rapid voltage changes, flicker severity, voltage unbalance, harmonic and interharmonic voltages and mains signalling, are mainly caused by the characteristics of the customers’ load. All of them however have their origin in either the network or within the final customers’ installation. Those whose origin is in the network can be very unpredictable events, such as faults and lightning, but also more predictable such as switching of capacitor banks and limitation of the short circuit power. Those whose origin is in the customer’s installation can be due to the starting of large motors, e.g. frequency converters and rectifiers, melting furnaces and, in general, use of electrical equipment. The effect on the voltage quality due to customer’s withdrawal of current will depend on the short circuit power at the point of connection. For more details see Annex 1.

Network management is very important for voltage quality. Network design and operation, protection strategy, relaying and grounding and so forth are all key points for disturbances related to voltage quality. The role and actions of grid companies – both distribution and transmission operators – is therefore of paramount importance.

## 1.3 Reasons for regulating voltage quality

Voltage quality is becoming an important issue in many countries, because of the sensitivity of end-use equipment and the increasing concern of both operators and customers. In the last few years, research has highlighted the costs borne by electricity final customers due to poor voltage quality. (Of course further research on voltage quality costs is still needed, see chapter 3). This means that voltage quality, as already largely done for continuity of supply, needs to be further explored in order to identify the potential for quality requirements and possible incentive regulation. At the moment VQ is still not adequately addressed by most regulators.

The main reasons for regulating voltage quality are described below, but not in a prioritized order (as priority order depends upon country-specific conditions):

- In general it is important to obtain a quality of supply that is beneficial for the society as a whole. The optimal level may vary between countries, depending, among other issues, the day's level of quality.
- Customers bear costs for poor voltage quality. This is the case even if the amount of these costs largely depends upon the sensibility of the single customer's plants and final use of electricity.
- Realistic reference levels or limits are needed for each parameter of VQ, at least in order to allow customers to adopt their own countermeasures if they have special needs for quality.
- Regulation by financial incentives, as revenue cap and price cap, gives the network companies strong incentives to reduce their costs. Reducing the overall costs may lead to a deterioration of the voltage quality. In order to prevent such an undesirable development, minimum requirements are needed.
- Only after setting requirements for the voltage (and current) quality and after appropriate measurements, it is possible to identify disturbing customers and therefore to adopt regulatory measures for these kinds of customers that provoke costs to both network operator and other customers connected nearby.
- It is important to provide good basis for handling disputes both between network companies and customers, but also between network companies (e.g. transmission-distribution interface). There is a need to clear up the responsibility borders between different parties.

Before setting VQ standards, knowledge about the level of quality that is supplied to the customers is important. New VQ standards will allow to improve the final customers' rights regarding quality of supply, and to focus on the network companies' ability to supply services and electricity with a satisfactory quality. Furthermore, setting minimum VQ standards is a preliminary step for the diffusion of power quality contracts. By means of power quality contracts, customers and network companies agree upon contractual voltage quality (or continuity) levels, special compensations for the customer in case the contractual levels are not respected and premium revenues for the network company.

## 2 Today's voltage quality limits and values in Europe (mainly EN 50160)

EN 50160 gives the main characteristics of the supply voltage at the customer's supply terminals in public low and medium voltage networks. Its object is to define and describe the characteristics of the supply voltage. This standard will be dealt with in detail below and in Annex 3.

EN 50160 is the main technical norm for voltage quality in Europe, but not the only one. There is also the IEC 61000 series of technical norms and reports on electromagnetic compatibility (EMC), which is very comprehensive and includes references about limits for voltage disturbances, immunity and emission limits for electrical equipment, measurements for voltage quality parameters and measurements techniques. The EMC framework is applicable to voltage variations, but it has not been developed for voltage events and its application to them has not been defined yet. EN 50160 is however not an EMC standard, as given in the scope of EN 50160: "*The voltage characteristics given in this standard are not intended to be used as electromagnetic compatibility (EMC) levels or user emission limits for conducted disturbances in public distribution systems.*" More details about the European (CENELEC) and the world-wide (IEC) standardisation bodies, including the 61000 series, are presented in Annex 2.

### 2.1 Definitions and measurement

Voltage quality parameters are listed and defined in the EN 50160. The quality of the definitions themselves is varying. For some parameters the definition is very clear, but for others the degree of freedom is huge, which means that the same parameter may be calculated or measured in different ways leading to different results. Some of the parameters are equally defined in IEC standards, but some are not. Flicker, flicker severity, supply voltage dips, harmonic and interharmonic voltages and mains signalling voltage are all well defined in EN 50160. Supply voltage dips and swells should, due to the different causes and consequences related to varying depth (dips) or height (swells) and durations, be classified by these relations. Designing such a classification table, it's important to take into account which deviations and durations that are caused by different causes and related problems for electrical equipment. The Information Technology Industry Council (ITIC) Curve (Figure 1) gives important address on voltage magnitude deviations and durations that may lead to problems for electrical equipment (even if it initially has been drawn from equipment connected to 120 V 60 Hz systems).

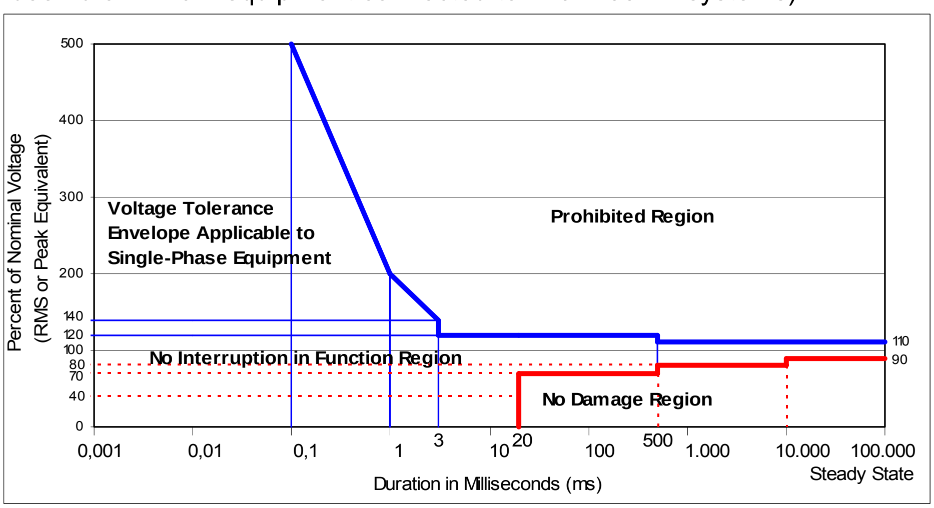


*Figure 1 - The Information Technology Industry Council (ITIC) curve.*

Some proposals for changing the definitions and measurement rules are given in chapter 4.1, Annexes 3 and 4. Other standards (IEC) are referred to for those parameters where appropriate.

## 2.2 Binding limits (at 95% of time) for variations and indicative values for events

EN 50160 describes electricity as a product (as required by Directive 85/374/EEC concerning liability for defective products, included electricity as stated by art. 2). It describes and defines the main characteristics of the supply voltage at the customer's supply terminals in public low-voltage (up to and including 1 kV, i.e. LV) and medium-voltage (from 1 kV up to 35 kV, i.e. MV) networks under normal operating conditions. "Voltage characteristics" are not requirements, but instead they describe the "product" electricity as it is now – even in the worse supply in Europe.

The distinction between voltage variations and voltage events (see chapter 1.1 above) is very useful to understand the content of EN 50160.

As regards voltage variations, EN 50160 gives binding limits. Binding limits are levels evaluated over a given period of time (whose importance is discussed below in chapter 2.3) and not to be exceeded for a given percentage of time in normal operating conditions:[7]

- *Binding limits for supply voltage variations*: 95 % of the 10-minute averages during one week shall be within the $\pm$ 10 % of the nominal voltage $U_n$ for LV (or the declared voltage $U_c$ for MV). Only for LV, 100 % of the 10-minute averages during one week shall be within the +10 %/ –15 % of the nominal voltage.
- *Binding limits for harmonic voltages*: For each harmonic component up to 25$^{th}$ order, limits are given (for instance, 6 % for 5$^{th}$ harmonic, 5 % for 3$^{rd}$ and 7$^{th}$ harmonic, 3,5 % for 11$^{th}$ harmonic, and so on). Even for individual harmonic voltage limits, these refer to 95 % of 10-minutes averages in a week. The total harmonic distortion ($THD_U$) shall not exceed 8 % during 95 % of the week. This applies for both LV and MV.
- *Binding limits for supply voltage unbalance:* 95 % of the 10-minutes average's of the ratio of negative-sequence and positive-sequence component shall not exceed 2 % in a week. In some areas and under some circumstances unbalance up to 3 % may occur. This applies for both LV and MV.
- *Binding limits for flicker severity*: 95 % of the long-term flicker severity (2-hour average) obtained during one week should not exceed 1. This applies for both LV and MV.
- *Binding limits for mains signalling voltage on the supply voltage:* The 3-second average of signal voltages shall be less than or equal to predefined limits (given in Figure 1 for LV and Figure 2 for MV in EN 50160) for more than 99 % of a day.

As regards voltage events, EN 50160 does not give any binding limits. For some types of voltage events, an indicative value (often, ranges of values) of the frequency with which voltage events could be expected are given:

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[7] The limits are referred to the customers' supply terminal. In EN 50160 low voltage (LV) is used for the supply of electricity, whose upper limit of nominal RMS value is 1 kV, but medium voltage (MV) is used for the supply of electricity, whose nominal RMS value lies between 1 kV and 35 kV.

- *Indicative levels for rapid voltage changes:* In LV network they generally do not exceed ± 5 % of the nominal voltage but changes up to ± 10 % might occur some times per day in some circumstances. In MV network the expected values are ± 4 % and ± 6 % respectively.
- *Indicative levels for supply voltage dips:* Frequency is expected between a few tens and one thousand dips per year; duration is mostly less than 1 second and voltage drops rarely below 40 % of the nominal value. This applies for both LV and MV.
- *Indicative levels for temporary overvoltages between live conductors and earth (swells):* If due to short-circuits upstream of a transformer, the voltage should not exceed 1,5 kV in LV networks. If due to earth faults, typical values for MV networks are given for different operational earthing. Voltage will generally not exceed 1,7x$U_C$ in systems with a solidly or impedance earthed neutral, and 2,0x$U_C$ in isolated or resonant earthed systems.
- *Indicative levels for transient overvoltages between live conductors and earth:* Generally should not exceed 6 kV peak in LV systems, but higher values occur occasionally. No indicative values for the MV networks.
- *Indicative levels for short interruptions:* Between a few tens and several hundreds per year; in 70 % of the cases the duration can be less than 1 second. This applies for both LV and MV.
- *Indicative levels for accidental long interruptions:* From less than 10 per year up to 50 per year, depending on the area.

Both binding limits and indicative values given in EN 50160 were introduced to encompass different national situations. Furthermore, the 95 %-of-time clause combined with the exclusion of not-normal operating conditions lead to binding limits that are only very rarely exceeded in Europe, and to indicative values that are always formulated in ambiguous terms. Such indicative levels are of no practical use for customers in order to install proper countermeasures. Furthermore, the main drawbacks of the indicative limits are that these are the only available references for courts deciding about damages claims.

## 2.3 Measuring time intervals for averaging measured values of voltage variations

The time interval used for to average values of voltage variations is of great importance. As an example we mention supply voltage variations, which according to EN 50160 should be measured as a 10-minute average. Most electrical equipments are designed to function satisfactory within ± 10 % of the nominal voltage. But using a 10-minute average to verify this limit can hide voltage variations that occur with only short duration. As a consequence, it can happen that the 10-minute average is within the tolerance band, but the supply voltage may have been very much deviated from the nominal band. The Figure 2 below shows an example on how a 10-minute average may hide some severe deviations. In the example considered in the figure, the 10-minute average is below $U_n$ -10 % (207 V) only for 3,5 % of the time, but using the 1-minute average the voltage is below $U_n$ -10 % for 28 % of the time. According to some countries experience even a 1-minute measurement average may not be satisfactory from the final customer point of view.[8]

[8] In order to cope with this Hungary proposes to measure 3 second averages during each 10-minute period. In order to avoid enormous increase of memory capacity it is suggested to select from the norm-like measured 3 second averages (Tvs) the maximum and minimum values of every 10 minutes. The maximum value of Tvs should be limited in 1.15 p.u. However, the difference of these 3s average values relative to the nominal voltage is a very good indication of the steadiness of the voltage level ten minutes by ten minutes.

According to the ITIC curve presented in chapter 2.1, IT and process equipment may be damaged due to a voltage deviation up to +120 % with a duration from 3 ms to 0,5 sec, and up to 110 % with a duration above 0,5 sec. For under-voltage events IT and process equipment may only handle a residual voltage at 70 %, 80 % and 90 %, when the duration of the event are between 20 ms and 0,5 s, between 0,5 s and 10 s and above 10 s respectively. Using a 10-minute average may give satisfactory protection for thermal phenomena, but are not sufficient to protect against equipment damage or failure. Protection against equipment damage or failure may be obtained by (1) a shorter time interval to average measured values, or (2) by keeping a 10-minute average for thermal protection and in addition introduce limits for short-duration overvoltages (voltage swells). The shorter the time interval used for averaging measured values are, the more accurate are the measurement results.

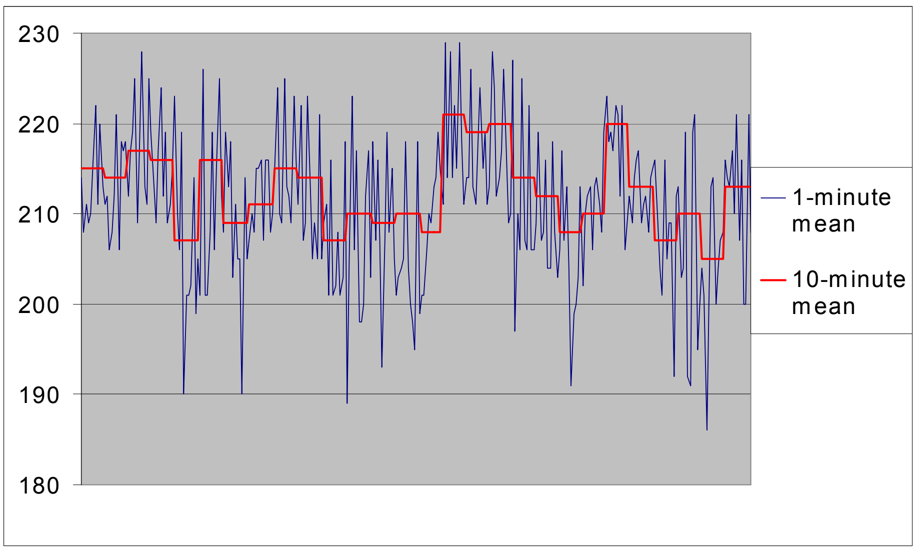


*Figure 2 - The voltage RMS value measured as a ten-minute and one-minute average simultaneously in the same point of connection. The ten-minute and one-minute average is below 207 V 3,5 % and 28 % of the time respectively. Source: SINTEF Energy Research (Norway).*

# 3 Voltage quality regulation and monitoring within EU member states

## 3.1 Today's regulation – in general

The 3rd CEER Benchmarking Report on Quality of Electricity Supply (December 2005) describes different national voltage quality regulations in its chapter 4. Below are some highlights, but for further details view the report on the CEER website www.ceer-eu.org.

*Voltage quality standards or regulations:*

In recent years, some regulators have introduced voltage quality standards different from those indicated in EN 50160. Supply voltage variations is one of a few parameters having enforceable limits set by EN 50160. Still some countries have introduced different, more restrictive limits for voltage variations. The restrictions affect both the "95% of time intervals" clause foreseen by EN 50160, the width of the allowed variation band and the time interval to average measured values. Spain, Hungary, Norway, France[9] and Portugal have introduced national requirements as regards supply voltage variations. Only the Norwegian regulator (NVE) has introduced limits for rapid voltage changes, and limits for the supply voltage unbalance different from EN 50160 and for all voltage levels. Norway has introduced limits for harmonics different from EN 50160 and for all voltage levels. Portugal has introduced limits for harmonics different from EN 50160 for higher voltage levels than the scope of EN 50160.

*Voltage quality monitoring systems:*

Unlike continuity of supply, monitoring voltage quality disturbances requires installing specific voltage quality recorders and cannot be obtained through ordinary SCADA systems (as in the case of interruptions). Nonetheless, a growing number of European countries have monitoring systems installed or plan to install them in the near future.

In Italy, Norway, Portugal and Czech Republic there are voltage quality monitoring systems at both transmission and distribution level and Hungary only in the distribution system. Spain and Sweden are at a proposal stage for continuously monitoring system for voltage quality. In France, network operators place a VQ recorder on site[10]:

- if a customer complains about voltage quality;
- if a customer applies for contractual commitments on voltage dips (the customer has to pay for that special commitment);
- if an operator wants to check the level of perturbations generated by the installation.

Even if these monitoring systems are different from each other in many respects, a common point is that at least short and long interruptions, voltage magnitude, voltage dips and harmonic distortion of the voltage waveform are monitored. The number and location of voltage recorders is quite different from one country to another.

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[9] In France requirements have not been set by the regulator but by a legal decree (29th may 1986) for LV customers and by contracts for MV customers, both for the 95% of time and the variation band. Also see chapter 3.2.3.

[10] Several countries have regulations in force where network operators are obliged to carry out individual measurements upon request, even though only France is mentioned here.

The availability, in coming years, of voltage quality data on both transmission and distribution grids will not only allow a deeper knowledge of actual voltage quality levels, but is also likely to enable regulators to define action plans to improve voltage quality and to set standards in the interest of consumer protection.

*Power quality contracts:*

France and Italy use power quality contracts with some ex-ante intervention of the regulator. Slovenia uses such contracts only with ex-post intervention of the regulator. Power quality contracts, with no intervention of the regulator, are used in Czech Republic, Spain, Great Britain, Latvia and Portugal. E.g. in France the voltage quality limits are set in the contracts between the customer and the distribution/transmission operator. The French regulator surveys these contracts but does not set standards.

## 3.2 Today's regulation – country specific and experience

### 3.2.1 Norway

The Norwegian quality of supply regulation contains both incentive based regulations and specific requirements. Informal translation of NVE's regulations concerning quality of supply, along with regulations for contingency planning, system operation and more, are available at NVE's English website www.nve.no. NVE introduced absolute limits for several voltage quality parameters January 1st 2005. Those voltage quality parameters are the voltage frequency, supply voltage variations, rapid voltage changes, flicker severity, voltage unbalance and harmonic voltages. In the following a few of these parameters will be emphasized as regards measuring time interval and limits. The main purpose of the Norwegian quality of supply regulation is "(…) *to contribute to ensure a satisfactory quality of supply in the Norwegian power system and a social rational operation, expansion and development of the power system. This includes taking into account public and private interests affected.*" One of NVE's aims making this regulation was to uphold the today's quality and not to cause a general increase in the quality of supply.

*Supply voltage variations:*

For decades limits for supply voltage variations in the Norwegian power system have been ± 10 % of the nominal voltage value in points of connections in the low voltage system. Both customers and network companies have adjusted to this level. Earlier this was not part of a public regulation, but part of national standards and standardised agreements between network companies and final customers. Until 2002 such standardised agreements did not state the time interval to average measured values. From 2002 these standard agreements referred to the European standard EN 50160 as regards the measuring time interval, but not as regards limits. Over the years NVE has experienced lots of complaints from customers regarding symptom of too high voltage deviation, e.g. damage of electrical equipment, without the 10-minute average voltage value exceeding +10 % of the nominal voltage. As shown in chapter 2.3 a 10-minute average may hide some severe voltage deviations. A ten-minute average may be satisfactory due to thermal effects, but indeed not to properly protect against equipment damage or equipment failure. Also see further comments in chapter 2.3.

To better ensure that supply voltage variations are kept inside the range of ± 10 % of the nominal voltage, NVE introduced in the new quality of supply regulation in 2005 that supply voltage variations shall be measured as 1-minute averages. The particular provision reads:

"*Network companies shall ensure that supply voltage variations (RMS value) are within an interval of ± 10 % of the nominal voltage, measured as a mean value over one minute, in points of connection in the low voltage network.*"

For connections above 1 kV, supply voltage variations will differ due to inter alia the extent of the low voltage network, possible tap changes of transformers and special requirements for customers connected. Depending on the extent of the LV network, possible alternations in the MV network voltage may be allowed only to be ± 1-2 %. This will vary a lot. NVE has considered it not to be optimal at this stage to introduce limits for slow supply voltage variations (RMS values) above 1 kV.

*Rapid voltage changes:*

A *rapid voltage change* is a term used for rapid (fast) voltage changes within ± 10 % of the nominal or declared voltage level, which means within the range not to be defined as supply voltage dips or swells. Important factors when defining a rapid voltage change are described in Annex 3. Rapid voltage changes within this range will mainly lead to visual annoyance, and not cause any damage or malfunction of electrical equipments. Rapid voltage changes may have different characteristics due to the cause of the voltage change. Different RMS voltage change characteristics are shown in Figures 3a, 3b and 3c. For the voltage change characteristics in Figures 3a and 3b, the maximum and the steady-state voltage changes are equivalent. But for the voltage change characteristic in Figure 3c, which is typical due to the start-up of an induction motor, the maximum and steady-state voltage changes are not equal.

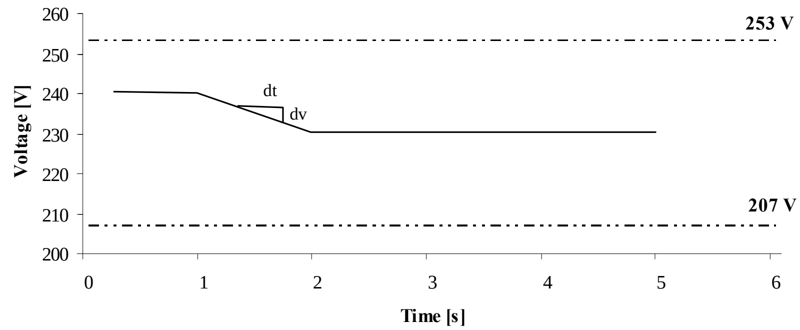


*Figure 3a - A Rapid voltage change: Gradual change indicating the voltage change per time (dv/dt).*
*The maximum change equals 10 V and the steady-state change equals 10 V.*

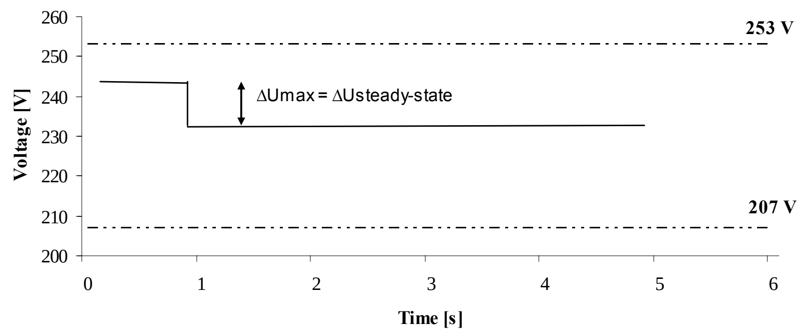


*Figure 3b - A Rapid voltage change: Instantaneous change.*
*The maximum change equals 10 V and the steady-state change equals 10 V.*

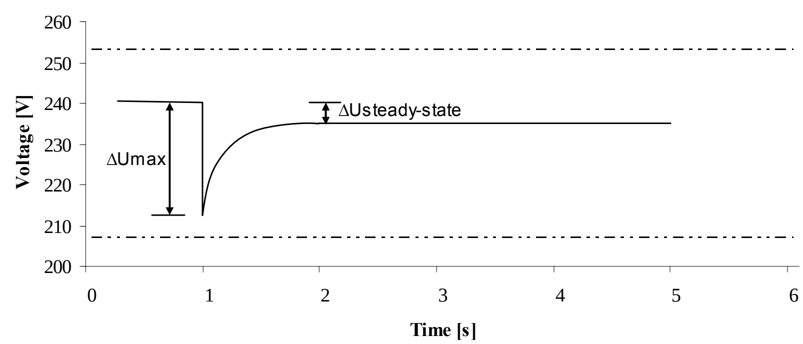


*Figure 3c - A Rapid voltage change: Exponential change, typical due to the start-up of an induction motor.*
*The maximum change equals 27 V and the steady-state change equals 5 V.*

NVE's main reason for introducing limits for rapid voltage changes is to cope with rapid changes that lead to visual annoyance for people but do not occur frequently enough to be covered by limits for flicker severity. It's further important to focus on causes that can be dealt with in a cost-effective manner. The main consequence is mainly the same as for flicker, visual annoyance. There can in periods of time be several rapid voltage changes giving rise to visual annoyance, without causing high $P_{st}$ or $P_{lt}$ flicker values. NVE introduced limits for maximum voltage change that occur during a voltage change characteristic, in 2005. The limits were based upon recommendations from research environment, emission limits given in relevant IEC standards and indicative levels given in EN 50160. The definition of rapid voltage change is based on IEC 61000-3-3 which is also adopted by CENELEC. The definition of rapid voltage changes given in IEC 61000-3-3 and other international standards, has however a few weaknesses which are described in more detail in Annex 3.

In late 2005 NVE initiated a research project on rapid voltage changes, which was carried out by SINTEF Energy Research (Trondheim – Norway). The results were available June 2006, and gave basis for a better and more accurate definition of and requirements for rapid voltage changes.  Based on this NVE has in a public hearing proposed changes in both the definition (see Annex 3) on and requirements for rapid voltage changes in the Norwegian quality of supply regulation. The new requirements are differentiated for the maximum and the steady-state voltage change, and take into account also the cause of the rapid voltage changes. To differentiate requirements for the maximum and the steady-state voltage change is very important because they give rise to different degree of visual annoyance. This was shown in the above mentioned research project carried out by SINTEF.

*Harmonics:*

NVE introduced requirements for harmonics 1st January 2005, based on the following items (not in priority order):

- The actual level of harmonics in the today's Norwegian power system.
- The levels of different individual harmonics and THD, which historical have caused problems.
- Consider more strict requirements at higher voltage levels.
- Avoid unnecessary costs and requirements.
- Provisions that apply for 100 % of the time unless exemptions are granted.
- International standards (CENELEC, IEC, IEEE)
- Compatibility between regulations, including emission and immunity standards.

Results from several years with measuring harmonics in the Norwegian power system, and the national research institute SINTEF Energy Research's experience for decades dealing with both practical and theoretical studies on harmonics, gave a sound basis for the final limits for both $THD_U$ and the individual harmonics. As regards voltage level up to and including 35 kV, limits for individual harmonics given in EN 50160 seem satisfactory, given that they apply as a ten-minute average for 100 % of the time. EN 50160 has a limit for $THD_U$ at 8 % as a ten-minute average. In the Norwegian power system it has historical been problems for customers when the $THD_U$ has been between 5 % and 8 %. With $THD_U$ always less than 5 %, problems have only been experienced due to resonance phenomena. Based on this NVE introduced limits for $THD_U$ at 8 % as a ten-minute average and $THD_U$ at 5 % as a week-average (seven days) and those limits apply for 100% of the time.

The influence of the voltage due to harmonic currents will depend upon differences in the short circuit power (system impedance) in the network. Harmonic currents at one voltage level may also give rise to harmonic voltages at other voltage levels depending on the network structure. To make it possible to deal with harmonic limits in LV and MV network, it is necessary to have stricter limits at higher voltage levels. From 35 kV up to and including 245 kV, NVE introduced limit for $THD_U$ at 3 % for 100 % of the time. Above 245 kV NVE introduced limit for $THD_U$ at 2 % for 100 % at the time. Limits for individual harmonics above 35 kV, please see The 3rd CEER Benchmarking Report on Quality of Electricity Supply (December 2005), or visit NVE's website www.nve.no.

### 3.2.2 Hungary

Supply voltage variations shall be within $U_n$ ±7,5 % for 95 % of the time as a 10-minute average. Maximum voltage level is $U_n$ +15 % as a 1-minute average. All 10-minute averages must be within the +10 and -15 % range of the nominal voltage. These limits apply for both MV and LV network. For other voltage quality parameters EN 50160 limits apply.

Reasons behind is, that earlier than EN 50 160 was prepared, there was a norm (MSZ 1) in Hungary which - based on researches and polls in the years 1970 - 1977 - set the limits of supply voltage variation at ± 7.5 % of the nominal voltage at the LV customer connection points. Hungary has been adhering to this norm since then. Aim is that the customer shall have the same quality of voltage throughout the country he got used to.

Hungary regulated after the preparation of 3rd CEER Benchmarking Report on Quality of Electricity Supply (December 2005) the number of short interruptions caused by fast and slow fault clearing (automatic reclosing) by maximum 70 cases in order to overcome the problems of the indicative levels for short interruption written in the EN 50 160 ("Between a few tens and several hundreds per year; in 70 % of the cases duration can be less than 1 second"). This was done to protect the consumers. Reasons behind it is that the EN 50 160 gives very loose and even indicative levels.

### 3.2.3 France

In France the voltage quality limits are set both in legal decrees and through contracts, where they can be negotiated between the customer and the distribution/transmission operator. Voltage quality regulation in France does not really exist. The regulator only surveys the contracts' models but does not set standards.

Requirements have been developed by agreements between networks' users, manufacturers and operators, for some of them before the regulator's existence.

For MV and HV customers, contracts' models include limits required for voltage fluctuations, flicker, voltage unbalance, frequency fluctuations and voltage harmonics (only on the global rate). They also include the possibility for the customer to pay for an extra requirement related to the maximum number of voltage dips per year. This special service only takes into account voltage dips deeper than 30 % of $U_n$ and longer than 600 ms. It is based on historical performances for the transmission network and on the local conditions for distribution networks.

A legal decree from the 29th May 1986 specifies that supply voltage variations on low voltage networks shall be within 358 V and 423 V for $U_n$ = 400 V and within 207 V and 244 V for $U_n$ = 230 V. In this case, EN50160 measuring conditions apply.

Two other legal decrees (17th March 2003 for distribution networks and 4th July 2003 for transmission network) specify that before connecting a customer, the operator should verify that limits set in those decrees will be respected. In case the limits could be breached, the connection cannot happen before proceeding to works on the network in order to reach the standards. The way to survey requirements on voltage quality perturbations is then to oblige operators to control the respect of the requirements before doing a connection.

### 3.2.4 Portugal

The first Quality of Service Code of Portugal, published in 2000, established the obligation of quality waveform monitoring. Considering the lack of expertise in this mater, and since EN 50 160 is a European standard, this standard has been adopted. Since then, it has been already published two others quality of service codes, one in 2003 and the last one in 2006. In general, the quality of service code in force maintains the same provisions of the previous codes related to the voltage quality. However some changes have been done considering the experience.

The transmission and distribution operators are responsible for the network voltage waveform quality. They have the duty to look out for the levels of each characteristic. However, the other installations connected to the network are responsible for their installations disturbances emissions to the network.

Operators have to monitoring the following characteristics:

- Frequency
- Voltage magnitude
- Harmonic voltage
- Voltage dip
- Voltage unbalance
- Flicker severity

Additionally, operators monitor overvoltages and interruptions.

The limits or values defined to voltage waveform characteristics in the delivery point are the ones established in the NP EN 50 160 (translation of the European Standard EN 50160), for LV and MV[11], and the Complementary Instructions published by DGGE in accordance with Quality of Service Code for HV and VHV[12]. For this voltage level the limits or values established for each voltage waveform characteristic were the same as the ones established in the following documents:

- Frequency: NP EN 50 160.
- Harmonic voltage: For even harmonics (HV and VHV) and odd harmonics (VHV) the values are the ones established in the standard IEC 1000-2-6 to compatibility levels to HV and VHV.
- Voltage unbalance: NP EN 50 160, the values are the same as the ones established in the compatibility standards.
- Flicker severity: NP EN 50 160.

The declared voltage limit, $Uc=Un\pm7\%Un$, translates the agreement established between the transmission and the distribution operator.

The Complementary Instructions published in accordance with the two last Quality of Service Codes (2003 and 2006) established higher values to the 5th harmonic. This change was made because the values established before were hard to fulfil by the transmission operator in some points where the measured values in the network were higher than the limits.

In what concerns to voltage dips, and considering the difficulties related to the results recorded, since the second Quality of Service Code the standard “IEC 61000-2-8: Electromagnetic compatibility (EMC) - Part 2-8 Environment - Voltage dips and short interruptions on public electric power supply systems with statistical measurement results” was adopted.

The two previous quality of service codes established that the voltage quality monitoring should be done in the transmission and distribution networks in accordance with an annual plan. All procedures related to the plans’ development and approval should be completed the year before their application. Until the end of October, the plans should be developed by each operator and presented for approbation.

The quality of service code in force establishes that the voltage quality verifications must be done with the objective of charactering the quality waveform of all grid and identifying zones that required an improvement of it quality. It is established a period of two years for the monitoring of every delivered point in the HV and VHV and a period of four years to characterise the voltage quality in the distribution (all HV/MV substation in MV bus bar and at least in two PT of each municipality).

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[11] LV – Low Voltage (voltage between phases whose rms value is equal or lower than 1 kV).

MV – Medium Voltage (voltage between phases whose rms value is higher than 1 kV and equal or lower than 45 kV).

[12] HV – High Voltage (voltage between phases whose rms value is higher than 45 kV and equal or lower than 110 kV).

VHV – Very High Voltage (voltage between phases whose rms value is higher than 110 kV).

During these years no fulfilments that have been identified relate to voltage magnitude, flicker severity and harmonic voltage.

The Quality of Service Code does not establish any kind of penalty to companies when the limits are not fulfilled. In this situation, ERSE points out the no fulfilment results and asks to the operator to clarify the situation. The company is asked to identify the problem that gives rise to that situation, to identify the solutions and after to confirm the effectiveness of the implemented solution with new monitoring measurements.

The costs associated to the voltage waveform monitoring are supported by each operator.

When a client complains about subjects related to the voltage quality and the distribution operator does not have enough information to typify the voltage waveform in the client delivery point, the operator has to make additional measurements. After the monitoring, the distributor has to give to the client the following information:

- Monitoring period.
- Type of equipment that was used during monitoring.
- Type of disturbances that have been registered.
- Analysis of the regulated values or limits fulfilment.
- Entity responsible for the disturbances.
- Deadline to solve the no fulfilments.

If results reveal that waveform characteristics are in accordance with the Quality of Service Code values or if the waveform characteristics are not in accordance with the code values due to the client, then the client has to pay the costs related to the extra measurements. The amount that the client has to pay in this situation is limited to an amount established and published each year by ERSE.

The client can install equipment to measure his installation voltage quality. If the equipments are installed and sealed after a writing agreement with the distribution operator, its measured values are valid as prove in a claim.

However, some non systematic events can occur, and even it affected the quality of voltage supplied to client installation, the following operator voltage monitoring will not revel that situation. On that account, is necessary that the voltage monitoring be integrated with systems that registered the events in the network and analysed it consequences in the clients installations.

Complaints registered are in most of the cases related to voltage dip. However, in some situations the problems are associated with the layout of client installation and the equipments protection.

The Complementary Instructions establish the limits of disturbances that each installation can emit to the network. These limits are defined in accordance with the contracted power. The methodology is established based on the following standards:

- IEC 61000-3-6 (1996-10): "Electromagnetic compatibility (EMC) – Part 3: Limits – Section 6: Assessment of emission limits for distorting loads in MV and HV power systems".
- IEC 61000-3-7: "Electromagnetic compatibility (EMC) – Part 3: Limits – Section 7: Assessment of emission limits for fluctuating loads in MV and HV Power Systems – Basic EMC publication".

The definition of the allowed emissions from the client to the network and it appliance is a very complex mater and need to be study and analysed in a deep way.

The transmission and the distribution operators may advice the clients connected to their network on the best way to mitigate the disturbances caused by their installations on the network. But, if the disturbances due to a client cause damages to the voltage waveform quality, the network operator has to contact the client and agree with him on a dead line to solve the problem. When there is no agreement between operator and client, the decision is submitted to ERSE. If at the end of that time the problem is maintained or causes serious damages, for instance related to the safety of the equipments of other clients, the entity responsible for the network can disconnected the polluter installation. This situation must be communicated to ERSE and DGGE.

During the appliance of the quality of service code it has been identified some difficulties related to the voltage waveform quality of voltage disposals that in most of the cases become from the appliance of NP EN 50 160 and in other case the inexistence of national or international orientations to lead with some issues.

Summarizing, the main difficulties related to the voltage quality monitoring are related to:

- The period necessary to characterise each voltage waveform characteristic.

- The voltage quality measurements reporting, namely how to select and report the values that characterize the network performance and how to report the results related to voltage dips.

- The establishment and verification of the limits for the client's pollution, considering the distribution of the disturbances limits in one point for more than one client the possibility of new clients.

### 3.2.5 Spain

In Spain maximum limits for supply voltage variations are ±7 % of the declared voltage measured as ten-minute average values and apply for 95 % of the time. For the remaining 5 % of the time and other voltage quality parameters the limits in EN 50160 apply.

## 3.3 Costs related to poor voltage quality and short interruptions

Several European countries have estimated customers' costs related to short and long interruptions over the past years and decades. These costs are normally based upon nation wide customer surveys. Very few countries have estimated customers costs related to poor voltage quality. When voltage quality has been involved in customer surveys, only a few parameters have been included. This area needs indeed further research, but there are reasons to believe that the society's costs are high because of unsatisfactory voltage quality.

Below, different countries' costs related to voltage quality parameters and short interruptions[13] are described.

In Norway, a national research project finished in 2002 based on a nation wide customer survey including both long and short interruptions, and some selected voltage quality parameters. Results from the project have given the following costs[14] for final customers in Norway related to large deviations for some voltage quality parameters and short interruptions:

- *Supply voltage variations:* Annual costs because of too high and too low stationary voltage, based on the response from seven companies within the process industry, are approximately 5 375 € and 17 875 € respectively per respondent.

- *Transient overvoltages:* Annual costs, based on the response from eight companies within the process industry, are approximately 3 125 € per respondent.

- *Supply voltage dips:* Annual costs for Norwegian final customers is *estimated* to be between approximately 21,3 M€ and 41,3 M€.

- *Short interruptions:* Annual costs for Norwegian final customers is *estimated* to be between approximately 47,5 M€ and 66,3 M€.

In Sweden, a research project finished in 2003 based on an earlier made customer survey, resulted in *estimated* annual costs for industrial customers related to short interruptions and voltage dips, from 105 M€ to 157 M€ (actual costs).

In France actual value of compensations paid to LV and MV customers for damages due to poor quality (interruptions and voltage quality) are listed in the table below:

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[13] This paper mainly deals with voltage quality issues. But in the case of costs, short interruptions are included due to the close relation to voltage dips as regards cause and consequences.

[14] The Norwegian costs are 2002 level and the rate of exchange used is 1€ = 8 NOK.

| | 2003 | 2004 | 2005 |
|---|---|---|---|
| Amount of compensations | 35 M€ | 37 M€ | 26 M€ |
| Number of cases | 480 000 | 400 000 | 380 000 |

*Table 1– Actual value of compensation paid to customers connected to low and medium voltage networks in France. Compensation is due to interruptions and poor voltage quality.*

In Italy a nation wide survey was carried out in 2004 detecting customers' costs related to interruptions and voltage dips. The survey included 256 industrial companies. The results are presented in Figure 4, but bear in mind that the results include both dips and interruptions. In many cases it's difficult for the customers to know whether the machinery stops because of an interruption or a supply voltage dip.

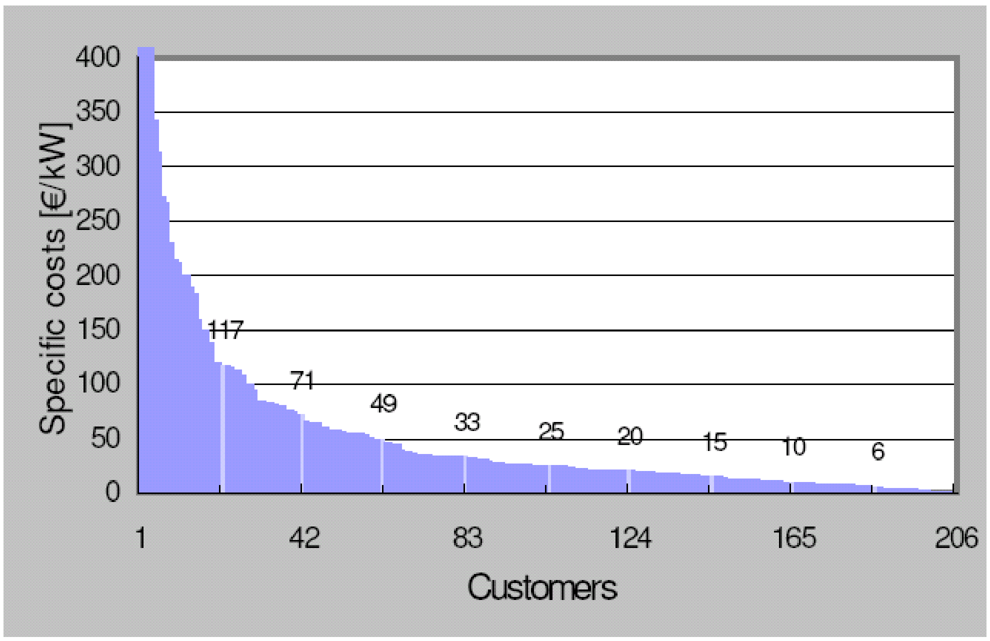


*Figure 4 - Cumulative curve for specific annual costs because of interruptions and supply voltage dips in Italy based on a survey including 206 industrial companies (source Cired 2005, Chiumeo* et al.*, paper n. 356)*

A further research is now in progress in Italy, aimed to evaluate the costs borne by industrial customers for voltage dips and transient interruptions[15].

[15] In Italy, interruptions with a duration of maximum one second due to automatic reclosures are named "transient interruptions".

# 4 Recommendations to CENELEC for revising EN 50160

In this chapter, some recommendations to CENELEC for revising EN 50160 are proposed. The recommendations are based on experience of monitoring voltage quality levels in some European countries (especially Norway, Hungary and Italy) and on first cases of setting voltage quality standards different from limits and values stated in EN 50160.

Recommendations are aimed to promote cost-effective investments in networks taking public and private interests into account. It is worth highlighting that changing measuring time intervals, limits and so forth in EN 501610 does not necessarily lead to higher costs for the society. The change in the society's costs will depend upon the difference between new requirements and the present level of quality and will differ from country to country. For a country with much better quality than stated in the present EN 50160, it may be a cost for the society to allow a deterioration of quality to the levels in EN 50160. As EN 50160 was conceived in mid-90s, there is no information available that limits in that norm were based on cost-benefit analysis.

The following recommendations to CENELEC for revision of EN 50160 are given in a priority order.

## 4.1 Improve definitions and measurement rules

Not all voltage quality parameters are defined in a totally satisfactory manner in EN 50160. Sometimes other standards can help defining some parameters in greater detail, but for the sake of simplicity and clearness EN 50160 should be reviewed in order to incorporate advancements in definitions. A large international consensus on VQ definitions should be actively searched for. To ensure good and uniform measurement of results of voltage quality parameters, it is of paramount importance that the same parameters are uniformly defined. EN 50160 includes both good and poor definitions for voltage quality parameters. The present state of EN 50160 is therefore not in a condition to ensure uniform calculations, registrations and measurements of voltage quality parameters. Based on this, some proposals for improving definitions are described in technical detail in Annex 3.

In the following passages problems are raised and solutions are proposed, as a contribution for a debate among experts and different standardisation bodies.

Firstly, some types of voltage events appear to require improvements in definitions:

- *Rapid voltage changes*, which are currently defined in EN 50160 as: "a single rapid variation of the RMS value of a voltage between two consecutive levels which are sustained for definite but unspecified durations." It is evident that this is a definition needing reconsideration. The NVE proposal for defining rapid voltage changes, described in details in Annex 3, may be considered. Rapid voltage changes are important for two reasons: (1) they are source of visual annoyance for human eyes, and (2) they are a symptom of insufficient short-circuit power in the point of connection.

- *Supply voltage dips* are currently defined in EN 50160 as "a sudden reduction of the supply voltage to a value between 90 % and 1 % of the declared voltage. Conventionally the duration of a voltage dip is between 10 ms and 1 minute". This definition, that is substantially correct and useful, could be re-evaluated for some aspects:

- *The threshold for distinguishing dips and interruptions.* This is currently set at 1% of retained voltage. This should be considered to move to 10 %, given the inherent accuracy of VQ recorders, and the possibility of voltage being induced because of power lines nearby.

- *The threshold for distinguishing dips and rapid voltage changes.* This is currently set at 90 % of retained voltage. This should be evaluated taking into consideration electrical equipments critical levels for different durations (as an example, the ITIC curve can be considered) including the voltage drop inside customers' installation. Further, experience on both the number and different causes of dips and rapid voltage changes close to the today's threshold may play a role.

- *The minimum duration of a voltage dip.* This is currently set to 10 ms. A voltage dip begins when the $U_{rms(1/2)}$ falls below the dip threshold where $U_{rms(1/2)}$ is the value of the RMS voltage measured over 1 cycle (20 ms), commencing at a fundamental zero crossing, and refreshed every half cycle (10 ms), c.f. IEC 61000-4-30. Due to this, it is possible to measure a supply voltage dip with duration of 10 ms. According to the ITIC curve, a dip duration at 10 ms will however not harm electrical equipment. This should be looked into.

- *The maximum duration of a voltage dip.* This is currently set at 60 s (1 minute). This should be looked into taking into consideration dip duration caused by typical dip causes. If the maximum duration shall be lowered, a new definition for longer durations may be needed.

- *Temporary (power frequency) overvoltages (voltage swells),* which are currently defined in EN 50160 as "an overvoltage, at a given location, of relatively long duration". A voltage swell is the opposite phenomena to a voltage dip and should be equally well defined. According to the ITIC curve and experience from research environment a voltage swell with duration of only 10 ms may damage equipment. This should be taken into account when defining the parameter. See Annex 3 for more details.

Secondly, some problems are still open regarding VQ measurement. Among these is the issue of total uncertainty in case of VQ measurements on MV networks, due to the contribution of voltage transducers. To solve these measurement problems with sound definitions and measurement methods, a preliminary step towards setting VQ standards is necessary. Measurements of power quality should be carried out in accordance with relevant international standards. As regards measurement methods, it is in general satisfactory to refer to IEC 61000-4-7, IEC 61000-4-15 and IEC 61000-4-30[16], given that EN 50160 is changed with proper definitions (also see Annex 3). Further, calibration traceability for the different parameters is of paramount importance[17]. It

[16] The only suggested change to IEC 61000-4-30 is about the specification of accuracy class for measurement instruments. A new class (class S) is currently under public inquiry and its approval would contribute to an easier diffusion of VQ measurement cases. ERGEG considers that class S can be adopted for contractual applications, even for disputes. Class A could be used only for calibration.

[17] In the International Vocabulary of Basic and General Terms in Metrology (1993) "traceability" is defined as: "Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties."

is doubtful that there is traceability for each of the voltage quality parameters described above. This should be looked into.

Thirdly, *short interruptions* should be defined as interruptions having duration comprised from 1 second up to and including 3 minutes, separately from *transient interruptions*[18] with duration below 1 second. A further harmonization in operational rules for calculating main continuity indices for both short and long interruptions (SAIDI, SAIFI and MAIFI)[19] is openly recommended, especially for rules on sequences of interruptions affecting the same customers. Operational procedures currently used in European countries, generally inherited by the former integrated utility, are still too different and hinder full comparability, especially for re-interruptions and short/transient interruptions.

Lastly, some aggregated indicators could be developed not only for continuity of supply but also for voltage variations and events. Among these, SARFI[20] could be introduced as reference indicator for voltage dips, in relationship with the classification of dip severity.

### 4.2 Limits for voltage variations - Avoid "95%-of-time" clause and avoid long time intervals for averaging measured values

Most of the limits for voltage variations in EN 50160 are given for typical 95 % of the time. This means that, according to EN 50160, for 8 hours every week there can be severe voltage deviations in the supply voltage without exceeding the limits in the standard. This is the case even when the variations are of such a character that the network company should be able to cope with them. This is a huge problem for customers. The manufactures will not design equipment for handling the remaining 5 % of the time, which leaves the risk to the customers. 95 % of the time may be satisfactory for statistical purposes but not in order to protect against equipment damage or equipment failure.

The clause of 95-%-of-time (applicable to most of the parameters in EN 50160) is too loose and therefore there is lack of customer protection. *Ideally* voltage quality requirements should apply for 100 % of the time (at least 100% of normal operating conditions). Different provisions should apply only for the consequences of exceptional events – that should be better defined[21] – and for taking into account some special conditions of network management (as for instance back-feeding to restore supply after faults). Allowing different provisions for certain conditions is most (if not only) relevant for deviations that do not lead to severe damages for electrical equipment. If a certain condition causes voltage deviation that may lead to damage for electrical equipment, than for the customer it's better to experience an interruption.

[18] In EN 50160 it is stated that "the duration of approximately 70% of short interruptions may be less than 1 second". In some countries, like France and Italy, interruption with a duration of maximum one second are counted separately from other short interruptions.

[19] Some continuity indices are defined in the American standard IEEE1366 Guide for Electric Power Distribution Reliability Indices. Continuity indices are widely used among European countries, but not always in the exact same way. It is therefore considered to be a need to define continuity indices at European level. Some of the uncertainties are especially as regards counting sequences of interruptions and defining Major Event Day.

[20] Source: CIGRÉ JWG C4.07 "Power Quality Indexes and Objectives", 2004

[21] EN 50160 gives a rather long list of exceptional events, which should also be discussed in dialogue with different stakeholders including the ERGEG.

An extremely critical point is also the time interval used for averaging measured values in order to verify limits of voltage variations (especially as regards supply voltage variations and flicker severity). As seen in chapter 2.3, the currently used 10-minute average is related only to thermal effects and may hide some voltage variations that could damage equipment. Hence, a change of the time interval used to average measured values should be considered consistently with the 95%-of-time issue. Hungary and Norway deal with this problem in two different ways. Hungary uses a 10-minutes average for verifying the minimum and maximum compatibility levels of voltage threshold at 95% of the time, but all 10 minutes averages of the supply voltage shall be within the range of Un+10/-15% (no exemption for remote areas), and uses 1-minute average for verifying the maximum limit of voltage threshold at 100 %. Norway uses only 1-minute average for verifying the minimum and maximum limits for supply voltage variations at 100 % of the time.

In general, limits for supply voltage variations should be very clear and uncontroversial. All limits for voltage variations should be given by the term *shall*, in order to ensure compliance. The new revision project of EN 50160 (prEN 50160:2006) does not seem to be very consistent with this need for clarity, as in requirements for supply voltage variations in LV networks (clause 4.3.1) it is written that voltage variation should not exceed $U_n$ ± 10 %" (under normal operating conditions). But the old test method has been kept with no changes in respect of the current edition of the norm. Further, the envisaged review of voltage tolerance band for reducing it[22] has not been started yet. Of course, for the limits to supply voltage variations different solutions can be adopted for LV, MV and HV customers. For the latter, declared voltage $U_c$ is a better reference than nominal voltage $U_n$. Figure 5 shows how different stakeholders interpret the today's limits in EN 50160 differently. There is indeed a need for clarity.

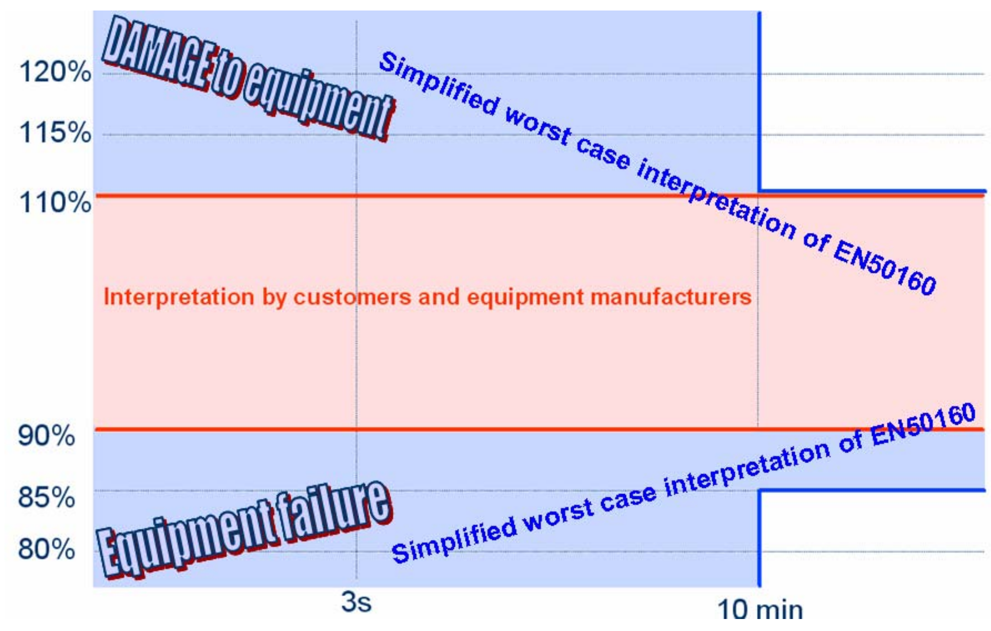


*Figure 5 – A picture of interpretation of the today's limits for voltage variations by different stakeholders. (Courtesy: Mr Helge Seljeseth (SINTEF), workshop CEER on Voltage quality standards, Milan September 29th 2006)*

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[22] A clear address in a reduction in the tolerance band for supply voltage variations is given in the CENELEC harmonisation document HD 472S1.

## 4.3 Enlarge the scope of EN 50160 to high and extra-high voltage systems

The present EN 50160 limits and indicative levels apply only to MV[23] and LV[24] networks. Incidents or actions leading to voltage variations or voltage events occur also at higher voltage levels than those to which final customers normally are connected. Voltage disturbances at one voltage level may be transferred to a lower or higher voltage levels. This will however depend upon several factors among other network structure and short circuit power. In general, it is easier for disturbances to be transferred from higher to lower voltage levels due to differences in the short circuit power. Voltage quality standards should be developed and should apply to all voltage levels, including HV[25] and EHV[26].

## 4.4 Avoid ambiguous indicative values for voltage events

As seen in chapter 2.2 (voltage events), EN 50160 does not give binding limits but only indicative (non-binding) values. Especially for dips and interruptions, indicative values are given with rather vague formulas (e.g. "up to several hundreds") that are not useful for customers, neither for claiming damages when these occur nor even for designing their own protection systems in an economically sound manner, or for taking appropriate countermeasures. Indicative values for rapid voltage changes are only given with regard to the magnitude and not the frequency. Indicative values for voltage events are no longer acceptable if they are expressed in such an ambiguous manner.

Since EN 50160 was conceived, a vast knowledge about stochastic distribution of voltage events has been cumulated and it's now time to rethink the approach, specifying limits even for voltage events.

As a preliminary step, a *classification of severity of voltage dips and swells* is needed. This can be done through the definition of a "voltage dip table" that classifies dips by depth and duration, in order to distinguish group of events having common severity characteristics. The same can be done for voltage swells by height and duration. The "voltage dip table" proposed by UNIPEDE some years ago proved not be effective and should be reviewed. It's important that such a classification table takes into account electrical equipments critical levels and the dips different causes. A Rationalized User Specification (NRS 048-2:2004) from South Africa, contains an interesting classification of voltage dips based upon inter alia customer plant immunity and possible causes of voltage dips. This user specification is however not a national or international standard (see Annex 4). ERGEG proposes to have an expert evaluation of a dip and swell classification table taking into account following items:

- Voltage depth and duration for voltage dips. Voltage height and duration for voltage swells.

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[23] In EN 50160 low voltage (LV) is used for the supply of electricity, whose upper limit of nominal RMS value is 1 kV.

[24] In EN 50160 medium voltage (MV) is used for the supply of electricity, whose nominal RMS value lies between 1 kV and 35 kV.

[25] In IEC standards HV is used for networks with nominal RMS values from 35 kV up to and including 230 kV. In IEC standards MV include 35 kV networks.

[26] In IEC standards EHV is used for networks with nominal RMS values above 230 kV.

- Electrical equipments critical levels (e.g. the ITIC curve), and different consequences (trip, malfunction, damage etc).
- Different typical causes; short circuits, earth faults, motor start-ups, transformer inrush currents etc. Zone 1, zone 2 clearance etc.
- Location of the incident; close or remote incident.
- Simplicity has to be evaluated against usefulness.

Such classification of voltage dips and swells should enable regulators to put measures into place were it's most cost-effective and will be useful for both monitoring and investigations; further, it is a first step towards a possible future regulation of voltage dips and swells. The classification of voltage dips and swells is a very important change for EN50160 (that currently does not contain any dip or swell requirements or classification tables).

## 4.5 Consider duties and rights of all parties involved

The revised EN 50160 should indicate responsibilities of all interested parties: network companies (both distribution and transmission grid operators), customers and equipment manufacturers. In this field, a sound coordination among technical standards (both system-related and product-related) is of paramount importance. Limits given in EN 50160 must not be in conflict with other technical standards, for instance product standards, emission and immunity standards. EN 50160 should not contain limits which will lead to severe costs if electrical equipments are to handle them.

Sharing responsibilities between the parties involved is of key importance from the regulators' viewpoint. The revision of EN 50160 should lead to a first milestone in the coordination between technical standards: this may be achieved by introducing suitable curves in the plan voltage/time. A possible approach is depicted in Figure 6.

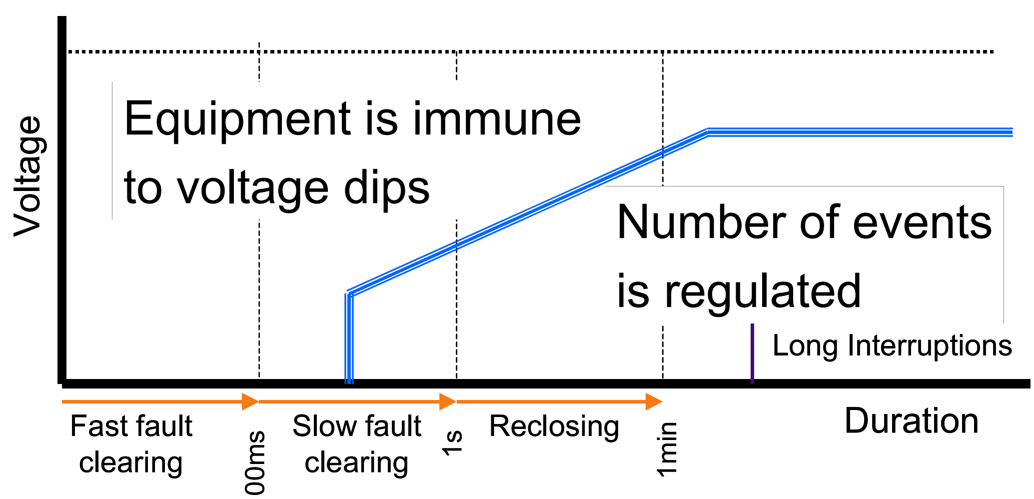


*Figure 6 - Hypothetical curve for responsibility sharing.*
*(Courtesy: prof. Matt Bollen, workshop CEER on Voltage quality standards, Milan September 29th 2006)*

The blue line in Figure 6 is a hypothetical border for discriminating network and equipment responsibility. The zone above this line represents the permitted behaviour of the network, and no action by the regulator is needed. Within this above-the-curve area, negative effects, like visual annoyance, related to rapid voltage changes are captured by flicker indices[27]. CE marked equipment should also be able to operate satisfactory above the curve. The zone below the curve can be considered (in a further stage of the technical standardization) as a minimum immunity area for equipment (process). This immunity area will be even wider, depending on the class of equipment or type of process. As for the network performance, all the event falling below the curve might be subjected to regulation, with different limits (e.g., different number of events allowed in rural areas vs. urban areas), varying among different countries or among different network structures. Furthermore, network performances may vary significantly depending also on the protection systems put in place by both distributors and customers.

The approach followed in NRS-048-2 for voltage dips is a practical example of this framework (see Annex 4), that can be enlarged to all voltage variations and events.

Duties and rights of all the parties should be taken into account. Characteristics of withdrawal (e.g. harmonics currents) should be explored, as well as minimum level of short-circuit power provided by operators, in order to clearly identify responsibilities for voltage quality disturbances. To this aim, also the presence of “disturbing” customers has to be accounted for. The level of disturbance that customers are allowed to inject has to be compliant with the short circuit power at the connection point to achieve the prescribed voltage quality. If special network features are needed (e.g. high values of short circuit power) they should be arranged for by suitable contracts.

Measurements should be considered as well in order to simply obtain a non controversial measure of disturbances, and as far as possible, a meaningful one for detecting responsibilities.

## 4.6 Introduce limits for voltage events according to network characteristics

The costs borne by customers for poor voltage quality require a new technical answer about reference levels applicable in the specific situation. The new approach to setting limits for voltage events must take into account that the present level of voltage quality may differ a lot both among the European countries and within the same country. Different countries may have different requirements or different network structures: e.g. neutral grounding is different among European countries and is very important for short interruptions and dips.

New limits for voltage events should be studied taking into account different network structures as far as possible in order to give realistic values. In this way, new limits should be differentiated according to main characteristics of the network (not only voltage level, but also: overhead/underground; neutral point configuration; short-circuit power; etc.). The availability of field data from the monitoring systems recently installed in some countries could be extremely helpful for this purpose.

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[27] Another way of measuring network performances within the “shaded” area is to use steadiness indicators, like the ones in force in Hungary, discussed during the Milan workshop

*VLSI= (Umax-Umin)(3s)/Umean(10min).*

Still the frequency of rapid voltage changes may have to be limited.

New limits, differentiated according to network characteristics, should not longer be referred to the worse situation throughout Europe, as some indicative levels currently given in EN 50160. New limits for voltage events should be given by the term "shall", as it is recommended for supply voltage variations.

### 4.7 Develop the concept of power quality contracts

It is stated in EN 50160 that "this standard may be superseded in total or in part by the terms of a contract between the individual customer and the electricity supplier" (point 1.1, last period). In 61000-4-30 the issue of power quality contracts is briefly presented in the informative Annex 6.
Power quality contracts are still at a starting phase but they can be useful for revealing customer preferences for quality, especially for customers with the greatest need for continuity and voltage quality. These contracts require that customers requiring better voltage quality have a clear willingness to pay for it. This is a reason why this kind of contracts is not yet widely diffused. The concept of power quality contracts should be developed, taking into account experiences and regulations in some European countries (especially France).

# 5 Towards voltage quality regulation

## 5.1 Voltage quality standards [28]

Many problems are still open for VQ measurements. Solving these measurement problems with sound definitions and measurement methods is a necessary preliminary step towards setting VQ standards. The highest priorities of the ERGEG recommendations given in the previous chapter are focused to improve the EN 50160 standard only for more precise and detailed definitions and measurement specifications. Given these first necessary improvements (that will take a considerable amount of time, due to the consensus basis upon which technical standards are based on), the open issue of setting minimum limits for every parameter of voltage quality (especially voltage events, for which only indicative values are yet given) still remains.

Some national energy regulatory authorities have already gone beyond EN 50160. It is too early now to tell if this will be a general trend in the future or not. Several options are still open; some countries will probably always refer to EN 50160 no matter how loose limits or definitions may be, and some countries will instead choose a “two-level” option, adopting definitions and measurement rules given in international standards (like EN 50160, adequately revised) but introducing national VQ limits and requirements by the national regulators, as has already happened in Norway and some other countries. The future will probably depend upon how satisfactory future editions of international standards (e.g. EN 50160) will turn out to be.

As voltage quality is a complex matter, regulators have to be very conscious in order to avoid the risk of making errors in setting standards and incentives for this very technical issue. The attention shall be drawn upon the right balance between technical requirements and consequent costs. Eliminating voltage quality perturbations through interventions on the networks can be very costly. Therefore, it can be inefficient to look only at network design and operations. Electrical equipment manufacturers and customers can participate to the effort of reducing voltage quality perturbations and to mitigate their effects on the correct functioning of electrical plants.

To this aim, cooperation between regulators and academics and researchers is strongly anticipated. As the specific matter is technically complex, and voltage quality depends on several factors (network structure, control, protections, selectivity, short circuit power and so forth) the knowledge and the skills of academic experts will help regulators in their effort.

## 5.2 Important items when introducing a national VQ regulation

Recommendations on important items to look into when making a national voltage quality regulation are given below. These recommendations are based upon the experience from countries that have developed such regulations.

When a national regulator wants to introduce a voltage quality regulation, it is important to consider following items as a minimum:

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[28] Voltage quality standards may normally be set by a standardisation body or by the regulator. Standards set by regulators may also be referred to as „regulations” or, in some countries, „requirements”.

- The level of quality during the specific period should be measured and detected; it is absolutely necessary to collect data on actual levels through adequate monitoring systems.

- It has to be evaluated whether the level of quality during the specific period of measurement is satisfactory or not, and whether it should be changed or not. Customer complaints' analysis, results from monitoring systems and ad hoc research can be used in this process.

- Not all deviations from the ideal voltage wave shape lead to problems for customers. A list identifying priority VQ parameters for regulation needs to be prepared. It is important to detect which level of different disturbances causes problems.

- There may be satisfactory international standards that can be referred to in the regulation. The deviation between limits in international standards and a country's quality level is of key importance. International standards may among others be referred to as regards limits or as regards definitions and measurement methods.

- In any case, it is important that national requirements take into account international emission and immunity standards, especially those used for testing electrical equipment and standards for emission limits.

- It is further important to be aware that society's costs connected to enforcing voltage quality requirements will depend on a possible deviation between the new requirements and the level of quality during the specific period of measurement. Network companies and customers have often adjusted to the today's level of quality.

- Regulators should also consider that there can be a side effect of continuity of supply incentive regulation for reducing some voltage disturbances related to network faults, like for instance supply voltage dips.

## 6 Invitation to Interested Parties to Comment

This document sets out ERGEG's consultation paper towards voltage quality regulation in Europe. ERGEG invites stakeholders to comment on issues raised in this paper and in particular on the issues for consultation pointed out in the document (chapter 7).

Responses should be received by **22 February 2007** and sent by email to:
**voltagequality@ergeg.org**

Any questions on this document should, in the first instance, be directed to:

Mrs. Fay Geitona
Secretary General
CEER
Rue le Titien 28
1000 Brussels
Belgium
Tel.: +32 2 788 73 30
Fax: +32 2 788 73 50

Unless marked as confidential, all responses will be published by placing them on the ERGEG website. If there is anything confidential please include it in a separate annex to your main response.

## 7 Issues for Consultation

The ERGEG invites stakeholders to comment on issues raised in the text.
Specifically ERGEG would like responses to the following questions:

*a.* ***General questions on the recommendations to CENELEC for revising EN 50160****: Do you agree with the general messages of the 7 recommendations given in chapter 4? Are there any other major voltage quality issues missing from those that have been considered in this document? Do you have any evidence, based on survey on both networks conditions and customers' needs in given countries, about costs and benefits related to the implementation of recommendations? Can you help us in qualifying and quantifying these costs and benefits?*

*b.* ***Specific questions on the recommendations to CENELEC for revising EN 50160****:*

- *What is an appropriate responsibility-sharing curve between equipments and grid in the voltage-duration plan (both for voltage dips and swells)?*
- *What is an appropriate way of protecting equipment against damage or failure due to short-duration overvoltages (voltage swells): limits for voltage swells (as events) or a shorter time interval (than the today's 10-min in EN 50160) for averaging continuously measured values (related to supply voltage variations)?*
- *Are there benefits, further than customer protection (for instance: reduction of losses), important enough to give reasons for reducing the range of voltage variations from Un ± 10 % to a narrower band?*
- *How to consider random year-by-year variations in setting limits especially for voltage dips and other events correlated to weather influence?*
- *For some topics (as for instance voltage steadiness within the tolerance band) the research made already available aggregate voltage quality indexes; should those aggregate indexes be used for regulatory purposes? Why or why not?*
- *How can power quality contracts be defined in order to focus improvements in voltage quality levels according to customers' preferences?*

*c.* ***Questions on the future of voltage quality regulation:*** *as discussed in chapter 5, setting minimum limits for every parameter of voltage quality (especially voltage events, for which only indicative values are given in EN 50160) still remains an open issue. Which are pros and cons of introducing national VQ limits and requirements by the* *national regulators? Do you believe that a "two level" option (definitions and measurement rules set homogeneously at EU level; limits set country by country by relevant authorities) can be a more effective way for improving or at least not deteriorating voltage quality?*

## Annex 1 – Technical overview

This Annex includes some details about the distinction among some different parameters.

Starting with continuity of supply, it can be stated that interruptions are typically originated by a fault in the system or by a planned disconnection. This can happen at any voltage level, although faults and planned disconnections affecting higher voltage levels seldom lead to customers being interrupted, depending on grid configuration and operation.

As for VQ parameters, voltage dips, swells and rapid voltage changes are given a major attention in this paper. These are among the most annoying deviations for customers. A voltage dip is a voltage RMS reduction to a level between (according to EN 50160) 90 % and 1 % of the nominal or declared voltage level, with a duration from ten millisecond up to one minute. Voltage swells are the opposite phenomena of voltage dips, i.e. a temporary increase in the voltage. A rapid voltage change is a single rapid voltage RMS variation in between ± 10 % of the nominal or declared voltage level. For a better understanding of these parameters, it has to be considered that every branch of a power system is characterized by its impedance. Thus every increase in the value of current flowing in that branch causes a corresponding reduction in the voltage. Usually, these reductions are small enough that the voltage remains within normal tolerances, and slow enough not to cause visual annoyance from the light intensity variations.

When a large increase in current happens, or when the system impedance is high, the voltage can drop significantly. Voltage dips are mainly caused by earth faults, short circuits in the network, inrush currents from large transformers and starting of large loads. The depth and duration of a voltage dip are of severe importance regarding which consequences this may lead to. Malfunction and trip of electrical equipment, damages and consequential losses may be the case when voltage dips occurs. All use of electrical equipment may lead to rapid voltage changes, but the voltage deviation will depend on the short circuit power (system impedance) in the network. Annoying rapid voltage changes are mainly caused by large motors, especially direct-on-line started induction motors, and coupling of capacitor banks. Earth faults and short circuits may lead to rapid voltage changes in connection points far away from the location of the fault. Rapid voltage changes will mainly lead to visual annoyance in the light, and will normally not lead to damage for electrical equipment. Please notice that the same cause may sometime lead to a rapid voltage change, and sometime to a voltage dip, depending on the short circuit power in the network. The consequences will however depend on the voltage deviation and its duration.

The number and severity of voltage dips, swells and rapid voltage changes depends on the

- extension and meshing of the HV network;
- extension and meshing of the MV network fed by the substation;
- extension of the LV network feeding the final customer;
- presence of cable or overhead lines;
- neutral grounding (isolated, solidly or impedance grounded);
- short circuit power;
- characteristics of final customers electrical equipment;
- dispersed generation.

## Annex 2 – Standardisation bodies

This Annex includes a short description about the standardisation bodies CENELEC and IEC. For more information please visit their homepages www.cenelec.org and www.iec.ch respectively.

*CENELEC - European Committee for Electrotechnical Standardization:*

CENELEC is a non-profit technical organization set up under Belgian law and composed of the National Electrotechnical Committees of 29 European countries. In addition, 8 National Committees from Eastern Europe and the Balkans are participating in CENELEC work with an Affiliate status. CENELEC members works together in the interests of European harmonization creating both standards requested by the market and harmonized standards in support of European legislation and which have helped to shape the European Internal Market. CENELEC has adopted several IEC standards, which also function as CENELEC standards. See information about IEC below.

*IEC – International Electrotechnical Commission:*

IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. The IEC charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment.

The IEC produces two categories of publications:

- **International consensus products**
  - International Standards (full consensus)
  - Technical Specifications (full consensus not (yet) reached)
  - Technical Reports (information different from an IS or TS)
  - Publicly Available Specifications
  - Guides (non-normative publications)
- **Limited consensus products**
  - Industry Technical Agreement
  - Technology Trend Assessment

The IEC 61000 series is comprehensive and includes standards about limits for voltage disturbances, immunity and emission limits for electrical equipment, measurements for voltage quality and measurements techniques. In general the IEC 61000 series can be divided into:

- 61000-1-XX General consideration (introduction, fundamental principles) Definitions, terminology.
- 61000-2-XX Description and classification of the environment, compatibility levels.
- 61000-3-XX Emission and immunity limits.
- 61000-4-XX Testing and measuring techniques.
- 61000-5-XX Installations and mitigation guidelines.
- 61000-6-XX Generic standards.
- 61000-9-XX Miscellaneous.

## Annex 3 – Technical comments and recommendations for the revision of EN 50160

### - Definitions

Supply voltage variations

Supply voltage is in EN 50160 defined as:
"*The rms value of the voltage at a given time at the supply terminals, measured over a given interval.*"

The time interval to average measured values will be of major importance as regards which deviations that will be measured. EN 50160 includes limits measured as a ten-minute average. This will neglect severe deviations which may lead to damage or malfunction using electrical equipment. It's therefore strongly recommended to re-evaluate the length of the measuring time interval used, also see chapter 2.3 and 4.2.

Rapid voltage changes

A *rapid voltage change* is a term used for rapid (fast) voltage changes within ± 10 % of the nominal or declared voltage level. Important factors to define rapid voltage changes (see chapter 3.2.1 and Figure 3) in a proper manner are:

- The minimum rate of change (dv/dt) before this leads to visual sensation from the light intensity variations.
- The steadiness of the steady state condition.
- The minimum duration of the steady state conditions (between two voltage change characteristics).
- Voltage deviation: The maximum voltage change and/or the steady state voltage change.
- Which voltage level to relate the voltage change to: The operating voltage right before the voltage change characteristic occurs or the nominal/declared voltage level?

Of these five bullets the last three is more or less covered by definitions in international standards, especially IEC 61000-3-3[29]. IEC 61000-3-5[30] and IEC 61000-3-11[31] are both referring to IEC 61000-3-3 as regards definition of rapid voltage changes. IEC 61000-4-30[32] does not deal with rapid voltage changes in the normative part of the standard, but gives only a general description in an informative annex.

[29] IEC 61000-3-3 Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated currents ≤ 16 A per phase and not subject to conditional connection.

[30] IEC 61000-3-5 Limitation of voltage fluctuation and flicker in low-voltage power supply systems for equipment with rated current grater than 16 A.

[31] IEC 61000-3-11 Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems – Equipment with rated current ≤ 75 A and subject to additional connection.

[32] IEC 61000-4-30 Testing and measurement techniques – Power quality measurement methods.

The first two bullets are today not covered in international standards. But in Norway SINTEF Energy Research has on behalf of NVE recently carried out a research project, which results indicate reasonable values for these two bullets. Based on major findings in this project it can be stated that a voltage change more rapid than 0,5 % of nominal/declared voltage level pr second, will lead to visual sensation for most people.

In EN 50160 rapid voltage changes are defined as:
"*A single rapid variation of the rms value of a voltage between two consecutive levels which are sustained for definite but unspecified durations.*"

This definition is not sufficient in order to calculate or measure the parameter in an uniformly manner.

The definition should be improved. As a result of the above mentioned research project carried out in Norway by SINTEF, NVE has in a public hearing proposed changes for the definition on rapid voltage changes in the Norwegian quality of supply regulation. The new proposed definition is:

*"A change in the voltage rms value within ± 10 % of nominal/declared voltage level, more rapid than 0,5 % of the nominal/declared voltage level per second. Rapid voltage changes are expressed by the steady state voltage change and the maximum voltage change given respectively:*

$$\%U_{steadystate} = \frac{\Delta U_{steadystate}}{U_{N/d}} \cdot 100\%$$

*and*

$$\%U_{max} = \frac{\Delta U_{max}}{U_{N/d}} \cdot 100\%$$

*where* $\Delta U_{steadystate}$ *is the steady state voltage change separated between at least two voltage change characteristics,*
$\Delta U_{max}$ *is the difference between maximum and minimum rms values of a voltage change characteristics*
*and* $U_{N/d}$ *is the nominal or declared voltage level."*

A voltage change characteristic is defined in IEC 61000-3-3:
"*the time function of the r.m.s. voltage change evaluated as a single value for each successive half period between zero-crossings of the source voltage between time intervals in which the voltage is in a steady-state condition for at least 1 s.*"

According to the above, the steadiness of the steady state condition can be stated to be when the voltage increase or decrease slower than 0,5 % of nominal/declared voltage level per second.

Figure 7 shows a voltage change characteristic where it is indicated what to be defined as a maximum rapid voltage change, and a steady-state rapid voltage change. Please notice that it is the voltage RMS value that is shown, and not potential transients. 10 ms indicates the measurements of a 20 ms gliding window. A similar figure is also presented in IEC 61000-3-3. The use of different types of electrical end-use equipment will cause different voltage change characteristics.

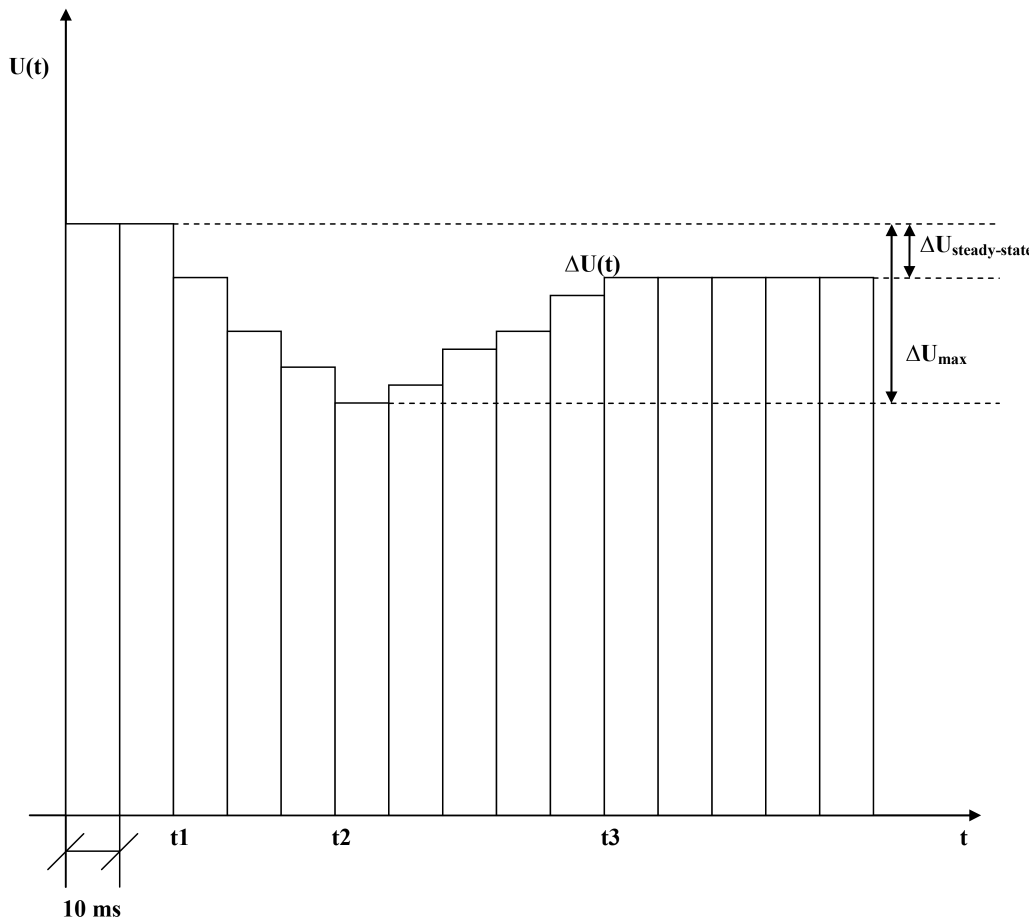


*Figure 7 - A representative voltage change characteristic, with statement of rapid voltage changes. U(t) = a voltage change characteristic, ∆Umax = maximum voltage change and ∆Usteadystate = steady-state voltage change.*

The definition on rapid voltage changes in EN 50160 should be improved taking into account the above.

Supply voltage dips

A voltage dip is a temporary reduction of the voltage at a point in the electrical system cf. IEC 61000-4-30. A voltage dip should be defined by:

- The minimum and maximum threshold for which the voltage reduction is to be considered a voltage dip
- The minimum and maximum duration of a voltage dip

EN 50160 states these to be respectively:

- A sudden reduction of the supply voltage to a value between 90 % and 1 % of the declared voltage level, followed by a voltage recovery after a short period of time
- Conventionally the duration of a voltage dip is between 10 ms and 1 minute

The depth and the duration of a voltage dip is of severe importance as regards different causes and possible consequences. Voltage dips should be considered classified by its depth and duration. This is further explained in chapters 2.1 and 4.1 and Annex 4.

Temporary (power frequency) overvoltages (= voltage swells)

A voltage swell is a temporary increase of the voltage at a point in the electrical system cf. IEC 61000-4-30. A voltage swell is the opposite phenomena as a voltage dip and should be equally well defined. A definition should cover:

- The minimum and maximum threshold for which the voltage increase is to be considered a voltage swell
- The minimum and maximum duration of a voltage swell

EN 50160 defines a voltage swell as:

"*An overvoltage, at a given location, of relatively long duration.*"

This definition is rather vague, and is rather useless in order to measure the parameter. It's strongly recommended that the definition for voltage swells is changed to be more in accordance with the definition of voltage dips, as the two phenomena are interrelated.

Voltage unbalance

Voltage unbalance is a condition in a polyphase system in which the RMS values of the line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equal, cf. IEC 61000-4-30.

Voltage unbalance is evaluated using symmetrical components. The most important relation to investigate is the ratio of the negative and the positive sequence component. In IEC 61000-4-30 this ratio is defined by:

$$u_2 = \frac{negativesequence}{positivesequence} \cdot 100\% = \sqrt{\frac{1-\sqrt{3-6\cdot\beta}}{1+\sqrt{3-6\cdot\beta}}} \cdot 100\%$$

where

$$\beta = \frac{U_{12\,fund}^4 + U_{23\,fund}^4 + U_{31\,fund}^4}{(U_{12\,fund}^2 + U_{23\,fund}^2 + U_{31\,fund}^2)^2}$$

EN 50160 defines voltage unbalance as:

"*In a three-phase system, a condition in which the rms values of the phase voltages or the phase angles between consecutive phases are not equal.*"

It's strongly recommended that the definition for voltage unbalance in EN 50160 is to be changed towards line voltages instead of phase voltages.

## - Measurements

Some relevant IEC standards as regards measurements are described below.

*IEC 61000—4-7:*
*Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.*

This standard is applicable to instrumentation intended for measuring spectral components in the frequency range up to 9 kHz which are superimposed on the fundamental of the power supply systems at 50 Hz and 60 Hz. The standard distinguishes between harmonics and interharmonics. The standard defines the measurement instrumentation intended for testing individual items of equipment in accordance with emission limits given in certain standards, as well as for the measurement of harmonic currents and voltage in actual supply systems. Instrumentation for measurements above the harmonic frequency range, up to 9 kHz is tentatively defined.

*IEC 61000-4-15:*
*Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications.*

This standard gives a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms. Information is given for the evaluation of flicker severity on the basis of the output of flickermeters complying with this standard.

*IEC 61000-4-30:*
*Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurements methods.*

This standard gives measurement methods but does not set thresholds. It is a performance and not a design specification. The standard defines the methods for measurement and interpretation of results for power quality parameters in 50/60 Hz ac power supply systems. Measurement methods are described for each relevant type of parameter in terms of that will make it possible to obtain reliable, repeatable and comparable results regardless of the compliant instrument being used and its environmental conditions.  The basic measurement time interval for parameter magnitudes (supply voltage, harmonics, interharmonics and unbalance) in this standard shall be a 10-cycle time interval for 50 Hz power system. Further measurements time intervals aggregated over three different intervals are 3 sec, 10 min and 2 hours. Other aggregation intervals may be used if the instrument handles them. In all cases the basic measurement method will be the same.

For harmonics and flicker the standard refers to IEC 61000-4-7 and IEC 61000-4-15 respectively.

Measurements of rapid voltage changes and transient overvoltages are not defined in this standard, but shortly described in an informative annex.

## Annex 4 – First stage proposals for classification of supply voltage dips

A South African user specification (NRS 048-2, Edition 2, 2004) contains an interesting classification table for voltage dips that may be considered when doing an expert evaluation of such. The South African classification table was also presented by Robert Koch, Eskom Resources & Strategy Division, at CIRED 2005 (Round Table on Voltage Dips Indices & Benchmarking).

<table>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td rowspan="2">Range of dip depth<br>$\Delta U$<br>(expressed as<br>a % of $U_d$</td><td rowspan="2">Range of residual voltage $U_r$<br>(expressed as<br>a % of $U_d$</td><td colspan="3">Duration<br>t</td></tr>
<tr><td>$20 < t \leq 150$ ms</td><td>$150 < t \leq 600$ ms</td><td>$0,6 < t \leq 3$ s</td></tr>
<tr><td>$10 < \Delta U \leq 15$</td><td>$90 > U \geq 85$</td><td rowspan="3"></td><td rowspan="2">**Y**</td><td></td></tr>
<tr><td>$15 < \Delta U \leq 20$</td><td>$85 > U \geq 80$</td><td rowspan="2">**Z1**</td></tr>
<tr><td>$20 < \Delta U \leq 30$</td><td>$80 > U \geq 70$</td><td rowspan="3">**S**</td></tr>
<tr><td>$30 < \Delta U \leq 40$</td><td>$70 > U \geq 60$</td><td>**X1**[a]</td><td rowspan="3">**Z2**</td></tr>
<tr><td>$40 < \Delta U \leq 60$</td><td>$60 > U \geq 40$</td><td>**X2**</td></tr>
<tr><td>$60 < \Delta U \leq 100$</td><td>$40 > U \geq 0$</td><td colspan="2">**T**</td></tr>
<tr><td colspan="5">NOTE In the case of measurements on LV systems it is acceptable to set dip threshold at 0,85 pu.</td></tr>
<tr><td colspan="5">[a] A relatively large number of events fall into the X1 category. However, it is recognized that dips with complex characteristics (such as phase jump, UB, and multiple phases) might have a significant effect on customers' plant, even though these might be small in magnitude. Customers might not have the mans to mitigate against the effects of such dips on their plant.</td></tr>
</table>

*Table 2 – Characterization of depth and duration of voltage dips. Example from South Africa. Source: South African Rationalized user specification NRS 048-2:2004. Edition 2.1. Y area is according to this source recognized as minimum plant immunity. Note and footnote in the table are also according to the source.*

The different cells are based on potential consequences including minimum and desired plant immunity, potential trip of drives, motor recovery without stalling and motor stalling. Further they are based on typical causes including Zone 1 and Zone 2 clearance, back-up and thermal protection clearance. The South African user specification (NRS 048-2) defines dip duration to be between 20 ms and 3 s and the dip threshold to be 90 % of the nominal or declared voltage level. Voltage dips with longer duration than 3 s are in NRS 048-2 considered as under-voltage events. NRS 048-2 contains however no classification of under voltage events. Based on the classification in NRS 048-2 voltage dips may be presented as total numbers that occur differentiated on the seven categories Y, X1, X2, T, S, Z1 and Z2.

This will also enable a monitoring of the development of the quality of the protection scheme in a geographical area or in a specific grid company.

## Annex 5 - Technical Workshop on Voltage Quality Standards

## Organised by the CEER (Electricity Working Group) Quality of Supply Task Force
*Hosted by Fondazione Politecnico di Milano*

## Milan, 29 September 2006, 9.00 – 17.00

## PROGRAM

9.00 Registration
9.15 Welcome by CEER Vicepresident (Ortis) and Fondazione Politecnico/Rescom Forum (Bracchi, Silvestri)
9.30 Introduction: the objectives of the meeting (Lo Schiavo, on behalf of Szorenyi, CEER EWG EQS TF Chairman)

9.45 - 11.15 First session: Measurement and classification issues for voltage variations and events
- Voltage variations, voltage dip threshold and dip tables: a framework (Bollen, STRI – 45')
- Voltage variations averaging interval: 10 minutes or 1 minute (Seljeseth, SINTEF – 30')
- Questions and answers – 15'

11.15-11.30 break

11.30 - 13.30 Second session: VQ regulatory requirements and field evidence on actual VQ levels
- Norway (Brekke, NVE & Sand, SINTEF & – 15')
- Hungary (Tersztyanszky, HEO & Dan, Budapest Tech.University – 15')
- Italy (Villa, AEEG & Porrino, CESI & Ferrero, Milan Tech.University – 15')
- Austria (Haber, E-control & Renner, Graz Tech.University – 15')
- Czech Republic (Frano, ERU & Motejzik, ČEZ – 15')
- France (Delestre, CRE & Gonbeau EDF-RD– 15')
- Portugal (Falcao, ERSE – 15')
- Spain (Candela Martinez, CNE – 15')

13.30 - 14.30 lunch break

14.30 - 16.00 Third session: toward the revision of EN 50160
- The concern of regulators for existing VQ standards (Brekke, CEER EQS TF – 45')
- Round table (chaired by Brekke, CEER EQS TF 45')
  - Manufacturers: Azzis (IBM, EICTA)
  - Distributors: Gutierrez Iglesias (Eurelectric)
  - Cenelec: Rocherau, Pestka (CLC TC8X)
  - Research: Nucci (CIGRE')

16.00 - 17.00 Final free discussion (1hour) and closing

## Venue

Politecnico di Milano, Aula Magna del Rettorato
Piazza Leonardo da Vinci 32
Milano (Italy)