European Copper Institute
Copper Alliance

Leonardo ENERGY

APPLICATION NOTE

STANDARD EN 50160

VOLTAGE CHARACTERISTICS OF ELECTRICITY SUPPLIED BY PUBLIC ELECTRICITY NETWORKS

Antoni Klajn, Marta Bątkiewicz-Pantuła

March 2013

ECI Publication No Cu0147

Available from www.leonardo-energy.org/node/145851

Document Issue Control Sheet

Document Title:	Application Note - Standard EN 50160 / Voltage characteristics of electricity supplied by public electricity networks
Publication No:	Cu0147
Issue:	02
Release:	March 2013
Author(s):	Antoni Klajn, Marta Bątkiewicz-Pantuła
Reviewer(s):	Stefan Fassbinder, David Chapman, Roman Targosz

Document History

Issue	Date	Purpose
1	July 2004	First publication, in the framework of the Power Quality Application Guide
2	March 2013	Completely rewritten, in the framework of the Good Practice Guide
3		

Disclaimer

While this publication has been prepared with care, European Copper Institute and other contributors provide no warranty with regards to the content and shall not be liable for any direct, incidental or consequential damages that may result from the use of the information or the data contained.

CONTENTS

INTRODUCTION

Electricity is a form of energy which is characterised by its versatility and simple application. It is utilized by being converted into many other forms of energy, including heat, light, mechanical energy and the many electromagnetic, electronic, acoustic and visual forms which are the basis of modern telecommunications, information technology and entertainment.

Electricity, as delivered to network users, has several characteristics which are variable and which affect its usefulness to the network user. With respect to the use of electricity, it is desirable that the supply voltage should alternate at a constant frequency, with a perfect sine wave and a constant magnitude. In practice, there are many factors which cause deviations from this, including the way in which it is used. Also, electrical energy is a unique product because it is consumed at the instant at which it is generated, so measurement and evaluation of the power quality (PQ) must also be instantaneous. Standard EN 50160 describes the characteristics of electricity, at the point of supply to the consumer, in terms of the alternating voltage.

The assurance of PQ is a complex problem, because it is influenced by the actions of three parties:

- The producer of energy and operator of the system
- The manufacturer of electrical equipment
- The network user (energy consumer), the user of this equipment.

The relationships are illustrated in *Figure 1*:

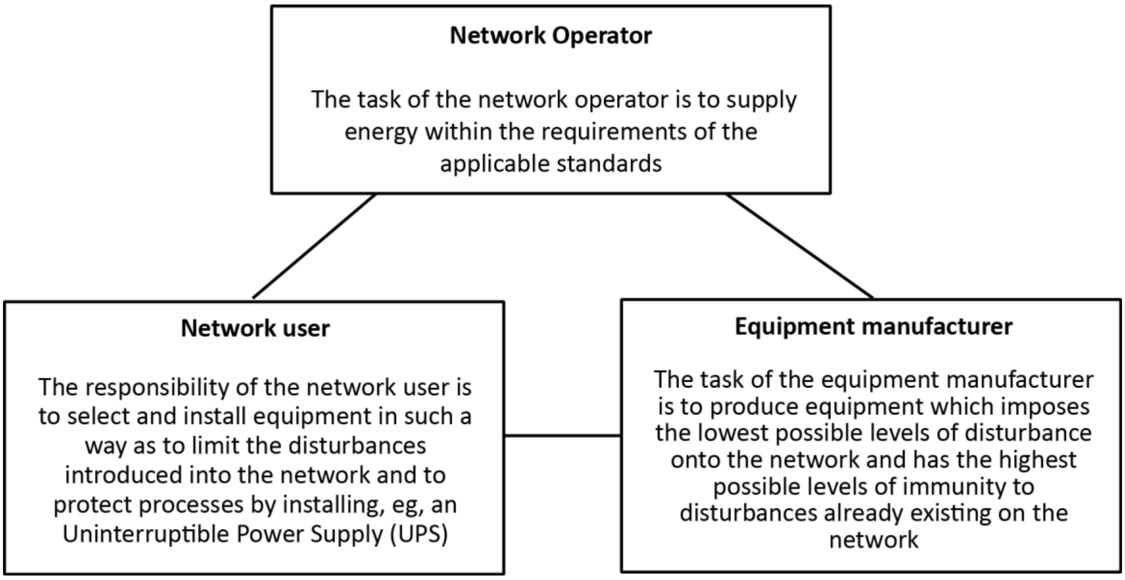

Figure 1 – Illustration of reciprocal correlation between three parties, the co-originators of power quality.

Each of these parties has an influence on PQ to a different degree as well as having duties and responsibilities.

- **On the part of the network operator:** supply energy to meet the demand on the network, maintain the network in a good condition, e.g. sustain the short-circuit power at a sufficient level, as well as providing redundancy in network operation in order to meet the requirements of applicable standards.
- **On the part of the network user:** select equipment and ensure its correct installation and operation to limit the level of electromagnetic disturbances introduced into the network; install uninterruptible power supplies (UPS) or other backup systems in appropriate situations. Equipment is influenced by disturbances on the supply and by other equipment in the installation, as well as itself influencing the

supply; correct operation requires the level of electromagnetic influence on equipment and immunity to be maintained below certain limits. These problems are summarised in the EN 61000 series of EMC standards, in which limits of conducted disturbances are characterised.

- **On the part of the equipment manufacturer:** provide the market with equipment with acceptably low levels of emission of disturbances onto the network and a sufficiently high level of immunity to the level of disturbances likely to exist in the network.

The flow of energy to network users' appliances gives rise to electric currents which are proportional to the magnitudes of their demands. As these currents flow through the conductors of the supply system, they cause voltage drops. The magnitude of the supply voltage for an individual network user at any instant is therefore a function of the cumulative voltage drops on all the components of the system through which that network user is supplied, and determined both by the individual user's demand and by the simultaneous demands of other network users (*Figure 11*). The impact of PQ on individual network users is a complex problem.

The subject of this document is a detailed presentation and analysis of the requirements of the EN 50160 standard. Methods of measuring supply voltage parameters as well as examples of measuring cases are presented.

BASIC DEFINITIONS OF VOLTAGE PARAMETERS

For the purposes of the EN 50160 standard, the following terms and definitions apply.

Definitions concerning the normal (regular) state of the network operation

Network operator - the party responsible for operating, maintaining and, if necessary, developing the supply network in a given area in order to ensure that the network is able to meet reasonable long term demands for electricity supply.

Network user - a party being supplied by or supplying to an electricity supply network.

Nominal voltage U_n – the voltage by which a supply network is designated or identified and to which certain operating characteristics are referred.

Supply terminal – a point in a public supply network designed as such and contractually fixed, at which electrical energy is exchanged between contractual partners. This point may differ from, for example, the electricity metering point or the point of common coupling.

Point of common coupling (***PCC***) – the point on a public power supply network, electrically nearest to a particular load, at which other loads are, or could be, connected.

Supply voltage – the r.m.s. value of the voltage at a given time at the supply terminals, measured over a given time interval.

Declared supply voltage U_c – the supply voltage agreed by the network operator and the network user. Generally the declared supply voltage U_c is the same as nominal voltage U_n but it may be different according to agreement between network operator and the network user.

Reference voltage (for interruptions, voltage dips and voltage swells evaluation) – is a value specified as the basis on which residual voltage, thresholds and other values are expressed in per unit or percentage terms. For the purpose of this standard, the reference voltage is the nominal or declared voltage of the supply system.

Frequency of the supply voltage – the repetition rate of the fundamental wave of the supply voltage measured over a given time interval.

Nominal frequency – the nominal value of the frequency of the supply voltage.

Levels of voltage have been divided as follows:

> ***High voltage*** – a voltage whose nominal r.m.s. value is 36 kV<U_n<150 kV.
>
> ***Medium voltage*** – a voltage whose nominal r.m.s. value is 1 kV<U_n≤36 kV.
>
> ***Low voltage*** – a voltage whose nominal r.m.s. value is U_n≤ 1 kV.

In some countries, the boundary between MV and HV may be different as a result of pre-existing network structures.

Normal operating condition – an operating condition for an electricity network, where load and generation demands are met, system switching operations are made and faults are cleared by an automatic protection system, in the absence of exceptional circumstances, such as:

A. temporary supply arrangements
B. in the case of non-compliance of a network user's installation or equipment with relevant standards or with the technical requirements for connection
C. exceptional situations, such as:
    1. exceptional weather conditions and other natural disasters
    2. third party interference
    3. acts by public authorities
    4. industrial actions (subject to legal requirements)
    5. force majeure
    6. power shortages resulting from external events.

Flicker - the impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time. Usually, it applies to cyclic variation of light intensity of lamps caused by fluctuation of the supply voltage. Flicker is typically a symptom of voltage disturbance caused by the use of large fluctuating loads, i.e. those that have rapidly fluctuating active and reactive power demand.

The threshold above which flicker becomes annoying depends on the frequency and amplitude of the fluctuation and at certain repetition rates even very small amplitudes can be disturbing, often causing headaches among other symptoms *Figure 2*.

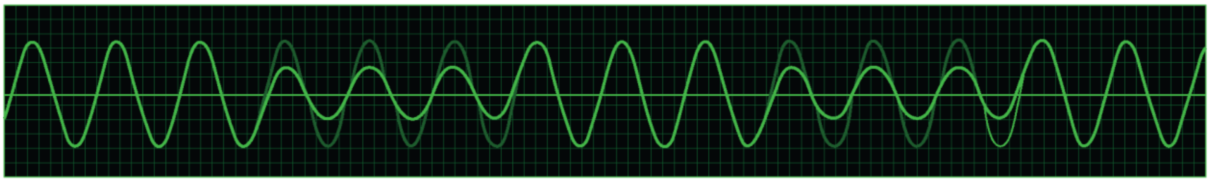

Figure 2 – Example oscillogram showing the phenomenon of flicker.

Flicker severity - the intensity of flicker annoyance is defined in terms of:

- ***short term severity*** (P_{st}) measured over a period of ten minutes,
- ***long term severity*** (P_{lt}) calculated from a rolling sequence of twelve P_{st} values over a two hour interval, according to the following expression:

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

P_{st} is calculated according to a standardised formula which takes into account the response of the human eye and brain. It is scaled in such way that 50% of observers will find that a long or short term flicker intensity of ≥1 is at least noticeable and perhaps disturbing.

Definitions concerning the abnormal (fault) state of the network operation

Conduced disturbance - an electromagnetic phenomenon propagated along the line conductors of a supply network. In some cases an electromagnetic phenomenon is propagated across transformer windings and hence between networks of different voltage levels. These disturbances may degrade the performance of a device, equipment or system or they may cause damage.

Supply interruption – a condition in which the voltage at the supply terminals is **lower than 5% of the reference voltage.**

Supply interruption can be classified as:

A. **pre-arranged,** when network users are informed in advance. Prearranged interruptions are typically due to the execution of scheduled work on the electricity network.
B. **accidental,** caused by permanent or transient faults, mostly related to external events, equipment failures or interference. Accidental supply interruptions are unpredictable, largely random events. An accidental interruption is classified as:
   1) A long interruption (longer than 3 min.);
   2) A short interruption (up to and including 3 min.).

The effects of a prearranged interruption can be minimized by network users by taking appropriate measures to avoid disruption.

Normally, accidental interruptions are caused by the operation of switches or protective devices in response to a short circuit or the failure of a device on the network.

Figure 3 shows a supply interruption where:

t_f is the fall time during which the voltage is falling
t_s is the duration of reduced voltage
t_r is the rise time during which the voltage is recovering.

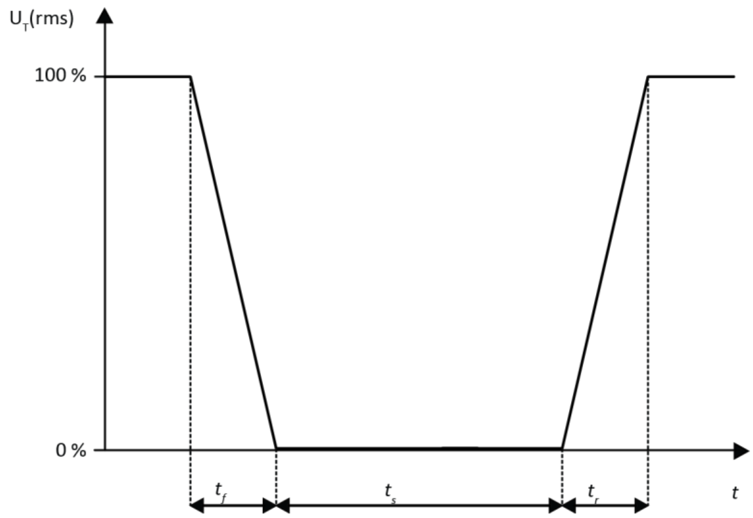

Figure 3 – Illustration of a supply interruption [2].

For **polyphase systems**, an interruption occurs when the voltage drops below 5% of the reference voltage on all the phases. Otherwise, it is considered to be a dip on the affected phases.

In some countries, the terms **Very Short Interruptions (VSI)** or **transitory interruptions** are used to classify interruptions with durations shorter than 1 to 5 s. Such interruptions are related to the operation of automatic reclosing devices.

Long interruption of the supply voltage – under normal operating conditions, the annual frequency of voltage interruptions **longer than three minutes** varies substantially across areas. This is due to, among other things, differences in system layout (e.g. cable systems versus overhead line systems) and environmental and climatic conditions. To obtain information about what can be expected in a particular location, the local network operator should be consulted. In some countries, national interruption statistics are available giving indicative values.

Short interruption of supply voltage – the duration of the short interruptions is up to and including 3 minutes. Often, the duration of short interruptions may be less than seconds. When comparing statistical values for short interruptions, the following issues should be considered:

- Principles for aggregating events (by adding up events)
- The possible exclusion of **Very Short Interruptions (VSI)** or **transitory interruptions**.

In some documents, short interruptions are considered to have durations not exceeding 1 minute. Sometimes control schemes are applied which need operating times of **up to 3 minutes** in order to avoid long voltage interruptions.

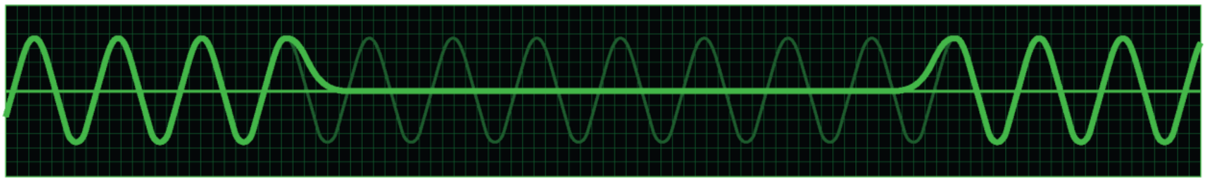

Figure 4 – Example oscillogram of the voltage in a single phase, showing a short interruption.

Rapid voltage change – a single rapid variation of r.m.s. value of a voltage between two consecutive levels which are sustained for definite but unspecified durations.

Transient overvoltage – a short duration oscillatory or non-oscillatory overvoltage, usually highly damped and with a duration of a few milliseconds or less. Transient overvoltages are usually caused by lightning or by switching operations. The rise time of a transient overvoltage can vary from less than a microsecond up to a few milliseconds.

Voltage dip – a temporary reduction of the r.m.s. voltage below a specified start threshold. For the purpose of the standard, the dip start threshold is equal to 90%, but above or equal to 5%, of the reference voltage. Typically, a dip is associated with the occurrence and termination of a short circuit or other extreme current variation on the system or an installation connected to it.

For the purpose of the standard, a voltage dip is a two dimensional electromagnetic disturbance, the level of which is determined both by the residual voltage and the time duration.

Voltage dip duration - the time between the instant at which the r.m.s. voltage at a particular point of an electricity supply system drops below the start threshold and the instant at which it rises above the end threshold. For the purposes of this standard, the duration of a voltage dip is from 10 ms up to and including 1 minute.

For polyphase events, a dip begins when the voltage of at least one phase drops below the dip start threshold and ends when all voltages are equal to or higher than the dip end threshold.

Voltage dip start threshold - the r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the start of a voltage dip.

Voltage dip end threshold - the r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the end of a voltage dip.

Voltage dip residual voltage - the minimum value of r.m.s. voltage recorded during a voltage dip. For the purpose of this standard, the residual voltage is expressed as a percentage of the reference voltage.

Figure 5 shows a dip with a residual voltage of 40%. The symbols are as defined for Figure 3.

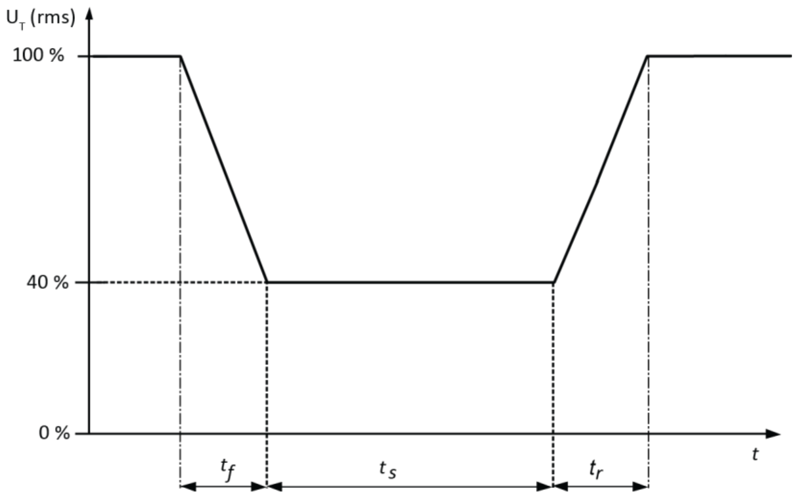

Figure 5 – Illustration of a voltage dip with 40% retained voltage [2].

Figure 6 shows the voltage waveform during a dip to 30% residual voltage.

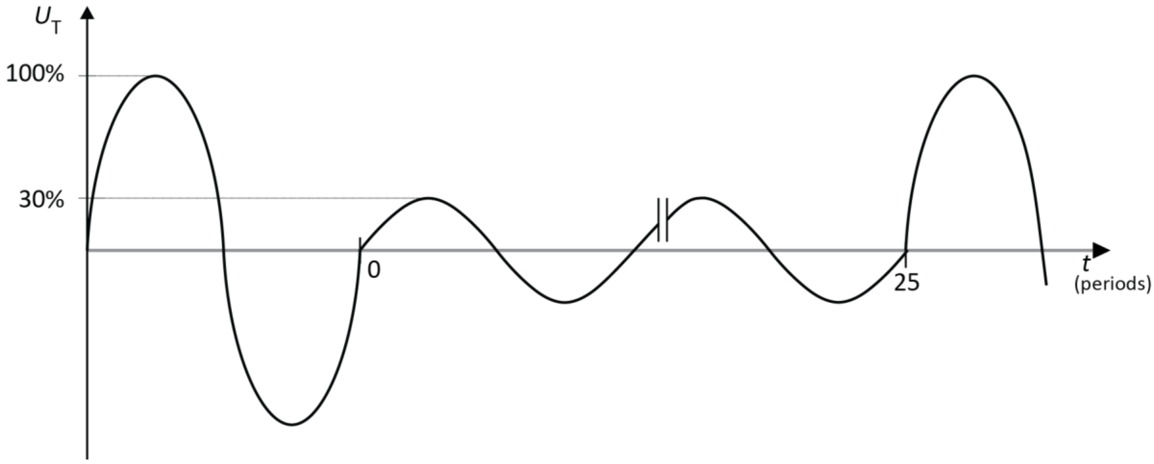

Figure 6 – Illustration of voltage dip waveform during a voltage dip [2].

Voltage fluctuation - a series of voltage changes or a cyclic variation of the voltage envelope.

Voltage swell – temporary power frequency overvoltage - a temporary increase of the r.m.s. voltage at a point in the electrical supply system above a specified start threshold. For the purpose of this standard, the following will be assumed:

- The swell start threshold is equal to 110% of the reference voltage
- A voltage swell is a two dimensional electromagnetic disturbance, the level of which is determined by both voltage and time of duration
- Voltage swells may appear between live conductors or between live conductors and earth. Depending on the neutral arrangement, faults to ground may also give rise to overvoltages between healthy phases and neutral.

Voltage swell start threshold - the r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the start of a voltage swell.

Voltage swell end threshold - the r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the end of a voltage swell.

Voltage swell duration is the time between the instant at which the r.m.s. voltage at a particular point of an electricity supply system exceeds the start threshold and the instant at which it drops below the end threshold.

For the purpose of this standard, the duration of a voltage swell is from 10 ms up to and including 1 min.

Voltage unbalance - the condition in a polyphase system in which the r.m.s. values of the line-to-line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equal.

The degree of the inequality is usually expressed as the ratios of the negative and zero sequence components to the positive sequence component. In this standard, voltage unbalance is considered in relation to three-phase systems and negative phase sequence only. *Figure 7* shows an example of an unbalanced three-phase system.

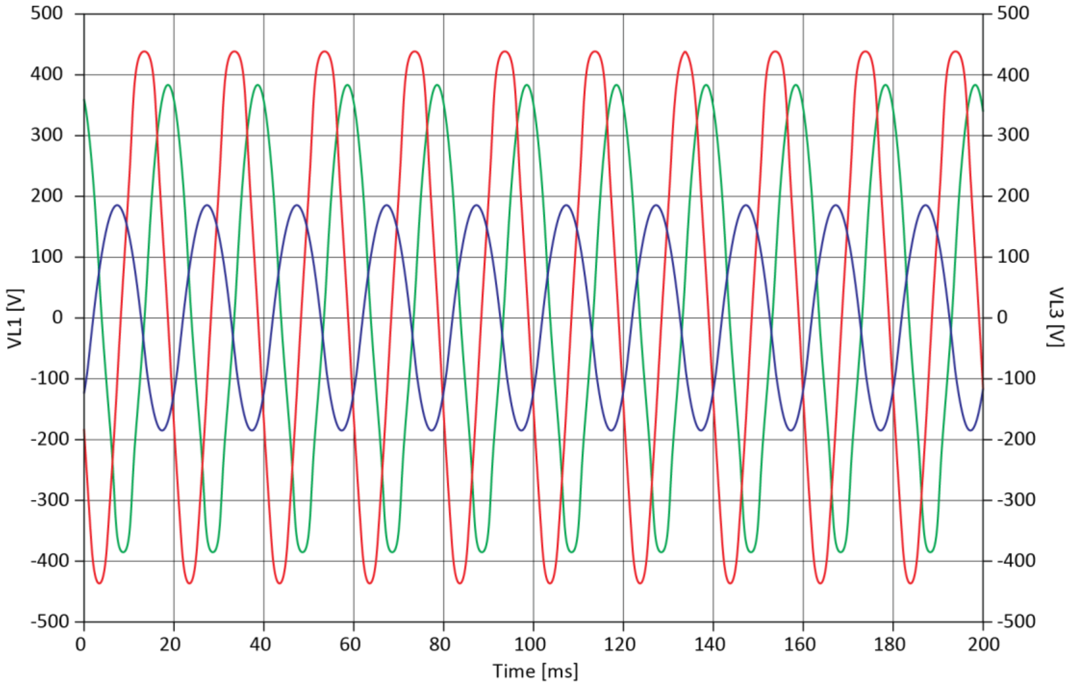

Figure 7 – An example of voltage unbalance in a 3-phase system.

Figure 8 shows the voltages from Figure 7 as vectors. Note that the angle between vectors is not 120°.

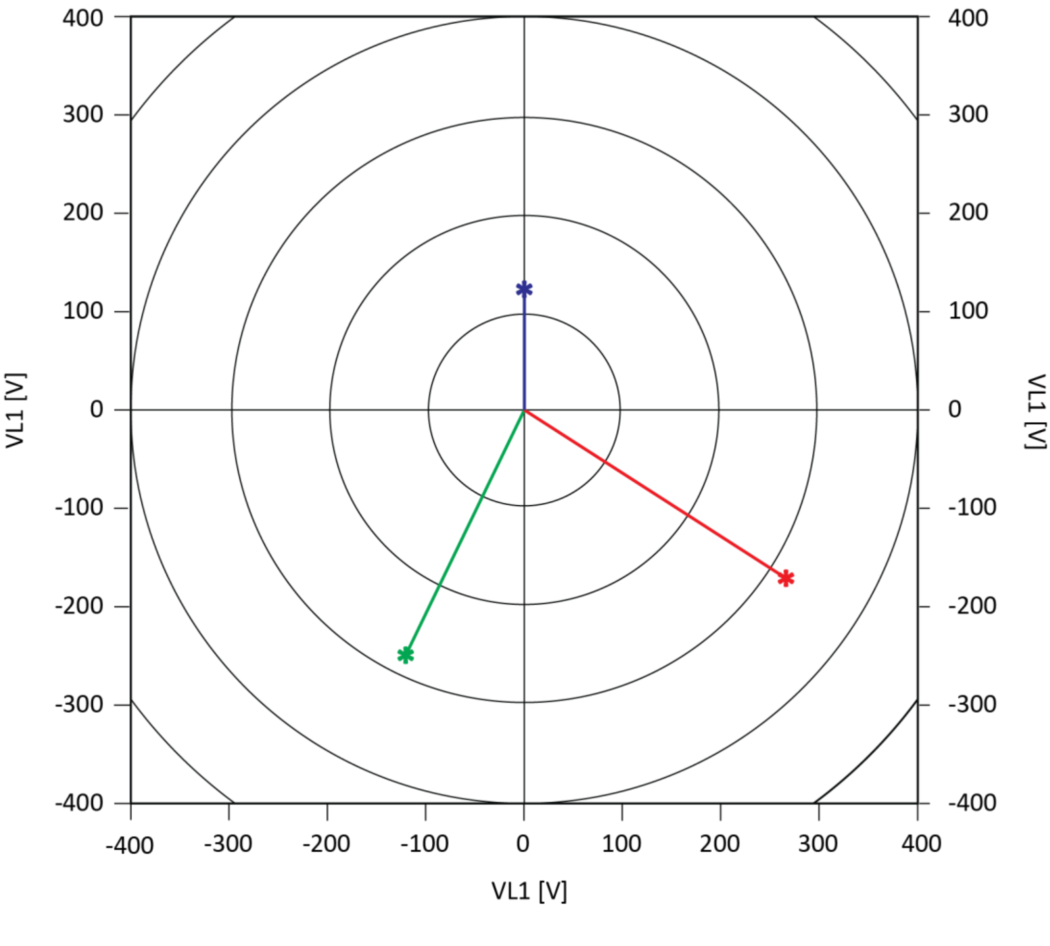

Figure 8 – Illustration of vector voltages from Figure 7.

Voltage variation – an increase or decrease of r.m.s. voltage normally due to load variations. *Figure 9* shows an example waveform of a voltage dip and voltage variation (blue plot) and the load (red plot) according to this variation of voltage.

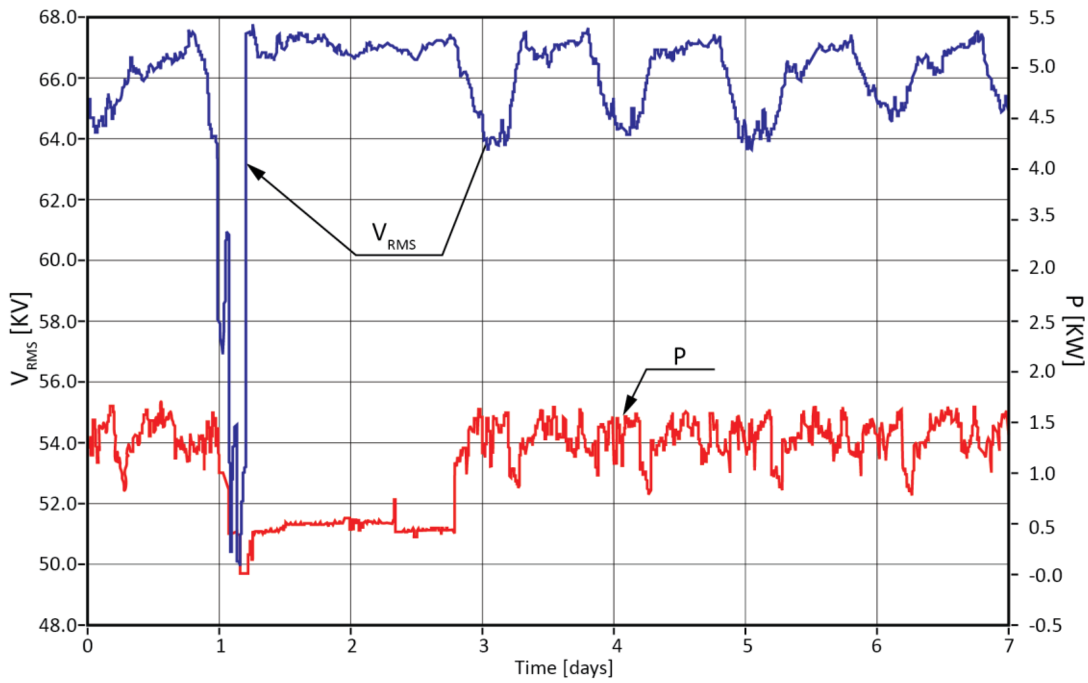

Figure 9 – Exemplary oscillograms of voltage dip and voltage variation.

To summarize the chapter about the basic definitions of voltage parameters according to EN 50160 the most important parameters are presented in the graphical form in *Figure 10*.

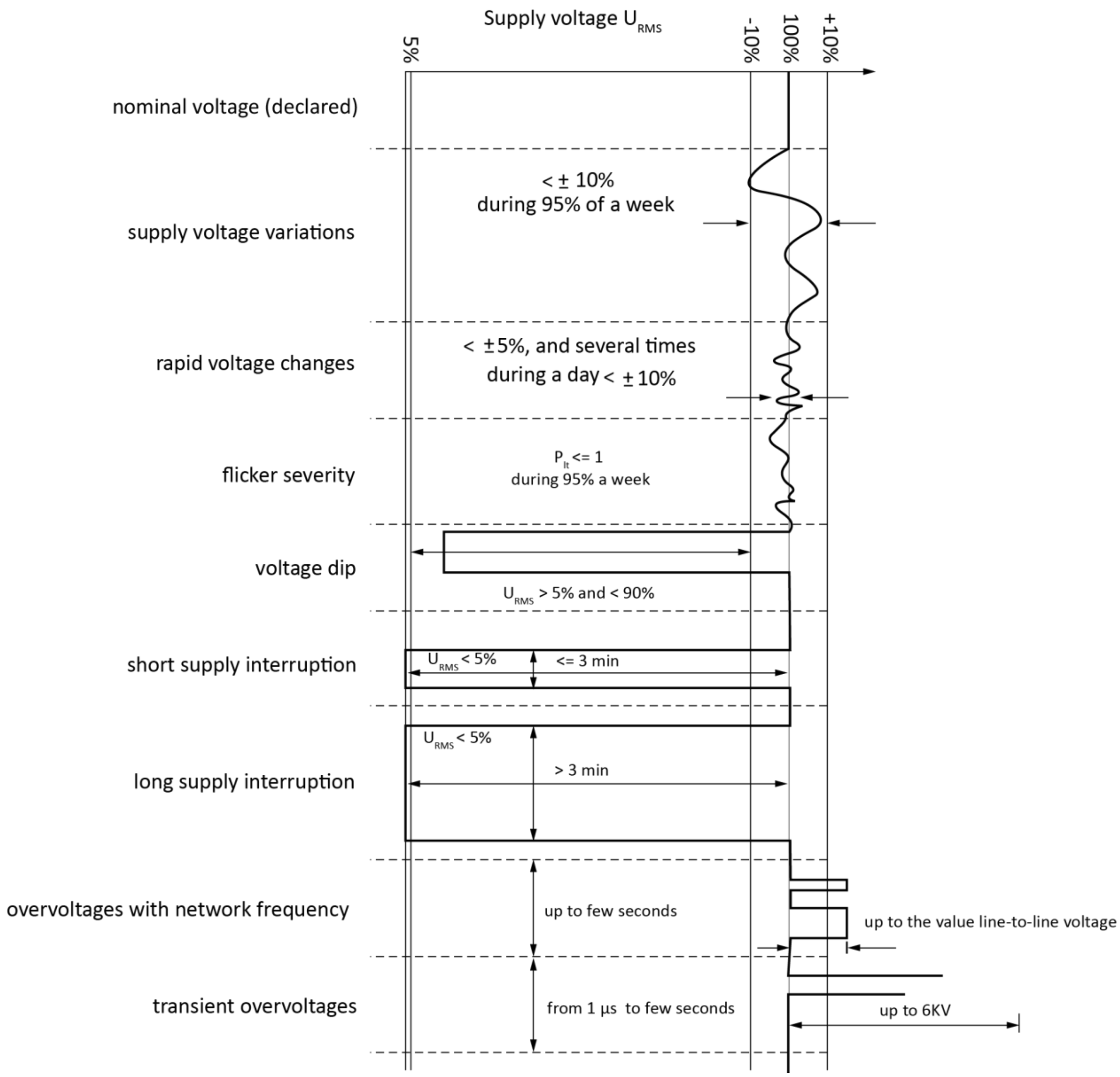

Figure 10 – The most important parameter of the standard EN 50160 in the graphical form.

STATISTICAL PHILOSOPHY

The magnitude of the supply voltage for an individual network user at any instant is a function of the cumulative voltage drops caused by current flows through the components of the system through which the user is supplied (represented by R_S and L_S in *Figure 11*). It is consequently a function of current flows on all other network users ($I_\Sigma(t)$ in *Figure 11*). The magnitude of the voltage supply is therefore determined both by the individual user's demand and by the simultaneous demands of other network users. Since the demands of every network user and the degree of coincidence between them constantly varies, so does the supply voltage seen by each user.

Figure 11 shows a notional network with three network users where:

- $I_i(t)$ is the load current of an individual network user
- $I_\Sigma(t)$ *is the* sum of load currents of all network users supplied from this PCC
- ΔU_i is the resulting voltage drop
- R_S, L_S is the resistance and the inductance of the network.

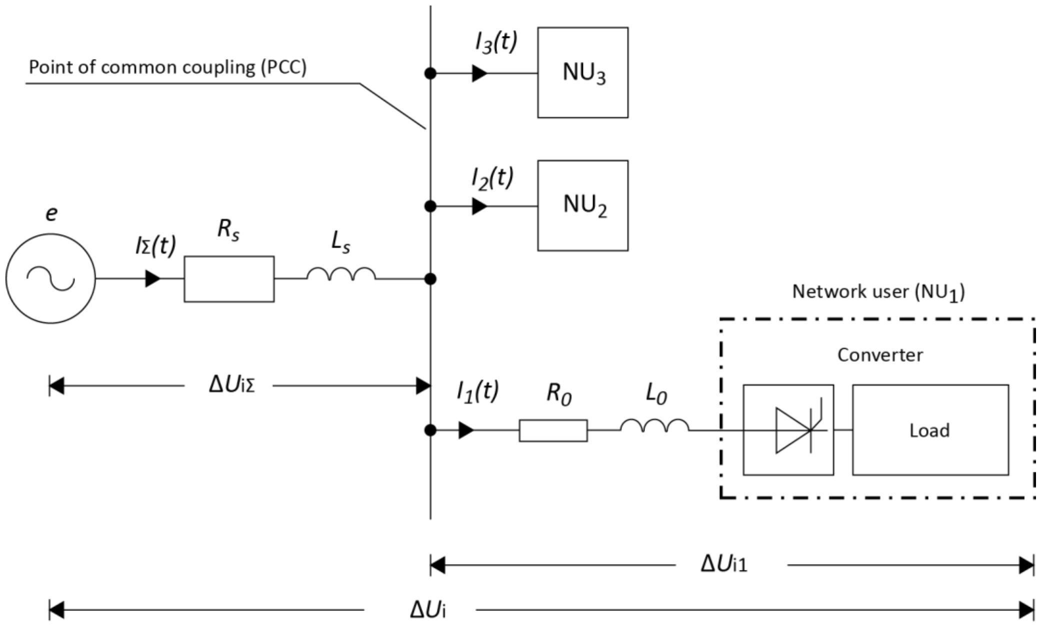

Figure 11 – Illustration of the effect of cumulative voltage drops on an individual network user.

Electricity reaches the user through a large system of generation, transmission and distribution equipment. Each component in the system is subject to potential damage or failure due to the electrical, mechanical and chemical stresses which arise from several causes, including extremes of weather conditions, the ordinary processes of wear and deterioration with age and interference by human activities, animals, etc. Such damage can affect or even interrupt the supply to one or more network users.

It is also necessary to keep the frequency constant. This requires the capacity of running generation to be continuously matched to the instantaneous aggregate demand. Because both the generation capacity and demand are liable to change in discrete amounts, especially in the event of faults on the generation, transmission or distribution networks, there is always a risk of a mismatch, resulting in an increase or decrease of the frequency. The size of frequency variations is reduced by connecting many systems into one large interconnected system, the generation capacity of which is very great relative to any changes that are likely to occur.

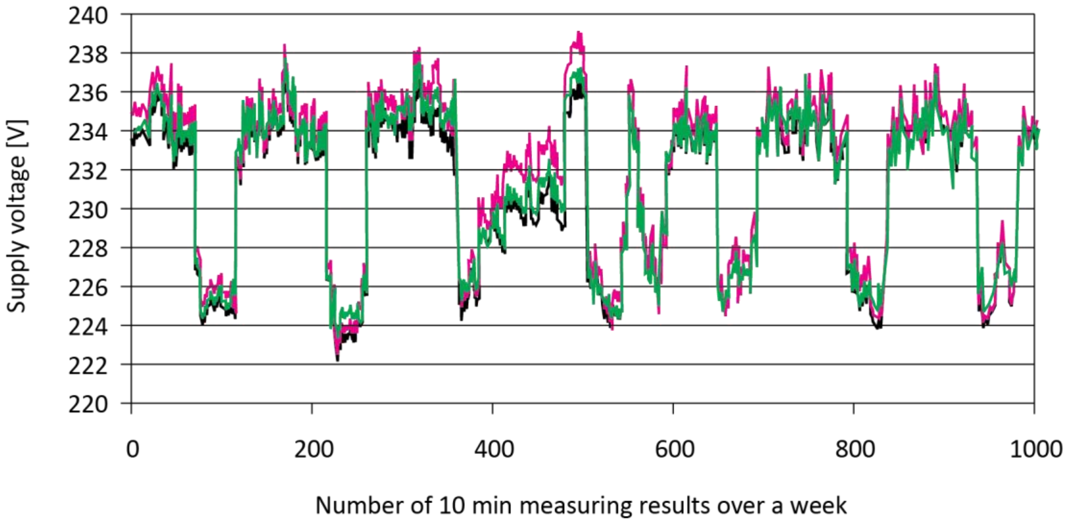

Figure 12 – Oscillogram of low voltage AT a PCC over the week (1008 of 10 min measurements).

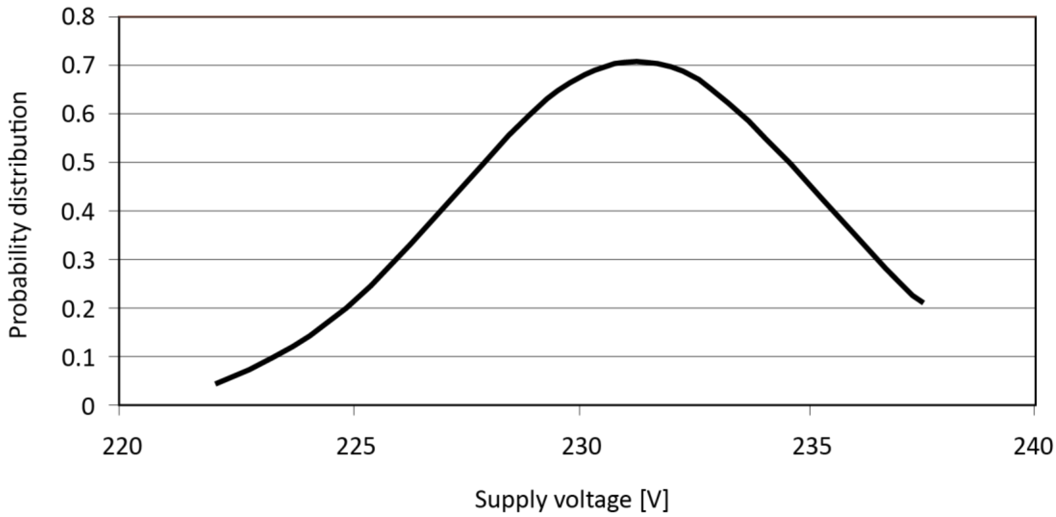

Figure 13 – Statistical distribution of voltage from Figure 12.

Another problem is that of the immunity of equipment to disturbances coming from the network. This is generally an issue for manufacturers to ensure by careful equipment design in accordance with international standards and for installation designers to preserve by good installation practice. In some market segments pre-standards were established by consortiums of manufacturers who acted to establish requirements. An example of this is the Computer and Business Equipment Manufacturers' Association (CBEMA) curve shown in *Figure 14*.

The CBEMA curve dates from the era of analogue power supplies so its low voltage characteristic reflects the energy storage capacity of the filter capacitor. The ITIC curve (*Figure 15*) is a straight-line version which is easier to interpret.

The CBEMA characteristic can be divided into three areas shown as Type I, II and III in *Figure 14*. Starting with Type III, where the duration of the deviation exceeds 2 seconds, both CBEMA and ITIC curves are in agreement requiring a tolerance of ±15% of $\boldsymbol{U}_n$.

The next category, Type II, represents swells or surges and sags or dips. The time period is from one half-cycle up to the boundary with Type III. For disturbances in this range, energy is supplied or stored by the power supply reservoir capacitor.

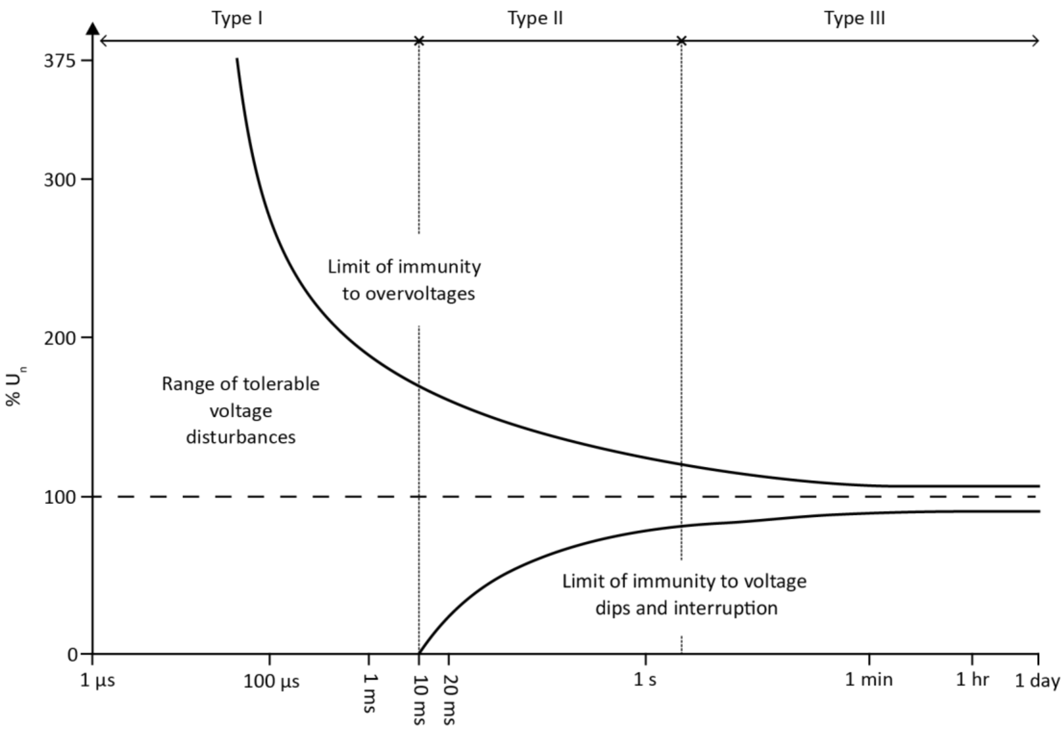

Figure 14 – Immunity of equipment on to supply voltage variations – cbema characteristic.

Type I disturbances range from simple ‘spikes’, at the sub-microsecond end of the range, up to one half-cycle. These disturbances have extremely fast rise and fall times and their high frequency components are easily trapped by the EMC filters found in modern power supplies.

The EMC filter prevents noise from the power supply reaching equipment and also prevents noise generated within the equipment from propagating on to the supply. It does not prevent the propagation of low frequency disturbances such as harmonics.

Figure 15, which shows the more modern characteristic curve developed by the Information Technology Industry Council (ITIC). These curves take account only of voltage variations and were originally used to allow manufacturers and users to understand the capabilities and limitations of computers and business equipment and their voltage stability requirements; the CBEMA curve predates most other standardisation in this field.

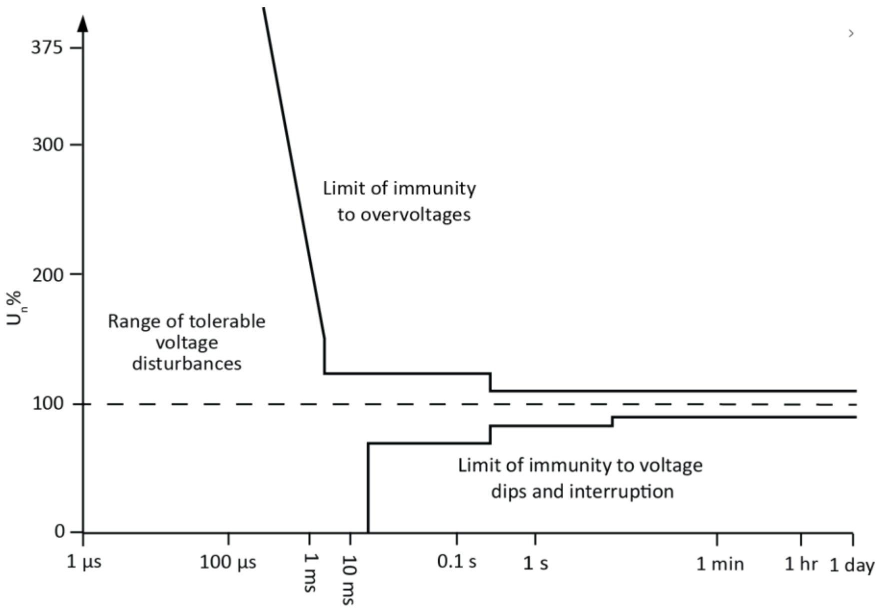

Figure 15 – Immunity of equipment on to supply voltage variations – ITIC characteristic.

Apart from the voltage tolerance characteristics addressed by the CBEMA and ITIC curves there are other types of network disturbances to which immunity is important, as exemplified by the network testing carried out by EPRI [6].

Some power quality disturbances arise from unavoidable transient events in the supply system itself, resulting from faults or switching, or from atmospheric phenomena, e.g. lightning. Others, however, are the result of various uses of electricity which directly alter the waveform of the voltage, impose a particular pattern on its magnitude, or superimpose signalling voltages. Coincidentally with the modern proliferation of equipment which has these effects, there is also an increase in the equipment which is susceptible to the disturbances. It is a particular feature of electricity that, with respect to some of its characteristics, its quality is affected by the user as well as by the producer or network operator. In these cases the network user is an essential partner of the network operator in the effort to maintain the quality of electricity.

Modern standardisation is based on the concept of compatibility. For each relevant parameter a compatibility level is established. Standard development aims to establish, for example, limits for disturbances on the network that can be met for, e.g., 95% of the time for each location, and standards for products that can operate reliable with that level of disturbance. The concept is illustrated in Figure 16, where probability distributions are presented and the idea of the electromagnetic level is explained.

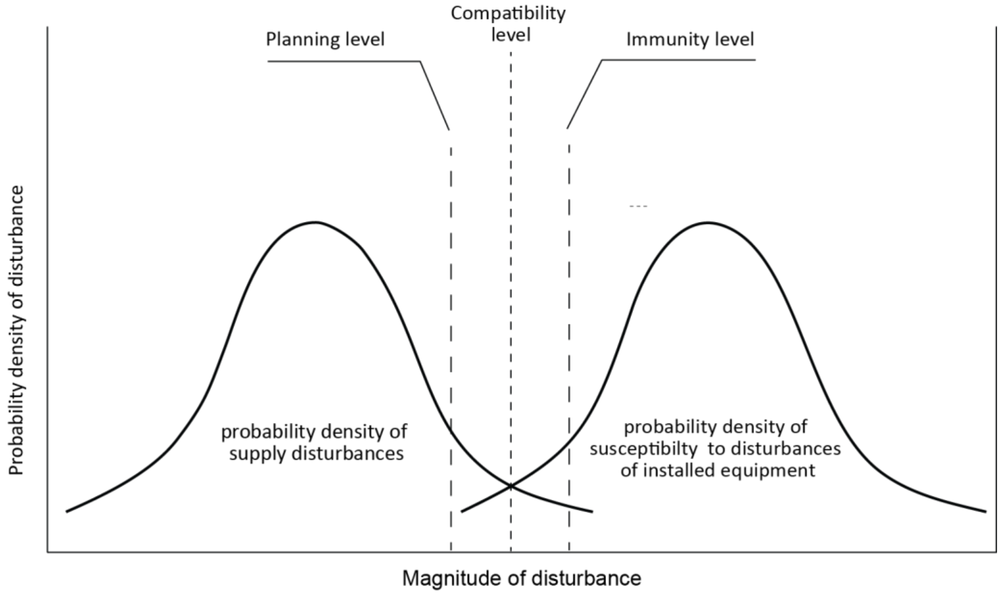

Figure 16 – The Concept of Compatibility.

The left-hand bell-curve represents the probability of a particular level of the disturbance existing at a particular time at a PCC on the network. The compatibility level is that defined by standards such as EN 50160, and it can be seen that, at any particular PCC, the disturbance level will be within the requirements of the compatibility level for a very large proportion of the time. Network operators may design their networks and the manner in which they arrange customer connections according to a 'Planning level'. The difference between the planning and compatibility levels differs for different parameters. For example, for flicker severity and harmonic pollution – which are generated by users' equipment and outside the control of the network operator – the margin will be greater, especially at low voltage, to allow for local conditions. It is important to point out that keeping the bell curve well to the left – i.e. to keep disturbance on the network low - is highly desirable, but doing so is also expensive; setting standards is a compromise between technical excellence and economic reality.

The right-hand bell-curve illustrates an idealised distribution of the immunity level of installed equipment on the network. It shows that the immunity level of most equipment, for most of the time, will be above the compatibility level, thus ensuring reliable operation. The 'Immunity level' is the level described by equipment standards, such as the EN 61XXX series.

Diagrams similar to *Figure 16* can be prepared for many parameters that may influence the performance of users' equipment, such as harmonic voltage level, flicker severity, voltage tolerance, etc.

Consequently, EN 50160 deals with the voltage characteristics in statistical or probabilistic terms. It gives recommendations that, for a percentage of measurements (e.g. 95%) over a given time, the value must be within the specified limits. This boundary value will be accepted as the compatibility level between the level of disturbances in the network and the level of immunity of equipment. In this way, the responsibilities of the network operator, equipment manufacturer and user are matched and clarified.

It is in the economic interests of the network user that the standard of supply should relate to normally expected conditions rather than to rare contingencies, such as an unusual degree of coincidence between the demands of several appliances or several network users. This standard defines, where possible, variations of the characteristics that may be normally expected. In other cases, the standard provides the possible indication of what, in quantitative terms, is to be expected.

In the case of voltage dips, EN 50160 gives guidance only on what may be expected; the level of dips allowed is far more severe than the immunity level of equipment as defined by *Figure 14* and *Figure 15*, so most equipment will not be immune. Where an improved performance is required, the user must be responsible for installing the equipment required to provide it.

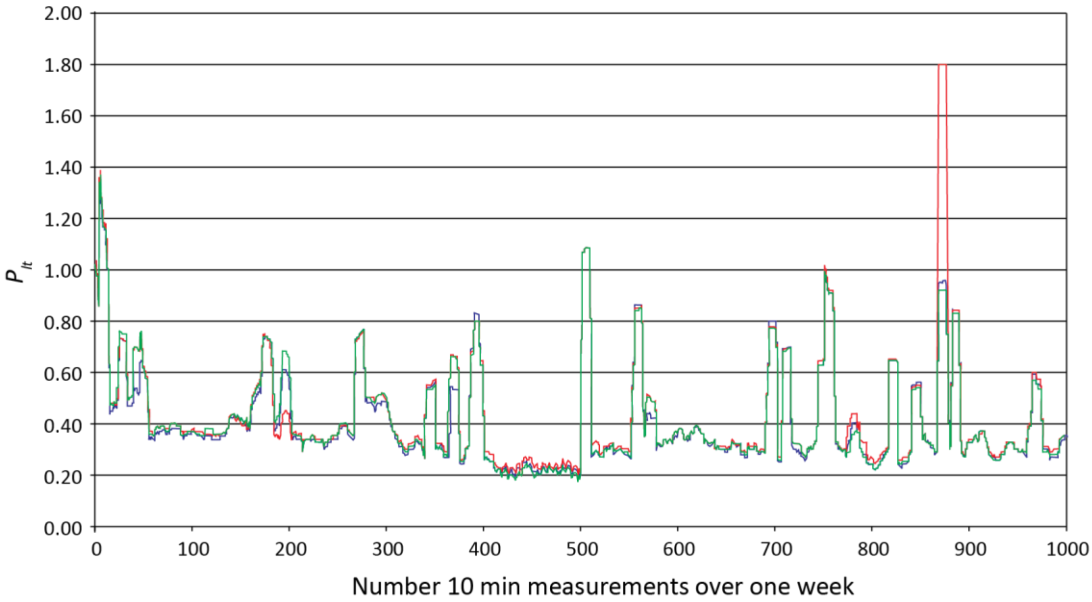

Figure 17 – Example trace of long term severity of flicker P_{lt} for one week (1008 10-minute measurements) in a 3-phase system.

Taking the example of flicker severity, Figure 17 shows a recording of long-term flicker over a one week period; there are 1082 ten-minute readings. In order to easily assess the impact, the readings are reordered in decreasing order of value, as shown in Figure 18. In such a plot, it is clear whether 95% of the values are within the standard limit.

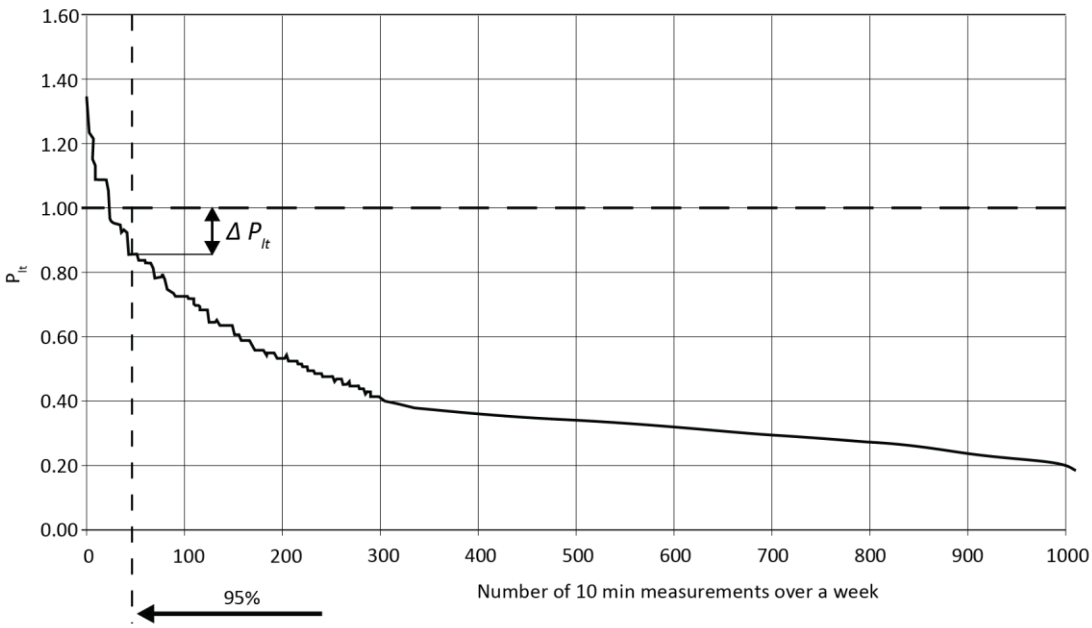

Figure 18 - Ordered diagram of long term severity of flicker P_{lt} for one phase from Figure 17.

Although this standard has obvious links with the concept of compatibility levels, it is important to note that it relates only to voltage characteristics of electricity. It does not specify compatibility and immunity levels of equipment. The performance of equipment might be impaired if the equipment is subjected to supply conditions more severe than specified in their product standard.

LOW-VOLTAGE SUPPLY CHARACTERISTICS

See also [1].

GENERAL

This clause describes the voltage characteristics of electricity supply by public low voltage networks. In the following, a distinction is made between:

- Continuous phenomena, i.e. deviations from the nominal value that occur continuously over time. Such phenomena occur mainly due to load pattern, changes of load or nonlinear loads.
- Voltage events, i.e. sudden and significant deviations from normal or desired wave shape. Voltage events typically occur due to unpredictable events (e.g. faults) or to external causes (e.g. weather conditions, third party actions).

For some continuous phenomena, limits are specified:

- For single rapid changes, only indicative values are given for the time being
- For some specific parameters, in some national regulations stricter limits may exist.

For voltage events, only indicative values can be given at present.

The standard nominal voltage U_n for public low voltage is **U_n = 230 V**, either between phase and neutral, or between phases:

- For four-wire three phase systems, **U_n = 230 V** between phase and neutral
- For three-wire three phase systems, **U_n = 230 V** between phases.

In low voltage systems the declared and nominal voltages are equal.

CONTINUOUS PHENOMENA

POWER FREQUENCY AND SUPPLY VOLTAGE VARIATION

The nominal frequency of the supply voltage in this European Standard shall be 50 Hz.

Under normal operating conditions the mean value of the fundamental frequency measured over 10 s shall be within a range of – see *Table 1*.

Related monitoring is usually done by the Control Area Operator.

Table 1 – Requirements regarding power frequency and supply voltage variation [1].

Parameter	For systems with synchronous connection to an interconnected system	Duration	For systems with no synchronous connection to an interconnected system (e.g. supply system on certain islands)	Duration
Power frequency	50 Hz ± 1 % (i.e. 49.5 Hz ÷ 50.5 Hz)	99.5% of a year	50 Hz ± 2 % (i.e. 49 Hz ÷ 51 Hz)	95% of a week
	50 Hz + 4% / -6% (i.e. 47 Hz ÷ 52 Hz)	100 % of the time	50 Hz ± 15 % (i.e. 42.5 Hz ÷ 57.5 Hz)	100 % of the time
Supply voltage	Under normal operating conditions (excluding interruptions) U_n ± 10 %	95 % of the 10 min mean r.m.s. values over each one week period All 10 min mean r.m.s. values shall be within the range of U_n +10% / -15%	**Incl. special remote users** U_n + 10% / -15%. Network users should be informed of the conditions. Network user equipment typically designed to tolerate supply voltages of ±10% of U_n.	95 % of the 10 min mean r.m.s. values over each one week period should be within ±10% of U_n All 10 min mean r.m.s. values shall be within the range of U_n +10% / -15% [1)]

1) The actual power consumption required by individual network users is fully predictable, in terms of amount and of simultaneousness. As a consequence, networks are generally designed on a probabilistic basis. If, following a complaint, measurements carried out by the network operator according to the above requirements indicate that the magnitude of the supply voltage is outside the limits given in the above requirements. which can have negative consequences for the network user. The network operator should take appropriate remedial action in collaboration with network user(s), depending on a risk assessment. Pending resolution, voltage variations should be within the range +10% / -15% of U_n, unless otherwise agreed with network users.

In accordance with relevant product and installation standards, network users' appliances are typically designed to tolerate supply voltages of ±10% around the nominal system voltage, which is sufficient to cover an overwhelming majority of supply conditions. Generally, appliances do not need to be designed to handle wider voltage variations.

Identification of what is a "special remote network user" can vary between countries, taking into account different characteristics of national electric systems as, for instance, limitation of power on supply terminal and/or power factor limits.

Supply voltage variation

Requirements

Under normal operating conditions excluding the periods with interruptions, supply voltage variations should not exceed ± 10% of the nominal voltage U_n.

In cases of electricity supply in networks that are not interconnected with transmission systems or for special remote network users, voltage variations should not exceed **+10 % / -15 %** of U_n. Network users should be informed about the conditions.

Test method

Under normal operating conditions:

- During each period of one week 95% of the 10 min mean r.m.s. values of the supply voltage shall be within the range of $\boldsymbol{U_n}$ ± 10 %; and
- All 10 min mean r.m.s. values of the supply voltage shall be within the range of $\boldsymbol{U_n}$ +10% / -15%.

Rapid voltage changes

Single rapid voltage changes

Rapid voltage changes of the supply voltage are mainly caused either by load changes in the network users' installations, by switching operations in the system, or by faults.

If the voltage magnitude during a change crosses the threshold for voltage dips and/or swells, the event is classified as a voltage dip and/or swell rather than a rapid voltage change.

Flicker severity

Under normal operating conditions, during each period of one week the long term flicker severity P_{lt} caused by voltage fluctuation should be less than or equal to 1 for 95% of measurements.

It is worth noting that the reaction to flicker is subjective. It can vary depending on the perceived cause of the flicker and the period over which it persists. In some cases P_{lt} = 1 gives rise to annoyance, whereas in other cases higher levels of P_{lt} may not.

Supply-voltage unbalance

Under normal operating conditions, during each period of one week, 95% of the 10 min mean r.m.s. values of the negative phase sequence component (fundamental) of the supply voltage **shall be within the range 0% to 2%** of the positive phase sequence component (fundamental).

In this European Standard only values for the negative sequence component are given because this component is the relevant one for the possible interference of appliances connected to the system.

In some areas where there are some users with largely single-phase or two-phase loads, unbalance up to about 3% may occur at three-phase supply terminal.

Harmonic voltage

The content of harmonics in the supply voltage is characterised in two ways:

a) Individually by their relative amplitude ($\boldsymbol{u_h}$), which is the harmonic voltage related to the fundamental voltage $\boldsymbol{u_1}$, where $\boldsymbol{h}$ is the order of the harmonic (Table 2)
b) Through the total harmonic distortion factor THD, calculated using the following expression:

$$THD = \sqrt{\sum_{h=2}^{40} (u_h)^2}$$

The limitation to order 40 is conventional and in some countries other values may be used (e.g. order 50 in the UK).

Ad a)

Under normal operation conditions, **during each period of one week, 95% of the 10 minute** mean r.m.s. values of each individual harmonic voltage shall **be less than or equal to the values given in Table 2.** In this table, no values are given for harmonics of order higher than 25, as they are usually small, but largely unpredictable due to resonance effects.

Table 2 – Values of individual harmonic voltages at the supply terminals for harmonic orders up to 25 given in percent of the fundamental voltage u_1 [1].

Odd harmonics				**Even harmonics**	
Not multiples of 3		**Multiples of 3**			
Order h	**Relative amplitude u_h**	**Order h**	**Relative amplitude u_h**	**Order h**	**Relative amplitude u_h**
5	6,0 %	3	5,0 %	2	2,0 %
7	5,0 %	9	1,5 %	4	1,0 %
11	3,5 %	15	0,5 %	6 to 24	0,5 %
13	3,0 %	21	0,5 %		
17	2,0 %				
19	1,5 %				
23	1,5 %				
25	1,5 %				

Ad b)

Moreover, the **THD of the supply voltage** (including all harmonics up to the order 40) shall **be less than or equal to 8%**.

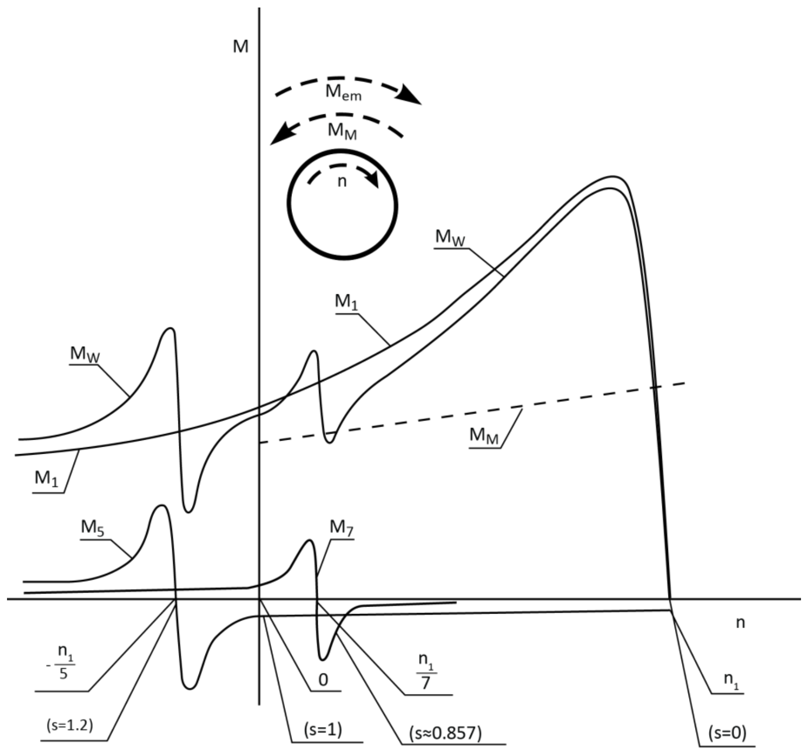

Figure 19 – Illustration of influence harmonics on torque (M) during operation of an electrical asynchronous motor.

Figure 19 shows an example of the torque characteristics of an asynchronous induction motor connected to a distorted voltage supply in which

M_1 undisturbed torque due to fundamental supply frequency
M_i torque due to harmonic *i*
M_m load torque
M_w resultant torque.

Harmonic voltage components cause harmonic current components in the motor.

If the motor is supplied with a distorted supply, the corresponding harmonic currents flow in the stator and are therefore reproduced in the magnetic field. These field components cause parasitic torque which can result in vibration, accelerating bearing wear, excess heating and reduced service life. If the resultant torque curve, $M_{w,}$ crosses the load torque curve M_m (as indicated in *Figure 19*), the motor can stall.

INTERHARMONIC VOLTAGES

The level of interharmonics is increasing due to the development of frequency converters and similar control equipment. Levels are under consideration, pending more field experience.

In certain cases interharmonics, even at low levels, give rise to flicker, or cause interference in ripple control systems.

MAINS SIGNALLING VOLTAGES

In some countries the public networks may be used by the network operators for the transmission of signals voltages. Three types of signals in the public supply network can be classified:

- Ripple control signals – superimposed sinusoidal voltage signals in the frequency range 110 Hz to 3000 Hz;
- Power-line-carrier signals – superimposed sinusoidal voltage signals in frequency range 3 kHz to 148.5 kHz;
- Mains marking signals – superimposed short time alterations (transients) at selected points of the voltage waveform.

These may be used in network users' installation and in power line carrier signalling with frequencies in the range from 95 Hz to 148.5 Hz. Voltages of these frequencies up to 1.4 V r.m.s. in the public LV network have to be taken into account. However, the use of the public LV network is not permitted for the transmission of signals between network users. Because of the possibility of mutual influences of neighbouring network users' signalling systems, the network user may need to apply protection or appropriate mitigation measures for his signalling installation.

For PLC purposes, in some networks also frequencies above 148.5 kHz are used.

For 99% of a day the 3 s mean value of signal voltages shall be less than or equal to the values given in Figure 20.

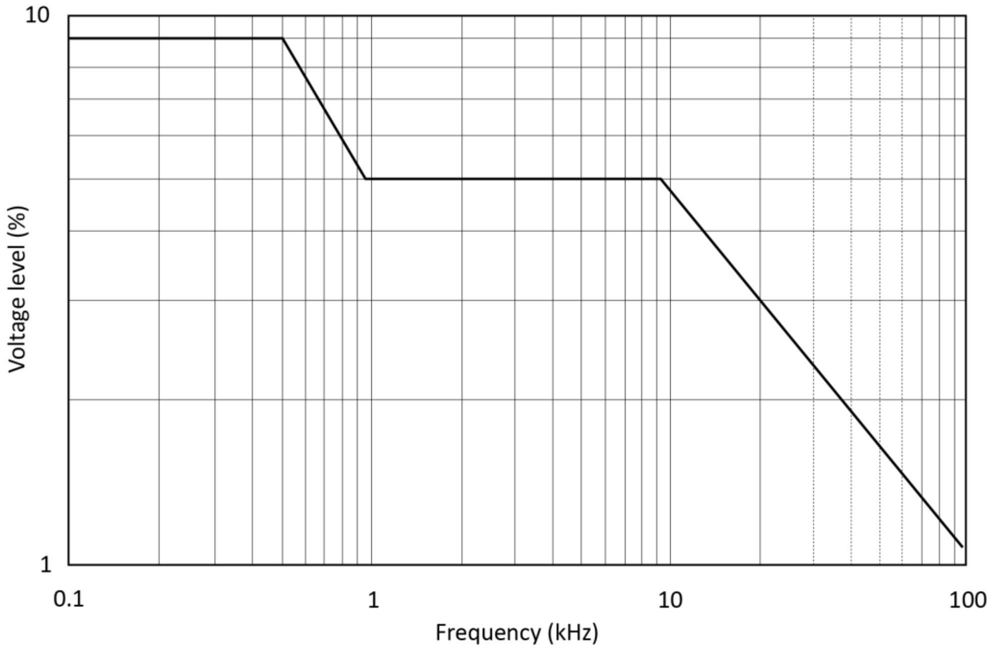

Figure 20 – Voltage levels of signal frequencies in percent of nominal voltage U_n used in public LV and MV networks from EN50160 standard.

VOLTAGE EVENTS AND CLASSES OF ELECTROMAGNETIC ENVIRONMENT

See also [2, 3].

INTERRUPTIONS OF THE SUPPLY VOLTAGE

Interruptions are, by their nature, unpredictable and vary from place to place and from time to time. For the time being, it is not possible to give fully representative statistical results of measurements of interruption frequency covering the whole of European networks. A reference for actual values recorded in European networks concerning interruptions, divides interruptions into long and short interruptions of supply voltage as previously defined.

At national level, more precise statistics may be available; furthermore, national regulations may exist.

SUPPLY VOLTAGE DIPS/SWELLS

GENERAL

Voltage dips typically originate from faults occurring in the public network or in network users' installations of network users.

Voltage swells are typically caused by switching operations and load disconnections. The swells treated in this clause are between live conductors.

Both phenomena are unpredictable and largely random. The annual frequency varies greatly depending on the type of supply system and on the point of observation. Moreover, the distribution over the year can be very irregular.

VOLTAGE DIP/SWELL MEASUREMENT AND DETECTION

Voltage dips/swells shall be measured and detected using as reference the nominal supply voltage. The voltage dips/swell characteristics of interest for this standard are residual voltage (maximum r.m.s. voltage for swells) and duration. In this standard, values are expressed in percentage terms of the residual voltage by the reference voltage for dips and maximum r.m.s. voltage for swells and duration. On LV networks, for four-wire three phase systems, the line to neutral voltages shall be considered. For three-wire three phase systems the line to line voltages shall be considered. In the case of a single phase connection, the supply voltage (line to line or line to neutral, according to network user connection) shall be considered.

Conventionally, the dip start threshold is equal to 90% of the nominal voltage. The start threshold for swell is equal to 110% of the nominal voltage.

For polyphase measurements, it is recommended that the number of phases affected by each event is detected and recorded.

VOLTAGE DIPS EVALUATION

The method of analyzing the voltage dips (post treatment) depends on the purpose of the evaluation.

Typically on LV networks:

- If a three-phase system is considered, polyphase aggregation shall be applied. Polyphase aggregation consists of defining an equivalent event characterized by a single duration and a single residual voltage.
- Time aggregation applies. Time aggregation consists of defining an equivalent event in the case of multiple successive events; the method used for the aggregation of multiple events can be set according to the final use of data.

PERFORMANCE CRITERIA USED FOR VOLTAGE DIPS/SWELLS CLASSIFICATION

Performance criterion A; The apparatus shall continue to operate as intended during and after the test. No degradation of performance or loss of function below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. If the minimum performance level or permissible performance loss is not specified by the manufacturer, either of these may be derived from the product description and documentation.

Performance criterion B; The apparatus shall continue to operate as intended after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer is allowed when the apparatus is used as intended.

During the test, degradation of performance is however allowed. No change of actual operating state or stored data is allowed.

If the minimum performance level or the permissible performance loss is not specified by the manufacturer, either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

Performance criterion C; Temporary loss of function is allowed, provided the function is self-recoverable or can be restored by operation of the controls.

CLASSIFICATION OF VOLTAGE DIPS AND CLASSES OF THE ELECTROMAGNETIC ENVIRONMENT

If statistics are collected, voltage dips shall be classified according to Table 3. The figures to be put in the cells are the number of equivalent events, and the residual voltage is calculated by polyphase aggregation.

Further information is needed to consider events affecting an individual single phase voltage in three-phase systems. To calculate the latter, a different evaluation method has to be applied.

For existing measurement equipment and/or monitoring systems, Table 3 is to be taken as a recommendation.

Table 3 – Classification of dips according to residual voltage and duration.

Residual voltage *u* **%**	**Duration *t*** **ms**				
	10 ≤ *t* ≤ 200	**200< *t* ≤500**	**500< *t* ≤1000**	**1000< *t*≤5000**	**5000<*t* ≤60000**
90 > ***u*** ≥ 80	CELL **A1**	CELL **A2**	CELL **A3**	CELL **A4**	CELL **A5**
80 > ***u*** ≥ 70	CELL **B1**	CELL **B2**	CELL **B3**	CELL **B4**	CELL **B5**
70 > ***u*** ≥ 40	CELL **C1**	CELL **C2**	CELL **C3**	CELL **C4**	CELL **C5**
40 > ***u*** ≥ 5	CELL **D1**	CELL **D2**	CELL **D3**	CELL **D4**	CELL **D5**
5 > ***u***	CELL **X1**	CELL **X2**	CELL **X3**	CELL **X4**	CELL **X5**

Voltage dips are, by their nature, unpredictable and variable from place to place and from time to time. For the time being, it is not possible to give fully representative statistical results of measurements of voltage dip frequency covering the whole of European networks.

As detailed in product standards, voltage dip and swells, according to their severity, can impair the operation of equipment. For reference, electromagnetic environment is characterized by following classes:

<u>Class 1</u>

This class refers to protected supply systems and in this instance the compatibility levels are lower than in public supply network. It refers to environments where equipment which is highly sensitivity to the disturbances is used, e.g., in technical laboratories, measurement facilities, computer centres and certain automation and protection equipment. Extra protection will be provided by example such as UPS, filters or overvoltage limiters.

<u>Class 2</u>

This class refers to the point of common coupling (PCC) and internal points of common coupling (IPCC) in an industrial environment.

<u>Class 3</u>

This class refers to internal points of common coupling (IPCC) in an industrial environment.

For certain disturbances the compatibility levels are higher than in class 2. For example, the consideration of this class is recommended, if any of these conditions are fulfilled:

- The main part of the load is supplied intermediately by a isolating transformers
- Welding machines are in use
- Large motors are frequently switched-on
- Frequent load changes occur.

Although the cells of Table 3 are not exactly coincident with the test levels table, it can be expected that equipment tested according to the relevant product standard should cope with voltage dips as indicated in the cells:

- A1, B1, A2, B2 for class 2
- A1, B1, C1, A2, B2, A3, A4 for class 3.

Table 4 – Recommended test level and duration of the voltage dips.

Class	**Test level and duration of the voltage dips (50 Hz / 60 Hz)**				
Class 1	**Dependent on the case, according to the requirements of equipment**				
Class 2	**0% during ½ cycle**	**0% during 1 cycle**	**70% during 25/30 c) cycles**		
Class 3	**0% during ½ cycle**	**0% during 1 cycle**	**40% during 10/12 cycles**	**70% during 25/30 cycles**	**80% during 250/300 cycles**

b) – 25/30 cycles, mean "25 cycles for test at 50 Hz" as well "30 cycles for test at 60 Hz".

Table 5 – Recommended test level and duration of the short interruptions.

Class	**Test level and duration of the voltage dips (50 Hz / 60 Hz)**
Class 1	**Dependent on the case, according to the requirements of equipment**
Class 2	**0 % during 250/300 cycles**
Class 3	**0 % during 250/300 cycles**

MEDIUM-VOLTAGE SUPPLY CHARACTERISTICS

GENERAL

The standard distinguishes between:

- **Continuous phenomena**, i.e. deviations from the nominal value that occur continuously over time. Such phenomena occur mainly due to load pattern, changes of load or nonlinear loads
- **Voltage events.**

CONTINUOUS PHENOMENA

POWER FREQUENCY AND SUPPLY VOLTAGE VARIATION

The nominal frequency of the supply voltage in this European Standard shall be 50 Hz.

Under normal operating conditions the mean value of the fundamental frequency measured over 10 seconds shall be within the range given in *Table 6*. Monitoring is the responsibility of the Control Area Operator.

Table 6 – Requirements regarding power frequency and supply voltage variation.

Parameter	For systems with synchronous connection to an interconnected system	Duration	For systems with no synchronous connection to an interconnected system (e.g. supply system on certain islands)	Duration
Power frequency	50 Hz ± 1 % (i.e. 49.5 Hz ÷ 50.5 Hz)	99.5% of a year	50 Hz ± 2 % (i.e. 49 Hz ÷ 51 Hz)	95% of a week
	50 Hz + 4% / -6% (i.e. 47 Hz ÷ 52 Hz)	100 % of the time	50 Hz ± 15 % (i.e. 42.5 Hz ÷ 57.5 Hz)	100 % of the time
Supply voltage	Under normal operating conditions, excluding periods of interruption, supply voltage variations should not exceed ±10 % of the declared voltage U_c	99 % of the 10 min mean r.m.s. value over one week none of the 10 min mean r.m.s. values shall exceed ± 15 % of U_c	**(Incl. special remote users)** U_n + 10% / -15%. Network users should be informed of the conditions.	99 % of the 10 min mean r.m.s. value over one week none of the 10 min mean r.m.s. values shall exceed ± 15 % of U_c

FLICKER SEVERITY

Under normal operation condition, during each period of one week the long term flicker severity P_{lt} caused by voltage fluctuations **should be less or equal to 1 for 95% of the time**.

SUPPLY VOLTAGE UNBALANCE

Under normal operation condition, during each period of one week, 95% of the 10 min r.m.s. values of the negative phase sequence component of the supply voltage shall be within the **range 0% to 2% of the positive phase sequence component.**

HARMONIC VOLTAGE

Under normal operation condition, during each period of one week, 95% of 10 min mean r.m.s. values of each individual harmonic voltage **shall be less than or equal to values given in Table 2.**

Moreover, the THD of the supply voltage (including all harmonics up to the order 40) **shall be less than or equal to 8%.**

HIGH-VOLTAGE SUPPLY CHARACTERISTICS

GENERAL

Network users with demands exceeding the capacity of a medium voltage network are generally supplied at nominal voltages above 36 kV. This clause applies to such electricity supplies at nominal voltages up to and including 150 kV.

CONTINUOUS PHENOMENA

The nominal frequency of the supply voltage in this European Standard shall be 50 Hz.

Under normal operating conditions the mean value of the fundamental frequency measured over 10 s shall be within a range given in *Table 7*.

Table 7 – Requirements regarding power frequency and supply voltage variation.

Parameter	**For systems with synchronous connection to an interconnected system**	**Duration**	**For systems with no synchronous connection to an interconnected system (e.g. supply system on certain islands)**	**Duration**
Power frequency	50 Hz ± 1 % (i.e. 49.5 Hz ÷ 50.5 Hz)	99,5% of a year	50 Hz ± 2 % (i.e. 49 Hz ÷ 51 Hz)	95% of a week
	50 Hz + 4% / -6% (i.e. 47 Hz ÷ 52 Hz)	100 % of the time	50 Hz ± 15 % (i.e. 42.5 Hz ÷ 57.5 Hz)	100 % of the time
Supply voltage	As the number of network users supplied directly from HV networks is limited and normally subject to individual contracts, no limits for supply voltage variations are given in this standard. Existing product standards for HV equipment should be considered.			

FLICKER SEVERITY

Under normal operation conditions, during each period of one week the long term flicker severity P_{lt} caused by voltage fluctuations **should be less than or equal to 1 for 95% of the time**.

In the case of complaints, the HV limit and appropriate HV, MV and LV mitigation measures shall be chosen in such a way that at LV the P_{lt} values do not exceed 1.

SUPPLY VOLTAGE UNBALANCE

Under normal operation conditions, during each period of one week, 95% of the 10 minute mean r.m.s. values of the negative phase sequence component of the supply voltage should be **within the range 0% to 2% of the positive phase sequence component**.

HARMONIC VOLTAGE

Under normal operating conditions, during each period of one week, 95% of the 10 minute mean r.m.s. values of each individual harmonic voltage should be less than or equal to the indicative values given in *Table 8*. Resonances may cause higher voltages for an individual harmonic.

No values are considered for harmonics of order higher than 25, as they are usually small, but largely unpredictable due to resonance effects.

Table 8 – Values of individual harmonic voltages at supply HV terminals for orders up to 25 given in percent of the fundamental voltage u_1.

Odd harmonics				**Even harmonics**	
Not multiples of 3		**Multiples of 3**			
Order h	**Relative amplitude u_h**	**Order h**	**Relative amplitude (%) u_h**	**Order h**	**Relative amplitude (%) u_h**
5	**5.0**	**3**	**3.0**	**2**	**1.9**
7	**4.0**	**9**	**1.3**	**4**	**1.0**
11	**3.0**	**15**	**0.5**	**6 … 24**	**0.5**
13	**2.5**	**21**	**0.5**		
17	**u.c.**				
19	**u.c.**				
23	**u.c.**				
25	**u.c.**				

Harmonics of order higher than 13 and not multiple of 3 are under consideration.

CLASSES OF MEASUREMENT METHODS

See also [3].

For each parameter measured, three classes (A, S and B) are defined. For each class, measurement methods and appropriate performance requirements are included.

Class A

This class is used where precise measurements are necessary, for example for contractual applications, that may require resolving disputes, verifying compliance with standards etc.

Any measurements of a parameter carried out with two different instruments complying with the requirements of class A, when measuring the same signals, will produce matching results within the specified uncertainty for that parameter.

Class S

This class is used for statistical applications such as surveys or power quality assessment, possibly with a limited subset of parameters. Although it uses equivalent intervals of measurement as class A, class S processing requirements are lower.

Class B

This class is defined in order to avoid making many existing instruments designs obsolete. Class B instruments cannot be used to resolve disputes. Class B methods are not recommended for new designs.

Measurement aggregation over time intervals

The following measurement aggregation apply:

Class A:

The basic measurement time intervals for parameter magnitudes (supply voltage, harmonics, interharmonics, unbalance) shall be 10-cycle time interval for 50 Hz power system or 12-cycle time interval for a 60 Hz power system. The 10/12-cycle values are then aggregated over 3 additional intervals:

- 150/180-cycle interval (150 cycles for 50 Hz nominal or 180 cycles for 60 Hz nominal),
- 10 minute interval,
- 2 hour interval.

Class S:

Same time intervals as class A.

Class B:

The manufacturer shall specify the number and duration of aggregation time intervals.

Measurement aggregation algorithm

Aggregation shall be performed using the square root of the arithmetic mean of the squared input values.

Conclusions

Standard EN 50160 should be understood as representing a compromise between the three parties which exert an influence on the power quality, i.e. network operator, network user, and manufacturer of equipment. Each of these three parties has an interest in playing their part. It is essential that electricity suppliers provide, as a minimum, a nominally adequate quality of supply. If the customer has higher requirements, mitigation measures should be provided by the user, or a separate agreement for a higher supply quality must be negotiated with the supplier. However, the important advantages of this standard are:

- Definition of the voltage parameters important for power quality
- Quantitative determination of reference values that can be used in the evaluation of the power quality

It is the task of the electricity regulator to set a level of quality that requires best practice from the supplier, while not setting the level so high that the price of electricity increases for everybody.

References

[1] EN 50160: July 2010. Voltage characteristics of electricity supplied by public electricity networks,.

[2] EN 61000-3-3: 2008. Electromagnetic compatibility (EMC), Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection.

[3] EN 61000-4-30:2009. Electromagnetic compatibility (EMC), Part 4-30: Testing and measurement techniques – Power quality measurement methods.

[4] Asensi R. Harmonics. How should be understood the compatibility level. Power Quality Application Guide, Part 3.4.1., 2005.

[5] http://www.marcspages.co.uk/pq/5130.htm

[6] http://f47testing.epri.com/faq.html