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Application guide to the European Standard EN 50160 on "voltage characteristics of electricity supplied by public distribution systems"

Electricity Product Characteristics and Electromagnetic Compatibility

UNION OF THE ELECTRICITY INDUSTRY
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SUMMARY

The aim of this report is to provide explanations and complementary information on the Standard EN 50160 issued by CENELEC in November 1994, in order to promote a common understanding and interpretation among the electricity distributors.

The approach followed in preparing the report has been to include, beside the comments strictly related to the Standard, also a discussion of the fundamental motivations which determine the policies of electricity distributors.

Moreover the document can be made available also to third parties as a UNIPEDE contribution to reach a consensus on the subject of voltage characteristics.

After an exposition of background information on the development of the Standard, the report deals in detail with the different voltage characteristics, trying to point out the reasons for the specifications there given and provides additional comments and clarifications.

Moreover it was felt necessary to include detailed indications on the evaluation of the voltage characteristics, as the CENELEC Standard states only the fundamental principles and there was a risk that many different approaches could be put into practice, waiting for further developments of the standardisation activity.

The measuring and evaluation methods proposed in the present report, together with the indications contained in the associated UNIPEDE report "Measurement Guide for Voltage Characteristics" constitute a complete reference for a uniform approach to the problem on the part of the electricity distributors and can be adopted also for standardisation purposes.

The last part of the report is devoted to explain the nature and implications of the EN 50160 with respect to the other standards in the field of electromagnetic compatibility (EMC), showing how the objective of keeping the voltage characteristics within certain bounds is the outcome of a process where EMC standardisation, electricity distributors, equipment manufacturers and users must co-operate successfully.

1. INTRODUCTION

The aim of this document is to give explanations, background information and complements related to the standard EN 50160 on the "Voltage characteristics of electricity supplied by public distribution systems", which CENELEC developed to fulfil a mandate of the Commission of the European Communities (EC).

By its very nature, a standard has to be concise and cannot give a comprehensive treatment of the subject being dealt with. It was accordingly considered worthwhile by UNIPEDE to prepare a guide providing an interpretation of the standard, with a review of the problems related to the characteristics of electricity supply at the user terminals, covering also some aspects of electromagnetic compatibility, to make the text self contained.

2. BACKGROUND INFORMATION

2.1 The EC approach to the definition of supply voltage characteristics

From the very beginning of their association, the Member States of the European Communities decided to create a wide economic space without barriers to internal trade.

For this purpose a number of directives have been issued by the Commission of the European Communities (EC), to remove the differences in the legislation of the Member States, which could affect the free exchange of goods and services.

In particular the EC, recognising the energy market as an important component of the internal market, issued two Directives [1,2]:

- **Directive 85/374** on Product Liability [1], states in Article 2 that electricity is to be considered a product and, as a consequence, made it necessary to define the essential characteristics of the electricity supply.

- **Directive 89/336** on Electromagnetic Compatibility [2] declares, that the Member States are responsible for ensuring that electricity distribution networks are protected from electromagnetic disturbances, which can affect them and, consequently, the connected equipment.

In September 1989 UNIPEDE prepared a document (DISNORM 12, [3]) which defines the physical characteristics of electric energy supplied by low and medium voltage public distribution systems.

The initial aim of the document was to give information to users and manufacturers in a synthetic and organised form. Taking note, however, of their interest in the internal market of electricity, the document was forwarded to the Commission.

The task of preparing a standard, based on the UNIPEDE contribution, was assigned to CENELEC (European Committee for Electrotechnical Standardisation). The mandate specified the different aspects to be covered, which were exclusively related to the following characteristics of the supply voltage: **frequency**, **magnitude**, **waveform** and **symmetry** of the three-phase-voltages

CENELEC set up a Task Force (BTTF 68-6), attended by representatives of most of the Member Countries, which produced the standard EN 50160 [4].

2.2 Nature of electricity supplied by public distribution systems

Electricity has become a primary resource on which a great number of activities have become dependent. It has several characteristics which can be critical to the satisfactory operation of electrical equipment. This is increasingly so in the case of modern equipment.

It is the nature of electricity that many of the voltage characteristics are quite variable. There is a large number of influences which give rise to this variation, and the distributor's ability to control these influences is limited.

Although the electricity, as produced in the generating stations, has highly controlled characteristics, considerable variation can be present at the customer's supply terminals. These variations are brought about by the nature and operating characteristics of customer's equipment as well as by the physics of operation of the supply system.

Because the variation of the voltage characteristics can cause degradation of the performance of electrical equipment, these phenomena are frequently referred to as **electromagnetic disturbances**.

Atmospheric phenomena (lightning, wind, etc.) and environmental conditions (including pollution, man-made or of natural origin) are an important source of some disturbances, notably supply interruptions and voltage dips.

Another important source of disturbances is the electricity user's own equipment. The design of this equipment, or its mode of operation, or both, can have the effect of injecting disturbances (such as harmonic or interharmonic distortion, voltage fluctuations, etc.) into the distribution networks, on which they are then conducted to customers' supply terminals at some distance from their source.

Apart from the above influences, the voltage characteristics of electricity are a function of the design and operating characteristics of the supply system itself, and of its response to the time-varying electricity demands of the users. Despite the daily, weekly, seasonal and other cyclical trends which can be observed in these demands, they are essentially random events, and are largely unpredictable, particularly at level of an individual user or small group of users.

Finally, the voltage characteristics can be affected by the actions of various third parties (accidental or intentional damage to supply installations, strikes and industrial disputes, action or instruction by public authorities, etc.).

Accordingly, the voltage characteristics are under the influence of several parties:

- end users

- equipment and system manufacturers

- designers of plants and installations

- electricity distributors

- public authorities

- general public

Unlike common commercial goods or equipment, whose properties can be controlled within close tolerances by appropriate design and manufacturing processes, the voltage characteristics of electricity are much less subject to close control. This is especially so because the use of electricity is simultaneous with its generation and distribution; any disturbance which arises occurs at the same instant, so that between the occurrence of the disturbance and its taking effect there is not a time interval within which the distributor can intervene with a specific corrective action. Therefore the voltage characteristics of electricity are specified in terms of:

- range of values

- statistics of occurrence of faults and other disturbances

- by reference to specific operating conditions of the supply systems, excluding extreme conditions.

2.3 Electricity supply systems and voltage characteristics

It is evident from the above, that the electricity distributor must design the supply system to keep the voltage characteristics within preassigned limits, chosen as a compromise between the objective of giving the majority of the users a satisfactory service and the aim of keeping the cost of supply as low as possible.

Electricity supply systems have thus evolved during the years, according to local policies aimed to meet at an optimum cost/benefit ratio the requirements of the users, so that the existing systems are greatly different in the various countries, depending on their history of economic, industrial and social development, on the environmental conditions and on the choice of specific technical options among those available in power systems engineering.

This leads to the fact that the voltage characteristics of supply networks in areas which are similar in terms of load density (load per unit surface) and other parameters can be different in some respect and it is not possible to establish a precise relationship between the performance of an electric power system and the type of supplied area.

Laying down the voltage characteristics in a standard, it was necessary to consider:

- the actual supply characteristics existing throughout Europe including the fact that these characteristics generally permit satisfactory performance of equipment

- cost aspects deriving from the interdependence between the supply networks and the design of equipment.

It is clear that all costs, whether incurred on the supply system or on customers' equipment are ultimately borne by the customer. Moreover, there is a very wide variation in the costs involved, particularly in relation to the supply systems.

The most significant factor causing this variation is the difference in customer density which occurs in different areas, often compounded by differences in the level of electricity consumption by different customers.

These differences are compounded further by the fact that low density areas tend to be supplied by overhead lines, whereas underground cable systems are much more likely to be used in high density areas. For overhead lines there is a much greater margin between the capacity required purely for energy supply and that required to limit the range of voltage variations.

For many of the voltage characteristics dealt with by EN 50160, the actual values are strongly dependent on the network equivalent impedance (also expressed, at the fundamental, by the inversely proportional quantity "fault level", or "short circuit level").

This parameter is a function of the "electrical distance" of the considered supply terminals from the feeder transformer(s) or, in more practical terms, of the characteristics of connecting lines and transformers (length and conductors of the lines, rating and design of the transformers, etc.).

For some of the characteristics the load connected on the supply network can be an important component of the equivalent impedance.

The network impedance is therefore quite variable at any given supply terminals, because not only are the other loads connected to the same supply network varying in time, but the configuration of the network is also subject to change because of necessary switching operations (resupply manoeuvres, maintenance and construction work, etc.).

Moreover network impedances tend to be low in urban areas where the load density is high, and the network is composed of lines with large cross section areas connecting closely spaced large rating transformers.

Impedances tend to be higher in sparsely populated rural areas, where the characteristics of the supply system are tailored to smaller loads in order to avoid additional costs, which the electricity consumption could not economically justify.

In contrast to all this, for obvious manufacturing and marketing optimisation, the equipment available to users should be designed according to uniform standards, particularly with a view to the European Single Market.

3. APPLICATIONOF THE CENELEC STANDARD

3.1 Introduction

The standard EN 50160 was developed taking into account the problem of providing adequate conditions for the operation of user equipment and, at the same time, avoiding unnecessary increases of the cost of the electricity supply.

Accordingly, the levels set in the standard balance the costs of compliance with the requirements for customers' equipment, having regard to the diverse conditions which exist throughout Europe.

3.2 Scope of the standard

It is important to note that EN 50160 is confined to the electricity supplied, and does not deal with the supply system itself.

The Scope of EN 50160 specifically **excludes** compatibility levels or emission limits. Its sole function is to give values for the main voltage characteristics of electricity supplied by LV and MV public networks.

Notwithstanding the similarities between these values and those given in standards for electromagnetic compatibility levels, EN 50160 is not itself a standard for electromagnetic compatibility, but covers the voltage characteristics at the supply terminals.

It is to be noted that the voltage characteristics within the customer's installation may be different from those at the supply terminals. It is the customer's responsibility to avoid or overcome any problems with the performance of his equipment due to internally generated changes in voltage characteristics at the equipment terminals.

The point designated as **user supply terminals** varies considerably according to local custom and practice. In practical terms the supply terminals coincide with the point on the supply conductors, where the responsibility of the distributor ends and that of the user begins.

The standard is applicable only under **normal operating conditions** of the supply system.

This is intended to exclude any condition outside the supplier's control, which causes one or more of the voltage characteristics to go beyond the values given in the standard.

The listed exceptional conditions are :	**exceptional weather conditions and other natural disasters** **third party interference** **industrial actions (subject to legal requirements)** **force majeure** **power shortages resulting from external action** **acts of public authorities**

The standard does not apply if the supplier is prevented from carrying out necessary alterations to the supply system, by government or other public authorities.

An example of a condition in which application of the standard is temporarily suspended, is that in which part of the supply system is made unavailable for use, due either to a fault of large impact or to the need to carry out maintenance or construction work.

In these circumstances, if supply can be maintained to all or as many customers as possible, even at the expense of some deterioration of one or more of the voltage characteristics, this is generally accepted to be preferable to an outright interruption of the supply.

Particular note should be taken of the exclusion in respect of non-compliance of customers' equipment or installation with related standards or regulations.

The same principle applies to all connections to the public supply system, including private generation embedded in the public supply system.

Moreover the standard allows for its requirements to be superseded in the case of a customer who makes a special contract with the supplier. In this case, the values of the voltage characteristics are a matter for mutual agreement between the customer and the supplier. Such a contract is most likely to arise for customers with relatively large electricity demands, probably supplied from the MV network.

3.3 Groups of Voltage Characteristics

EN 50160 contains the following two groups of characteristics:

a) Characteristics for which values can be specified in definite terms

b) Characteristics for which only indicative values can be given

3.3.1 Definite Values

For some characteristics it is feasible to set limits which can be complied with for most of the time, however, there still remains the possibility of relatively rare excursions beyond these limits.

The essential randomness of the factors involved precludes declaring any bounds within which there could be a reasonable expectation that such excursions could be contained.

The following table gives the characteristics for which definite limits have been specified. Interharmonics have been included even if no indications have been given, as the EN states that limits will be established once that additional experience will allow to do so.

Limits are set with a view to compliance for a percentage of the observation time, e.g. 95% of the observations in any period of one week.

For the reason stated above, no limit is set for the remainder of the time. However, experience shows that in practice the frequency with which excursions outside the 95% limits occur decreases very rapidly with the magnitude of such excursions.

TABLE I THE SET OF CHARACTERISTICS WITH DEFINITE VALUES:

Voltage Characteristic	Compliance with stated limits	Observation period
frequency	100 % 95 %	week
slow variations of voltage magnitude	95 %	week
rapid voltage changes	some exceptions per day are admissible	day
fluctuations of voltage magnitude (flicker)	95 %	week
unbalance of three phase voltages	95 %	week
harmonic distortion of the voltage waveform	95 %	week
interharmonic voltages	to be defined	to be defined
mains-borne signalling voltages	99 %	day

An exception is made in the case of power frequency: Here limits are given for compliance over a 100% of the time, in addition to the 95% limits. This is possible because such a deviation would imply a seriously abnormal condition on the supply system and would be, therefore, beyond the scope of the standard.

A special case is that of the rapid voltage changes, for which allowance is made for a few occurrences per day exceeding the limit.

3.3.2 Indicative Values

The remaining characteristics of the voltage are, by their nature, so unpredictable and so variable from place to place and from time to time, that it is possible only to set down indicative values, which are intended to provide users with information on the order of magnitude which can be expected.

The characteristics which are dealt with in this way are:

- **voltage dips**
- **short interruptions**
- **long interruptions**
- **temporary and transient overvoltages**

3.4 Voltage Terminology

In EN 50160 the following voltage terms are used:

- **supply voltage**
- **nominal voltage Un**
- **declared voltage Uc**

In other standards additional terms are used, like:

- **highest voltage of a system [5]**
- **lowest voltage of a system [5]**
- **highest voltage for equipment [5]**
- **rated voltage (Ur; UN in [6])**

The following explanations should help to avoid misinterpretations.

Supply voltage

The r.m.s. value of the voltage which occurs at the supply terminal at a given time. This value may differ from supply terminal to supply terminal; moreover, because of the voltage drop in the customer's installation circuits the voltage at the utilisation points inside the installation is generally lower than that at the supply terminals.

The actual value of the supply voltage may be used as a reference for the measurement and the indication of values for several phenomena like flicker, earth fault factor.

Nominal voltage (U_n) and Declared voltage (U_c)

The nominal voltage identifies the reference voltage level of a supply system or user installation.

The actual r.m.s. value of the supply voltage is usually different from the nominal value. Standardised values for nominal LV voltages are given in HD 472S1 [5].

The term declared voltage is more general and includes the nominal voltage and has an essential contractual character.

MV supply networks are sometimes operated with reference to a voltage which differs from the nominal voltage. This is done to give a more precise definition of the actual range of slow voltage variations at the user supply terminals.

In low voltage supply networks the declared voltage is normally equal to the nominal voltage ($U_c = U_n$).

The nominal or declared voltages are used in the EN as a reference value for the evaluation of some of the voltage characteristics and must be interpreted as interchangeable, as appropriate, in the rest of the present document.

Highest / Lowest voltage of a system

These terms are used for the highest/lowest value of voltage which occurs under normal operating conditions at any time and at any point on a electric system. They exclude voltage transients, such as those due to system switching and temporary voltage variations.

Both terms are not mentioned explicitly in EN 50160, but can be derived from the tolerances of the supply voltage relative to the nominal voltage or declared voltage, respectively.

Highest voltage for equipment

This term defines the maximum value of the "highest system voltage" (see above) for which the equipment may be used. It is indicated for nominal system voltages higher than 1000 V only.

Rated voltage

The rated voltage is the quantity for which equipment, devices or components are designed and is specified by the manufacturer. It may be different from the nominal voltage of the supply system to which the equipment is connected, because when designing equipment, several parameters like the actual supply voltage, reliability aspects and costs of maintenance have to be taken into account.

3.5 Measurement and evaluation of voltage characteristics

The levels given in the EN are related to the user supply terminals and there must be located the point of measurement. At points inside the customer's installation the levels may be different , due to the additional impedance between supply terminals and these internal points, which is also likely to produce a greater effect of the disturbance emission from customer's equipment.

As said in the introductory considerations, the voltage characteristics must be evaluated using a statistical approach, it is therefore necessary to define, for each individual characteristic:

- method to obtain a measurement value (e.g. averaging, r.m.s, peak value, algorithmic)

- statistical method of evaluation (classification) with indication of the probability of not exceeding a certain value (e.g. 95%, 99%, 100%)

- integrating interval for obtaining a single elementary measurement value (e.g. 10 ms, 3s, 10 s, 10 min).

- observation period (e.g. 1 week, 1 year)

It can be seen from the above that the required measurement equipment and techniques are quite complex, and involve considerable data processing and data management effort, so that it is not economically feasible to have systematic comprehensive programmes of measurement to ensure compliance with the standard.

Since the standard applies at the supply terminal of each customer, the issue of compliance arises at many tens of millions of locations in Europe. Measurement, therefore, can only be undertaken on a relatively small scale, generally on an ad hoc basis, in response to problems which are suspected or to complaints which are made by customers.

The principal method by which compliance with the standard can be ensured is through the normal methods by which the technical management of the supply systems is carried out: calculations based on available information on loads and system characteristics and implementation of standard network designs, verified as necessary by actual measurements.

It is unavoidable that isolated cases for non compliance will occasionally arise. In such cases, measurements will be undertaken if problems become apparent, particularly if customers raise queries in regard to such problems.

The cost may be so great, however, that it may become necessary to make a charge for the necessary measurement. This payment could be refunded in the event that non compliance was found to be a fact.

To get unambiguous results about compliance, it is necessary to provide more detailed information with respect to that given in the EN standard. The following section contains indications of fundamental principles to measure and evaluate the voltage characteristics, with a view to the practical aspects of the problem. A detailed discussion of proposed measuring techniques is contained in a dedicated UNIPEDE report [20].

3.6 Description of the main voltage characteristics

3.6.1 Power frequency

The EN states that the nominal value of the frequency is 50 Hz. Taking into account the fact that the frequency in a supply system depends on the interaction between generators and load and that the range of variation is smaller the higher the ratio between generation capacity and load, a distinction is made between power supply systems with a synchronous interconnection to adjacent systems and weaker isolated system as those which typically exist in islands.

The ranges of frequency variations given in the EN are:

- for interconnected supply systems: 50 Hz ± 1 % for 95 % and 50 Hz + 4 - 6 % for 100 % of a week

- for non interconnected supply systems: 50 Hz ± 2 % for 95 % and 50 Hz ± 15 % for 100 % of a week

In practical terms the statistical assessment requires the definition of a basic measurement, which could be carried out by determining the mean value of the frequency over successive fixed time intervals of 10 seconds.

The compliance with the limits given in the EN will than be assessed over an observation period of one week, including Saturday and Sunday, by a statistical analysis carried out over the sequence of 10 second measurements.

3.6.2 Magnitude of the supply voltage

The magnitudes of the supply voltage correspond:

- for LV to the standard nominal voltage given at sub-clause 2.2 of EN 50160

- for MV to the declared voltage as stated at sub-clause 3.2 of EN 50160.

3.6.3 Supply voltage variations

Under normal operating conditions load changes cause variations of the average supply voltage, which are in general compensated by automatic voltage regulation, on a time scale of a few tens of seconds.

The EN indicates that the range of variation of the r.m.s. magnitude of the supply voltage, whether line to neutral or line to line to phase, is Un ± 10 % or Uc ± 10 % for 95 % of a week.

In practice the r.m.s. value could be determined over a fixed interval of 20 milliseconds and the basic measurement could be made by determining the average of these values over a period of 10 minutes.

The assessment of compliance over an observation period of one week, including Saturday and Sunday, could be then performed checking that 95 % of the ten minutes values fall within the specified range.

3.6.4 Rapid voltage changes

3.6.4.1 Magnitude of rapid voltage changes

A rapid voltage change is a fast depression of the r.m.s. value of the supplied voltage caused by the switching on of a specific load, like for instance a motor.

Load switching, to be noticeable from this point of view, requires that the rating of the load be a significant fraction of the fault level of the supply at the point of connection of the load and generally the rapid voltage change starts with a steep downgoing step followed by an upgoing ramp ending at a voltage value less than that existing before the switching (FIG. 1).

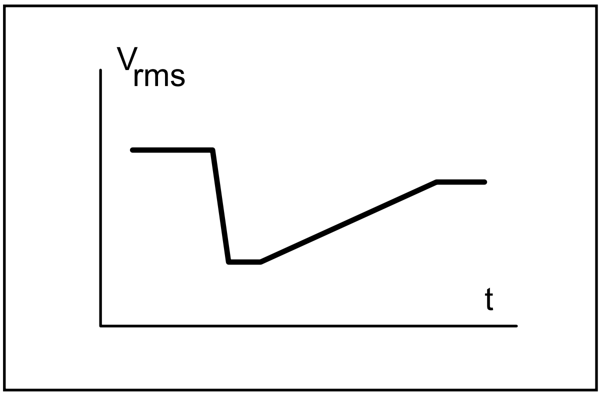

FIG. 1 Schematic form of a rapid voltage change

The front can be as short as 10 ms, whilst the recovery ramp can last several cycles of the supply voltage.

It is important to stress that a rapid voltage change, to be classified as such, must not cause a crossing of the lower voltage tolerance limit (U_n - 10 %), as it would then be considered a voltage dip.

EN 50160 gives an indication that typically rapid voltage changes do not exceed a depth of 5 % of the nominal or declared voltage (because connection of loads capable of creating rapid voltage changes is usually subjected to regulations), but higher depths up to 10 % may occasionally occur.

This phenomenon is not fully defined by EMC standards, in particular with reference to the time duration. However a practical approach to measurement could be based on the maximum depth which would occur over a basic time interval of 100 - 200 milliseconds.

The observation period and the limit repetition rate cannot be fixed, because they are too dependent on specific cases.

3.6.4.2 Flicker severity

Flicker is the effect produced on the visual human perception by a changing emission of light by lamps subjected to fluctuations of their supply voltage.

Voltage fluctuations consist of a sequence of rapid voltage changes, spaced in time close enough to stimulate the response of the eye-brain defined as flicker.

As the annoyance created by flicker is a function of both the intensity of the perception and the duration of exposure, the severity of the disturbance is described by two parameters: the short term severity P_{st}, and the long term severity P_{lt}.

The EN gives an indication only for the P_{lt} parameter, because this quantity has been considered more significant to describe the supply voltage.

The basic measurement is the short term flicker indicator P_{st}, evaluated each 10 minutes by instrumentation complying with IEC Publication 868. The measurements shall be carried out line to line (between phases) in MV networks and line to ground (phase to ground) in LV networks[(1)] .

Only short term values P_{st} measured during the time when the supply voltage magnitude is within ± 15% of the nominal voltage (or declared voltage) and not affected by voltage dips should be considered for the evaluation.

The long term severity P_{lt} shall be evaluated every 2 hours from 12 consecutive P_{st} values, following IEC Publication 868.

The compliance with the limit given in the EN (Plt ≤ 1 for 95 % of the measured values) will than be assessed over an observation period of one week, including Saturday and Sunday, by a statistical analysis carried out over the sequence of the evaluated P_{lt} values.

[(1)] In any case on LV the connection of the measuring instrument will follow that of lighting installations.

3.6.5 Supply Voltage Dips

A voltage dip is a sudden reduction of the r.m.s. voltage value below 90 % of the nominal (or declared) value, followed by a return to a value higher than 90 % of the nominal, in a time varying from 10 ms to 60 s. Figure 2 shows a simplified form of a voltage dip, to point out the fundamental parameters by which it is characterised: depth (ΔV) and duration (Δt).

The definition of voltage dips is clearly a convention, derived from practical experience, but also depending on the context in which the phenomenon is discussed. This explains why, at the moment, there exist different definitions, with reference to the following aspects:

a) criterion concerning the depth of voltage reduction, for classification as a dip

b) duration (lowest, highest value of the voltage for the period of time to be considered)

c) reference value to assess the depth

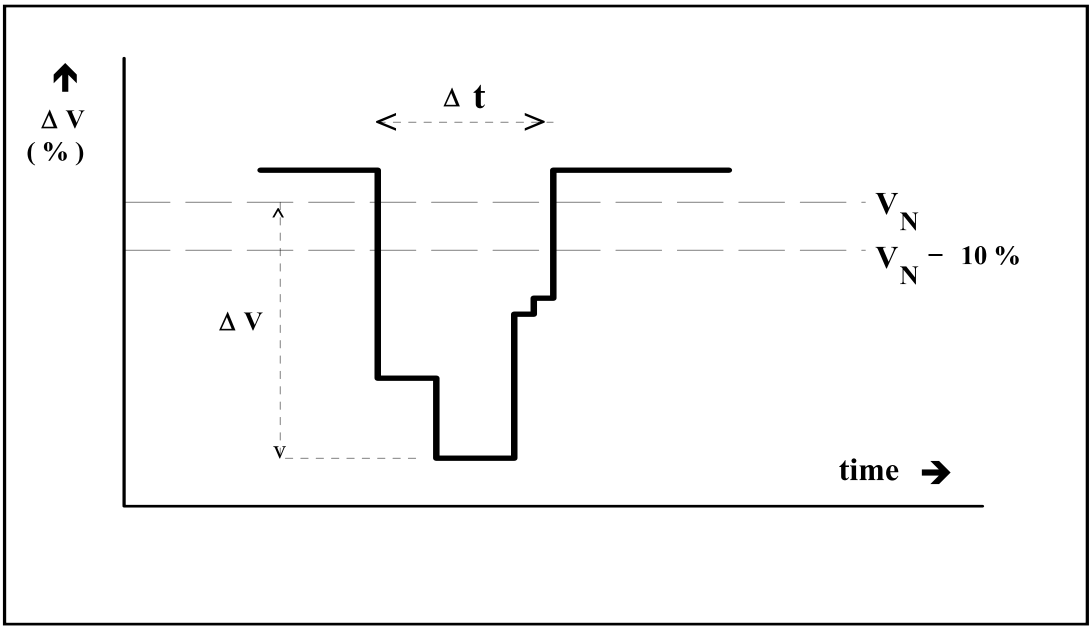

FIG. 2 Simplified form of a voltage dip

Depth

IEV defines as a dip any reduction of the r.m.s. value of the supply voltage, independently from the depth.

This definition is too vague and, besides, it is not applicable for the measurement of dips, because it contains no indication concerning a reference value against which the depth of the dip should be gauged.

It is then necessary to set a minimum depth below which the reduction, being of no practical significance, is not classified as a voltage dip and to choose a reference value, in order to express the depth as a percentage of this value.

The first problem can be solved satisfactorily by considering only the reductions that bring the voltage value below the lower limit of the tolerance on supply voltage variations (90 % of the nominal value or declared voltage in the EN).

The second task could be accomplished in two ways: either the reference voltage is selected as the actual value existing immediately before the dip, or it is set equal to the nominal voltage (or declared voltage if different).

The last option was adopted in EN 50160, in order to use as a term of comparison a well defined quantity.

The requirements of practical measurement make it necessary to classify voltage dips by reference to the nominal voltage rather than to the actual supply voltage at the starting time of the dip.

To ensure that a reduction of the supply voltage down to 0 V may correspond to a reduction of 100 % relative to the reference voltage, this has to be chosen equal to the nominal voltage.

A voltage dip is classified as one event, irrespective of the shape and of the number of phases affected. This is because most industrial and commercial user receive a three phase supply, but also single phase installations may contain equipment which is sensitive to voltage dips.

A multiphase event is counted as a single occurrence if the events on the different phases overlap in time.

According to the before mentioned definition, any temporary reduction of the supply voltage starting from a value above 90% Un to a value below it, is a voltage dip, irrespective of the depth. As an example, a reduction starting from a supply voltage of 92 % Un, with a value of 3 % Un would be classified as a voltage dip of 11 %.

It is also necessary to make a distinction between a voltage dip and an interruption (no supply voltage). As a matter of fact, short interruptions, lasting less than 60 seconds could also be seen as a 100 % voltage dip and there would be inevitable confusion when making a classification. It was therefore adopted the criterion of establishing a threshold at 1 % of the nominal voltage. If the supply voltage value drops below 1 % U_n the event is considered an interruption, otherwise it is classified as a voltage dip.

The implications following from the previous consideration should be fully understood, because it is clear that situations were the supply voltage is closer to the lower tolerance (0.9 Un), are prone to show an higher number of voltage dips as also small voltage variations due to load switching will be classified of voltage dips.

However these dips will have no effect on the user equipment, as only voltage dips with depth exceeding, say , 15 or 20 % are of real significance, although their impact on the statistics may be relevant.

In regions with weaker networks, like in rural areas, as mentioned also in EN 50160, the occurrence of voltage dips may therefore appear very frequent, just because of the increased influence of voltage reductions in the range from 90% to 85% Un.

This also explains the indicative value "up to one thousand" given in EN 50160, based on the values of Table I, taken from the UNIPEDE-Report quoted below [7], considering:

- additional voltage reductions originating from the LV supply network itself
- worse weather conditions at consideration of longer periods as well as of the conditions throughout Europe.

Duration

It must be stressed that the duration is the time during which the voltage is less than 90 % Un as in IEC Publications 1000-2-1 and -2 [9, 10].

IEV 161-08-10/1986 [8] defines some 50 Hz cycles for the lowest and a few seconds for the highest duration of a voltage dip.

This probably stems from the consideration that in practice voltage dips are mainly caused by faults, which are cleared by the tripping of a circuit breaker in a time of 100 ms to some hundreds of milliseconds, or by switching of large inductive loads (e.g. motors), although in case of starting of large motors the duration of the voltage reduction may last several seconds.

The lower limit for duration can be set by considering that 10 ms (half a 50 Hz cycle) is the minimum time period over which an r.m.s. value can be calculated.

The upper limit of duration was subsequently increased to 60 s, to include the effects of load switching in the supply network and of the energization of transformers.

The UNIPEDE survey

To get a better knowledge of voltage dips occurring in the European MV supply networks, the UNIPEDE group of experts DISDIP carried out a co-ordinated measurement campaign over a period of three years, in nine countries with different climates and network configurations.

The survey was carried out in 126 sites with standardised measurement and evaluation criteria, extending the maximum duration of a dip up to 60 seconds, in order to include also more seldom occurring dips.

Table I summarises the results obtained in the survey. Each cell of the table represents, as a combination of the results from all locations, the number of events belonging to the corresponding classes of depth and duration, which may be expected to occur per year, with a probability of 95 % of not being exceeded. It should be noted that, according to the criterion stated before, data on the last row are to be considered as interruptions and not as voltage dips.

TABLE I UNIPEDE survey on the characteristics of voltage dips: frequency of occurrence per annum with a 95 % probability of not being exceeded

Depth (% of nominal voltage)		Duration					
		(ms)	(ms)	(s)	(s)	(s)	(s)
from	**to less than**	**10 < 100**	**100 < 500**	**0.5 < 1**	**1 < 3**	**3 < 20**	**20 < 60**
10	30*	111	68	12	6	1	0
30	60	13	38	5	1	0	0
60	99	12	20	4	2	1	0
99	100	1	12	16	3	3	4

As the results of the UNIPEDE measurements have shown, the majority of voltage dips have a duration less than 1 second, as mentioned also in EN 50160 (Sub-clause 2.2.3).

Depth and duration of voltage dips can be obtained by measuring the r.m.s. value of the voltage every half cycle and the statistical evaluation can be performed using the classification method established by UNIPEDE and already used in EMC standardisation.

3.6.6 Short and long interruptions of the supply voltage

Concerning the duration of a supply voltage interruption UNIPEDE DISDIP and IEC Publ. 1000-2-1 name an upper limit of 1 min, related only to short interruptions.

EN 50160 subdivides voltage interruptions into:

- short supply interruptions (duration less or equal to 3 min)

- long supply interruptions (duration > 3 min),

This classification takes into account the characteristics of protection and automatic reclosing systems in use in the supply networks.

On medium voltage overhead networks it is common practice to perform a fast automatic reclosing after the initial tripping of a line circuit breaker on a fault.

The delay for the fast reclosing is in general between 300 ms and 500 ms and in most cases less than 1 second.

* UNIPEDE DISDIP has decided to split this class into two classes : 10 - 15 and 15 - 30

In case of a successful reclosing which clears the fault, the user supplied by the line are affected by a usually deep voltage dip, lasting the operating time of the circuit breaker (about 100 ms) followed by an interruption lasting the delay set for the automatic reclosing.

The other lines connected to the same busbar of the line where the fault occurs experience a voltage dip lasting the operating time of the circuit breaker, whose depth depends on the distance of the fault location from the substation busbar.

If, at reclosing, the fault is still present, another voltage dip will occur on the concerned line and on the others lines supplied by the same busbars and the circuit breaker will trip again.

Depending on the operation scheme adopted in case of faults, the supply will be interrupted until the fault is localised and the line section is isolated for inspection and repair, or a slow automatic reclosing is performed, after a delay commonly ranging between 30 seconds and 3 minutes.

The users supplied by the line will accordingly experience another short interruption followed by restoration of supply or a final tripping of the circuit breaker, depending on whether the fault has cleared spontaneously or keeps being present.

Moreover in some cases the practice is to use automatic sectionalising of faulted line sections, operating switches cascaded along the line, in order to isolate as fast as possible the line section where the fault is located and resupply the healthy sections of the line.

It must be stressed that these techniques are applied in order to improve as much as possible the continuity of supply, and minimise the number of users subjected to the interruption caused by a permanent fault, at the price of subjecting the users connected to the healthy lines to a few additional voltage dips.

As far as the low voltage networks are concerned, the probability that a fault clears spontaneously when the voltage is switched off is very low, so that the tripping of the line circuit breaker or the blowing of a fuse are final and a fault is always permanent.

Low voltage users are therefore subject to the events on the medium voltage network to which their supply lines are connected and to those occurring on their specific and adjacent low voltage circuits.

In the EN the protection and supply restoration schemes have been considered an intrinsic feature of "normal operation" of a supply system and this explains why the duration of short interruptions has been increased to three minutes, instead of keeping the duration of one minute, as in the EMC standards.

It can also be useful to discuss some practical aspects of evaluating the statistics of occurrence of short interruptions.

From the point of view of most users, the tripping of a circuit breaker followed by a sequence of automatic reclosing and by possible additional switching operations, occurring within a short time from the onset of the fault, is equivalent to a continuous interruption, so that it would be more significant to combine all the sequence of related individual events into a single, equivalent interruption, with a duration equal to the time elapsed from the initial tripping of the circuit breaker to the final reclosing operation.

Another important remark is that supply continuity depends in no small proportion also on the performance of the user installations connected to the distribution network, as a lack of maintenance or an inadequate insulation of the user installations will affect significantly the overall performance of the supply system, by increasing the number of faults, either transitory or permanent.

3.6.7 Temporary (power frequency) overvoltages between live conductors and earth

Temporary overvoltages mainly occur at the power frequency and can last from several cycles up to hours or days, depending on specific situations.

A) LV distribution systems

The majority of LV public distribution systems are operated with a solidly grounded neutral, therefore limited temporary overvoltages are experienced; these overvoltages can arise as a consequence of faults and switching on of power factor improvement capacitors.

The magnitude is generally limited below 1.5 kVrms.

B) MV distribution systems

Events originating temporary overvoltages on the MV networks are mainly of two types:

- single line to earth faults
- ferroresonance phenomena due to the saturation of magnetic cores (these overvoltages are not power frequency overvoltages, but are characterised by a heavy distortion due to the presence of subharmonic and harmonic voltage components, generally from a few Hz up to 150 Hz).

B1) Overvoltages due to single line to ground faults

In MV networks with isolated or impedance grounded neutral, this kind of fault can produce line to ground temporary overvoltages on the healthy phases. Their magnitude is in general below 2.0 p.u. of the nominal phase to ground voltage; the overvoltages last for the duration of the fault.

B2) Overvoltages due to ferroresonance

Practically two conditions might originate this kind of overvoltages in MV networks :

- open conductors
- grounded voltage transformers in MV networks with an isolated neutral.

Open conductors condition

This condition stems from one or two open conductors (fuse operation, broken conductors, etc.) that remain energised by the primary of a MV/LV transformer with a delta winding connection or isolated neutral on the primary and in light load condition.

The phenomena is governed by the zero sequence capacitance of the open conductors, the no load impedance of the MV/LV transformer and the load condition on the transformer LV side.

Phase to ground overvoltages maximum magnitude is in the range 2.5 - 3 p.u. of the nominal voltage with a waveform affected by harmonic distortion (up to 150 Hz). These overvoltages appear only on the feeder interested by the open conductor condition.

Grounded voltage transformers in isolated neutral MV networks.

The condition prone to give ferroresonance takes place for well defined system characteristics (particular ranges of: ratio between zero sequence capacitive impedance of the MV network / equivalent magnetising impedance of the voltage transformers; zero sequence damping).

Line to ground overvoltages appear if excited by a sudden change in the network: fault application/clearing, switching manoeuvres, etc..

The overvoltage maximum magnitude is in the range 1.8 - 2.5 p.u. with a waveform affected by subharmonic and/or harmonic distortion (from few Hz to 150 Hz); these overvoltages do not affect the line to line voltage.

Measurement of temporary overvoltages

Temporary overvoltages at power frequency can be measured(2) by detecting the r.m.s. value of the supply voltage on a basic interval of one cycle.

Ferroresonance overvoltages characterised by heavy distortion of the waveforms must be evaluated by the use of adequate recorders.

The measurement shall be carried out line to ground.

3.6.8 Transient overvoltages between live conductors and earth

Transient overvoltages present very different characteristics and might be classified in relation to: amplitude, occurrence, duration, surge main frequency, rate of voltage change and energy content. In the following a short description of transient overvoltages occurring in LV and MV distribution systems grouped in relation their duration is given.

(2) When measuring overvoltages in MV distribution systems with isolated neutral, attention must be paid to the characteristics of the voltage transformers being used, because this piece of equipment can affect the zero sequence response of the network (for example inductive voltage transformers may introduce ferroresonance conditions).

A) LV distribution systems

A1) Long duration surges: >100 μs

The origins are mainly:

- operation of current-limiting fuses (generally: amplitude: up to 1 - 2 kV, waveform: unidirectional, high energy levels)

- switching of power factor correction capacitors (generally: amplitude: up to 2 - 3 times nominal peak voltage, waveform: oscillatory with frequency in the range a fraction to a few kHz, high energy levels)

- transference of transient overvoltages from MV to the LV of the transformers by electromagnetic coupling (generally: amplitude: up to 1 kV, waveform: oscillatory with frequency in the range a fraction to a few ten kHz)

A2) Medium duration surges: >1 to ≤100 μs

The origins are mainly:

- induction of the nearby lightning strikes along LV lines conductors (generally: amplitude: up to 20 kV, waveform: unidirectional some times unidirectional oscillatory, high energy levels)

- lightning strikes on LV lines conductors directly (no controlled surges: amplitude: up to 20 kV, waveform: unidirectional, high energy levels)

- resistive coupling that due to lightning ground currents flows in the common ground impedance paths and in a partially common ground resistance gives surges (amplitude generally up to 6 - 10 kV, unidirectional or sometimes unidirectional oscillatory waveform, high energy levels)

- transference of surges (due to direct lightning strokes on MV, rapid drops of voltage following operation of gap-type arresters on MV, fault application/clearing on MV) from MV to LV by capacitive transformer coupling (amplitude generally up to 4 - 6 kV, unidirectional or sometimes oscillatory waveform)

- minor switching in LV with (giving voltage escalation) and without multiple reignitions or restrikes generally exciting the natural frequency of the nearby system (amplitude generally up to several times the nominal voltage, oscillatory complex waveform with voltage escalation, frequency in the range from a few tens kHz to 1 MHz)

- operation of breakers with very short arcing times, < 2 μs (amplitude generally up to several times the nominal voltage, oscillatory waveform, with frequency in the range from a few tens kHz to 1 MHz)

A3) Short duration surges: <1 μs

The origins are mainly:

- local load switching of small inductive currents and short wiring (amplitude generally up to 1 - 2 kV, oscillatory waveform with frequency from a few MHz to a few tens MHz)

- fast transients due to switching (closing and opening) in LV by air-gap switches (relays and contactors) giving a succession of clearings and reignitions (bursts of surges, one surge: rise time of about 5 ns, duration of about 50 ns)

For a reliable operation of equipment in LV networks, the surge withstand capability of the equipment connected to the network should be properly co-ordinated to the LV environment, possibly making use of surge protective devices.

Successful application of surge- protective devices has to consider theirs lifetime, that should not be sacrificed for the sake of a low remnant

B) MV distribution systems

B1) Long duration surges: >100 μs

These overvoltages are mainly caused by switching events (opening of inductive loads with/without virtual chopping, opening/closing of power factor compensating capacitors with/without restrikes, main MV feeders, etc.), fault application, arcing ground faults, transient overvoltages transferred from HV to MV of the transformer by electromagnetic coupling.

In the most important points of the systems the amplitude of these overvoltages is limited by the protection levels of gaps and/or surge arresters required for insulation co-ordination (amplitude generally up to 3 - 5 times the peak line to earth voltage, oscillatory waveform with frequency in the range from a few hundred Hz to some hundreds kHz)

B.2) Medium duration surges: >1 to ≤100 μs

The origins are mainly:

- induction of the nearby lightning strikes along MV lines conductors and lightning strikes on MV lines conductors directly (rather rare). Along the line the maximum amplitude of these stresses is limited by the clearance sparkover of the line; in primary HV/MV substations and MV/LV secondary transformers it is limited by the protection levels of gaps and/or diverters. The majority of the stresses are of induced type (amplitude depending on clearance sparkover voltage and protection levels ensured by insulation co-ordination, unidirectional waveform sometimes oscillatory, rise time in the range from 1 to 50 μs, half value time about 100 μs, high energy content).

- breaker operation with proneness to reignition, for example vacuum circuit breakers (amplitude depending on protection levels assured by insulation co-ordination; in general up to 8- 10 times the peak value of the nominal voltage, oscillatory waveform with a frequency of a few MHz)

B3) Short duration surges: <1 µs

The origin is mainly related to switching in IGS equipment (SF6) (amplitude generally up to a few times the peak value of the nominal voltage, oscillatory waveform with frequency higher than one MHz)

C) Measurement of transient overvoltages

The measurement of transient overvoltages requires adequate equipment (transient recorders, voltage transducers, etc.) depending on the nature of the investigated transient.

3.6.9 Supply voltage unbalance

The unbalance of a three phase supply voltage consists of a loss of symmetry of the phase voltage vectors (magnitude and/or angle), created mainly by an unbalance of the load.

Practically the unbalance U_u of the supply voltage is defined by the negative sequence component U_i expressed in p.u or % of the positive sequence component U_d ($U_u = U_i/U_d$).

The basic measurement shall be the r.m.s. value(3) evaluated over a fixed interval of 10 minutes over the observation period of one week, including Saturday and Sunday.

Each 10 minutes r.m.s. value is obtained from a series of elementary measurements (each performed, for example, on one or more cycles).

The very short term effect of unbalance is generally not of interest; therefore gaps between elementary measurements may be allowed (an effective measuring time of the order of 2 - 5 % of the observation time is sufficient).

Only 10 minutes r.m.s. values measured during the time when the phase to phase supply voltage magnitude is within ± 15 % of the nominal voltage should be considered for the evaluation.

Compliance with the EN is verified when 95 % of the sequence of valid 10 minutes values are within the specified tolerance (2 % or 3%).

As far as the measurement technique is concerned, a feasible approach is given in Appendix A, subclause A2.

3.6.10 Harmonic voltage

The general approach of EN 50160 is to express all voltage characteristics by reference to the nominal voltage or declared voltage, as appropriate.

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(3) The 10 minutes r.m.s. values corresponds to the true r.m.s. value evaluated with an integrating time equal to the chosen effective measuring time in a 10 minutes interval; its evaluation is carried out as given for harmonics in Appendix A, subclause A1, footnote (6).

Thus, although it defines harmonic voltages in relation to the fundamental voltage (sub-clause 1.3.21 of EN 50160), it gives LV values (table 1) in relation to the nominal voltage, and MV values (table 2) in relation to the declared voltage (sub-clauses 2.11 and 3.11 of EN 50160, respectively).

This deviates from the general practice (also followed by several standards), which is to express harmonic voltage components as percentage values relative to the fundamental.

It must also be mentioned that many instruments used for harmonic measurements express their output with reference to the fundamental component of the voltage, especially those indicating the Total Harmonic Distortion Factor (THD).

Therefore, it will be necessary to apply a conversion factor to any measurement of harmonics expressed as a percentage of the fundamental, before comparing it with the values in Table I and 2 of EN 50160. In most cases, however, this will not lead to significant differences, since the scaling factor will be very close to unity.

Harmonic values are specified only up to order 25, for the practical reason that for higher orders the values are generally so small as to be impractical to measure, and because of the difficulty of giving values which would be relevant to all networks.

In the following the harmonic distortion of voltage and current are characterised by the following parameters:

- Individual Harmonic Distortion (IHD): the value of each single harmonic component

- Total Harmonic Distortion (THD): the value of the total harmonic distortion including single harmonic components from 2nd to 25th order.

The basic measurement consists of the 10 minutes r.m.s. values[(4)] of IHD and THD, evaluated by instrumentation and methods complying with IEC Publication 1000-4-7 (EN 61000-4-7) [11].

The measurements shall be carried out at the supply terminals (line to line voltage for MV and line to neutral voltage for LV), as applicable according to the terms of the supply contract.

For example a line to ground connection of the voltage tranformers is needed on MV to measure the zero sequence voltage distortion. In this case it must be noted that on networks with an isolated neutral, the use of inductive voltage transformers with primary connected to ground could modify the zero sequence response of the network and introduce ferroresonance phenomena.

The observation period shall be of one week, including Saturday and Sunday.

Only 10 minutes r.m.s. values measured during the time when the input voltage magnitude is within ± 15 % of the nominal voltage should be considered for the evaluation.

[(4)] see Appendix A, subclause A1, footnote (6).

Compliance with the EN exists when 95 % of the 10 minute r.m.s. values are less than or equal to the specified limits.

As far as the measurement technique is concerned, a feasible approach is given in Appendix A, subclause A1.

3.6.11 Interharmonic voltage

The phenomenon is still under consideration as far as standardisation is concerned, but the specification of the measurement instrumentation practically corresponds to that used for harmonics.

For time-domain instrumentation a window width in the range from 0.16 to 0.5 sec. is recommended; in any case the window width and the dedicated software, if any, have to match the required bandwidth.

Statistical evaluation of interharmonics, if necessary, should be carried out as described for harmonics.

Generally in the measurement of interharmonics it is recommended to consider a frequency range; its centre and width must be chosen in accordance to the investigated phenomenon. For example in the analysis of interharmonic interferences on ripple control receivers, a bandwidth of 5 Hz at -3 dB centered on the frequencies of interest is suitable.

3.6.12 Mains Signalling voltage on the supply voltage

With regard to signal transmission over the public supply network there is to distinguish between:

- ripple control systems, operating in a frequency range from 100 Hz to 3 kHz

- carrier wave communication systems, operating in a frequency range from 3 kHz to 148,5 kHz

The voltage levels given in EN 50160 are based on the following:

- 100 Hz to 900 Hz: The values are taken about from the so-called "Meister-curve" which defines the maximum permissible ripple control voltages in LV-networks. It consists of a horizontal part for the low frequency range with a maximum level of 20 V and a following decrease, starting at 500 Hz, according to the function 10.000/f (f in Hz). The Meister-curve is contained also in EN 61000-2-2, 1993 [10].

- 900 Hz to 3 kHz: The value of 5% Un corresponds with the maximum level for control voltages as given in EN 61000-2-2:1993 for the frequency range from 500 Hz to 2 kHz

- 3 kHz to 95 kHz: The values are defined on basis of EN 50065-1 [12], being doubled taking into account the defined measuring method

- 95 kHz to 148,5 kHz: The values are defined on basis of EN 50065-1, being doubled taking into account the defined measuring method

Levels are defined equally for LV and MV in the range from 100 Hz to 9 kHz; for frequencies above 9 kHz the MV-part of EN 50160 doesn't give levels because of lack of experience and with a view to possible future developments.

The values given in EN 50160 for mains communication equipment/systems (MCES) operating at frequencies > 3 kHz, are based on the maximum transmitter output levels according to EN 50065-1, paying attention to the fact that those levels express what is measured by a meter having an internal impedance equal to that of the transmission line, so that the actual levels on the line are to be doubled (see FIG. 3).

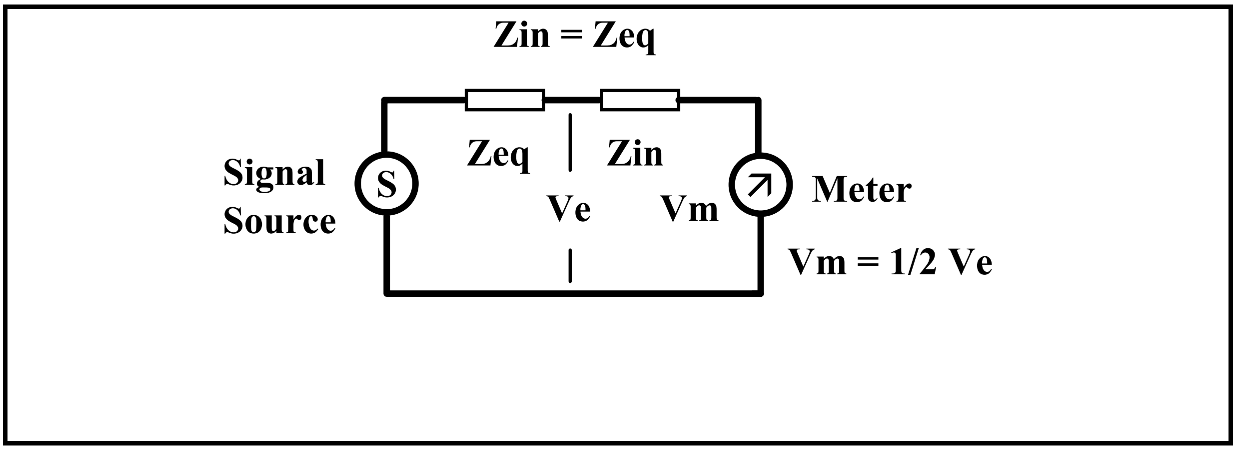


FIG. 3 Measuring arrangement for injected signals

The observation period shall be one day. Only 3 second mean values measured during the time when the input voltage magnitude is within ±15 % of the nominal voltage should be considered for the evaluation. Compliance with the EN exists when 99 % of the 3 seconds mean values are less than or equal to the specified limits.

According to CENELEC EN 50065-1 the frequency-range from 95 kHz to 148,5 kHz is reserved for the operation of mains communications equipment/systems in customers' installations exclusively.

The use of the public low voltage supply network for customers' MCES depends on the consent of the electricity supplier as well as possibly of competent (e.g. postal) authorities.

However a migration of such signals into the public supply network with a residual voltage level is to be foreseen in any case.

To avoid disturbing effects of these residual levels upon other customers' MCES or equipment, as well as on the communication systems of the power utilities (in the frequency range up to 95 kHz), a limitation of such residual voltages according to the specifications of the above-mentioned standard, if necessary, is to be provided by the user by taking appropriate mitigation measures (e.g. installing filters). EN 50160 mentions the problem with the aim of giving a comprehensive description of all the phenomena which may affect the voltage at the user terminals.

Figure 4 (courtesy of OKA - Oberösterreichische Kraftwerke AG) gives a synthetic view of the emission limits related to harmonics and mains signalling as reported by EN 50160 and other standards.

3.7 Private generation

Electricity, as produced by the public power stations, is generally free of defects.

When energy is supplied to the public networks from private generators, it is important to keep the level of disturbances under control.

In this context, private generation is in the same position as any customer's installation and therefore has to comply with the related emission standards.

Such compliance is therefore also a condition for the applicability of the EN standard.

4. ELECTROMAGNETIC COMPATIBILITY STANDARDS AND EN 50160

4.1 Introduction

The basic concepts of electromagnetic compatibility are described by the following terms:

Electromagnetic disturbance	Any electromagnetic phenomenon, which may degrade the performance of a device, equipment or system or adversely affect living or inert matter. (An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself)
Disturbance level	The value of a given electromagnetic disturbance, measured in a specified way. (Disturbance levels are generally designated as 95 % probability values on a basis of a time statistics)
Electromagnetic Compatibility (EMC)	The ability of an equipment or system to function satisfactorily in its electromagnetic environment and without introducing intolerable electromagnetic disturbances to anything in that environment
Electromagnetic Compatibility level	The specified disturbance level at which an electromagnetic compatibility should exist. (The compatibility levels are reference values for purpose of co-ordinating emission and mainly immunity of equipment; they are generally designated as 95 % probability values on a basis of time and system locations statistics)
Planning level	The specified disturbance level used mainly for planning purposes in evaluating the impact on the system of all disturbing consumers or equipment. (Planning levels are: -internal reference values of the utilities -generally equal to or lower than compatibility levels -not standardised values, but only indicative values -often used for emission co-ordination in determining the emission allowed to the consumers - generally designated as 95 % probability values on a basis of a time statistics)

Total disturbance level	The level of a given electromagnetic disturbance caused by the superposition of the emissions of all pieces of equipment in a given system (Total disturbance levels are generally designated as 95 % probability values on a basis of a time statistics)
Conducted disturbance	Electromagnetic phenomenon which propagates along the electricity supply conductors and/or signal-control connections. (In transmission distribution systems conducted disturbances can propagate along power lines and in some cases across transformers so that they may affect equipment distant from their source. The main types of conducted disturbances are harmonics, interharmonics, voltage fluctuations, voltage dips and short supply interruptions, voltage unbalance, mains frequency variation.)
Emission	The phenomenon by which an electromagnetic disturbance emanates from a source
Emission level	Level of a disturbance injected into the surrounding space or into the supply conductors (Emission levels are generally designated as 95 % probability values on a basis of a time statistics)
Immunity	The ability of a device, equipment, or system to function without degradation of its specified performance in the presence of an electromagnetic disturbance
Immunity level	The maximum level of a given electromagnetic disturbance, incident in a specified way on a particular device, equipment or system, at which no degradation of its specified performance occurs (Immunity levels are test levels)
Susceptibility	The inability of a device, equipment, or system to function without degradation of its specified performance in the presence of an electromagnetic disturbance

The fundamental objective of EMC co-ordination is to ensure that:

- emission from each separate source of disturbance are such that the combined emissions from all sources do not exceed the conventionally accepted level of disturbance to be expected in the environment.

- equipment immunity is provided to permit the appropriate, specified, level of performance at the conventionally expected level of disturbance.

This environment is determined by the specific characteristics of the user plant (internal electric installation and loads) and by the voltage characteristics available at the supply terminals.

A task carried out by EMC standardisation has been therefore to establish the compatibility levels against which the immunity of equipment can be gauged. This has been done by defining some reference environments [21]:

- protected supply systems	(Class 1)
- public supply systems	(Class 2)
- industrial internal supply systems	(Class 3)

As far as the public supply systems are concerned, the compatibility levels chosen by EMC standardisation, although derived from the practical experience, are also the result of a compromise between the requirements of equipment manufacturers and those of electricity suppliers.

As a matter of fact, choosing compatibility levels too low, would imply an excessive restriction of emissions or costly upgradings of the supply systems, whilst levels too high would require excessive immunity levels, which would produce unacceptable increases in the cost of user equipment, although in presence of less restrictions in emission requirement.

Prerequisite for compliance with compatibility levels is then the specification of user plant emission limits with an appropriate margin below the compatibility levels, considering to this effect the summation of the emissions of all the users´ installations supplied by the same network. This can be done on a case by case basis for large MV user plants, but the approach would not be practical for other MV users and LV users.

EMC standardisation takes care of this problem by issuing "product standards", which specify emission limits for families of equipment. The general idea is that having established these limits, the equipment can be used without need of further verification of the compliance between emission and compatibility.

4.2 Voltage characteristics versus compatibility levels

In the sense of the actual definitions given in the existing standardisation the compatibility levels ought to reflect the real conditions in supply networks. With regard to the task of the compatibility levels - to represent the basis for management of EMC in the public networks - they should also represent a mirror of the expectable network conditions, at least for the nearer future.

From today's point of view the compatibility levels appear as levels which may be complied with considering economic aspects, with high probability, taking into account:

- an effective co-ordination of emission and immunity, by application of appropriate emission limits and immunity requirements for customers' equipment and installations

- local reinforcement of supply networks if occasion arises.

Just so the compatibility levels serve as guiding values for designing and selecting the immunity of electrical equipment, that to be done corresponding with the kind of application and the needs for reliability. Compatibility levels don't give information about the excursions of the disturbance levels.

Moreover compatibility levels can be exceeded with a 5 % probability in time and also in locations of the supply network, whilst voltage characteristics can be exceeded for 5 % of a specified observation period, but are referred to **all supply terminals in a network**. This explains why for some of the voltage characteristics the EN 50160 values are higher than the compatibility levels, as they dispense with the possibility that in a few locations the levels can be exceeded.

Summing up, to correspond with the reality of supply networks throughout the different network structures and geographical situations in Europe, for the description of the characteristics of the supply voltage a choice of values higher than the compatibility levels has been sometimes necessary.

It must be stressed that the voltage characteristics serve as a reference concerning the electricity supply, as an indication on its expected performance and as a guiding criterion for selecting the immunity of user equipment. Test levels for proving immunity of electrical equipment should therefore be chosen with an appropriate margin, depending on the kind of application and the required reliability.

Figure 5 shows the relationships and the mutual effects between the standardisation process, the supply system and the user installation.

Figures 6 and 7 show the interaction of the different before mentioned levels in the perspective of EMC co-ordination, in a deterministic and statistical representation, respectively.

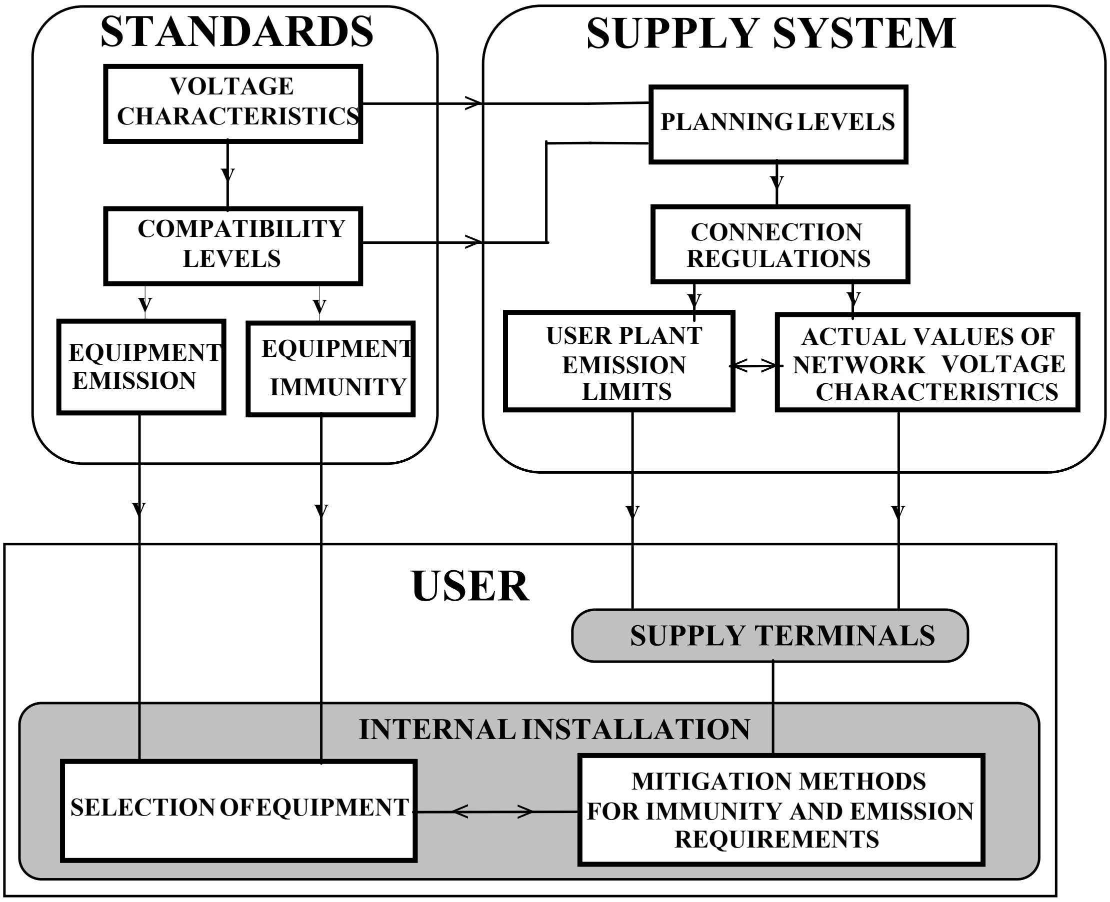


FIG. 5 Relation between standardisation, management of voltage characteristics, user equipment and installation options

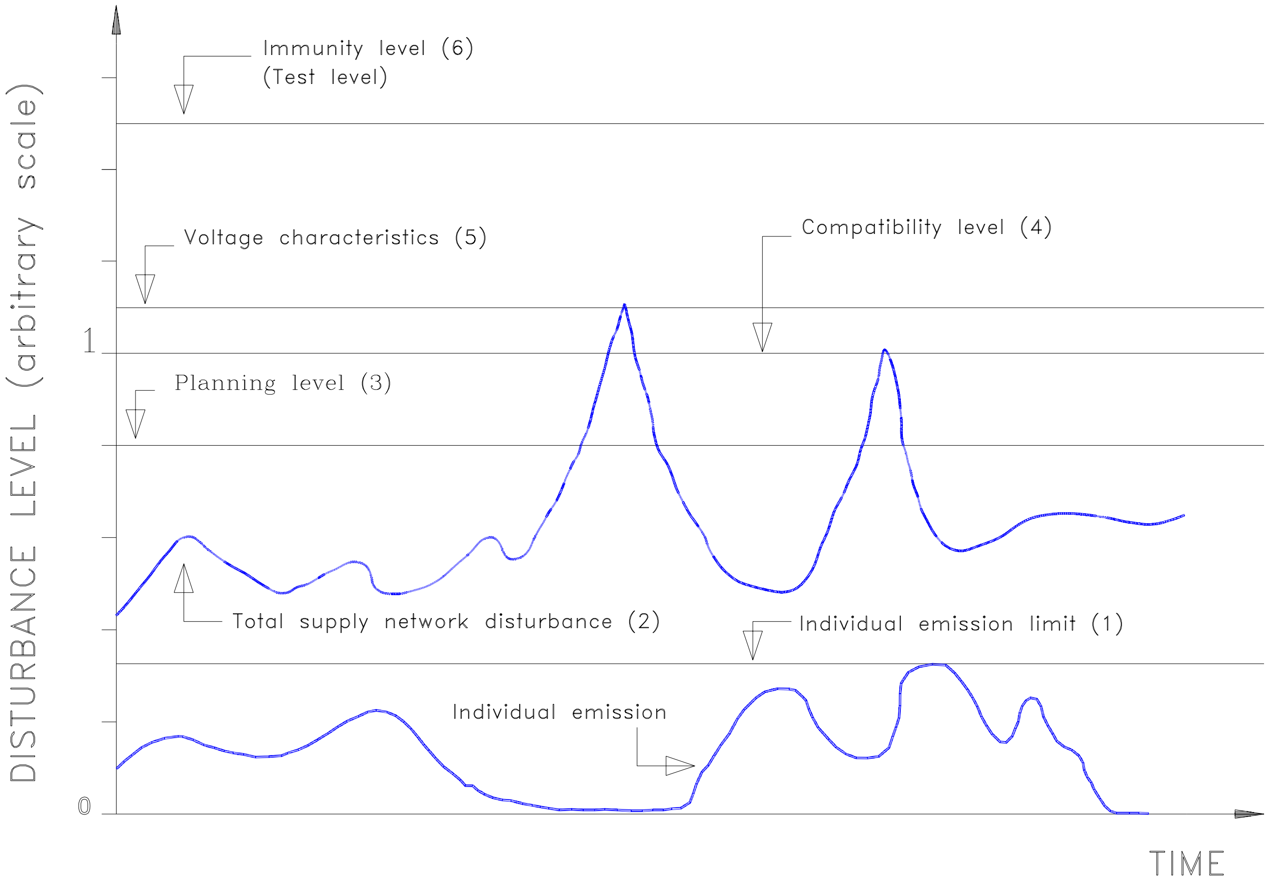
It is to be recognised that emission limitation and the consequent disturbance levels in the supply networks, compatibility levels, product levels and the selection of equipment immunity form a closed process.

That requires a careful dimensioning of all standardising choices and appropriate construction of equipment - and possibly iterative modifications, to ensure compliance with the product levels and in particular with the compatibility levels.

Attention should be paid to the fact that measures of adaptation in the course of this process, for restoration of previous EMC levels, will involve longer time and higher costs.

Compatibility levels are already exceeded at some locations and this will become more common in the future. This is because the emission from customers' installations are increasing more than expected, due to insufficient limitation of emission by the product standards [14, 15, 16].

That means that EMC compliance with regard to the existing immunity of equipment is not guaranteed any longer. Regarding this situation, setting of increased compatibility levels seems to be a solution for the above mentioned problems, only to a small degree.



(1): Defined by Standards or Electricity Supplier (maximum or 95% value)

(2): For a network location with a medium-high disturbance

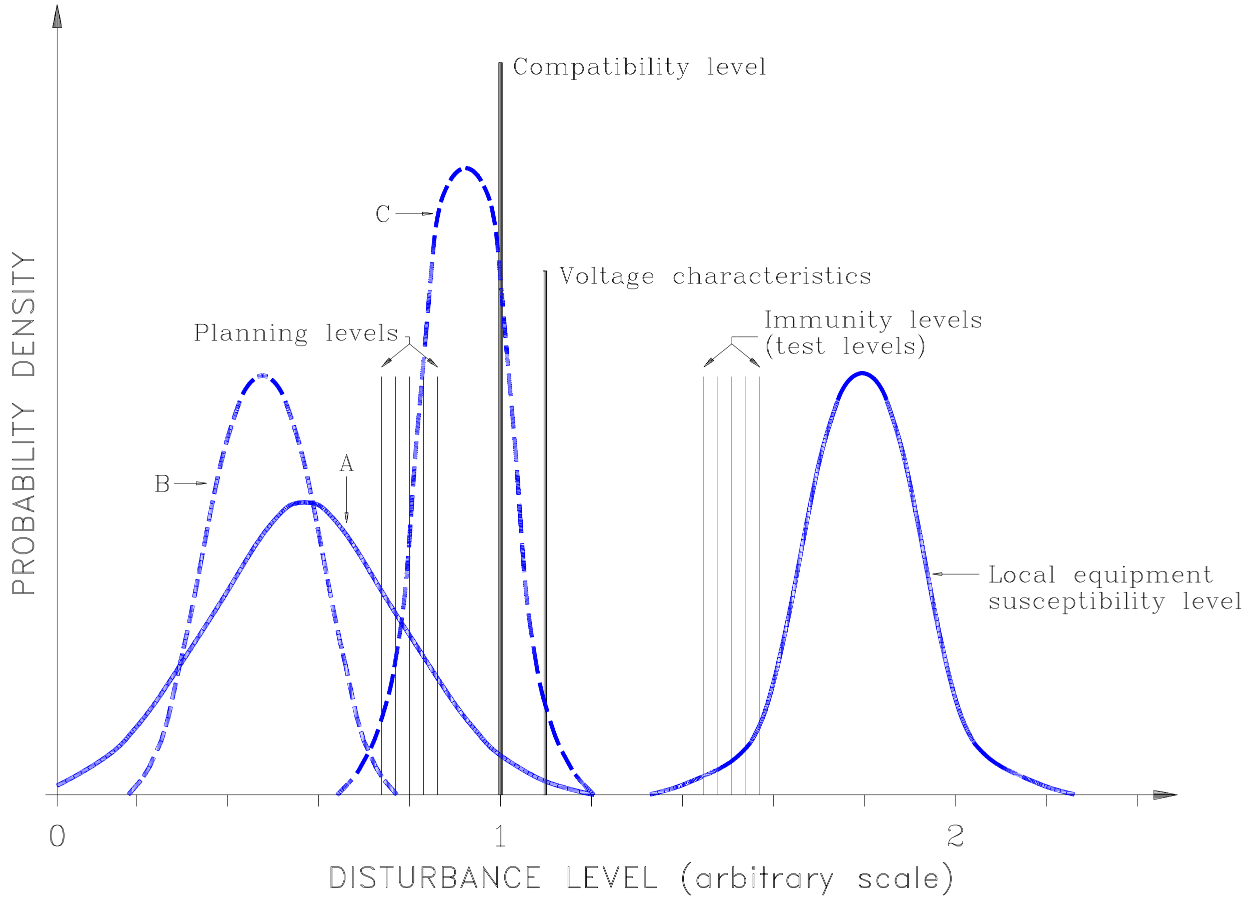
(3): Defined by Electricity Supplier (time statistics, 95% value)

(4): Defined by Standards (time and location statistics, 95% value)

(5): Defined by Standards (time statistics, 95% value)

(6): Defined by Standards or agreed between User and Manufacturer

FIG. 6 Deterministic representation of the co-ordination of conducted disturbances. Mutual relationships of an individual plant emission, total supply system disturbance, planning level, voltage characteristic and immunity level.



A: Total supply network disturbance (time/location statistics)

B: Location with medium-low total disturbance

C: Location with an high total disturbance

FIG. 7 Co-ordination of equipment immunity with the expected statistical distribution of total disturbance and position of the EMC reference levels and voltage characteristics

4.3 Electromagnetic Compatibility and the role of the electricity distributors

The electricity distributors are concerned particularly with the electromagnetic disturbances which are described as "conducted disturbances". The distributors are the operators of a network which is provided for the sole purpose of delivering an electricity supply to the consumers, but which unintentionally on their part becomes the medium on which electromagnetic disturbances are conducted from their sources to susceptible equipment.

In the case of many of the disturbances, both the sources and the susceptible equipment are situated within the electricity consumers' installations, outside the direct control of the distributors.

Nevertheless, since it is the ambition of the distributors to deliver electricity which is as free from disturbances as possible and feasible, they have a vital interest in ensuring that the emission of conducted disturbances is kept within acceptable limits. For this reason, they give strong support to international standardisation which seeks to establish effective limits to disturbance emission.

In common with all other environments which are subject to pollution, the electromagnetic environment is best protected by limiting emissions at source, rather than by attempting corrections at other points in the environment, after problems have been detected. Because some degree of emission of disturbances is inevitable, the distributors also support immunity standards which promote the design of equipment tolerant of a reasonable level of disturbance.

An increasingly large proportion of conducted disturbances have their source in the section of the environment described as residential, commercial and light industrial.

As the equipment in this environment is comprised of large numbers of individually small items, the most appropriate, in fact the only feasible way to promote electromagnetic compatibility, is to ensure that the design of the equipment is such that disturbance emissions are adequately controlled, having regard to the additive effect of emissions from multiple sources and that there is adequate equipment immunity to disturbances.

This implies that appropriate standards for both emission and immunity are not only adopted but implemented in practice [14, 15, 16 and future IEC Guide for harmonic emission of equipment > 16 A].

The distributors are concerned also with the larger installations which may be the source of significant levels of disturbance emission.

It is mandatory, and usually is a condition of supply, that these emissions be maintained below levels which, in combination with emissions from all other sources, would interfere unduly with the performance of other users' equipment.

It is generally necessary, therefore, to set down specific emission limits for each large installation. In setting such limits distributors are confronted by the difficulty of estimating the levels of disturbances which will be emitted from other sources, how these will be propagated through the supply networks and what their aggregate effect will be at any specific location.

All these matters are largely unpredictable, being dependent on numerous random factors.

The limits set, therefore, are subject to continuous review in the light of actual experience.

Apart from the difficulty of making accurate estimates or predictions of the resultant levels of emissions from multiple sources, the need for review may arise from other factors also.

One is that there can be no certainty that the limits set by international emission standards will prove to be effective in promoting compatibility.

Moreover manufacturers, users, etc. may fail to comply with the standards that have been set, and it may not be possible to ensure enforcement.

In these circumstances it must be accepted that, whenever necessary, the users of equipment will bear the costs of maintaining emissions from that equipment below the levels which are prescribed, including the cost of reducing emissions to whatever new limits may prove to be necessary from time to time.

As an alternative to the direct reduction of emissions from a particular installation, it may occasionally be feasible to choose either a method of connection to the supply system or a point at which the connection is made, so that the emissions are mitigated to an acceptable degree.

The cost of any such special arrangement is chargeable to the user in respect of whom it is undertaken.

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APPENDIX A: MEASUREMENT APPROACHES

A1 Harmonic and interharmonic voltage

As far as the measurement of harmonics and interharmonis is concerned, it must be noted that at the present time the problem is still open and the relevant standards are not yet complete. The following basic measurement aspects in agreement with IEC Publication 1000-4-7 and verified by experience [17], [18] are given as a feasible approach:

- Instrumentation operating both in frequency-domain and time-domain (Fast Fourier Transform or digital filters) may in principle be used; for fast changing harmonics it is recommended to use time-domain instrumentation

  - <u>for frequency-domain instrumentation:</u>

    A bandwidth in the range 3 Hz to 10 Hz is normally suitable, but a bandwidth of 3 ±0.5 Hz (-3 dB) with a minimum attenuation of 25 dB at frequencies f_h±15 Hz is recommended in critical cases (for instance harmonic emissions close to the limit levels).

  - <u>for time-domain instrumentation:</u>

    Sampling rate: ≥ 5 kHz

    Rectangular and Hanning windowing are both suitable. For the rectangular windowing, which is the most commonly used, the following ranges of opening times (T_W) are recommended, in order to comply with the measurement requirements related to the different situations which can be met in practice:

    Quasi-stationary harmonics: T_W = 0.1 to 0.5 sec(5)

    Fluctuating harmonics T_W = 0.16 to 0.32 sec

    Fast changing harmonics T_W = 0.08 to 0.16 sec

    In case of fluctuating harmonics it is to be noted that a rectangular window of 16 cycles (16*0.02=0.32sec) gets an equivalent selectivity of 3 Hz at -3dB. In any case experience has shown that larger windows may be used if the adjacent rows of the spectrum are taken into account through suitable weighting [17]

- Gaps between windows:

  <u>Quasi-stationary harmonics</u>: gap-times may be introduced; following IEC Publication 1000-4-7 it is preferred not to exceed a gap-time of 10 sec, but experience has shown that longer gap-times may be used.

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(5) window width or duration of the window.

Fluctuating and fast changing harmonics: following IEC Publication 1000-4-7 no gap is recommended; experience has shown [17, 18] that gap-times up to 10-40 times the window width are allowed with a good accuracy.

- The basic measurement of 10 minute r.m.s. value(6) is derived from a series of 3 sec. r.m.s. values (time consecutive values). The integrating time of 10 minutes is understood as a basic fixed time interval and not as an effective measuring time (following IEC Publication 1000-4-7 at least 100 elementary windows should be considered).

- Each 3 second r.m.s. value is obtained from a series of consecutive elementary windows; it is recommended that this integrating time of 3 seconds correspond to an effective measuring time. Figure A1 shows the proposed scheme of measuring timing.

- The evaluation of the measurements should be equivalent to a response characteristic matching the frequency-domain instumentation with an output time constant of 1.5 seconds, achieved by analogue or software handling of the acquired data.

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(6) In the case of an effective measuring time equal to 10 minutes (no gaps between measuring windows), the 10 minute r.m.s. value corresponds to the true r.m.s. value evaluated with an integrating time equal to 10 minutes

In case of an effective measuring time less than 10 minutes (with gaps between windows), the integration time for the evaluation of the r.m.s. value is obviously equal to the effective measuring time.

The 10 minute r.m.s. value U_{hSh} for a voltage Individual Harmonic Distortion of order h , is then given by:

$$U_{hSh} = \sqrt{\left(\sum_{i=1}^{N} \left(U_{hVs,i} \right)^2 \right) / N}$$

where: N = number of 3 seconds r.m.s. values evaluated during any interval of 10 minutes

$U_{hVs,i}$ = i^{th} 3 seconds r.m.s. value of the harmonic voltage of order h, given by:

$$U_{hVs} = \sqrt{\left(\sum_{k=1}^{M} \left(U_{h,k} \right)^2 \right) / M}$$

where: M = number of samples in the effective measuring time of about 3 seconds

U_{hk} = individual harmonic voltage of order h of the k^{th} sample (each sample is relevant to a single calculated Fast Fourier Transform (FFT) values C_h corresponding to the chosen sampling window T_w)

The THD is then evaluated from the measured IHD values, with a similar approach.

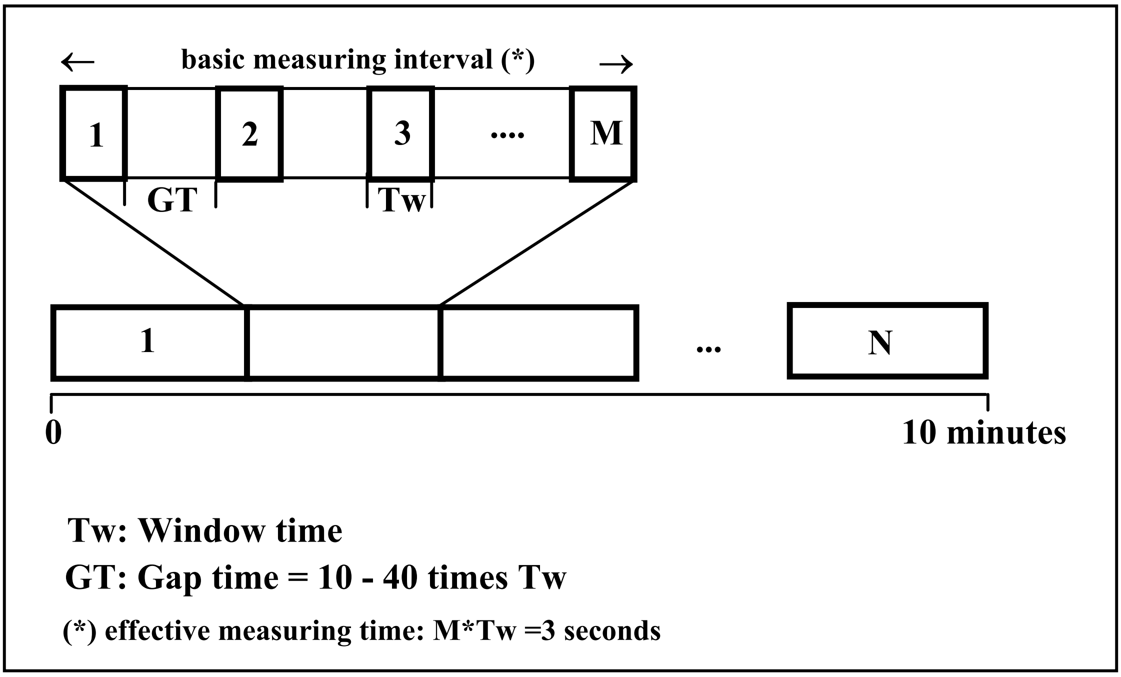

FIG.A1 Scheme of measuring timing for harmonics

A2 Supply voltage unbalance

An option for voltage unbalance measurement taken from [19] consists of using three voltmeters connected between phases (L_1-L_2, L_2-L_3 and L_3-L_1) and applying the following expressions:

$$U_u = \sqrt{\frac{1 - \sqrt{3 - 6 * \beta}}{1 + \sqrt{3 - 6 * \beta}}} \qquad \beta = \frac{U_{LL1-2}^4 + U_{LL2-3}^4 + U_{LL3-1}^4}{\left(U_{LL1-2}^2 + U_{LL2-3}^2 + U_{LL3-1}^2\right)^2}$$

Where: U_u = voltage unbalance

U_{LL1-2}, U_{LL2-3} and U_{LL3-1} = line to line voltages