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Electromagnetic compatibility (EMC) –

Part 2:
Environment –
Section 1: Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems

Compatibilité électromagnétique (CEM) –

Partie 2:
Environnement –
Section 1: Description de l'environnement –
Environnement électromagnétique pour les perturbations conduites basse fréquence et la transmission de signaux sur les réseaux publics d'alimentation

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For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV).

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC)

Part 2: Environment

Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

This section of IEC 1000-2, which has the status of a technical report, has been prepared by IEC Technical Committee No. 77: Electromagnetic compatibility between electrical equipment including networks.

The text of this section is based on the following documents:

Six Months' Rule	Report on Voting	Two Months' Procedure	Report on Voting
77(CO)26	77(CO)30	77(CO)32	77(CO)34

Full information on the voting for the approval of this section can be found in the Voting Reports indicated in the above table.

INTRODUCTION

IEC 1000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)
Definitions, terminology

Part 2: Environment

Description of the environment
Classification of the environment
Compatibility levels

Part 3: Limits

Emission limits
Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques
Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines
Mitigation methods and devices

Part 9: Miscellaneous

Each part is further subdivided into sections which can be published either as International Standards or Technical reports.

These standards and reports will be published in chronological order and numbered accordingly.

This section is a Technical Report serving as a reference document for those associated parts of IEC 1000 that give values of compatibility level, for example IEC 1000-2-2.

ELECTROMAGNETIC COMPATIBILITY (EMC)

Part 2: Environment

Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems

1 Scope

This section of IEC 1000-2 is concerned with conducted disturbances in the frequency range up to 10 kHz with an extension for mains signalling systems. Separate sections give numerical compatibility levels for different system voltage levels.

This section does not deal with the application of compatibility levels to assess, for example, the permissible interference emission from specific items of equipment or installations, because other system parameters, such as its impedance as a function of frequency, have also to be considered. Furthermore, it does not prejudge the specification of immunity levels by the product committees but merely provides a guide.

The disturbance phenomena considered are:

- harmonics;
- inter-harmonics;
- voltage fluctuations;
- voltage dips and short supply interruptions;
- voltage unbalance;
- mains signalling;
- power frequency variation;
- d.c. components.

The object of this section is to give information on the various types of disturbances that can be expected on public power supply systems. It is a reference document for those associated parts that give values of compatibility level.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this section of IEC 1000-2. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this section of IEC 1000-2 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid international standards.

IEC 38: 1983, *IEC standard voltages.*

IEC 50(161): 1990, *International Electrotechnical Vocabulary (IEV), Chapter 161: Electromagnetic Compatibility.* (Under consideration.)

IEC 146: 1985, *Semiconductor convertors. Second impression 1985 incorporating: Supplement 146A (1974) and Amendment No. 1 (1975).*

IEC 555-3: 1982, *Disturbances in supply systems caused by household appliances and similar electrical equipment. Part 3: Voltage fluctuations.*

IEC 868: 1986, *Flickermeter. Functional and design specifications.*

IEC 1000-2-2: 1990, *Electromagnetic compatibility (EMC). Part 2: Environment. Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems.*

3 Definitions

The definitions are taken from IEC 50(161): International Electrotechnical Vocabulary (IEV), Chapter 161: Electromagnetic compatibility.

The relevant basic definitions are:

3.1 Electromagnetic compatibility; EMC (abbreviation) (IEV 161-01-07)

The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

3.2 (Electromagnetic) compatibility level (IEV 161-03-10)

The specified maximum electromagnetic disturbance level expected to be impressed on a device, equipment or system operated in particular conditions.

NOTE - In practice the electromagnetic compatibility level is not an absolute maximum level, but may be exceeded with a small probability.

3.3 Electromagnetic disturbance (IEV 161-01-05)

Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.

NOTE - An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.

3.4 Disturbance level (not defined in IEV 161)

The value of a given electromagnetic disturbance, measured in a specified way.

3.5 Limit of disturbance (IEV 161-03-08)

The maximum permissible electromagnetic disturbance level, as measured in a specified way.

3.6 Immunity level (IEV 161-03-14)

The maximum level of a given electromagnetic disturbance incident on a particular device, equipment or system for which it remains capable of operating at a required degree of performance.

3.7 (Electromagnetic) susceptibility (IEV 161-01-21)

The inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

NOTE - Susceptibility is a lack of immunity.

4 Purpose of specifying electromagnetic compatibility levels

NOTE - An interpretation of the basic definitions for practical application in IEC is in preparation. The main results are considered in this clause.

From the definition of electromagnetic compatibility level it can be seen that it is a reference value by means of which the disturbance level on the system and the immunity level for various equipment types can be coordinated.

For practical purposes the "limit of disturbance" is the maximum disturbance level appearing with a certain probability in the electromagnetic environment of a device, equipment or system. This is the reference value to which the other levels have to be related, in order to avoid causing interference.

In some cases, this maximum disturbance level is the result of the superposition of several sources (e.g. harmonics), in other cases it is produced by a single source (e.g. non-repetitive voltage dip).

It must be emphasized that in general, the disturbance level is not a single value, but varies with position and time. In practice, the statistical distribution of the disturbance must be considered.

The maximum disturbance level may be derived from actual network measurements or, possibly, theoretical study.

Because of this variability of the disturbance level, it is often very difficult or even impossible to determine the actual highest level of disturbance which may appear very infrequently. It is also generally not economical to define the compatibility level in terms of this highest value to which most devices would not be exposed most of the time.

It therefore seems appropriate to define the compatibility level not as the "maximum value" of a disturbance but as the level of the disturbance that would be exceeded in only a small or very small number of cases - the aim being for the compatibility level to cover at least 95 % or so of situations.

The immunity level of equipment should be equal to the compatibility level or higher.

The immunity level has to be checked by an appropriate test. Determining its value and the test procedure is the responsibility of a relevant Technical Committee (or is subject to agreement between the parties involved).

The susceptibility level of equipment is the level of disturbance which would disturb the function of the equipment. It should be equal to, or higher than, the immunity level fixed for the tests.

The susceptibility level should be fixed by the manufacturer taking into account anticipated service conditions and the specified immunity limit. The susceptibility level may require consideration in statistical terms.

The compatibility level is intended to serve as a reference value for trouble-free operation, in particular for public power supply systems to which items of equipment are connected by independent consumers not normally in contact with each other.

The relation between the different levels of disturbance taking into account the statistical features is illustrated by figure 1.

In dedicated or independent systems, servicing for example only one customer’s equipment of a particular kind, other compatibility levels may be agreed.

5 Harmonics

5.1 Description of the phenomenon

Harmonics are sinusoidal voltages or currents having frequencies that are whole multiples of the frequency at which the supply system is designed to operate (e.g. 50 Hz or 60 Hz).

Harmonic disturbances are generally caused by equipment with a non-linear voltage/current characteristic. Such equipment may be regarded as current sources of harmonics.

The harmonic current from the different sources produces harmonic voltage drops across the impedance of the network. This phenomenon is represented in figure 2 in a simplified way. In reality, the different harmonic currents add vectorially.

As a result of the connection of reactive loads (e.g. power factor correction capacitors) and the effect of cable capacitance, shunt and series resonance may occur in the network and cause a voltage magnification even at a point remote from the distorting load.

5.2 Sources of harmonics

Harmonic currents are generated to a small extent and at low distortion levels by generation, transmission and distribution equipment and to a larger extent, at relatively large distortion levels, by industrial and domestic loads. Normally there are only a few sources generating significant harmonic currents in a network; the individual harmonic power rate of the majority of the other devices is low.

The following sources generate significant harmonic currents in a network:

- equipment with phase-control and high power;
- uncontrolled rectifiers, especially with capacitive smoothing (e.g. used in televisions, frequency converters, and self-ballasted lamps), because these harmonics are in phase to each other and there is no compensation in the network.

Sources may produce harmonics at a constant or varying level, depending on the method of operation.

5.2.1 Generation, transmission and distribution equipment

This category covers equipment used by utilities to supply electricity, especially generators, transformers and more recently, though to a limited extent, equipment like static compensators and frequency converters.

Since it is impossible for the designer of a generator to obtain a pure sine wave, rotating machines generally represent a source of harmonics. However the magnitude of these harmonics is normally negligible as proper selection of slots per pole, coil pitches etc. ensures that almost sinusoidal generated waveshape can be obtained. However, unbalanced operation will result in the generation of third and higher harmonics.

Distortion from transformers is caused by the saturation of iron in the magnetic circuit of the transformer coil.

5.2.2 Industrial loads

Industrial loads which may be a source of significant levels of harmonic distortion include power converters (rectifiers), induction furnaces, arc furnaces etc.

Electronic power equipment may have a significant influence on the level of disturbance of networks. The use of this type of equipment is increasing in terms of numbers and the unit ratings involved.

According to theory, the characteristic harmonic current of power converters will be of the order:

$$n = p \times m \pm 1$$

where

n is the harmonic order;

p is the pulse number of the converter;

m is any integer (1, 2, 3 ...).

In practice, however, non-characteristic harmonics are also generated due to inaccuracies in the values of control angles, unbalance in supply voltages, and any causes liable to affect the balance of the bridge. For example, harmonic currents of orders 5 and 7 may be measured in the supply to 12-pulse rectifiers.

Theoretically the amplitude of a perfect instantaneous switching rectifier should decrease according to the law:

$$I_n = I_1/n$$

where

- I_n is the harmonic current of order n;
- I_1 is the magnitude of the fundamental current.

In reality, rectifiers do not switch instantaneously and the current waveforms are not truly of the square-wave type.

The amplitude of harmonic currents depends on the inductive voltage drop due to circuit inductances and the switching angle. The amplitude of harmonic currents flowing in lines supplying rectifiers may be approximated by the following law:

$$I_n = I_n / (n - 5/n)^{1,2} \quad \text{for } 5 \leq n \leq 31$$

where n is the harmonic order.

This applies if there is good smoothing of the d.c. current, otherwise the level of 5th harmonic can be higher.

More detailed values of harmonic currents, considering delay angle and inductive voltage drop, are given in IEC 146.

Arc furnaces may be represented as generators of harmonic currents with an internal impedance consisting of an inductance and a damping resistance. The current spectrum shows a discrete spectrum superimposed on a continuous spectrum.

5.2.3 Residential loads

Residential loads have a lower power rating, but may be a major source of harmonic distortion on account of the large number of appliances used simultaneously and for long periods. The most important contributors in this area are television receivers, thyristor-controlled devices (lamp dimmers, household appliances) and fluorescent lamps. Existing standards do not allow the use of phase-controlled heating loads.

Television receivers are generally supplied through a rectifier and a high smoothing capacitor with the result that the current drawn from the network consists of short impulses containing a high percentage of harmonics.

The use of thyristor-controlled loads is increasing. Although, the power involved in each load may be low, the cumulative effects may result in a high distortion of the supply voltage.

5.3 Effects of harmonics

The main detrimental effects of harmonics are:

- defective operation of regulating devices;
- malfunction of ripple control and other mains signalling systems, protective relays and, possibly, other means of control;
- additional losses in capacitors and rotating machines;
- additional noise from motors and other apparatus;
- telephone interference.

An influence on induction-disc electricity meters is not discernible.

The phenomenon of interference with telephone and communication circuits by inductive coupling is discussed by CCITT and is not considered further here.

The harmful effects of harmonics on equipment may be classified as either instantaneous or long-term.

5.3.1 Instantaneous effects

These effects are associated with failures, malfunctions or downgraded performance of devices through displacement of zero crossing of the voltage wave. Regulation devices, electronic equipment and computers are especially susceptible.

High amplitudes of harmonics may cause a malfunction of ripple control receivers and protective relays.

5.3.2 Long-term effects

Long-term effects are principally thermal. Additional losses and overheating result in excessive ageing or even damage to capacitors and rotating machines.

6 Interharmonics

6.1 Description of the phenomenon

Between the harmonics of the power frequency voltage and current, further frequencies can be observed which are not an integer of the fundamental. They can appear as discrete frequencies or as a wide-band spectrum. Summation effects of interharmonics are not likely and need not be considered.

6.2 Sources of interharmonics

Sources of interharmonics can be found in low-voltage networks as well as in medium-voltage and high-voltage networks. The interharmonics produced by low-voltage sources mainly influence devices in their vicinity; the interharmonics produced in the medium-voltage/high-voltage networks flow in the low-voltage networks they supply.

The main sources are static frequency converters, cyclo-converters, subsynchronous converter cascades, induction motors, welding machines (low-voltage networks) and arc furnaces (medium-voltage/high-voltage networks only).

There is also low-level background noise superimposed on the low-voltage curve, even in the absence of a local source of interharmonics.

NOTE - The signals of mains signalling systems could also be considered as interharmonics in the broadest sense, but it is thought preferable to deal with these separately.

6.2.1 Static frequency converters

Static frequency converters transform the mains voltage into an a.c. voltage of frequency lower or higher than the mains frequency. They consist of two parts, namely an a.c.-d.c. rectifier and a d.c.-a.c. inverter. The d.c. voltage is modulated by the output frequency of the converter and as a result interharmonic currents appear in the input current, causing interharmonic voltages to be generated in the mains voltage.

Static frequency converters are used mainly for variable frequency drives and are developing rapidly. Small drives up to some tens of kW are connected directly to the low-voltage network, larger drives are connected to the medium-voltage network via dedicated transformers. Similar converters are used to supply medium-frequency furnaces.

Several forms of static frequency converters exist with different characteristics. The harmonic and interharmonic frequencies are given by the following formula:

$$f_v = [(p_1 \times m) \pm 1] \times f_1 \pm [p_2 \times n] \times F$$

where

- p_1 is the pulse number of the rectifier;
- p_2 is the pulse number of the converter;
- m are 0, 1, 2, 3 ...(integers);
- n are 0, 1, 2, 3 ...(integers);
- F is the output frequency;
- f_1 is the fundamental frequency of the supply voltage (e.g. 50 Hz or 60 Hz);
- f_v is the produced harmonic or interharmonic.

The combination of p_1 and m gives the harmonics. These harmonics in combination with p_2, n and F give the interharmonics.

6.2.2 Cyclo-converters

Cyclo converters are electronic converters of high rating (several MW) which draw symmetrical three-phase power from the power system to produce a three-phase or single phase output of low frequency (generally less than 15 Hz) for large slow motor drives. They consist of two or more controlled rectifiers connected as a bridge.

The formula which gives the harmonic and interharmonic frequencies is the same as for static frequency converters.

6.2.3 Subsynchronous converter cascades

The purpose of the subsynchronous converter cascade is to control the speed of an induction motor while reducing the losses when the motor is operating out of the rated conditions. The usual resistors connected to the rotor terminal of the wound rotor motor are replaced by a frequency converter connected between the rotor terminal and the lines that supply the stator of the motor. Interharmonic emission is often low.

6.2.4 Induction motors

Induction motors may give rise to an irregular magnetizing current due to the slots in the stator and rotor — possibly in association with saturation of the iron — which generates interharmonics in the low-voltage network. At the normal speed of the motor, the disturbing frequencies are practically in the range 500 Hz to 2 000 Hz but during the starting period they run through the whole frequency range up to their final values.

Such motors can be disturbing when they are installed at the end of long overhead low-voltage lines (>1 km). Interharmonic voltages of up to 1% of the nominal voltage have been measured. These interharmonic voltages have disturbed ripple control receivers in a few cases.

6.2.5 Arc welding machines

Welding machines also generate a continuous wide-band frequency spectrum. Welding is an intermittent process with the duration of the individual welding actions varying between a second and several seconds.

Welding machines are mostly connected to the low-voltage network. At present no measurements of interharmonic voltages produced by welding machines are available. However, due to the intermittent character of the welding process and the high power involved, the impedance of the supplying networks has to be quite low in order to avoid disturbing flicker effects. It seems that the limits imposed thereby on the network impedance reduce interharmonic voltages sufficiently.

6.2.6 Arc furnaces

Arc furnaces produce continuous but randomly varying interharmonic frequency spectra due to the irregular input current. These devices have a high rating (50 MVA to 100 MVA) but are always connected to the medium-voltage/high-voltage network. In order to avoid excessive voltage fluctuations and flicker disturbances the network impedance should be low. Consequently interharmonics emission is also low.

The highest interharmonic voltages occur during the starting phase of a melting process. Typical values are to be investigated.

6.2.7 Background noise

Background noise appears as a Gaussian noise, with a continuous regular frequency spectrum between the harmonics.

Up to now little detailed investigation has been carried out. Typical voltage levels seem to be in the range of:

- 40 mV to 50 mV (≈ 0,02 % of U_N) when measured with a filter bandwidth of 10 Hz;
- 20 mV to 25 mV (≈ 0,01 % of U_N) when measured with a filter bandwidth of 3 Hz.

6.3 Effects of interharmonics

An effect of interharmonics is the perturbation of ripple control receivers by discrete frequencies. This effect has been observed with induction motors and arc furnaces, though it could be caused by the other types of equipment referred to above.

A flicker effect could also appear with discrete frequencies close to the fundamental frequency. These frequencies may produce amplitude modulation of the fundamental current and this would be particularly perceptible if the modulation frequency were close to 10 Hz (see 7.3.1). Investigations into this phenomenon are continuing.

7 Voltage fluctuations

7.1 Description of the phenomenon

Voltage fluctuations can be described as a cyclical variation of the voltage envelope or a series of random voltage changes (see figures 3 and 4) the magnitude of which does not normally exceed the range of operational voltage changes mentioned in IEC 38 (up to ±10%).

A clear distinction must be drawn between voltage fluctuations and slow voltage variations within the same limit of up to ±10% due to gradual load changes in the networks.

Voltage dips and short interruptions, which have amplitudes of between 10% and 100% of the nominal voltage, are infrequent and are caused in the main by faults and the operation of protective systems (see clause 8).

There are various types of voltage fluctuations, which have been classified as follows (IEC 555-3):

Type *a)*: periodic rectangular voltage changes (step changes) of equal magnitudes (e.g. switching of single resistive loads) (see figure 5a);

Type *b)*: a series of step changes of voltage which are irregular in time. Their magnitudes may be equal or not, and in either the negative or positive direction (e.g. switching of multiple loads) (see figure 5b);

Type *c)*: clearly separated voltage changes which are not all step changes (e.g. switching of non-resistive loads) (see figure 5c);

Type *d)*: a series of random or continuous voltage fluctuations (e.g. cyclic or randomly changing loads) (see figure 5d).

Note that two or more changes in the same direction occurring in a total period of not more than 30 ms are considered to be a single change.

The type of voltage fluctuation may be deduced from the characteristics of the appliance, or observed by instrumentation.

7.2 Sources of voltage fluctuations

In low-voltage networks domestic appliances are significant sources, but each appliance will affect only a limited number of consumers.

In general, the main sources are industrial loads:

- resistance welding machines;
- rolling mills;
- mine winders (or large motors with varying loads);
- arc furnaces;
- arc welding plant.

Of a similar nature are step voltage changes that occur with the connection (or disconnection) of capacitor banks, or more generally when switching large loads.

It is important to point out that these industrially-produced fluctuations can affect a large number of consumers from the same source. Operation of all this equipment ranges from continuous to very infrequent. As there is a wide range of supply impedance on the public networks, conditions change substantially from the substation to the end of a feeder.

7.3 Effects of voltage fluctuations

Generally, since voltage fluctuations have an amplitude not exceeding ±10%, most equipment is not disturbed by this type of disturbance. The main disadvantage which can be attributed to them is flicker, or fluctuation of luminosity of an incandescent lamp (the important point is that it is, in practice, impossible to change the characteristics of the filament). The physiological discomfort associated with this phenomenon depends on the magnitude, the component frequencies, the rate of occurrence of voltage changes and the duration of the disturbance.

There is, however, a perceptibility threshold under which flicker is not visible.

Some equipment, for instance heating elements with long time constants, are almost unaffected by voltage fluctuations. Other equipment, for instance television receivers, electronic control devices and computers, are inherently sensitive to voltage fluctuation.

7.3.1 Continuous variations (e.g. arc furnaces and cyclo-converters)

In this case, the fluctuations can be associated with a modulation frequency spectrum, in the band 0 Hz to 30 Hz.

Generally the effect of superposition of several frequencies may be evaluated by means of a flickermeter (see IEC 868).

Moreover, the amplitude of modulation basically depends on the ratio between the impedance of the supply network installation and impedance of the disturbing installation (ratio which is equal to the complex inverse ratio of the short-circuit capacities).

7.3.2 Step voltage changes (e.g. welding machines, starting-up of motors, switching of capacitor banks etc.)

The discomfort in this case is primarily a function of the amplitude of the step voltage changes and the rate of repetition.

8 Voltage dips and short supply interruptions

8.1 Description of the phenomena

A voltage dip is a sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds.

A short supply interruption is the disappearance of the supply voltage for a period of time not exceeding 1 min.

Short supply interruptions can be considered as voltage dips with 100% amplitude.

8.1.1 Shape

The amplitude of a voltage dip is defined as the difference between the voltage during the voltage dip and the nominal voltage of the system (see figure 6). The amplitude is expressed as a percentage of the nominal voltage.

A voltage dip whose amplitude is constant during its duration may be characterized by the two values, amplitude ΔU and duration Δt.

A voltage dip with a complex shape (see figure 6) may be characterized by two, or more, pairs of values (ΔU, Δt). Such complex-shaped voltage dips are, however, relatively rare and for all practical purposes they may be characterized by their maximum amplitude and overall duration.

8.1.2 Amplitude and duration

Voltage changes which do not reduce the system voltage at the point under consideration to less than 90% of the nominal voltage are not considered to be voltage dips, as this is the range of slow voltage variations (due to gradual load changes) and voltage fluctuations due to rapid and repetitive load changes (see the first voltage change in figure 6).

Durations of less than half a cycle are not considered because voltage changes of this duration are a characteristic of an a.c. supply. Occasional voltage deviations lasting less than half a cycle are considered as transients.

It is essential to understand that a certain number of voltage dips cannot be avoided in supply networks and that for most equipment it is normal to accept the risk of a limited number of incorrect operations due to this type of disturbance.

The two parameters ΔU and Δt, amplitude and duration, cannot be practically limited in a supply network. All the amplitudes between 10% and 100% and all the durations with Δt longer than half a cycle can be expected.

What can be stated for a given network is the rate of occurrence of voltage dips with amplitudes and durations contained in given intervals. Amplitudes are not, however, necessarily the same on the three phases.

8.2 Sources of voltage dips and short supply interruptions

A voltage dip may be caused by a switching operation involving heavy currents or by the operation of protective devices (including auto-reclosers) resulting from faults. These events may emanate from the consumer’s systems or from the public supply network.

8.3 Effects of voltage dips and short supply interruptions

Voltage dips and short supply interruptions may disturb the equipment connected to the supply network. The types of incorrect operations which may be produced are:

- extinction of discharge lamps;
- incorrect operation of regulation devices;
- speed variation or stopping of motors;
- tripping of contactors;
- failures and computation errors for computers or measuring instruments equipped with electronic devices;
- loss of synchronism of synchronous motors and generators;
- commutation failure in thyristor bridges operating in the inverter mode.

Some of the inconveniences mentioned above are made worse by the fact that restarting a machine may take from a few minutes to a few hours.

9 Voltage unbalance

9.1 Description of the phenomenon

Voltage unbalance is a condition in which the three-phase voltages differ in amplitude or are displaced from their normal 120° phase relationship, or both.

The degree of unbalance is usually defined using the method of symmetrical components, by the ratio of the negative sequence (or zero sequence) component to the positive sequence component. The negative sequence (or zero sequence) voltages in a network mainly result from the negative sequence (or zero sequence) currents of unbalanced loads flowing in the network.

9.2 Sources of voltage unbalance

The predominant cause of unbalance is unbalanced single-phase load. In low voltage networks single-phase loads are almost exclusively connected phase-to-neutral but they are distributed more or less equally on the three phases. In medium-voltage and high-voltage networks single-phase loads can be connected either phase-to-phase or phase-to-neutral. Important single-phase loads include a.c. railway supplies and single-phase furnaces.

The voltage unbalance can be calculated approximately as follows by the formula:

$$\frac{\text{Maximum deviation of any of the three-phase voltages from the average phase voltage}}{\text{Average phase voltage}}$$

The voltage unbalance caused by a single-phase load connected between two phases is practically equal to the ratio of the load power to the network three-phase short-circuit power.

The propagation of negative sequence voltages from lower to higher voltage networks occurs with high attenuation. In the direction from higher to lower level any attenuation depends on the presence of three-phase rotating machines, which have a balancing effect.

9.3 Effects of voltage unbalance

The negative sequence impedance of a three-phase induction machine is similar to its impedance during starting. Consequently a machine operating on an unbalanced supply will draw a current with a degree of unbalance several times that of the supply voltage. As a result, the three-phase currents may differ considerably and the increased heating in the phase(s) with the higher current will be only partly offset by reduced heating in the other phases and the temperature rise of the machine will be increased. The most extreme form of unbalanced supply is the disconnection of one phase, a condition that can quickly lead to destruction of the machine. Motors and generators, particularly the larger and more expensive ones, may be fitted with protection to detect this condition and disconnect the machine: if the supply unbalance is sufficient, the "single phasing" protection may respond to the unbalanced currents and trip the machine.

Polyphase converters, in which the individual input phase voltages contribute in turn to the d.c. output, are also affected by an unbalanced supply, which causes an undesirable ripple component on the d.c. side, and non-characteristic harmonics on the a.c. side.

Since the main effect of unbalance is heating of machine windings, higher short-term levels of unbalance may be acceptable, for a few seconds or even a few minutes.

10 Mains signalling

Public networks are built for the supply of electric energy to customers but can be used incidentally by the utilities for the transmission of signals. (The use of the public networks or the transmission of signals between customers is not allowed.) Electromagnetic compatibility has to be ensured with regard to the signalling systems themselves and their influence on the network and its loads, taking into account their utilization (i.e. load control, remote reading of meters, etc.).

10.1 Description of the phenomenon

Signal frequencies ranging from 110 Hz to 500 kHz are used in networks or parts of it in order to transfer information from a sending point to one or more receiving points.

Mains signalling on a supply system can be used from a central station to the consumer’s installation to carry out operations such as tariff changing or load switching by sending information or from a network point to a central station to obtain information such as status indication or metering values.

Systems which send information or commands out are called "outbound" and systems which collect information from remote points are called "inbound".

Various outbound systems are in operation. Inbound systems are still under development.

10.2 Sources of mains signals

Mains signalling systems which use the distribution network (high-voltage, medium-voltage and low-voltage lines) for the transmission of signals can be classified into four types according to the transmission frequency or kind of signal:

a) *Ripple control systems* (or low-frequency power-line carrier systems)

use sinusoidal signals in the range from 110 Hz to 2 000 Hz, however, generally in the range 110 Hz to 500 Hz.

These systems are installed mainly in utilities' networks (sometimes in industrial networks) with signal injection at the high-voltage, medium-voltage or low-voltage network level.

b) *Medium-frequency power-line carrier systems*

also use sinusoidal signals but in the frequency range 3 kHz to 20 kHz (with a preference for the range 6 kHz to 8 kHz).

Such systems are intended mainly for utilities' purposes. They have been under development for some years but only a few outbound systems are in operation with signal injection at the medium-voltage level. Their characteristics are not standardized and vary from system to system.

c) *Radio-frequency power-line-carrier systems*

use sinus signals in the frequency band 20 kHz to 150 kHz (in certain countries up to 500 kHz), which are injected at low-voltage level.

These systems have application in utilities' networks (≤95 kHz) industrial/ commercial low-voltage installations with separate medium-voltage supply and within the installations of domestic and commercial consumers (e.g. remote control devices, "baby alarms", mains-borne telephones, ... > 95 kHz).

d) *Mains-mark systems*

Such systems utilize non-sinusoidal marks on the mains voltage waveform.

Several kinds of signals have been considered:

- "long pulses" in the form of voltage depressions of 1,5 ms to 2,0 ms (preferably at the zero crossing of the voltage wave in order to avoid flicker phenomena);
- "short pulses" in the form of notches of the voltage wave with a duration of 20 µs to 50 µs;
- "pulses of the fundamental frequency 50/60 Hz" with a duration of half a cycle or one cycle.

These systems are intended mainly for utilities' networks with injection at medium-voltage or low-voltage level.

10.3 Effects of mains signalling and on mains signalling equipment

The sinusoidal signals in the low and medium frequency range can be considered as similar to harmonics or interharmonics pulses of 1 s or less (in early systems up to 6 s) and can produce similar effects such as an influence on radio or television receivers and electronic devices like electronic regulators, computers, etc.

In some cases the effects may be similar to changes of the r.m.s. value of the power voltage and should be examined in terms of voltage fluctuations (flicker).

The signals in the radio frequency range could cause conducted or radiated disturbances mainly on radio and television receivers.

Mains signalling systems may be influenced by network disturbances, particularly of harmonics and interharmonics. It is also necessary to consider the mutual influence of neighbouring systems.

11 Power frequency variation

11.1 Description of the phenomenon

The frequency of a.c. power derived from public supply systems is directly related to the rotational speed of the generators, as is the frequency of a.c. power derived from an alternator which is separate from the public supply. The frequency depends at any instant on the dynamic balance between the load and the capacity of the generating plant. Consequently, as this dynamic balance changes, small changes in frequency will also occur. The size and duration of these changes depends on the characteristics of the load changes and the response of the generating plant to the load changes. Where the supply is derived from an inverter, the frequency may be derived from the control circuitry and is then fixed.

The frequency of public supply systems is, under normal conditions, generally declared by the supplier in terms of a nominal value (50 Hz or 60 Hz) with a small bandwidth within which these changes in frequency will normally be limited.

11.2 Sources of power frequency variation

In public supply systems there is normally an excess of capacity over load demand in order to maintain frequency changes within the declared bandwidth. However, rare fault conditions may arise under which, for example, a large block of load or generation is disconnected with a resultant change in frequency outside the normal tolerance band. In such cases some of the load or generation will be automatically or manually disconnected to restore the balance as far as possible.

Rotating loads which are not speed controlled usually take less power at lower frequency so that loss of generation may to some extent be compensated by lower demand.

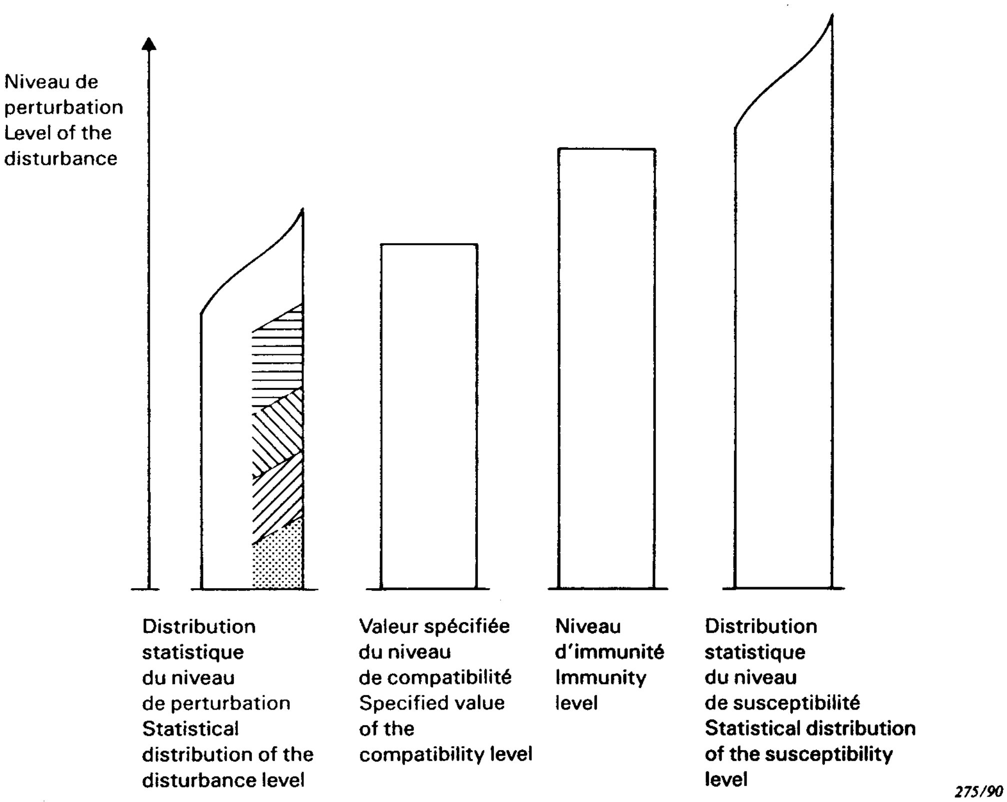
11.3 Effects of power frequency variation

Within the normal tolerances encountered, the main effect of a change in power frequency is on the speed of rotating machines. Hence, mains electrical clocks will lose or gain time and other motors will deliver more or less power, the change depending on the speed/torque relationship of the load. Power frequency variation may have a de-tuning effect on harmonic filters.

Any electronic equipment using the power supply frequency as a time reference will also be affected.

12 D.C. components

Under consideration.



NOTE – Possibly the summation of several sources — Covering at least 95% of the cases — Checked by appropriate tests

Figure 1 — Coordination between:
- **The disturbance level in the environment**
- **The compatibility level**
- **The immunity level**
- **The susceptibility level**

Network structure

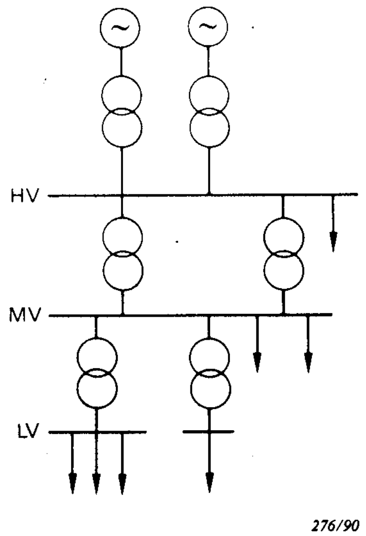


Figure 2a

Equivalent circuit diagram

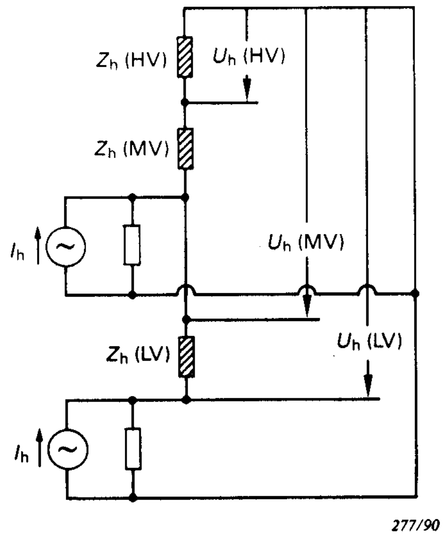
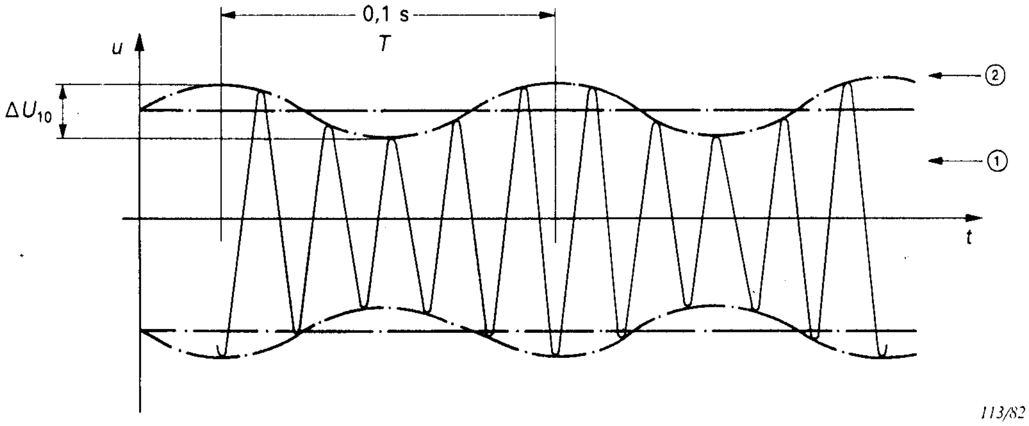


Figure 2b

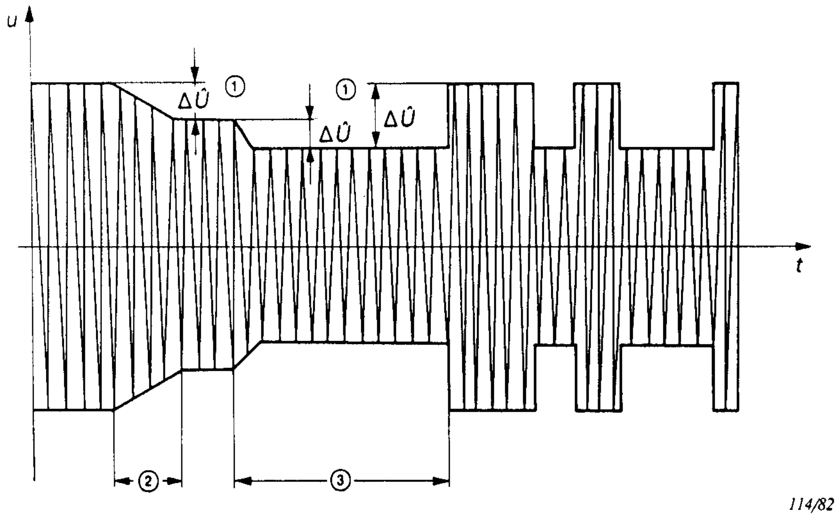
Figure 2 – Superposition of harmonic currents



① instantaneous voltage network frequency: 50 Hz

② sinusoidal voltage fluctuation of magnitude ΔU_{10}

Figure 3 - Sinusoidal voltage fluctuation of 10 Hz frequency



① voltage change of magnitude ΔU

NOTE − Seven voltage changes are shown on the figure.

② duration of the voltage change

③ voltage change interval

Figure 4 - Illustration of peak voltage changes

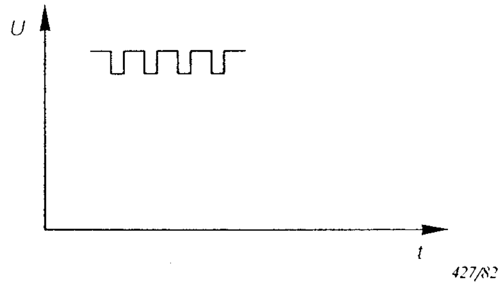


FIGURE 5 a - Type *a)* is composed of a periodic series of regular rectangular voltage changes (step changes).

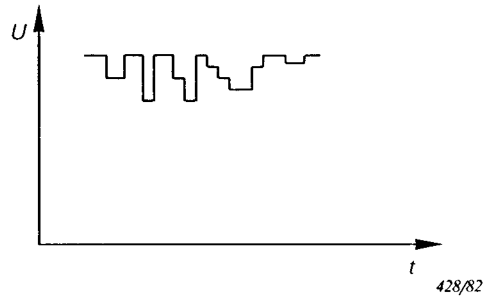


FIGURE 5 b - Type *b)* is composed of a series of step changes of voltage which are irregular in time. Their magnitudes may be equal or not, and in either the negative or positive direction.

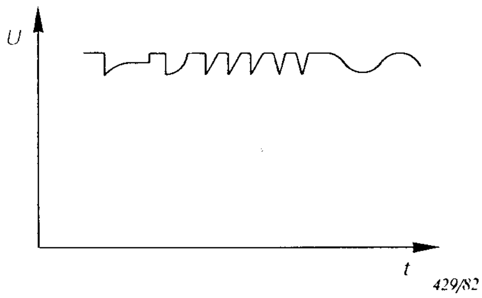


FIGURE 5 c - Type *c)* is composed of a series of voltage changes which may or may not include some step changes. Their magnitude may be equal or not, and in either the negative or positive direction.

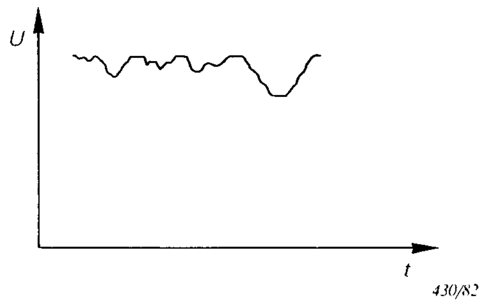


FIGURE 5 d - Type *d)* is composed of random or continuous voltage fluctuations

Figure 5 - Some illustrations of voltage fluctuation waveforms

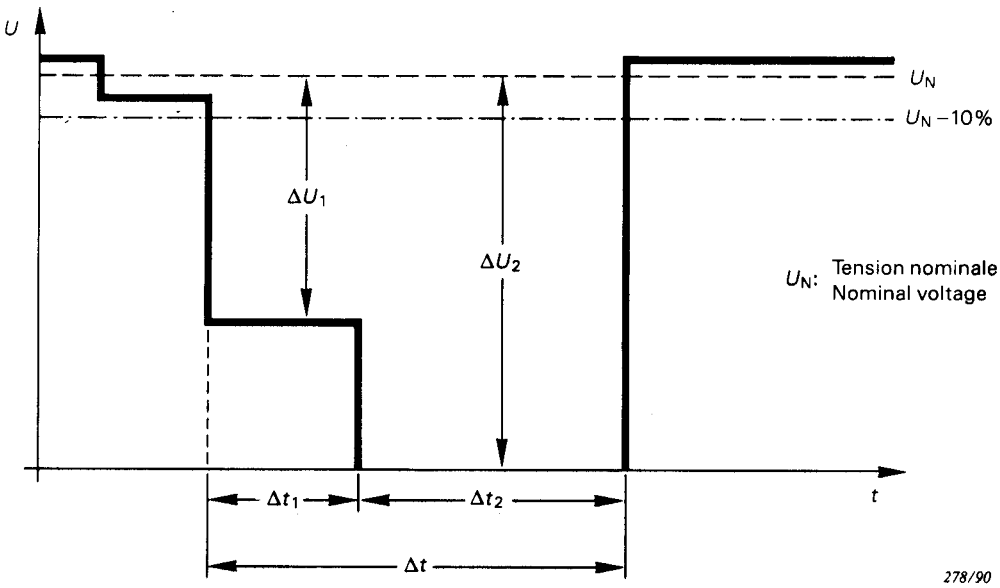


Figure 6 - Illustration of a voltage dip (ΔU_1) or a voltage interruption (ΔU_2 = 100%)

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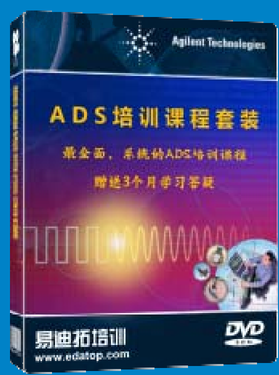

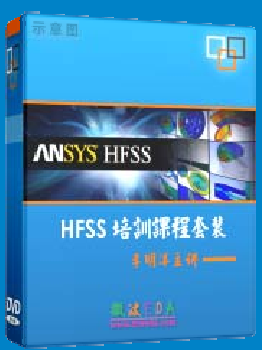

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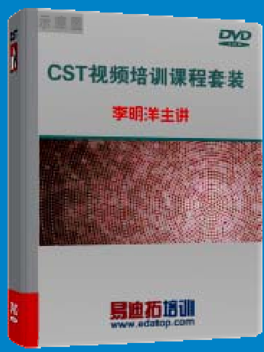

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