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AS/NZS IEC/TR 61000.2.8:2009

Australian/New Zealand Standard™

Electromagnetic compatibility (EMC)

Part 2.8: Environment—Voltage dips and short interruptions on public electric power supply systems with statistical measurement results

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PREFACE

This Technical Report was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-034, Power Quality. This document is informative and of a more descriptive nature than a normative Standard.

The objective of this Technical Report is to provide the users of electromagnetic emissions Standards with a description of the electromagnetic disturbance phenomena that can be expected on public electricity supply systems, and their effects on electrical equipment when subjected to voltage dips and short interruptions. It includes some statistical measurement results as a general reference.

This Technical Report is identical with, and has been reproduced from IEC/TR 61000-2-8, Ed. 1.0 (2002), *Electromagnetic compatibility (EMC)—Part 2.8: Environment—Voltage dips and short interruptions on public electric power supply systems with statistical measurement results.*

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INTRODUCTION

IEC 61000 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 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as International Standards, technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and completed by a second number identifying the subdivision (example: 61000-6-1).

Detailed information on the various types of disturbances that can be expected on public power supply systems can be found in IEC 61000-2-1.

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Australian/New Zealand Standard

Electromagnetic compatibility (EMC)
Part 2.8: Environment—Voltage dips and short interruptions on public electric power supply systems with statistical measurement results

1 Scope

This technical report describes the electromagnetic disturbance phenomena of voltage dips and short interruptions in terms of their sources, effects, remedial measures, methods of measurement, and measurement results (in so far as these are available). They are discussed primarily as phenomena observed on the networks of public electricity supply systems and having an effect on electrical equipment receiving its energy supply from those systems.

“Voltage sag” is an alternative name for the phenomenon voltage dip.

2 Definitions

2.1
voltage dip
voltage sag
sudden reduction of the voltage at a particular point on an electricity supply system below a specified dip threshold followed by its recovery after a brief interval

NOTE 1 Typically a dip is associated with the occurrence and termination of a short circuit or other extreme current increase on the system or installations connected to it.

NOTE 2 A voltage dip is a two-dimensional electromagnetic disturbance, the level of which is determined by both voltage and time (duration).

2.2
short interruption
sudden reduction of the voltage on all phases at a particular point on an electricity supply system below a specified interruption threshold followed by its restoration after a brief interval

NOTE Short interruptions are typically associated with switchgear operation related to the occurrence and termination of short circuits on the system or installations connected to it.

2.3
(voltage dip) reference voltage
<measurement of voltage dips and short interruptions>
value specified as the base on which depth, thresholds and other values are expressed in per unit or percentage terms

NOTE The nominal or declared voltage of the supply system is frequently selected as the reference voltage.

2.4
voltage dip start threshold
<voltage dip measurement>
r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the start of a voltage dip

NOTE Typically values between 0,85 and 0,95 of the reference voltage have been used for this threshold.

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2.5
voltage dip end threshold
<voltage dip measurement>
r.m.s. value of the voltage on an electricity supply system specified for the purpose of defining the end of a voltage dip

NOTE Typically, the value used for the end threshold has been the same as the start threshold or has exceeded it by 0,01 of the reference voltage.

2.6
interruption threshold
<measurement of voltage dips and short interruptions>
r.m.s. value of the voltage on an electricity supply system specified as a boundary such that a voltage dip in which the voltage on all phases falls below it is classified as a short interruption

2.7
residual voltage (of voltage dip)
minimum value of r.m.s. voltage recorded during a voltage dip or short interruption

NOTE The residual voltage may be expressed as a value in volts or as a percentage or per unit value relative to the reference voltage.

2.8
depth (of voltage dip)
difference between the reference voltage and the residual voltage

NOTE 1 The depth may be expressed as a value in volts or as a percentage or per unit value relative to the reference voltage.

NOTE 2 Frequently the word 'depth' is used in a descriptive, non-quantitative sense, to refer to the voltage dimension of a voltage dip, without the intention of specifying whether that dimension is expressed as the *residual voltage* or *depth*, as defined above. Care is needed to ensure that this meaning is clear in the context in which it is used.

2.9
duration (of voltage dip)
time between the instant at which the voltage at a particular point on an electricity supply system falls below the start threshold and the instant at which it rises to the end threshold.

NOTE In polyphase events, practice varies in regard to relating the start and end of the dip to the phases concerned. Future practice is likely to be that for polyphase events a dip begins when the voltage of at least one phase falls below the dip start threshold and ends when the voltage on all phases is equal to or above the dip end threshold.

2.10
(voltage dip) sliding reference voltage
<measurement of voltage dips and short interruptions>
r.m.s. value of the voltage at a particular point on an electricity supply system continuously calculated over a specified interval to represent the value of the voltage immediately preceding a voltage dip for use as the reference voltage

NOTE The specified interval is much longer than the duration of a voltage dip.

3 Description of voltage dips and short interruptions

3.1 Source of voltage dips

The primary source of voltage dips observed on the public network is the electrical short circuit occurring at any point on the electricity supply system.

The short circuit causes a very large increase in current, and this, in turn, gives rise to large voltage drops in the impedances of the supply system. Short circuit faults are an unavoidable occurrence on electricity systems. They have many causes, but basically they involve a breakdown in the dielectric between two structures which are intended to be insulated from each other and which normally are maintained at different potentials.

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Many short circuits are caused by overvoltages, which stress the insulation beyond its capacity. Atmospheric lightning is a notable cause of such overvoltages. Alternatively, the insulation can be weakened, damaged or bridged as a result of other weather effects (wind, snow, ice, salt spray, etc.), by the impact or contact of animals, vehicles, excavating equipment, etc., and as a result of deterioration with age.

The typical electricity supply system conveys energy from multiple sources (generating stations) to multiple loads (motors; resistive elements for lighting, heating, etc.; the power supply modules of electronic devices; etc.) The entire system, including generators, loads and everything between, is a single, integrated and dynamic system – any change of voltage, current, impedance, etc. at one point instantaneously brings about a change at every other point on the system.

Most supply systems are three-phase systems. The short circuit can occur between phases, phase and neutral, or phase and earth. Any number of phases can be involved.

At the point of the short circuit, the voltage effectively collapses to zero. Simultaneously, at almost every other point on the system the voltage is reduced to the same or, more generally, a lesser extent.

Supply systems are equipped with protective devices to disconnect the short circuit from the source of energy. As soon as that disconnection takes place, there is an immediate recovery of the voltage, approximately to its previous value, at every point except those disconnected. Some faults are self-clearing: the short circuit disappears and the voltage recovers before disconnection can take place.

The sudden reduction of voltage, followed by voltage recovery, as just described, is the phenomenon known as voltage dip (also known as voltage sag).

The switching of large loads, energising of transformers, starting of large motors and the fluctuations of great magnitude that are characteristic of some loads can all produce large changes in current similar in effect to a short circuit current. Although the effect is generally less severe at the point of occurrence, the resulting changes in voltage observed at certain locations can be indistinguishable from those arising from short circuits. In that case they also are categorised as voltage dips. (In the management of public networks, however, limits are applied, as a condition of supply, to the permissible voltage fluctuations from this cause.)

3.2 Voltage dip duration

Unless a self-clearing fault is involved, the duration of voltage dips is governed by the speed of operation of the protective devices.

In the main, the protective devices are either fuses or circuit breakers controlled by relays of various kinds. Protection relays often are designed to have an inverse time characteristic, so that the lower the short circuit current, the longer is the fault clearance time. Fuses have similar characteristics. The time characteristics and settings of the fuses and relays are carefully graduated and co-ordinated, so that a short circuit detected by several devices is cleared at the most appropriate point.

Many short circuits are cleared in the time range 100 ms – 500 ms. Faster times are often achieved for short circuits on major transmission lines, while the clearance of short circuits on distribution circuits can be considerably slower.

When a current fluctuation other than a short circuit is the source of the voltage dip, the duration is governed by that of the causative event.

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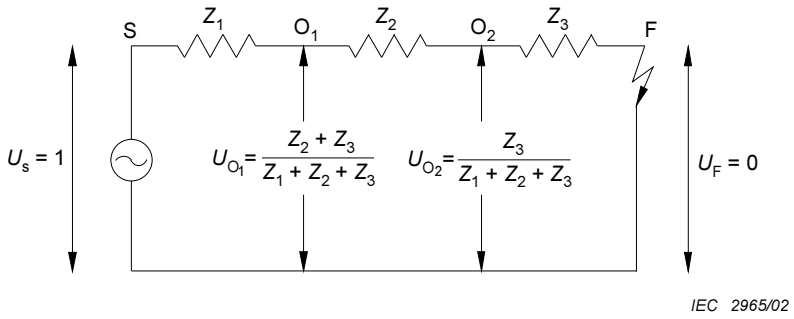
Some loads draw a large inrush of current as the voltage recovers at the end of a voltage dip. This has the effect of delaying the recovery of the voltage and extending the duration of the voltage dip. The same effect can occur when transformers go into saturation during voltage recovery.

3.3 Voltage dip magnitude

The magnitude of the voltage dip is governed by the position of the observation point in relation to the site of the short circuit and the source(s) of supply.

The system can be represented by a simple equivalent circuit connecting the observation point to a single equivalent source and to the site of the fault. (see Figure 1.) The entire voltage (100 %) is dissipated over the impedance between the source and the short circuit. The voltage drop to the observation point depends on the relative magnitudes of the two impedances connecting that point to the source and the short circuit. Depending on these impedances, the depth of the voltage dip can be anywhere in the range 0 % to 100 %.



Voltage dips at observation points O_1 and O_2 for short circuit at F and single equivalent source at S (expressed in terms of residual voltage per unit.)

Figure 1 – Equivalent circuit for voltage dips

In broad terms, the nearer the observation point is to the site of the short circuit, the closer the voltage at that point is to the voltage at the fault site. In other words, the voltage dip approaches the maximum possible depth (zero residual voltage) near the short circuit. On the other hand, if an observation point is near a generation source or sources of stored energy, such as rotating machines, the effect is to move the observation point nearer to the equivalent single source as represented in Figure 1. This mitigates the severity of the observed voltage dip. (However, if the dip duration is prolonged, increased current is drawn by decelerating motors, and this can increase the severity of the dip.)

Whether a short circuit results in an observable voltage dip at a particular observation point depends on their positions on the supply system. A short circuit on the transmission system is likely to result in an appreciable voltage dip that is observed over a very wide area, even at a distance of some hundreds of kilometres. On the other hand, a short circuit on a distribution circuit has a much smaller field of observable influence. Observation points on the same circuit are likely to experience severe dips, the dip severity will be moderated considerably on neighbouring circuits, and at larger distances the dip is hardly discernible.

Given an observation point within or near a private installation, it is, of course, possible that a short circuit or other causative event will occur within the same installation. The observed voltage dip that results can equal or exceed a dip caused by a short circuit on the public transmission or distribution system.

The observed magnitude of a voltage dip depends also on the phases involved, both in the short circuit and at the observation point, and on the winding connections (star-delta, star-star, etc.) of any transformers between those two points.

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3.3.1 Significance of transformer and load connections

The observed voltage dip magnitude arising from a particular causative event depends on whether the observation point and the event are on the same or different sides of a network or customer transformer. The phasing of the short circuit or other event, the phasing of the measurement system, and the connection methods of the primary and secondary transformer windings are all significant in this regard. For instance, considering the network or installations on either side of a step down transformer connected Dyn or Dy, a single line to ground fault can result, on the primary side, in a voltage dip of 0 V (residual voltage) on one phase, but, on the secondary side, a line to neutral voltage on two phases of 58% of the pre-existing voltage.

In practice, loads that are sensitive to voltage dips (power converters and drives, motors, control equipment, etc.) are often connected line-to-line in industrial installations. They would therefore be subjected to line-to-line voltage dips rather than line-to-neutral dips. This needs to be taken into account in considering whether measurements are conducted line-to-neutral, line-to-line, or both.

For example, Table 1 provides a summary of the voltage dips that would be observed at the secondary sides of different step down transformers, with a single line-to-ground fault on the primary, causing a 100% voltage drop on phase 1 on that side. (The supply network is assumed to be a directly grounded neutral system.)

Table 1 – Transformer secondary voltages with a single line-to-ground fault on the primary

Transformer connection [a]	Line-to-neutral voltage			Line-to-line voltage		
	V_1	V_2	V_3	V_{12}	V_{23}	V_{13}
YNyn or YNy	0,0	1,0	1,0	0,58	1,0	0,58
Yy, Yyn, or Dd	0,33	0,88	0,88	0,58	1,0	0,58
YNd or Yd	–	–	–	0,33	0,88	0,88
Dyn or Dy	0,58	1,0	0,58	0,88	0,88	0,33

[a] Capital letters refer to primary winding connection (supply network side) and lower case letters refer to secondary winding connection (load side). N and n designate a grounded primary and secondary transformer neutral, respectively.

See [6][1].

3.4 Short interruptions

The operation of a circuit breaker or fuse disconnects part of the system from the source of energy. In the case of a radial circuit, this interrupts the supply to all downstream parts of the system. In the case of a meshed network, disconnections at more than one point are necessary in order to clear the fault. Electricity users within the disconnected segment of network suffer an interruption of supply.

In the case of overhead networks, automatic reclosing sequences are often applied to the circuit breakers that interrupt fault currents. Their purpose is to restore the circuit to normal with the minimum of delay in the event that the fault proves to be a transient (self-clearing) one (as in the case of a flashover, due to over-voltage, resulting in no serious or permanent damage to the components involved). If the first reclosing attempt proves unsuccessful, there may be subsequent attempts at pre-set intervals. If the fault remains after the pre-set sequence of open-reclose operations is completed, the circuit breaker remains in the open position and is not closed again until the necessary repairs have been carried out at the fault site. (Of course, each reclosure while the fault still exists results in an additional voltage dip, the observed depth of which depends on the position of the observation point.)

[1] Figures in square brackets refer to the bibliography.

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In addition to the actual isolation of the fault, further switching is often carried out, either automatically or manually, in order to reduce the extent of network and number of users interrupted as a result of the initial fault clearance.

Thus, a single fault can result in a complex series of switching operations, observable to users as a series of interruptions of various durations. Depending on the structure of the network in the particular case and on the positions of individual users relative to the sites of the fault and the relevant switches, some users will experience very brief interruptions, while others may even have to wait for repairs to be completed before supply can be restored.

Interruptions having a duration up to 1 min (or, in the case of some reclosing schemes, up to 3 min) are classified conventionally as short interruptions.

3.5 Causes of voltage dips and short interruptions

As already stated, the cause of voltage dips (which sometimes extend to or are associated with short interruptions) is the major surge of current involved in a short circuit on an electrical system, and occasionally in large-scale load fluctuations. The flow of current through the impedances of the network components results in voltage drops, which briefly depress the voltage delivered to electricity users.

The dielectric breakdown involved in short circuits arises either from the stress of overvoltage or because the insulation is weakened, damaged or bridged in some way. The causes of the faults which have these results are many, including:

– atmospheric events: lightning and wind storms, snow, ice, deposition of salt or atmospheric pollutants on insulators, wind-borne debris;
– mechanical interference and damage: contact by vehicles, construction equipment, excavation equipment, animals and birds, growing trees, vandalism and malicious damage;
– breakdown of network plant: deterioration with age, corrosion, rot, latent manufacturing or construction faults;
– accidents or errors in operation and maintenance;
– major natural events: floods, landslides, earthquakes, avalanches.

A certain incidence of faults due to these causes is inevitable on all networks. Some types of network have a greater exposure to many of these causes or to a greater range of causes. In particular, overhead networks are exposed to most of the causes.

Voltage dips arising from load fluctuations are associated with the starting of large motors, especially those in isolated locations served by long lines, similar motors with gross fluctuations of load, arc furnaces, welding equipment, etc. (However, in the management of public networks, limits are generally applied to such fluctuations as a condition of supply.)

3.6 Example of fault on MV network

Figure 2 illustrates the voltage dips and short interruptions resulting from a fault on an MV feeder. Three cases are shown:

– a transient fault which is found to have cleared at the first reclose operation;
– a semi-permanent fault which still remains at the first reclose operation, but is found to have cleared at the second (delayed) reclose operation;
– a permanent fault which still remains after the full reclose sequence has been completed.

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In each case, the voltage dips and interruptions are shown as observed by two customers, one on the same feeder as the fault but upstream from it, and the other on another feeder from the same busbar. (The times shown are for illustration. Actual times depend on the settings adopted for a particular network.)

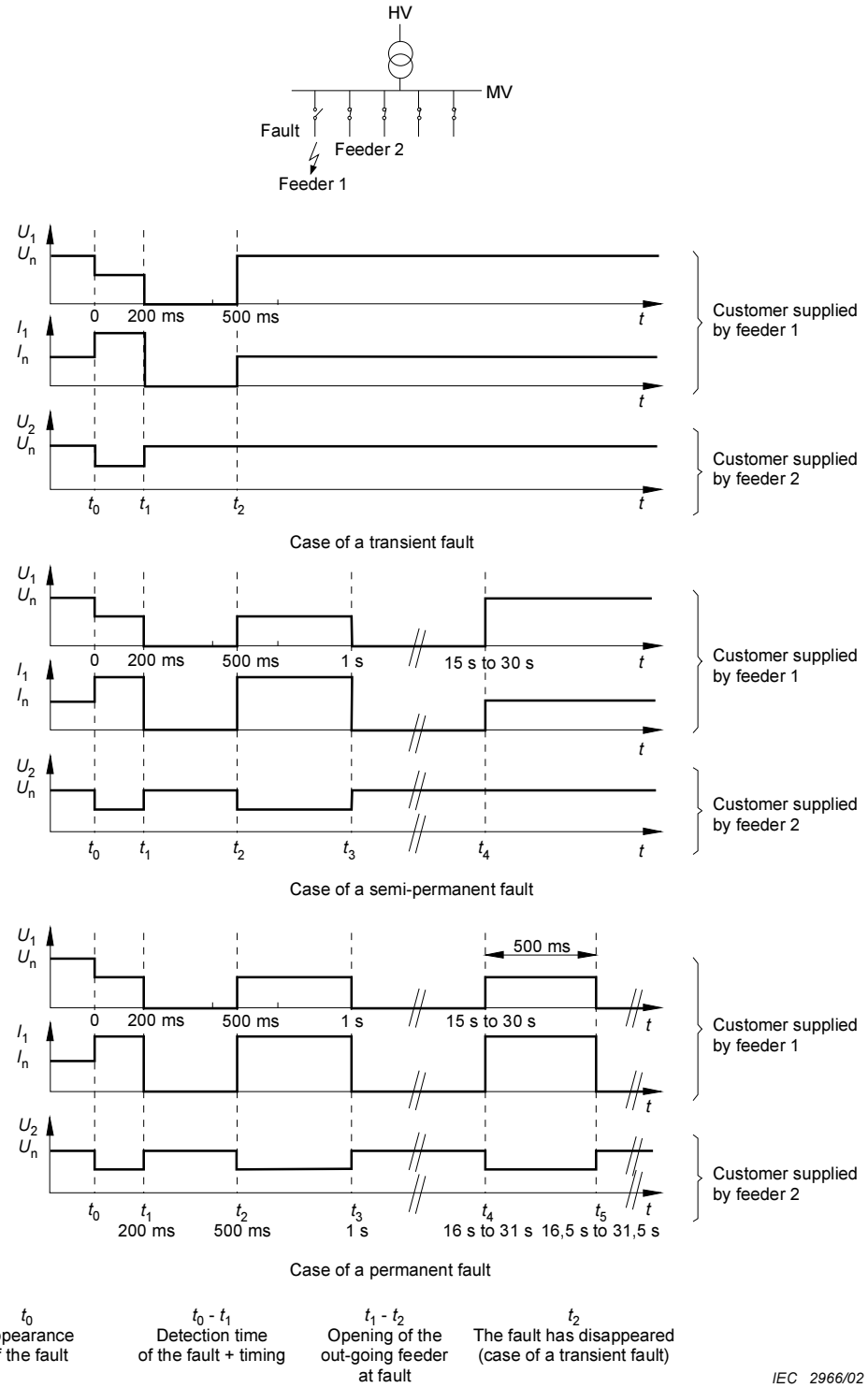

Figure 2 – Voltage dips and short interruptions resulting from fault on MV network

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4 Effects of voltage dips and short interruptions

4.1 General effects

In this document within the IEC 61000 series, the relevant effects are those relating to EMC, i.e. the possible degradation of the performance of equipment. As EMC phenomena, voltage dips and short interruptions can cause equipment connected to the supply network to perform in a manner other than that which is intended.

The fundamental relationship between the supply system and the equipment connected to it is that the system exists as an energy source from which the equipment draws whatever energy it needs to carry out its intended function. The amount of energy drawn and the use to which it is put is almost entirely a matter of the design and operation of the utilisation equipment (including the switching and control features incorporated in it), limited only by the capacity of the network to deliver energy at the point of connection of the equipment.

The energy delivery capacity of the network decreases as the voltage decreases. Voltage dips and short interruptions, therefore, cause a temporary diminution or stoppage of the energy flow to the equipment. This leads to a degradation of performance in a manner that varies with the type of equipment involved, possibly extending to a complete cessation of operation.

An option that is sometimes implemented in either the design or installation of the equipment is to incorporate a protective device for the purpose of interrupting the supply in the event of the voltage falling below a set threshold, thereby preventing damage or other unwanted effects in conditions of reduced voltage. Such protection can have the effect of converting a voltage dip into a long interruption for the equipment concerned. The long interruption is not caused by the voltage dip, but is the intended result of a protective feature that is designed to respond in that way to reduced voltage.

As with all disturbance phenomena, the gravity of the effects of voltage dips and short interruptions depends not only on the direct effects on the equipment concerned, but also on how important and critical is the function carried out by that equipment. For example, modern manufacturing methods often involve complex continuous processes utilising many devices acting together. A failure or removal from service of any one device, in response to a voltage dip or short interruption, can necessitate stopping the entire process, with the consequence of loss of product and damage or serious fouling of equipment. This can be one of the most serious and expensive consequences of voltage dips and short interruptions. Such consequential damage or loss, however, is a function of the design of the process and is an indirect or secondary effect of the voltage dip or short interruption.

EMC considerations are concerned with the direct effects on the performance of the actual appliances drawing an energy supply from the electricity network. Some of the more common effects are described more particularly for certain types of equipment in the subclauses that follow. The list is not an exhaustive one.

NOTE A sudden phase shift can accompany the voltage dip and can have a significant effect on some equipment. This phenomenon is not discussed further in this report.

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4.2 Effects on some particular devices

4.2.1 IT and process control equipment

Generally, the principal functional units of this equipment require d.c. power supplies, and these are provided by means of power supply modules which convert the a.c. supply from the public power supply system. Usually, it is the minimum voltage reached during a voltage dip that is significant for the power supply modules. Figure 3 shows the well-known ITIC curve for minimum immunity objectives concerning dips. (It includes also voltages above the normal range.) The user of the equipment must consider whether the consequences of dips that are more severe than shown by the curve are such that additional measures are necessary in order to maintain satisfactory performance. Depending on the application of the equipment, failures can have safety or other implications. Traffic signalling failure is one of many possible examples.

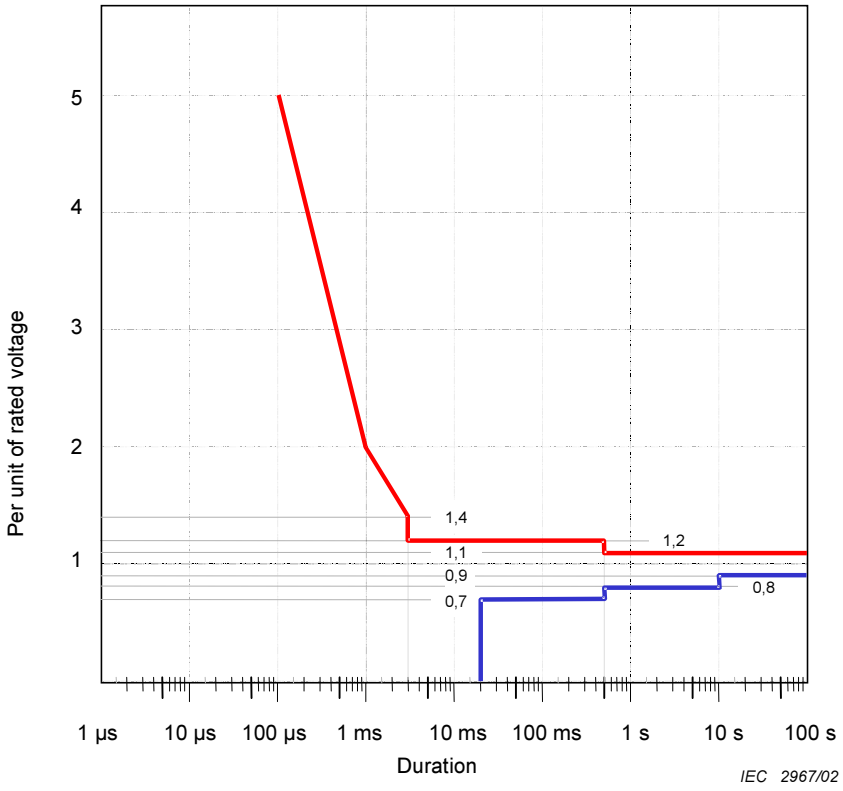

Figure 3 – ITIC (CBEMA) curve for equipment connected to 120 V 60 Hz systems

4.2.2 Relays and contactors

AC relays and contactors can drop out when the voltage is reduced below about 80% of nominal for a duration of more than one cycle. The consequences vary with the application, but can be very severe in safety or financial terms.

4.2.3 Asynchronous motors

The point of operation of an asynchronous motor is governed by the balance between the torque-speed characteristic of the motor, which depends on the square of the voltage, and that of the mechanical load. During a voltage dip, the torque of the motor initially decreases, reducing the speed, while there can be an increase in the current until a new point of operation is reached.

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