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ELECTROMAGNETIC COMPATIBILITY & FUNCTIONAL SAFETY

Annex B2 - Modern Buildings

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Annex B2

Achieving quality and reliability of supply In modern buildings

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Abstract

This annex starts from the same base as annex B1, but considers more specific items. The foreseeable effects on a number of pieces of apparatus, and the disturbances created by typical building loads are considered, showing what can generally be expected. Some safety implications of incorrectly specified equipment are described, and some example solutions are provided. Voltage dips, dropouts, and interruptions are singled out for concern.

This annex concludes with a general approach to identifying and resolving power quality problems, including recommendations for both new and existing equipment. The overriding recommendation is to take a holistic system approach to power supplies, power quality and equipment specification, and continually monitor to ensure that the required levels of power quality are being achieved and the entire system is operating with the reliability necessary to achieve the desired level of safety.

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B2- 1. Introduction

Power quality can be defined in a number of ways. Some authors have linked it with power supply reliability, service quality and supply quality [1]. However, to the end user, power quality is largely a perception that is coloured by the operating performance of the connected equipment.

Reliable, trouble free performance is equated with a supply of high quality. However, equipment performance has as much to do with its susceptibility to supply disturbances as it has with the actual characteristics of the supply that it operates on. It is also the case that supply characteristics will be influenced by the 'quality' of the load connected to it [2].

IEC and European electromagnetic compatibility (EMC) Standards have done much to improve the perception of power quality. However, the end user should be aware that gaps still exist between certain power quality disorders and typical levels of immunity specified by the EMC standards [2].

This paper considers the effects of building loads on the power supply (emissions), and also the effects of the power supply on typical building loads (susceptibility). Typical disturbances, their causes and effects are described. A methodology for identifying and resolving power quality problems is proposed. Some mitigation methods for various parts of the system are recommended.

B2- 2. Public electricity supply performance and quality - supplier standards and equipment standards

B2- 2.1 Relevant standards

The power quality characteristics of the supply delivered by the Public Electricity Supplier (PES) are described in Europe by BS EN 50160 [3]. In addition specific Engineering Recommendations apply in the UK, these include the most commonly referenced G5/3 (due to become G5/4) for harmonic limits and P28 for flicker (may be superseded by G5/4). The PESs rigorously enforce these recommendations. Equipment standards also specify the expected environment, the equipment tolerance levels (susceptibility of equipment to adverse power quality) and the equipment emission levels (which can influence power quality). These equipment standards are all parts of the IEC 61000 series [4]. In addition the standards provide protocols to allow disturbances and emissions to be measured.

Table B2-1 shows a comparison between the standards for LV systems. In general the compatibility levels set by IEC 61000-2-2 are comparable to, or slightly less stringent than, those defined by EN50160. Also, it can be seen that the level of immunity for some power quality phenomena would be insufficient to adequately protect terminating equipment from the disturbances defined in EN 50160. In particular, the frequency of occurrence of voltage dips, and the 95% per week basis for assessing most parameters, means that actual power quality could result in considerable disruption in equipment performance and yet meet EN 50160. In practice, the actual level of disturbance is likely to be equal or less than the immunity levels defined by the generic standards of IEC 61000-6-1 and 61000-6-2. Therefore, the likelihood of a disturbance affecting compliant terminating equipment is greatly reduced.

In addition much consideration must be given to site location. Rural locations with significant portions of overhead line feeding the site are likely to suffer from more frequent voltage fluctuations than an equivalent site in a city, where much of the distribution is likely to be by underground cable. Conversely sites in remote locations are less likely to suffer problems from externally generated harmonics than a site close to many other consumers.

IEC 61000-3-2 and IEC 61000-3-3 refer to harmonics and voltage fluctuations respectively. They are essentially emissions requirements for equipment to be connected to the electricity supply.

B2- 2.2 Harmonics

The standards dealing with low frequency harmonic currents have evolved with the objective of promoting power quality by limiting the harmonic currents imposed on the mains supply. The supply limits, as described in G5/3 and G5/4, place design limits on the last customer to connect their equipment to the supply network.

Recent changes to harmonic emission standards have provoked much debate. Some manufacturers have suggested [5] that the manufacturing life-span of information technology equipment (ITE) products is so short that the test requirements imposed by the proposed changes to ITE emissions and immunity standards may prevent products being imported into Europe. Nevertheless, the Electricity Supply Industry (ESI) in Europe is convinced of the need to limit harmonic and inter-harmonic current emissions from ITE and other sources through the use of appropriate equipment standards. Some have suggested that if supply voltage total harmonic distortion is allowed to reach

8 % then the supply network could prove unworkable. Variable speed drives and UPSs have possibly become the most common source of significant current harmonics in industrial and commercial systems. At present these high frequency harmonic sources continue to be manufactured and installed without harmonic reduction features. Thus in this area new IEC standards have not yet had any impact.

B2- 2.3 Voltage fluctuations

Using market research and by monitoring complaints, OFFER (the UK regulator) has noted an increase in customer complaints due to inconvenience caused by losses of supply for a minute or less. Equipment malfunction due to transient voltage dips continues to lead to complaints about adverse power quality. In some regions of Europe it may even be perceived that power quality is reducing due to a lack of voltage dip immunity alone.

The reality is more likely to be that such perception is influenced by an increase in the numbers of susceptible equipment, or changes in the application of equipment, despite the fact that dip immunity complies with present day EMC Standards. OFFER is encouraging PESs to report transient voltage fluctuations within the quality of service publications each PES circulates annually to their customers. However, this is not a requirement and the related power quality index has not been rigorously defined. Also the associated instrumentation in order to achieve this is not yet widely connected to the networks.

Generic immunity standards require that the limit for each parameter must be selected with respect to a severity criterion, which defines the effect upon the equipment that is considered acceptable. One of three severity criteria may be selected:

Criterion A: Normal performance is maintained upon application of the disturbance.

Criterion B: Temporary degradation or loss of function or performance is acceptable provided it is self-recoverable.

Criterion C: Temporary degradation or loss of function or performance that requires operator intervention or system reset.

Most users would prefer Criterion A in most cases. In fact Criterion B is normal for fast voltage transients, and Criterion C is usually applied to longer voltage dips. It is this level of dip that causes many of the problems experienced by consumers today, and equipment built to the present IEC generic immunity standards will still be susceptible to typical system dips. The knowledgeable consumer can specify equipment with a higher severity criterion, above the minimum required by the standards, and hence protect their site to a greater degree.

B2- 3. The impact of building loads

The overall quality of supply within a building is dependent on both the voltage supply quality provided by the PES and the current drawn by the various loads within the building. The loads fall into two categories, linear loads, which draw a sinusoidal current, and non-linear loads, which draw a non-sinusoidal current. The non-sinusoidal current contributes to the distortion in the voltage supply and can be characterised in terms of harmonic components.

With advances in technology, most of the small power single-phase equipment found in buildings utilise switch-mode power supply technology. Switch-mode supplies draw a non-sinusoidal current, which is high in triplen harmonics. The majority of single phase loads are connected at the end of distribution routes involving cables and sometimes ducted busbar systems and transformers. The high impedance between the load point and the supply source increases the voltage distortion levels evident in the system.

The current characteristics of typical building loads are tabulated in Table B2-2.

Table B2-2

Current characteristics of typical building loads

Type of Load	**Current Characteristics of Loads**
Personal computers	PCs utilise switch mode supplies. Typical non-sinusoidal current drawn by a PC when it is ON is shown in Figure 1. In addition the inrush current drawn by the PC when it is first turned on creates a transient in the neutral to earth voltage.
Laser printers	The current drawn by the printer is non-linear and cyclic in nature. When the printer is ON and idle, the heater operates at regular intervals of less than 1 minute. An inrush current is drawn each time the heater comes ON. The current drawn whilst printing is also non-linear.
Fluorescent lights	There are a wide range of fluorescent lights, some with electronic ballasts and other using non-electronic ballasts. The level of non-sinusoidal current drawn by the light is dependent on the type of ballast. Usually the non-electronic ballasts draw a higher degree of distorted current. The powering of the electronics when the lights are switched ON causes an inrush current which creates impulses in the phase voltage and neutral to earth voltage.
Chiller Motors	Most chiller motors in buildings are connected at 3.3, 6.6 or 11kV. The chiller starting current is typically in the order of 6 times its full load current. This is significant and will cause some level of voltage drop at the motor terminals. Its impact on the rest of the building is dependent on the source fault level. Some types of switched pole (i.e. 2-speed) direct connected motors can also impose non-linear loading.

Power Factor Correction Capacitor (PFCC)	On an undistorted voltage supply the PFCC will draw linear current. However, all supplies have some degree of distortion. Figure 2 is an example of normal PFCC current in a building environment. The inrush current associated with the switching of PFCCs creates an initial voltage depression followed by an overshoot and oscillatory behaviour in the voltage due to resonance of the circuit. (See Figure 3).
Variable Speed Drives (VSDs)	The majority of variable speed drives give rise to system harmonics. The current characteristic is dependent on the type of VSD. For example the dominant harmonics produced by 6-pulse drives are 5th and 7th, and for 12-pulse drives 11th and 13th. The amplitude of the harmonics decrease as the harmonic number increases, thus the harmonic distortion created by higher pulse drives is less. In addition the current drawn by the VSD can cause notching in the voltage waveform. The multiple zero-voltage crossing caused by the voltage notching could affect any piece of equipment whose operation relies on the detection of zero voltage crossing. Figure 4 shows an example of the current drawn by a 6-pulse drive and its impact on the voltage.
Uninterruptible Power Supplies (UPS)	UPSs are available in many forms and can broadly be classified as either static or rotary. All the static and some of the rotary UPSs use power electronic inputs that impose harmonic rich load current on the system. In general the loading characteristics are similar to those of VSDs. Some UPSs offer better performance in this respect than others.

As indicated in Table B2-2, the current drawn by the majority of building loads is non-sinusoidal, which causes distortion in the voltage supply in one form or another. A typical office voltage waveform and harmonic content illustrating the voltage flat topping caused by increasing harmonics is shown in FigureB2-5. Voltage distortion increases with increasing non-linear load. Increased harmonics lead to higher losses which causes heating in electrical equipment such as cables and transformers.

B2- 3.1 Other considerations resulting from a distorted voltage supply

B2- 3.1.1 Neutral ratings in LV circuits

Information technology equipment and lighting are the major forms of small power load within offices. These are characteristically single phase loads and draw load current which is rich in 3rd harmonic and other higher order triplen components. Where balanced and linear single phase loads are fed from a three phase system, the net current flow on the neutral is zero. Prior to the advent of single phase non-linear loads it was normal to rate neutral conductors to carry only 50% of the line current since unbalance due to load diversity was the major consideration. When triplen harmonic components are present these will summate in the neutral even if the power frequency components are equal and cancel. This can result in high neutral currents, which in some cases exceed the phase current.

With the increase in IT loads in buildings, the level of neutral current increases and consists mainly of 3rd harmonic current. Apart from increased heating, it is also our experience that high levels of harmonic current can lead to vibration of busbars with subsequent weakening of joints. There have been cases where the neutral conductor has failed leading to higher voltages and subsequent major system collapse. In the majority of buildings today the neutral conductor is half the rating of the phase conductor – this may be inadequate. The neutral should at least be sized the same as the phase conductors. In some cases it would need to be twice the size of the phase conductor. This however has further implications for the switchgear and protection used at that location.

B2- 3.1.2 Impact of resonance due to Power Factor Correction Capacitors (PFCC)

PFCCs are usually installed for tariff reasons however their presence on the network can result in resonant modes close to the dominant harmonic current components of the system loads. Resonance occurs when the capacitive reactance of the PFCCs and the inductive reactance of the system (composed mainly of the incoming transformer reactance) become equal. The frequency at which this occurs is referred to as the natural frequency for the system. This natural frequency alters depending on the value of connected PFCC, thus as different stages of PFCC are switched in, the resonant frequency changes. The resonant frequency decreases with increasing capacitance.

Resonance becomes most likely when the natural frequency approaches or falls below the 11^{th} harmonic. This is because 5^{th}, 7^{th} and 11^{th} are typically the most dominant in system load currents. The operation of non-linear plant and small power loads could excite resonance and cause excessive current to flow into the PFCC, causing damage to elements internal to the PFCC bank and overheating of external system elements such as cables and transformers. Resonance can also significantly increase voltage distortion levels.

B2- 3.1.3 Impact of loads under varying supply arrangements

The type of supply can further accentuate the quality of supply within the building. Normally the building supply is derived from a Public Electricity Supply Network. However in some cases individual sites also have their own generation which either run in parallel with the main incomer or as standalone. Site generation is used either in emergency situations when the PES connection to the site is lost or during peak periods to reduce electricity purchase costs or even to sell power. The fault level at the point of common coupling when the PES is connected is a lot higher than when site generation is running islanded. Under low fault level conditions voltage quality is more readily degraded by non-linear loading. Building load is generally highest during the working day. This load consists mainly of single phase distorting load such as computers and lighting. As a result the voltage distortion increases. In instances where the network is only supplied by site generation during the working day, the level of distortion that would exist would be higher than if the network was connected to the PES.

Figure B2-6 shows an example of chiller motors connected at 3.3kV starting under both PES connected and generator connected periods. The supply is at 11kV. The figure illustrates that the chiller starts caused an 8% RMS voltage drop at LV under generator connected periods with virtually no change under PES connected periods. The variation in RMS voltage levels resulted in the oscillation of PC current on the office floor.

Figure B2-7 is an example of voltage harmonic distortion increase caused by a change in supply from PES to site generation. In this case the increase in total harmonic distortion was only 1% but could be higher where the distortion current is a larger proportion of generator rating.

B2- 4. Power Quality Requirements of Building Systems

The power quality requirements of typical building loads are considered here. In many cases the susceptible loads will be the same as the polluting loads described above. A selection of applications are considered; in practice each item of plant should be individually assessed. Much of the information in this section comes from ERA report 99-0632R [6].

B2- 4.1 Computers and Computer Systems

Virtually every business now relies on computers, either personal computers (PCs) or servers, for daily functioning. Some rely more heavily than others. Call centres and banks rely heavily on computers for most transactions. Offices rely on computers for data storage and day to day work.

B2- 4.1.1 Voltage dip sensitivity

Computers can be susceptible to dips on the supply voltage. Computer manufacturers do not appear to have volt dip tolerance information readily available. Any information that can be obtained is relatively limited and seems to require a lot of effort to obtain.

An example is given in Figure B2-8 of the measured sensitivities, maximum and minimum, of a computer. This example is given in a paper by Eskom Technology group [7].

Large consumers, purchasing large numbers of computers, should always specify the withstand characteristics of the PCs being purchased. Only in this way will computer manufacturers begin to make this information easily available.

B2- 4.1.2 Harmonic susceptibility

In addition computers are highly susceptible to harmonics. As computers get faster, they generate higher frequency harmonics. As the harmonics generated become higher the computers become more susceptible to them. High frequency harmonics do not travel very far, thus modern computers are more likely to suffer from locally generated harmonic problems. A large UPS feeding a group of computers may protect against supply interruptions, and, if the on-line type, against voltage dips. The same UPS however will have no effect on locally generated high frequency harmonics. In such cases perceived ‘supply’ disturbances are more likely to be load generated.

B2- 4.2 Lighting

B2- 4.2.1 Voltage dip sensitivity

High intensity discharge lamps are primarily used for area lighting. This can include floodlighting reception areas and display lighting. They are used anywhere that requires a compact source of light of great power and high light output. These lights, when extinguished, generally require a cool off period before they can be restarted. The recovery time can be from one to several minutes.

Voltage dips in the supply can cause such lamps to extinguish. According to Douglas Dorr et. al. [8] the drop out voltage can vary from a drop of 55% (i.e. to 45% voltage) for a new lamp of one type, to a drop of 2% (i.e. to 98% volts) at the end of another lamp’s life.

The potential problems associated with the lights extinguishing are relatively obvious. If the lamps were to extinguish in a display panel no great problems would be suffered. The lamps would re-ignite, or could be manually re-ignited, after a few minutes. Reception area lighting, or any area where the route is used as a fire escape, would need to be maintained at all times. Loss of external floodlighting could present a security risk. There are lamps sold which do have hot start facilities, to immediately re-ignite, and for those in critical positions lamps can be purchased with tungsten lamp back-up.

One British manufacturer has stated that there do not appear to be any such problems in the UK. This is probably due to a lack of complaints. A large foodstuffs manufacturer reports, however, that the lights go out each time there is a voltage dip and they keep torches handy in anticipation.

B2- 4.2.2 Lighting Flicker

The most common source of complaints, however, in respect of lighting is in the area of flicker. 100Hz light modulation is normal on ballasted lights. The light output varies as the input waveform changes. Some people are sensitive to this modulation, and it has been flagged as a possible contributor to sick building syndrome. It can be eliminated by the selection of fluorescent and other discharge lamps with high frequency control units.

The other source of flicker is rapid voltage fluctuations due to another connected load switching or malfunctioning. This is most perceptible to the human eye at 8.8Hz. The source of flicker can normally be determined by voltage monitoring combined with trials. Effects are minimised by proper design and decoupling of wiring systems, but it may be the first sign of a failing motor connected on the same supply as the lighting.

B2- 4.2.3 Waveshape susceptibility

Ballasted fluorescent lights can also suffer from distortion or disruption of the voltage waveform. Such lights should have a front end filter in order to minimise harmonic emissions into the system, if they are to meet EMC and CE marking standards (although not all lights have such a filter). The capacitor in this filter can melt due to losses caused by excessive currents from high harmonics on the system, hence causing the lights to fail. The capacitors may also be susceptible to large voltage spikes on their input, causing them to blow and again the lights to fail.

B2- 4.3 Programmable Logic Controllers – e.g. Building Management Systems (BMS)

Programmable Logic Controllers (PLCs) may be used in a multitude of systems. Their proliferation has been highlighted by the ‘millennium bug’ problem. Controllers could be used in BMSs, individually in security systems, lifts, telecommunications, environmental management and many other embedded systems.

B2- 4.3.1 Voltage dip susceptibility

Actual tests for voltage dip tolerance were conducted on a selection of processors and PLCs. These were referenced by Caldon, Fauri and Fellin [9]. The results that were obtained are shown in Figure B2-9.

The sensitivity of PLCs therefore varies greatly according to type and manufacturer. But, as always, a chain is only as strong as its weakest link; so all PLCs should be checked for their sensitivity so that appropriate actions can be directed and taken. Checks can either be from manufacturer’s information or from system tests. System tests can identify potential problem areas that may not have been foreseen and are always an extremely valuable diagnostic tool.

B2- 4.3.2 Waveshape susceptibility

PLCs may use part of the voltage waveform to control their operation. This can be counting zero crossings, measuring peak values, or by a separate independent threshold. Excessive harmonics from lighting, motor starting transients or PFCC switching, amongst other things, cause changes to the voltage waveshape that can inappropriately trigger the counter, or monitoring function. This can then cause PLCs to mal-operate and systems to fail.

B2- 4.4 Variable Speed Drives (VSDs) – e.g. Lifts, Heating & Ventilation

B2- 4.4.1 Voltage dip susceptibility

Many VSDs have undervoltage protection on the input, typically set to trip at a voltage drop of 15 to 30%. Thus the drive is thus undamaged by the dip, but the motor, and any associated process, stops.

The effects of a voltage dip on a variable speed drive depend on the manufacturer and the type of power electronic circuit used to produce the variable speed. The age of the drive can also be important as manufacturers steadily improve their products. The operating philosophy for the VSD should be defined prior to installation. Drives have been found fitted with options which have not been used, which could serve as solutions to dip induced problems [10].

Voltage dips on the supply can cause damage to VSDs in a number of ways, they can lead to overcurrents in the drive[11], overvoltage due to mal-operation of the thyristors and commutation failures of the converter thyristors (this is tantamount to their being short-circuited).

Usually undervoltage setting can be desensitised slightly; it is important to check the withstand characteristic of the drive before making any changes. There are a number of new dip tolerant drives, and add-on devices, that can ensure a VSD will ride through voltage dips.

B2- 4.4.2 Waveshape susceptibility

In addition, phase angle jumps during a fault (which can be experienced during a voltage dip), even if the voltage does not dip to a value that causes the protection to trip, can still damage the drive. The thyristors fire in sequence, typically on zero crossings, any change in the voltage waveform can cause the thyristors to fire out of sequence and hence cause failure of the drive. Similarly, if multiple zero crossings are experienced, the thyristors can mis-fire and cause problems[12].

B2- 4.5 Small induction motors

Much of the load in the UK is induction motor load, this is true in buildings as well as in industry.

B2- 4.5.1 Voltage dip susceptibility

Most induction motors have the advantage that they have no, or little, complex electronics to suffer from voltage dip problems. Induction motors that are fitted with assisted start devices do have electronics but this is effectively bypassed when the motor is recovering from a dip. Motors can actually help in relieving a dip due to their inertia; they re-generate and can support the voltage (as do embedded generators).

The re-start current drawn by several motors following a supply voltage dip may cause problems in that it will tend to prevent the voltage from recovering as quickly as it might have otherwise. The duration of the dip is therefore extended. This extension may have an effect on nearby electronic equipment. If the induction motor is out of phase when the voltage is restored, then the motor could be damaged as the rotor attempts to abruptly re-align.

A typical re-acceleration curve is shown in Figure B2-10.

B2- 4.5.2 Waveshape susceptibility

Induction motors can act as sinks for excess harmonic current. The harmonic current is not normally of an order such that the motor would need de-rating because of the increased current. Neither are the induction motors, a large enough sink to mitigate the need for filters where harmonic levels are high.

B2- 4.6 AC coil contactors

Electrical contactors are electrically controlled switches and are used in large numbers in industrial and commercial premises.

B2- 4.6.1 Voltage dip susceptibility

Contactors have been found to be a weak link in control systems as a sudden dip in voltage can cause them to open and hence cause unplanned shutdown of the systems they feed.

A paper by Collins and Bridgwood [13] analyses in detail the effects of voltage dips on AC coil contactors. The paper describes the reaction of contactors to sudden voltage drops (step changes), followed by a recovery, as would be seen in a real fault situation (not related to the published minimum hold in voltage). It also measures the differences in drop out voltage found when the fault was applied at different points on the supply waveform. Their results show that, in addition to operation being dependent on dip magnitude and duration, whether the contactor will ‘drop out’ is highly dependent on the point on wave the fault is applied. Thus contactors may drop out unexpectedly.

B2- 4.7 Uninterruptible power supplies (UPSs)

UPSs are normally considered from the point of view of improving power supply reliability, and subject to UPS type supply quality. They are also, however, electronic equipment and as such can suffer from adverse power quality themselves.

In the case of supply interruptions, transients or voltage dips, line-interactive, on-line or conditioning UPSs are designed to support the load and trim any overvoltages, the extent depending on the UPS characteristics. Off-line UPSs also support the load, although usually after a short time. The UPS itself is therefore not usually vulnerable to such supply variations but the quality of the delivered supply can be affected with off-line designs.

B2- 4.7.1 Waveshape susceptibility

UPSs can, however, be susceptible to waveform distortion imposed by lighting, PFCCs etc. They are similar to PLCs in that they may monitor zero crossings or another threshold. Any waveform distortion, whether transient or permanent, that causes the electronics to count additional crossings of the threshold will lead to mal-operation of the UPS.

B2- 5. Recommended Measures

Poor power quality could lead to equipment malfunction, equipment failure, and disconnection of major parts of your network. This could have a significant impact on the operation of your business. It is therefore important to periodically ensure that the quality of supply within your building is within acceptable limits. When purchasing new equipment, it is also important to assess the impact on supply quality caused by the introduction of the equipment and its susceptibility to the existing power quality.

ERA has considerable experience of identifying and resolving power quality problems in commercial buildings. A general approach to identifying and resolving power quality problems is detailed in section B2-5.1. Some solutions to power quality problems are detailed in section B2-5.2.

B2- 5.1 General approach to identifying and resolving power quality problems

It is vital that the environment is suitable for the requirements of the equipment. This helps reduce equipment malfunction and/or damage. To overcome or prevent mismatch between equipment and environment the following options are available.

For existing equipment

a) Conduct a power quality survey to ascertain existing conditions and quantify the magnitude of power quality disorders where problems exist.

b) Improve the quality of supply centrally within the building or to individual floors either by the use of filtering equipment or isolation transformers

c) Insert a power conditioning device between the equipment and its supply to ensure acceptable supply to the equipment, or

d) Replace with equipment more tolerant of the environmental conditions.

For new equipment

e) Characterise the power quality condition in the building and correctly specify for the environment.

f) Assess the level of distortion that will be introduced by the equipment and how that will impact on existing equipment.

g) Confirm by measurement that the quality of the existing system is satisfactory for the requirements of the equipment.

B2- 5.2 Power quality surveying and benchmarking

a) Establish the objective of the power quality assessment – Gain an understanding of the site, the problem areas, and accessibility to various locations on the network from discussions with the problem owner. Power quality measurement will be mostly effectively made if it is targeted at specific quality parameters e.g. RMS voltage and current trends, harmonic levels, waveform distortion, transients, flicker etc

b) Select suitable instrumentation – Once the objectives of the assessment have been agreed, an instrument that most effectively addresses the requirements can be selected. There are instruments available, which have the capability of event and data logging. The problem will dictate the type of logging that should be the primary focus of the investigation.

c) Event logging – This functionality allows the recording of events outside set thresholds. Limits defined in EN 50160 and relevant parts of IEC 61000 series provide guidelines for setting thresholds. The susceptibility limits of connected equipment (defined by standards and specifications) should also be consulted.

d) Data logging – Enables trending of voltage and current characteristics. The recommended parameters to trend include rms phase to neutral and neutral to earth voltages, rms line and neutral currents, harmonic voltage distortion, harmonic current levels and flicker levels.

e) Conduct a monitoring survey to assess existing supply quality or investigate the reason for problems – Monitor supply quality at the problem location as well as other voltage levels and locations within the building, starting from the intake down to the LV supplies. This enables the correlation of events on the network. Particular attention should be paid to the effect of equipment switching, harmonic levels and neutral current levels.

f) Analyse survey results to identify actual or potential problems – Compare parameters recorded with limits specified in the standards as well as specific equipment specifications. It is also important to assess waveform distortion in terms of harmonic content and time domain profile (zero voltage crossing, peak voltage etc).

g) Benchmark quality of supply – We recommend the periodic assessment of the quality of supply within a building, either a new facility or one which is fully operational. The benefits of benchmarking include:

   Provides prior knowledge of supply quality, which can then be used in defense against manufacturers who automatically blame supply quality for equipment malfunction.

   Forewarns of impending problems.

   Provides trends over a period to establish if supply quality is progressively deteriorating or improving. This assists in informed decision-making when introducing changes to the system or specifying equipment.

B2- 5.3 Solutions

Power Quality problems within a building can either be imposed by the supply, caused by the building loads or a combination of the two. Consequently there are a number of ways of resolving the problem; system level (i.e. on the building distribution system), equipment level (i.e. internally or at the terminals of the equipment) or a hybrid of the two. The choice of the solution will depend on the nature of the problem at hand and the cost of achieving a satisfactory solution. Some of the solutions available are listed below.

B2- 5.3.1 System solutions

- **Active Filters.** Active filtering has the benefit that it reduces distortion without altering the characteristics of the system. In addition it is not affected by changing distortion on the network. It can be installed either at the point of common coupling (PCC) or at the individual load point to reduce harmonics. The most common type involves the use of power electronic devices that inject distorted components of current, which combine with the distorted load to create a resultant undistorted current demand at the point of connection [14]. The cost of an active filter is at least twice that of a passive filter. However a passive filter alters the characteristics of the system and could also be affected by changing non-linear load characteristics.

- **Phase shifting transformers.** They can be used to create a quasi higher-order harmonic system at the point of common coupling from low order harmonic generating loads e.g. 6-pulse VSDs. The elimination of the lower order harmonics reduces the harmonic current distortion and consequently the voltage distortion. The success of this solution is dependent on the load profiles of the treated loads, the proportion of treated loads to the size of the system, and the baseline voltage THD at the PCC [15].
- **Neutral isolation transformers.** These are transformers with conventional delta/star or zig-zag windings which provide coupling between 3-wire, 3-phase distribution and a 4-wire, 3-phase+neutral system. By locating close to the load centre, the transformer allows the circuit length of the neutral to be minimised. Such transformers are of use in power distribution units (PDUs) but can also be used to supply a complete floor of the building.
- **UPSs.** These ensure stable and reliable supplies to connected load as well as sustained supplies in the event of mains failure. They can either be inserted at the supplies to a group of loads or individual loads that are sensitive to the quality of supply, both in terms of harmonics and voltage dips.
- **Custom Power** [16]. This term describes a range of power electronic devices that have been developed to allow the quality of power delivery from the PES to be improved. Installed at the point of common coupling to insure that the building is immune to voltage drops imposed on it by the regional electricity company. There is very little experience of its use in the UK however this solution should be considered if the majority of power quality issues in a building are related to external network voltage fluctuations.
- **Power conditioners.** These devices are installed in the supply and are available in a range of ratings. A range of passive and power electronic devices is available. The simplest consist of transformers or variacs with automatic voltage control. Other examples include ferroresonant designs and motor generator (MG) sets. MG sets offer the benefit of a small amount of flywheel energy storage to ride through supply voltage dips. Otherwise power conditioners have no energy storage. However, the cost per kVA tends to be low and typically less than 10% of that of a UPS. Also, in general, they impose less distortion on the supply than a UPS.
- **Design Considerations.** The electrical design and operating philosophy of the building can be used to reduce the impact that building loads have on each other. Every attempt should be made to decouple supplies to various load groups as much as possible. The fewer interactions there are between load groups the less impact their operation would have on each other. For example making the riser a point of common coupling between supplies to small power office loads (PCs and printers) and lights is a good practice. Consequently, waveform distortions caused by switching lights have no significant impact on the voltage supply to the desktop supplies in the office area.

B2- 5.3.2 Equipment solutions

- **Linearised equipment** [17]. The technology exists for linearising equipment power supplies, thereby imposing a linear rather than non-linear load on the system. Currently this is more costly than normal switch mode supplies. However with increasing IT demand the cost of improving the quality of supply within buildings should be weighed against improving the equipment supplies. Manufacturers by themselves will not push necessarily for change however consumers with significant buying power could influence matters and drive change.

- **Reduced emission equipment.** Manufacturers can use lower cost options than full linearisation to reduce harmonic current. For example this can simply be achieved using an input inductance at the input circuit to the switch-mode power supply[2]. It is recommended that the harmonic current loading of equipment be compared when making buying decisions. Alternatively comparative tests should be made where the manufacturer cannot supply the information.
- **Reduced voltage starters.** They are used to reduce the current drawn by the motors on starting and consequently the associated voltage drop on the network. The motor will be connected to the switchboard via the voltage starter.
- **Detuning PFCC.** By inserting an inductor in series with the capacitor the PFCC is tuned to a frequency below that of the dominant load harmonics. Thus the PFCCs are prevented from resonating and thus prevented from being damaged or affecting the system.

B2- 6. References

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Table B2-1

Comparison between EN 50160 (supply) and IEC 61000-2-2 (compatibility) and also between environmental levels, specified by EN 50160, and end user equipment immunity specifications defined by European EMC regulations

	Compatibility Levels **(IEC 61000-2-2)**	**IEC 61000-6-1/ 61000-6-2** **Generic Residential, Commercial, Light Industry/Industrial Immunity Standard**	**Voltage characteristics of electric supplies** **(EN 50160)**	
	LV	**LV**	**LV**	**MV**
Frequency	2%		1% for 95% of week -6%/+4% for 100%	1% for 95% of week -6%/+4% for 100%
Voltage Magnitude		± 10 % applied for 15 minutes (EN 50082-2)	±10% for 95% of week, 10min rms	±10% for 95% of week, 10min rms
Rapid voltage changes	3% 8% infreq Pst<1.0 Plt<0.8	(Covered by IEC 61000-3-3)	5% normal 10% infreq Plt <1 for 95% wk	4% normal 6% infreq Plt <1 for 95% wk
Temporary overvoltage			<1.5kV	170% (solid or impedance earth) 200% (unearthed or resonant earth)
Transient overvoltage		± 1 kV (±2 kV EN 50082-2) 5/50 ns Tr/Th 5 kHz Repetition Frequency	Generally <6kV Occasionally higher	
Voltage unbalance	2%		2% for 95% of week , 10min rms 3% in some locations	2% for 95% of week , 10min rms 3% in some locations
Harmonic voltage	6% 5th 5% 7th 3.5% 11th 3% 13th THD <8%	(IEC 61000-3-2)	6% 5^{th} 5% 7^{th} 3.5% 11^{th} 3% 13^{th} THD <8% 95% week, 10min rms	6% 5^{th} 5% 7^{th} 3.5% 11^{th} 3% 13^{th} THD <8% 95% week, 10min rms
Interharmonic	0.2%		under consideration	under consideration
Mains signalling	0.11-0.5kHz : 3.5-6% 0.5-2kH : 2-5% 3-20kH : 2% 20-150kHz : 0.3%	(Covered by EN 50065-1)	1-0.5kHz : 9% 1-10kHz : 5% 99%, 3s mean	1-0.5kHz : 9% 1-10kHz : 5% 99%, 3s mean
DC components	Under consideration			
Voltage dips	urban: 1 to 4 month rural: much more	30 % Reduction for 10 ms No detrimental effects 60 % reduction for 100 ms Can be manually reset	<u>Majority</u> Duration < 1 s Depth < 60 % <u>Some Locations</u> 1000/Year < 15 % = 2 or 3 per day	<u>Majority</u> Duration < 1 s Depth < 60 % <u>Some Locations</u> 1000/Year < 15 % = 2 or 3 per day
Short Interruptions		> 95 % Reduction for 5 s	<u>Majority</u> 20 - 500/year Duration 1 s; 100%	<u>Majority</u> 20 - 500/year Duration 1 s; 100%
Long interruptions			10 - 50 /year Duration > 180 s; 100%	10 - 50 /year Duration > 180 s; 100%

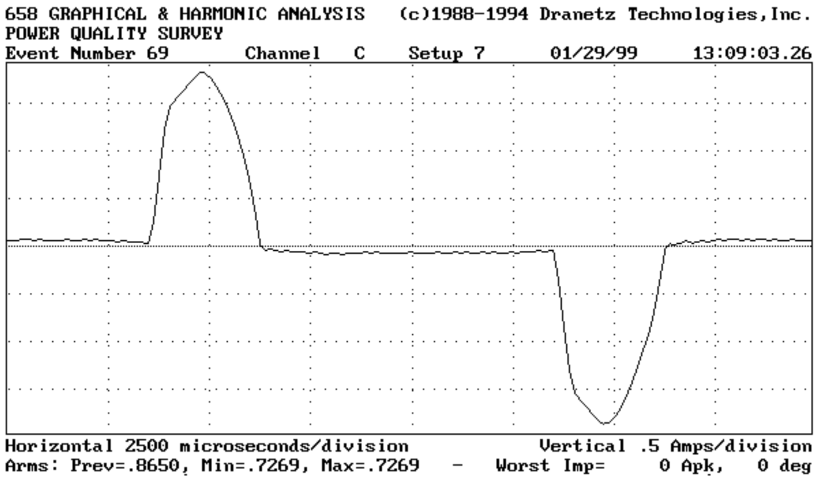

Figure B2-1
Typical PC current

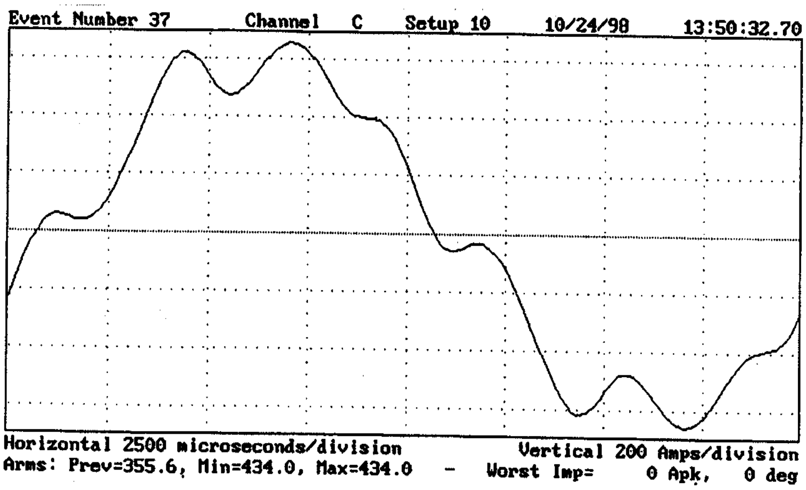

Figure B2-2
Power factor correction capacitor current

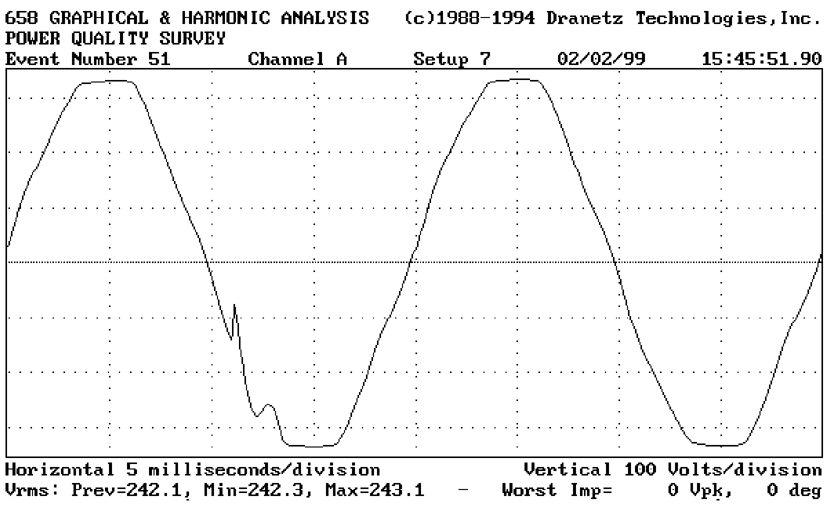

Figure B2-3
Impact of PFCC switching on voltage waveform

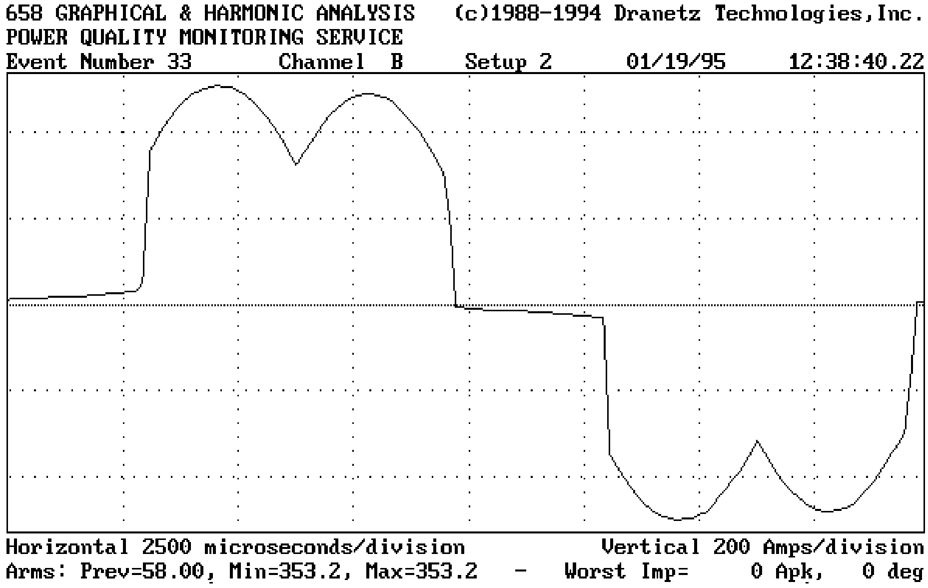

Figure B2-4a
Current drawn by a 450kW 6-pulse variable speed drive

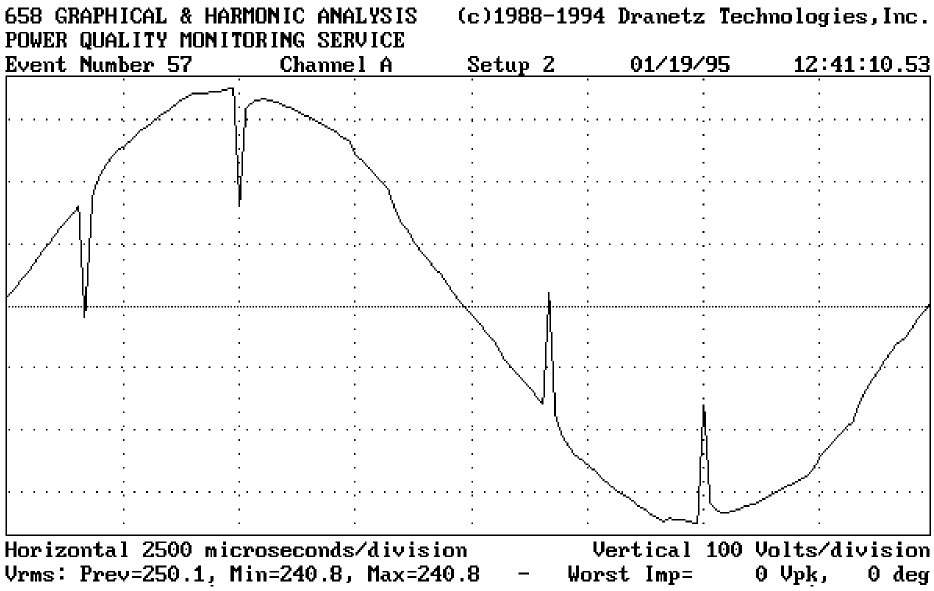

Figure B2-4b
Impact of variable speed drive on voltage

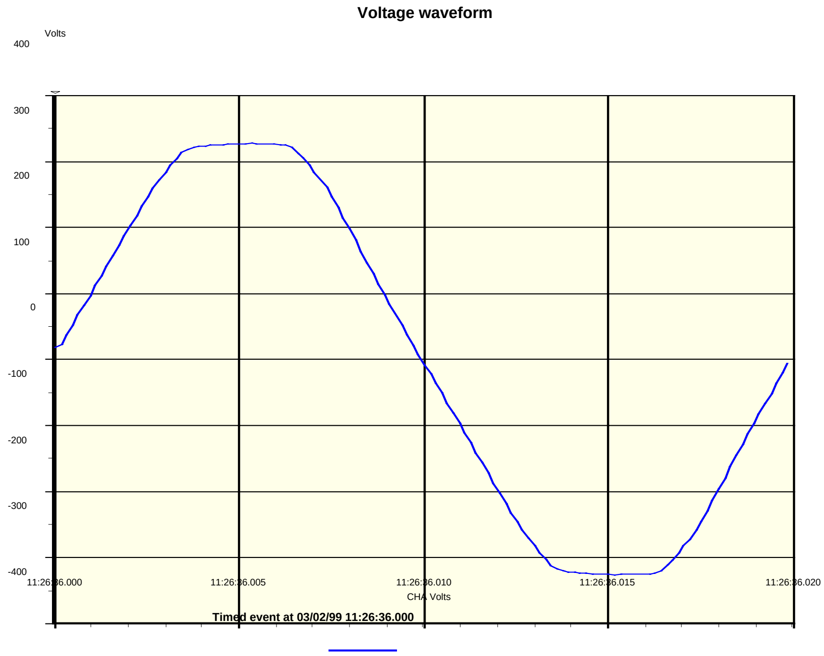

Figure B2-5
Typical office voltage waveform

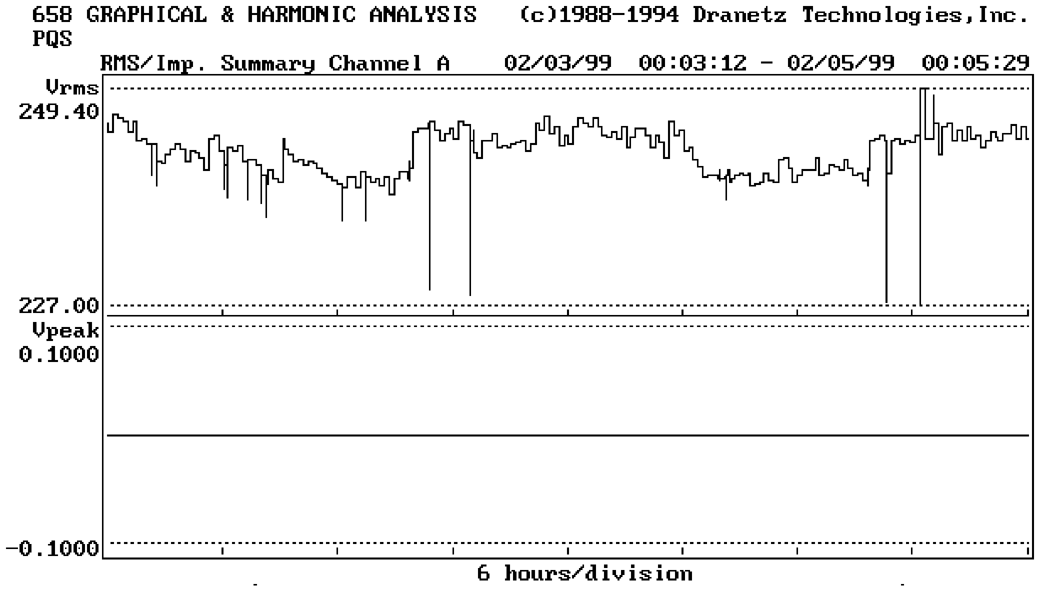

Figure B2-6
Impact of 3.3kV chiller motors on 415V voltage during generator-only connected periods

Total harmonic voltage distortion

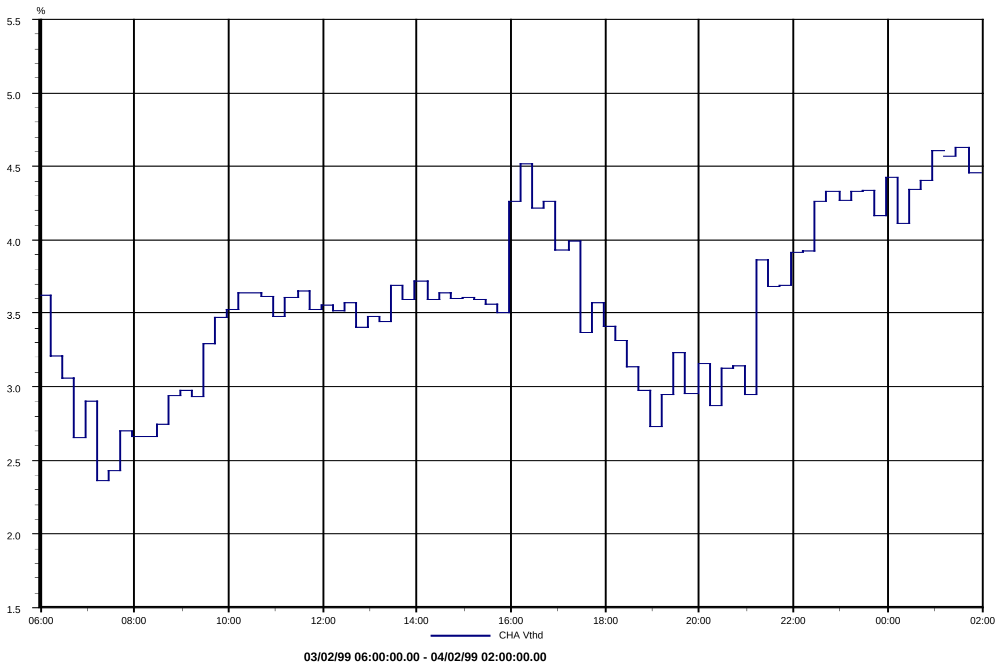

Figure B2-7
Step change in voltage distortion when supply changed from PES to generator only at 4pm.

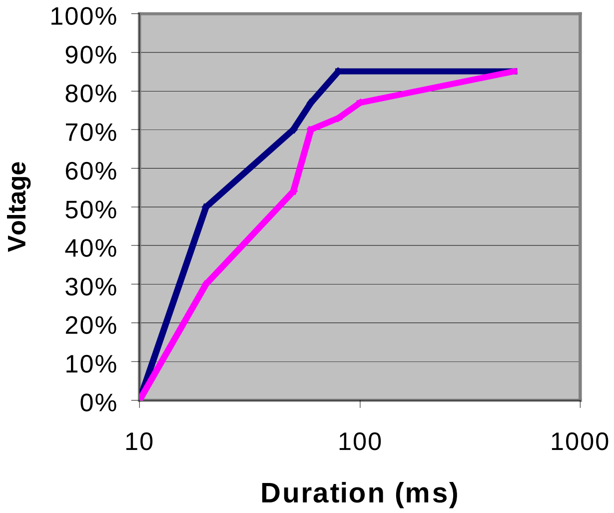

Figure B2-8
Sample measured maximum and minimum sensitivities of a computer to voltage dips, magnitude and duration

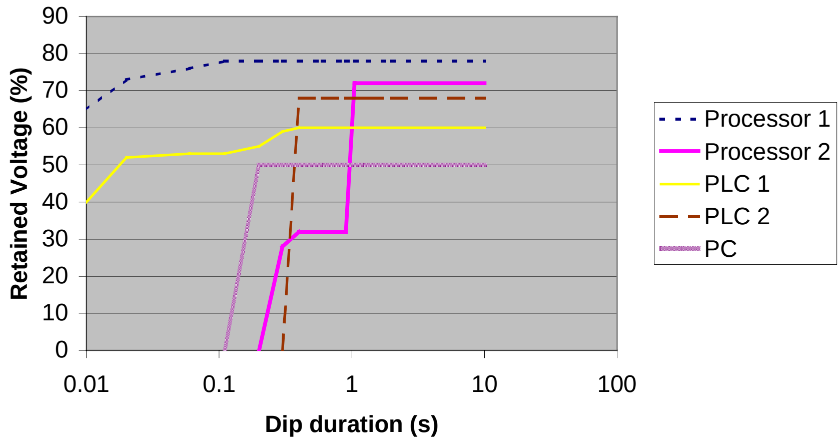

Figure B2-9
Experimental test results on PLC type equipment

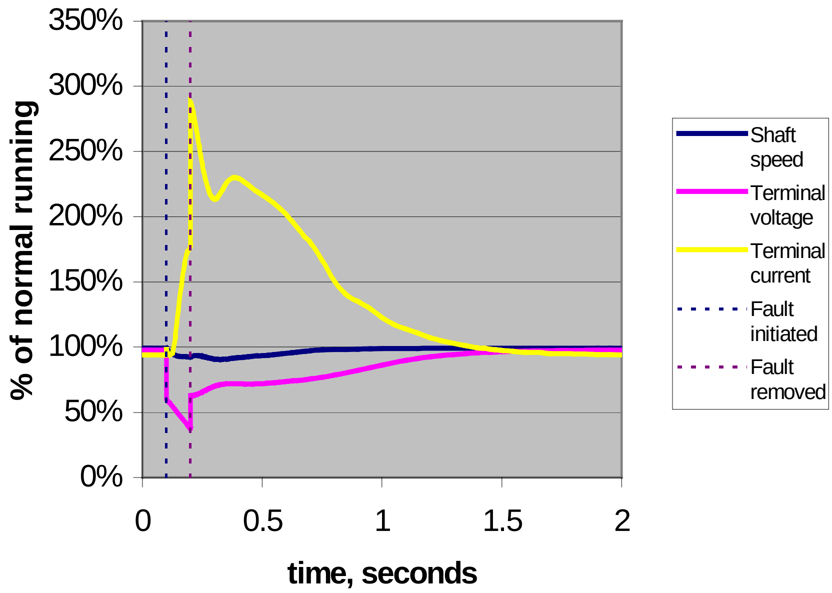

Figure B2-10
Motor re-acceleration curve, 50% dip for 0.2 seconds at remote source