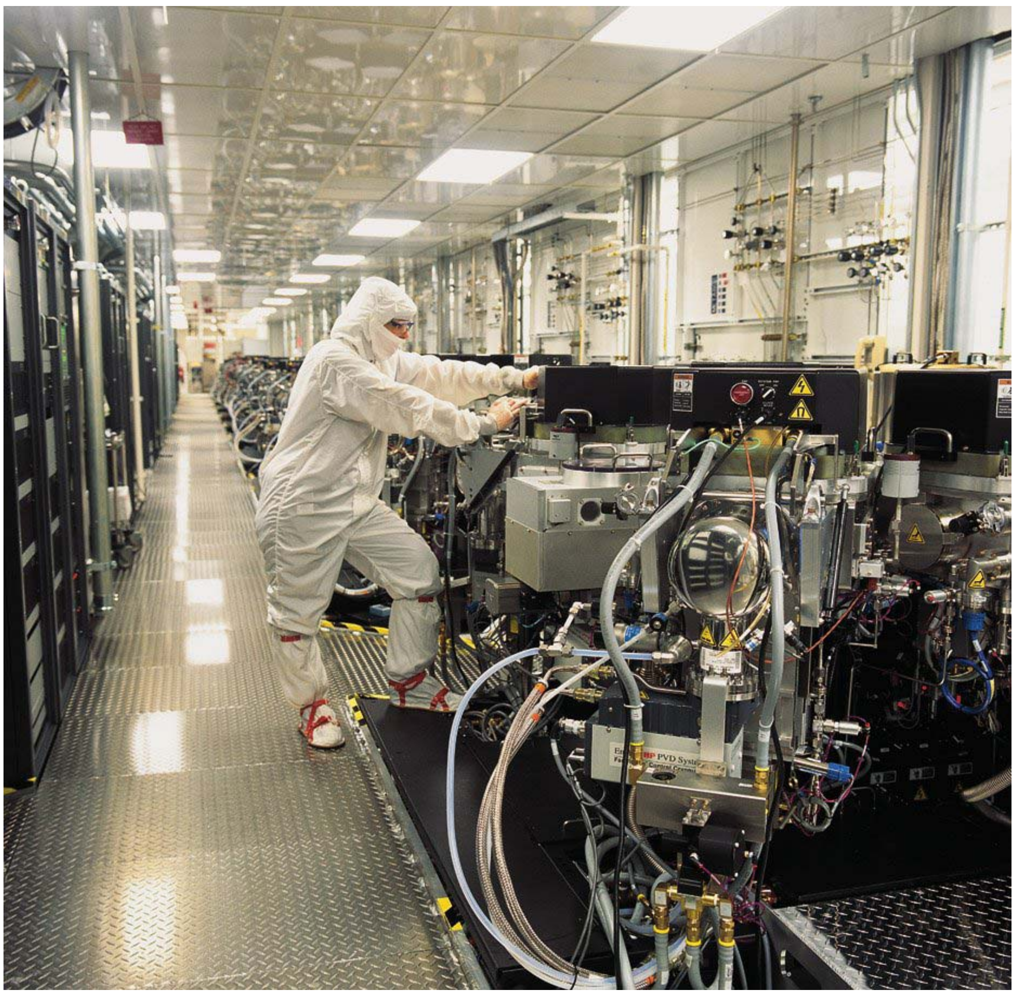
TENAGA NASIONAL

Voltage Sag Solutions for Industrial Customers



A guidebook by Tenaga Nasional Berhad

Disclaimer

The suggestions contained in this book are generic in nature. The reader must always consult the equipment manufacturer before applying any suggestions. TNB or its representatives shall not shall not be held responsible for any consequences arising from application of any suggestion contained herein.

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Foreword by Chairman of Energy Commission

I would like to congratulate TNB on its effort to produce this book on power quality titled “Voltage Sag Solutions for Industrial Customers”.

This book comes at an opportune time as the impetus of growth for the nation is being focused on capital intensive industries and as such the demand for quality of supply from the utility is of importance. As such the focus has now shifted from addressing issues related to reliability in the late nineties to that of power quality now.

The new economy with an array of other global pressures has increased the need for industries to remain competitive and as such the drive for automation. Technology brings with itself other manifested issues and among them is power quality.

The Government through the Ministry of International Trade and Industry (MITI) has set up a National Committee on Business Competitiveness to look at measures to be adopted and implemented for maintaining our competitive edge. As such, the effort taken by SIRIM and Department of Standards Malaysia (DSM) in coming up with the MS IEC standards is definitely a step forward in achieving a more compatible power supply and equipment relationship, in line with similar efforts all over the world. We are proud to know that the committee had adopted several IEC 61000 series standards to be the standards for power quality compatibility in Malaysia.

While power quality seems to be a concern for both the customer and the utility it requires an equal understanding of the issue from all industry players including consultants, equipment manufacturers, the government and the regulator. As such, TNB and the affected consumer need to co-operate and work hand in hand to find the most effective and economical solution to mitigate the problems. Whilst TNB is spending billions on system improvement, customers need to ensure all their equipment meet or exceed the MS IEC standards on power quality compatibility.

Finally, I congratulate TNB again for this effort and hope that this education process would be continuous.

Dato’ Pian Sukro
Chairman
Energy Commission

Foreword by President/CEO of TNB

First of all, congratulation, to the Engineering Department (Distribution Division) for taking the initiative in producing this book called "Voltage Sag Solutions for Industrial Customers".

At TNB, we care about the reliability, consistency, and quality of power supply more than ever. The reason is straightforward. People are using more and more sophisticated electronic controls in their business equipment, most of which are sensitive to voltage variations. Minor fluctuations in power supply such as momentary voltage sags or transients can cause problems with electronic business equipment like never before.

The electricity electromagnetic environment has never been one of constant voltage and frequency. Until recently, most electrical equipment could operate satisfactorily during expected deviations from the nominal voltage and frequency supplied by the utility. In the modern industrial facility, many electrical and electronic devices have been incorporated into the automated processes. No doubt that programmable logic controllers (PLCs), adjustable-speed drives (ASDs), energy efficient motors, CNC machines, and other power electronic devices increase productivity, increase the quality of products, and decrease the cost to customers of those products. However, they also increase the potential for problems with the electrical compatibility requirement because they are not as forgiving of their electrical environment as the earlier technologies. As a result of this recent increase in equipment vulnerability, the owners of industrial processes have experienced unexplained process interruptions and unplanned equipment shutdowns.

Many process interruptions due to electromagnetic disturbances can actually be prevented. With a little knowledge of power quality issues, owners of industrial processes can learn to identify causes of electromagnetic disturbances and take action to prevent their recurrence. This guidebook identifies the most common electromagnetic disturbances that can trouble industrial processes. It also discusses process equipment that are vulnerable to these disturbances and solutions that make the equipment more compatible with the electromagnetic environment.

We at TNB are always willing to provide information and support our customers in their efforts to improve the electromagnetic compatibility (EMC) of their installations.

Dato' Sri Che Khalib Mohd Noh
President/CEO
Tenaga Nasional Berhad

Foreword by Vice President (Distribution Division of TNB)

Power quality, which could be generally understood by many as the variations in the supply voltage, is indeed another critical dimension of service quality that TNB, customers and other industry stakeholders need to appreciate and contribute to manage under current and future business scenarios. The most significant category of power disturbance from the perspective of both customers and utility like TNB is the short duration voltage disturbance or more commonly known as voltage sag. Such a power quality variation invariably has major impact in terms of production losses on many modern manufacturing industries and businesses that are equipped with sophisticated microprocessor-based technologies.

Voltage sag is normally associated with the utility's network operations at both transmission (T) and distribution (D) levels. It is TNB's obligation to continuously improve its' T and D power delivery system in terms of reducing the number of interruptions. Having said that, there will always be incidences of tripping due to external disturbances especially atmospheric activity, and subsequently voltage sags that will impact the highly sensitive customers. Such inherent incompatibility will continue to exist as much as TNB tries to close the gap from its reliability improvement initiatives.

The above scenario therefore requires greater collaboration between TNB and such sensitive customers in understanding the impact of voltage sag performance on processes and particularly in identifying the most critical equipment or controls for possible application of power conditioners. Based on TNB's experience in studying impact of voltage sags on highly sensitive customers, there are certainly proven and economic mitigating solutions.

It is important to note that TNB considers network performance as its prime agenda. For the past few years, the annual SAIDI figures have shown marked improvement.

This PQ guidebook is intended to provide useful illustrations to customers and utility engineers on many possible solutions towards ensuring adequate equipment immunity against voltage sag. Improving the immunity of highly sensitive equipment or controls will go a long way in ensuring electromagnetic compatibility of customer's equipment and processes to the utility's supply environment. Such investments on mitigating solutions can indeed minimize costly equipment mal-operations and disruptions to manufacturing and business processes.

Dato'Ir. Aishah bte Dato' Hj.Abdul Rauf
Vice President (Distribution)
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Section 1 Overview of Power Quality in Malaysia

1.1 The present power quality environment in Malaysia

One of main driving force that helps to accelerate industrialization process in a country like Malaysia is direct foreign investment in manufacturing. In the majority of cases, the manufacturers are establishing or refurbishing plants with high-tech equipment for increased productivity that requires high quality power. Therefore, one particular luring attribute is the ability of the country's power utility to provide the power quality requirement demanded by these customers. With the increased use of power electronics in the manufacturing (commercial and industrial) sectors, new power quality problems such as harmonics have emerged which has to be addressed by power utilities worldwide.

Power quality has now become an important component of service reliability to both utility and customers. The power quality problem has now become more critical due to industrial equipment becoming more sensitive to minor voltage variations.

1.2 Equipment has become more sensitive to voltage disturbances

In Malaysia, electronic equipment has become much more sensitive than their counterparts 10 or 30 years ago. Not only has equipment become more sensitive, companies have also become more intolerant to loss of production time due to their reduced profit margins and competitiveness.

The sensitivity of small ac induction motors to voltage sags is found to be very much dependent on the performance of the contactors used in the control circuitry. In the majority of cases, the sensitivity of the contactors could be adjusted to override most of the voltage sags.

Large ac induction motors are normally connected through circuit breakers with under-voltage relays. On many occasions, the under-voltage relays (UVR) were found to trip instantaneously. Direct Current (DC) motors with variable speed drive (VSD) or adjustable speed drives (ASD) are commonly provided with under-voltage relays that are easily affected by voltage sags. The drive controller unit has also been found to be sensitive to voltage sags resulting in mal-operation. In many cases, motors equipped with ASDs also generate harmonics into the installation compounding the power quality problems.

1.3 Voltage disturbances generated by customer's equipment

Most of the power quality problems experienced by the customers in Malaysia are voltage sags. Voltage sags that occurred are due to short-circuits in the transmission systems, distribution systems as well as from customers' installations.

There are widespread beliefs among utility customers that voltage sags are problems that only originate from the utility systems. Utility has on several instances experienced cases of short-circuits in the customers' installations including internal transformer faults, cable failures and motor starting phenomena that resulted in the malfunction of sensitive equipment of other customers connected to the same source of supply.

There are also proven cases where the sources of the power quality disturbances were linked to the end-user equipment. Modern electronic equipment is not only sensitive to voltage disturbances but could also be the source of the voltage disturbance itself. The increased use of converter-driven equipment (from consumer electronics and computers, to adjustable speed drives) has led to a large growth in the number of voltage disturbances. The main issue here is the non-sinusoidal current drawn by rectifiers and inverters. The input current not only contains a power frequency component but also the so-called harmonic components with frequencies equal to multiples of the fundamental power frequency of 50 Hz.

The harmonic distortion of the current leads to the existence of harmonic components in the supply voltage. Equipment has produced harmonic distortion for a number of decades. However, harmonic distortion issues become serious due to substantial growth of load fed via power electronic devices in the last 20 years or so. The cumulative impact of such equipment could cause a serious distortion of the supply voltage.

Section 2 Steady State Supply Voltage performance

Before more details are presented on the definition of electromagnetic disturbances, it is good that we first understand the definition of voltage regulation. Most customers and consultants often dispute the definition of voltage regulation and electromagnetic disturbances.

The term "voltage regulation" is used to discuss long-term variations in voltage. It does not include short-term variations, which are generally called voltage sags or voltage swells.

The ability of equipment to handle steady state voltage variations varies from equipment to equipment. The steady state voltage variation limits for equipment is usually part of the equipment specifications. The Information Technology Industry Council (ITIC) specifies equipment withstand recommendations for IT equipment according to the ITI Curve (formerly the CBEMA curve). The 1996 ITI Curve specifies that equipment should be able to withstand voltage variations within +/- 10% of nominal voltage (variations that last longer than 10 seconds) [1].

In Malaysia, the voltage regulation requirements are defined in two categories: -

- Range A is for normal conditions and the required regulation is as follows:

Table 1: Steady -state voltage level fluctuation limits under normal conditions

Nominal Voltage	% Variation of nominal voltage
415V and 240V	-10% and +5%
6.6kV, 11kV, 22kV, 33kV	± 5%
132kV and 275kV	-5% and +10%

- Range B is for short durations or unusual conditions. Under contingency condition, when one or more circuit elements are on outage, the power frequency steady-state voltage at all points in the utility's distribution system including the points before the consumer metering must be planned to be maintained as follows:

Table 2: Steady-State Voltage Fluctuation Limits under Contingency Condition

Nominal Voltage	% Variation of nominal voltage
415V and 240V	±10%
6.6kV, 11kV, 22kV, 33kV	±10%
132kV and 275kV	±10%

Section 3 Understanding Power Quality and EMC

3.1 Definition of Power Quality

Power quality is a term used to discuss events in electric power grids that can damage or disrupt sensitive electronic devices. There are many ways in which a power feed can be poor in quality, and so no single figure can completely quantify the quality of a power feed.

Power quality is actually a compatibility problem, or to be exact electromagentic compatibility (EMC) problem. Is the equipment connected to the power grid compatible with the events on the grid, and is the power delivered by the grid, including the events, compatible with the equipment that is connected? Compatibility problems always have at least two solutions: in this case, either clean up the power, or make the equipment tougher.

Ideally, electric power would be supplied as a sine wave with the amplitude and frequency given by national standards (in the case of mains) or system specifications (in the case of a power feed not directly attached to the mains) with an impedance of zero ohms at all frequencies.

However, no real life power feed will ever meet this ideal condition. It can deviate from it in the following ways (among others):

- Variations in the peak or rms voltage (both these figures are important to different types of equipment). When the rms voltage exceeds the nominal voltage by a certain margin, the event is called a "swell". A "dip" (in British English) or a "sag" (in American English - the two terms are equivalent) is the opposite situation: the rms volage is below the nominal voltage by a certain margin.

- An "undervoltage" or brownout occurs when the low voltage persists over a longer time period

- Variations in the frequency

- Variations in the wave shape - usually described as harmonics

- Quick and repetitive variations in the rms voltage. This produces flicker in lighting equipment.

- Abrupt, very brief increases in voltage, called "spikes", "impulses", or "surges", generally caused by large inductive loads being turned off, or more severely by lightning.

- Non zero low-frequency impedance (when a load draws more power, the voltage drops)

- Non zero high-frequency impedance (when a load demands a large amount of current, then stops demanding it suddenly, there will be a dip or spike in the voltage due to the inductances in the power supply line)

3.2 Understanding Electromagnetic Compatibility (EMC)

Electromagnetic Compatibility (EMC) is the branch of electrical sciences which studies the unintentional generation, propagation and reception of electromagnetic energy with reference to the unwanted effects that such an energy may induce. To this purpose, the goal of EMC is the correct operation, in the same electromagnetic environment, of different equipment which involve electromagnetic phenomena in their operation [2].

In order to achieve such an objective, EMC pursues different issues: emission issues, in particular, are related to the reduction of unintentional generation of electromagnetic energy and/or to the countermeasures which should be taken in order to avoid the propagation of such an energy towards the external environment and susceptibility or immunity issues, instead, refer to the correct operation of electrical equipment in the presence of electromagnetic disturbances.

Noise mitigation and hence electromagnetic compatibility is achieved by addressing both emission and susceptibility issues, i.e., quieting the sources of interference, making the disturbance propagation path less efficient, and making the potentially victim’s installation less vulnerable.

When the propagation of electromagnetic disturbances in guiding structures, i.e. conductors, transmission lines, wires, cables, printed circuit board (PCB) traces, is by a guided propagation mechanism, conducted emission and susceptibility issues are considered, whereas, when open-space propagation of electromagnetic disturbances is addressed, the point of focus becomes radiated emission and susceptibility phenomena.

3.3 Understanding Electromagnetic Disturbances

Electromagnetic disturbance is an electromagnetic event, which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or an immediate change in the propagation medium.

3.4 Common Power System Electromagnetic Phenomena

The IEEE 1159:1995 contains several additional terms related to the IEC terminology. The term sag is used synonymously with the IEC term, dip. The category short duration variation is used to refer to the voltage dips and short interruptions as defined by the IEC standards[3].

The category waveform distortion is used as a container category for the IEC harmonics, inter harmonics and dc in ac networks phenomena as well as an additional events from IEEE 519 called notching. Table 3 describes the IEEE categorization of electromagnetic phenomena used for power quality community.

Table 3: Categories and typical characteristics of power system electromagnetic phenomena defined in IEEE 1159:1995

Item	Category	Typical duration	Typical voltage magnitude in per unit
1.0	Transients		
	1.1 Impulsive	< 50 ns	
	1.1.1 Nanosecond	50 ns – 1ms	
	1.1.2 Microsecond	> 1ms	
	1.1.3 Millisecond	< 1ms	
	1.2 Oscillatory		
	1.2.1 Low frequency	0.3 – 50 ms	0-4 pu
	1.2.2 Medium frequency	20 µs	0-8 pu
	1.2.3 High frequency	5 µs	0-4 pu

2.0	Short duration variations		
	2.1 Instantaneous		
	2.1.1 Interruption	0.5 – 30 cycles	< 0.1 pu
	2.1.2 Sag (dip)	0.5 – 30 cycles	0.1-0.9 pu
	2.1.3 Swell	0.5 – 30 cycles	1.1-1.8 pu
	2.2 Momentary		
	2.2.1 Interruption	30 cycles-3s	< 0.1 pu
	2.2.2 Sag (Dip)	30 cycles-3s	0.1 –0.9 pu
	2.2.3 Swell	30 cycles-3s	1.1 – 1.4 pu
	2.3 Temporary		
	2.3.1 Interruption	3s – 1min	< 0.1 pu
	2.3.2 Sag (Dip)	3s – 1min	0.1 –0.9 pu
	2.3.3 Swell	3s – 1min	1.1 – 1.2 pu
3.0	Long duration variations		
	3.1 Interruption sustained	> 1 min	< 0.1 pu
	3.2 Under voltages	> 1 min	0.1-0.9 pu
	3.3 Over voltages	> 1 min	1.1 – 1.2 pu
4.0	Voltage unbalance	Steady state	0.5 –2 %
5.0	Waveform distortion		
	5.1 dc offset	Steady state	0-0.1 %
	5.2 Harmonics	Steady state	0-20 %
	5.3 Inter harmonics	Steady state	0-2 %

3.5 Overcoming Electromagnetic Compatibility (EMC) issues

EMC is a characteristic of equipment or systems that mutually withstand their respective electromagnetic emissions. Equipment and systems are always subject to electromagnetic disturbances, and any electro technical equipment is, itself, more or less an electromagnetic disturbance generator.

According to the IEC 61000-2-1[4], EMC is the ability of a device or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

For all electro technical equipment, EMC must be considered right from the initial design phase and the various principles and rules carried on through to manufacture and installation. This means that all those involved, from the engineers and architects that design a building to the technicians that wire the electrical cabinets, including the specialists that design the various building networks and the crews that install them, must be concerned with EMC - a discipline aimed at achieving the "peaceful" coexistence of equipment sensitive to electromagnetic disturbances (which may therefore be considered as the "victim") alongside equipment emitting such disturbances (in other words, the "source" of the disturbances).

EMC is now becoming a discipline aimed at improving the coexistence of equipment or systems, which may emit electromagnetic disturbance and/or be sensitive to them [5].

Section 4 Understanding Voltage Sags

4.1 Definition of voltage sags

Voltage sags are one of the electromagnetic disturbances that exist in the electromagnetic environment that affect sensitive equipment. Voltage sag is a short-term reduction of rms voltage. It is specified in terms of **duration** and **retained voltage**, usually expressed as a percentage of the nominal rms voltage remaining at the lowest point during the sag. Voltage sag means that the full required energy is not being delivered to the load and this can have serious consequences depending on the type of load involved. The MS IEC 61000 series define voltage sag as a sudden reduction in voltage to a value between 90% to 10 % of nominal voltage, for a duration of 10 ms (1/2 cycle) to 60 seconds [5].

<table>
<tr><td rowspan="4">Event Magnitude</td><td>110%</td><td>Transients</td><td colspan="2">Swell</td><td>High voltage</td></tr>
<tr><td>90%</td><td colspan="4">Normal operating voltage</td></tr>
<tr><td>10%</td><td rowspan="2">Transient</td><td colspan="2">Voltage Sag</td><td>Under voltage</td></tr>
<tr><td></td><td>Momentary</td><td>Temporary</td><td>Sustained interruption</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>0.5 cycle</td><td>3sec</td><td></td><td>1 min</td></tr>
<tr><td colspan="4">Event duration</td></tr>
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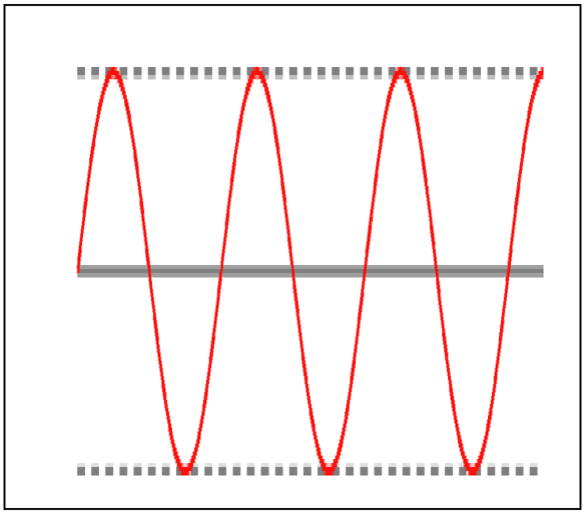
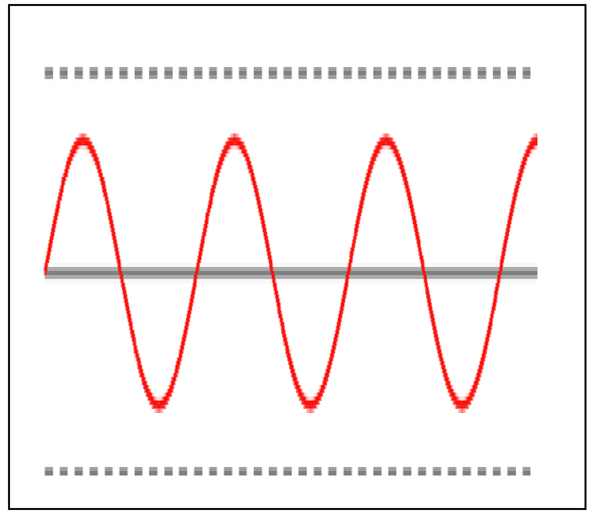
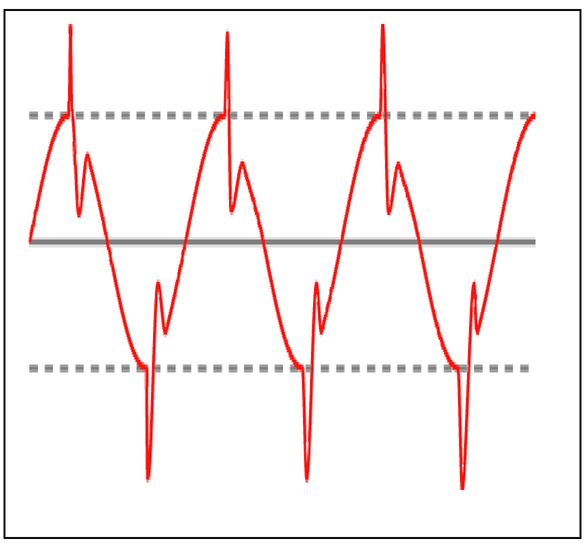
Figure 1: Definition of Voltage Disturbances



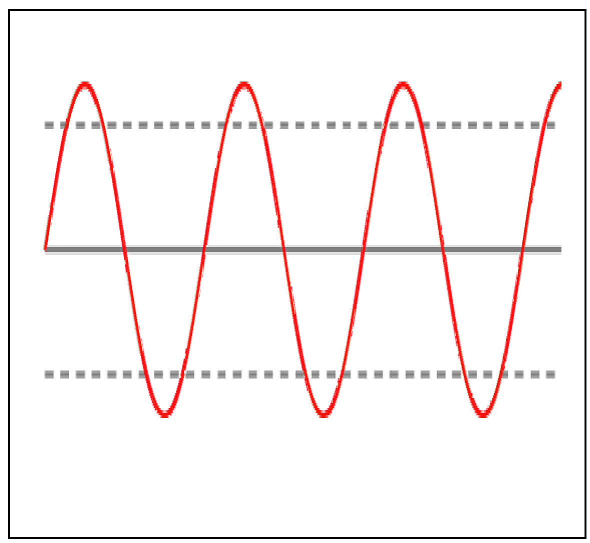
Normal Voltage waveform



Voltage Sag/Under voltage waveform



Transient waveform



Voltage Swell/High Voltage

Figure 2: Voltage waveforms

4.2 Sources of voltage sags

There are three main causes of voltage sags; starting of large motor loads either on the affected site or by a consumer on the same circuit, faults on other branches of the supply network, and faults in the internal supply scheme of the customers installation.

The primary source of voltage sags observed on the supply 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 [7]. 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 are maintained at different potentials.

Many short circuits are caused by over voltages, which stress the insulation beyond its capacity [7]. Atmospheric lightning is a notable cause of such over voltages. Alternatively, the insulation can be weakened, damaged or bridged as a result of other weather effects 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.

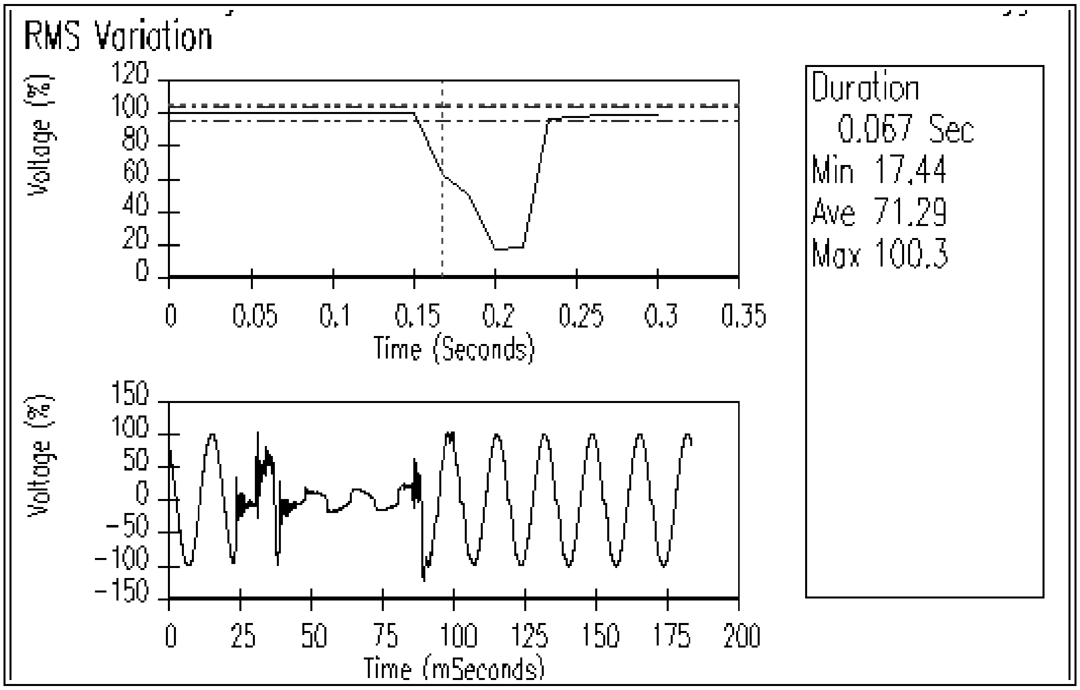
Most supply systems are three-phase systems. The short circuit can occur between phases, phase and neutral, or phase and earth. Any number of phases can be involved.

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, are the events known as voltage sags.

Figure 3: Common causes of voltage sags



Voltage Sag Caused by a SLG Fault

Figure 4: Voltage sag waveform due to faults in the supply networks

The switching of large loads, energizing 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 categorized as voltage sags. (In the management of public networks, however, limits are applied, as a condition of supply, to the permissible voltage fluctuations from this cause) [8].

Since the supply and the cabling of the installation are dimensioned for normal running current, the high initial current causes a voltage drop in both the supply network and the installation. Voltage sags caused by starting currents are characterized by being less deep and much longer than those caused by network faults –typically from one to several seconds or tens of seconds, as appear to being less than one second.

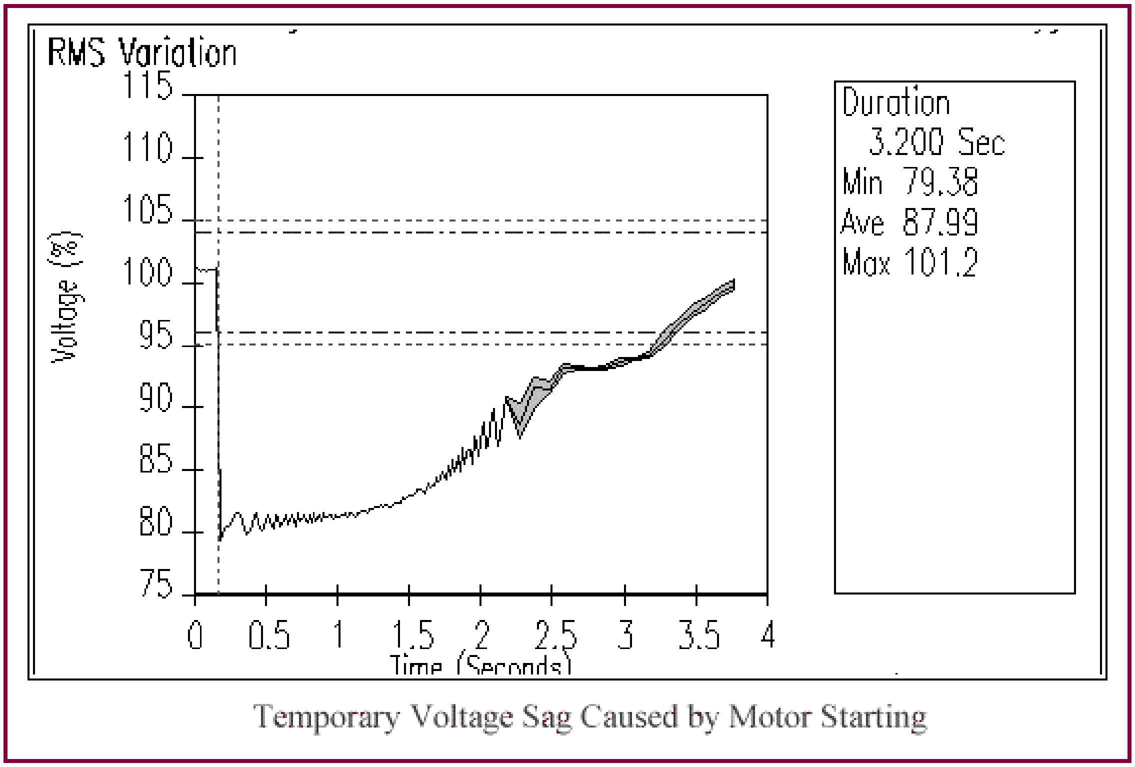


Figure 5: Voltage sag waveform due to motor stating

Figure 6: A large motor in an industrial plant

4.3 Impact of voltage sags to industrial equipment

Electronic equipment, which is now so integral to industrial and commercial power systems, can fail or malfunction if subjected to a voltage, current, or frequency deviation.

Before the era of solid-state electronics, power quality was not discussed because it had little or no effect on most loads connected to electrical distribution systems. When an induction motor suffered a voltage sag, it did not shut itself down but simply "spun out" fewer horsepower until the sag ended. The same was true for incandescent or fluorescent lighting systems in a facility-the lumen output just decreased temporarily.

But today, as sensitive equipment and processes become more complex and downtime costs increase, contractors and engineers have to specify and install specialized equipment to avoid undesirable situations.

The ideal power-supply voltage for sensitive electronic equipment is an uninterrupted sinusoidal waveform of constant amplitude. Any event that comprises this condition is called a power quality disturbance. Power quality disturbances as brief as one-half cycle can affect the operation of sensitive electronic equipment.

4.3.1 Impact of voltage sags to electronic equipment

Electronic devices require a more controlled electrical environment than most other loads. This is especially true when it comes to the input voltage. If the voltage of the power supply varies beyond the specifications of the device, then problems can occur.

Recall that a voltage sag is not simply a change in the rms magnitude, but a change over a discrete period of time. This time interval is important in terms of determining acceptable voltage.

The fundamental issue behind the symptoms related to voltage sags is how much energy is being transferred into the power supply. If inadequate energy is going into the power supply due to voltage sag, then the dc voltage applied to the integrated circuits drop [9]. If this happens, the device will shut down, lock up, or garble data. If the device shuts down, it will usually restart as soon as enough energy gets back into the supply.

On the other hand, if too much energy goes into the supply because of a voltage swell, it will probably cause damage. Blown power supplies are the most common result of large swells. Obviously, if the power supply fails then the whole device goes down.

Figure 7: Common electronic equipment in office

4.3.2 Motors

Motors are extremely tolerant of voltage sags and voltage swells. Unless the rms magnitudes are either very low or very high, motors typically have little response to these voltage variations. Keep in mind that if the motors are controlled by electronic drive controllers, the discussion on electronic equipment applies.

If the magnitudes are extreme, or if these disturbances occur frequently, then several symptoms may develop. First, extreme swells will electrically stress the windings on the stator. This leads to premature motor failure. Second, extreme sags may cause the motor to lose enough rotational inertia to affect its performance or task. Third and last, if sags happen frequently enough, the motor may draw high inrush currents often enough to trip a breaker.

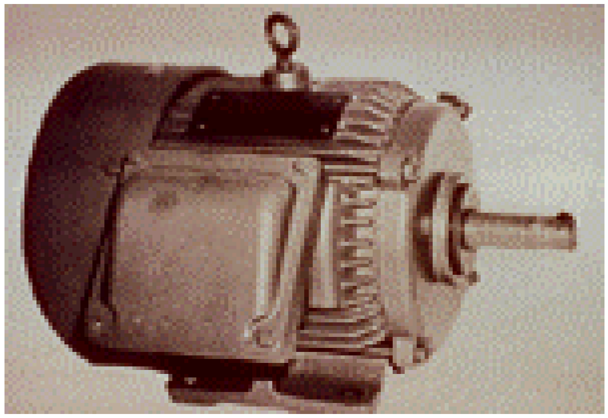


Figure 8: Electric motor

4.3.3 Lighting

Most lighting systems are tolerant of voltage sags and voltage swells. Incandescent systems will simply burn brighter or dimmer. Overall life expectancy may be affected, and the change in brightness may be annoying, but no other adverse reactions usually occur. This change in brightness is often called "flicker."

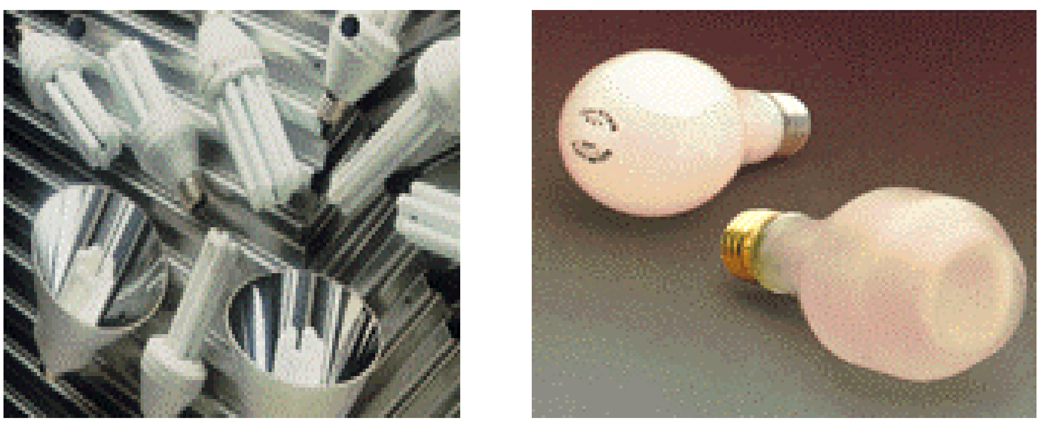


Figure 9: Lighting facilities

Fluorescent systems may not fare quite as well. Standard ballasts are typically more tolerant than are electronic ballasts. In both cases there may be some flicker, but the real concerns are with restarts and reliability. If voltage sags are deep enough, then the ballast will no longer be able to provide the energy needed to generate the arc inside the fluorescent tube. This means a dark lamp. If swells are extreme, then the ballast is stressed, causing premature failure. High intensity discharge, or HID lighting such as mercury vapor, metal halide, and high and low pressure sodium lights are also more sensitive to sags and swells. While their response is very similar to electronic fluorescent ballasts, the lamps themselves are typically more sensitive than the ballasts.

A common problem is HID systems turning off during voltage sag. Sodium discharge lamps have a much higher striking voltage when hot than cold, so that a hot lamp may not restart after a dip. The magnitude of dip that will cause a lamp to extinguish may be as little as 2 % at the end of life or as high as 45 % when new.

Unlike fluorescent systems that will quickly turn back on, the HID system must wait several minutes before being restarted. This is not only annoying but can be dangerous.

4.3.4 Sensitive equipment in industrial plants

Voltage sags and swells give severe impact to the industrial customer's equipment. Truly severe swells may stress components to the point of failure, but other than that there is seldom disruption or damage [9].

Problems may arise as the system responds to the reaction of the load to the sag or swell. It is possible that if a sag or swell is extreme enough and lasts long enough, the resultant over current could trip breakers, blow fuses or damage the electronic components.

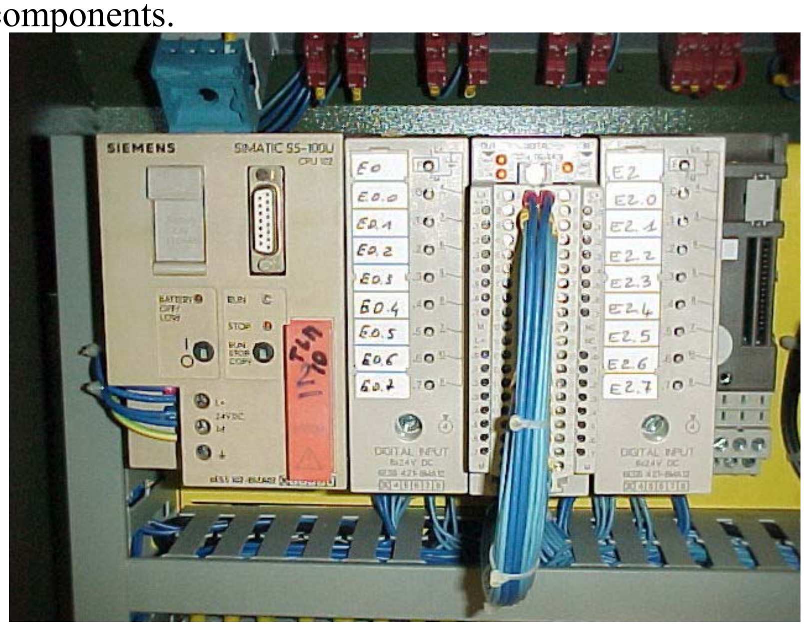


Figure 10:

Programmable Logic Control (PLC)

Section 5 Equipment Compatibility Requirement

5.1 Power quality design philosophy

The effect of a voltage sag and short duration interruption on the user's equipment must be considered, with particular regard to the depth-duration characteristics that are critical, and the user must take due account of the possible consequences of any deterioration of performance or lapse in operation of that equipment.

In the light of those consequences, the installation should from the very first stage of planning, be designed to minimize disturbance and loss arising from voltage sags, with due regard given to the economic considerations that apply.

Satisfactory operation of the distribution system and customers' equipment is only obtained where electromagnetic compatibility (EMC) exists between them. The normal approach to electromagnetic compatibility is to observe coordinated limits for both emission and immunity for the disturbance events involved [10].

5.2 Understanding equipment immunity requirement

There are two aspects to EMC: (1) a piece of equipment should be able to operate normally in its environment, and (2) it should not pollute the environment too much. An agreement on immunity is a matter of foremost concern between equipment manufacturers, utilities and customers.

The IEC standards set minimum requirements for voltage sag immunity for sensitive equipment. It is important that all sensitive equipment should be immune to its electromagnetic environment [11].

A device connected to the power system is exposed to an electromagnetic environment not only due to the combined emission of all other devices connected to the system but also due to all kinds of events in the power system (like switching actions, short circuit faults and lightning strokes).

The immunity of the device should be assessed with reference to this electromagnetic environment.

For some locations and in some countries it may be possible for the electricity utilities to provide basic information on the level of the electromagnetic environment for example the frequency of voltage sags to be expected at the location concerned, subject to the uncertainties that are unavoidable.

5.3 Voltage Sag Immunity requirement

Immunity standards define the minimum level of electromagnetic disturbances that a piece of equipment shall be able to withstand. Before being able to determine the immunity of a device, a performance criterion must be defined.

5.3.1 Available equipment compatibility levels

Compatibility levels are reference values used for the coordination of emission and immunity of equipment making up, or being supplied by, a network in order to ensure electromagnetic compatibility throughout the whole system [12].

A range of standards had been published to address the fundamental electromagnetic compatibility (EMC) issues governing the connection of IT equipment and plant resources to a power system. Standards documentation sets out guidelines for IT plant and equipment connectivity and regulation of both conducted and radiated EMC emission and susceptibility. A sub-set of most EMC standards documentation governs the susceptibility of IT equipment to voltage sags and surges.

5.3.2 Voltage tolerance curve

5.3.2.1 CBEMA curve

The existing CBEMA (Computer and Business Equipment Manufacturers' Association) power quality graph plots the depth of voltage sags on the vertical axis against the duration of voltage sags on the horizontal axis. See Figure 11.

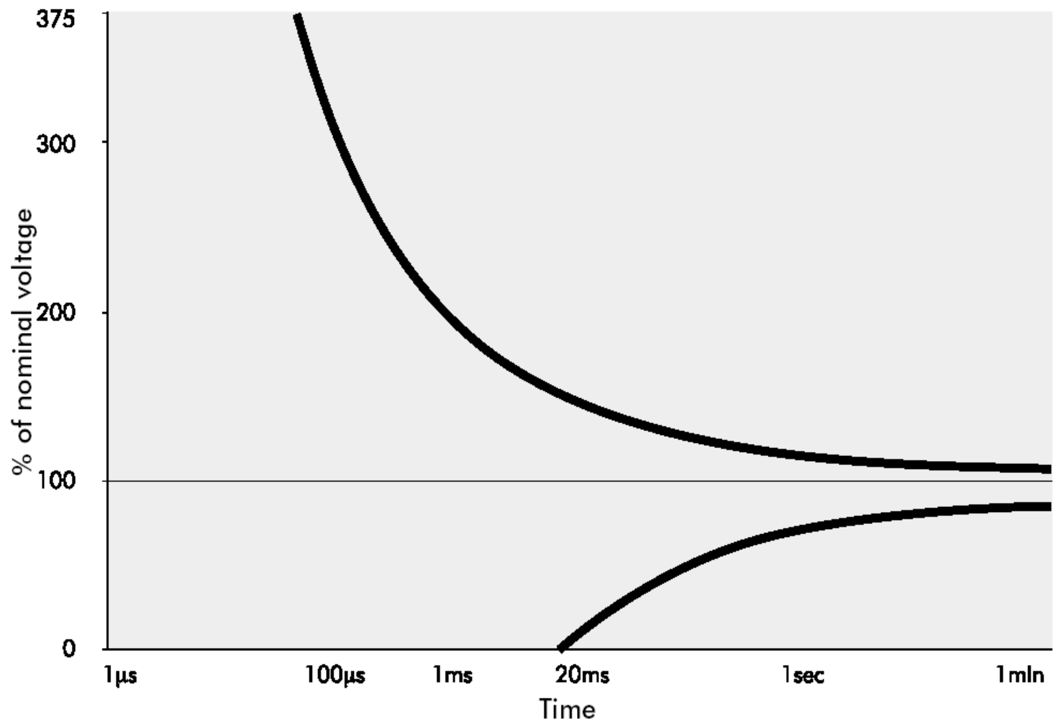


Figure 11: CBEMA curve

The line on the graph shows the sag immunity suggested by CBEMA. The sags shown in the graph, shown as dots, were collected at worldwide semiconductor plants. This observation led the semiconductor industry to establish its own voltage immunity standard, SEMI F47.

5.3.2.2 SEMI F47 curve

A notable addition to industrial and IT process PQ standards has been the recent specification SEMI F47-0706. The requirements of the SEMI specification were developed to satisfy the needs of the semiconductor industry. This specification sets minimum voltage sag immunity requirements for equipment used in the semiconductor industry. Immunity is specified in terms of voltage sag depth (in percent of nominal voltage remaining during the sag) and voltage sag duration (in cycles or seconds). This specification also sets procurement requirements, test methods, pass/fail criteria, and test report requirements.

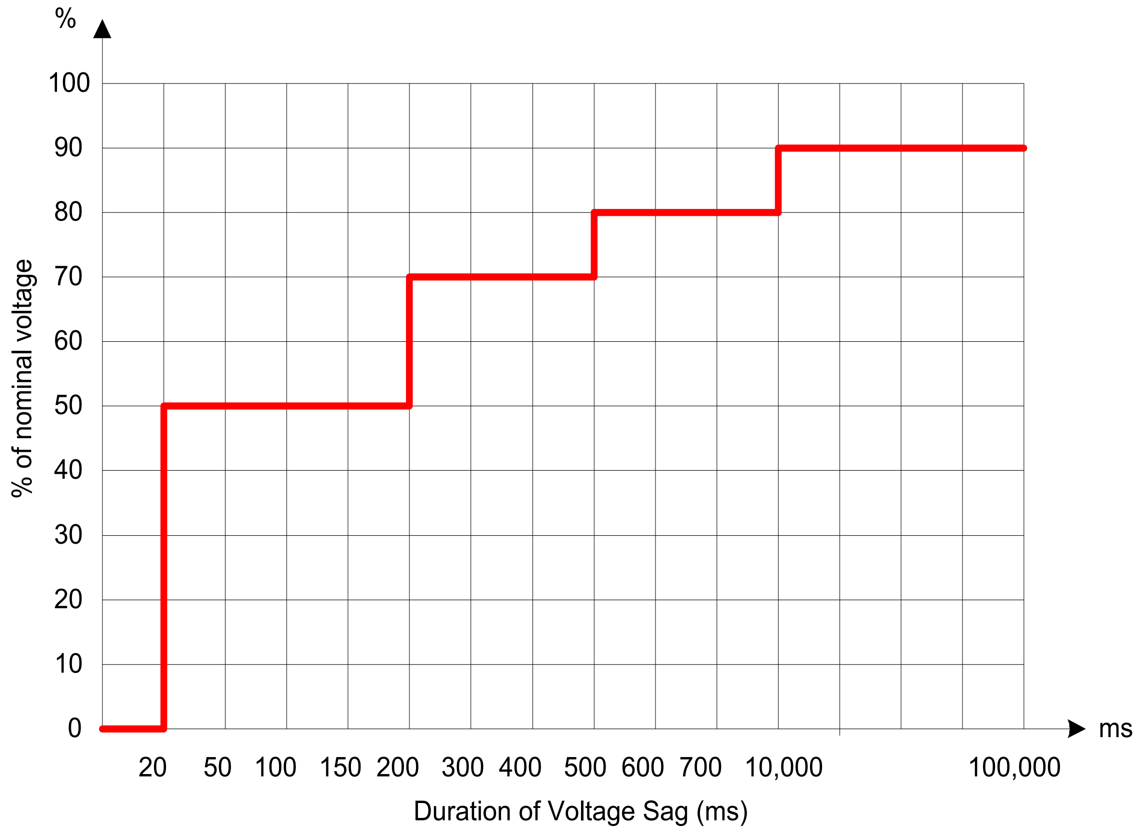


Figure 12: SEMI F47-0706 curve

Thus, the requirements developed in the SEMI specification are better suited to the semiconductor industry. The SEMI (curve) *staircase* is specified for voltage dips with a duration 0.05s – 1s, Figure 18. An arguable advantage of the SEMI curve as a benchmark for site performance profiling and CBEMA equipment testing and approval is the stringent requirement on equipment to continue to function down to 50% retained voltage (cf. 70% in the ITI – CBEMA curve) for dips of duration 0.05 – 200 ms [13].

Although specified for semiconductor equipment, the tighter limits imposed by the SEMI curve, (if applied as a benchmark for compliance) present the ESI and IT industrial process and manufacturing industries with a more robust basis for ride-through declaration (cf. the ITIC – CBEMA curve). While delivering greater constraints at all levels in the supply chain, compliance with a more rigid benchmark breeds a higher level of confidence in equipment operability.

5.4 **MS IEC 61000-4-11** – Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current less than 16 A per phase

The MS IEC 61000-4-11 standard defines the immunity test methods, minimum immunity requirement and range of preferred test levels for electrical and electronic equipment connected to low-voltage power supply networks for voltage dips (Graph A), short interruptions (Graph B), and voltage variations.

The MS IEC 61000-4-11 covers equipment installed in residential areas as well as industrial machinery, specifically voltage dips and short interruptions for equipment connected to either 50 Hz or 60 Hz arc. networks, including 1-phase and 3-phase mains. [14].

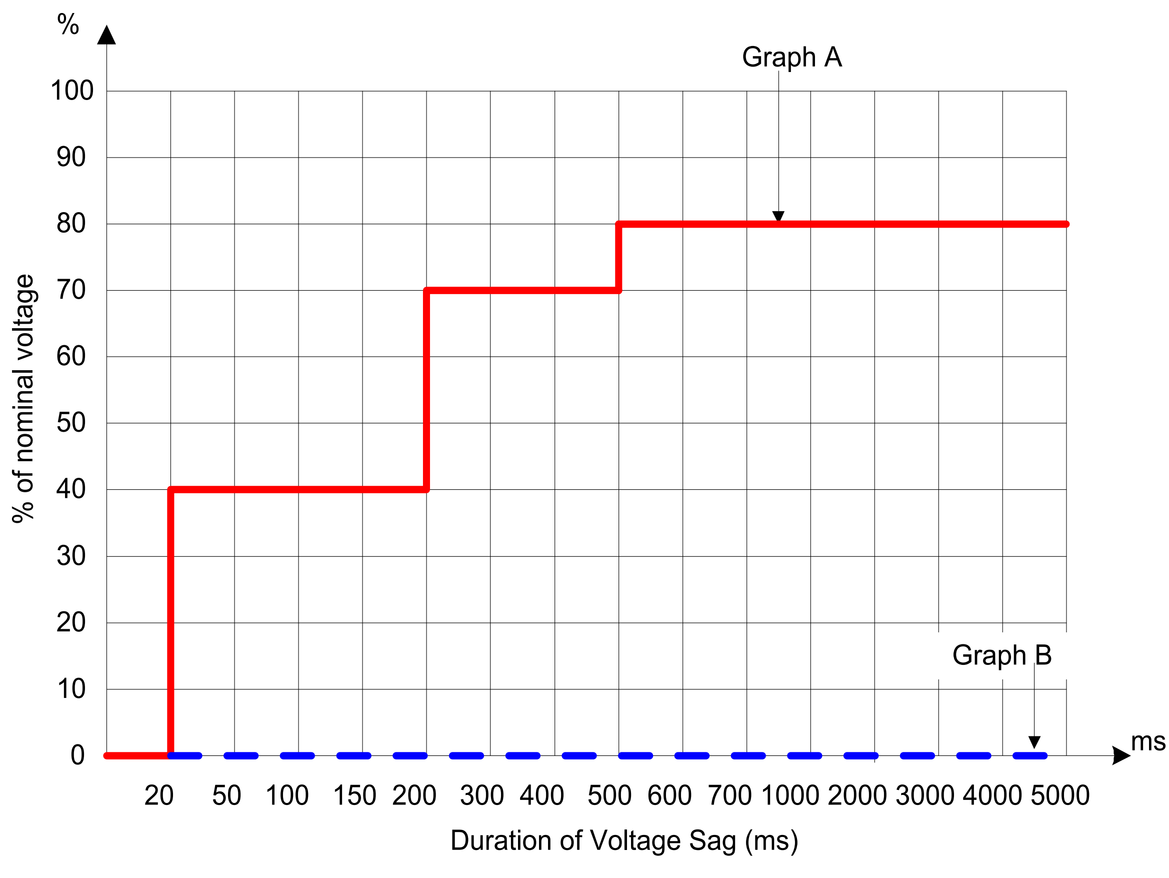


Figure 13: MS IEC 61000-4-11 (Class 3) curve

5.5 MS IEC 61000-4-34 – Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase

The MS IEC 61000-4-34 standard is similar to the MS IEC 61000-4-11 standard. The main difference is that it only applies to electrical and electronic equipment having a rated input current exceeding 16 A per phase [15].

It also covers equipment installed in residential areas as well as industrial machinery, specifically voltage dips and short interruptions for equipment connected to either 50 Hz or 60 Hz a.c. networks, including 1-phase and 3-phase mains.

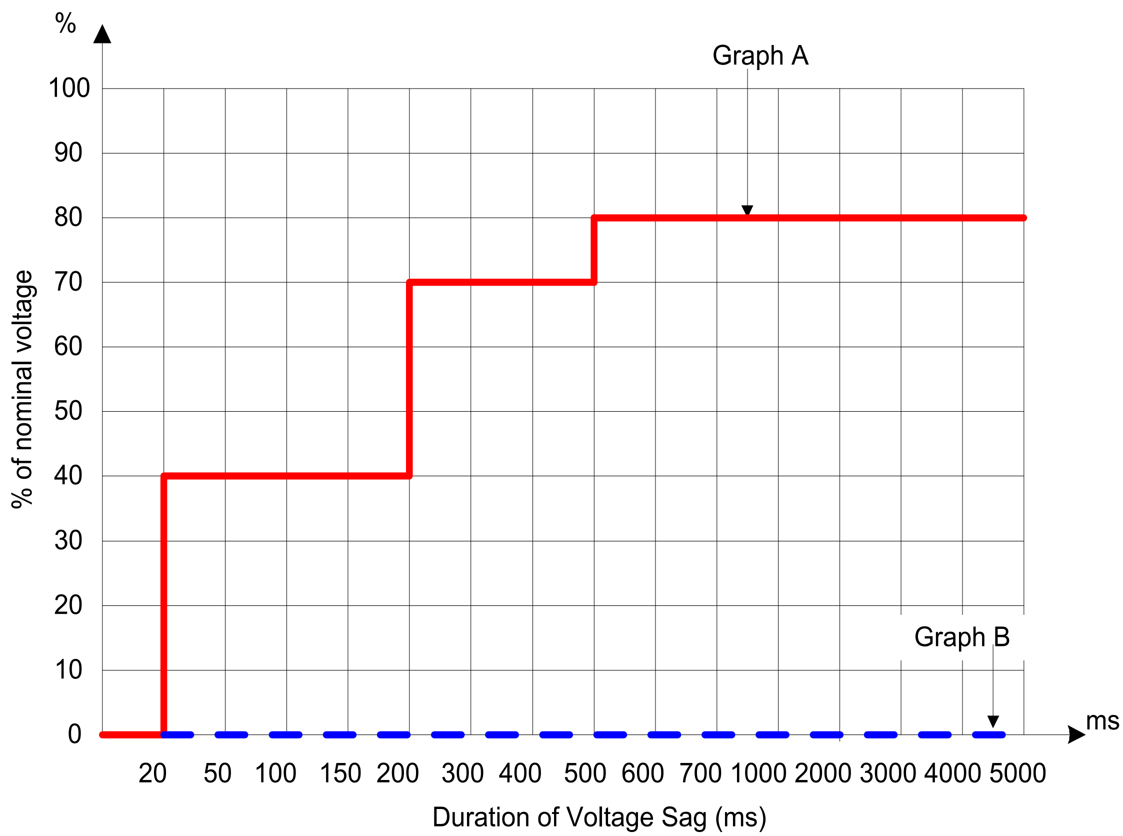


Figure 14: MS IEC 61000-4-34 (Class 3) curve

To understand the MS IEC 61000-4-11 and MS IEC 61000-4-34 curves better, please refer to section 6.2 of this guidebook (page 42).

Section 6 Characterizing Equipment Sensitivity

Voltage sag at equipment terminals are influenced by the transformer connections between the fault location on the supply system and the equipment connection point. The transformer connections will influence both the magnitude and the phase relationship of the voltage sag experienced by the equipment.

These phenomena are random in nature and can be minimally characterized for the purpose of laboratory simulation in terms of the deviation from the rated voltage, and duration. Consequently, different types of tests are developed to simulate the effects of abrupt voltage change. These tests are to be used only for particular and justified cases, under the responsibility of product specification or product committees.

6.1 Objective of equipment immunity testing

The objective of this section is to define the test method used to characterize the susceptibility of automated processes and automated test equipment to voltage sags. In this section, the scope covers: -

a. Characterizing the susceptibility of equipment to voltage sags by showing voltage sag duration and magnitude performance data for the equipment.

b. Qualifying equipment to meet voltage sag ride-through specifications by comparing the equipment voltage sag ride-through performance to industry standards.

Sensitive machinery will be experiencing mal-operation every time a voltage sag event occurs. This is due to the incapability of the equipment to ride through the voltage sag event or in other words the immunity of the equipment is very low.

The typical equipment sensitivity to voltage sag is shown in Table 4.

Table 4: Typical equipment sensitivity

Type of Equipment	Remaining voltage [%]	Time duration max [ms]
Motor starter	50	40
Variable speed motor with electronics	85	10
PLC I/O Device	50-90	8-20
Frequency inverter	82	1.5
Variable Speed Drive rectifier	50-80	2-3
Process controller	70	< 8
Computerized numerical controlled lathe	70	< 8
Direct Current drive controller	88	< 8
Personal Computer	50-70	60-160
Contactors	50-60	20-30
Electromagnetic disconnecting switch	50	10
Electromagnetic relays	50-60	15-40
Medical equipment	60	130
Servo drives	80	50
Laser marker	90	100

Figure 15:

Programmable Logic Control (PLC)

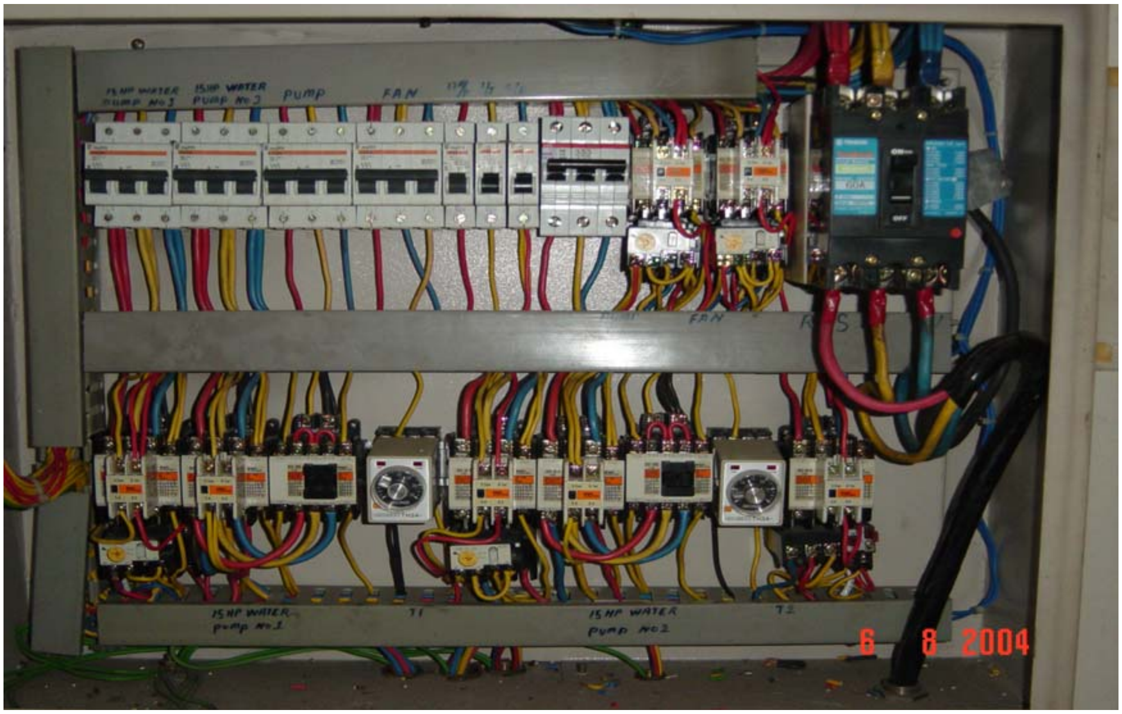


Figure 16: Secondary control panels

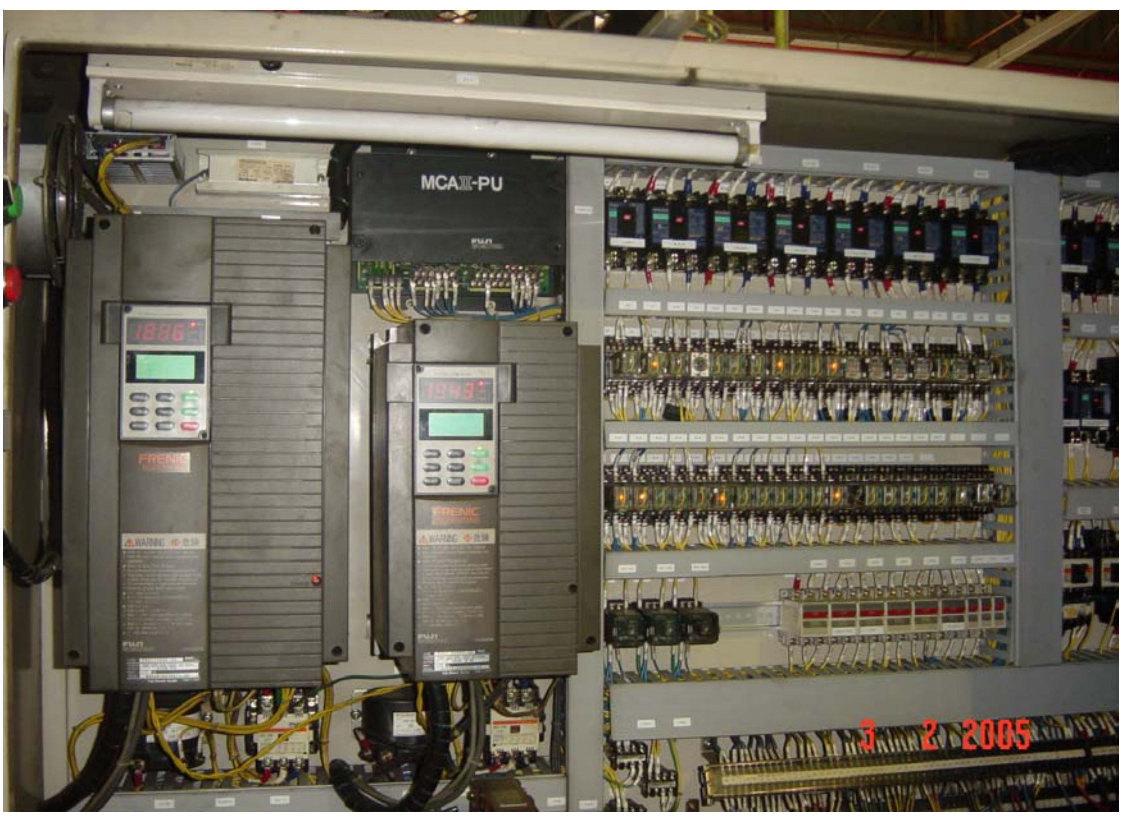


Figure 17: Frequency Inverter

Figure 18: Alternating current (AC) drive

Figure 19: Direct current (DC) drive

Figure 20: Servo drive

6.2 Analyzing machinery immunity and sensitivity to voltage sag

The first step towards a cost-effective solution is to understand the sensitivity of the electronic equipment to momentary interruptions and voltage sags. Customers can find this information by consulting the equipment manufacturer's specifications and testing data.

Another way to identify the sensitivity of equipment to voltage sags is by using a measuring device called a voltage sag generator, which can generate controlled voltage sags and records the responses of the equipment. In the market today, there are a few types of programmable sag generators available. Examples are the *basic programmable ac source* and the *industrial power corruptor (IPC)*.

Figure 21: Programmable AC source

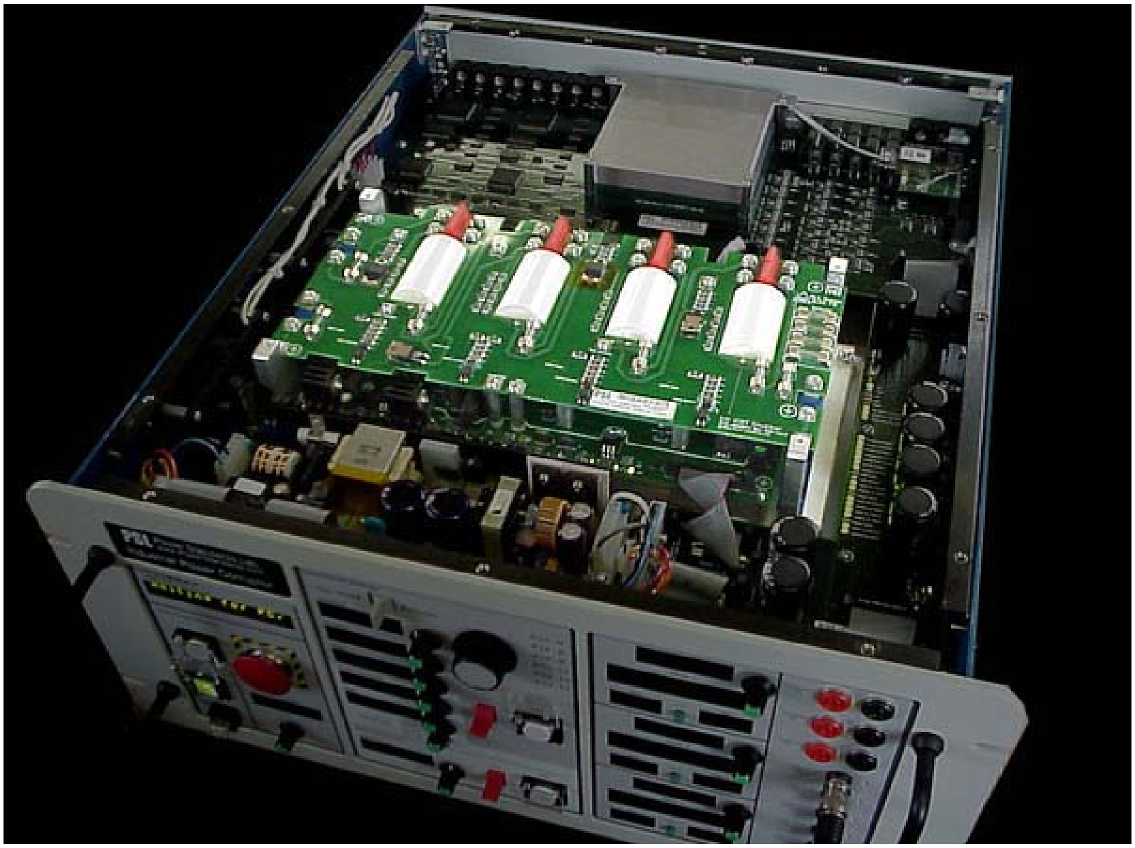


Figure 22: Industrial Power Corruptor (IPC)

The standards that describe how to obtain voltage tolerance of equipment are MS IEC 61000-4-11, MS IEC 61000-4-34 and SEMI F47. The overall testing requirements are referred to these same standards: MS IEC 61000-4-11, MS IEC 61000-4-34 and SEMI F42.

The preferred test levels for voltage dip/sag immunity are shown in Table 5[15].

Table 5: Preferred test level and durations for voltage sags at 50 Hz

Classes	Test level and durations for voltage dips				
Class 1	Case by case according to the equipment requirement				
Class 2	0% during ½ cycle	0% during 1 cycle	70% during 25 cycle		
Class 3	0% during ½ cycle	0% during 1 cycle	40% during 10 cycle	70 % during 25 cycle	80 % during 250 cycle
Class X^b	X	X	X	X	X

Note: *The types of classes are defined in MS IEC 61000-2-4*
X^b – To be defined by product committee
Sensitive equipment in industrial plants must be tested at minimum Class 3.

6.2.1 Test instrumentation

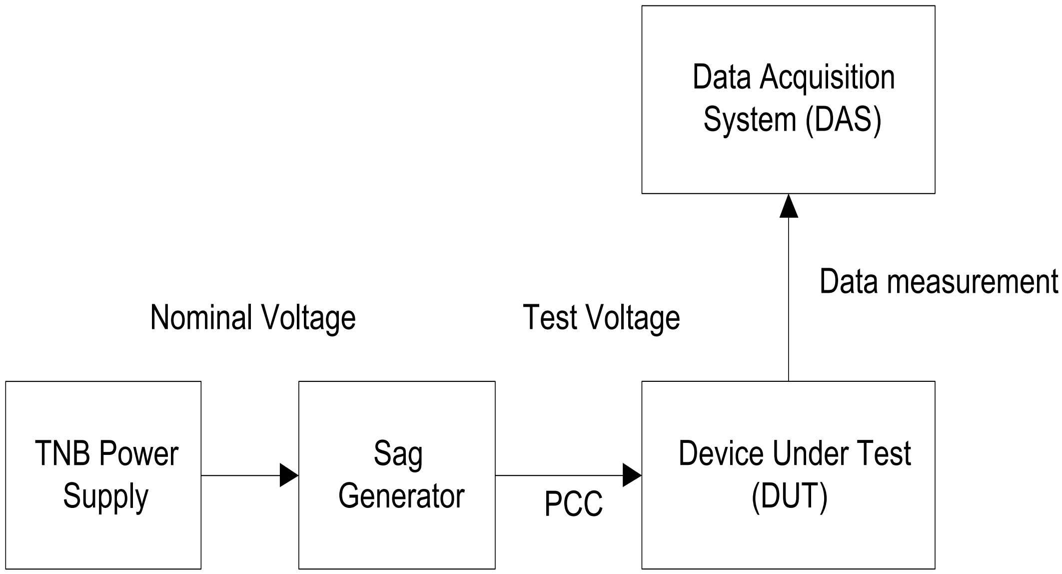
6.2.1.1 Sag generator

The following features are common to the generator for voltage sags, short interruptions and voltage variations. The generator shall have provision to prevent the emission of heavy disturbances, which, if injected in the power supply network, may influence the test results [15].

Table 6: Characteristics and performance of the sag generator

Output voltage at no load	As required in Table 5. ±5% of residual voltage values
Voltage at the output of generator during equipment test	As required in Table 5, ± 10% of residual voltage value, measured as r.m.s. value refreshed each ½ cycle per MS IEC 61000-4-30
Output current capability	Less than 16 A r.m.s (MS IEC 61000-4-11) or more than 16 A r.m.s (MS IEC 61000-4-34) per phase at rated voltage.
Voltage rise (and fall) time *t*r (and *t*f), during abrupt change, generator loaded with resistive load	Between 1 µs and 5 µs
Phase angle at which the voltage dip begins and ends	0° to 360° with a maximum resolution of 5°
Phase relationship of voltage dips and interruptions with the power frequency	Less than ± 10 °
Zero crossing control of the generators	± 10°

The test setup should consist of the above equipment as shown in Figure 23.



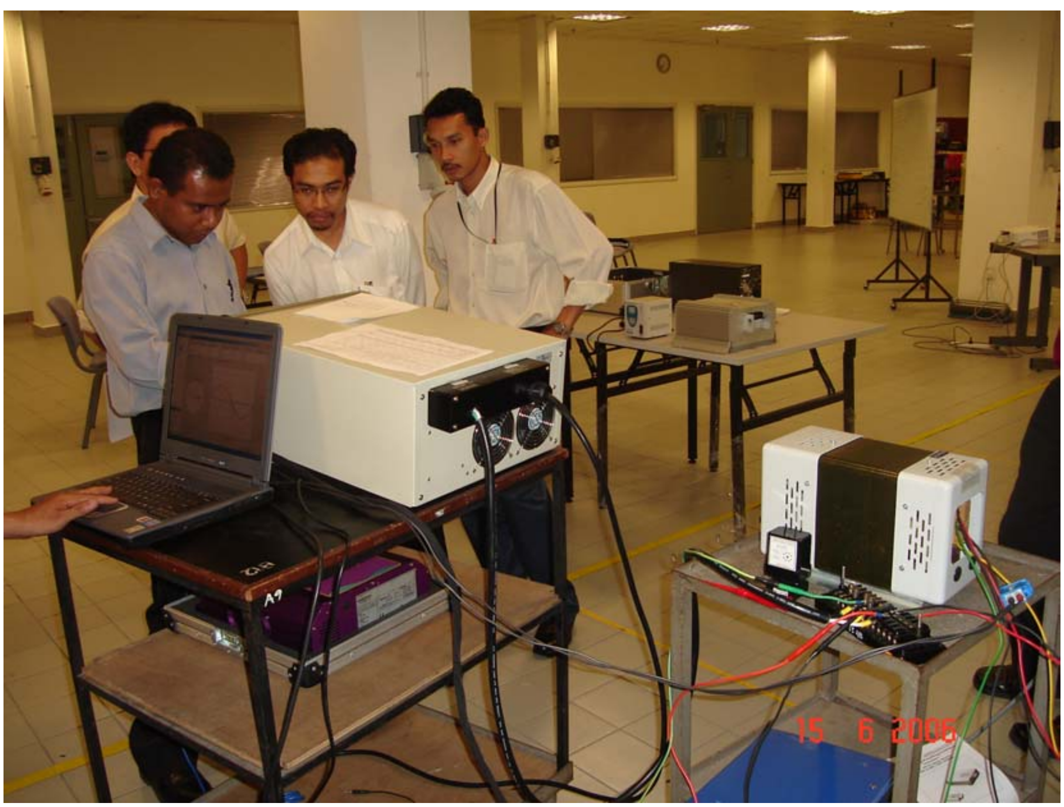


Figure 23: Voltage immunity test

6.2.2 Evaluation of test results [15]

The test results shall be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product.

The recommended classification is as follows [15]:

a) normal performance within limits specified by the manufacturer, requestor or purchaser;
b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;
c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;
d) loss of function or degradation of performance, which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define the effects on the DUT, which may be considered insignificant, and therefore acceptable. This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example in instances where no suitable generic, product or product-family standard exists.

6.3 Improving equipment immunity to voltage sag

After the voltage sensitivity of the equipment is known, analysis can now be done to identify measures to improve its immunity to voltage sag. With regard to voltage sags that are moderate in depth and duration, some equipment can have a certain level of inherent immunity, for example by virtue of its inertia or energy storage capacity. Alternatively, it may be possible to make design adjustments or use of additional support equipment so that this property is manifest.

However, for short interruptions and the more severe voltage sags, immunity is not, in its strict sense, a feasible concept. The essential character of the event is that it involves the complete cessation or severe diminution of the energy supply for a brief interval. No electrical device can continue to operate as intended in the absence of its energy supply.

Therefore, such immunity as can be provided from these disturbances tends to be extrinsic—it is a matter of either providing for:

- fast restoration of energy from an alternative source or,

- arranging for the equipment and its associated process to adapt in an intended manner to the brief interruption or diminution of power.

Section 7 Common solutions to electromagnetic disturbances

The common acceptable solutions for power quality problems frequently involve some combination of wiring and grounding upgrades and the use of mitigation equipment. In some cases, it may be more cost effective for the customer to purchase and install mitigation equipment than to re-wire all or part of a facility. This is particularly true when the facility includes numerous additions or has undergone many remodeling.

7.1 Understanding grounding solution

The primary purpose of grounding electrical systems is to protect personnel and property if a fault (short circuit) were to occur. A second purpose of a grounding system is to provide a controlled, low impedance path for lightning-induced currents to flow to the earth harmlessly.

All metal objects that enclose electrical conductors, or are likely to become energized in the event of a fault or electrostatic discharge, must be effectively grounded to provide personnel safety, as well as equipment performance. It is best to use solidly grounded ac supply systems.

Grounding is an extremely important electrical consideration for the proper operation of electronic equipment. The ground conductor provides a designed path to ground (earth). A properly designed grounding system should have as low an impedance as is practically achievable for proper operation of electronic devices as well as for safety. It is also important that the ground should be continuous from the central grounding point at the origin of the building system.

Electronic equipment can be sensitive to stray currents and electronic noise. It is important to utilize a continuous, dedicated ground for the entire power system so as to avoid a ground differential between various grounds being used. The connection to earth or the electrode system, needs to have sufficiently low resistance to help permit prompt operation of the circuit protective devices in the event of a ground fault, to provide the required safety from shock to personnel, and protect the equipment from voltage gradients that may damage the equipment.

7.1.1 Understanding isolated ground

Isolated grounding is a loosely defined technique that attempts to reduce the chances of electrical noise entering the sensitive equipment through the equipment grounding conductor. The exact methods used in isolated ground wiring vary somewhat from case to case, and there is no defined standard method.

In a typical branch circuit, the grounding conductor of the equipment is connected to the metallic outlet box through the connection of the grounding conductor screw to the mounting strap, as well as to the green grounding conductor for that circuit. It is then further connected to the metallic panel board enclosure where the branch circuit originated. There, it can pick up noise from adjacent circuits sharing the panel board.

7.1.2 Exterior ground ring

A buried exterior ground ring is a technique to help achieve low impedance from the building's grounding system to the earth itself, and a convenient means to connect various grounds leading from the building.

Usage of multiple rods with a ground ring is advisable to ensure low resistance to ground (10 ohms or less is desirable, even less for certain sensitive applications, such as telecommunications facilities).

7.2 Understanding wiring solutions: Separation of sensitive electronic loads from other equipment

A dedicated "computer" circuit in each office is a good idea, at least back to the branch circuit panel. A better idea, and required in some cases, is to power sensitive equipment from separate branch circuits emanating from separate panel boards, fed from separate feeders back to the main service entrance.

The neutrals and grounding conductors need to be kept separate also. A dedicated circuit means separate phase wires, a separate neutral, with a separate grounding conductor, run in its own separate metal conduit, back to the source.

Avoid having sensitive equipment on the same circuits, or even panel boards, as motor loads. Such equipment as laser printers, copying machines and fax machines should be kept separate from computers.

For better understanding on wiring and grounding solutions, the IEC standards to be referred are: -

IEC document	Description
IEC 60364-1	Electrical installations of buildings – Part 1: Scope, object and fundamental principles
IEC 60364-4-41	Electrical installations of buildings – Part 4-41: Protection for safety- Protection against electric shock
IEC 60364-4-43	Electrical installations of buildings – Part 4-43: Protection for safety – Protection against overcurrent.
IEC 60364-4-44	Electrical installations of buildings – Part 4-44: Protection for safety – Protection against electromagnetic and voltage disturbances.
IEC 60364-5-53	Electrical installations of buildings – Part 5-53: Selection & erection of electrical equipment – Isolation, switching and control.
IEC 60364-5-54	Electrical installations of buildings – Part 5-54: Selection & erection of electrical equipment – Earthing arrangement

7.3 General power quality improvement equipment for customer

There is a variety of mitigating equipment available for improving the quality of electric power for the sensitive loads. They range from those that are inexpensive and provide little protection to those that protect against almost all eventualities at a much higher price. The **typical** power disturbances and types of protection equipment advisable to be used for customers' installations are shown in Table 7.

Table 7: Typical Power Disturbances and General Protection Equipment for customer (Low Voltage)

Type of disturbances	Impact	Protection Equipment
Voltage sag is a momentary decrease in voltage outside the normal tolerance. Voltage sags are caused by lightning, power system faults and starting of heavy loads.	Incorrect operation of power-down sensing circuitry in computers and controls. Equipment shutdown and damaged.	Install power conditioner at the control circuit (Secondary Equipment AC or DC) • Dip Proofing Inverter (DPI) • Voltage Dip Compensator (VDC) • Constant Voltage Transformer (CVT) • Dynamic Sag Corrector (DySC) • Dynamic Compensator (Dynacom) • Etc Install low voltage 3-phase power conditioners at the incoming feeders of the sensitive areas • Dynamic Sag Corrector (DySC) • Dynamic Compensator (Dynacom) • Active Volt Conditioner • Flywheel UPS • Etc Install medium voltage 3-phase power conditioners at the incoming of the plants:

		• Dynamic Voltage Restorer (DVR) • Etc
Voltage swell is a momentary increase in voltage outside normal tolerance. Swells are caused by sudden decrease or turn-off of heavy loads.	Damage to equipment by breaking down insulation.	Voltage regulators, motor-generator set, Flywheel, LV DVR, UPS, etc.
Electrical noise is a distortion of normal sine wave power. Noise can be caused by poor contacts in wiring and switchgear, improper grounding and radio equipment.	Incorrect operation of microprocessor-based equipment	Isolation transformer, etc
Impulses (also known as spikes and surges) are short duration voltage increase. Impulses are caused by lightning, power system faults and switching of heavy loads.	Damage to electronic equipment. Insulation breakdown in transformer and motor loads.	Transient voltage Surge Suppressors (TVSS), Surge Protective Device (SPD), etc
An outage is a total loss of power. It may be caused by power system faults, accidents involving power lines.	Equipment shutdown	Flywheel UPS etc.
Harmonic distortion is a periodic deviation from the true sine wave and it may be caused by arc furnaces, gas discharge lighting, power converters etc.	Overheating of motor loads, incorrect operation of relays and insulation breakdown.	Harmonic Filter, etc.

Under voltage or over voltage are conditions of abnormally high or low voltage persisting for more than a few seconds. They are caused by poor voltage regulation, circuit overloads etc.	Damage and shutdown of equipment depending on their tolerance to abnormal voltage.	Voltage regulator, motor generator set or UPS.

Section 8 Solutions to voltage sags

In the blink of an eye, a voltage sag can bring production to a halt. Fortunately, there are ways to prevent sags from disrupting operations. To the human eye, sags can cause the lights to dim. To automation equipment, sags can mean shutdown of equipment, loss of data and unexplained resets. Over time, sags can stress components, resulting in premature wear and failure.

For processes that rely on high speed, any interruption can lead to significant production shortages. For processes that take hours to create one part, or a single batch of parts, process interruptions have a significant impact on company profits. Shutdowns result in scrapped work in process, production shortages, reduced service levels to customers and less income for the company.

Many manufacturing and process industries need to focus on ensuring full protection against voltage sag to maintain maximum competitiveness, productivity and quality. The Semiconductor Equipment and Materials Institute (**SEMI, www.semi.org**) has gone so far as to establish a minimum standard with regard to sag immunity performance for semiconductor tools and equipment. SEMI F47 introduced a well thought out voltage-to-time curve that most equipment will be exposed to during normal operation. In addition, a specific method of test and reporting has been developed.

The MS IEC 61000-4-11 and MS IEC 61000-4-34 also promotes minimum voltage sag immunity requirement. These standards also specify the requirement for the sag generator and testing methodology.

The previous sections of this guidebook identified some of the electrical disturbances that can occur on a power distribution system and how they can affect an industrial facility. The adverse effects of these disturbances can be mitigated by installing power-conditioning equipment or by utilizing different wiring or power-distribution methods.

As with most system enhancements, the cost of the solution must be evaluated against the losses associated with the disturbance. This section will identify the most common solutions, when to apply them, and the approximate cost of applying them.

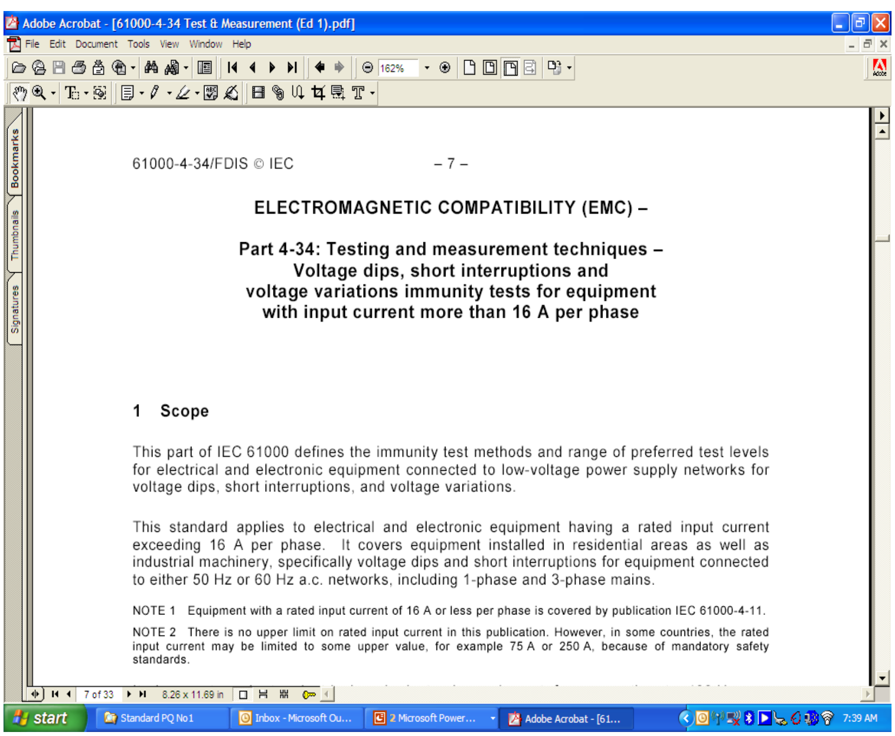
8.1 Equipment procurement specifications

Generally, the least expensive approach is to purchase controls and other electronic equipment designed with the minimum immunity requirement mentioned above.

Improvement of equipment immunity is probably the most effective solution against equipment trips due to voltage sags. But it is often not suitable as a short time solution.

A customer often only finds out about equipment immunity after the equipment has been installed. For customer electronics, it is very hard for a customer to find out about immunity of the equipment, as he is not in direct contact with the manufacturer. Even most adjustable-speed drives have become off the shelf equipment where customer has no influence on the specifications. Only large industrial equipment is custom-made for a certain application, which enables the incorporation of voltage tolerance requirements.

The very best way to insure that a machine meets the above requirements for voltage sag ride through is to include the requirement in the purchase contract terms and to demand proof of compliance.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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-34: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase

1 Scope

This part of IEC 61000 defines the immunity test methods and range of preferred test levels for electrical and electronic equipment connected to low-voltage power supply networks for voltage dips, short interruptions, and voltage variations.

This standard applies to electrical and electronic equipment having a rated input current exceeding 16 A per phase. It covers equipment installed in residential areas as well as industrial machinery, specifically voltage dips and short interruptions for equipment connected to either 50 Hz or 60 Hz a.c. networks, including 1-phase and 3-phase mains.

NOTE 1 Equipment with a rated input current of 16 A or less per phase is covered by publication IEC 61000-4-11.

NOTE 2 There is no upper limit on rated input current in this publication. However, in some countries, the rated input current may be limited to some upper value, for example 75 A or 250 A, because of mandatory safety standards.

Figure 24:

Power quality requirement in new equipment specification

Therefore, the best solution is to keep problem equipment out of the plant through equipment procurement specifications. Equipment manufacturers should design equipment with ride through capability curves available.

8.2 Voltage sag solutions for existing industrial plant

The first step to improve the immunity of any industrial plant is to identify which process in the plant is sensitive to voltage sags. Secondly, we must understand the product manufacturing process and the equipment operation related to the process.

Next, identify which components are critical to the related machine operation and would be adversely affected by voltage sag. Most motors, lighting and indicators can tolerate short-duration sag with negligible detriment to production.

The most critical and normally sag-sensitive component is normally the AC-DC power supply used to power all dc control and logic circuits. A majority of power supply modules currently available on the market average 10 to 20 ms of hold-up time at full load. These devices will not meet the sag immunity performance needed to work during common sag events without special considerations taken by the system designer.

The immediate action plan that we can consider is to protect the control and logic circuits from voltage sags. There are a few methods available to protect these circuitries. By implementing these methods the control circuitries will be protected against voltage sags but not the primary equipment they are controlling.

For chillers and compressors, by protecting their control circuitries only, the motors will be experiencing a reduction in speed during a voltage sag event. The plant engineer must understand the impact of the motors slowing down. The production process in the plant must not be affected by the reduction of the motor speeds.

The other thing to consider is the impact of the voltage sags to the primary equipment, for example motors, etc. The protected control circuitry will ensure the primary equipment is still connected and exposed to the short duration voltage sags. Does this affect the motors in the long run?

Therefore, to ensure a successful voltage sag solution for existing industrial plants, a detailed discussion must be done with the plant engineer and equipment supplier before implementing the voltage sag immunity solutions.

8.2.1 Immunity solutions for control and logic circuits

One option is to use a universal input power supply (85-264 Volt) and power from the higher line voltage (208/240 Volt). This, of course, only meets the needed level of performance when powered from the higher line voltage. Another would be to de-rate the power supply to a lower output current in the hope that it will perform better when exposed to input sags. The preferred method is to use a power supply that meets the standard at full power and all voltage ranges.

8.2.1.1 Semi F47 compliance power source

Another simple method is to use a SEMI F47 compliance power supply to power the control circuit.

Figure 25:

Example for a SEMI F47 compliance power supply

8.2.1.2 Change the trip setting for control circuit

Another inexpensive and simple solution is to adjust the trip thresholds of sensitive equipment. If a relay that is frequently tripping during a voltage sag, try to change its settings—either the **voltage threshold** or the **trip delay**.

However, this measure can be done if only the original trip settings were set too conservative, so it is important to understand what they were designed to protect.

If an unbalance relay, an under voltage relay, or an internal reset or protection circuit that is inadvertently tripping during a voltage sag, first try to change its settings.

Consider changing the voltage threshold, and consider changing the trip delay, either or both to slow it down. Sometimes this can be as simple as twisting a knob; sometimes it may take a component change or firmware adjustment.

It is important to note that this simple solution can be implemented if the trip settings were set too conservatively to begin with; trips are useful and important, so we do not want to eliminate them completely. Always refer to the equipment manufacturer before changing the relay settings.

Figure 26:

Changing the Voltage threshold and time delay

8.2.1.3 Installing a coil hold-in device

Another option is to install a coil hold-in device. These devices are designed to mitigate the effects of voltage sags on individual relays and contactors. Coil hold-in devices are installed between the relay or contactor coil connection terminals and the incoming alternating current (ac) control line. They allow a relay or contactor to remain engaged until the voltage drops to about 25 % of nominal, significantly improving its voltage sag tolerance without interfering with emergency shutoff functions. The best application for this type of device is to support relays and contactors in an emergency off (EMO) circuit, master control relay, or motor control circuit.

Figure 27: A coil hold-in device

During a voltage sag, this device maintains a current flow through the coil that is sufficient to hold in the contacts closed. The circuit is designed to provide current to hold in the coil for sags down to 15-25% voltage. It is not designed to hold in the coil for cases where the voltage goes below 15%.

This allows "emergency stop" circuits to act correctly and will prevent any problems with out-of-phase conditions following an interruption.

8.2.2 Auto restart schemes

Reprogramming an Adjustable Speed Drive (ASD) response to a voltage sag may be an option if the process requirements will allow deviations in the speed and torque of the motor. If the application does not require an operator to restart the process, the ASD may be able to be reprogrammed to provide a non-synchronous time-delay restart. Once the motor coasts down to zero speed, this feature will restart the motor after a user-defined time delay.

Figure 28:

Adjustable Speed Drive (ASD)

Another programming option is to reduce the dc bus under voltage trip point. Some processes require precise speed and torque regulation. Because the torque and speed vary when the dc bus reaches the under voltage trip point, some drive manufacturers offer software revisions for existing drive applications that allow users of ac drives to lower the dc bus under voltage trip point. By lowering the trip point, drives and processes can ride through longer and deeper voltage sags without interrupting production. Often, the software revisions are not part of the standard drive control software and must be requested from the manufacturer. The drawback to this approach is that rectifiers and fuses may be damaged due to high inrush current and over current conditions. The current increases as the dc bus under voltage trip point decreases. These conditions should be considered when lowering the under voltage trip point.

8.3 Single phase power conditioner for voltage sag mitigation

Another method employed to protect against short-term power sags is to use power-conditioning devices to regulate and protect power. The alternative to adding these mitigating devices to the production equipment is to purchase and develop equipment designed to tolerate sags. This proactive approach takes more planning, but results in lower overall system costs [16].

To ride through a voltage sag event, the load will need some kind of system that can react within about ½ cycle and provide near-normal power for a few seconds until the voltage is fully restored. This requires either a source of stored energy at the site or an alternate source of energy. These devices must either be capable of being switched very quickly or be always on-line.

To achieve this condition, one needs to install some form of a power-conditioning device. These solutions increase in cost with the size and scope of the equipment or circuits being protected. The locations to install the power conditioner will also highlight the coverage areas of protection against voltage sags.

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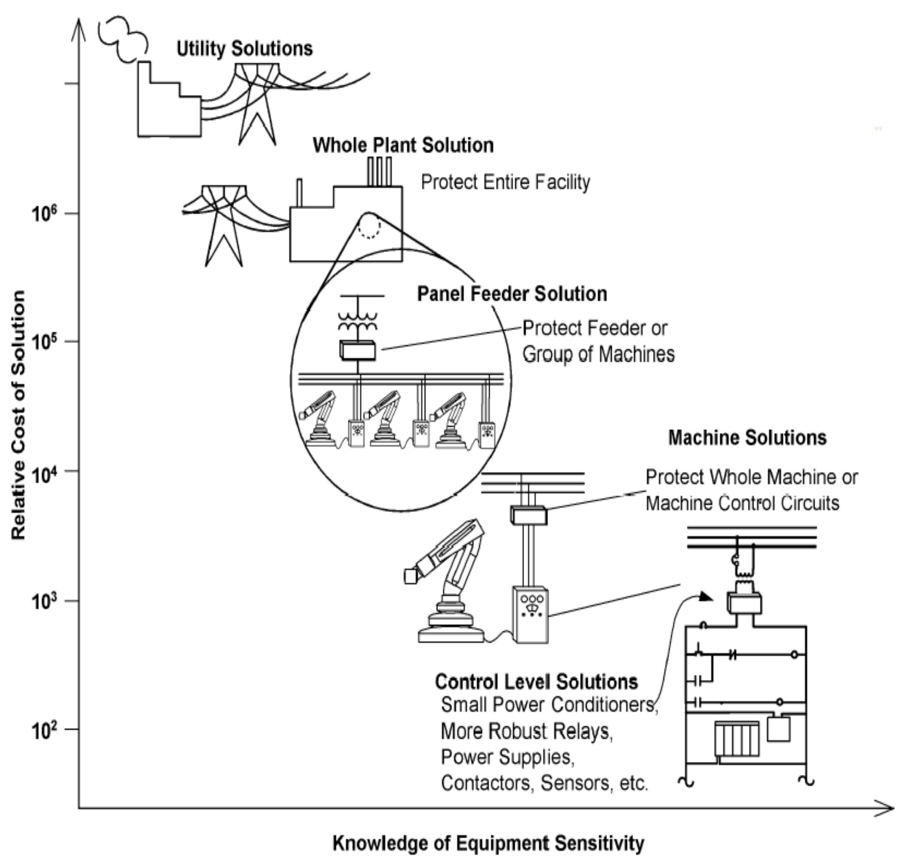
Figure 29:

Locations for Power Conditioners



8.3.1 Single-phase power conditioners for control level protection

8.3.1.1 Uninterruptible Power Supply (UPS)

Installing an uninterruptible power supply, on a PC, PLC or controls to switch to battery during a voltage sag or an interruption will minimize process interruption. The down side to this approach is the battery. Batteries have the following disadvantages: a) generates hydrogen gas, must be ventilated, b) battery lead is a hazardous waste, and c) battery life is limited and decreases rapidly when cycled often. An advantage is that the UPS will ride through not only sags, but also momentary and extended interruptions up to the limit of the battery capacity, maybe 5 to 10 minutes. For a full on-line UPS, the cost doubles but you add the benefit of filtering out all disturbances.

A UPS can be installed off-line, which is cheaper, or on-line, which doubles the cost but adds the ability to filter out all types of voltage disturbances, including spikes and harmonic distortions.

Figure 30: Uninterruptible Power Supply (UPS)

8.3.1.2 Constant Voltage Transformer (CVT)

Most voltage-sag solutions can be handled by ferroresonant transformers. These power conditioners are also known as constant-voltage transformers (CVTs). CVTs are ideally suited for constant, low-power loads. Unlike conventional transformers, the CVT allows the core to become saturated with magnetic flux, which maintains a relatively constant output voltage during input voltage variations such as under voltages, over voltages, and harmonic distortion.

Installing a ferroresonant (constant voltage transformer-CVT) transformer on PC, PLC or controls will provide sag ride through capability. They also provide filtering of transients. CVT will not ride through a momentary or sustained interruption. They have no moving parts, no battery and are very reliable. Another consideration when sizing a CVT is the load characteristic. A CVT must be sized for the maximum load. When the transformer is overloaded, the voltage will decrease and collapse to zero at approximately 150% of loading. Therefore, if the load profile includes an inrush current or a starting motor, the transformer must be sized for this transient load, not the steady-state load. CVTs provide voltage sag ride-through of 25 % for 1 second and also filter spikes, but they are not able to protect against interruptions, either momentary or sustained. CVTs are often used for relatively constant, low-power loads, and have the advantage of lower operating and maintenance costs than UPSs, because CVTs do not require batteries.

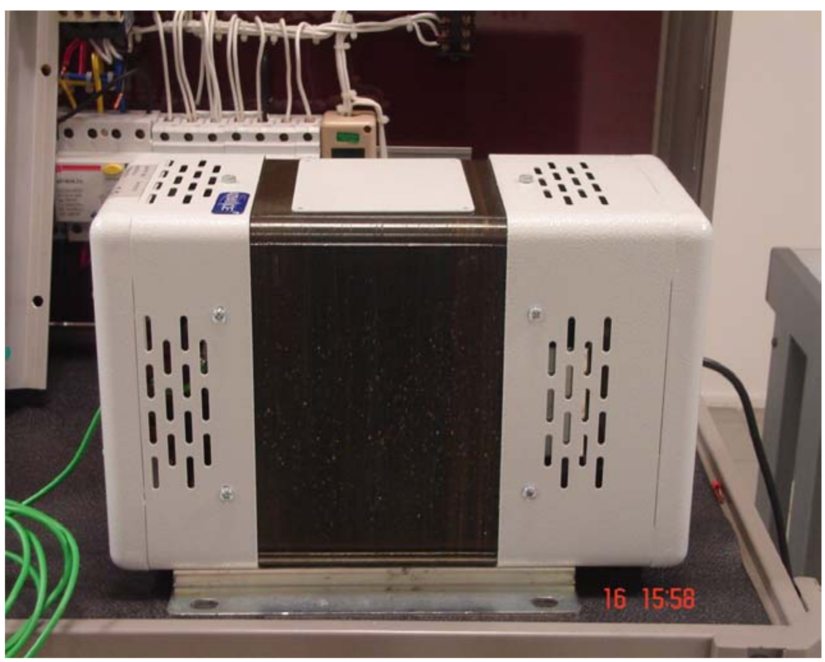


Figure 31:

Constant Voltage Transformer

8.3.1.3 Dip Proofing Inverters

For an individual computer, process control circuits or a group of machines, another simple solution is to install a Dip Proofing Inverter (DPI), which can ride through a voltage sag event down to 0 % of nominal voltage for up to 3.1 seconds.

Figure 32: Dip Proofing Inverters (DPI)

8.3.1.4 Voltage Dip Compensator (VDC)

A Voltage Dip Compensator (VDC), which can ride through a sag down to 37 % of nominal voltage for up to 3.1 seconds can also be used to protect single phase equipment and control circuits.

Figure 33: Voltage Dip Compensator (VDC)

8.3.1.5 Dynamic Compensator (Dynacom)

DynaCom is a low voltage dynamic voltage compensator designed to mitigate voltage sags by injecting a compensating voltage directly into the power supply.

Under normal system operating conditions, Dynacom allows system voltage to pass through with high efficiency. In the event of a voltage sag, Dynacom produces a compensating voltage of an appropriate magnitude and duration to “fill in” the sag, thus reproducing the original voltage waveform. The direct injection technique used in Dynacom provides accurate and efficient voltage compensation.

The Dynacom can correct input voltage to as low as 40 % of nominal voltage up to 1 second.

Figure 34: Dynamic Compensator (Dynacom)

8.3.1.6 Dynamic Sag Corrector (MiniDySC)

The *DySC* (pronounced ‘disk’), rated at 250VA to over 3,000 kVA specifically protects sensitive equipment and manufacturing processes from deep voltage sags and momentary interruptions, the most common power quality ‘events’.

The *DySC* can correct input voltage to as low as 0 % of nominal voltage for 50 ms and 50 % voltage for 2 seconds.

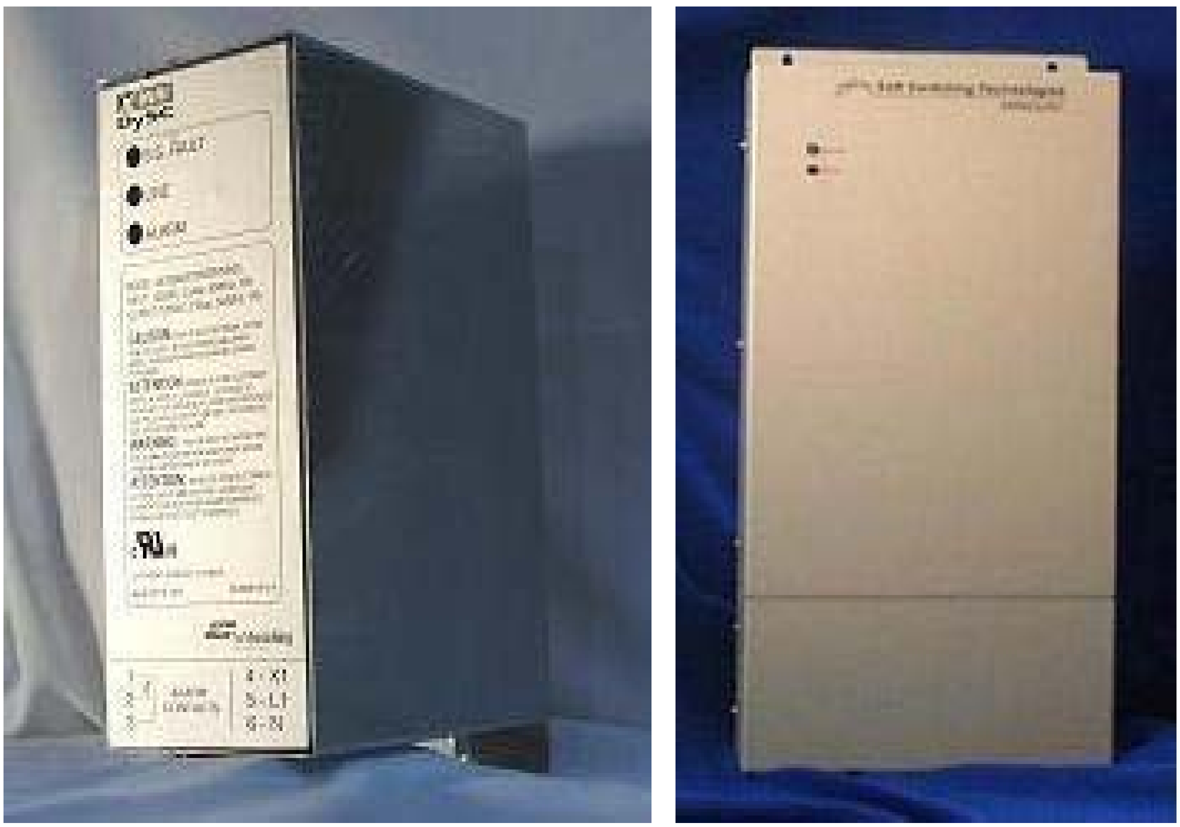


Figure 35: MiniDySc

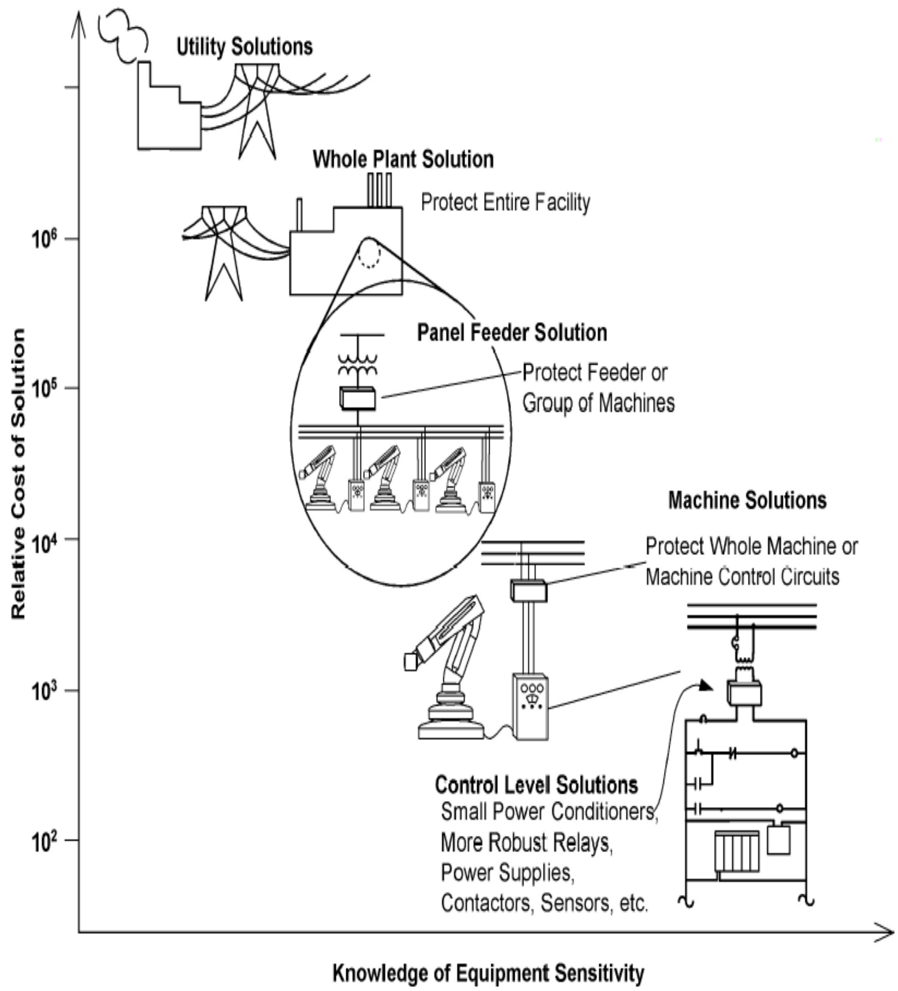
Section 9 Large scale solutions to voltage sags

In section 8 of this guideline, solutions related to the control level solutions were discussed. The solutions range from equipment specifications to the use of single phase power conditioners.

Other level of solutions to voltage sags, which are more comprehensive, are the panel feeder and whole plant solutions. These solutions increase in cost with the size and scope of the equipment or circuits being protected.

From Figure 29:

Locations for Power Conditioners



To achieve the large scale solutions for voltage sag requires the use of three-phase power conditioners [17]. Descriptions of a few three-phase power conditioners available in the market are described in the following pages.

9.1 Active Voltage Conditioner (AVC)

The Vectek Active Voltage Conditioner (AVC) is an inverter-based system that protects sensitive industrial and commercial loads from voltage disturbances. It provides fast, accurate voltage sag correction as well as continuous voltage regulation and load voltage compensation.

It has been optimally designed to provide the required equipment immunity from the level of voltage sags expected on the ac supply network. The AVC is available in load capacities of 20kVA - 10MVA and has an operating efficiency exceeding 98%. It offers extremely fast response to three-phase sags down to 50% (duration: 30 cycles), and single-phase sags down to 25% (duration: 12 seconds) on the ac supply network. Standard models are optimized for sag correction and for enhanced regulation allowing correction of voltage sags and surges, the AVC-R is available. All AVC models provide continuous regulation within –10% of the nominal mains voltage and can remove voltage unbalance from the supply. Optionally, models can be configured to remove flicker and harmonic voltages from the supply.

Figure 36: Active Voltage Conditioner

9.2 Datawave

The Datawave is a Magnetic Synthesizer that generates a stable output waveform to distribute to the sensitive electronic equipment. The self-contained system can be used to condition utility power, distribute it to sensitive electronics, and monitor power parameters. Systems are available with outputs ranging from 15 to 200 kVA.

This system available total power conditioning under the worst power conditions – maintaining consistent output quality even during - 40% under voltages and +40% over voltages for 1 second. Power conditioning, monitoring and flexible output distribution from a single factory tested unit. Handling of non-linear loads and high neutral current without over sizing.

The general specifications are:

Voltage Regulation: For input voltages of ± 40%, output voltage is within +5% for any load condition up to full load.

Single Phase Protection: For loss of one input phase, output voltages remain within 6% and –4% up to 60% load.

Figure 37: Datawave Magnetic Synthesizer

9.3 Flywheel UPS

A flywheel is a simple form of mechanical (kinetic) energy storage. Energy is stored by causing a disk or rotor to spin on its axis. Stored energy is proportional to the mass of the flywheel and the square of its rotational speed. Advances in power electronics, magnetic bearings, and flywheel materials coupled with innovative integration of components have resulted in direct current (DC) flywheel and increasing battery life.

A flywheel together with a motor-generator (M/G) set can immunize critical processes against all voltage sags. When a voltage sag occurs, the motor-generator set feeds the load, the energy being supplied by slowing down the flywheel. Different connection topologies of the flywheel to the M/G set exist of which Figure 38 shows the main components of a connection using power electronics.

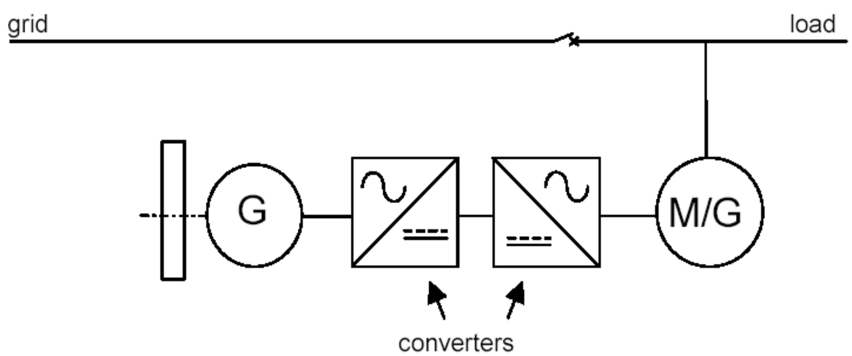


Figure 38: Flywheel UPS

9.4 Dynamic Voltage Restorer (DVR)

The PureWave DVR is designed for series connection in a medium voltage distribution line. It maintains the voltage applied to the load during sags and swells by injecting a voltage of compensating amplitude and phase angle into the line.

The PureWave DVR is a means to satisfy the stringent power quality demands of industrial and commercial customers. It also provides a means for energy users to isolate themselves from voltage sags, swells, and unexpected load changes originating on the transmission or distribution system.

The general specifications for the DVR are as follows:

Phase	Three Phase
Voltages	4.6 – 34.5 kV
Power	2-30 MVA
Ride Through Capability	50% for single phase fault for 1 second 50% for three phase fault for 333 ms

Figure 39: Dynamic Voltage Restorer

9.5 Three phase Dynamic Compensator (Dynacom)

Under normal system operating conditions, DynaCom allows system voltage to pass through with high efficiency. In the event of a voltage sag, DynaCom produces a compensating voltage of an appropriate magnitude and duration to "fill in" the sag, thus reproducing the original voltage waveform. The direct injection technique used in DynaCom provides accurate and efficient voltage compensation.

The specifications for the Dynacom are as follows:

Phase	Three Phase
Voltages	208-690 volts
Power	342 - 987 kVA
Ride Through Capability	40% for 1 second 0% for 60 ms

Figure 40: Three phase Dynacom

9.6 Dynamic Sag Corrector (ProDysc)

The second version of the Dynamic Sag Corrector is called the ProDysc.

The ProDysc is suitable to protect the entire equipment or the panel feeders depending on the loading capacity of the feeder.

The specifications for the ProDysc are as follows:

Phase	Three Phase
Voltages	208-480 volts
Power	10-164 kVA
Ride Through Capability	0% for 50 ms 50% for 2 second

Figure 41:

ProDysc

9.7 Dynamic Sag Corrector (MegaDysc)

The third version of the Dynamic Sag Corrector is called the MegaDysc.

The MegaDysc is suitable to protect whole panel feeders (process level) depending on the loading capacity of the feeder. The specifications for the ProDysc are as follows:

General Specifications

Phase	Three Phase
Voltages	480 volts
Currents	400-2400 Amps
Power	333 kVA- 2 MVA

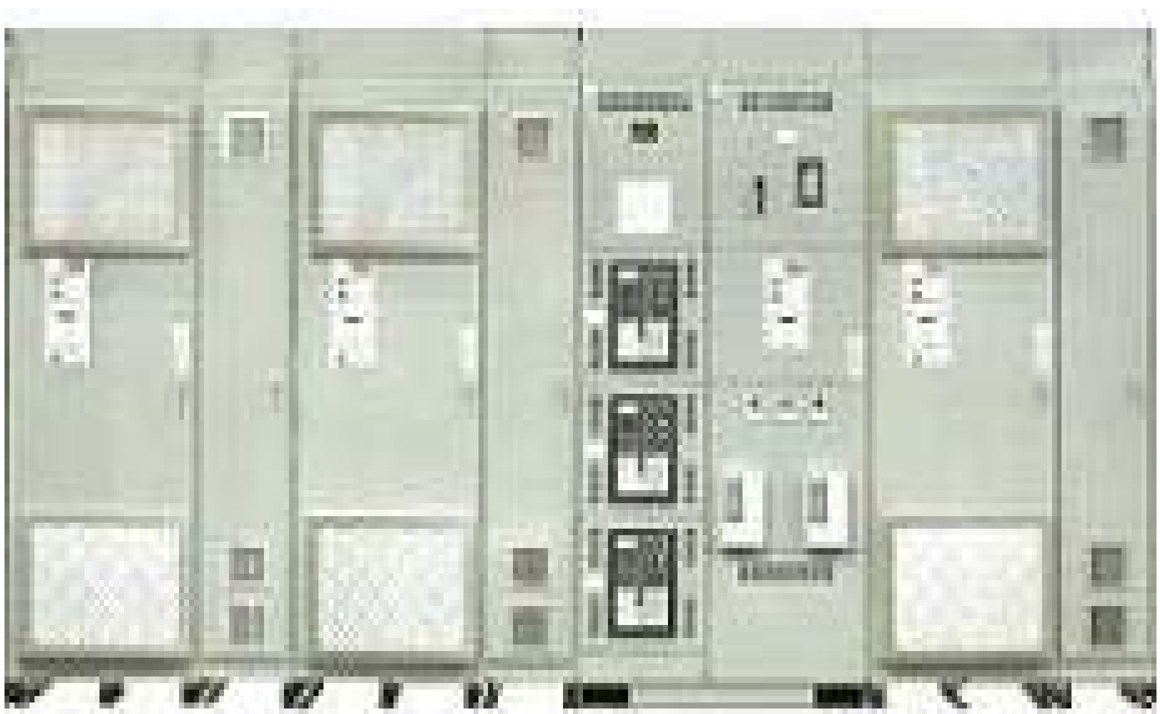


Figure 42: 1 MVA MegaDySc

References

[1] Information Technology Industry Council (ITIC), 1996

[2] Cahier technique no. 149. EMC: electromagnetic compatibility by Jacques DELABALLE, 2001

[3] IEEE 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, 1995

[4] IEC 61000-2-1 Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems

[5] MS IEC 61000-2-2: Compatibility levels for low frequency conducted disturbances and signaling in public low voltage power supply system.

[6] Power Quality Application Guide, Voltage Dips introduction, Copper Development Association, November 2001

[7] MS 1760: 2004 Guide on voltage dips and short interruptions on Public Electric Power Supply system

[8] Understanding Power Quality Problems (Voltage Sag and interruption), Math Bollen, IEEE Press, 2000

[9] Electrical Power Systems Quality, Roger C. Dugan, Mark McGranaghan, Wayne Beaty, McGraw Hill, 1996

[10] MS IEC 61000-2-4: Compatibility levels in industrial plants for low frequency conducted disturbances.

[11] Power Quality Handbook, Southern California Edison, Power Quality Department, California

[12] MS IEC 61000-2-12: Compatibility levels for low frequency conducted disturbances and signaling in medium voltage power supply system.

[13] SEMI F47-0706 Specification for Semiconductor Processing Equipment Voltage Sag Immunity

[14] MS IEC 61000-4-11 Testing and measurement techniques – voltage dips, short interruption and voltage variation immunity tests for equipment less than 16 A per phase

[15] MS IEC 61000-4-34 Testing and measurement techniques – voltage dips, short interruption and voltage variation immunity tests for equipment more than 16 A per phase

[16] Power Quality Application Guide, Voltage Dips Mitigation, Copper Development Association. November 2001

[17] Power Quality Primer, Barry W.Kennedy, McGraw Hill, 2000

Other related internet resources:

SEMI – www.semi.org

IEC – www.iec.ch

Power Standards Lab - www.powerstandards.com

Epri PEAC – www.epri.com

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