CHAPTER 2

Voltage sags and power quality

This chapter includes the study power quality, voltage sags characteristics, the causes and effects of voltage sags of electric and also tested with the international standard for testing immunity of electrical equipment.

2.1 Power Quality

The definition of power quality given in the IEEE dictionary originates in IEEE Std 1100. Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment. Despite this definition the term power quality is clearly used in a more general way within the IEEE: e.g., see [22] also covers standards on harmonic pollution caused by loads.

The following definition is given in IEC 61000-1-1: Electromagnetic compatibility is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Recently the IEC has also started a project group on power quality which should initially result in a standard on measurement of power quality. The following definition of power quality was adopted for describing the scope of the project group: Set of parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude and waveform).

Certainly, this definition will not stop the discussion about what power quality is. The author's impression is that it will only increase the confusion, e.g., because power quality is now suddenly limited to "normal operating conditions."

From many publications on this subject and the various terms used, the following terminology has been extracted. The reader should realize that there is no general consensus on the use of these terms.

- Voltage quality is concerned with deviations of the voltage from the ideal. The ideal voltage is a single-frequency sine wave of constant frequency and constant magnitude. The limitation of this term is that it only covers technical aspects, and that even within those technical aspects it neglects the current distortions. The term voltage quality is regularly used; especially in European publications. It can be interpreted as the quality of the product delivered by the utility to the customers.
- A complementary definition would be current quality. Current quality is concerned with deviations of the current from the ideal. The ideal current is again a single-frequency sine wave of constant frequency and magnitude. An additional requirement is that this sine wave is in phase with the supply voltage. Thus where voltage quality has to do with what the utility delivers to the consumer, current quality is concerned with what the consumer takes from the utility. Of course voltage and current are strongly related and if either voltage or current deviates from the ideal it is hard for the other to be ideal.
- Power quality is the combination of voltage quality and current quality. Thus power quality is concerned with deviations of voltage and/or current from the ideal. Note that power quality has nothing to do with deviations of the product of voltage and current (the power) from any ideal shape.
- Quality of supply or quality of power supply includes a technical part (voltage quality above) plus a nontechnical part sometimes referred to as "quality of service." The latter covers the interaction between the customer and the utility, e.g., the speed with which the utility reacts to complaints, or the transparency of the tariff structure. This could be a useful definition as long as one does not want

to include the customer’s responsibilities. The word “supply” clearly excludes active involvement of the customer.

- Quality of consumption would be the complementary term of quality of supply. This would contain the current quality plus, e.g., how accurate the customer is in paying the electricity bill.
- In the IEC standards the term electromagnetic compatibility (EMC) is used. Electromagnetic compatibility has to do with mutual interaction between equipment and with interaction between equipment and supply. Within electromagnetic compatibility, two important terms are used: the “emission” is the electromagnetic pollution produced by a device; the “immunity” is the device’s ability to withstand electromagnetic pollution. Emission is related to the term current quality, immunity to the term voltage quality. Based on this term, a growing set of standards is being developed by the IEC.

The power quality is concerned with deviations of the voltage from its ideal waveform (voltage quality) and deviations of the current from its ideal waveform (current quality). Such a deviation is called a “power quality phenomenon” or a “power quality disturbance.” Power quality phenomena can be divided into two types, which need to be treated in a different way.

- A characteristic of voltage or current (e.g., frequency or power factor) is never exactly equal to its nominal or desired value. The small deviations from the nominal or desired value are called “voltage variations” or “current varia¬tions.” A property of any variation is that it has a value at any moment in time: e.g., the frequency is never exactly equal to 50 Hz or 60 Hz; the power factor is never exactly unity. Monitoring of a variation thus has to take place continuously.
- Occasionally the voltage or current deviates significantly from its normal or ideal waveshape. These sudden deviations are called “events.” Examples are a sudden drop to zero of the voltage due to the operation of a circuit breaker (a voltage event), and a heavily distorted overcurrent due to switching of a non- loaded transformer (a current event). Monitoring of events takes place by using a

triggering mechanism where recording of voltage and/or current starts the moment a threshold is exceeded.

2.2 Voltage and Current variations

Voltage and current variations are relatively small deviations of voltage or current characteristics around their nominal or ideal values. The two basic examples are voltage magnitude and frequency. On average, voltage magnitude and voltage frequency are equal to their nominal value, but they are never exactly equal. To describe the deviations in a statistical way, the probability density or probability distribution function should be used. Figure 2.l shown a fictitious variation of the voltage magnitude as a function of time. This figure is the result of a so-called Monte Carlo simulation. The underlying distribution was a normal distribution with an expected value of 230 V and a standard deviation of 11.9 V. A set of independent samples from this distribution is filtered by a low-pass filter to prevent too large short-time changes. The probability density function of the voltage magnitude is shown in Figure 2.2.

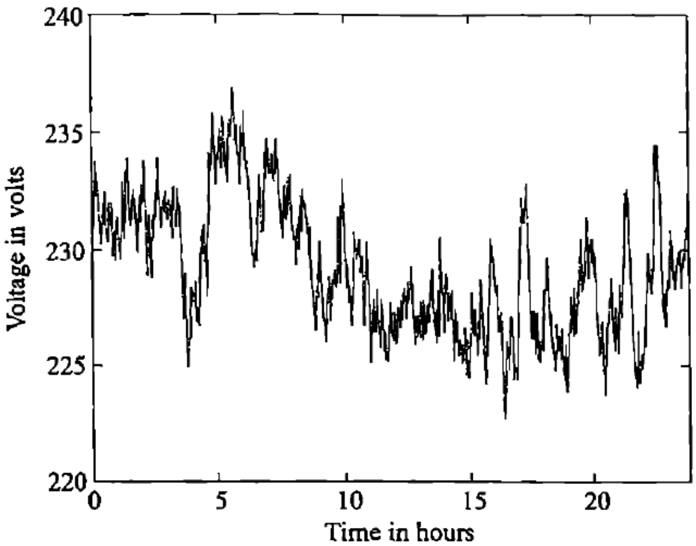


Figure 2.1 Simulated voltage magnitude as a function of time.[2]

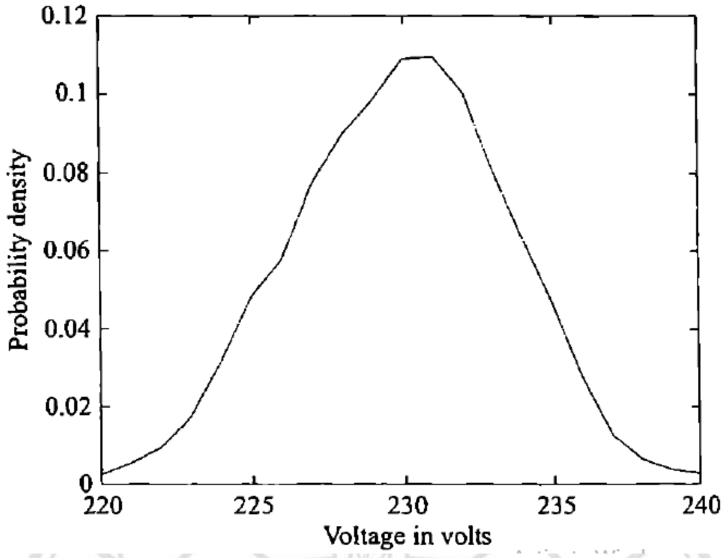


Figure 2.2 Probability density function of the voltage magnitude in Figure 2.1

An overview of voltage and current variations is given below. This list is certainly not complete, it merely aims at giving some example. There is an enormous range in end-user equipment, many with special requirements and special problems. In the power quality field new types of variations and events appear regularly. The following list uses neither the terms used by the IEC nor the terms recommended by the IEEE. Terms commonly used do not always fully describe a phenomenon. Also is there still some inconsistency between different documents about which terms should be used.

2.2.1 Voltage magnitude variation. Increase and decrease of the voltage magnitude, due to

- Variation of the total load of a distribution system or part of it;
- Actions of transformer tap-changer;
- Switching of capacitor banks reactors.

2.2.2 Voltage frequency variation. Like the magnitude, also the frequency of supply voltage is not constant. Voltage frequency variation is due to unbalance between load and generation.

2.2.3 Voltage and current unbalance. Unbalance, or three phase unbalance, in which the rms values of the voltages or the phase angle between consecutive phases are not equal.

2.2.4 Voltage fluctuation. If the voltage magnitude varies, the power flow to equipment will normally also vary. If the variations are large enough or in a certain critical frequency range, the performance of equipment can be affected. Cases in which voltage variation affects load behavior are rare, with the exception of lighting load. If the illumination of a lamp varies with frequencies between about 1 Hz and 10 Hz, our eyes are very sensitive to it and above a certain magnitude the resulting light flicker can become rather disturbing. It is this sensitivity of the human eye which explains the interest in this phenomenon. The fast variation in voltage magnitude is called "voltage fluctuation," the visual phenomenon as perceived by our brain is called "light flicker." The term "voltage flicker" is confusing but sometimes used as a shortening for "voltage fluctuation leading to light flicker."

2.3 Harmonic voltage distortion.

The voltage waveform is never exactly a single-frequency sine wave. This phenomenon is called "harmonic voltage distortion" or simply "voltage distortion." When we assume a waveform to be periodic, it can be described as a sum of sine waves with frequencies being multiples of the fundamental frequency. The nonfundamental components are called "harmonic distortion."

There are three contributions to the harmonic voltage distortion:

- The voltage generated by a synchronous machine is not exactly sinusoidal due to small deviations from the ideal shape of the machine. This is a small contribution; assuming the generated voltage to be sinusoidal is a very good approximation.
- The power system transporting the electrical energy from the generator stations to the loads is not completely linear, although the deviation is small. Some components in the system draw a nonsinusoidal current, even for a sinusoidal voltage. The classical example is the power transformer, where the nonlinearity is due to saturation of the magnetic flux in the iron core of the transformer. A

more recent example of a nonlinear power system component is the HVDC link. The transformation from ac to dc and back takes place by using power-electronics components which only conduct during part of a cycle.

The amount of harmonic distortion originating in the power system is normally small. The increasing use of power electronics for control of power flow and voltage (flexible ac transmission systems or FACTS) carries the risk of increasing the amount of harmonic distortion originating in the power system. The same technology also offers the possibility of removing a large part of the harmonic distortion originating elsewhere in the system or in the load.

- The main contribution to harmonic voltage distortion is due to nonlinear load. A growing part of the load is fed through power-electronics converters drawing a nonsinusoidal current. The harmonic current components cause harmonic voltage components, and thus a nonsinusoidal voltage, in the system.

The voltage waveform is never exactly a single frequency sine wave. This phenomenon is called "harmonics voltage distortion", it can be describes as a sum of sine waves with frequencies being multiples of the fundamental frequency.

2.4 Voltage sags and definition of voltage sags

Voltage disturbances can occur anywhere in the power system and within an electric customer's facility. Voltage sags is one of the power quality problems affecting industry. It is a momentary disturbance that can cause a failure to electrical equipment operation. Among various types of power quality disturbances in a power system, voltage sags are particularly troublesome since they occur rather randomly and their characteristics are difficult to predict.

The definition of voltage sags is often set based on two parameter, magnitude or depth and duration [Figure 2.3]. However, these parameter are interrupted differently by various sources. Other important parameters that describe voltage sags are:

1) The point-on-wave where the voltage sags occurs, and

2) How the phase angle changes during the voltage sag. A phase angle jump during a fault is due to the change of the X/R-ratio. The phase angle jump is a problem especially for power electronics using phase zero-crossing switching.

The voltage sags as defined by IEEE Standard 1159 [Figure 2.4], IEEE Recommended Practice for monitoring Electric Power Quality, is “a decrease in RMS Voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage”. Typical values are between 0.1 p.u. and 0.9 p.u., and typical fault clearing times range from three to thirty cycles depending on fault current magnitude and the type of over current detection and interruption.

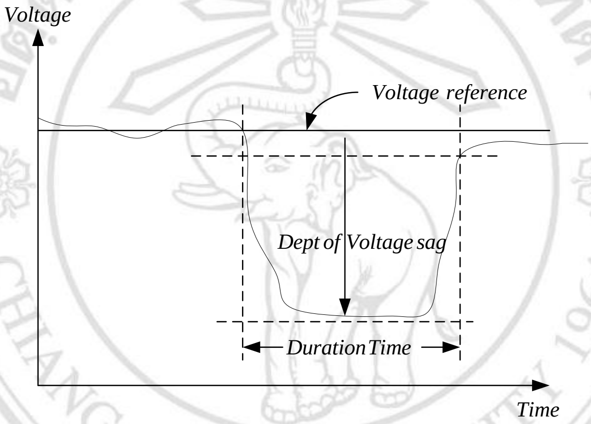


Figure 2.3 Voltage sag definition in term of its parameters

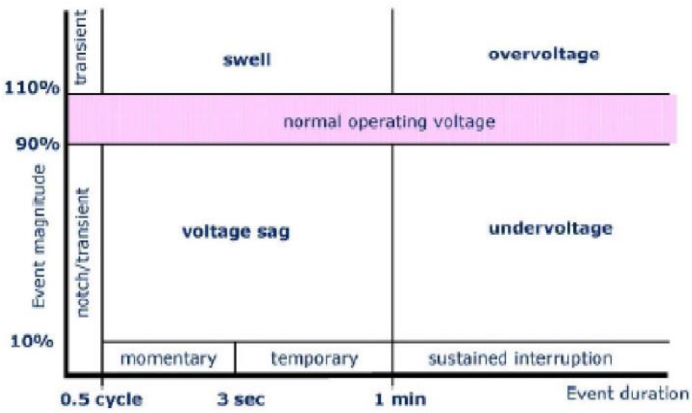


Figure 2.4 Voltage sag definition based on IEEE Standard

Figure 2.5 shown the Information Technology Industry Council (ITIC) curve that has been introduced to suggest a guideline for voltage quality in power distribution systems serving main computers, and it has become an industry reference for acceptable voltage tolerance. This curve specifies the voltage dip magnitude and the duration of the voltage sag for 120 V single-phase applications.

The curve shows that a 10% voltage deviation is acceptable even if the voltage sag or swell remains for a long time, but a 30% voltage drop for a time period longer than 0.5 second is not acceptable. This curve is useful for providing general insight into acceptable voltage quality. The SEMI F47 specifies the requirement of voltage quality for the voltage sag immunity of semiconductor manufacturing processing.

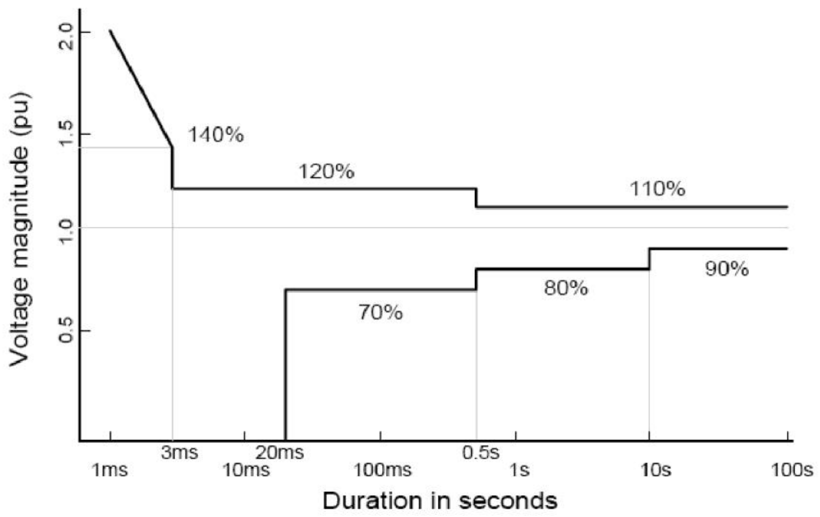


Figure 2.5 Information Technology Industry Council (ITIC) curves

2.5 Cause of voltage sags

Disruptive voltage sags are usually caused by fault conditions on the utility transmission and distribution systems or within a customer’s facility. Voltage sags are generally created on the electric system when faults occur due to lightning, accidental shorting of the phases by trees, animals, birds, human error such as digging underground lines or automobiles hitting electric poles, and failure of electrical equipment.

In the case of a short-circuit fault, the utility system would detect the resulting over-current, and perform a feeder breaker trip for disconnecting the downstream loads from the system, followed, if it is possible, by a re-closure operation for clearing the fault and therefore maintain the service continuity of the electric supply for the majority of its customers.

Faults in the distribution or transmission line can be classified as single-line- to-ground (SLG), and line-to-line (L-L) faults. SLG faults often result from severe weather conditions such as lightning, ice, and wind. Animal or human activity such as construction or accidents also causes SLG faults. Lightning may cause flashover across conductor insulators and is the major source of SLG faults,

Sags also may be produced when large motor loads are started, or due to operation of certain types of electrical equipment such as welders, arc furnaces and smelters. Motors starting within the customer facilities can also result in voltage sags for neighborhood customers. The characteristics of these voltage sags are predictable and can be prevented.

The duration of the sag caused by motor starting is generally longer, but the voltage drops are usually small and do not cause serious problems at the customer locations. In case of starting large motors, the voltage sags are usually shallow and last a relatively long time.

2.6 Equipment sensitive to voltage sags.

In this research will discuss three types of equipment which are perceived as most sensitive to voltage sags.

- Computers, consumer electronics, and process-control equipment which will be modeled as a single-phase diode rectifier. Under voltage at the dc bus is the main cause of tripping.
- Adjustable-speed ac drives which are normally fed through a three-phase rectifier. Apart from the under voltage at the dc bus, current unbalance, dc voltage ripple, and motor speed are discussed.

- Adjustable-speed dc drives which are fed through a three-phase controlled rectifier. The firing-angle control will cause additional problems due to phase-angle jumps. Also the effect of the separate supply to the field winding is discussed.

This chapter closes with a brief discussion of other equipment sensitive to voltage sags: induction and synchronous motors, contactors, and lighting.

2.6.1 Adjustable-speed drives

Many adjustable-speed drives are equally sensitive to voltage sags as process control equipment discussed in the previous section. Tripping of adjustable-speed drives can occur due to several phenomena:

- The drive controller or protection will detect the sudden change in operating conditions and trip the drive to prevent damage to the power electronic components.
- The voltage drop in dc bus which results from the sag will cause mal operation or tripping of the drive controller or of the PWM inverter.
- The increased ac currents during the sag or the post-sag over currents charging the dc capacitor will cause an overcurrent trip or blowing of fuses protecting the power electronics components.
- The process driven by the motor will not be able to tolerate the drop in speed or the torque variations due to the sag.

After a trip some drives restart immediately when the voltage comes back; some restart after a certain delay time and others only after a manual restart. The various automatic restart options are only relevant when the process tolerates a certain level of speed and torque variations. In the rest of this section, we will first look at the results of equipment testing. This will give an impression of the voltage tolerance of drives. The effect of the voltage sag on the dc bus voltage, the main cause of equipment tripping, will be discussed next. Requirements for the size of the dc bus capacitor will be formulated. The effect of the voltage sag on the ac current and on the motor terminal voltage will also be discussed, as well as some aspects of automatic restart. Finally, a short overview of mitigation methods will be given.

2.6.2 Operation of AC Drives

Adjustable-speed drives (ASD's) are fed either through a three-phase diode rectifier, or through a three-phase controlled rectifier. Generally speaking, the first type is found in ac motor drives, the second in dc drives and in large ac drives. We will discuss small and medium size ac drives fed through a three-phase diode rectifier in this section, and dc drives fed through controlled rectifiers in the next section.

The three ac voltages are fed to a three-phase diode rectifier. The output voltage of the rectifier is smoothened by means of a capacitor connected to the dc bus. The inductance present in some drives aims at smoothening the dc link current and so reducing the harmonic distortion in the current taken from the supply.

The dc voltage is inverted to an ac voltage of variable frequency and magnitude, by means of a so-called voltage-source converter (VSC). The most commonly used method for this is pulse-width modulation (PWM). Pulse-width modulation will be discussed briefly when we describe the effect of voltage sags on the motor terminal voltages.

The motor speed is controlled through the magnitude and frequency of the output voltage of the VSC. For ac motors, the rotational speed is mainly determined by the frequency of the stator voltages. Thus, by changing the frequency an easy method of speed control is obtained. The frequency and magnitude of the stator voltage are plotted in Figure 5.13 as a function of the rotor speed. For speeds up to the nominal speed, both frequency and magnitude are proportional to the rotational speed.

2.7 Characterization of voltage sags

Voltage sags are characterized by its magnitude and duration as shown in Figure 2.6 The magnitude is defined as the percentage of the remaining voltage during the sag and the duration is defined as the time between the sag commencement and clearing. This characterization is fine for single phase systems and three-phase balanced faults.

However for three-phase unbalanced sags, the three individual phases would be affected differently leading to a case where we have three different magnitudes and three different durations. In this instance, the most affected phase is taken as sag magnitude and the duration is the longest of the three durations.

However, several studies have shown that some other characteristics associated with sags, such as phase-angle jump, point-on-wave of initiation and recovery, waveform distortion and phase unbalance, may also cause problems for sensitive equipment.

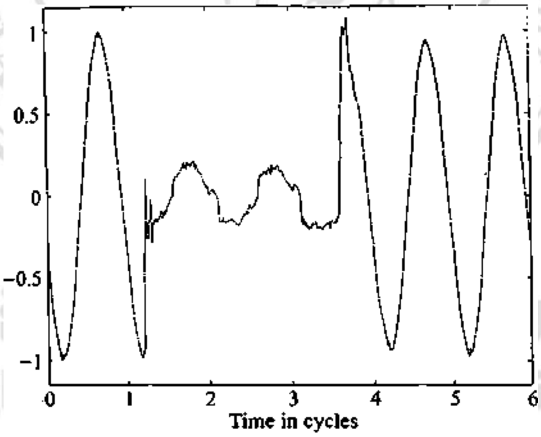


Figure 2.6 Voltage sag characteristic [5]

2.8 Seven types of three-phase unbalanced sags

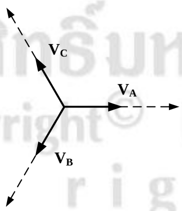
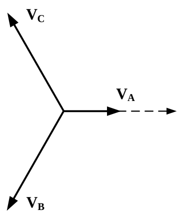
Voltage sags are primarily caused by system faults. Each fault type has a different effect to the voltages at the fault point, which subsequently defined the voltage sag types.

- Single-Line-to-Ground (SLG) Fault
- Line-to-Line (LL) Fault
- Double-Line-to-Ground (LLG) Fault
- Three Phase (3P) Fault

In this section this research will derive a classification for three-phase unbalanced voltage sags, based on the following assumptions:

- Positive- and negative-sequence impedances are identical.
- The zero-sequence component of the voltage does not propagate down to the equipment terminals, so that we can consider phase-to-neutral voltages.
- Load currents, before, during, and after the fault, can be neglected.

Table 2.1 Classification for three-phase unbalanced voltage sags type A-D.

Type	Vector diagram	Equation	Cause of voltage sags and Load Connection
A Three-Phase Faults.		$V_A = V$ $V_B = -\frac{1}{2}V - \frac{1}{2}jV\sqrt{3}$ $V_C = -\frac{1}{2}V + \frac{1}{2}jV\sqrt{3}$	The three-phase fault Star-connected Load or Delta-connected Load
B Single-Phase Faults		$V_A = V$ $V_B = -\frac{1}{2} - \frac{1}{2}j\sqrt{3}$ $V_C = -\frac{1}{2} + \frac{1}{2}j\sqrt{3}$	The single phase-to-neutral voltages due to a single- phase-to-ground fault Star-connected Load

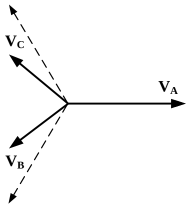
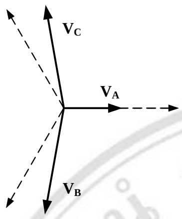
C Phase to Phase Faults		$V_A = 1$ $V_B = -\frac{1}{2} - \frac{1}{2} jV\sqrt{3}$ $V_C = -\frac{1}{2} + \frac{1}{2} jV\sqrt{3}$	Phase to phase fault Star-connected Load
D Phase to Phase Faults		$V_A = V$ $V_B = -\frac{1}{2}V - \frac{1}{2} j\sqrt{3}$ $V_C = -\frac{1}{2}V + \frac{1}{2} j\sqrt{3}$	Phase to phase fault Delta-connected Load

Table 2.2 Fault type, sag type, and load connection

Fault Type	Star-connected Load	Delta-connected Load
Three-phase	sag A	sag A
Phase-to-phase	sag C	sag D
Single-phase	sag B	sag C*

The results are summarized in Table 2.2 for the origin of sags and in Table 2.3 for their propagation to lower voltage levels

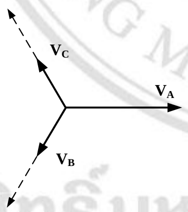
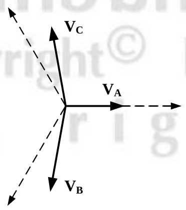
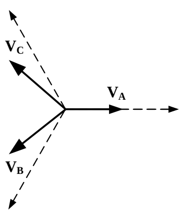
Table 2.3 Transformation of sag type to lower voltage levels

Transformer Connection	Sag Type A	Sag Type B	Sag Type c	Sag Type D
YNyn	type A	type B	type C	type D
Yy, Dd, Dz	type A	type D*	type C	type D
Yd, Dy, Yz	type A	type C*	type D	type C

Transformer winding connections. Transformers come with many different winding connections, but a classification into only three types is sufficient to explain the transfer of three-phase unbalanced sags from one voltage level to another.

- Transformers that do not change anything to the voltages. For this type of transformer the secondary-side voltages (in p.u.) are equal to the primary-side voltages (in p.u.). The only type of transformer for which this holds is the star-star connected one with both star points grounded.
- Transformers that remove the zero-sequence voltage. The voltages on the secondary side are equal to the voltages on the primary side minus the zero-sequence component. Examples of this transformer type are the star- star connected transformer with one or both star points not grounded, and the delta-delta connected transformer. The delta-zigzag (Dz) transformer also fits into this category.
- Transformers that swap line and phase voltages. For these transformers each secondary-side voltage equals the difference between two primary-side vol¬tages. Examples are the delta-star (Dy) and the star-delta (Yd) transformer as well as the star-zigzag (Yz) transformer.

Table 2.4 Classification for three-phase unbalanced voltage sags type E-G.

Type	Vector diagram	Equation	Cause of voltage sags and Load Connection
E **Two-phase-to-ground faults**		$V_A = 1$ $V_B = -\frac{1}{2}V - \frac{1}{2}jV\sqrt{3}$ $V_C = -\frac{1}{2}V + \frac{1}{2}jV\sqrt{3}$	Two Phase to ground fault Star-connected Load
F **Two-phase-to-ground faults**		$V_A = V$ $V_B = -\frac{1}{3}j\sqrt{3} - \frac{1}{2}V - \frac{1}{6}jV\sqrt{3}$ $V_C = \frac{1}{3}j\sqrt{3} - \frac{1}{2}V + \frac{1}{6}jV\sqrt{3}$	Two Phase to ground fault Delta-connected Load
G **Two-phase-to-ground faults**		$V_A = \frac{2}{3} + \frac{1}{3}V$ $V_B = -\frac{1}{3} - \frac{1}{6}V - \frac{1}{2}jV\sqrt{3}$ $V_C = -\frac{1}{3} - \frac{1}{6}V + \frac{1}{2}jV\sqrt{3}$	Two Phase to ground fault Delta-connected Load

Origin of sags and transformation to lower voltage levels for all seven types of three-phase unbalanced sags are summarized in Tables 2.5 and 2.6.

Table 2.5 Origin of three-phase unbalanced sags

Fault Type	Star-connected Load	Delta-connected Load
Three-phase	Type A	Type A
Two-phase-to-ground	Type E	Type F
Phase-to-phase	Type C	Type D
Single-phase	Type B	TypeCc*

Table 2.6 Transformation of sag type to lower voltage levels

	Sag on Primary Side						
Connection	Type A	Type B	Type c	Type D	Type E	Type F	Type G
YNyn	A	B	C	D	E	F	G
Yy, Dd, Dz	A	D*	C	D	G	F	G
Yd, Dy, Yz	A	C*	D	C	F	G	F

2.8.1 Factors Affecting Sag Characteristics

1) Type of fault: Type of fault in the power system is the first factor which affects sag characteristic. Depending whether the fault type is balanced or unbalanced, sag will be balanced or unbalanced in all three phases. The magnitude and phase angle of sag will also depend on the type of fault.
2) Location of fault: Along with the type, the location of faults in the system have a great impact on the magnitude as well as the phase-angle jump of the sag. The sensitive load is at distribution level but the faults at distribution as well as at hundreds of kilometres away at the transmission level will have an influence on the magnitude as well as the phase-angle of the sag at PCC.
3) X/R ratio of the lines: With change in the X/R ratio of the line there is change in the X/R ratio of fault to source impedance which will affect the magnitude as well

as phase-angle jump [1]. To study the effect, the X/R ratio of one of the lines can be changed and the magnitude and the phase angle jump of voltage at observed node can be analyzed.

4) Point on wave of sag initiation: The point on wave of sag initiation is the phase angle of the fundamental voltage wave at which the voltage sag starts. This angle corresponds to the angle at which the short circuit fault occurs. As most of the faults are associated with a flashover, they are more likely to occur near the voltage maximum than near the voltage zero. Upward crossing of the fundamental voltage is an obvious choice for reference to quantify the point of wave initiation. With change in point on wave of sag initiation it is expected that the phase-angle jump will change more as compared to the magnitude of sag.
5) Single/Double circuit transmission: In the power system it is common practice to have double circuit transmission to improve reliability. Another interesting analysis on studying the influence of disconnection of lines on the sag magnitude and phase angle can be carried out by keeping any the transmission line as a double circuit. The results are compared with single circuit configuration of the same line. With changes in the transmission configuration basically there will be change in X/R ratio of impedances, which will affect the characteristic of sag.

2.8.2 Phase-angle jump

A short circuit in a power system not only causes a drop in voltage magnitude but also a change in the phase angle of the voltage. In a 50 Hz or 60 Hz system, voltage is a complex quantity (a phasor) which has magnitude and phase angle. A change in the system, like a short circuit, causes a change in voltage. This change is not limited to the magnitude of the phasor but includes a change in phase angle as well. This thesis will refer to the latter as the phase-angle jump associated with the voltage sag. The phase-angle jump manifests itself as a shift in zero crossing of the instantaneous voltage. Phase- angle jumps are not of concern for most equipment. But power electronics converters using phase-angle information for their firing instants may be affected.

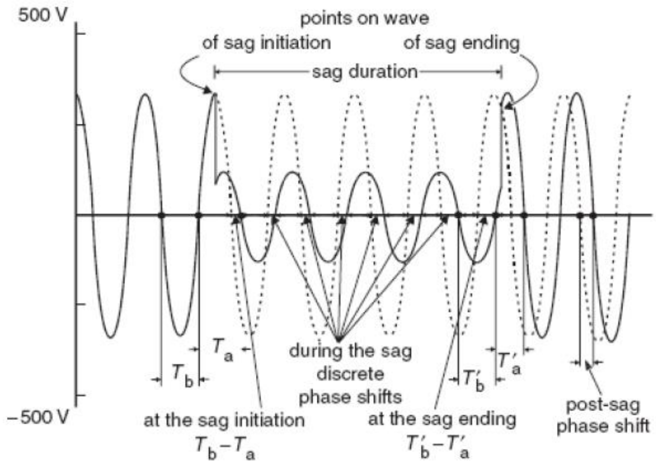


Figure 2.7 Synthetic sag with a magnitude of 70% and a phase-angle jump of +45°.

2.9 International standard test SEMIF47 and IEC61000-4-11

2.9.1 The SEMI International Standard Program is a services offered by Semiconductor Equipment and Material International (SEMI). Its purpose is to provide the semiconductor and flat panel display industries with standard and recommendations to improve productivity and business. SEMI standard are written documents in the form of specifications, guides, test methods, terminology, and practices. The standards are voluntary technical agreement between equipment manufacturer and end-user. The standard ensure compatibility and interoperability of goods and services. Considering voltage sags, two standards address the problem for the equipment.

SEMI F47-0200, “Specification for semiconductor processing equipment voltage sag immunity”

The standard addresses specifications for semiconductor processing equipment voltage sag immunity. It only specifies voltage sags with duration from 50ms up to 1s. It is also limited to phase-to-phase and phase-to-neutral voltage incidents, and presents a voltage-duration graph.

SEMI F42-0999, “Test method for semiconductor processing equipment voltage sag immunity”

This standard defines a test methodology used to determine the susceptibility of semiconductor processing equipment and how to qualify it against the specifications. It further describes test apparatus, test set-up, test procedure to determine to susceptibility of semiconductor processing equipment, and finally how to report and interpret the result and the standard considered two variable one is %sags and two duration time of sags happen. SEMI F47 required that semiconductor processing equipment tolerate voltage sags connected onto their AC powerline. They must tolerate sags to 50% of equipment nominal voltage for duration of up to 200ms sags to 70% for up to 0.5 seconds, and sags to 80% for up to 1.0 seconds. These requirements are shown in Table 2.6 and 2.7.

Table 2.7 Required voltage sags immunity

Sag depth[#1]	*Duration at 50 Hz*	*Duration at 60 Hz*
50%	10 cycles	12 cycles
70%	25 cycles	30 cycles
80%	50 cycles	60 cycles

Table 2.8 Recommended voltage sags immunity

Sag depth	*Duration at 50 Hz*	*Duration at 60 Hz*
0%	1 cycle	1 cycle
80%	500 cycles	600 cycles

2.9.2 SEMI F47-0706 Test Modes

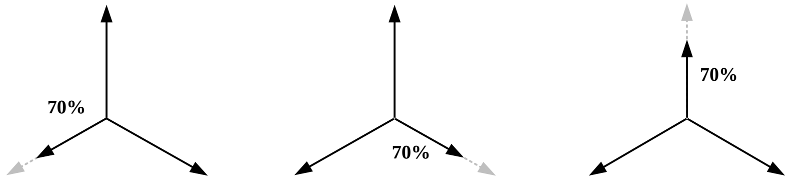
SEMI F47 standard for the semiconductor industry

– Voltage sag immunity testing

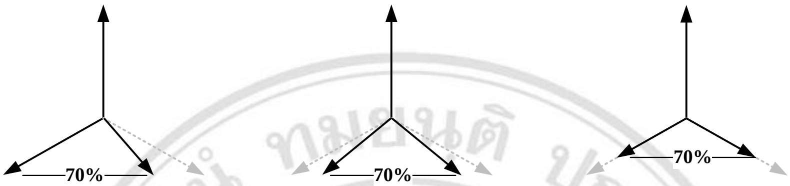
– Relevant for single, two and three phase manufacturing equipment

For test the method of SEMI F47 will be test 3 types sags follow:

- Phase-to-neutral testing (Sags Type B)



- Phase-to-phase testing (Sags Type C, D)



- No three-phase voltage dips

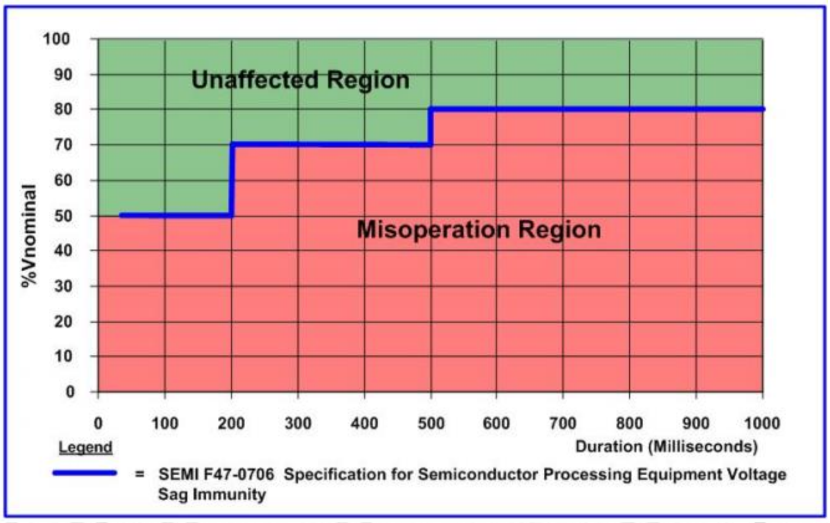


Figure 2.8 SEMI F47 Standard Test

2.9.3 The IEC International Standard test, held its inaugural meeting on 26 June 1906, following discussions between the British Institution of Electrical Engineers, the American Institute of Electrical Engineers, and others, which began at the 1900 Paris International Electrical Congress, and continued with Colonel R. E. B. Crompton playing a key role. Currently, 82 countries are members while another 82 participate in the Affiliate Country Program, which is not a form of membership but is designed to help industrializing countries get involved with the IEC. Originally located in London, the commission moved to its current headquarters in Geneva in 1948. It has regional center in Asia-Pacific (Singapore), Latin America (São Paulo, Brazil) and North America (Boston, United States).

IEC 61000-4-11 is an EMC test standard titled ‘Testing and measuring techniques – Voltage dips, short interruptions and voltage variations immunity tests’. It defines the setup, equipment requirements, and other conditions for testing systems to changes in the AC mains voltage. It is frequently used to shown compliance (Figure 2.9-2.10).

2.9.3.1 The standard describes three different tests:

- Voltage dips are defined as sudden reduction in voltage to lower voltages for a short period of time, followed by recovery to the original voltage.
- Short interruptions are defined as a disappearance of AC voltage for a short period of time, typically not exceeding 1 minute, followed by recovery to the original voltage. Short interruptions can be considered as voltage dips to zero volts.
- Voltage variations are gradual changes of the supply voltage to a higher or lower value than the rated voltage. The duration can be short or long.

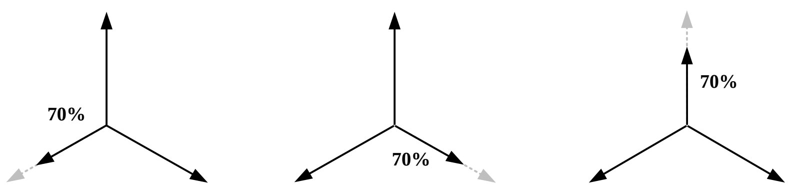
2.9.3.2 IEC 61000-4-11/34 Voltage Sag Test Modes

IEC standards 61000-4-11 (less than 16 amps) and 61000-4-34 (greater than 16 amps)

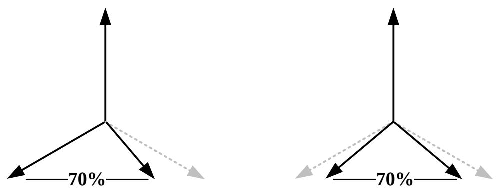
– Voltage sag and short interruption testing

– Relevant for single, two and three phase manufacturing equipment

- Phase-to-neutral testing



- Phase-to-phase testing



- No three-phase voltage dips

Table 2.9 Voltage Sags Test Levels from the IEC 61000-4-34 and -11 Standards

Class[a]	Test level and durations for voltage dips (t_s) (50 Hz/60 Hz)				
Class 1	Case-by-case according to the equipment requirements				
Class 2	0 % during ½ cycle	0 % during 1 cycle	70 % during 25/30[c] cycles		
Class 3	0 % during ½ cycle	0 % during 1 cycle	40 % during 10/12[c] cycles	70 % during 25/30[c] cycles	80 % during 250/300[c] cycles
Class X[b]	X	X	X	X	X

[a] Classes as per IEC 61000-2-4; see Annex B.

[b] To be defined by product committee. For equipment connected directly or indirectly to the public network, the levels must not be less severe than Class 2.

[c] "25/30 cycles" means "25 cycles for 50 Hz test" and "30 cycles for 60 Hz test".

Class 1 - This class applies to protected supplies and has compatibility levels lower than public network levels. It relates to the use of equipment very sensitive to disturbances in the power supply for instance the instrumentation of technological laboratories, some automation and protection equipment, some computers, etc.

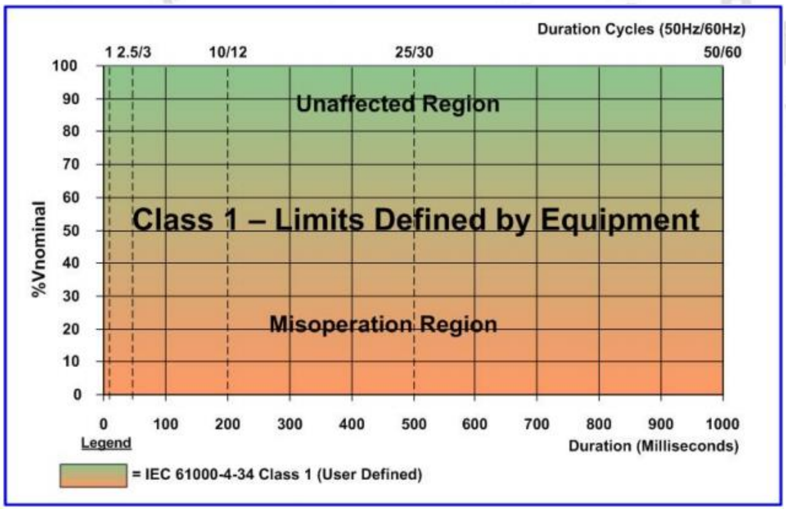


Figure 2.9 IEC61000-4-11 Class 1

Class 2 - This class applies to points of common coupling (PCC's for consumer systems) and points of common coupling (IPC's) in the industrial environment in general. The compatibility levels in this class are identical to those of public networks; therefore components designed for application in public networks may be used in this class of industrial environment.

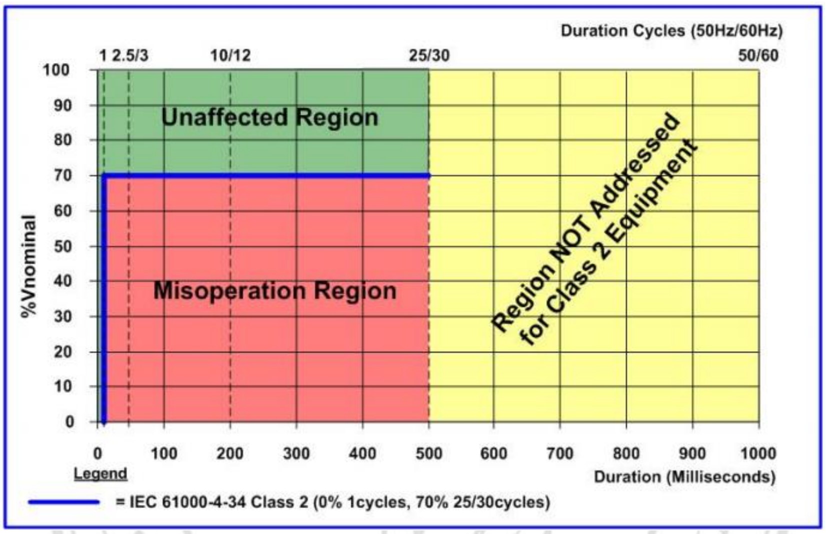


Figure 2.10 IEC61000-4-11 Class 2 test 70% sags 25/30 cycles (50/60Hz)

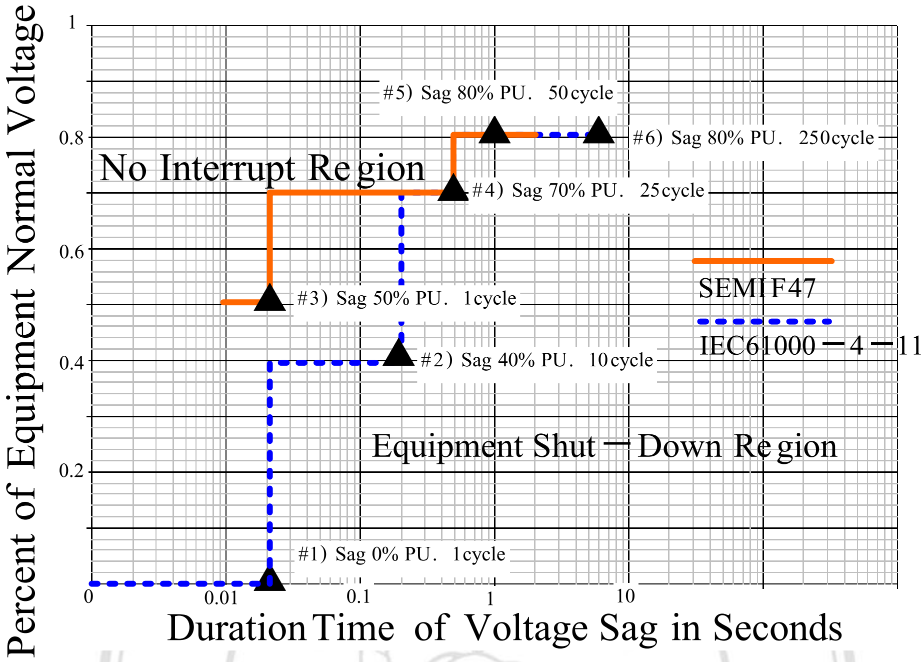


Figure 2.11 Different of Voltage sag and duration time between two standard

2.9.5 Harmonics [IEEE 519-2014]

At the PCC, system owners or operators should limit line-to-neutral voltage harmonics as follows:

– Daily 99th percentile very short time (3 s) values should be less than 1.5 times the values given in Table 1.

– Weekly 95th percentile short time (10 min) values should be less than the values given in Table 1.

All values should be in percent of the rated power frequency voltage at the PCC. Table 2.9 applies to voltage harmonics whose frequencies are integer multiples of the power frequency.

Information on voltage interharmonic limits is given in Annex A and is based on lamp flicker assessed using the measurement technique described in IEEE Std 1453 and IEC 61000-4-15. The information of Annex A is not based on the effects of interharmonics on other equipment and systems such as generator mechanical systems, motors, transformers, signaling and communication systems, and filters. Due consideration should be given to these effects and appropriate interharmonic current limits should be developed starting from the information in Annex A on a case-by-case basis using specific knowledge of the supply system, connected user loads, and provisions for future users.

* **point of common coupling (PCC):** Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.

Table 2.9 Voltage distortion limits.

Bus voltage *V* at PCC	**Individual Harmonic (%)**	**Total harmonic Distortion THD (%)**
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5

Planning Levels: PL and Compatibility Level: CL

For example planning Levels: PL and compatibility Level: CL in 400V with [IEC 61000-2-2] and Engineering Recommendation G5/4

Compatibility Level (CL)	Planning Level (PL)
[IEC 61000-2-2]	[ER G5/4]
$V_3 = 5.0\%$	$V_3 = 4.0\%$
$V_5 = 6.0\%$	$V_5 = 4.0\%$
$V_7 = 5.0\%$	$V_7 = 4.0\%$
$V_{11} = 3.5\%$	$V_{11} = 3.0\%$
$V_{13} = 3.0\%$	$V_{13} = 2.5\%$
$THD = 8.0\%$	$THD = 5.0\%$

In this chapter, all of the discussion it can be concluded that the characteristics of voltage sags. 7 types can be classified by the size of the voltage drop. Duration time of sags, phase shift of the voltage and cause of symmetric or asymmetric voltage sags, type single phase to ground fault, phase to phase fault, phase to phase to ground fault and the connected of load in a star or delta low voltage or high voltage side of transformer.

The next chapter will be designed inverter type amplifier 3-phase 4-wire topology used the technique to switch a carrier based PWM and voltage sags algorithm to build a voltage sags generator and design LC filter for low a distortion THDv AC voltage output for the standards of testing.