MODEL ANSWERS

FIRST SESSIONAL EXAMINATION, EVEN SEMESTER, (2019-2020)

Branch: EE & EN

Subject Code: REE 081 **Subject: Introduction to Power Quality & FACTS**

Time: 1 Hr. 30 Min **Maximum Marks: 30**

SECTION – A

1. Attempt **ALL** the questions in brief. **(1*5 = 5)**

Q.N.		QUESTION	Marks	CO	BL
1	a.	What is power quality? A utility may define power quality as reliability and a manufacturer of load equipment as those characteristics of the power supply that enable the equipment to work properly. More precisely, **power quality** is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.	1	1	2
	b.	Define overvoltage. An **overvoltage** is an increase in the rms ac voltage greater than 110 percent at the power frequency for a duration longer than 1 min. Overvoltages are usually the result of load switching (e.g., switching off a large load or energizing a capacitor bank).	1	1	1
	c.	Define total harmonic distortion (THD). The **total harmonic distortion (THD)** is a measure of effective value of harmonic distortion. It is defined as the ratio of rms value of harmonics and rms value of fundamental.	1	1	1
	d.	What is voltage sag? A **voltage sag** is a decrease to between 0.1 and 0.9 pu in rms voltage at the power frequency for durations from 0.5 cycle to 1 min. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors.	1	1	2
	e.	Define voltage imbalance. **Voltage imbalance/voltage unbalance** is defined as the maximum deviation from the average of the three-phase voltages or currents, divided by the average of the three-phase voltages or currents, expressed in percent. Using symmetrical components, it may be defined as the ratio of either the negative or zero sequence component to the positive sequence component can be used to specify the percent unbalance.	1	1	1

SECTION - B

2. Attempt any **TWO** parts of the following. **(2*5 = 10)**

Q.N.		QUESTION	Marks	CO	BL
	a.	Write short note on the transients. The term **transients** denote an event that is undesirable and momentary in nature. A transient is “that part of the change in a variable that disappears during transition from one steady state operating condition to another. Another word in common usage that is	5	1	2

2

often considered synonymous with transient is *surge*. A utility engineer may think of a surge as the transient resulting from a lightning stroke for which a surge arrester is used for protection. End users frequently describe anything unusual that might be observed on the power supply ranging from sags to swells to interruptions. The transients can be classified into two categories, impulsive and oscillatory.

An **impulsive transient** is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (primarily either positive or negative). Impulsive transients are normally characterized by their rise and decay times. Figure 1 illustrates a typical current impulsive transient caused by lightning.

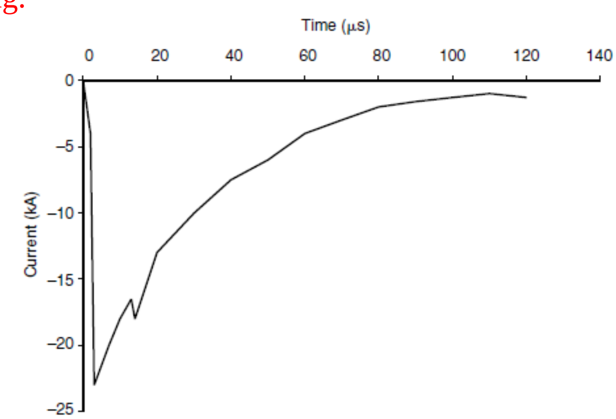


Fig.1: Lightning stroke current impulsive transient

Because of the high frequencies involved, the shape of impulsive transients can be changed quickly by circuit components and may have significantly different characteristics when viewed from different parts of the power system. They are generally not conducted far from the source of where they enter the power system, although they may, in some cases, be conducted for quite some distance along utility lines. Impulsive transients can excite the natural frequency of power system circuits and produce oscillatory transients.

An **oscillatory transient** is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values. An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly and described by predominate frequency, duration, and magnitude.

The spectral content subclasses are high, medium, and low frequency. Oscillatory transients with a primary frequency component greater than 500 kHz and a typical duration measured in microseconds (or several cycles of the principal frequency) are considered high-frequency transients. These transients are often the result of a local system response to an impulsive transient. A transient with a primary frequency component between 5 and 500 kHz with duration measured in the tens of microseconds (or several cycles of the principal frequency) is termed a medium-frequency transient. Back-to-back capacitor energization results in oscillatory transient currents in the

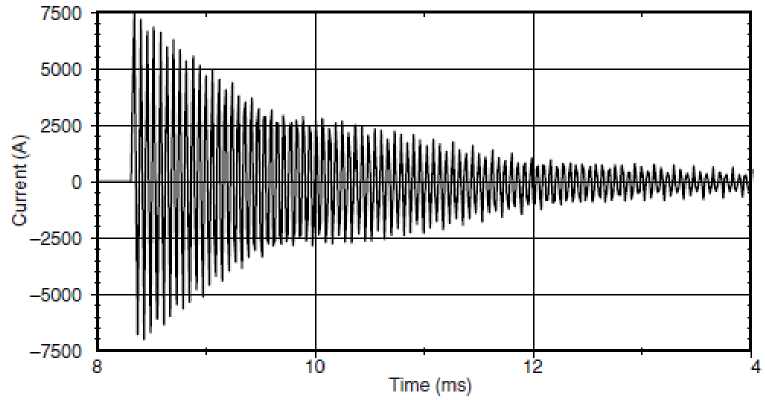
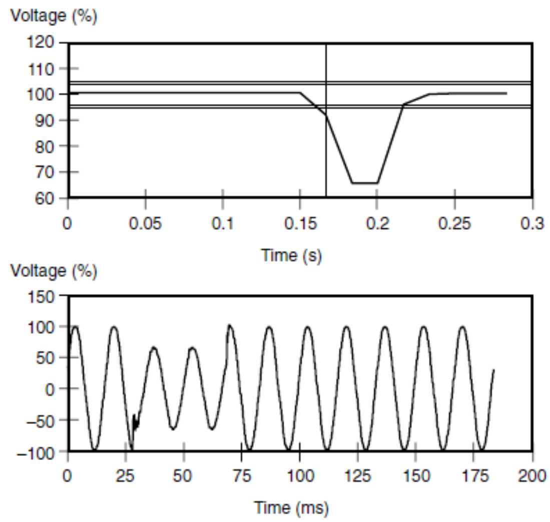
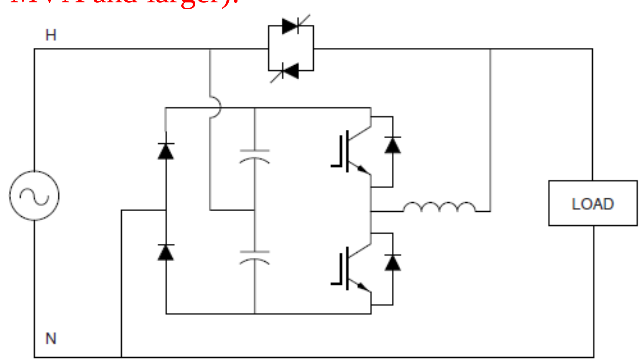
<table>
<tr>
<td></td>
<td></td>
<td>tens of kilohertz as illustrated in Figure 2. Cable switching results in oscillatory voltage transients in the same frequency range.


Fig.2: Oscillatory transient current caused by back-to-back capacitor switching
A transient with a primary frequency component less than 5 kHz, and a duration from 0.3 to 50 ms, is considered a low-frequency transient. This category of phenomena is frequently encountered on utility subtransmission and distribution systems and is caused by many types of events.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b.</td>
<td>Explain briefly the waveform distortion.
Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.
There are five primary types of waveform distortion:
• DC offset
• Harmonics
• Interharmonics
• Notching
• Noise
The presence of a dc voltage or current in an ac power system is termed dc offset. This can occur as the result of a geomagnetic disturbance or asymmetry of electronic power converters. Direct current in ac networks can have a detrimental effect by biasing transformer cores so they saturate in normal operation. This causes additional heating and loss of transformer life. Direct current may also cause the electrolytic erosion of grounding electrodes and other connectors.
Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (termed the fundamental frequency; usually 50 or 60 Hz). Periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics. Harmonic distortion originates in the nonlinear characteristics of devices and loads on the power system. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is also common to use a single quantity, the total harmonic distortion (THD), as a measure of the effective value of harmonic distortion.</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
</table>

		Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz) are called interharmonics, which appear as discrete frequencies or as a wideband spectrum. The main sources of interharmonic waveform distortion are static frequency converters, cycloconverters, induction furnaces, and arcing devices. Power line carrier signals can also be considered as interharmonics. The interharmonic currents can excite quite severe resonances on the power system as the varying interharmonic frequency becomes coincident with natural frequencies of the system. They have been shown to affect power-line-carrier signaling and induce visual flicker in fluorescent and other arc lighting as well as in computer display devices. **Notching** is a periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to another. Since notching occurs continuously, it can be characterized through the harmonic spectrum of the affected voltage. The frequency components associated with notching can be quite high and may not be readily characterized with measurement equipment normally used for harmonic analysis. The notches occur when the current commutates from one phase to another. During this period, there is a momentary short circuit between two phases, pulling the voltage as close to zero as permitted by system impedances. **Noise** is defined as unwanted electrical signals with broadband spectral content lower than 200 kHz superimposed upon the power system voltage or current in phase conductors, or found on neutral conductors or signal lines. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies. Basically, noise consists of any unwanted distortion of the power signal that cannot be classified as harmonic distortion or transients and disturbs electronic devices such as microcomputer and programmable controllers. The problem can be mitigated by using filters, isolation transformers, and line conditioners.			
	c.	Discuss the different sources of voltage sags. • Voltage sags are usually associated with system faults • A sudden increase in load results in a corresponding sudden drop in voltage • Switching large loads (starting of large motors and arc furnaces) causes voltage sags **Voltage sags** are generally caused by faults (short circuits) on the utility system. If there is a fault on the same feeder, the customer will experience a voltage sag during the fault followed by an interruption when the breaker opens to clear the fault. If the fault is temporary in nature, a reclosing operation on the breaker should be successful and the interruption will only be temporary. It will usually require about 5 or 6 cycles for the breaker to operate, during which time a voltage sag occurs. The breaker will remain open for typically a minimum of 12 cycles up to 5 s depending on utility reclosing practices.	5	2	4

		A much more common event would be a fault on one of the other feeders from the substation, i.e., a fault on a parallel feeder, or a fault somewhere on the transmission system. In either of these cases, the customer will experience a voltage sag during the period that the fault is actually on the system. As soon as breakers open to clear the fault, normal voltage will be restored at the customer. Any of the fault locations can cause equipment to misoperate in customer facilities. The relative importance of faults on the transmission system and the distribution system will depend on the specific characteristics of the systems (underground versus overhead distribution, lightning flash densities, overhead exposure, etc.) and the sensitivity of the equipment to voltage sags. Figures 3 shows the rms voltage variation with time, an interesting utility fault event recorded in the power system.  Fig.3: Voltage sag due to a short-circuit fault on a parallel utility feeder			
	d.	Discuss the active series compensator. Advances in power electronic technologies and new topologies for these devices have resulted in new options for providing voltage sag ride-through support to critical loads. One of the important new options is a device that can boost the voltage by injecting a voltage in series with the remaining voltage during a voltage sag condition. These are referred to as **active series compensation devices**. They are available in size ranges from small single-phase devices (1 to 5 kVA) to very large devices that can be applied on the medium-voltage systems (2 MVA and larger).  	5	2	2

<table>
<tr><td></td><td></td><td>Fig. 4: Topology illustrating the operation of the active series compensator
A one-line diagram illustrating the power electronics that are used to achieve the compensation is shown in Fig.4. When a disturbance to the input voltage is detected, a fast switch opens and the power is supplied through the series-connected electronics. This circuit adds or subtracts a voltage signal to the input voltage so that the output voltage remains within a specified tolerance during the disturbance. The switch is very fast so that the disturbance seen by the load is less than a quarter cycle in duration. This is fast enough to avoid problems with almost all sensitive loads. The circuit can provide voltage boosting of about 50 percent, which is sufficient for almost all voltage sag conditions.</td><td></td><td></td><td></td></tr>
</table>

SECTION - C

3. Attempt any **<u>ONE</u>** part of the following. **(1*5 = 5)**

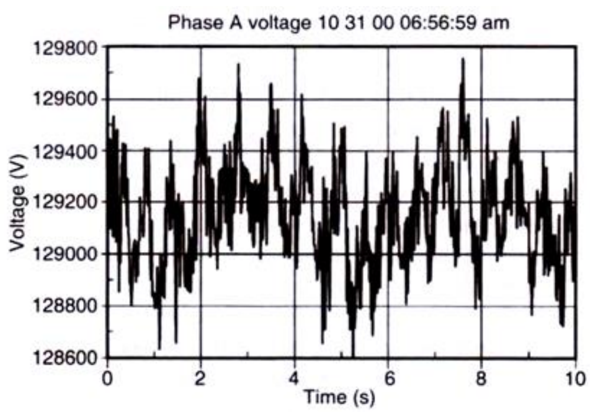
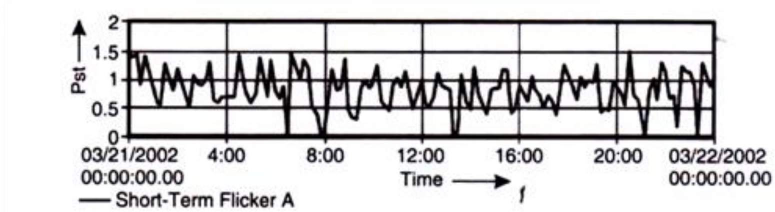
<table>
<tr><th colspan="2">Q.N.</th><th>QUESTION</th><th>Marks</th><th>CO</th><th>BL</th></tr>
<tr><td>3</td><td>a.</td><td>Explain the voltage fluctuations.
Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges of 0.9 to 1.1 pu.
Loads that can exhibit continuous, rapid variations in the load current magnitude can cause voltage variations that are often referred to as flicker. The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker. The voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads. However, the two terms are often linked together in standards. Therefore, the common term voltage flicker will be used to describe such voltage fluctuations.


Fig. 5: Example of voltage fluctuations caused by arc furnace operation
An example of a voltage waveform caused by an arc furnace, which is one of the most common causes of voltage fluctuations on utility transmission and distribution systems, produces flicker as shown in Fig.5. This. The flicker signal is defined by its rms magnitude expressed as a percent of the fundamental. Voltage flicker is measured with respect</td><td>5</td><td>1</td><td>2</td></tr>
</table>

		to the sensitivity of the human eye. Typically, magnitude of 0.5 percent can result in perceptible lamp flicker if the frequencies are in the range of 6 to 8 Hz. The visible light flicker through voltage measurements method simulates the lamp/eye/brain transfer function and produces a fundamental metric called short-term flicker sensation (Pst). This value is normalized to 1.0 to represent the level of voltage fluctuations sufficient to cause noticeable flicker to 50 percent of a sample observing group. Another measure called long-term flicker sensation (Plt) is often used for the purpose of verifying compliance with compatibility levels established by standards bodies and used in utility power contracts. This value is a longer-term average of Pst samples.  Fig. 6: Flicker (Pst) at 161-kV substation bus measured according to IEC Standard 61000-4-15 Figure 6 illustrates a trend of Pst measurements taken at a 161 kV substation bus serving an arc furnace load. Pst samples are normally reported at 10-min intervals. A statistical evaluation process defined in the measurement standard processes instantaneous flicker measurements to produce the Pst value. The Plt value is produced every 2 h from the Pst values.			
	b.	Discuss the estimating voltage sag performance. It is important to understand the expected voltage sag performance of the supply system so that facilities can be designed and equipment specifications developed to assure the optimum operation of production facilities. The following is a general procedure for working with industrial customers to assure compatibility between the supply system characteristics and the facility operation: • Determine the number and characteristics of voltage sags that result from transmission system faults • Determine the number and characteristics of voltage sags that result from distribution system faults (for facilities that are supplied from distribution systems) • Determine the equipment sensitivity to voltage sags. This will determine the actual performance of the production process based on voltage sag performance calculated in steps above • Evaluate the economics of different solutions that could improve the performance, either on the supply system (fewer voltage sags) or within the customer facility (better immunity). The steps in this procedure are: **1. Area of vulnerability:** The concept of an area of vulnerability helps to evaluate the likelihood of sensitive equipment being subjected to voltage lower than its minimum voltage sag ride-through capability. The voltage sag ride-through capability is defined as the minimum voltage magnitude	5	2	4

a piece of equipment can withstand or tolerate without misoperation or failure. This is also known as the equipment voltage sag immunity or susceptibility limit. An area of vulnerability is determined by the total circuit miles of exposure to faults that can cause voltage magnitudes at an end-user facility to drop below the equipment minimum voltage sag ride-through capability.

2. Equipment sensitivity to voltage sags: Equipment within an end-user facility may have different sensitivity to voltage sags. Equipment sensitivity to voltage sags depend on the specific load type, control settings, and applications. Consequently, it is often difficult to identify which characteristics of a given voltage sag are most likely to cause equipment to misoperate. The most commonly used characteristics are the duration and magnitude of the sag. Other less commonly used characteristics include phase shift and unbalance, missing voltage, three-phase voltage unbalance during the sag event, and the point-in-the-wave at which the sag initiates and terminates. Generally, equipment sensitivity to voltage sags can be divided into three categories:

- Equipment sensitive to only the magnitude of a voltage sag
- Equipment sensitive to both the magnitude and duration of a voltage sag
- Equipment sensitive to characteristics other than magnitude and duration.

For end users with sensitive processes, the voltage sag ride-through capability is usually the most important characteristic to consider.

3. Transmission system sag performance evaluation: The voltage sag performance for a given customer facility will depend on whether the customer is supplied from the transmission system or from the distribution system. For a customer supplied from the transmission system, the voltage sag performance will depend on only the transmission system fault performance. On the other hand, for a customer supplied from the distribution system, the voltage sag performance will depend on the fault performance on both the transmission and distribution systems. Transmission line faults and the subsequent opening of the protective devices rarely cause an interruption for any customer because of the interconnected nature of most modern-day transmission networks. These faults cause voltage sags. Depending on the equipment sensitivity, the unit may trip off, resulting in substantial monetary losses. The type of fault must also be considered in this analysis. Single-line-to-ground faults will not result in the same voltage sag at the customer equipment as a three-phase fault.

4. Utility distribution system sag performance evaluation

The customers supplied at distribution voltage levels are impacted by faults on both the transmission and the distribution system. The analysis at the distribution level includes momentary interruptions caused by the operation of protective devices to clear the faults. These interruptions will most likely trip out sensitive equipment. The overall voltage sag performance at an end-user facility is the total of the expected voltage sag performance from the transmission and distribution systems. The critical information needed to compute voltage sag performance can be

		summarized as follows: • Number of feeders supplied from the substation • Average feeder length • Average feeder reactance • Short-circuit equivalent reactance at the substation • Feeder reactors, if any • Average feeder fault performance which includes three-phase-line to-ground (3LG) faults and single-line-to-ground (SLG) faults There are two possible locations for faults on the distribution systems, i.e., on the same feeder and on parallel feeders. **Faults on parallel feeders:** Voltage experienced at the end-user facility following a fault on parallel feeders can be estimated by calculating the expected voltage magnitude at the substation. The voltage magnitude at the substation is impacted by the fault impedance and location, the configuration of the power system, and the system protection scheme. **Faults on the same feeder:** In this step the expected voltage sag magnitude at the end-user location is computed as a function of fault location on the same feeder. Note that, however, the computation is performed only for fault locations that will result in a sag but will not result in a momentary interruption, which will be computed separately.			

4. Attempt any **ONE** part of the following. **(1*5 = 5)**

Q.N.		QUESTION	Marks	CO	BL
4	a.	Discuss the short duration voltage variations. Short duration voltage variation encompasses the IEC category of voltage dips and short interruptions. Each type of variation can be designated as instantaneous, momentary, or temporary, depending on its duration. Short-duration voltage variations are caused by fault conditions, the energization of large loads which require high starting currents, or intermittent loose connections in power wiring. Depending on the fault location and the system conditions, the fault can cause either temporary voltage drops (sags), voltage rises (swells), or a complete loss of voltage (interruptions). The fault condition can be close to or remote from the point of interest. In either case, the impact on the voltage during the actual fault condition is of the short-duration variation until protective devices operate to clear the fault. **An interruption** occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min. Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The interruptions are measured by their duration since the voltage magnitude is always less than 10 percent of nominal. The duration of an interruption due to a fault on the utility system is determined by the operating time of utility protective devices. **A sag** is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. The power quality community has used the term sag for many years to describe a	5	1	2

<table>
<tr><td></td><td></td><td>short-duration voltage decrease. Although the term has not been formally defined, it has been increasingly accepted and used by utilities, manufacturers, and end users. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors. An induction motor will draw 6 to 10 times its full load current during start-up. If the current magnitude is large relative to the available fault current in the system at that point, the resulting voltage sag can be significant.

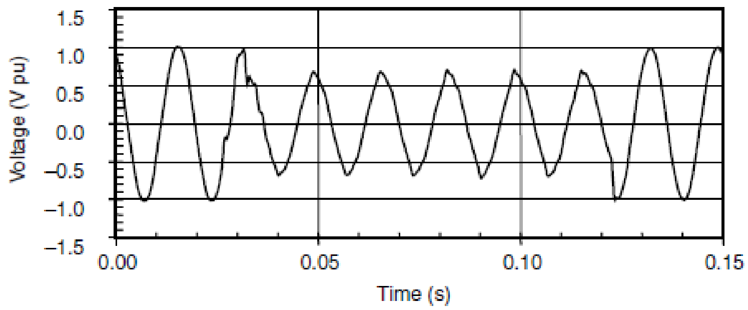


Fig.7: Voltage sag caused by an SLG fault (Voltage sag waveform)

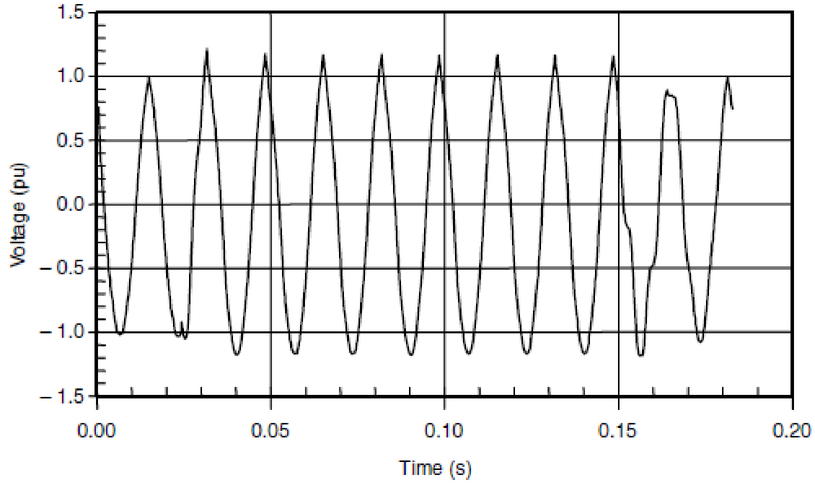


Fig.8: Instantaneous voltage swell caused by an SLG fault

A swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. Swells are usually associated with system fault conditions, but they are not as common as voltage sags. One way that a swell can occur is from the temporary voltage rise on the unfaulted phases during an SLG fault. Swells are characterized by their magnitude (rms value) and duration. The severity of a voltage swell during a fault condition is a function of the fault location, system impedance, and grounding. On an ungrounded system, with an infinite zero-sequence impedance, the line-to-ground voltages on the ungrounded phases will be 1.73 pu during an SLG fault condition. Close to the substation on a grounded system, there will be little or no voltage rise on the unfaulted phases because the substation transformer is usually connected delta-wye, providing a low-impedance zero-sequence path for the fault current. The term momentary overvoltage is used by many writers as a synonym for the term swell.</td><td></td><td></td><td></td></tr>
<tr><td></td><td>b.</td><td>Discuss briefly the principle of voltage sag protection.
Several things can be done by the utility, end user, and equipment</td><td>5</td><td>2</td><td>2</td></tr>
</table>

manufacturer to reduce the number and severity of voltage sags and to reduce the sensitivity of equipment to voltage sags. Figure 8 illustrates voltage sag solution alternatives and their relative costs. As this chart indicates, it is generally less costly to tackle the problem at its lowest level, close to the load. The best answer is to incorporate ridethrough capability into the equipment specifications themselves. This essentially means keeping problem equipment out of the plant, or at least identifying ahead of time power conditioning requirements.

Several ideas, outlined here, could easily be incorporated into any company's equipment procurement specifications to help alleviate problems associated with voltage sags:

1. Equipment manufacturers should have voltage sag ride-through capability curves (similar to the ones shown previously) available to their customers so that an initial evaluation of the equipment can be performed. Customers should begin to demand that these types of curves be made available so that they can properly evaluate equipment.

2. The company procuring new equipment should establish a procedure that rates the importance of the equipment. If the equipment is critical in nature, the company must make sure that adequate ride-through capability is included when the equipment is purchased. If the equipment is not important or does not cause major disruptions in manufacturing or jeopardize plant and personnel safety, voltage sag protection may not be justified.

3. Equipment should at least be able to ride through voltage sags with a minimum voltage of 70 percent (ITI curve). The relative probability of experiencing a voltage sag to 70 percent or less of nominal is much less than experiencing a sag to 90 percent or less of nominal.

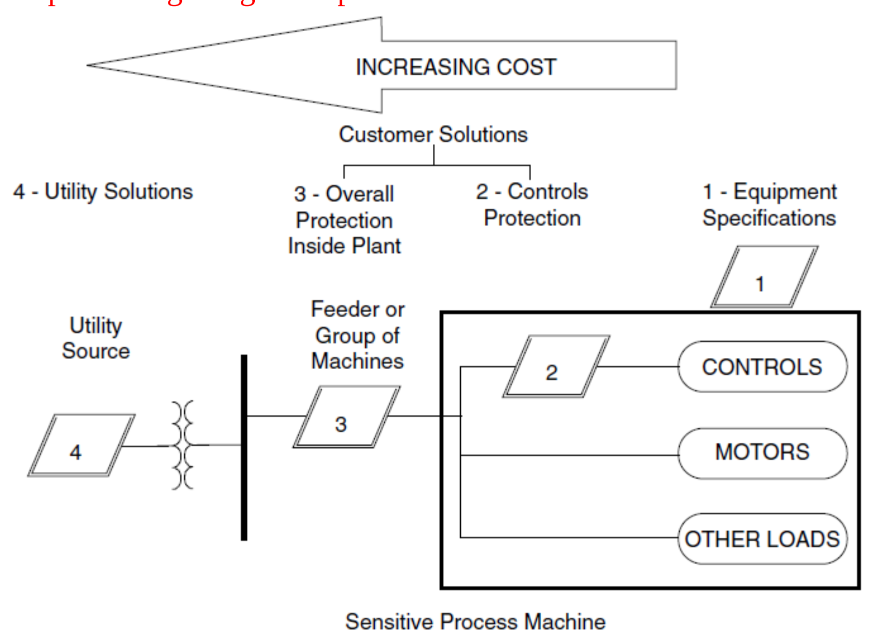


Fig.8: Approaches for voltage sag ride-through

As we entertain solutions at higher levels of available power, the solutions generally become more costly. If the required ride-through cannot be obtained at the specification stage, it may be possible to apply an uninterruptible power supply (UPS) system or some other type of power

		conditioning to the machine control. This is applicable when the machines themselves can withstand the sag or interruption, but the controls would automatically shut them down.			

5. Attempt any **<u>ONE</u>** part of the following. **(1*5 = 5)**

<table>
<tr><th colspan="2">Q. N.</th><th>QUESTION</th><th>Marks</th><th>CO</th><th>BL</th></tr>
<tr><td rowspan="2">5</td><td>a.</td><td>
Explain the power frequency variations.

Power frequency variations are defined as the deviation of the power system fundamental frequency from it specified nominal value (e.g., 50 or 60 Hz). The power system frequency is directly related to the rotational speed of the generators supplying the system. There are slight variations in frequency as the dynamic balance between load and generation changes. The size of the frequency shift and its duration depend on the load characteristics and the response of the generation control system to load changes. Figure 9 illustrates frequency variations for a 24-h period on a typical 13-kV substation bus. Frequency variations that go outside of accepted limits for normal steady-state operation of the power system can be caused by faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going off-line.

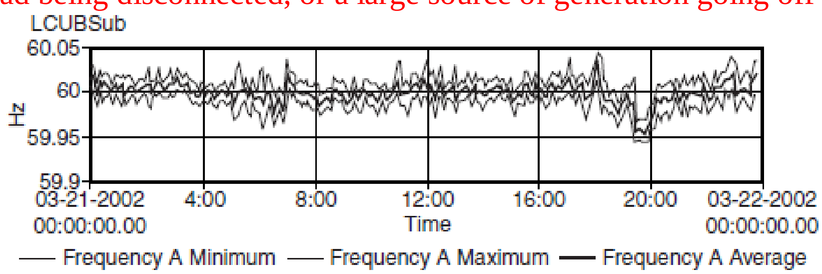


Fig.9: Power frequency trend and statistical distribution at 13-kV substation bus

On modern interconnected power systems, significant frequency variations are rare. Frequency variations of consequence are much more likely to occur for loads that are supplied by a generator isolated from the utility system. In such cases, governor response to abrupt load changes may not be adequate to regulate within the narrow bandwidth required by frequency-sensitive equipment. Voltage notching can sometimes be mistaken for frequency deviation. The notches may come sufficiently close to zero to cause errors in instruments and control systems that rely on zero crossings to derive frequency or time.
</td><td>5</td><td>1</td><td>2</td></tr>
<tr><td>b.</td><td>
Discuss briefly the voltage sag solutions at end-user level.

Solutions to improve the reliability and performance of a process or facility can be applied at many different levels. The different technologies available should be evaluated based on the specific requirements of the process to determine the optimum solution for improving the overall voltage sag performance. Following are the major technologies available and the levels where they can be applied:

(1) Ferroresonant transformers

Ferroresonant transformers, also called constant-voltage transformers (CVTs), can handle most voltage sag conditions. CVTs are especially attractive for constant, low-power loads. Ferroresonant transformers are
</td><td>5</td><td>2</td><td>3</td></tr>
</table>

basically 1:1 transformers which are excited high on their saturation curves, thereby providing an output voltage which is not significantly affected by input voltage variations. Ferroresonant transformers should be sized significantly larger than the load. As the loading is increased, the corresponding ride-through capability is reduced, and when the ferroresonant transformer is overloaded (e.g., 150 percent loading), the voltage will collapse to zero.

(2) Magnetic synthesizers

Magnetic synthesizers use a similar operating principle to CVTs except they are three-phase devices and take advantage of the three-phase magnetics to provide improved voltage sag support and regulation for three-phase loads. They are applicable over a size range from about 15 to 200 kVA and are typically applied for process loads of larger computer systems where voltage sags or steady-state voltage variations are important issues.

(3) Active series compensators

Advances in power electronic technologies and new topologies for these devices have resulted in new options for providing voltage sag ride-through support to critical loads. One of the important new options is a device that can boost the voltage by injecting a voltage in series with the remaining voltage during a voltage sag condition. These are referred to as active series compensation devices and are available in size ranges from small single-phase devices (1-5kVA) to very large devices that can be applied on the medium-voltage systems (2 MVA and larger).

(4) On-line UPS

In online UPS, the load is always fed through the UPS. The incoming ac power is rectified into dc power, which charges a bank of batteries. This dc power is then inverted back into ac power, to feed the load. If the incoming ac power fails, the inverter is fed from the batteries and continues to supply the load. In addition to providing ride-through for power outages, an on-line UPS provides very high isolation of the critical load from all power line disturbances. However, the on-line operation increases the losses and may be unnecessary for protection of many loads.

(5) Standby UPS

A standby power supply is sometimes termed off-line UPS since the normal line power is used to power the equipment until a disturbance is detected and a switch transfers the load to the battery backed inverter. The transfer time from the normal source to the battery-backed inverter is important. A standby power supply does not typically provide any transient protection or voltage regulation as does an on-line UPS. The UPS specifications include kVA capacity, dynamic and static voltage regulation, harmonic distortion of the input current and output voltage, surge protection, and noise attenuation.

(6) Hybrid UPS

Similar to the standby UPS, the hybrid UPS utilizes a voltage regulator on the UPS output to provide regulation to the load and momentary ride-through when the transfers from normal to UPS supply.

(7) Motor-generator sets

Motor-generator (M-G) set is a mature technology that is still useful for isolating critical loads from sags and interruptions on the power system. A motor powered by the line drives a generator that powers the load. Flywheels on the same shaft provide greater inertia to increase ride-through time. When the line suffers a disturbance, the inertia of the machines and the flywheels maintains the power supply for several seconds. This arrangement may also be used to separate sensitive loads from other classes of disturbances such as harmonic distortion and switching transients.

(8) Flywheel energy storage systems

A modern flywheel energy system uses high-speed flywheels and power electronics to achieve sag and interruption ride-through from 10 s to 2 min. While M-G sets typically operate in the open and are subject to aerodynamic friction losses, these flywheels operate in a vacuum and employ magnetic bearings to substantially reduce standby losses. Since the amount of energy stored is proportional to the square of the speed, a great amount of energy can be stored in a small space. To store energy, the rotor is spun up to speed as a motor. When energy is needed, the rotor and armature act as a generator. As the rotor slows when energy is extracted, the control system automatically increases the field to compensate for the decreased voltage. The high-speed flywheel energy storage module would be used in place of the battery in any of the UPS concepts previously presented.

(9) Superconducting magnetic energy storage (SMES) devices

An SMES device can be used to alleviate voltage sags and brief interruptions. The energy storage in an SMES-based system is provided by the electric energy stored in the current flowing in a superconducting magnet. Since the coil is lossless, the energy can be released almost instantaneously. Through voltage regulator and inverter banks, this energy can be injected into the protected electrical system in less than 1 cycle to compensate for the missing voltage during a voltage sag event.

(10) Static transfer switches and fast transfer switches

There are a number of alternatives for protection of an entire facility sensitive to voltage sags include dynamic voltage restorers (DVRs) and UPS systems using technology similar to the systems described previously but applied at the medium-voltage level. Another alternative that can be applied at either the low-voltage level or the medium-voltage level is the automatic transfer switch. Automatic transfer switches can be of various technologies, ranging from conventional breakers to static switches. Fast transfer switches that use vacuum breaker technology are available that can transfer in about 2 electrical cycles. Static switches use power electronic switches to accomplish the transfer within about a quarter of an electrical cycle. The most important consideration in the effectiveness of a transfer switch for protection of sensitive loads is that it requires two independent supplies to the facility.