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A Technical Investigation of Voltage Sag

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Abstract: *Voltage sag is regarded as one of the most harmful power quality disturbances due to its costly impact on sensitive loads. The vast majority of the problems occurring across the utility, transmission and industrial sides are voltage sags. The source of sag can be difficult to locate, since it occurs either inside or outside facilities. So, this paper analyses some aspects of voltage sag such as the cost of voltage sag, their characteristics, types of voltage sag, its occurrence, percentage of sag present in power system, acceptable level of voltage sag curve, voltage sag indices, its economical impact, ways to mitigate the voltage sag and finally few devices used to mitigate voltage sag.*

Keywords: *Voltage sag, impact, types, occurrence etc.*

I. INTRODUCTION

The name power quality has become one of the most productive concepts in the power industry since late 1980s. Power quality is the *"Degree to which both the utilization and delivery of electric power affects the performance of electrical equipment"* [1].Power quality is decided by magnitude of voltage and frequency. Voltage quality problem is divided into under voltage, overvoltage, interruption, voltage sag, voltage swell and so on, and frequency quality problem could be classified into frequency variations, transient, harmonics, etc. [2].

Voltage sag or Voltage dip the two terms are equivalent. According to the IEEE defined standard (IEEE Std. 1159, 1995), voltage sag is the decrease of rms value of voltage from 0.1 to 0.9 per unit (pu), for a duration of 0.5 cycle to 1 minute. The International Electrotechnical Commission, IEC, has the following definition for a dip (IEC 61000-2-1, 1990). "A voltage dip is a sudden reduction of the voltage at a point in the electrical system, followed by a voltage recovery after a short period of time, from half a cycle to a few seconds".

Voltage sags are present in power systems, but only during the past decades customers are becoming more sensitive to the inconvenience caused [3]. Voltage sag can cause serious problems to sensitive loads, because these loads often drop off-line due to voltage sag. As a result, some industrial facilities experience production outage that results in economic losses [4, 5, 6]. In several processes such as semiconductor manufacturing or food processing plants, the voltage dip of very short duration can cost a substantial amount of money [7]. Voltage dip is the main power quality problem for the semiconductor and continuous manufacturing industries, and also to the hotels and telecom sectors [8].

International Joint Working Group (JWG) C4.1110 sponsored by CIGRE, CIRED and UIE has addressed a number of aspects of the immunity of equipment and installations against voltage dips and also identified areas were additional work is required. The work took place between 2006 and 2009 and resulted in a technical brochure distributed via CIGRE and UIE [9]. Voltage sag on a power grid can affect facilities within a 100-mile radius. According to Electric Power Research Institute the voltage sag causes 92% of distribution & transmission power quality problems.

A typical electric customer in the U.S experiences 40 to 60 sag events per year with those events resulting in the voltage dropping to between 60 to 90% and lasting several cycles to more than a second. The large majority of faults on a utility system are single line-to-ground faults (SLGF). Three phase faults can be more severe, but much less common. System wide, an urban customer on average may see 1 or 2 interruptions a year whereas the same customer may experience over 20 voltage sag occurrences a year depending on how many circuits are fed from the substation.

II. COST OF VOLTAGE SAG

Voltage sag lasting for a few cycles result in losses of several million dollars includes:

a. Repairs cost.
b. Increased buffer inventories.
c. Product quality issues affect brand name, fame of the industry and even the country.
d. Customer dissatisfaction due to huge loss in business.
e. Penalties and disposal fees.
f. Product-related losses, such as loss of product/materials,
hampered production capacity, disposal charges, and increased inventory requirements.
g. Labor-related losses, such as idle employees, overtime, cleanup and repair.
h. Ancillary costs, such as damaged equipment, lost opportunity cost and penalties due to shipping delays.

III. CHARACTERISTICS OF VOLTAGE SAG

The magnitude of voltage and the frequency are the parameters that specify the voltage sag.

a. Magnitude:

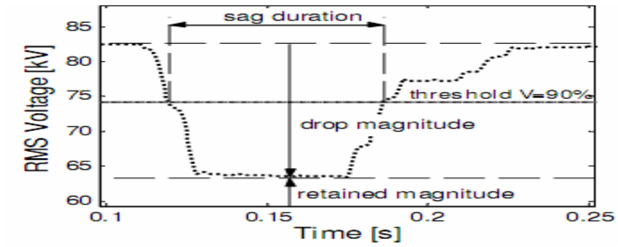


Figure 1. Voltage sag characteristics

The sag magnitude is the minimum of rms voltage and refers to the retained voltage or to the drop of the voltage (IEEE P1564). Thus, a 70% sag in a 230-V system indicates the voltage dropped to 161 V. One could be tricked into thinking that 70% sag refers to a drop of 70%, thus a remaining voltage of 30% [10].The most common approach to obtain the sag magnitude is to use rms voltage. There are other alternatives, e.g. rms voltage of fundamental component and peak voltage [11,12].The rms voltage is calculated over one cycle using equation 1

$$V_{rms}(k) = \sqrt{\frac{1}{N}\sum_{i=k-N+1}^{k} v_i^2}$$ **--------------- (1)**

The rms value using one half cycle is given by equation 2

$$V_{rms(1/2)}(k) = \sqrt{\frac{2}{N}\sum_{i=k-(N/2)+1}^{k} v_i^2}$$ -----------------(2)

Where N is the number of samples per cycles, V(i) is the instantaneous sampled voltage and k is the instant when the rms voltage is estimated.

b. Duration: Sag duration is commonly determined by the speed of the fault clearing time. The voltage sag duration is nothing but the period of time in which the voltage is lower than the stated limit; normally sag duration is less than 1 second (IEEE Std. 493, 1997). According to IEEE Std. 1159, 1995 voltage sag has been classified into three types based on their duration i) Instantaneous (0.5-30cycle) ii) Momentary (30 cycles-3sec) iii) Temporary (3sec-1min). For measurements in the three-phases systems the three rms voltages have to be considered to determine duration of the sag. The voltage sag starts when at least one of the rms voltages drops below the sag-starting threshold. The sag ends when all three voltages have recovered above the sag-ending threshold.

c. Unbalance of Sag: In the power system the faults are classified as symmetrical (balanced) and unsymmetrical (unbalanced) depending on the type of fault. If three phase fault occurs, the sag will be symmetrical but if the fault is single phase, double phase or double phase to ground faults the sag in three phases will not be symmetrical.

d. Phase-Angle Jump: A short circuit in a power system not only causes voltage sag, but also changes the phase angle of the voltage leading to phase-angle jump. The phase-angle jump is visible in a time-domain plot of the sag as a shift in voltage zero-crossing between the pre-event and the during-event voltage. If source and feeder impedance have equal X/R ratio, there will be no phase-angle jump in the voltage at the Point of Common Coupling. This is the case for faults in transmission systems, but normally not for faults in distribution systems. The distribution systems may have phase-angle jumps up to a few tens of degrees.

For unsymmetrical faults, the analysis becomes much more complicated. A consequence of unsymmetrical faults (single-phase, phase-to-phase, two-phase-to-ground) is that single-phase load experiences a phase-angle jump even for equal X = R ratio of feeder and source impedance. From the measured voltage wave shape, the phase angle of the voltage during the event must be compared with the phase angle of the voltage before the event.

IV. TYPES OF VOLTAGE SAG

Based on the phases affected during the sag, the voltage sag has been classified into three types:

a. Single Phase Sags: The frequently occurring voltage sags are single phase events which are basically due to a phase to ground fault occurring somewhere on the system. On other feeders from the same substation this phase to ground fault appears as single phase voltage sag. Typical causes are lightning strikes, tree branches, animal contact etc. It is common to see single phase voltage sags to 30% of nominal voltage or less in industrial plants.

b. Phase to Phase Sags: The two phase or phase to phase sags are caused by tree branches, adverse weather, animals or vehicle collision with utility poles. These types of sags typically appear on other feeders from the same substation.

c. Three Phase Sags: These sags are caused by switching or tripping of a 3 phase circuit breaker, switch or recloser which will create three phase voltage sag on other lines fed from the same substation. Symmetrical 3 phase sags arise from starting large motors and they account for less than 20% of all sag events and are usually confined to an industrial plant or its immediate neighbors.

V. OCCURRENCE OF VOLTAGE SAG

Voltage sag occurs at almost all locations in the power system and avoiding them is only practically possible up to a certain extent. Voltage sag is caused by faults on the system, transformer energizing, or heavy load switching. -Reducing the number and severity of voltage sag experienced by a customer, beyond what is normally considered as good engineering practice, can be very expensive [11].

Utility side voltage sag occurs due to operation of reclosers & circuit breakers, equipment fails(due to overloading, cable faults), bad weather (thunderstorms and lightning strikes cause a significant number of voltage sags), animals & birds(squirrels, raccoons and snakes occasionally find their way onto power lines or transformers and can cause a short circuit or either phase to phase or phase to ground), Vehicles occasionally collide with utility poles (causing lines to touch, protective devices trip and voltage sags occur), Construction activity(Digging foundations for new building construction can result in damage to underground power lines and create voltage sags).

Salt spray builds up on power line insulators over time in coastal areas, even many miles inland, can cause flash over especially in stormy weather. Dust in arid inland areas can cause similar problems. As circuit protector devices operate voltage sags appear on other feeders. If electrical equipment fails due to overloading, cable faults etc., protective equipment will operate at the sub-station and voltage sags will be seen on other feeder lines across the utility system.

Industrial side voltage sags occurs within an industrial facility (due to factory equipment, office equipment, air conditioning & elevator drive motors) or a group of facilities by the starting of large electric motors either individually or in groups. The large current inrush on starting can cause voltage sags in the local or adjacent areas even if the utility line voltage remains at a constant nominal value. Starting a large load, such as an electric motor or resistive heater, typically draw 150% to 500% of their operating current as they come up to speed. Resistive heaters typically draw 150% of their rated current until they warm up. Even 80% of all power quality problems occur in a company’s distribution and grounding/bonding systems.

Electronic process controls, sensors, computer controls, PLC’s and variable speed drives, conventional electrical relays are all to some degree susceptible to voltage sags. In many cases one or more of these devices may trip if there is a voltage sag to less than 90% of nominal voltage even if the duration is only for one or two cycles i.e. less than 100 milliseconds. The time to restart production after such an unplanned stoppage can typically be measured in minutes, hours or even days. Costs per event can be many tens of thousands of dollars. Voltage sag cannot be eliminated fully so, Industrial customers who have invested heavily in production equipment which is susceptible to voltage sags must take responsibility for their own solutions to voltage sags or lose some benefit from their investment.

VI. PERCENTAGE OF SAG PRESENT IN POWER SYSTEM

The most common types of voltage abnormalities are: harmonics, voltage sags, voltage swells and short interruptions. Among these, voltage sags account for the highest percentage of occurrences in equipment interruptions, as shown in Figure 1. The figure 1 indicates that voltage sags account for the highest percentage of equipment interruptions, i.e., 31%. Voltage sags are also major power quality problem that contributes to nuisance tripping and malfunction of sensitive equipment in industrial processes and Table 1 below gives causes of voltage sag on distribution system based on number of voltage sag occurrences and its percentage.

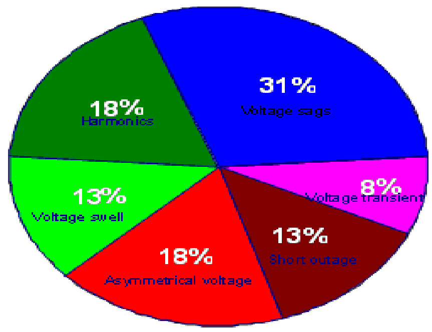


Figure 1 Power quality disturbances [28]

Table 1. Causes of voltage sag on distribution system

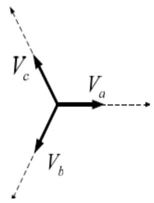
Sl. No	Causes	Number of Occurrences	Percentage
1.	Wind & lightning	37	46%
2.	Utility equipment failure	8	10%
3.	Construction or traffic accident	8	10%
4.	Animals	5	6%
5.	Tree limbs	1	1
6.	Unknown	21	26%
Total		80	100%

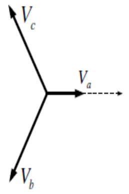
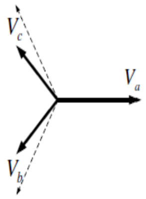
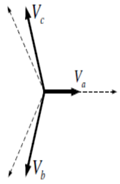
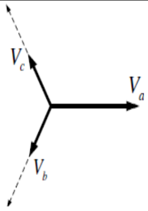
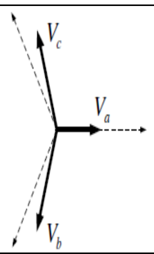
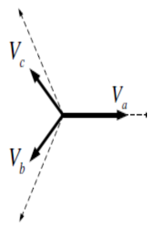
VII. CLASSIFICATION OF VOLTAGE SAG

There are two methods for classification the three phase voltage sags i) ABC Classification (First method) ii) Symmetrical Components (Second method). Due to simplicity, first method is more used than the symmetrical components classification. However, this classification is based on a simplified model of the network and it is not recommended to use for the classification of voltage sags obtained from measured instantaneous voltages.

In the first classification, in 1997, Bollen has proposed a four type's classification for voltage sags (A, B, C, D) based on type of fault which generates the sag [13]. This classification isn't so good for voltage sags generated by 2PN (2 phase to neutral) faults [14, 15]. So, Bollen has proposed a new by adding another three (E, F, G) types of voltage sags. Types of voltage sag are:

Table 2. The phasor diagram and equations

Type of voltage sag	Phasor diagram	Phase to neutral equations
Type A: Voltage sag during the event is equal (symmetrical) in all the three phases and they are generated by 3P (3 phase or 3PN (3 Phase to neutral) faults.		$\bar{V}_a = V$ $\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}V$ $\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}V$

Type B: The voltage sags generated by PN (phase to neutral) faults are classified as type B, if the consumer has star connection, these sag are rare to occur.		$\bar{V}_a = V$ $\bar{V}_b = -\frac{1}{2}\bar{E}_1 - j\frac{\sqrt{3}}{2}\bar{E}_1$ $\bar{V}_c = -\frac{1}{2}\bar{E}_1 + j\frac{\sqrt{3}}{2}\bar{E}_1$
Type C: Voltage sags generated by 2P (2 Phase) faults are classified as type C, if the consumer has star connection. Even voltage sag generated by PN faults, are classified as type C if the consumer has delta connection.		$\bar{V}_a = E_1$ $\bar{V}_b = -\frac{1}{2}E_1 - j\frac{\sqrt{3}}{2}V$ $\bar{V}_c = -\frac{1}{2}E_1 + j\frac{\sqrt{3}}{2}V$
Type D: Voltage sags generated by 2P (2 Phase) faults are classified as type D if the consumer has delta connection.		$\bar{V}_a = V$ $\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}E_1$ $\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}E_1$
Type E: It shows a symmetrical relation between PP (Phase to Phase) and PN voltage. These are also rare to occur and can be seen only when a LLG fault is located at the same voltage level or when the fault propagates through a star-star connected transformer grounded at both sides.		$\bar{V}_a = E_1$ $\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}V$ $\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}V$
Type F: It is a reduction in one phase voltage. It is caused by the propagation of a LLG fault through a delta star connected transformer. For this type of sag, when the PN voltage is zero, the minimum PP voltage is 1/3.		$\bar{V}_a = V$ $\bar{V}_b = -\frac{1}{2}V - j(\frac{\sqrt{3}}{6}V + \frac{\sqrt{3}}{3}E_1)$ $\bar{V}_c = -\frac{1}{2}V + j(\frac{\sqrt{3}}{6}V + \frac{\sqrt{3}}{3}E_1)$
Type G: These sags are obtained by the propagation of a sag type F through a delta – star connected transformer. For this type of sag the minimum PN voltage is 1/3 when PP voltage is zero.		$\bar{V}_a = \frac{2}{3}E_1 + \frac{1}{3}V$ $\bar{V}_b = -\frac{1}{3}E_1 - \frac{1}{6}V - j\frac{\sqrt{3}}{2}V$ $\bar{V}_c = -\frac{1}{3}E_1 - \frac{1}{6}V + j\frac{\sqrt{3}}{2}V$

The pre-event voltage in phase A is denoted as E1, recalling to the equivalence between phase A voltage and positive sequence voltage in a balanced system. The voltage in the phase that has experienced the sag or between the phases that has experienced the sag is indicated as V. In table 1 sag types are shown considering phase A as the reference phase. It means that another set can be derived for phase B or C are set as the reference phase. This classification is the base for international standard IEC 61000-4-11[18], because it makes possible generation of the seven types of voltage sag.

VIII. ACCEPTABLE LEVEL OF VOLTAGE SAG CURVE

This is generally determined by power quality curves, a plot of voltage magnitude versus time. Power quality curves represent the intensity and duration of voltage disturbances. The Computer and Business Equipment Manufacturers' Association (CBEMA), and Semiconductor Equipment and Materials Institute (SEMI) have published information defining what levels of poor power quality, specifically voltage sag, equipment should be able to tolerate. Other power quality curves in common use today were developed by the American National Standards Institute (ANSI) and the Information Technology Industry Council (ITIC).

The ANSI curves plot the deviation from nominal voltage as a percentage of nominal voltage compared to the duration or the maximum length of time the voltage is permitted to reach. For example, the limit for voltage occurrences greater than 1 second duration might be ± 10%. The ITIC and CBEMA curves also plot voltage with respect to duration, but as a percentage of absolute voltage. Electronic equipment can typically withstand high voltages provided they last for less than 1 millisecond in duration, but voltages greater than +10% or -20% for between 0.5 seconds and 10 seconds duration are to likely create problems.

ITIC also shows that computer equipment should be able to ride through short-duration voltage sags, if the voltage doesn't go below 70%. For sags of longer duration, voltages below 80% could affect the equipment. Even SEMI F47 semiconductor industry standard specifies an improved voltage sag ride-through for process tools. It requires a ride-through down to 50% voltage for 200 milliseconds, which will significantly reduce the number of voltage sags that may cause process disruptions in semiconductor plants. These curves are merely guidelines, and some electronic equipment may require higher power quality conditions than those represented in these standards.

IX. VOLTAGE SAG INDICES

PQ indices are key issue to indicate the different performance experienced at the transmission, sub-transmission, substation and distribution circuit levels. There are various ways of presenting voltage sag performance [16].

a.SARFI (System Average Rms Variation Frequency Index)
b.SIARFI (System Instantaneous Average Rms Variation Frequency Index)
c.SMARFI (System Momentary Average Rms Variation Frequency Index)

The most common index use is the SARFI. This index represents the average number of voltage sags experienced by a end user each year with a specified characteristic. For SARFI_X, the index would include all of the voltage dips where the minimum voltage was less than X(where X is a number between 0 and 100)gives the number of events with a duration between 10 milliseconds and 60 seconds and a retained voltage less than X%. SARFI_70 gives the number of events with retained voltage less than 70% [17, 18]. Standard voltage thresholds are 140, 120, 110, 90, 80, 70, 50, and 10 % of nominal.

X. ECONOMICAL IMPACT OF VOLTAGE SAG

The cost associated with the voltage sag is more compared to other power quality issues:

a. The cost to North American industry of production stoppages caused by voltage sags now exceeds U$250 billion per annum [9].

b. In South Africa, a recent study showed that major industries suffer annual losses of more than 200 US$ million due to voltage sag problems [11].

c. A study in United States (U.S.), the total damage by voltage sag may amount to 400 Billion Dollars [12].

d. Manufacturing facilities have cost ranging up to millions of dollars attributed to a single disruption of the process whereas the cost to commercial customer (e.g., banks, data center, customer service centers, etc.) can be just as high if not higher [14].

e. In automotive industry, four-cycle voltage sag can lost over 700,000 US$ in the following 72 minutes due to shut down of process and required rework from malfunction of programmable controllers and drive systems working in a real-time process environment [19].

f. One automaker estimated that the total losses from momentary voltage sag at all its plants runs to about $10M a year [1].

g. Manufacturing facilities have costs ranging from Rs.4, 00,000 to millions of rupees associated with a single interruption to the process. Momentary interruptions or voltages sags lasting less than 100 ms can have the same impact as in outage lasting many minutes [20].

h. If an interruption costs Rs.16, 00,000, the total costs associated with voltage sags and interruptions would be Rs.2, 70, 40,000/-year. (The total cost is appro. 17 times the cost of an interruption) [21].

The table 3 shows some industries and their loss per event due to voltage sag and table 4 shows Cost of Momentary interruption due to voltage sag.

Table 3. Industries and their loss per event

Sl.No	Industry	Loss per event (US$)
1.	***Semiconductor industry***	2,500,000
2.	***Credit card processing***	250,000
3.	***Equipment manufacturing***	100,000
4.	***Automobile industry***	75,000
5.	***Chemical industry***	50,000
6.	***Paper Manufacturing***	30,000

Table 4. Shows industries & their Cost of Momentary interruption [22]

		Cost of Momentary interruption	
Sl.No	Industry	Minimum	Maximum
1.	***Semiconductor Manufacturing***	$20.0	$60.0
2.	***Pharmaceutical***	$5.0	$50.0
3.	***Electronics***	$8.0	$12.0
4.	***Communications, Information Processing***	$1.0	$10.0
5.	***Automobile manufacturing***	$5.0	$7.5
6.	***Food processing***	$ 3.0	$ 5.0
7.	***Glass***	$4.0	$6.0
8.	***Petrochemical***	$3.0	$5.0
9.	***Textile***	$2.0	$4.0
10.	***Rubber & plastics***	$3.0	$4.5
11.	***Metal fabrication***	$2.0	$4.0
12.	***Mining***	$2.0	$4.0
13.	***Hospitals, Banks, Civil services***	$2.0	$3.0
14.	***Paper***	$1.5	$2.5
15.	***Printing (News Paper)***	$1.0	$2.0
16.	***Restaurants, bars, hotels***	$0.5	$1.0
17.	***Commercial shops***	$0.1	$0.5

XI. MITIGATION OF VOLTAGE SAG

There are several ways to mitigate the voltage sag:

a. From Fault to Trip: The equipment trip is the main cause of voltage sag, if there are no equipment trips due to short-circuit fault, there is no voltage sag problem. Due to short circuit at the fault position, the voltage drops to zero, or to a very low value. This zero voltage is changed into an event of a certain magnitude and duration at the interface between the equipment and the power system. If the fault takes place in a radial part of the system, the protection intervention clearing the fault will also lead to an interruption. If there is sufficient redundancy present, the short circuit will only lead to voltage sag. If the resulting event exceeds a certain severity, it will cause an equipment trip. The equipment trip due to short circuit fault can be minimized by:

• Reducing the fault-clearing time.
• Changing the system such that short-circuits faults result in less severe events at the equipment terminals or at the customer interface.
• Connecting mitigation equipment between the sensitive equipment and the supply.
• Improving the immunity of the equipment.

b. Reducing the Number of Faults:

Short circuits cannot be entirely eliminated. The majority of failures are due to faults on one or two distribution lines. Below mentioned fault mitigation measures may be expensive, especially for transmission systems but their costs have to be weighed against the consequences of the equipment trips. The actions taken are:

- Replacing overhead lines with cables.
- The use of insulated conductors on overhead lines.
- Regular tree cutting in the area of the transmission line and fencing against animal.
- Shielding overhead conductors with additional shield wires and by increasing insulation level.
- Increased frequency of overhaul and periodic maintenance, cleaning insulators etc.

c. Reducing the Fault-Clearing Time: To minimize the fault clearing time several types of fault current limiters(able to clear a fault within one half-cycle) are in use for low and medium voltages system i.e. few tens to kilovolts, but actually they do not clear the fault, they only reduce the current magnitude within one or two cycles. Reducing the fault clearing time of any event does not reduce the number of events occurring, but can reduce the severity of fault impact. Recently introduced static circuit breaker has the same characteristics as fault current limiters. Fault-clearing time is not only the time needed to open the breaker, but also the time needed for the protection to make a decision.

d. Changing the Power System: The cost associated with changing the supply system may be high, especially for transmission and sub transmission voltage levels. But in case of industrial systems, the design stage will outweigh the cost. Some other ways to mitigate the voltage sags are:

- By installing a generator near the sensitive load. The generators will keep up the voltage during remote sag.
- Split buses or substations in the supply path to limit the number of feeders in the exposed area.
- Determine the frequency, depth & duration of the voltage sag. Collection of data is essential if the optimal solution is to be determined.
- In order to provide a cost effective solution to voltage sag problems, it is necessary to determine which equipment is more subjected to voltage sag.

XII. INSTALLING VOLTAGE SAG MITIGATING EQUIPMENT

There are number of mitigating devices used to mitigate the voltage sag:

a. ***Device Voltage Restorer (DVR):*** DVR uses modern power electronic components to insert a series voltage source between the supply and the load. The voltage source compensates for the voltage drop due to the sag. The DVR is a series connected facts device to protect sensitive loads from supply side disturbances; it can also act as a series active filter, isolating the source from harmonics generated by loads. This is often the best solution when voltage sags are the dominant concern. DVR is also used for protecting individual loads or group of loads.

b. ***Uniform Power Quality Conditioner (UPQC):*** is the integration of series and shunt active filters, connected back to back on the dc side and share a common DC capacitor. The series connected UPQC is responsible for mitigation supply side disturbances such as voltage sags, flickers, voltage unbalance and harmonics. The shunt component is responsible for mitigating the current quality problems caused by consumer: poor power factor, load harmonic currents, load unbalance etc. It can perform the function of both DSTATCOM and DVR [23].

c. ***Uninterruptable Power Supply (UPS):*** Utilize batteries to store energy that is converted to a usable form during outage or voltage sag. This is the most commonly used device to protect low-power equipment (computers, etc.) against voltage sags and interruptions. During the sag or interruption, the power supply is taken over by an internal battery. The battery can supply the load for, typically, between 15 and 30 minutes.

d. ***Motor-Generator Sets (M-G Sets):*** It usually utilizes flywheels for energy storage. They completely decouple the load from the electric power system. Rotational energy in the flywheel provides voltage regulation and voltage support during under voltage conditions. M-G sets have relatively high efficiency and low initial capital cost. They are only suitable for industrial environment due to noise and the maintenance required compare to office environment.

e. Ferro resonant, Constant Voltage Transformers (CVTs): can be used to improve voltage sag ride through capability. CVTs are especially attractive for constant, low power loads, variable loads, especially with high inrush currents, present more of a problem for CVTs because of the tuned circuit on the output. CVTs are basically 1:1 transformers which are excited high on their saturation curves, thereby providing output voltage which is not significantly affected by input voltage variations.

f. ***Static transfer switch:*** A static transfer switch switches the load from the supply with the sag to another supply within a few milliseconds. This limits the duration of sag to less than one half cycle, assuming that a suitable alternate supply is available.

XIII. CONCLUSION

Voltage sag is an avoidable natural phenomenon in a power system; faults in the system are the main reason for the voltage sag. The issues related to voltage sag are gaining importance because a small power outage has a great economical impact especially on the industrial consumers. A longer interruption harms practically all operations of modern society sensitive equipment. So it is necessary to have awareness regarding damages caused by voltage sag by analyzing their characteristics, types, its places of occurrence, percentage of damages caused by the presence of sag, acceptable level of sag curve and its indices. Lastly by taking following some strict measures and by installing mitigating equipment the voltage sag can be avoided upto certain extent.

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