VOLTAGE SAGS: AN EXPLANATION - CAUSES, EFFECTS AND CORRECTION - PART I

By Ian K.P. Ross, MIEE, Omniverter Inc.

1.0 VOLTAGE SAG DEFINITION

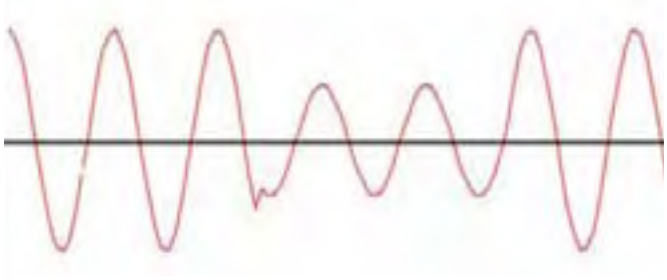
1.1 Voltage Sag

A voltage sag as defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is a decrease in RMS voltage at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage.

The measurement of a voltage sag is stated as a percentage of the nominal voltage, it is a measurement of the remaining voltage and is stated as a sag to a percentage value. Thus a voltage sag to 60% is equivalent to 60% of nominal voltage, or 288 volts for a nominal 480 Volt system.

1.2 Voltage Dip

In North America a voltage dip is usually understood to mean the amount by which the nominal voltage declines - in



Voltage Sag - A reduced voltage for a limited period
Figure 1

percentage terms this, is 100-voltage sag. Thus, a voltage dip of 40% equates to a voltage sag to 60%.

Unfortunately in practice there is confusion, and the terms voltage sag and voltage dip are sometimes interchanged. It is therefore important that data is clarified.

2.0 WHERE DO VOLTAGE SAGS OCCUR?

2.1 Utility Systems

Voltage sags can occur on utility systems both at distribution voltages and transmission voltages. Voltage sags that occur at higher voltages will normally spread through a utility system and will be transmitted to lower voltage systems via transformers.

2.2 Inside Industrial Plants

Voltage sags can be created within an industrial complex without any influence from the utility system. These sags are typically caused by starting large motors or by electrical faults inside the facility.

3.0 CAUSES OF VOLTAGE SAGS

3.1 Utility Systems

3.1.1 Operation of Reclosers and Circuit breakers

If, for any reason, a sub-station circuit breaker or a recloser is tripped, then the line that it is feeding will be temporarily disconnected. All other feeder lines from the same substation system will see this disconnection event as a voltage sag which will spread to consumers on these other lines (See Fig.2). The depth of the voltage sag at the consumer's site will vary depending on the supply line voltage and the distance from the fault. Typically, a higher supply voltage will have a larger sag affected zone.

3.1.2 Equipment Failure

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.

3.1.3 Bad Weather

Thunderstorms and lightning strikes cause a significant number of voltage sags. If lightning strikes a power line and continues to ground, this creates a line-to-ground fault. The line-to-ground fault in turn creates a voltage sag and this reduced voltage can be seen over a wide area. Note the lightning strike to ground causes voltage sags on all other lines (See Fig 2). Circuit breakers and reclosers operate more frequently in poor weather conditions:

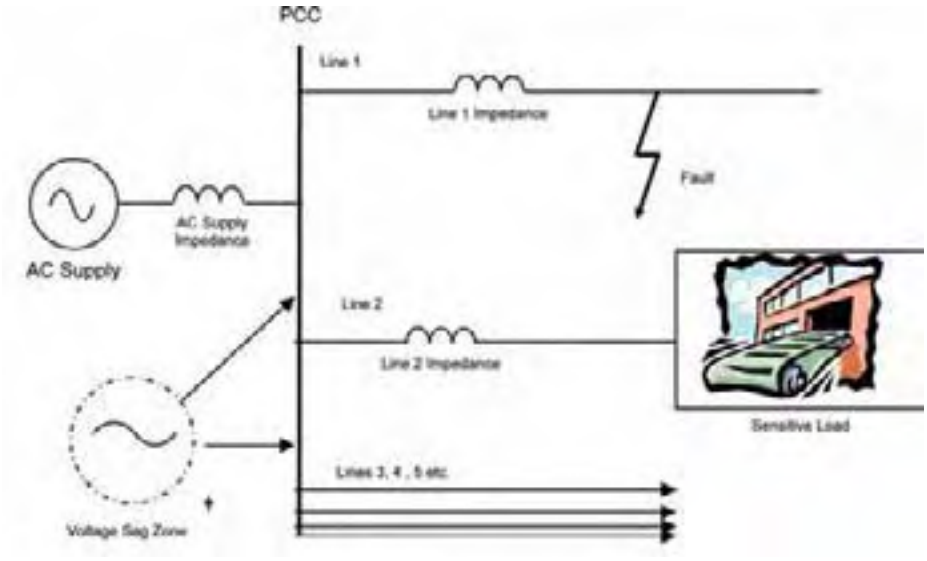


Figure 2

• High winds can blow tree branches into power lines. As the tree branch strikes the line, a line-to-ground fault occurs which creates a voltage sag. If the line protection system does not operate immediately, a series of sags will occur if the branch repeatedly touches the power line. Broken branches landing on power lines cause phase-to-phase and phase-to-ground faults.

• Snow and ice build-up on power line insulators can cause flash-over, either phase-to-ground or phase-to-phase. Similarly, snow or ice falling from one line can cause it to rebound and strike another line. These events cause voltage sags to spread through other feeders on the system.

3.1.4 Pollution

Salt spray build-up on power line insulators over time in coastal areas, even many miles inland, can cause flashover, especially in stormy weather. Dust in arid inland areas can cause similar problems. As circuit protector devices operate, voltage sags appear on other feeders.

3.1.5 Animals & Birds

Animals, particularly squirrels, raccoons and snakes occasionally find there way onto power lines or transformers and can cause a short circuit either phase-to-phase or phase-to-ground. Large birds, geese and swans, fly into power lines and cause similar faults. While the creature rarely survives, the protective circuit breaker operates and a voltage sag is created on other feeders.

3.1.6 Vehicle Problems

Utility power lines frequently run alongside public roads. Vehicles occasionally collide with utility poles causing lines to touch, protective devices trip and voltage sags occur.

3.1.7 Construction Activity

Even when all power lines are underground, digging foundations for new building construction can result in damage to underground power lines and create voltage sags.

3.2 Industrial Plants

Voltage sags can be caused within an industrial facility 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.

4.0 MULTI-PHASE SAGS AND SINGLE-PHASE SAGS

4.1 Single-Phase Sags

The most common voltage sags, over 70%, are single-phase events which are typically due to a phase-to-ground fault occurring somewhere on the system. This phase-to-ground fault appears as a single phase voltage sag on other feeders from the same substation. Typical causes are lightning strikes, tree branches, animal contact etc. It is not uncommon to see single-phase voltage sags to 30% of nominal voltage or even lower in industrial plants.

4.2 Phase-to-Phase Sags

Two-phase, phase-to-phase sags may be caused by tree branches, adverse weather, animals or vehicle collision with utility poles. The two-phase voltage sag will typically appear on other feeders from the same substation.

4.3 3 Phase Sags

Symmetrical three-phase sags account for less than 20% of all sag events and are caused either by switching or tripping of a three-phase circuit breaker, switch or recloser which will create a three-phase voltage sag on other lines fed from the same substation.

Three-phase sags will also be caused by starting large motors, but this type of event typically causes voltage sags to approximately 80% of nominal voltage and are usually confined to an industrial plant or its immediate neighbours.

5.0 VOLTAGE SAGS AFFECT PRODUCTION

Both single-phase and multi-phase voltage sags can cause unplanned production stoppages but single-phase (120V) control devices and electronic sensors can be very vulnerable to voltage sags.

Modern electronic equipment requires more precise voltage regulation than traditional devices such as induction

motors. When the manufacturing industry used mechanical devices and gearboxes to control the speed of its processes, many of which were relatively slow and required manual operation or intervention by operators, voltage variations were not such a serious issue.

Automation has lead to high speed processes, automatic electronic sensing and controls; precision machine tools have sophisticated electronic controls, variable speed drives have replaced many gearboxes and any unplanned manufacturing stoppage can be very expensive.

Electronic process controls, sensors, computer controls, PLCs and variable speed drives, even 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.

5.1 Cost Of Voltage Sags

A recent EPRI study (Ref 2) suggests that the cost to North American industry of production stoppages caused by voltage sags now exceeds US$250 billion per annum.

6.0 WHO IS TO BLAME?

Frequently, industrial customers blame their local electrical supply utility for unplanned production stoppages and claim that other jurisdictions have "much better power quality".

Unfortunately, in many cases there is little or nothing the utility can do. It is true that certain parts of North America experience more storms than others, so voltage sags are more prevalent in some areas.

Even in desert areas devoid of trees, storms and lightning strikes occur. Given the large distances between power plants and consumers in North America, the cost of underground conductors at all voltages would be prohibitive, even if underground rights-of-way were available. Few consumers would wish to see their utility power bill increase several fold in order to pay for this.

Very few utilities, anywhere in the world, escape voltage sags. Even those with total underground systems in a small geographic area such as Singapore suffer voltage sags. These may be due to damage to cables by digging for new construction or due to failure of electrical equipment from cable faults, overloads etc.

7.0 INDUSTRIAL RESPONSIBILITY

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.

Voltage sags are a fact of life – they cannot readily be eliminated from regular utility systems.

For the industrial customer the solution may involve replacement of components or devices, which are especially sensitive, with less voltage sensitive substitutes or installation of some form of protection against voltage sags.

8.0 THE SOLUTION

8.1 First Identify the Problem

8.1.1 Equipment Identification

In order to provide an optimal and cost effective solution to voltage sag problems, it is necessary to determine which equipment is susceptible to unplanned stoppages. In most industries, there is still a significant amount of electrical equipment which is not sensitive to voltage variation or which can be restarted at little or no cost. Usually it is not necessary to protect an entire industrial facility, it is sufficient to protect the key sensitive equipment.

8.1.2 Identify the Voltage Sags

The next stage is to determine the frequency, depth and duration of the voltage sags.

These can vary widely even in apparently similar industrial facilities. Collection of this data is essential if the optimal solution is to be identified.

In North America, only a small proportion of manufacturing businesses have installed electrical metering which is capable of measuring and recording the voltage variations which are responsible for the majority of their very costly Unplanned Production Stoppages.

Look in the January/February issue for the conclusion of this article