Voltage Sags

Many businesses routinely condition and filter incoming water and even air for their facilities, and set up filters for computer and e-mail systems as well. Why not consider the same treatment for electrical equipment? Service reliability and quality of power have become growing concerns for many industrial facilities, especially with the increasing sensitivity of electronic equipment and automated controls. Although utilities do their best to supply reliable, high-quality power, periodic sags and surges on utility lines will continue to be a fact of life. If even a brief shutdown of your process equipment can result in large additional production costs (such as from downtime or scrap product), you should consider protecting your electronic equipment from the effects of power surges, sags, and other disturbances. In this brief we focus on the problem of voltage sags.

What Are Voltage Sags?

Electronic devices function properly as long as the voltage (or driving force) of the electricity feeding the device stays within a consistent range. There are several types of voltage fluctuations that can cause problems, including surges and spikes, sags, harmonic distortions, and momentary disruptions. (For definitions of these terms, see the "Power Quality Glossary" sidebar, next page.) A voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. Most voltage sags do not go below 50 percent of the nominal voltage, and they normally last from 3 to 10 cycles—or 50 to 170 milliseconds. Voltage sags are probably the most significant power quality (PQ) problem facing industrial customers today, and they can be a significant problem for large commercial customers as well.

There are two sources of voltage sags: external (on the utility's lines up to your facility) and internal (within your facility). Utilities continuously strive to provide the most reliable and consistent electric power possible. In the course of normal utility operations, however, many things can cause voltage sags. Storms are the most common cause of external sags and momentary interruptions in most areas of the U.S. A storm passing through an area can result in dozens of major and minor PQ variations, including sags. For example, consider how PQ would be affected by a lightning strike on or near a power line or by wind sending tree limbs into power lines. Other common causes of external voltage sags are ice storms, animals (particularly squirrels), and the start-up of large loads at neighboring facilities. Internal causes of voltage sags can include starting major loads and grounding or wiring problems.

Whether or not a voltage sag causes a problem will depend on the magnitude and duration of the sag and on the sensitivity of your equipment. Many types of electronic equipment are sensitive to voltage sags, including variable speed drive controls, motor starter contactors, robotics, programmable logic controllers, controller power supplies, and control relays. Much of this equipment is used in applications that are critical to an overall process, which can lead to very expensive downtime when voltage sags occur.

If your facility is having frequent voltage sag problems, a good place to start is with your utility. Ask about the utility's statistics regarding performance in your area. You should also look into possible internal causes. But whether the causes are mainly external or internal, you should consider taking charge of the problem and working toward a cost-effective solution for your facility.

Power Quality Glossary

Although specialists use complex equations for precise descriptions and analysis, the following definitions are adequate for most discussions with your local utility account managers, distribution engineers, and PQ consultants and vendors.

- *Harmonic distortion.* Continuous or sporadic distortions of the 60-hertz (Hz) voltage sine waveform, usually caused by microprocessor-based loads in the building such as computer power supplies, lighting ballasts, and electronic adjustable speed drives. Harmonics can also be transmitted from an energy user down the block. These can cause telecommunications or computer interference; overheating in motors, transformers, or neutral conductors; decreased motor performance; deterioration of power factor–correction capacitors; or erratic operation of breakers, fuses, and relays.
- *Interruption, momentary.* A very short loss of utility power that lasts up to 2 seconds, usually caused by the utility switching operations to isolate a nearby electrical problem.
- *Interruption, temporary.* A loss of utility power lasting from 2 seconds to 2 minutes, caused by a nearby short circuit due to something like animals, wet insulators, or accidents. Corrected by automated utility switching.
- *Long-term outage.* A loss of utility power lasting more than 2 minutes due to major local, area, or regional electrical events.
- *Noise.* Sporadic voltage changes consisting of frequencies higher than the normal 60-Hz power frequency due to any number of causes, including arc welders, loose wiring, and nearby radio and TV transmitters.
- *Sag.* A short-term decrease in voltage lasting anywhere from milliseconds up to a few seconds. Sags starve a machine of the electricity it needs to function, causing computer crashes or equipment lock-ups. Usually caused by equipment start-up—such as elevators, heating and air-conditioning equipment, compressors, and copy machines—or nearby short circuits on the utility system.
- *Spike.* A very brief (nanoseconds to milliseconds) change in voltage ranging from tens to thousands of volts. Can be produced by utility and customer equipment operations, nearby lightning strikes, falling tree limbs on power lines, and even static discharges.
- *Surge.* A short-term increase in voltage, lasting up to a few seconds. They are due either to customer equipment operation, such as air conditioners or motors switching on and off, or to utility activities, such as capacitor switching.
- *Transient.* A sudden momentary change in voltage. Also called a spike.
- *Undervoltage.* A decrease in voltage lasting longer than a few seconds. Usually due to undersized wiring at the facility but can also be caused by overloaded utility circuits and result in brownouts.

Solutions to Voltage Sag Problems

The first step toward a cost-effective solution is to understand the sensitivity of your electronic equipment to momentary interruptions and voltage sags. You can find this information by consulting the equipment manufacturer's specifications and testing data. You can also test the sensitivity of your equipment to voltage sags using a measuring device called a sag generator, which generates voltage sags and records the responses of the equipment.

There are several possible solutions to voltage sag problems. Generally, the least expensive approach is to purchase controls and other electronic equipment designed with a greater tolerance to voltage sags. Information on these tolerances should be included in the equipment's specifications. Another inexpensive and simple solution is to adjust the trip thresholds of sensitive equipment. If you identify a relay that is inadvertently tripping during a voltage sag, you can change its settings—either the voltage threshold or the trip delay. However, you can only do this if the trip settings were set too conservatively, so it is important to understand what they were designed to protect.

Another option is to install a coil hold-in device. These devices are designed to mitigate the effects of voltage sags on individual relays and contactors. Coil hold-in devices are installed between the relay or contactor coil connection terminals and the incoming alternating current (AC) control line. They allow a relay or contactor to remain engaged until the voltage drops to about 25 percent of nominal, significantly improving its voltage sag tolerance without interfering with emergency shutoff functions. The best application for this type of device is to support relays and contactors in an emergency off circuit, master control relay, or motor control circuit. Coil hold-in devices normally cost less than $50 and are small enough to be installed next to the contactor, relay, or motor starter.

The next level of potential solutions in terms of cost is to consider modifying the power supplied to the sensitive equipment. For example, it may be possible to substitute a direct current (DC)–operated power supply for an AC supply. This would allow you to use simple capacitors or batteries to help support the DC bus. This is the approach that high-reliability telecommunications systems commonly use. (For other relatively simple and low-cost solutions of this type, please refer to Power Standards Testing Lab, "How to Increase Voltage Sag Immunity," available at http://powerstandards.com/tutorials/immunity.htm.)

The remaining solutions for voltage sag problems involve installing some form of power conditioning device. These solutions increase in cost with the size and scope of the equipment or circuits being protected. (See **Table 1**.)

There are several technologies that serve as quick-acting voltage regulators on the AC power supply. One of the most common of these is an uninterruptible power supply (UPS). UPSs have the disadvantage of relying on a battery, which has a limited life, generates hydrogen gas (requiring ventilation), and becomes hazardous waste when it is disposed of at the end of its useful life. On the plus side, UPSs can help the equipment plugged into them ride through sags, momentary interruptions, and even extended interruptions up to the limit of the battery—10 minutes or more. A UPS

Table 1: Typical voltage sag mitigation technologies and costs

The cost of the technology used to condition the power provided to sensitive devices increases with the size and scope of the equipment or areas to be protected. The costs shown here are examples; more up-to-date and specific cost information for products suited to a specific facility's problems should be used for a final evaluation.

Alternative category	Typical cost ($)	Total initial cost[a] ($)	Operating and maintenance costs (% of initial costs per year)
Controls protection (< 5 kVA)			
CVT	1,000/kVA	1,000–5,000	10
UPS	500/kVA	500–2,500	25
Dynamic sag corrector	250/kVA	250–1,250	5
Machine or group of machines protection (10–300 kVA)			
UPS	500/kVA	5,000–150,000	15
Flywheel	500/kVA	5,000–150,000	7
Dynamic sag corrector	200/kVA	2,000–60,000	5
Facility protection (2–10 MVA)			
Dynamic voltage regulator (50% voltage boost)	300/kVA	600,000–3,000,000	5
Static switch (10 MVA)	600,000	600,000	5
Fast-transfer switch (10 MVA)	150,000	150,000	5

Note: a. For the Controls protection category, total initial cost was calculated in the range of 1 kilovolt-ampere (kVA) to 5 kVA.
CVT = constant voltage transformer; UPS = uninterruptible power supply; MVA = megavolt-ampere.
Table adapted from Mark McGranaghan and Bill Roettger, "Economic Evaluation of Power Quality," *IEEE Power Engineering Review*, v. 22, no. 2 (February 2002).

Source: Platts

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

Another common quick-acting voltage regulator is a constant voltage transformer (CVT). CVTs provide sag ride-through and also filter spikes, but they are not able to protect against interruptions, either momentary or sustained. CVTs are often used for relatively constant, low-power loads, and have the advantage of lower operating and maintenance costs than UPSs, because CVTs don't require batteries.

For an individual computer or a group of machines, another solution is to install a dynamic sag corrector, which can ride through a sag down to 50 percent of nominal voltage for up to 2.0 seconds and through an interruption of up to 0.2 seconds. Dynamic sag correctors are available in single- or three-phase configurations, for loads of 1.5 to 2,000 kilovolt-amperes (kVA). The single-phase configuration is more expensive, because it requires a storage device. UPSs and CVTs are available in smaller capacities than 1.5 kVA, and therefore may be cheaper for these smaller loads.

Economic Evaluation

If the less-expensive solutions mentioned in this brief are not effective, the next step is to evaluate the life-cycle costs and effectiveness of voltage sag mitigation technologies. This task can be very challenging and tends to be beyond the expertise of most industrial facility managers. This type of evaluation requires an analysis of the costs of your voltage sag problems in terms of downtime and lost production, the costs of the devices, and an understanding of how the mitigation devices work, including partial solutions. A good place to start in performing this type of analysis is to ask your utility or a power quality consultant for assistance. Many utilities offer power quality mitigation services or can refer you to outside specialists.