HOW FACTS ON THE DISTRIBUTION SYSTEM ARE BEING USED TO IMPROVE POWER QUALITY

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ABSTRACT

FACTS, Flexible AC transmission systems, which use power electronic, based controllable systems for transmission systems can now be scaled for use on the distribution system. Solutions like this can mitigate the source of distribution power quality problems while providing an inherent power quality improvement to other customers on the connected network. In the last decade, commercial electric customers have become increasingly interested in the relative 'quality' of the power they purchase. Although it may be difficult to imagine that some supplies of electricity can be better than others, variations in the flow or the voltage can actually damage and disrupt sensitive electronics, computers, and microprocessors. As businesses rely more heavily on modern high-tech processes, power quality is becoming even more important.

INTRODUCTION

Voltage sags and flicker are some of the most common power quality problems observed on the distribution network. Electric utility supply systems are sprawling and employ numerous components, exposing the utility system to frequent service impairment problems. Wide-ranging impacts include short circuits (faults) on the utility supply system. Faults can be single-phase, phase-to-phase, three-phase, or an evolving combination of all three phases. Large amounts of current flowing into the fault are typically drawn from many utility sources, creating a voltage drop along the fault current collection path in the utility system, and lowering the system's voltage along the current path. Even for faults that do not cause a complete outage to a customer, momentary voltage sags can branch out to a large area of the utility system, affecting many industrial plants and their processes. EPRI has published a document discussing many different aspects of power quality, including voltage sags covered in Chapter 4 [1]. The report discusses that for some industries even short voltage sags can have the same impact as a full blown outage. Some industrial processes can take as long as two days to restart, which can cost millions of dollars in losses. These events cause the majority of customer power interruptions, from large manufacturing facilities to residential customers around the world.

Sags and flicker problems on the distribution network itself can also occur due to normal operation of large loads such as welders, rock crushers, and the starting of large pump, and compressor motors. These voltage disturbances, driven by these industrial loads, are not isolated to the facilities that cause them. Other loads miles away from the source of the problem, but on the same circuit, can also be adversely affected. These voltage disturbances can interrupt sensitive customer operations, interfering with variable speed drives, protective relays, and robotics. For manufacturing facilities, the resulting loss of production can be very costly in terms of overall factory productivity.

THE BASIC POWER QUALITY PROBLEM

In order to improve power quality, it is important to know what kind of disturbance has occurred. Power quality disturbances can come in many different forms. Thus, before deciding on the type of power quality (PQ) solution, one must fully analyze the power quality problem. In general, the problems can be broken into the following three categories:

1. Momentary voltage sags, voltage swells, voltage flicker, and faults
2. Power interruptions of varying durations
3. Varying harmonic interference

Figure 1 shows the most prevalent type of PQ problem which is the voltage sag. Voltage sags are a momentary reduction in voltage on one or more phases. Typical causes of voltage sags are weather (i.e. lightning, wind, and ice), vehicle vs. pole contests, animal contacts (i.e. birds or squirrels) with phase wires, and other sources such as the starting of large motors. Voltage sags reduce the voltage – they are not a complete outage. Voltage sags are very common on worldwide utility grids.

A second type of problem that can occur is a voltage swell. A voltage swell is a momentary increase in voltage on one or more of the phases. This kind of PQ problem is more common on weakly connected grids with long transmission lines such as in the western US and Australia. It often occurs when a large load trips off-line. While this is definitely less common occurrence, it can also cause equipment to trip off-line and represents a preventable PQ problem.

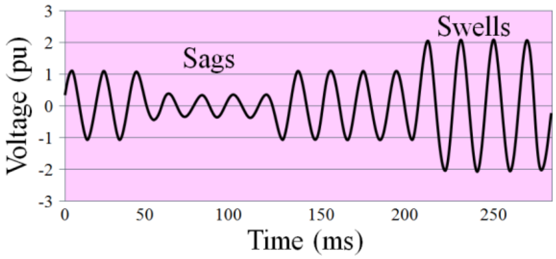

Figure 1 – Momentary Voltage Sags and Swells

Another type of PQ problem is a momentary power interruption. This is a complete loss of voltage as shown in Figure 2.Momentary power interruptions are typically caused by faults on utility system that caused the previously mentioned sags. The difference is that the problem is on the facilities serving the customer and the only way to clear the fault is to allow the protection system to operate, opening of the circuit breaker or recloser, and allow the fault to clear. For this reason, there is a momentary power interruption – a temporary outage. The outage is needed to allow utility fault interrupting device(s) to attempt to clear the fault. After the fault interrupting device opens, the protection system typically recloses and the voltage returns if the temporary fault is cleared. If the fault is not cleared, a second operation will occur and power may or may not return. If the fault is permanent, say a phase wire is in contact with the ground, then an outage will occur that may require up to several hours to find and repair.

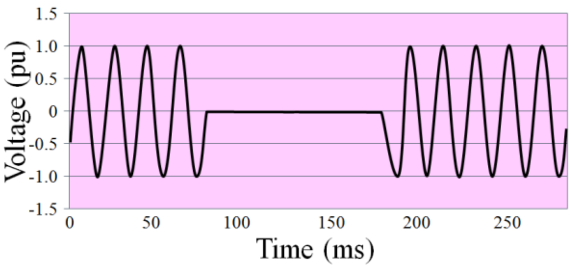

Figure 2 – Power Interruptions

The last type of PQ problem is excessive harmonic voltage distortion, which is shown in Figure 3.This type of PQ problem is common to many industrial customers and has many sources including non-linear loads such as inverters, computers, motor drives, etc.These types of loads tend to distort the voltage and current sine wave causing problems for other types of equipment that may cause them to trip off-line or fail to operate properly.

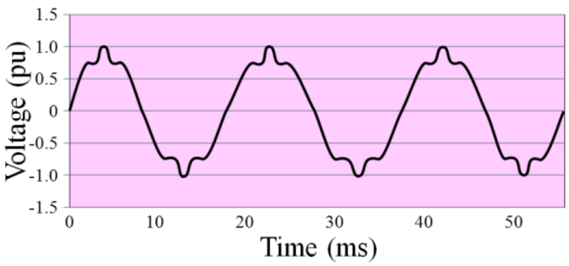

Figure 3 – Harmonic Interference

The voltage sag and swell problems can be addressed using dynamic reactive power solutions. AMSC's FACTS devices, PQ-IVR STATCOM and D-SVC solutions, can be designed to quickly restore the voltage to a safe operating level to reduce or even eliminate the impact of this problem on the distribution system. While AMSC's FACTS equipment does not eliminate harmonic problems, the analysis that AMSC conducts investigating a plant's PQ problems does include an investigation into harmonics. Shunt filter capacitor banks, used to mitigate harmonics and correct power factor, are often part of the complete voltage sag or swell solution.

The power interruption type problems require some type of uninterruptible power supply (UPS).The type of UPS system that is needed is often determined by the length of the interruption protection and the cost of that system.A UPS system can be made of a simple battery back-up system, a fly wheel energy storage system, a back-up conventional generation, or even renewable generation.

This paper focuses on the use of FACTS solutions to address distribution voltage sag and swell problems.

THE BUSINESS STEPS TO PQ IMPROVEMENT

Voltage sag (or swell) problems can result in adverse financial and commercial impacts on businesses, but there are steps that can be taken to minimize or eliminate the impacts. To begin with, are these sags events caused by events on the utility grid or by some internal process?

If they originate on the utility grid, the preliminary work should start with the local utility. The utility can be a good source of data on the voltage sag history including their depth, duration, and cause. Inquiries can be made as to what might be done to fix these problems. The utility may be making a major change in the power system configuration such as building a new line or substation that would greatly reduce the business' exposure to these voltage problems. The utility can also reduce its existing delivery systems' exposure to these voltage problems by improving its tree trimming, by adding squirrel and bird guards, by infrared scanning of its faculties looking for potential equipment failures, by adjusting normally open points, etc. Typically utility solutions can have long lead times, be comparatively expensive, and may not fully fix the PQ problems. Once it is determined that the utility is doing all that it can, or is willing to do, and if the problem still persists, then the business will need to do some serious data collection. Typically, data will need to be collected for a number of years to see trends and to verify that the problems are occurring throughout time and not just in the past few months. Utility sag events typically happen at random times during the year which causes the data gathering process to occur over long period of time. If these sag events are caused by some known internal process, then data gathering can happen at a significantly faster rate.

The business will need to meet internally with its financial, maintenance, and operating people to begin to assign monetary values to the various costs associated with each sag event that impacts the business's production. As the data gets collected, the business should be able to predict what kind of voltage sag events cause problems, and this includes the minimum depth and duration of the voltage sag that causes these problems.

This information is needed when the business goes to a consultant or PQ equipment supplier so that they can tailor a solution to the business' needs. If the business cannot accurately describe what voltage levels cause the problems, they should not expect the equipment manufacturer to be able to supply a solution that will correctly solve the problem. The solution will then be either too large or too small, an undesirable situation for all parties.

After developing a specification for the PQ improvement equipment and after receipt of proposals, the business' finance team will assist in determining whether the savings associated with PQ mitigation are going to produce a net profit or payback for the business. If the business has not done its homework collecting the data up front, it is not likely that it will be able to justify the expense of PQ mitigation. Only through careful data collection and identification of all of the hard and soft costs of each outage will the business be able to present a convincing story that clearly demonstrates a financial reason to improve its power quality.

TYPICAL PQ IMPROVEMENT CUSTOMER

AMSC has investigated many businesses with PQ problems. These investigations have proven that only businesses with a certain common set of characteristics are good candidates for the installation of PQ sag and swell mitigation equipment that must be justified on a pure economic basis. In other words, if the investment in PQ mitigation equipment must be cost justified and must show a positive return on investment, industrial type businesses will typically need to have the following characteristics:

- Large load – greater than 10,000 KVA
- Multiple electric service delivery points
- Process industry with computerized controls
- Precision control required for production
- High dollar volume
- High facility utilization rate

From AMSC's PQ investigations and solution simulations, we have come to recognize that there are certain types of businesses that are more likely to be able to justify improved PQ for voltage sag problems. The best candidates are the following industries:

- Semiconductor chip fabrication
- Pulp and paper production
- Auto/truck assembly or parts production
- Chemical process industry
- Mining
- Server farms – computer data facilities

The business with the most significant positive return on investment for a PQ solution for sag mitigation is the worldwide semiconductor fabrication industry. They generally meet all of the above requirements, and a single sag event can result in losses of between £500,000 and £1,000,000.

THE STATCOM PQ SOLUTION

STATCOM solutions are a good fit for sag (or swell) mitigation. Other UPS type systems (i.e. batteries, fly wheels, and standby generation) are more applicable to total outage situations and are generally more expensive. The STATCOM system shown in Figure 4 is a simple one-line diagram of AMSC's STATCOM system.

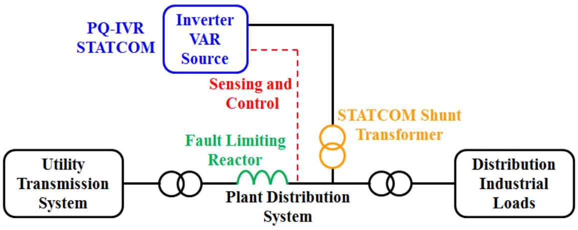

Figure 4 – STATCOM System

The STATCOM provides a sub-cycle response that is based upon its reactive power injection and takes advantage of the AMSC inverters' overload capability of 3 times their continuous current rating. See Figure 5.

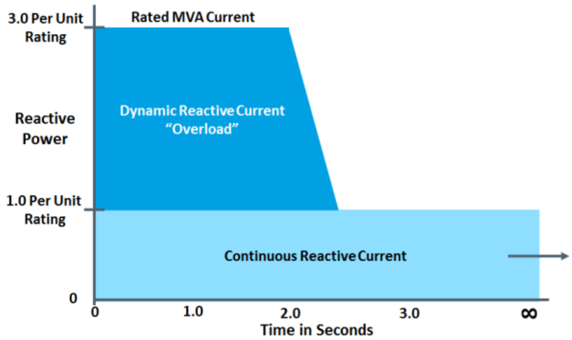

Figure 5 – AMSC STATCOM's Capability

This overload capability enables a very large reactive power injection and reduces the STATCOM's size required to solve these short-duration sag events. During these events, the STATCOM will regulate the voltage at the bus supplying the critical loads and greatly improve its voltage.

Another key feature of the STATCOM system is the fault current limiting reactor. When the local fault current is limited by the series reactor, the STATCOM system's capability to correct the voltage is magnified. Detailed analysis must take place so that the series reactor is properly sized. If the reactor is sized too large, normal plant function like motor starting can be adversely impacted.

The benefits of a STATCOM system are the following:

- Based on reactive power injection
- Can provide facility wide sag/swell protection
- Sub-cycle response
- Rebuilds both external and internal sags
- Rebuilds three phases by up to 65%
- Is not impacted by growth of protected loads
- Does not trip due to internal faults or motor starting
- Has low electrical losses

HOW DOES THE STATCOM SYSTEM WORK

The STATCOM system applies the exact same voltage regulation principles that utility generation uses to adjust or regulate voltage. Utility generators do not hold the voltage by delivering megawatts of real power; they regulate and control voltage by injecting or absorbing reactive power. That same exact principle is the basis for how the shunt connected STATCOM system works.

To support the voltage of a large industrial facility, the STATCOM system uses the impedance of the power system itself. Specifically, it utilizes the combined impedances of the transmission system represented by a Thevenin source impedance, the transmission to distribution transformer impedance, the distribution system, and the distribution fault current limiting reactor. By injecting capacitive VARs into this combined impedance, it yields a voltage rise to compensate for the source's voltage sag. If the voltage sag is unbalanced, the injected VARs are adjusted to correct the voltage of each phase. Capacitive VARs flowing through an impedance will produce a voltage rise which will then correct the voltage sag at the industrial facility's site; as illustrated in Figure 6.

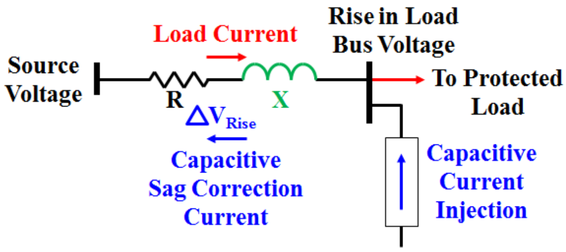

Figure 6 – Injected Capacitive VARs Provide Voltage Boost

Figure 7 shows the one-line diagram of the various components of a typical AMSC STATCOM solution. The current limiting reactor is sized to yield the maximum boost for the STATCOM system while not impacting normal industrial load operations (typically motor starting).If analysis shows the presence of a harmonic issue; the harmonic filter eliminates these problems. The filter also makes up for the reactor losses thus improving the industrial load's power factor.

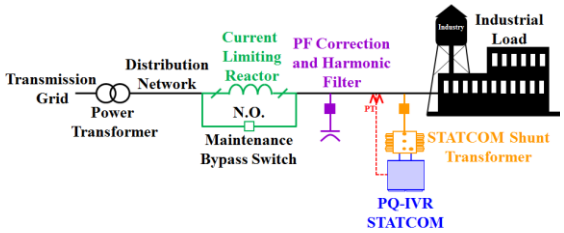

Figure 7 – PQ System Solution One-Line Diagram

Figure 8 shows a voltage vs. time plot of a typical high speed capture of a PQ voltage sag event following the installation of the STATCOM system. The **red** line is the unprotected supply side voltage during the sag event. The **green** line is the voltage at the protected load bus during the sag event. The voltage for the protected load is built back to at least 90% within 1.55 cycles of the beginning of the sag event. This is very fast and is sufficient to prevent the tripping of production process related equipment. The **blue** line is the STATCOM's output. It quickly recognizes the voltage sag event and immediately begins to restore the protected load's voltage.

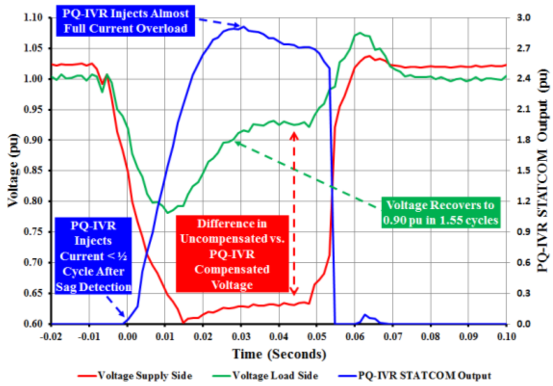

Figure 8 – PQ Voltage Sag and Recovery Event

THE DISTRIBUTION SVC PQ SOLUTION

On a distribution system, many voltage sag events are caused by such processes as the starting of large motors, welding, and melting of metals. Thus, some type of load tied to an industrial process. These voltage sag events can impact the business that using them and other utility customers on that same distribution circuit. The depth of this voltage sag is typically less than that caused by a fault event, but to a depth that most certainly can cause problems. Reactive support from a FACTS device can be used to support the voltage during these kinds of events. AMSC has developed a distribution Static VAR

Compensator or SVC, called the D-SVC that solves these types of problems very effectively. This SVC is only made up of a series of TSC – thyristor switched capacitor banks. These SVCs, located on the distribution system, can be directly connected to any 15 kV to 4160V distribution feeder. They do not need to be installed within a substation fence since they are directly connected to a distribution line. This eliminates the requirement for a connection transformer, a building, and simplifies environmental siting which significantly reducing its costs.

HOW DOES THE DISTRIBUTION SVC WORK

An SVC can be sized and controlled to significantly reduce the impact of these industrial processes on the distribution voltage and also all the other customers on the feeder system. To support the voltage, the SVC, like the STATCOM, also uses the impedance of the power system itself. It utilizes the combined impedances of the transmission system represented by Thevenin source impedance, the transmission to distribution transformer impedance and the distribution system. It does not require a fault current limiting reactor due to the much lower fault power at the entrance of most feeder distribution industrial facilities. Again, by injecting capacitive reactive current into this combined impedance, it yields a voltage rise to compensate for the voltage sag caused by the industrial process. The SVC essentially “cancels out” the impact, for example of the motor start, on the distribution circuit by providing voltage sag and flicker control/mitigation for these industrial processes. The duty cycle frequency for these applications can range from every 1/4 second to once a day or less.

Figure 9 shows a voltage vs. time plot of a typical high speed capture of a PQ voltage sag event **with** and **without** the installation of the SVC. The **red line** shows the voltage response of a motor start no SVC present. The **blue line** shows a voltage response where the SVC is on-line. Typically, with the SVC assisting the industrial process, there is significantly less sag/flicker, the motor start occurs faster, and the industrial process runs better.

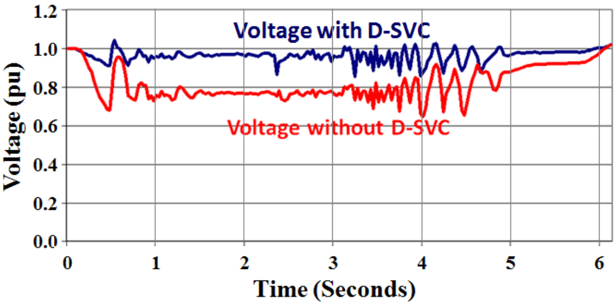

Figure 9 – SVC Motor Starting Comparison

CONCLUSIONS

The challenges to supply clean, stable, and low cost energy have been obstacles that utilities and end-users have been trying to solve for years. It is now becoming even more important, with today’s economic environment and technological advances, to ensure that manufacturing and industrial production stay at their peak performance while being efficient with their energy use. Industrial loads both large and small can have an adverse impact on their own facilities as well as their neighboring customers’ facilities. These power quality problems due to voltage sags/flicker impact businesses on a daily basis somewhere in the world. Cost effective PQ system solutions which reduce the impact of these voltage sags exist. Some businesses affected by these PQ problems have taken the initiative and have installed the AMSC PQ-IVR STATCOM and D-SVC solutions. As a result, all of these sites have experienced a significant reduction in production losses. Many of the AMSC PQ FACTS solutions have paid for themselves in a very short time after their installation.

REFERENCES

[1] EPRI,2005, "PQ Encyclopedia Chapter 4 – Understanding Voltage Sags", EPRI, Palo Alto, USA,24.