POWER QUALITY SOLUTIONS TO MITIGATE THE IMPACT OF VOLTAGE SAGS IN MANUFACTURING FACILITIES

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ABSTRACT

The dominant power quality problems in industrial manufacturing applications are short duration voltage sags and momentary interruptions. For 'normal' grid customers, the EPRI Distribution Power Quality study clearly demonstrated that the vast majority of power line disturbances are of short duration. For customers connected to 'premium' grids, realized with dual independent distribution feeds with high speed make before break ATS systems, connection to transmission grids, or use of highly meshed grids, short duration voltage sags represent essentially 100% of the power disturbances they experience. Power quality solutions, which protect against all short duration power line disturbances, provide protection against virtually 100% of all the events experienced by those customers who have the highest cost of downtime, the 'premium' grid customers.

With the increasing demands for minimizing downtime in manufacturing operations, facilities managers have been challenged to identify cost effective solutions to address power quality related problems. This paper will provide an overview of the power protection issues faced by industrial facilities, based on a review of utility PQ problems, typical plant power distribution systems, and sensitivity of various equipment and processes. Select applications experience of power electronics based PQ solutions such as the Dynamic Sag Corrector® (DySC® – pronounced 'disk') in critical manufacturing operations will be presented. The selection criteria will be highlighted to demonstrate how the solution configuration, rating and placement within a facility impacts its economic viability. The pros and cons of 'facility wide' versus 'point of use protection will be discussed. Finally, the issues related to ROI for manufacturing processes will be discussed.

INTRODUCTION

The impact of power quality and power reliability problems on productivity and downtime in US industry range in the many tens of billions of dollars annually. Estimates from independent EPRI and DOE studies put this cost as high as $150 billion, yet, according to the results of the EPRI Distribution Power Quality (DPQ) study conducted several years ago, only 3 % of events experienced by distribution grid industrial customers were outages. The vast majority of the offending 'events' were found to be short duration disturbances, primarily voltage sags and momentary loss of power. This result has refocused many power equipment suppliers and end users in their efforts to address these problems, since the normally 'reliable' distribution-level utility service does not provide the high 'quality' of power delivery needed by many industrial and commercial electricity users. This distinction between power reliability (the absence of utility voltage) and power quality (the corruption of the 'ideal' utility voltage) problems is therefore becoming better understood as manufacturers attempt to identify solutions to their power quality problems.

Most manufacturers have only recently begun to develop an appreciation of the view of the quality of power entering their plants in the same way that they view other raw materials. Recent rolling black-outs in California (a power reliability/availability problem), have certainly heightened the awareness of the impact of power problems on operations, yet, with the exception of the semiconductor industry, there is not a broad organized approach to addressing the impact of power quality on industrial productivity. This is due in part to a lack of understanding of the nature of PQ events created on the utility grid (or internal to a plant) and of the sensitivities of manufacturing equipment and processes to the most common PQ events. In addition, effective solutions have only recently become available, thus the view 'there is nothing that can be done cost effectively' has prevailed.

Semiconductor industry initiatives through the SEMI organization (Semiconductor Equipment and Manufacturers International) have led to the development of the SEMI F47 standard, that is being specified in the procurement of 'tools' (very expensive high tech equipment) used in the manufacture of IC chips. This standard is more stringent than the old CBEMA Curve (Computer Business Equipment Manufacturers Association, now the Information Technology Industry Council, now the ITIC Curve) that provides a ride through specification for IT equipment design, but which is not stringent enough to be effective for industrial equipment. Semiconductor manufacturers (e.g. TI, IBM, Intel, etc.), pushed very hard for this standard since their cost of downtime due to power events is very high, and is well documented. This standard is having a positive impact, and there are efforts being made to 'move' this standard into the industrial arena.

SoftSwitching Technologies has been in the forefront in the development of cost effective solutions to power quality problems, beginning with the introduction of the Dynamic Sag Corrector (DySC, pronounced 'disc') in late '98, and recently with the introduction of the I-Grid™ web enabled power-monitoring system based on the I-Sense™ ultra low cost monitor. DySC systems have been successfully applied in a broad range of critical manufacturing applications, including semiconductor tools and chip fab plants, as well as automotive, fibre optics, plastics, paper, steel, and other manufacturing applications. Some of this applications experience is shared in this article.

This paper will further review the most common power quality characteristics of the electric supply to plants and equipment, the sensitivity of equipment and processes to these events, and the solutions that are currently available. Applications experience of SoftSwitching's power electronics based DySC solution will be provided, including selection criteria. In addition, the decision drivers, including the pros and cons of facility wide vs point of use deployment, as well as ROI, will also be discussed.

VOLTAGE SAGS AND THE IMPACT OF ELECTRIC DISTRIBUTION

Voltage sags are generally created on the electric system when faults occur due to lightning; accidental shorting of the phases by trees, animals, birds, human error such as digging underground lines or automobiles hitting electric poles, and failure of electrical equipment. Sags also can occur when large motor loads are started, or due to operation of certain types of electrical equipment such as welders, arc furnaces, smelters, etc.. In the case of a fault, the utility would detect the resulting over-current, and perform a feeder breaker re-closure operation that disconnects the down-stream loads from the system, in its attempt to clear the fault and therefore maintain the reliability (availability) of the electric supply to the majority of its customers.

This scenario can be highlighted in Figure 1 that shows an elementary distribution system. The fault created on the feeder L1 is 'fed' from the entire grid, the utility operates the feeder breaker supplying L1, thus the downstream customers (e.g. A, in the circle shown) experience a voltage sag and a subsequent momentary interruption when the feeder breaker is open. Customers such as on feeder B, would experience a voltage sag until the fault is cleared. The magnitude and depth of the sag and momentary interruption outage depends on the nature of the fault, where on the grid the re-closure operation occurs, and how the utility operates its protective equipment.

Re-closure breakers on the transmission system (typically over 100 kV) operate faster compared to breakers on the lower voltage distribution system (3 to 10 cycle range vs 10 to 30+ cycles at the distribution level). In addition, the time when the re-closing breaker is left in the off state varies widely from utility to utility, and even within the same utility's service territory. The fastest first re-closure operation at the distribution level is in the 10 cycle range. Generally, if the fault is not cleared in the first attempt, the off interval is increased during each subsequent attempt. It should be noted that the voltage does not collapse immediately upon opening of the breaker due to voltage hold-up by the back emf (or generator action) of connected rotating loads.

From the scenario described earlier, it can be seen that the potential for voltage sags is much greater than for momentary interruptions, since the entire section of the grid that feeds the fault experiences a sag, whereas, only the customers downstream of the re-closing breaker experiences a momentary interruption. Many more customers (each with the potential for internally generated faults) are connected to the distribution system vs the transmission grid. Thus, with more distribution lines and substation exposure to the elements such as lightning, trees, squirrels, etc., many more sags occur at the distribution level compared to the transmission grid. At the transmission level, the very fast re-closure operations coupled with large loads with significant rotating motor content, result in very few momentary interruptions. This is less true at the distribution level where the re-closure operations are longer.

The distribution level electrical supply can therefore be categorized as a 'normal grid' compared to a 'premium' transmission grid. A premium grid at distribution level voltages can also be realized by a highly interconnected meshed distribution network like exists in New York City, or with dual independent distribution feeds with high speed make before break Automatic Transfer Switch (ATS) systems. The net effect is fewer, short duration voltage sag events on the premium grid, vs more sags and some long duration events on the normal grid. This is summarized in Table 1, which shows a typical distribution of events on both grids, and the type of customers that are generally fed by each service. Undoubtedly, critical manufacturing operations that use large amounts of power such as in the semiconductor, fibre-optic, automotive sectors, almost always command premium utility service, with its superior characteristics. It must be noted however, that the typical events that occur on the transmission grid, are sufficient to shut down critical manufacturing processes. Thus, while the utility reliability level characterized by the "9's" reliability concept suggests acceptable high 9's premium power, if each event results in a (conservative) downtime of 1 hour, the effective "9's" reliability level is essentially the same as for distribution level service.

The results of the EPRI Distribution Power Quality (DPQ) study, which is the only comprehensive distribution power monitoring study to date, provides clear validation that the majority of events are short duration voltage sags down to 50 % remaining voltage. The summary data from the DPQ study is presented in the Magnitude – Duration plot in Figure 2. This format is a common way of displaying voltage sag events, and enables the protective coverage zone of mitigation devices to be overlaid, thereby highlighting which historical events would not be covered. The SEMI F47 and the ITIC equipment susceptibility curves are also presented in this format.

The three phase nature of events (i.e. whether the event is a single line to ground, line to line or symmetrical sag) is not highlighted in this format. It may be helpful to know what the three phase nature of the event at the equipment being considered for protection since a single line to ground sag will be transformed to two phases through distribution transformers within a plant (due to delta : wye transformations). In addition, some mitigation equipment can correct for deep line to line sags, without using energy storage.

The issue of availability of PQ monitoring data that shows historical sag events has been problematic, since without this information, it is difficult to correlate a PQ event with process and equipment shutdown, thereby making it difficult justify some solutions. SoftSwitching's experience suggests the high valued manufacturers, particularly the semiconductor fabs, have their own monitoring and in many cases, several years of event data. The broader manufacturing sector generally has no historical data, but know from experience that when the lights flicker – their process or machine is down. While all the major utilities have some level of monitoring, this is done primarily at the transmission level, and to a much lesser extent at the distribution level. As a result, in most cases this data is not available. This is due in large part to the high cost of traditional monitoring equipment, and the need to become proficient at using what is sometimes complex applications software.

SoftSwitching has struggled with this lack of data, and is addressing this using a web enabled PQ monitoring system called the I-Grid that is based on an ultra low cost I-Sense monitor. Once the I-Sense monitor is installed, the user requires only a telephone line connection to the monitor, which dials out via the web when an event occurs, and transfers the key information of sag depth, duration, a time stamp and waveforms to the I-Grid server. In addition, a near real time e-mail notification of the event information is sent to designated recipients, who can log on to the I-Grid web site using any web browser to view detailed data from that monitor. This system offers a plant or facilities manager an affordable mechanism to monitor multiple facilities and/or sections within a facility, thereby providing the on-going historical event data upon which a sag mitigation solution can be based.

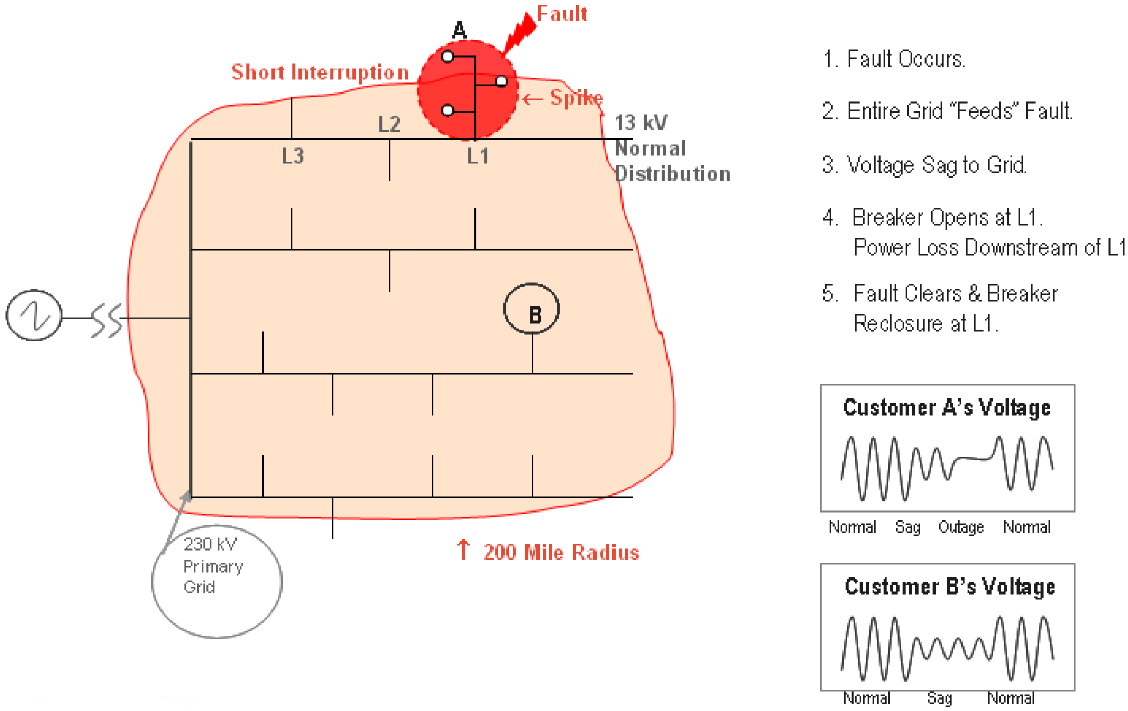

Figure 1. Elementary Distribution System Highlighting how Voltage Sags are Created.

NORMALGRID				PREMIUM GRID			
Normal Utility Events	Utility Reliability Level	Process Uptime 1 Hr Downtime per Event	Typical Applications	Premium Utility Events	Utility Reliability Level	Process Uptime 1 Hr Downtime per Event	Typical Applications
25 events/yr: 22 at ¼ s, 1at 2 s, 1 at 5 min, 1 at ½ hour	2107 seconds total/yr, 99.99%, 4-nines	25 Hrs total downtime/yr, 99%, **2-nines** No protection	Plastics, PCs, Machinery, Textiles, Cell towers, Residential	10 events/ yr, 0.25 s each	2.5 seconds total/yr, 99.99999%, 7-nines	10 Hrs total downtime/yr, 99%, **2-nines** No protection	Semi manuf, Auto manuf, Fiber optic cables, Web farms, Continuous processes
92% Events Protected with a DySC 2 events/yr, 2 hours total downtime/yr, 99.9% Process Uptime : **3-nines**				100% Events Protected with a DySC 100% Process Uptime : **9-nines**			

9's = (time in a year – time in a year when voltage is out of spec.) x 100 / (time in a year) : Rounded to the least significant 9 >> No. of 9's

Table 1: *Availability vs. Process Uptime in Normal & Premium Grids.*

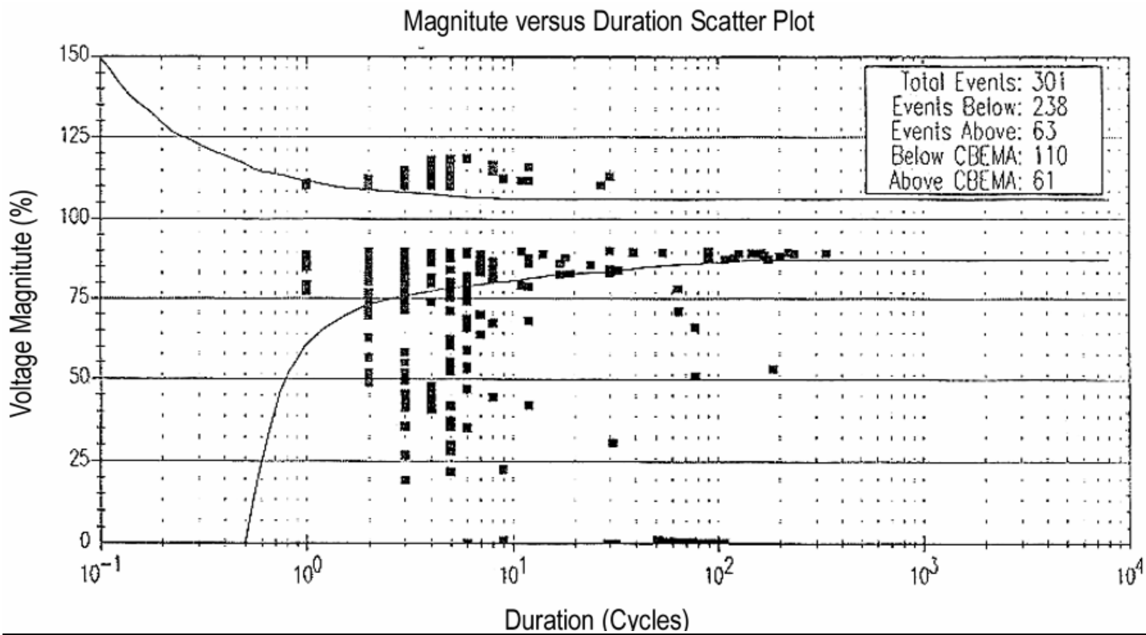

Figure 2. Magnitude – Duration Scatter Plot of summary data from the EPRI DPQ Study

EQUIPMENT/PROCESS SUCCEPTIBILITY

Today's industrial manufacturers increasingly utilize a broad range of sensitive electrical and automation equipment to control their operations and processes. These include variable speed ac and dc drives, servo drives, PLC's, contactors, starters, relays, instrumentation, sensors, industrial computers, and power supplies, to name a few. These devices have various levels of susceptibility based on their specified voltage tolerances. Thus, since these devices are configured to control various elements in a machine or process, the sensitivity of the process will be determined by the most sensitive device in the configuration. For example, many control panels use small inexpensive 'Ice Cube' 120 Vac relays. Some of these relays are known to drop out when the input voltage decreases below 90 % of nominal voltage. Therefore, if such a relay is used in a motor starter control circuit, that motor will drop out when such a sag occurs.

Continuous processes are most challenging to address. Examples include plastics extrusion, wire drawing, food processing, fibre-optic manufacturing, printing, textile manufacture, and bottling, to name a few. The difficulty is compounded because their control systems are highly integrated, thus, even though there may be a few critical components that are sensitive, the integrated nature of the controller makes it difficult to isolate the sensitive elements, thus the whole process may need to be protected. In addition, process control manufacturers may void warranties when the equipment end user inserts external components into 'their' system. Interestingly, while primary focus is to maintain a process or machine operating through a sag, one may easily overlook HID lighting systems which are very sensitive to sags, and can represent a safety hazard or limite productivity when sags occur.

With the advent of the SEMI F47 Standard, semiconductor tool vendors are pushing the requirements 'down the food chain' to the component suppliers. As a result, more robust contactors, relays, etc. are being developed that ride through events that traditional components would not.

SAG MITIGATION SOLUTIONS

There are currently a modest range of solutions available for mitigating voltage sags at the component, equipment, or plant entrance level. Devices are available in single phase, at low distribution voltages of 208/240/480/600 Vac, and at medium voltages for higher power plant entrance applications. Some devices use energy storage technologies such as capacitors, batteries, or flywheels to provide energy to ride through the sag event in the same as when there is an outage, essentially acting as a UPS. More recently, power electronics based devices have emerged that do not require energy storage, yet can provide very effective correction of the vast majority of sags and momentary interruptions. These devices use a series voltage injection principle, utilizing either transformer coupling or novel power electronics circuitry to achieve the voltage injection function. The traditional Constant Voltage Transformers (CVT's) which was designed to provide voltage regulation, has been applied to correct for sags, however, it requires over-sizing to correct sags and to operate without significant voltage distortion in the presence of load harmonic currents. In addition, CVT's are heavy, bulky and inefficient.

Additional component level solutions have recently been introduced such as coil hold up devices that can be added to contactor coils to provide additional hold-up time, thereby enabling them to ride through sags. The challenge with using these devices is the need to understand the detailed operation of the control system so that all of the sensitive components are identified and protected and to ensure that the addition of the hold-up device does not affect any control system timing. Ride-through of ac drives can be achieved by adding storage energy to the dc bus capacitors to enable sag ride through. Care needs to be taken in applying these devices to ensure other sensitive system components are identified and protected. It should be noted that phase controlled dc drives have no dc bus, thus cannot benefit from dc bus hold-up systems, and require input side devices to enable ride through of sags.

In should be noted that battery based solutions are viewed with increasing disfavor in the industrial arena as can be seen by the SEMI F47 Standard, and with the advent of flywheel UPS's. Looking forward, there will be a strong move towards battery-less solutions for industrial applications. Table 2 provides a summary of various solutions available, with highlights of their ratings, and comments on their operation/application.

Device	Voltage Rating	No. of Phases	kVA Ratings	Comments
Coil Hold-up device	CV	1	<100 VA	• Applied to contactors, relays, and magnetic devices with low pf. • Surrounding controls and system remain unprotected.
CVT	CV, LV	1	<10 kVA	• Needs to be oversized to be effective with sags, inrush, & load current harmonics • Large, heavy and inefficient • 480 V:120 V versions avail.
Capacitor based UPS	CV	1	<5 kVA	• Responds to sags like an outage. • Sag correction interval limited by stored energy • Square wave output
Battery based UPS (Industrial)	CV	1	100 VA to 10 kVA	• Battery life is an issue in industrial environments. • Requires regular maintenance
Battery based UPS (Industrial)	LV, MV	3	500 kVA to 2 MVA	• Treats sags like they are outages • Many industrial facilities are moving away from battery based solutions (SEMI F47 recommends using battery-less solutions)
Flywheel UPS	LV, MV	3	300 kVA to > 5 MVA	• Lower efficiency, higher cost. • Primarily targeted for 15 second ride through to bring on back-up generators • Requires mechanical maintenance
DC Bus Hold-up Device for VFD's	LV	N/A (dc)	To 250 HP	• Applied to dedicated AC drive • Requires invasive integration into drive system • Surrounding controls and systems remain unprotected
Power electronics based series injection ride through device (e.g. the DySC)	CV, LV	1,3	250 VA to 3 MVA	• Offers flexibility to be applied at lowest cost point in process • Provides ride through of momentary interruptions • Requires no energy storage, but can be added for longer ride-through • Efficient and compact • Suitable for OEM equipment
Transformer based series injection ride through device (e.g. the DVR)	LV, MV	3	2 to 10 MVA	• Sag depth capability affects design and cost • Cannot ride through momentary interruptions without high cost • MV versions limited to plant entrance applications • Poor efficiency since transformer windings always carries current

CV = control voltages, 120 – 240 V; LV = low voltages, 208 – 480 V; MV = medium voltages, 2300 – 6900 V.

Table 2. *Basic Summary of Sag Mitigation Solutions*

SOLUTION SELECTION & DEPLOYMENT ISSUES

Plant operators, maintenance personnel, and production managers know from experience of the relationship between power line events and down time. The adage of 'the lights flicker and the process is down' is all too familiar to those who have to clean up scrap, restart processes, and explain why the process or plant went down and shipments are late. If the correlation between events and shut-down is strong, a power monitoring program may have been started to develop enough data to understand the nature of the power events so that cost effective solutions can be explored. Some manufacturers turn to their local utility for event data, sometimes with limited success. Increasingly, manufacturers look to power quality consultants to install power monitors and perform a site audit wherein the electrical distribution system, personnel experiences, equipment and processes are reviewed to identify obvious candidates for improvement. Sometimes, sag testing is performed on specific equipment to determine their susceptibility, and finally, recommendations to deploy various mitigation solutions are offered for consideration.

In general, deploying a sag correction device closest to the equipment that is susceptible, represents the lowest cost option. Conversely, a solution on the utility side of the meter can be the most expensive solution. The exception to this may be when there is a high percentage of sensitive loads within the plant, e.g. when there are multiple extrusion lines that are the primary loads in a plant. The overall cost of a large device coupled with the lower cost to install a single device, may be lower than for multiple smaller rated devices. In most applications, the optimum solution is somewhat between these scenarios, where a solution on a small line could be demonstrated, thereby providing validation and comfort that the solution does work, and the impetus to engage in a broad deployment. After the solution is installed, it is very desirable to validate the 'saves' to show improvements in operations compared to before installation. SoftSwitching's I-Grid provides a very cost effective mechanism to achieve this, wherein I-Sense™ monitors are permanently installed at the input and output of sag correction units

Table 3 provides an overview of the decision drivers that need to be taken into consideration when addressing voltage sag problems. In addition, comments on each of the issues are presented where applicable, to provide an awareness of how each of these issues may be approached.

Item No.	Decision Driver	Comments
1.	ROI	• Power quality is ultimately a financial problem. • A business case justification needs to be done. • Cost of ownership (not just equipment cost) should be considered. • Cost of downtime can be most difficult info to get.
2.	Availability of event data	• Your Utility may have historical event data. • The I-Grid power monitoring system will be of great value.
3.	Cost of down-time	• Need to consider all components, including scrap, stranded labor, time to get product quality and/or process parameters in spec., opportunity costs such as losing a contract due to late deliveries. • Equipment failure can result from repeated exposure to sags.
4.	Cost of ownership	• Some solutions are inefficient, with ongoing energy costs. • Consider extra air conditioning infrastructure required. • Maintenance costs add to this.
5.	Sensitivity of plant loads	• Need to understand which equipment is sensitive. • Wiring may make it difficult to separate non-sensitive loads.
6.	Installation costs	• Consider rewiring costs necessary to separate sensitive loads. • Consider process down time & logistics of installation.
7.	Evaluate on a small scale if possible	• In multiple line applications, evaluation on one line validates solution (especially when unprotected lines go down).
8.	Engineering effort to define and optimize solution	• Engineering effort may be required to integrate the solution, including drawing revisions, etc. • Don't spend \$20,000 to find out the solution costs \$4,000.

Table 3. *Decision Drivers for Identifying and Implementing Voltage Sag Mitigation*

While in general deploying a solution closest to the point of use is a more economical approach, it is important to understand the issues related to deploying point of use vs facility-wide protection. Some of these issues and consideration thereto are highlighted in Table 4.

Item No.	Point of Use Solutions	Facility Wide Solutions
1.	Available in 1 & 3 phase at 120V to 600 V	Typically are at medium voltage, 3 phase. Some LV solutions available
2.	Ratings range from 250 VA to 3 MVA	Ratings in the 1 to 10 MW range
3.	Protects only the critical loads	May protect significant non-sensitive loads
4.	Can be deployed in stages (evaluate on one process line)	All or nothing solution
5.	Engineering effort can be minimal	Typically requires major engineering effort
6.	Protects against internally generated PQ events (i.e. within the plant)	Does not protect against internally generated PQ events
7.	Failure of protection affects only connected load	Failure of protection affects entire plant
8.	Solution cost limited (rating of solution closely matches rating of sensitive load to be protected)	Overall cost of solution can be high (all loads may not sensitive)
9.	Deployment can be quick (short lead time)	Long delivery time
10.	Wiring of solutions to individual loads can be problematic. Sometimes it is not possible to separate sensitive loads.	Does not require re-wiring of loads
11.	Installation costs can be marginally higher, depends on number of units and required re-wiring	Installation costs can be lower. Generally, no re-wiring is required

Table 4. *Comparison of issues related to Point of Use Solutions vs. Facility Wide Solutions*

CASE STUDIES

The real world applications and experiences of actual companies are more illuminating than arguments based on statistics. Here are details from some actual installations.

I. Engines, Inc., a manufacturer/processor of large axles and rotors for railway and other applications located in West Virginia, was experiencing 10-15 sag events annually. This resulted in as much as 24 hours of downtime, scrapping of large expensive rotors, and delayed shipments. In cooperation with AEP and EPRI, SoftSwitching installed a 300 kVA PRODySC® unit to cover several CNC machines in the main production/processing line, as well as the offices. According the Engines, Inc. President Carl Grover, "The DySC has virtually eliminated the necessity for reworking damaged materials due to voltage sags." Unlike before the PRODySC was installed, the office personnel did not have to re-boot computers and restore data due to voltage sag events.

II. A major fiber-optic cable manufacturer was experiencing 6-10 voltage sags per year. As a premium grid customer, this company had over seven years of power monitoring data, which showed no power interruptions, only voltage sags. One cable finishing process line could realize losses reaching \$150,000 - \$500,000 per event. Due the integrated nature of the sheathing line control system that includes several dc drives, the only option was to install a single unit per line. Over a dozen PRODySC systems with a cumulative rating of over 3,500 kVA are now protecting a portion of the cable finishing area in this plant. In the first three months of operation two definite, documented 'saves' were recorded. The DySC investment was paid for with the first save.

III. A manufacturer of large-die plastic extrusion products, in cooperation with EPRI-PEAC, their local utility company, and SoftSwitching Technologies, installed a 300kVA PRODySC unit solution to protect several extrusion lines. Figure 3 shows how the PRODySC unit corrected a deep voltage sag to keep the process running. In this application, the economics favored using a single unit for up to 5 production lines, compared to utilizing a smaller unit for each of the extruder lines.

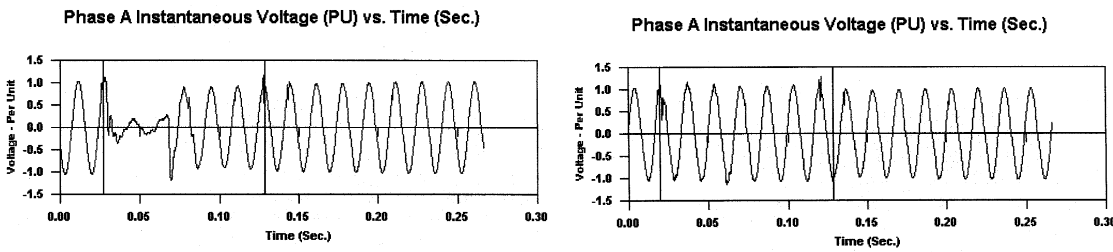

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Figure 3. *Typical Event Showing Both Incoming Line Voltage & Corrected Output*

IV. A major automotive manufacturer required protection for the distribution bus that supplied one of their body shops, which includes robotic welding, PLC based material handling and ancillary industrial controls. The body shop was a critical production cell because a shutdown of the robots during a body welding operation may cause the whole body to be scrapped. The size of the bus is 1600 A but the actual load at present is less than 1200 A. The customer found it most cost effective and convenient to cover the whole bus but only to the current level that was presently being used. A modular 1200 A PRODySC system was installed, with expansion capability to increase the current capability to 1600 A at a later date. Provisions were also included for future installation of capacitive energy storage, if warranted by PQ events identified through further monitoring data. The installation has also been equipped with I-Sense™ monitors, one for input voltage and one for output. The system has been operating since May of 2001 and several sag events have been recorded. One such event is depicted in Figure 4, and is based on reports derived from I-Sense monitors via the I-Grid system. The customer reports that for almost all events, the other equipment in the plant shut has down on 'power loss' while the bus protected by the PRODySC kept the body shop up and running.

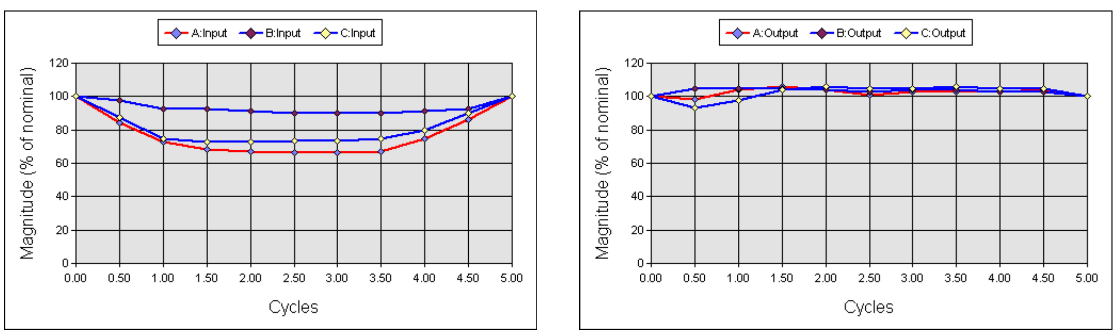

Figure 4. *Auto. Plant Data: Input voltage sag and PRODySC corrected output voltage (RMS)*

V. A major semiconductor manufacturer required sag correction for their photolithography tools. Voltage sags caused shutdowns resulting in scrap material and lost production capacity. This installation was ideal for distributing PRODySCs at the input of each tool. This was due to the huge logistical effort that would be required to gain access to the distribution transformer that powered several tools, since this would require shutting down all the tools that the distribution transformer powered. In the semiconductor fab business, access to tools for other than production is extremely difficult. Over ten 42 kVA PRODySCs were installed ahead of respective tools. The DySC units fit nicely into the facility as their small size allowed them to be arranged in accordance with the space limitations of the fab's sub-fab area. This customer has reported several sag events since August of 2001, again resulting in continued operation of the semiconductor tools while other less critical unprotected equipment were shut down.

CONCLUSIONS

The availability of sag correction devices now on the market offers the real potential for broad deployment to minimizing the negative effects of voltage sags and momentary interruptions on industrial productivity. Several of the more recently introduced devices have been validated and gained significant acceptance by both industrial users and Utilities, in a broad range of applications. While a number of applications have demonstrated an attractive ROI across a broad spectrum of industries, there is a significant need for PQ historical event data to help to identify the appropriate solution, and to support the business case justification for the capital expenditure. SoftSwitching's I-Grid web enabled monitoring system will be very beneficial to this end. In addition, there is a great need to educate end users about the availability and performance of mitigation devices, and how these devices can play an important role in significantly reducing the costs associated with voltage sags. It is hoped that this article has provided a sufficient overview of all the relevant issues to enable end users to ask and address the critical questions related to the application of sag mitigation devices.

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