POWER QUALITY AND CRITICAL MANUFACTURING

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ABSTRACT

Critical manufacturing applications, such as semiconductor, electronics, automotive, plastics, CNC machining, and others involving automated processes, are very susceptible to power disturbances. Even a quarter second voltage sag can cause the entire machine or process to shut down for hours, causing expensive downtime, scrap material, lost productivity, and long restart times. Recognizing their susceptibility to power disturbances, many high tech manufacturers obtain premium grid connections from the utility using a dual independent distribution feed, a special connection to the high voltage transmission grid, or a meshed power grid system. Such premium utility connections almost completely eliminate outages, and can routinely achieve very high levels of utility system reliability. However, short duration voltage disturbances, in particular voltage sags, cannot be eliminated, even on the most robust and reliable power grids, and constitute the most significant remaining power problem that needs to be tackled.

This paper covers several types of power quality solutions that are now commercially available. This will include conventional battery-based UPS units, flywheel energy storage systems, superconducting magnetic energy storage systems, and the Dynamic Sag Corrector® (DySC® – pronounced 'disk'), and will present a comparison of the various technologies. The DySC, a relatively new and unique solution, will be discussed in greater detail. The DySC corrects for deep voltage sags and momentary loss of power, and does so without batteries or energy storage devices. Ratings from 250 VA to 3,000 kVA allow the DySC to be deployed at point of use, on a process line, or at the input to a facility. The DySC has been applied across a wide range of critical manufacturing applications, including semiconductor fabs and tools, automotive, paper, steel, food processing, chemicals, and plastics.

With over 500 DySC units protecting critical manufacturing processes, there is now a wealth of information on the efficacy and impact of such devices. This paper will present case studies of several applications, including the automotive, semiconductor, and general manufacturing sectors, for customers on both 'normal' and 'premium' grids. The location and rating of the unit has a big impact on the economic returns, and specific examples of how the optimal ratings were chosen will be discussed. The pros and cons of 'facility wide' versus 'point of use' protection will also be presented.

HIGH 'NINES' POWER

Problems caused by power reliability and power quality events cost U.S. industry US$150 to $190 billion annually in lost productivity and downtime, according to independent EPRI and DOE study estimates. Results of the EPRI Distribution Power Quality Study refocused the entire power technology sector by showing that only 3% of events experienced by distribution grid industrial customers were outages, the balance were short duration disturbances. For countries with a higher reliability distribution grid, such as Singapore, the percent of events that represent outages is even lower. However, for all customers, those with normal radial distribution feeds, as well as those with premium feeds, one problem seems to be constant – that of process downtime caused by power quality events! It is clear that even the most 'reliable' distribution-level utility service cannot eliminate the short duration power quality events, the primary cause of process downtime for today's high-tech industrial manufacturers.

The notion of *high 9's* power for critical manufacturing processes is receiving increasing attention. The distinction between power reliability (the absence of utility voltage) and power quality (the corruption of the 'ideal' utility voltage) problems is becoming better understood. High-value manufacturing, e.g. semiconductors and automotive, are often served by a *premium grid*, realized with a meshed grid or dual independent distribution feeds, and typically experience incoming power reliability of seven 9's (99.99999% availability). Nevertheless, if their process can be interrupted by a quarter second voltage sag, it is very likely that the customer's process will have experienced only 99% to 99.9% up time (i.e. two to three 9's) (see Table 1). Because long outages are very rare, particularly with premium-grid connections, industrial manufacturing applications typically only require ride-through for short duration power disturbances, such as voltage sags, to achieve high 9's.

NORMAL GRID				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 mfr, Auto mfr, 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**			

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

This has a significant impact on the type of power quality solution required for backing up an industrial process. The traditional approach has been to use an on-line UPS with possibly a back-up generator, an expensive solution. Considering that the

UPS battery itself has a 2-5 year life (with significant monitoring and maintenance requirements) and has lower reliability than the incoming utility power, it is not surprising that the semiconductor industry (a technology leader in almost all respects) has promulgated the SEMI F47 standard for voltage sag susceptibility of equipment used in semiconductor fabrication, a standard that needs to be met without the use of batteries (see Figure 1). For all high-tech industrial manufacturing applications in particular, SEMI F47 defines a new approach to meeting all power quality requirements.

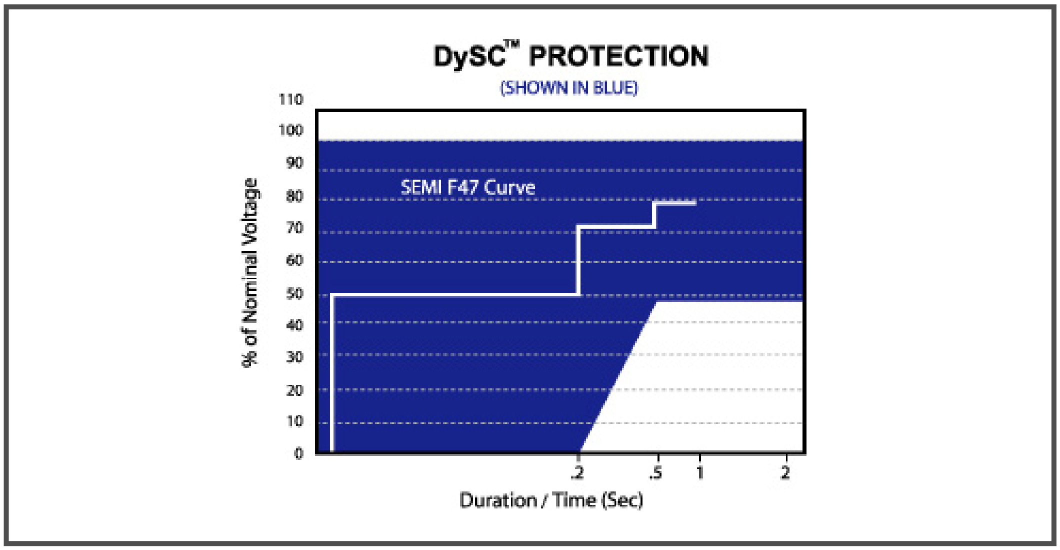

Figure 1: *DySC Meets & Exceeds Semiconductor Industry's SEMI F47 Standard*

BATTERY-LESS POWER QUALITY SOLUTIONS

As utility voltage characteristics have become better understood, the need for battery-less power quality solutions has become more pressing. The traditional power quality solution (the UPS), operated by sensing a power disturbance, isolating the load from the line, and feeding the load from energy stored in the battery. One approach to realizing a battery-less solution thus replaces the battery with alternate means of energy storage. Various products are currently available including, superconducting magnetic energy systems (rated at 2 to 10 megawatts), flywheel systems (rated at 500 kilowatts and higher), ultracapacitor systems (rated at up to 5 kVA), and electrolytic capacitor based systems (rated at up to 1 kVA). As batteries represent the lowest cost of energy storage, it should be no surprise that all these solutions typically cost more than battery-based systems.

Alternate solutions that do not use stored energy, but use power conditioning, include series transformer based voltage injection devices such as the dynamic voltage restorer (rated at 2-10 MVA). The Dynamic Sag Corrector® (DySC®) from SoftSwitching Technologies is a hybrid series/shunt device that protects sensitive loads from voltage sags and momentary interruptions. Rated at 250 VA to over 3,000 kVA, the DySC can be applied at the point of use inside a plant, or even inside sensitive equipment on an OEM basis. The DySC meets or exceeds the SEMI F47 requirement (see Figure 1), and has been widely applied in high-value critical manufacturing processes, including automotive, semiconductors, plastics, fiber-optic cable, paper, steel, cement, and food and beverage processing.

Figure 2 shows the basic circuit schematic for the Dynamic Voltage Restorer and the Dynamic Sag Corrector, two of the more mature solutions in use today. The DVR is typically rated at 2-10 MW, while the DySC is rated at 0.25 kW to 3,000 kW. The DySC operates in static bypass mode until a voltage sag or interruption is detected. The static bypass switch is then commutated by the inverter, and the inverter voltage is effectively injected in series with the incoming ac line. In the case of a voltage sag down to 50% of nominal, the DySC can, in principle, provide 100% output voltage indefinitely. For complete loss of voltage, the DySC is limited to 3-12 cycles of ride-through, limited by the amount of energy stored in the dc bus electrolytic capacitors. The DySC has been designed to provide up to 2 seconds of sag correction capability per minute of operation, more than sufficient to meet even the most demanding power line events encountered.

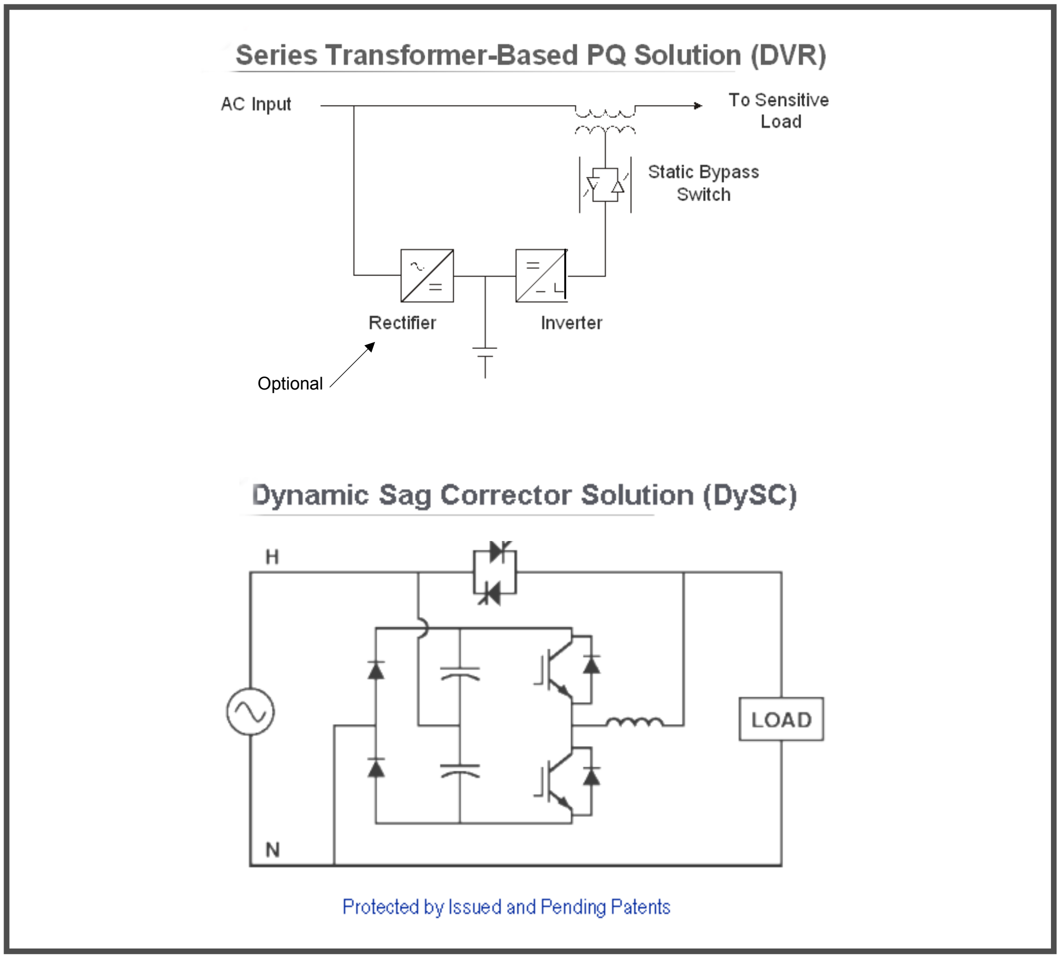

Figure 2: *Circuit Schematic for Various PQ Solutions*

Table 2 summarizes the attributes and protection range obtained by the various types of power quality solutions that are currently commercially available.

	UPS	DVR	SMES	Flywheel	DySC
Main principle	Battery and PE	Capacitor and PE	Superconductor coils and PE	Flywheels and PE	Power Electronic
Power rating / voltage	0-2 MW 480 V	2-10 MW 4-13 kV	2-5 MW 13 kV	0.2 – 1.5 MW (Piller) 0.25-0.5 MW (Active) 480 V	0-3 MW 480 V
SEMI F47	No	Depends (d-q corr)	Yes	Yes	Yes
Max correction time	0.5 – 15 min	Depends	2 secs	15 secs	2-3 secs
Extended ride-through	Yes	No	No	Yes	*Yes
First cost	Med	Med	High	High	Low
Operating cost	High	Low	Med	High	Low
Operating efficiency	92%	98%	98%	92-95%	99%
MTBF limit	Batteries	?	?	Bearings	Fan
Maintenance needs	High	Low	Med	Med	Low

* With dual independent buses

Table 2: *Comparison of Today's Power Quality Solutions*

POINT OF USE VERSUS FACILITY WIDE PROTECTION

One important consideration with a major impact on ROI is the issue of the 'best' approach to protect a sensitive process or load. Two distinct approaches have emerged:

- **Facility-wide protection**, typically medium voltage devices rated at 2-10 megawatts (examples include DVR and SMES)

- **Point-of-use protection**, typically 120-480 volt devices rated at 250 watts to 3,000 kilowatts (examples include the DySC and ESP)

The use of *facility-wide protection* seems attractive at first glance: the entire plant is protected. However, as only 20-30% of a plant's load is likely to be sensitive, *facility-wide protection* consistently results in a more expensive solution than is truly needed. Further, the medium voltage systems are custom, requiring long lead times. Finally, these units cannot protect the sensitive loads from sags caused by faults in other non-critical areas inside the facility. With *point-of-use protection*, the customer's can typically choose a unit rating that optimally matches their sensitive load. The ability to stage the deployment over several years, allows prioritization of limited budget dollars. Choosing among the DySC® family of products (see Figure 3) one can select the optimal protection to be deployed in a given facility and application. MINIDySC solutions are available for single phase loads rated from 250 watts to 20,000 watts. For three phase configurations, the PRODySC is rated from 9 kilowatts to 330 kilowatts in single modules, and paralleled module systems can realize up to 3,000 kilowatts. It is interesting to note that there is no single right solution, and that the choice of the correct solution can involve many factors.

Figure 3: *DySC® product family and ratings.*

Clearly, in a green-field installation where the equipment or process designer has full design flexibility and authority, one could in principle, design the overall equipment or process to be fully immune to externally-caused voltage sags and power disturbances of all types. However, as there is no guiding standard on equipment and components for voltage sag susceptibility, we see very wide variance in susceptibility, often even for similar products from the same manufacturer. For systems and equipment such as semiconductor tools—those that are assembled from readily available sub-systems and components—it is almost impossible to predict a priori what the overall sensitivity will be to voltage sags.

In such a case, one approach is to perform detailed tests and engineering analysis, painstakingly identifying all sensitive components and replacing them or protecting them with smaller single or three phase DySC type device. The alternative is to protect the entire machine or large sub-systems with larger three-phase DySC devices. Both approaches have been followed, as will be evident from the case studies that will follow later in this paper.

DEMONSTRATING PERFORMANCE IMPROVEMENTS

While generally validating the EPRI-DPQ Study statistics, our field experience has also identified an important exception. In particular, we see a clear discrepancy between events experienced by customers connected to the 'normal' distribution utility grid (the focus of the EPRI-DPQ Study), and 'premium' grid customers. 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. Semiconductor Fabs

A major semiconductor manufacturer in the US 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 several three phase DySC units (PRODySCs) at the input of each tool. Over ten 42 kVA PRODySC units 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 tool power supply room. 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 was shut down.

More generally, the important role of sag correction on improved process reliability has clearly been recognized by the semiconductor fabrication industry—as evidenced by their adoption of voltage sag susceptibility standard SEMI F47. The protection profile of the DySC product family completely overlays that required by SEMI F47—one of the reasons that the DySC has been successful as a drop-in global OEM solution for major tool manufacturers.

II. CNC Manufacturing

Engines, Inc., a manufacturer of large axles and rotors for railway and other applications located in West Virginia, was experiencing 10-15 sag events annually. This resulted in many hours of downtime, scrapping of large expensive rotors, and delayed shipments. In cooperation with AEP and EPRI, SoftSwitching Technologies installed a 300 kVA PRODySC unit to cover the main production line. According to Engines, Inc. President Carl Grover, "The DySC has virtually eliminated the necessity for reworking damaged materials due to voltage sags."

III. Fiber-Optic Cable Manufacturing

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, that showed no power interruptions, only voltage sags. One cable finishing process line could realize losses reaching US$150,000 - $500,000 per event. 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, with dozens of recorded saves. In the first three months of operation itself, two definite, documented 'saves' were recorded. The DySC investment was paid for with the first save.

IV. Plastics Extrusion

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 4 shows how the PRODySC unit corrected a deep voltage sag to keep the process running.

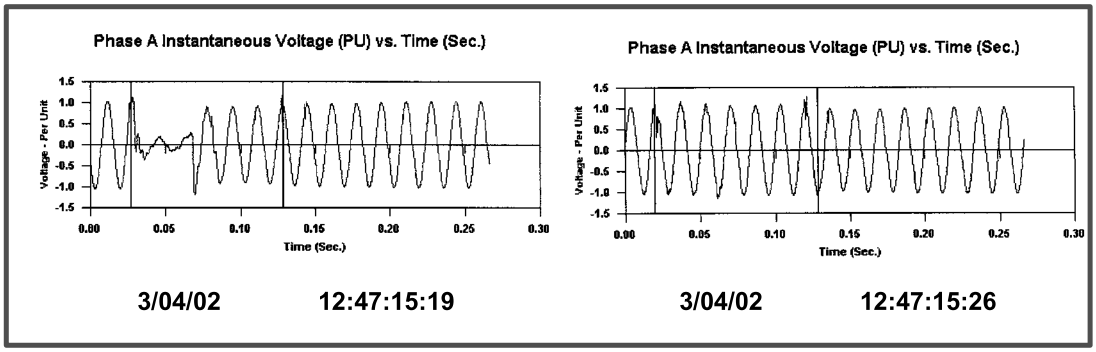

Figure 4. *Typical Event Showing Both Incoming Line Voltage & Corrected Output*

V. Automotive Applications

A major US 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 could cause the whole body to be scrapped. The size of the bus was 1600A but the actual load at present was less than 1200A. The customer found it most efficient to cover the whole bus, but only to the current level that was presently being used. A modular 1200A PRODySC system was installed, with expansion capability to 1600A at a later date. The system has been operating since May of 2001 and several process ‘saves’ have been recorded; one event is depicted in Figure 5. 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.

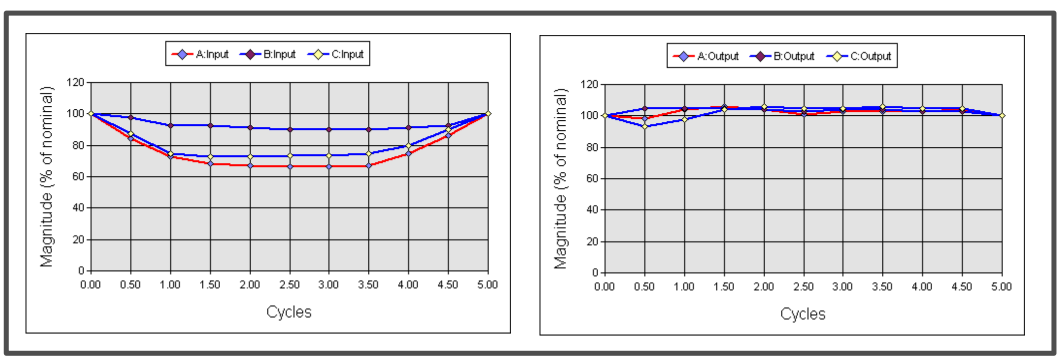

Figure 5. *Auto plant data: Input sag voltage and corrected output voltage (RMS)*

VI. DySC Applications in Singapore

A US chemical plant based at Jurong Island reported process interruptions due to voltage sag events. The sag typically caused the contactor circuit in the Motor Control Centre to drop-off, resulting in interruption of operation. Battery storage devices were not ideal because 1) Singapore’s premium grid minimizes outages, and 2) prolonged ride-through by a battery storage device during an extended power outage event would in any case require a shut down of the entire process. To save the contactor from tripping, a single phase DySC (MINIDySC) was applied. The DySC has since saved the company from several voltage dip events and prevented tripping of the motors.

A major US disk drive manufacturer in Singapore was having problem in their sputter machine operation during a voltage sag or dip. The entire machine would trip, causing unscheduled downtime costing about S$40,000 per machine per event. The clean-room had very limited space to install a battery storage system. A study was conducted identifying the EMO circuit, PLC, and the servo drives to be the weak link. A specially design DySC, which incorporated a single phase and three system, was supplied to mitigate the voltage sag problem. The system is now installed and running.

A Singapore-Taiwan-Netherlands joint venture wafer fabrication plant in Singapore had a problem with the facility chiller system that often tripped during a voltage sag event. Protecting the entire chiller system was not economically viable. EPRI-PEAC conducted a study and recommended that the control circuit of the chiller be protected using a single phase MINIDySC. The MINIDySC advantages included a small footprint, low cost and minimum maintenance. The DySC is presently in the final stage of discussion on the implementation.

CONCLUSIONS

Sag correction devices offer a proven solution for power quality protection across a broad spectrum of industries. For 'premium grid' environments such as in Singapore, the DySC virtually offers a 100% solution against all power quality events. The ability to deploy the DySC inside a facility at 'point of use', and to do so without batteries, significantly enhances the value proposition for the end-users. The DySC's ability to meet SEMI F47 and to operate with virtually any type of load, has led to a variety of successful applications. Over 500 DySC units are operational, protecting high-tech manufacturing applications in the US, Europe, South America, Singapore and the Far East.

While they offer the greatest incremental improvement in process reliability to premium grid customers, sag correction devices such as the DySC provide even normal grid customers with decreased downtime due to power events by more than an order of magnitude. As a result, proven products such as the DySC are uniquely positioned to have a dramatic impact on specific customers, industry sectors, and the overall economy.

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