# Power Quality The Invisible Thief

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Abstract: **Unacceptable power quality is the invisible thief that steals corporate profits. This paper introduces the business, the engineering and the technologies of stopping the invisible thief. It provides background for all aspects of the power quality business and explores the new entries in the market. This paper discusses examples of the various power quality situations and their economic impact.**

**In 1999, the industry estimates were $150 billion for losses due to unacceptable power quality. In that year, businesses spent more than $12 billion for power quality products and services. In 2002, it is estimated the market will be greater than $20 billion for PQ goods and services. The power quality situations responsible for these losses range from voltage sags to harmonics and ground loops. This paper will discuss the business of providing the $20 Billion of goods and services.**

**The power quality market includes end users, electric utilities, equipment and PQ mitigation equipment suppliers, , power quality measurement instruments, suppliers, consultants and regulatory bodies. This paper will discuss the roles and position of each in the market. This paper will also review a brief history of the power quality market and its projected short term and long-term growth both in the Southeast Asia and Worldwide.**

## I. History of Power Quality in Asia

The history of power quality in Asia traces back to early electrification of the region. The early issues were reliability and voltage variations. As manufacturing plants automated and sensitive electronic controls were introduced, the power quality issues changed to voltage sags, high speed transients and grounding problems. The well-documented case of power quality disturbances was recorded in Penang, Malaysia in 1989. It was widely referred to as the Penang micro outage. The incident is actually a misnomer because as it was actually a voltage sag caused by a fault on the utility grid. At about the same time in Thailand a manufacturer of disc drive parts complained to Provential Electrical Authority of voltage distortion causing problems. The result of both of these incidents was the utilities investing in instruments and training to document the power quality. During the 1990's, the utilities in Malaysia and Thailand began monitoring programs and engineering studies to determine the cause of the complaints and to investigate ways to reduce the causes. The results of these studies indicated that 80% of the complaints were caused by voltage sags. A recent survey of utilities in S.E. Asia (PQSynergy 2002) concluded 80% or greater of the PQ problems were caused by voltage sags.

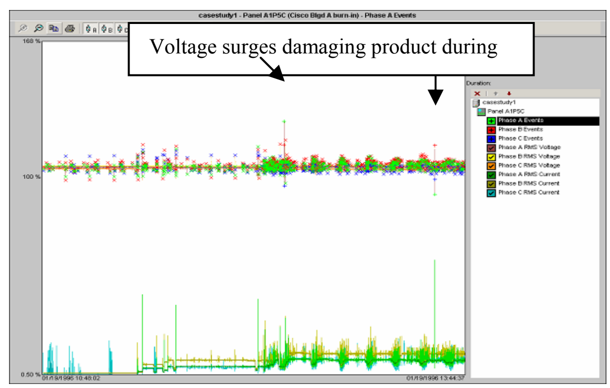
## II. Preventing Industry Losses Due to the Invisible Thief.

Actual loss per power quality incident is very difficult to quantify. The losses include equipment failure and repair, loss production time to restart automatic equipment, product waste, lost management time and many secondary costs. To reduce or eliminate these losses requires detailed data on the power quality incident, the process and financial consequences. The following examples provide the details of identifying the cause of the loss and way to prevent them from reoccurring.

### A. Example 1: Product failure

A large electronics equipment manufacturer was experiencing abnormal product failure during final test and burn-in. The site study revealed the problem to be voltage surges. See figure 1

Fig. 1




Are the voltage surges from the utility or generated internal to the facility? A closer look at the data and the electrical system reveals the voltage surges are generated by a voltage regulator in the facility. See figure 2.

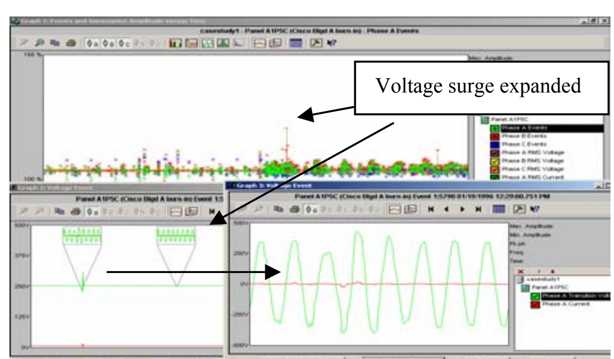



Fig. 2

Notice the detailed ac cycles shows the voltage surge preceded by a voltage sag. A close inspection of the electrical system revealed a voltage regulator that was reacting to the load changes. The regulator was performing to specification. The specification did not consider voltage changes caused by the sudden load switching. The incoming voltage was monitored for two months to verify if the regulation was operating within equipment specification. The solution to preventing the losses was removing the voltage regulator and monitoring the utility voltage to verify the voltage variations remained wit in the equipment specifications.

The losses of products were exceeding US$5000 per week not including the engineering time to resolve the problem. The cost to prevent the problem was less than $5,000 including all engineering time, monitoring costs and electrical system changes.

## B. *Example 2. Variable Frequency Drives Tripping*

A large alumina refinery facility in South America was experiencing losses due to VFDs tripping off line whenever a motor not on the drive experienced a phase to ground fault. This is a common occurrence in this outdoor facility. Motors not powered by a VFD did not experience any problems and motors powered by a VFD that had a fault would not cause other VFD's to trip. This factory had plans to install hundreds of VFD's to lower costs and improve process control. All were put on hold.

The PQ monitors were installed and a faulted motor was connected to distribution system. The monitors captured the following data clearly showing the problem was caused by grounding one phase of a delta circuit, which caused a phase shift. The VFD's sensed the phase shift and tripped. See Figure 3.

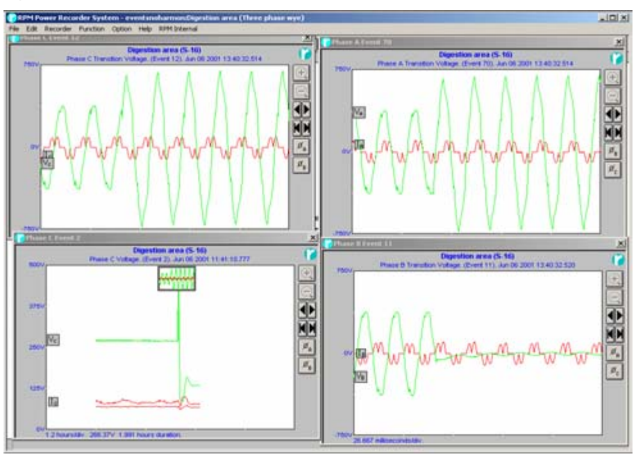


Fig. 3

Harmonic current and the distorted voltage at the buss and the grounding of one leg of the delta transformer caused a phase shift, which caused the VFD to trip due to phase shift error.

The solution to prevent the losses was to reprogram the VFD's to ignore the phase shift. The factory estimated this problem was costing US$10,000 per month and it was delaying a multi-million dollar facility upgrade program. The cost to document the problem and implement the changes in the VFD's was less than US$5000.

## C. *Example # 3 Automatic machine shutting down.*

A large fully automatic cereal factory in the USA was experiencing severe losses due to unexpected shut of a large critical machine. The machine contained a 600 hp motor powered by a variable speed drive. The drive would shut down for no apparent reason. All critical control circuits were powered by large UPS systems so power quality was not considered a source of the problem.

The costs of this problem were estimated at US$10,000 to US$20,000 in lost product and lost production time as it took 8 hours to clean and restart the machine.

The power quality monitors were installed at the machine and distribution system. Figure 3 shows the details of the data captured. The short duration voltage sag causes the large load to shutdown.

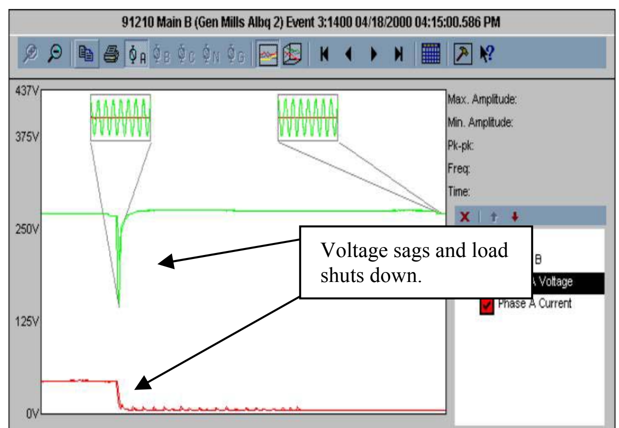



Fig. 4

In this case, the voltage sag originated at the utility. Further investigation showed the problem was the contactor for the motor. When the contactor was powered from the UPS the problem was prevented during voltage sags. Cost of the wiring change was less than US$100. Since a UPS was already installed.

## D. *Example # 4 Losses due to harmonics*

A large electronics manufacturer in Bangkok was installing new laser marking equipment in the production area. When the third unit was installed, the automatic test equipment began malfunctioning. This caused a delay in the project of upgrading to laser markers. No exact dollar losses were calculated; the estimated costs were US$1000 per day.

The harmonics were measured at laser markers and at each electrical panel back to the transformer. After analyzing the data, we determined the problem could be resolved by installing line reactors on the laser markers. The cost was less than US$ 500 per laser marker. The problem was resolved.

## III. The Economics of Power Quality

Power Quality is an economics problem. Reducing the losses taken by the invisible thief provide the funding for the engineering and solutions to stop the thief. The challenge for management is determining the costs and allocating the resources to capture the thief. The general costs have been reported by Electrical Power Research Institute (EPRI). A typical semiconductor fabrication facility loses as much as US$1 Million per incident. The automotive industry reports losses of more than $10 Million annually due to Power Quality Incidents. A typical Internet Service Provider measures downtime losses in the 1000's of Dollars per second.

As the examples demonstrate, the PQ thief can be stopped at a cost-effective price. The key to stopping the losses is in the data. The measurement and recording of the PQ parameters is the first step to cost-effective solutions. The data can be collected only when there is a problem (reactive) or the data can be continuously collected (proactive). The advantage of continuously monitoring is the ability to see trends and predict failures before they occur.

This predictive capability offers significant economic advantage. Preventing a single shutdown will return the investment of the automated monitoring and data collection system. In addition, the system can alarm and alert the user of any out of tolerance condition and record the power usage data for cost analysis.

There are several steps to ensure the most cost-effective methods of preventing and solving power quality related losses. During construction of new facilities or remodeling, the electrical design should be reviewed for delivery of quality and reliable power. The actual electrical system construction should be inspected and tested for the delivery of quality power. In cases where an existing facility is suffering losses, detailed studies will be required to determine which PQ parameter is the cause of the problem. After the parameter is determined then the selection of the most cost-effective solution is possible. The report from the PQ study should always offer alternative solutions.

## IV. Conclusions

The cost of power quality losses is growing every year. The following chart in Figure 5 shows the growth of the losses due to power quality and the growth of semiconductor device sales. EPRI reports that in 2001, approximately 30% of all electrical power passes though power electronics and by the year 2010, 70% of all electrical power will pass through power electronics. This means the economic losses displayed in the graph will continue to increase at a similar rate.

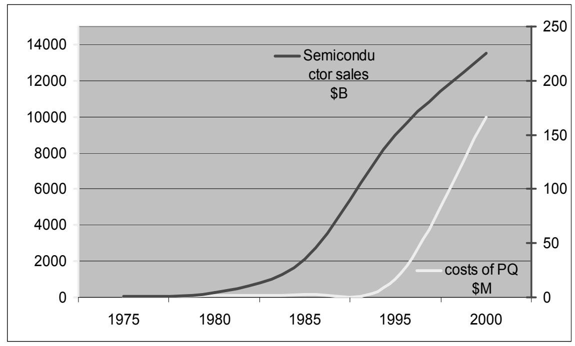



Fig. 5

The installation of permanent automated power quality recording systems provides the fastest and most cost-effective economic return. The automated data collection systems provide the user with easy to use graphs of all power consumption and power quality parameters. The user can review the data and take corrective action before a catastrophic shutdown occurs.

## V. Acknowledgment

*Mr. Buddy Groves, General Mills, coined the phrase, "the invisible thief."*

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## VII. Biography

**Education:** Terry attended the University of Maryland and the University of Minnesota. He regularly conducts seminars on Power Quality for companies and organizations around the world.

**Experience:** Founder and Director of Engineering of Power Quality Inc. A pioneer in the Power Quality Industry, he began his second engineering career in Power Quality in 1981, specializing in solving power quality problems for the semiconductor industry in Silicon Valley. He founded Power Quality Thailand LTD in 1986. With more than 20 years experience in the power quality field, Terry has studied all aspects of power quality, grounding and test equipment to monitor power quality.

**Relevant Research, Responsibilities and Interesting Data on Patents, Projects, Publications, Etc.:** Terry has presented numerous technical papers on power quality with special emphasis on grounding for electronic systems. He co-authored the book A Guidebook on Power Quality - Monitoring, Analysis & Mitigations, for Tenaga Nasional Berhad.

# Solving Power Quality Problems for Low and Medium Voltage Critical Process Loads

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**Abstract—Any industrial or commercial business with a critical process has expressed concern about utility disturbances that impact their operations. These companies spend millions each year on process improvements and automation, which often greatly increases the sensitivity of their plant loads to voltage sags and outages. Since the electrical service environment is different for each location, the mitigation of utility power problems is a "case-by-case" design.**

**This paper addresses alternatives that are available to mitigate these events and provide cost effective solutions. This paper covers voltage sag, voltage flicker and outage mitigation systems ranging from 300 kVA at low voltage to over 10 MVA at medium voltage levels. Examples of actual installations will be presented along with information as to how the mitigation system choice was made.**

## I. EVOLUTION OF POWER QUALITY SOLUTIONS

THE growing use of power electronic and computers sparked the need for more precise power quality solutions. Variable Frequency Drives (VFDs) and Programmable Logic Controllers (PLCs) provided the precision and control needed to accelerate industrial automation; and, large-scale computers revolutionized every business including medical systems in hospitals. As these devices provided huge productivity gains, their susceptibility to malfunction caused by voltage disturbances became apparent. Utility voltage fluctuations that were considered tolerable forty years ago now cause major problems with the performance of these devices.

In the early 1970s, great strides were made in the development of power electronic devices that had the ability to mitigate voltage sags and outages. The Uninterruptible Power Supply (UPS) industry grew rapidly in support of the mainframe computer market. Early UPS devices were very expensive and limited to low voltage (below 600 Volts) applications. Because of cost and size constraints, UPSs were applied to only the most critical loads.

During the 1990s, further advances in power electronics and control systems, coupled with better information about the actual performance characteristics of typical utility systems, has given rise to a variety of power quality solutions tailored to specific problems and load levels.

Utility power companies have improved the ways in which power disturbances are detected and isolated within their grids. Their goal has been to limit long term outages through the expanded use of circuit reclosers. Reclosers permit the rapid opening of faulted circuits to minimize damage to feeders, wires and equipment. However, the recloser operations can increase the number of voltage sags experienced in the vicinity of a fault. This approach is considered to be in the best interest of the majority of the total customer base.

Critical load customers in rural areas or island power systems see more events because of increased feeder lengths and primarily overhead distribution. Fortunately a greater spectrum of power quality solutions is available to solve these problems.

## II. LOW VOLTAGE POWER QUALITY SOLUTIONS

As a general rule, loads up to 2,500 kVA that are being impacted by utility disturbances can best be corrected using low voltage mitigation devices. The main issue becomes determining what elements or devices in the building or process are truly critical. A process dependent on VFDs may require only those devices be protected and not the entire plant. Unfortunately, the cost of rewiring the plant and the associated downtime may be more costly than installing a solution that protects the entire load.

In recent times the most popular solution in this kVA range has been on-line UPS systems. For these lower power ratings, UPSs offer mitigation of voltage sags as well as total power outages. Depending on the financial impact caused by extended outages, many users have opted to install back-up diesel or natural gas generators to provide long term protection. In response to a concern about power shortages in some areas, many utilities are offering "curtailment or interruptible" rates as an incentive to customers. Critical load customers who need the added protection of a back-up generator can use these incentives to help pay the cost of a total solution package.

The latest development in UPS systems is the availability of "short ride-through" devices, typically less than 30 seconds of outage protection. These systems provide adequate time to start a generator and transfer the critical load to generator power in a "seamless" fashion.

In a recent presentation, a leading expert on power system reliability stated that energy storage systems with shorter ride-through times tend to be more reliable. UPS users had concerns about battery problems for many years, which prompted the development of flywheel energy systems and alternative battery technologies to improve overall reliability and minimize maintenance.

These shorter ride-through UPS systems are typically off-line systems which only operate in the event of a utility voltage disturbance. The result is much higher operating efficiency and smaller equipment footprints. Fig. 1 shows a simplified one-line diagram of a modular off-line UPS approach.

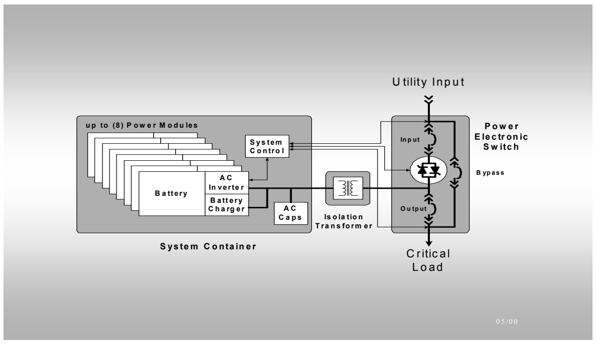


*Fig. 1. – Modular UPS System One-Line Diagram*

## III. Modular UPS Design

Newer UPS configurations take advantage of higher speed power electronic devices and more compact storage systems to construct small and large-scale units (250 – 2000 kW) configured as off-line systems that operate only when a utility disturbance occurs. In the off-line UPS case, the preferred source is normal utility input and the backup source is the UPS output (stored energy source). The Power Electronics Switch (PES) allows the critical load to be disconnected rapidly from the failing utility source. The total time to sense an impending problem and switch to the alternate source (battery power) averages 2-4 ms (less than ¼ cycle). As soon as the utility returns to normal, the critical load is “switched” back to the normal utility source by reclosing the system’s static switch.

The building block for this modular approach is a power conversion assembly consisting of an insulated gate bi-polar transistor (IGBT) inverter and an integral IGBT battery charger combined with a maintenance free battery string. Fig. 2 shows a 313 kVA/250 kW power conversion module rated for 30 seconds at full load.

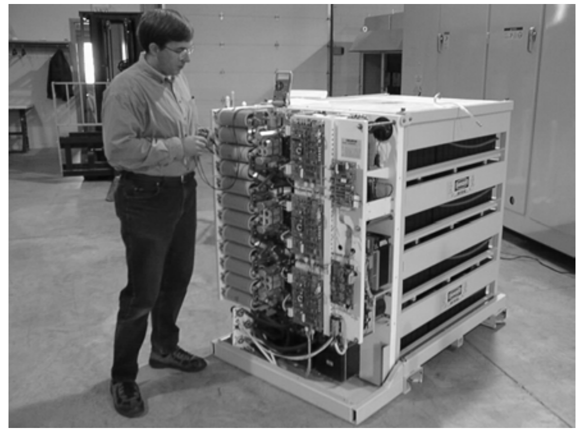

*Fig. 2 – 313 kVA/250 kW Power Conversion Module*

Since this approach is an off-line design, the ratings of the power electronics and electrical power circuits can be scaled down. Based on a duty cycle of 100 seconds of run time, the system components can be sized to less than 30% of their continuous current rating. This approach improves overall energy efficiency by a factor of five as compared to conventional UPS equipment.

Up to eight of these modules can be arranged to operate in parallel inside a UPS rated at 2.5 MVA/2.0 MW for a load at 480 volts or higher. Fig. 3 shows a 2.5 MVA UPS container suitable for outdoor installation.

*Fig. 3 – Outdoor 2.5 MVA UPS Container*

These UPS containers can be operated at low voltage or in parallel to create larger systems at medium voltage levels (5 – 25 kV).

## IV. Typical Low Voltage UPS Solutions

As discussed earlier, the key to solving any power quality problem hinges mostly on economics. The newer off-line devices can be used for protection of computer systems as well as industrial processes. Fig. 4 shows a 313 kVA, 480 V unit installed to protect Magnetic Resonant Imaging (MRI) scanners at a remote medical center. In this case, the UPS protects the power circuits that connect to trailer mounted MRI scanner trailers. These scanners are susceptible to costly damage during utility voltage sags or short outages. The option for installing these systems outdoors eliminates the need for major rewiring of the building and construction of an air conditioned interior room to house UPS equipment. The off-line design virtually eliminates all audible noise during normal operation. Typical on-line UPS systems have a sound level of 72-75 dba for solid-state systems and 80-85 for rotary systems.

*Fig .4 – Typical Outdoor UPS Installation at a Hospital*

For installations that experience long-term outages or load curtailment, these UPSs are combined with back-up generators. The UPS still operates as shown in Fig. 1, but now has an alternate input source from the generator. In this configuration, utility power must fail for more than two seconds before the generator is started and a transfer initiated. Another benefit of this configuration is the ability to transfer load manually between utility power and generator power without parallel operation between the two sources. The UPS provides ride-through for the critical load during the “open transitions” in the transfer switch.

Fig. 5 shows a 2,000 kVA UPS and a 1750 kW diesel generator protecting a critical process manufacturer that was subject to utility power curtailments in California.

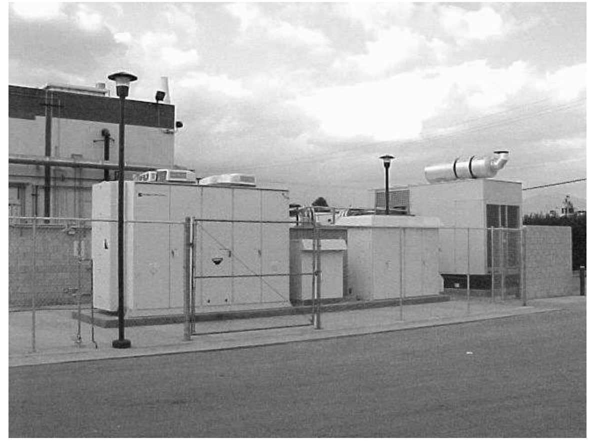

*Fig. 5 – Outdoor UPS with Back-Up Generator*

When a UPS of this type is installed at a site with more than one utility source, a fairly inexpensive automatic source transfer scheme can affect transfer from a failed feeder to an alternate in about 2-3 seconds. Based on feeder performance over time, this scheme may eliminate most outages on a single feeder and defer the need for generator back-up.

## V. Medium voltage power quality solutions

Perhaps the area of greatest financial investment by power quality system manufacturers is at the medium voltage level. Semiconductor wafer fabrication plans have led the way in recent years to foster newer and better solutions to protect very large critical loads at voltage levels up to 25 kV. Because of the size of these loads, the typical customer has a utility source at or near the transmission system and tends to experience voltage sags as opposed to sags and outages. In addition, these loads typically have at least two utility feeds. These conditions offer more solution options with a broader spectrum of solution costs. The options range from high speed source transfer schemes between two feeders to voltage sag mitigation devices known as Dynamic Voltage Restorer (DVR) systems or two medium voltage UPSs with or without back-up generation.

Another case is loads that actually cause disturbances on the utility distribution system, typically referred to as “voltage flicker” sources. Sawmills, rock crushers or large arc welding facilities can impact a wide area of the utility distribution. The typical solution is a VAR compensation system that can sense and correct rapid deviation of the voltage on a cycle-by-cycle basis.

## VI. High speed source transfer systems

As discussed previously, most large, critical facilities (generally 10 MVA or greater) have at least two incoming utility feeders. Depending upon the degree of independence between the two feeders, a very cost-effective solution to sags and outages may be a High Speed Source Transfer System (HSSTS). Power electronic switch devices are currently in service that allow HSSTSs to be constructed with up to 1200 amps, continuous duty at 15 kV and 600 amps at 25 kV. These systems have the ability to switch large blocks of load between feeders with a typical sense and transfer time of 4 milliseconds or "1/4 cycle response." Ideally, the two sources should be from separate substations; as a minimum they should be different busses in the same substation. An analysis is required to determine how many power quality events occur at the distribution level as opposed to the transmission level. If the majority of the sags occur on the transmission system, the total effectiveness of an HSSTS may be limited. Rapid switching of large blocks of load needs to be closely coordinated with the local utility to ensure proper operation. The most popular HSSTS scheme is a split buss design, which allows the critical load to be shared by the two feeders. Fig. 6 shows a split buss HSSTS scheme consisting of three power electronic switches (PESs). Two PESs are normally closed to conduct each portion of the load from each feeder. The third PES in the center is normally open. If either incoming source senses a sag or outage, the middle PES is gated closed and the affected feeder PES is gated open.

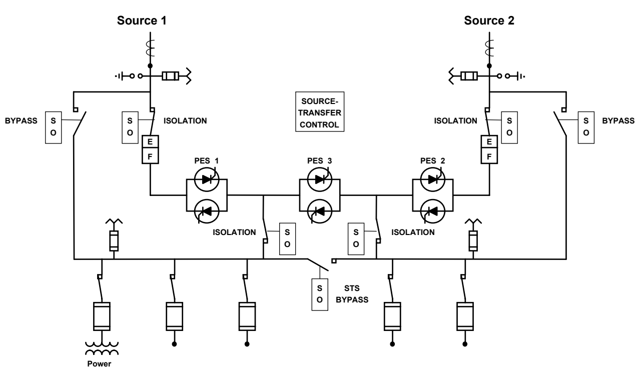


Fig. 6 – *Medium Voltage High Speed Static Transfer System Split Buss Configuration*

Fig. 7 shows a typical medium voltage 1000 Ampere HSSTS installation at a semiconductor wafer FAB. In this case, the total load is approximately 15 MVA split between two 12.47 kV feeders. Overall effectiveness in mitigation of power quality events should be greater than 90% for this solution to be cost effective as compared to other medium voltage alternatives.

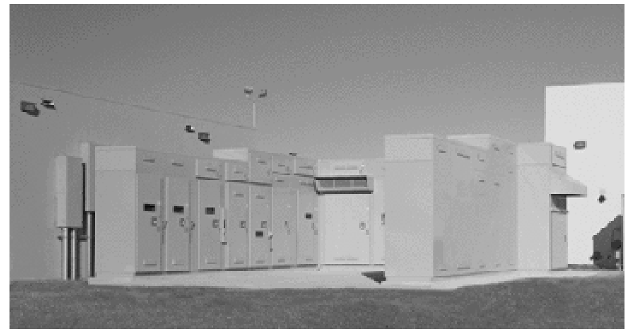

*Fig. 7 – Typical Medium Voltage High Speed Static Transfer System at a Semiconductor Wafer FAB*

## VII. Dynamic voltage restorer systems

Developed in the early 1990's, the Dynamic Voltage Restorer (DVR) achieves power quality improvement by injecting voltages of controlled phase and magnitude in series with a utility distribution line experiencing a sag event. A small amount of energy is stored in a capacitor bank to be the source of the injection voltage. Since most sags are the result of distribution or transmission momentary faults, the total sag event is generally less than 200 milliseconds in duration with magnitudes less than 50% of nominal voltage. The DVR system is generally rated for the amount of compensation being injected. For example, a DVR rated 2 MVA could be installed on a 5 MVA load and provide mitigation of sags down to 60% of nominal voltage (40% sag).

Since most sags are not symmetrical on each phase, the DVR sensing system must be capable of providing the appropriate amount of compensation needed on each phase. The degree of voltage boost can be adjusted as a function of the load. At lower load levels relative to the DVR rating, deeper sags can be corrected. If a sag occurs on only one phase of the utility, greater compensation can be achieved as well.

Fig. 8 shows the single-line of a DVR device and its interconnection to a utility feeder to a critical load.

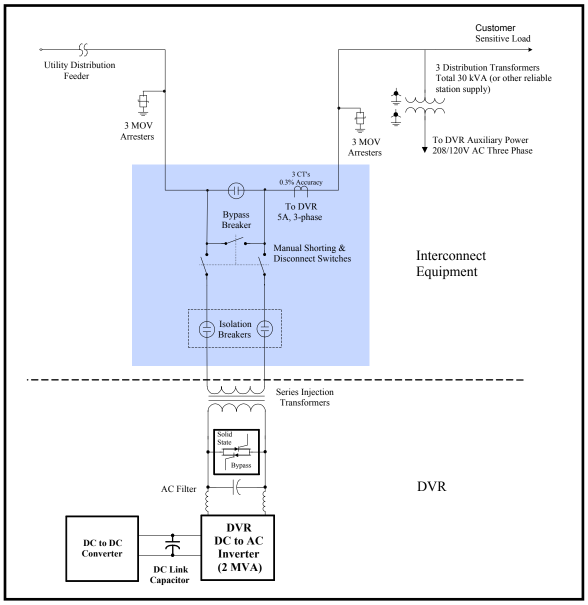


*Fig. 8 – Typical Medium Voltage DVR System One-Line Diagram*

Fig. 9 shows a typical DVR installation at a paper mill used to protect the 8 MVA critical load paper machine. In this case, the DVR consists of two – 2 MVA units operating at 11 kV and providing sag protection down to 0.50 per unit voltage.


*Fig. 9 – Typical DVR Installation at a Paper Mill*

DVRs have been applied to loads as large as 60 MVA and have provided effective sag mitigation for events as deep as 0.30 per unit voltage.

## VIII. VOLTAGE FLICKER MITIGATION SYSTEMS

Not all power quality disturbances are caused by problems with the utility distribution or transmission systems. Some customer loads such as rock crushers, saw mills or arc welding systems draw power from the utility systems with "pulses" of current due to mechanical or electrical surges caused by the process. As rocks enter a crusher, the drive motors can experience near lock rotor conditions that cause voltage sags commonly referred to as voltage flicker. Repeated dips in excess of 5% can cause an annoying pulsing in lighting systems and trigger customer complaints to the local utility. In some cases, this flicker can be as severe as 10 – 20% which starts to cause malfunction of critical loads at other customers connected to the same utility feeder.

Dynamic Static Compensator Systems commonly known as DSTATCOMs utilize high speed power electronics inverters coupled with a control system that senses these rapid voltage changes (flicker) and injects compensating voltages on a "cycle-by-cycle" basis to reduce or eliminate the flicker condition. Fig. 10 shows a single-line diagram for a typical DSTATCOM device.

Another solution is an Adaptive VAR Compensator (AVC) System. The AVC approach is typically a 3 or 4 stage capacitor bank system utilizing thysistor switches to turn on the capacitor banks in a binary arrangement to provide the necessary "fast VAR" compensation to eliminate flicker. The AVC approach is a lower cost solution and is scaleable to virtually any size application from 500 kVAR to 18,000 kVAR.

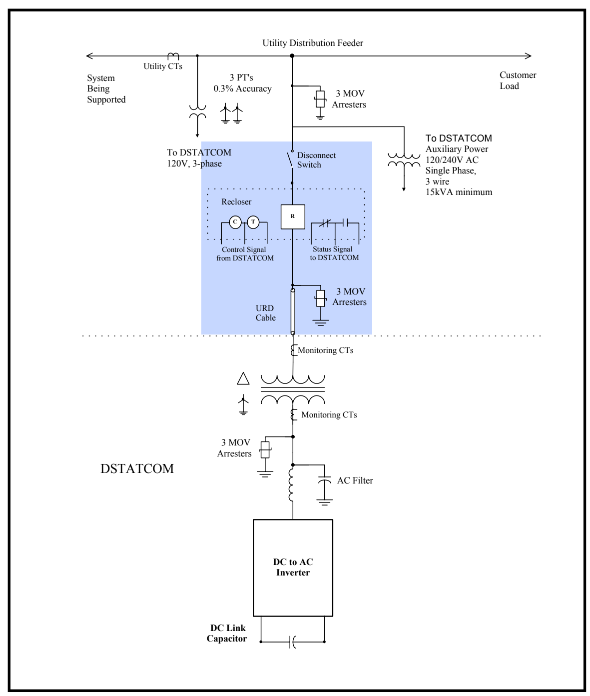


*Fig. 10 – Typical DSTATCOM Single-Line Diagram*

Fig. 11 shows a typical DSTATCOM installation at a rock crusher site. This system is at the end of an 11-mile, 12.47 kV feeder shared with 1,000 customers. The site has numerous 200 – 250 horsepower motors with a running load of 3 MVA. Installation of the DSTATCOM reduced an 8 – 12% voltage flicker problem to less than 4% nominal.

*Fig. 11 – DSTATCOM Installation at Rock Crusher Installation*

## IX. Medium Voltage UPS Systems

Large scale critical load sites that experience very deep voltage sags (40% or greater) coupled with occasional outages may require a mitigation system with a large amount of stored energy. Large scale medium voltage UPS systems have been developed that can ride-through complete outages up to 30 seconds at full load. Like the DVR, this design is based on a modular design, typically 2.0 – 2.5 MVA per container. The stored energy is sufficient to allow time to start back-up diesel generators and transfer the load to emergency power should a long-term outage occur.

One of the first uses of this modular UPS design applied at medium voltage was a pharmaceutical plant in Puerto Rico. A fault on any nearby feeder from the utility can cause a voltage sag, which impacts the production in the plant. Lightning strikes on the transmission lines and storms historically cause the majority of disturbances that impact the plant.

The plant has a total load of approximately 4.5 MVA consisting of 4.16 kV chillers and 480 Volt clean-room loads. Installing a protection system with total outage capability was deemed to be desirable by the customer to ensure mitigation of short outages as well as sags.

The UPS system is rated 5.0 MVA/4.0 MW at 4.16 kV with 120 megajoules of energy storage (30 seconds at 4.0 MW) as shown in Fig. 12. . A 4 MW diesel generator system protects the plant from long-term outages.

During normal operation, utility power flows through the system switchgear with the Power Electronics Switch (PES) closed. Should the system control logic sense a utility sag or swell greater than 10% of nominal voltage or an outage, the PES is gated off simultaneously with the turn-on of the inverters in the UPS containers. AC power generated from the battery storage (DC source) will power the load through sags and momentary outages. Once the utility input is restored, the UPS control re-synchronizes with the source and gates the PES on to reconnect utility power to the critical load.

For power outages greater than 2 seconds, the UPS system logic sends a start command to the diesel generator system. The generators accelerate to rated speed and synchronize to the UPS. The UPS then "soft loads" the generator system and completes the transfer of the critical load to generator power with 15 – 20 seconds. Once utility power returns and UPS battery recharge is complete the UPS initiates a return to utility power and shuts down the generator system. The installation is shown in Fig. 12.

*Fig. 12 – Medium Voltage UPS at a Pharmaceutical Plant*

## X. Conclusion

The number of power quality mitigation options has increased substantially in the last ten years, providing greater cost effectiveness. Local utilities have become more proactive in assisting critical load customers in analyzing the selection of the best power quality solution.

The knowledge and understanding of why utility voltage disturbances occur has also increased. This education has made critical load customers more aware of what limitations exist in building a utility distribution system with high immunity to voltage transients or outages.

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## XII. BIOGRAPHY

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Brad has over 30 years experience in the design and operation of critical power systems ranging from single phase UPS systems to medium voltage applications. He began his engineering work as a systems reliability engineer in the Apollo Lunar Module Program at Cape Kennedy. He held senior management positions in two of the major UPS manufacturers during his career. Brad is a member of IEEE and has published over 30 technical journal articles on critical power system design.

Brad is a registered professional engineer and has a BSEE (Bachelor of Science in Electrical Engineering) degree from the University of Florida. He is Vice Chairman of the IEEE Power Engineering Society's Emerging Technologies Committee and a member of the Board of Directors for the Electricity Storage Association.