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POWER QUALITY SOLUTIONS FOR LOW AND MEDIUM VOLTAGE CRITICAL LOADS

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ABSTRACT

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.

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.

KEYWORDS
Power Quality, UPS, Voltage Sags, Flicker, VAR Compensation

1. INTRODUCTION

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.

2. LOW VOLTAGE POWER QUALITY SOLUTIONS

As a general rule, loads up to 2,500 kVA that

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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.

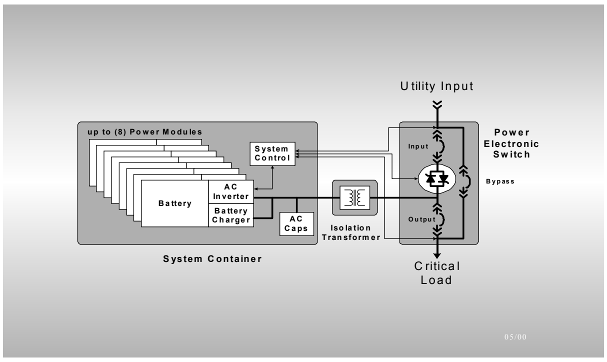

Fig. 1. – Modular UPS System One-Line Diagram

3. 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.

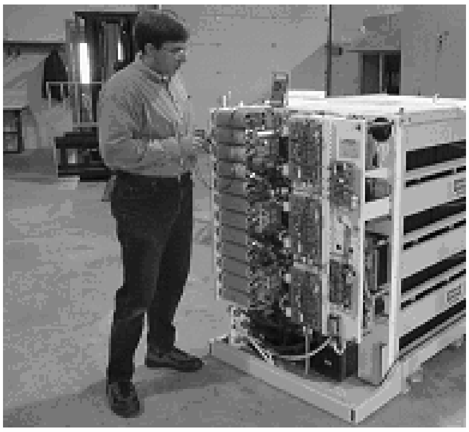

Fig. 2 – 313 kVA/250 kW Power Conversion Module

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.

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

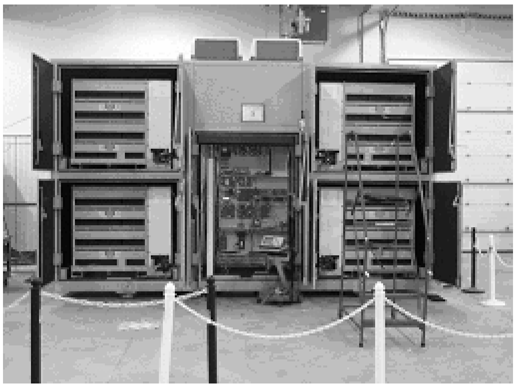

Fig. 3 – Outdoor 2.5 MVA UPS Container

4. TYPICAL LOW VOLTAGE UPS SOLUTIONS

At many installations, the critical parts of the load may represent a small fraction of the total electrical demand. Unless the electrical distribution system is wired with separate circuits for the critical loads, segregation of the critical and non-critical feeders can be more expensive than simply protecting the whole load. For some critical processes protecting a few key process elements can save thousands of dollars in equipment damage or production downtime. Figure 4 shows a 625kVA, 690 volt, 50 hertz UPS installed to protect several essential fans for a critical chemical process in Argentina.

Fig .4 – Typical Outdoor UPS Installation at Chemical Manufacturer

The process was susceptible to costly damage during utility outages lasting only a few seconds. There was no space available in the air-conditioned electrical equipment rooms so installing a UPS solution outdoors was deemed the most desirable choice.

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.

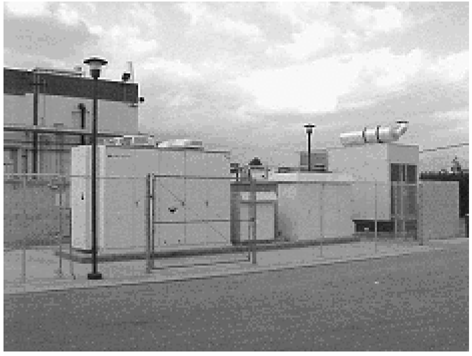

Fig. 5 – Outdoor UPS with Back-Up Generator

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.

5. LOW VOLTAGE VAR CONTROL

Management of reactive power has always been an issue for industrial power users who employ a large number of motors in their process application. If motors are lightly loaded the power factor can be negatively affected. Many utilities are starting to apply power factor penalties to customers who do not maintain a power factor demand of 0.9 lagging or better. Simply applying fixed capacitor banks to individual motor circuits or larger banks on main switchboards can cause voltage swells to occur as motors are loaded and unloaded. Too many capacitors can cause resonant conditions to occur as well. Simply switching capacitor banks can cause major voltage surges that can impact large areas of a utility grid and damage sensitive equipment. Solving dynamic load power factor problems can be addressed using reactive power management devices such as Active VAR Compensators (AVC’s).

Figure 6 shows an AVC devise with four stages of capacitance that can be injected into a circuit using thyristor controlled switches.

A microprocessor based control system measures the peak magnitude of the inductive component of the current (at the zero crossing of the corresponding line-to-neutral voltage) and "switches in" the correct amount of capacitance to maintain the necessary voltage or power factor. Since the switching occurs at the zero voltage crossing, no transients are generated. This type of AVC can respond within ½ cycle and maintain the desired voltage or power factor setting on a continuous basis for any dynamic load.

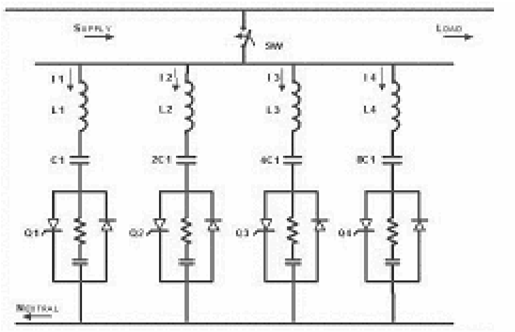

Fig. 6 – Active VAR Compensator with Four Stages

Figure 7 shows an AVC device applied in a container ship cargo facility. The operation of the cranes resulted in the power factor running as low as 0.39 lagging. The starting and stopping working cycles of the cranes created rapid fluctuation of the reactive power demand on the utility. The low power factor was causing large penalty charges on the utility bill for poor power factor. Installation of a 2400 kVAR AVC relieved the problem and generated a payback of less than two years.

Fig. 7 – Typical Adaptive VAR Compensator Installation

6. 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 plants 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 to 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.

7. 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. 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.

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.

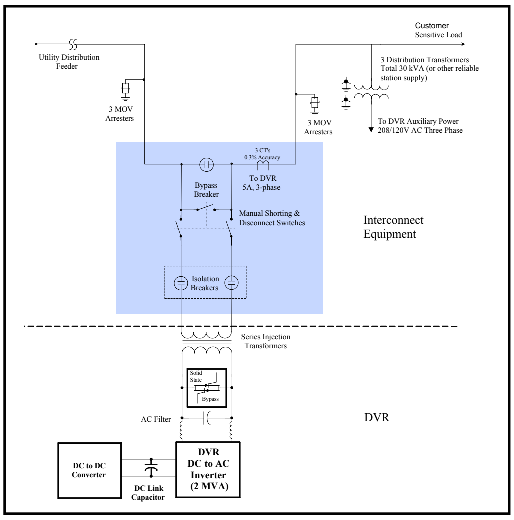

Fig. 8 – Typical Medium Voltage DVR System One-Line Diagram

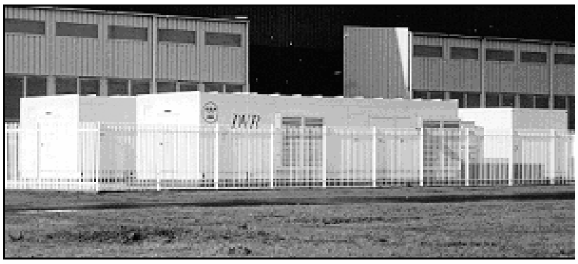

Fig. 9 – Typical DVR Installation at a Paper Mill

8. 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 thyristor 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.

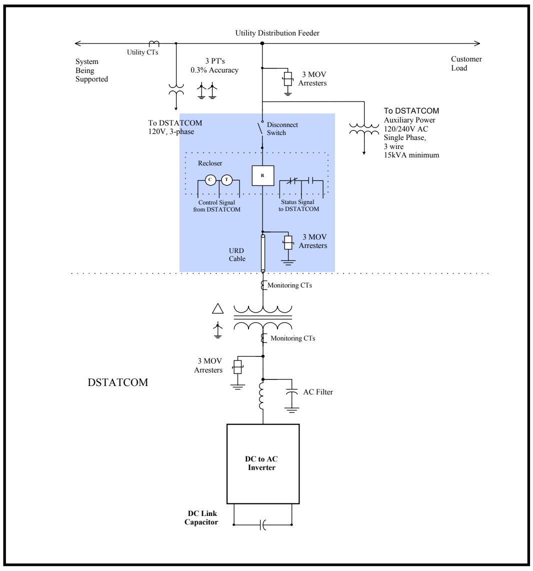

Fig. 10 – Typical DSTATCOM Single-Line Diagram

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

9. 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.

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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 in Puerto Rico

11. 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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