ENHANCING POWER QUALITY DELIVERED TO SENSITIVE CUSTOMERS WITH DISTRIBUTION-CLASS CUSTOM POWER PRODUCTS

George T. Gurlaskie and Michele Peel
Westinghouse Electric Corporation
4400 Alafaya Trail
Orlando, FL 32826-2399

ABSTRACT:

New technologies based on power electronics have been developed to help protect sensitive commercial and industrial customers from power quality problems inherent to electrical power distribution systems. These technologies are known as Custom Power Products. Custom Power products protect sensitive loads from voltage sags, swells, flicker and other power quality problems. By reducing the frequency of equipment malfunction and increasing the availability of sensitive equipment, Custom Power Products can help reduce costs associated with disruption of sensitive processes.

This paper will focus on the Dynamic Voltage Restorer [DVR] including analysis of actual waveforms documenting the successful restoration of voltage sags. This paper will also provide a brief introduction to the Distribution Static Compensator (DSTATCOM) and the Solid-state Transfer Switch (SSTS). Finally, the concept of a Custom Power Park where each of these technologies are utilized to provide various grades of power to customers with differing needs is presented.

KEYWORDS:

Custom Power Products, Dynamic Voltage Restorer, DVR, voltage sags, power quality, Distribution Static Compensator, Solid-state Transfer Switch.

INTRODUCTION:

The proliferation of electronics and electronic controls has caused power quality to become a critical issue for end users and electric providers. Poor power quality affects customer productivity, product quality, and most importantly, profitability. Projections from the Electric Power Research Institute predict that conditions will only worsen as electronically controlled loads will account for more than 60% of all electric loads by the year 2000.

The term Custom Power describes the value-added power that electric providers will offer their customers in the future utilizing new technologies based on power electronics. Custom Power Products help protect sensitive loads from voltage sags, swells, and flicker. By addressing these power quality problems, Custom Power Products can help reduce equipment malfunction due to power quality and increase the availability of sensitive equipment, thereby eliminating costs associated with disruption of sensitive processes.

Custom Power Products include the Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM) and the Solid-state Transfer Switch (SSTS). The DVR restores quality to voltage supplied from a faulted power system. The DSTATCOM reduces distribution system disturbance due to dynamic loads such as saw mills and rock crushing operations that have widely varying reactive power demands. The SSTS is a sub-cycle transfer switch that can transfer a sensitive customer between two independent sources.

THE DYNAMIC VOLTAGE RESTORER:

Traditional approaches to improving the level of power quality have focused on improving the delivery system topology to minimize customer feeder exposure to fault conditions. However, hardening of the individual feeder alone will not protect the customer service for voltage sags caused by faults on adjacent feeders or on the associated transmission system. The use of series connected, solid state voltage sources with energy storage can now provide entire facilities with a means of protection against voltage sags that may cause an adverse impact on end user operations.

Figure 1. 2 MVA DVR

The Dynamic Voltage Restorer [DVR], is a high speed switching power electronics converter that is connected in series with the distribution system serving a sensitive load. This device mitigates sags and swells by injecting a compensating voltage into the distribution system in synchronous real time.

The DVR mitigates voltage sags by injecting a compensating voltage into the power system in synchronous real time. The DVR is available in sizes from 2 to 10 MVA. A 2 MVA DVR is shown in Figure 1.

The heart of the DVR consists of an energy storage system that feeds three independent single phase PWM inverters. The compensating voltage that is synthesized by the inverters is injected into the distribution system by a series injection transformer. Figure 2 depicts the operation of the DVR. The input voltage to the DVR experiences a sag due to a fault on the transmission system or an adjacent distribution feeder fed by the same substation bus, the DVR injects a compensating voltage, and the sensitive load operates on the restored voltage, thereby avoiding process disruption.

The Block Diagram of the DVR is shown in Figure 3. The energy storage system for the DVR is usually a dc capacitor bank, however

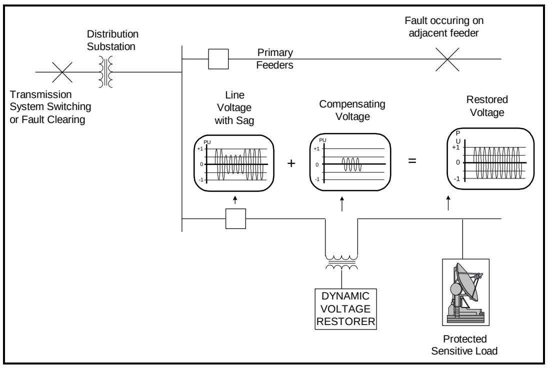

Figure 2. Operation of the DVR During a Sag

other energy storage devices (such as flywheel energy storage or SMES) could also be used. The energy storage capacitor bank is interfaced to the voltage source inverters by using a boost converter (dc to dc). The boost converter regulates the voltage across the dc link capacitor that serves as a common voltage source for the voltage source inverters. The three independently controlled voltage source single-phase PWM inverters (dc to ac) synthesize the appropriate voltage waveform as determined by the DVR's digital control system. The DVR control system compares the input voltage to an adaptive reference signal and controls the inverters to help keep the output voltage remains within the specifications to which the DVR is set.

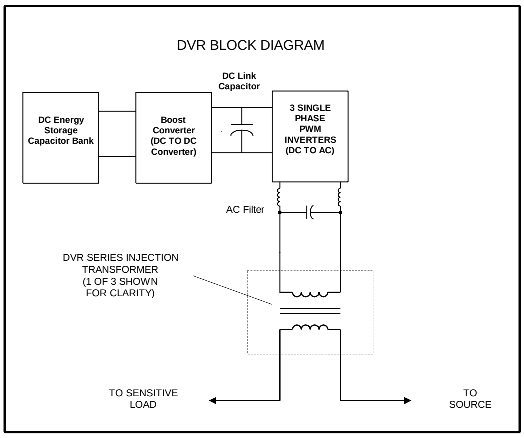

Figure 3. DVR Functional Block Diagram

Under normal operating conditions (no sag), the DVR injects only a small voltage to compensate for the series reactance of the injection transformers and device losses. During a sag, the DVR control system calculates and synthesizes the voltage required to maintain the output voltage and injects this voltage in synchronous real time.

The output of the inverters is applied to the DVR injection transformers. The voltage injected into the distribution feeder depends on the transformer ratio of the series injection transformer. The primary winding of the series injection transformers is connected in series with the distribution feeder. The primary and inverter winding currents are inductively coupled by the series injection transformer. The transformer ratio must be set so that the maximum feeder load current does not cause the inverter current to exceed its rating.

SIZING THE DVR:

The factors for determining the DVR size necessary for a particular application are: the size of the load, the types of sags experienced at the site and the voltage level necessary for the load to ride through a voltage sag[1]. The DVR is a partially rated device, which means in applying the device, it only needs to be sized to provide what is missing in the voltage waveform.

The nature of the sags experienced at a particular site are a major influence on the size of the DVR necessary to help protect a sensitive load. If a site experience deep sags the per unit injection (and therefore the DVR MVA rating) must be higher than a site that typically experiences more shallow sags. The sensitivity of the load to be protected is another quantity that is important in sizing a DVR for a particular site. Many loads that are based on CPUs can ride through a short term voltage sag to 0.70 per unit [2]. Some other sensitive loads experience problems at voltages below 0.90 per unit. [1].

Since the DVR only has to supply the voltage that is missing from the sagged waveform, the power rating of the DVR is usually much less that the load that it is protecting. Most DVRs are sized to provide 0.25 to 0.50 per unit insertion. The MVA rating of a DVR is determined by the product of the maximum injected voltage and the rated load current [1]. Primary voltage taps on the series insertion transformer can adjust the voltage injection at sites where the maximum load current has seasonal variations. The series injection transformers can be rated for application at voltages from 4 kV to 34.5 kV.

FIELD PERFORMANCE OF THE DVR:

DVRs have been installed on sensitive loads around the world, both at 50 and 60 hertz. Some of the applications include textiles, food processing, paper, electronics and even a distribution feeder serving residential and commercial customers. By monitoring voltage at some of these facilities, the field performance of the DVR has been documented for a variety of sag types.

Figure 4 shows the input voltage to the DVR during a single phase sag that occurred on 3/27/97. The voltage dropped to approximately 0.21 per unit for 8 cycles.

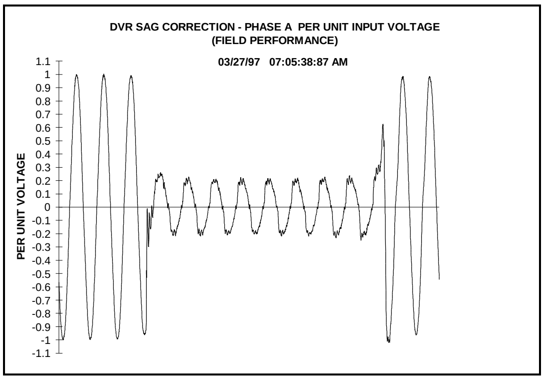

Figure 4. Input Voltage Sag on 3/27/97

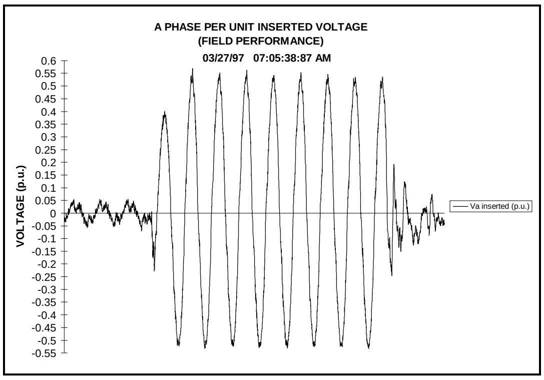

Figure 5. Injected Voltage During Sag on 3/27/97

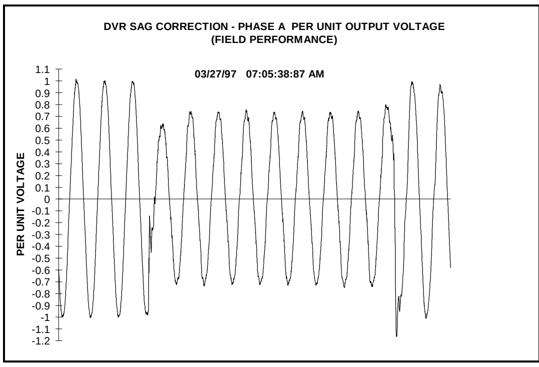

Figure 6. Output Voltage During Sag 3/27/97

The voltage injected by the DVR to restore this sag is shown in Figure 5. The DVR injected about 0.53 per unit. This is the maximum injection voltage of this 2 MVA DVR for the load size it is serving. Figure 6 shows the output voltage supplied to the sensitive load. The voltage was restored to about 0.74 per unit. It is important to note that although the DVR did not correct this sag to 1.0 per unit, it restored the voltage to a level that allowed the sensitive load to ride through the event.

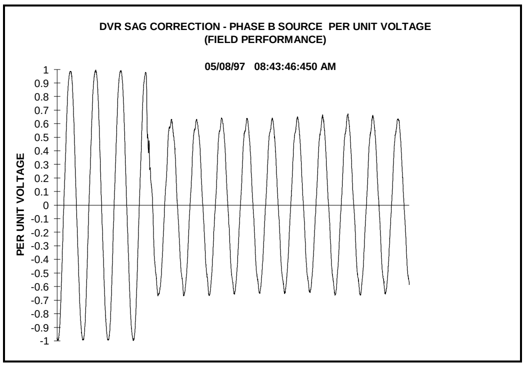

Figure 7. Input Voltage at Start of Sag 5/8/97

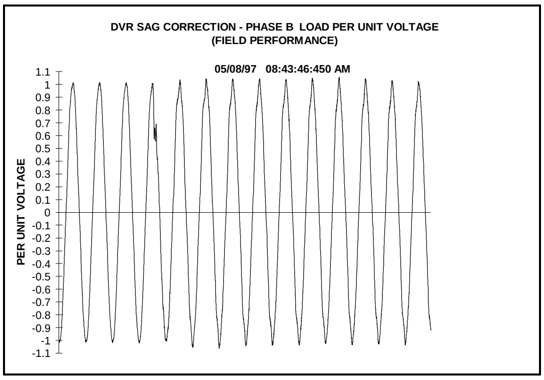

Figure 8. Output Voltage During Sag on 5/8/97

Another sag of interest occurred at 0843 on 5/8/97. This was a long B phase sag lasting approximately 26 cycles. The beginning of the sag is shown in Figure 7 and 8. Figure 7 shows the source voltage. Figure 8 show the load voltage. The B phase voltage sagged to about 0.58 per unit. The 2 MVA DVR with 600 kJ of energy storage corrected this sag by injecting 0.42 per unit voltage as shown in Figure 9.

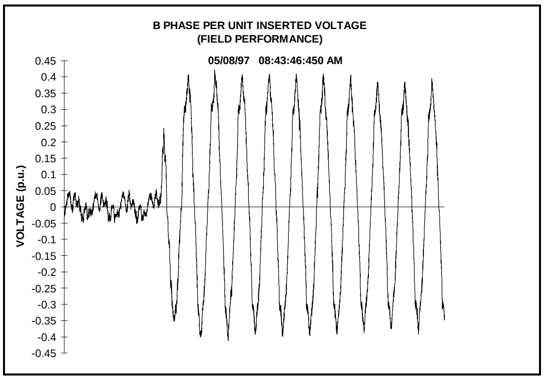

Figure 9. Injected Voltage During Sag 5/8/97

Figure 10 and 11 show the end of this sag. The DVR inserted approximately 32.7 kJ of energy into the distribution system during this sag. The energy remaining in storage was over 560 kJ. This sag only required about 6% of the capacity of the energy storage capacitor. The DVR recharged the energy storage system to full capacity in approximately 300 milliseconds. This data shows the DVRs effectiveness in restoring relatively long sags.

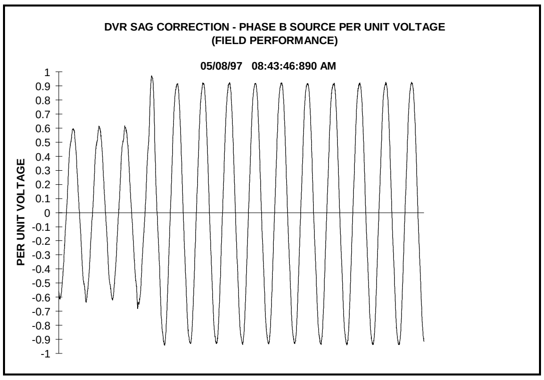

Figure 10. Input Voltage at End of Sag 5/8/97

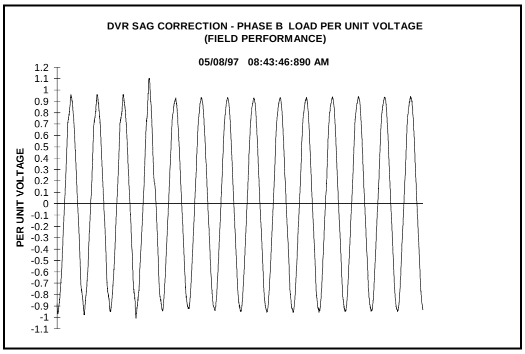

Figure 11. Output Voltage at End of Sag 5/8/97

OTHER CUSTOM POWER DEVICES

In addition to the DVR, there are two other power electronics based devices that can be used in Custom Power. The DSTATCOM is a shunt connected power electronic converter that regulates power distribution system voltage by reactive compensation. The DSTATCOM consists of a pulse-width modulated (PWM) voltage source inverter that is interfaced to the distribution system with a shunt connected transformer. The voltage source inverter synthesizes voltage in synchronism with the distribution system voltage. The DSTATCOM regulates the distribution line voltage by absorbing either lagging or leading reactive current. Loads such as saw mills, rock crushing operations and shredding operations produce large variations in reactive power. This causes in pulses reactive current to be drawn from the distribution system. This varying reactive current, which flows through the system impedance causes voltage flicker that affects all the customers served by this distribution line. The DSTATCOM supplies this variable reactive power at the site of the dynamic load. In this manner, the DSTATCOM compensates for voltage flicker due to dynamic loads.

The SSTS is a sub-cycle switch that can transfer a sensitive load from a faulted source to another independent source without disruption of that load. This switch can help protect loads up to 1200 A. This switch is applicable to sensitive loads that have two completely independent sources that are relatively stiff. This Custom Power Product is especially suited to solve problems due to momentary interruptions that are the result of faults on the distribution line serving the sensitive load. The control system monitors the incoming voltage and when a disturbance occurs, the sensitive load is transferred to the alternate feeder.

THE CUSTOM POWER PARK:

The three Custom Power products described can each provide additional value to energy supplied to endusers. However, in combination, Custom Power Products can allow electric distribution system designs and operation characteristics to offer a range of power quality.

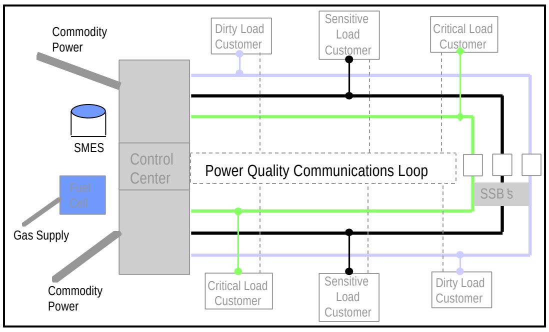

Figure 12 Power Park Concept

Tenants in a Custom Power Park or Premium Power Park, would be offered enhanced electrical service levels, in return for a premium rate. The justification for paying higher rates would be based on their cost savings realized through the reduced downtime and improved production made possible by enhanced power quality. This concept would also eliminate or reduce the need for purchasing, operating , and maintaining internal power conditioning equipment.

One park design shown in Figure 12 would include a utility corridor in the park, with multiple Custom Power load class connections available for tenant connection throughout the park. Technical solutions may incorporate the devices previously discussed with the addition of utility distribution primary loop feeder[s], located within the park boundaries, to obtain the advantages of network fault protection to further localize fault interruption. The customer who can segregate their load into non-critical and critical bus[s] could be provided multiple levels of service where appropriate to result in the lowest total energy cost consistent with customer special quality needs.

CONCLUSION

Custom Power Products make possible the retrofit of existing and design of new utility power distribution systems to accommodate the need for differing levels of power quality required by many electronically controlled production processes. The DSTATCOM regulates power distribution system voltage by reactive compensation. The SSTS can rapidly transfer load from a faulted bus to and alternate feeder. The DVR helps protect sensitive loads from voltage sags. Field results of the performance of the DVR shows that the DVR is effective at mitigating the effects of voltage sags. These products can be combined into a Custom Power Park, which enables industrial customers to choose the level of power quality that fits their needs.

REFERENCES:

[1] R.J. Nelson, J. R. Legro, G. T. Gurlaskie, N. H. Woodley, M. Sarkozi, A Sundaram "Voltage Sag Relief: Guidelines to Estimate DVR Equipment Ratings," Proceedings of American Power Conference, Vol. 58-II, April 1996, pp. 1138-1343.

[2] R.J. Nelson, N. H. Woodley, D. G. Ramey, and E. M. Gulachenski, "Requirements for Dynamic Voltage Restoration to Relieve Distribution Voltage Sags," 1995 Proceeding of the American Power Conference, April 1995, pp 1530 - 1534.

BIOGRAPHIES

George T. Gurlaskie received his Bachelor of Electricla Engineering with high honor from Auburn University in 1986. While attending Auburn, Mr. Gurlaskie worked as a cooperative education student for Alabama Power Company. After graduation, he went to work for Florida Power and Light [FPL] in Daytona Beach, Florida. During his 9 years at FPL, Mr. Gurlaskie held several positions including 5 years as a Load and Voltage Supervisor. Mr.Gurlaskie is currently an applications engineer for Custom Power Products for Westinghouse Electric Corporation.

Michele Peel is a 1984 graduate of Duke University with a Bachelor of Science in Electrical Engineering. Her professional experience includes over 13 years with Westinghouse Electric Corporation in various positions including operations management, quality, and marketing, of electrical distribution products and services for the industrial and utility marketplace. She is currently responsible for Custom Power Project Development for the Energy Management Division of Westinghouse, and is based in Orlando, Florida.