CASE STUDY

Elspec EQUALIZER and Power Factor Correction in Distributed Generation Applications

This case study examines dynamic electronically switched, real-time reactive power compensation systems used to correct power factor (PF) and to improve power quality at a variety of distributed generation installations. Power factor correction (PFC) systems stabilize voltage and current fluctuations caused by power system/load interactions that may arise due to an increase in non-linear loads such as variable speed drives, welding machines or the starting of large motors. Other power quality issues, such as the presence of harmonics and the need for "detuning" to avoid resonant conditions with capacitor banks, as well as the suitability of this type of technology for use with other distributed generation equipment such as wind turbines, micro turbines, and fuel cells are also examined.

Power Factor Correction

When power systems have purely resistive loads, the power conversion is called true power and is measured in watts. Systems with inductive loads, like those using motors that require magnetic fields to operate (and may also contain capacitance), will also have reactive power present which is measured in volt-amperes-reactive or VAr. The ratio of true power to apparent power delivered to an AC circuit is called the power factor, and is measured in kW/kVA. If the PF is low (less than 1.0) the current draw from the power utility will be higher than necessary, resulting in excessive power losses and inefficiency. Capacitors are commonly used to correct or increase the PF to 1.0 on AC power lines by electrically counteracting inductance, or lagging reactive power.

EQUALIZER and Switching

When banks of capacitors are switched on to a power line using a mechanical contactor, an impulse is created which has an associated rise time and peak voltage, as well as a decaying waveform such as the sample waveform illustrating current and voltage transients shown in Figure 1. Although the PF is corrected, a disturbance is created. This poor power quality may result in equipment not operating correctly.

The EQUALIZER uses power semiconductors and advanced microprocessors to monitor all three phases of the bus. The capacitors are switched electronically, rather than by traditional mechanical contactors or fixed banks which sometimes results in over or under compensation. The EQUALIZER precisely corrects dynamic load fluctuations typically within 0.25 to one cycle by using DSP (Digital Signal Processor) technology and Fast Fourier Transform Analysis, to provide accurate compensation on the main service, even in the presence of harmonics. A schematic of this type of electronic switch, which provides transient-free switching of capacitors onto the network is shown in Figure 2. It is ideal for use with any distributed generation installation supplying dynamic loads.

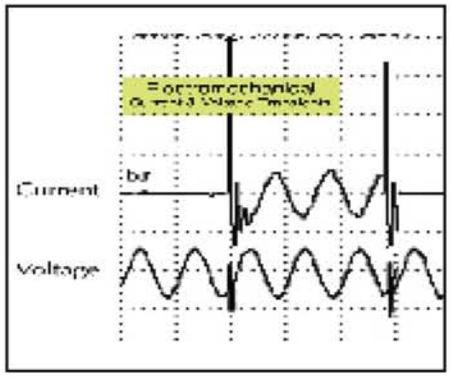

Figure 1: Capacitor Switching Transient

EQUALIZER and Harmonics

Another power quality concern when operating generators both in parallel and off-grid, or in "island" mode, is the predominance of non-linear loads connected to the generator and the presence of harmonic currents. Harmonic currents are multiples of the fundamental 60 Hz waveform and arise from such devices as DC adjustable speed drives, switch-mode power supplies, and other highly prevalent devices which use 6-pulse or 12-pulse rectifiers as part of the circuitry in the power supply and generate 5th and 7th, and 11th and 13th harmonics, respectively.

In This Document

Read how the Elspec EQUALIZER:

- Improves energy efficiency and power quality in a natural gas back-up generator at an Illinois, USA, high school
- Reduces voltage fluctuations in diesel generators during welding operations at an automobile plant
- Stabilizes supply voltage and reduces wind turbine start-up current

In the presence of harmonics, traditional fixed banks of capacitors could contribute to a resonant condition, with resultant damage to the capacitors and other equipment. The addition of inductors to electronically switched capacitors permits de-tuning below the resonant frequency. The Elspec EQUALIZER may also be "tuned" with passive harmonic filters to absorb harmonic currents, resulting in improved power quality on the network.

Engine-Generator Applications
Advances in microprocessor-based engine-generator controllers have enabled load control of three phase AC generators to be accomplished with digital synchronizers. These include load sensors and controls, dead bus closing systems and PF control. Reactive power may be produced by changing the reference PF on the generator controls. Some generator manufacturers achieve power quality under step load conditions by adjusting the air/fuel mixture to control generator speed and to maintain stable frequency. (The ISO 8528-5 standard details recovery time, voltage dip and frequency deviation at block loads up to 25%.) For large block loads, or for dynamic loads such as welding or the start up of large motors, electronic PFC may be used to mitigate voltage sags and stabilize voltage and current on the network. This type of supplemental equipment was used to complement a natural gas generator's basic capability to meet the reactive power requirements of chiller loads.

Natural Gas Generator at a High School
A suburban high school studied the benefits of on-site generation and implemented a turnkey solution which is being used for peak shaving on their campus near Chicago, Illinois. A desirable feature of the system was for use as an emergency backup resource with black start capability

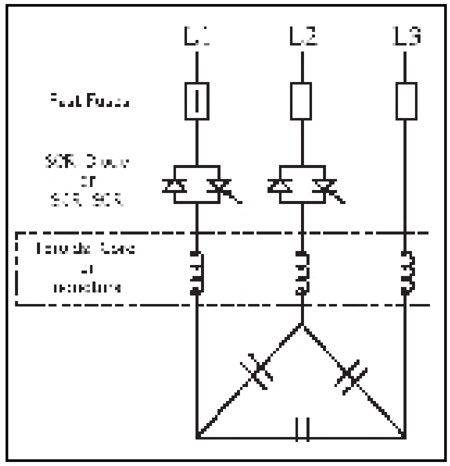

Figure 2: Electronically Switched Capacitor Diagram

(although initial operation is in grid connect mode). This would permit power to be supplied to the school in the event of a grid failure up to the limit of the generator's power rating. The system is integrated within the building energy management system which accommodates load shedding. When running independently of the grid, reactive power support would permit the start-up of the HVAC system's many motors and chillers.

During normal operation, a 1,750kW natural gas engine generator operates in parallel with the power utility. The use of two high efficiency electric chillers, such as those seen in Figure 3, and other large motor loads, which degrade PF, led to an evaluation of methods to improve the PF in addition to providing other benefits such as improved energy efficiency and power quality. The accommodation of future load growth was also considered, as the PFC system provided increased capacity on the transformer.

The EQUALIZER was recommended. The unit's total output is 895 kVAr with a maximum current rating of 1077A. The system is detuned to 245Hz to avoid resonance with the fifth harmonic. There are six switching steps with each step providing 149kVAr to provide for smooth compensation. A standard 6% inductor was specified to limit current inrush. When the chiller turns on, there is a correspondingly low PF, a voltage drop on the bus, high current and a high reactive energy requirement. The EQUALIZER provides reactive energy to stabilize voltage and current levels, and a smoother load profile. Figure 4 depicts the effect of a single chiller at 90% capacity (approximately 129kW) cycling on and off with the reactive power correction system initially off, and then switched on at the mid-point of the sampled period. When the EQUALIZER is off, base load is ~750kVAr at the main service; however, it is only 75kVAr when the EQUALIZER is on. Dynamic reactive power load at chiller startup is reduced 75%, with an overall current reduction of nearly 250A. This results in significantly less power losses in the facility wiring.

Diesel Generators at an Automobile Plant
A large automobile plant in India needed to operate independently from the power utility supply during outages in order to run a spot welding operation. Welding strikes from this type of operation place great stress on a facility's electrical system, expecially one running on distributed generation. The factory had installed five 1250kVA engine generators to meet production needs. Before installation of an unbalanced real time EQUALIZER, significant voltage fluctuations caused the plant to

Figure 3. Two 15-Ton Chillers

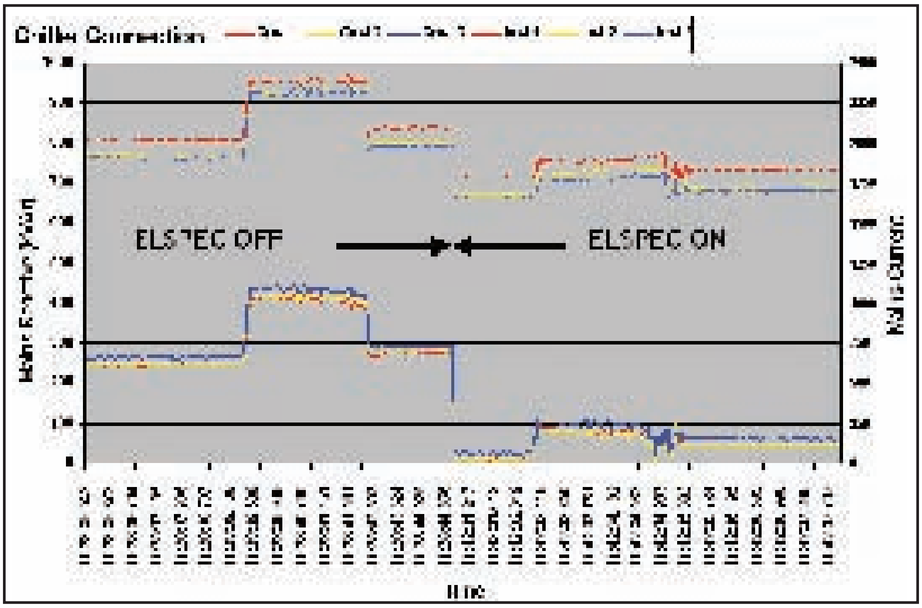

Figure 4: Effect of Chillers on Reactive Power and Current

trip off line, frequently interrupting production. After installation of the EQUALIZER, which consisted of three 600kVAr units specified at 415V with a 14% reactor, operation satisfactorily resumed.

Wind Turbine Generator Applications

The efficiency of an inductive wind turbine, such as seen in Figure 5, is affected by wind speed, location, site electrical system conditions, and the efficiency of its reactive PFC system. Improper compensation PFC creates power quality issues on the site electrical system by causing excessive voltage drops and increased current draw which may affect overall power production.

Inductive wind turbines are asynchronous generators that require reactive energy under all load conditions to create the magnetic fields which enable the generator to function. Peak requirements occur during start-up, which can occur on numerous occasions during normal daily operation. The start-up reactive consumption requirement of a wind turbine generator is extremely high, sometimes equivalent to the kW power rating of the turbine. This reactive power has traditionally been imported from the grid.

A typical inductive wind turbine generator's start-up creates significant harmonic current distortion. For a 1.3MW generator, the current levels at the transformer reach nearly 1,200A and the generator's reactive consumption is at its peak, exceeding 1,200kVAr. The impact of this high reactive power consumption on the supply transformer, and subsequently the supply voltage, is quite considerable. The voltage drops dramatically, which causes unacceptable disturbances, such as voltage flicker, on the grid. The situation becomes worse when there are multiple turbines connected to the same supply network. If the peak reactive consumption of the wind turbine generator can be eliminated or significantly reduced during the start-up sequence, the current level would be drastically lower, stabilizing the supply voltage. Consequently, voltage flicker disturbance would be limited, resulting in improved power quality on the grid.

Figure 5: Wind Turbines

Most wind turbines are equipped with conventional reactive PFC systems which use electromechanically switched capacitors. They are, however, normally rated to offer only basic correction. Typically, this rating is 25% of the true start-up reactive consumption requirements. These systems operate only after the turbine's start sequence has been completed and the wind turbine generator's main contactor has closed.

The Elspec EQUALIZER-W is designed to achieve complete PF compensation on a cycle-by-cycle basis throughout the entire start-up and full operating range of the turbine. The speed at which this system works is shown in Figures 6 and 7. Peak start-up current is reduced between 60% and 90% at various stages in the start-up cycle, and the voltage drop associated with start-up is virtually eliminated.

Please refer to APP NOTE SMN-0004-05E for further discussion of inductive wind turbine startup sequences.

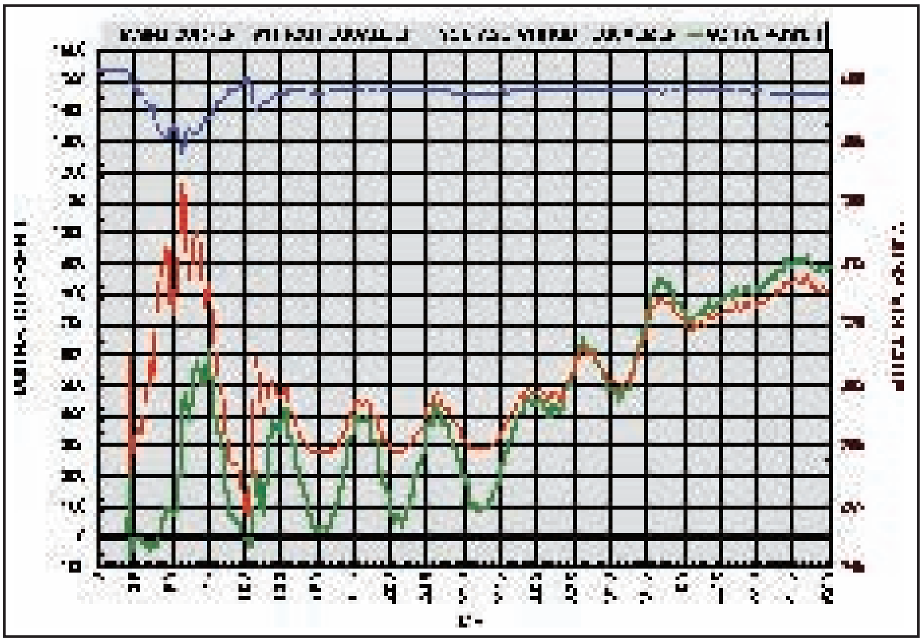

Figure 6: Typical Start-up Current and Voltage

Figure 7: Start-up Current and Voltage with the EQUALIZER-W

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