Case Study:

Distributed Generation & PFC

Reactive Power Compensation Systems for DG

In this document:

Overview

This paper examines dynamic electronically switched, real-time reactive power (VAr) compensation systems being used to correct power factor and improve power quality at a variety of distributed generation installations. One benefit of such systems is the stabilization of voltage and current fluctuations caused by power system/load interactions. These may arise due to an increase in nonlinear 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 is also examined. The suitability of this type of technology for use with other distributed generation equipment such as wind turbines, micro turbines, and fuel cells is also considered.

Power Factor Correction (PFC)

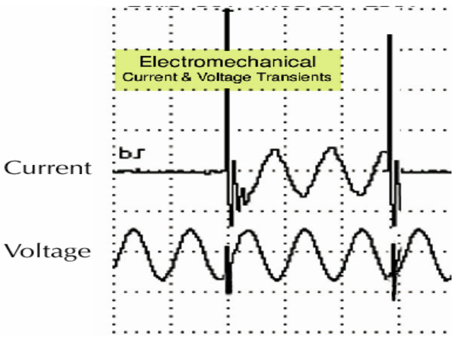
When power systems have purely resistive loads, the power conversion is called true power and is measured in watts. A system with inductive loads like motors which require magnetic fields to operate and may also contain capacitance will also have reactive power present which is measured in volt-amperes-reactive or VArs. The ratio of true power to apparent power delivered to an AC circuit is called the power factor (PF) which is equal to kW/kVA. If the power factor is low (less than one) the current draw from the utility will be higher than necessary resulting in excessive I^2R losses and inefficiency.

Capacitors, which supply leading VArs, are commonly used to correct or raise the power factor on AC power lines to 1.0 by electrically counteracting inductance, or lagging VArs.

Types of PFC Systems

When banks of capacitors are switched on to a power line with a mechanical contactor, an impulse is created which has an associated rise time and peak voltage as well as a decaying waveform. A sample waveform illustrating current and voltage transients is shown in Figure 1 below. Although the power factor is corrected, a disturbance is created, which can result in equipment mis-operation and can be considered an example of poor power quality.

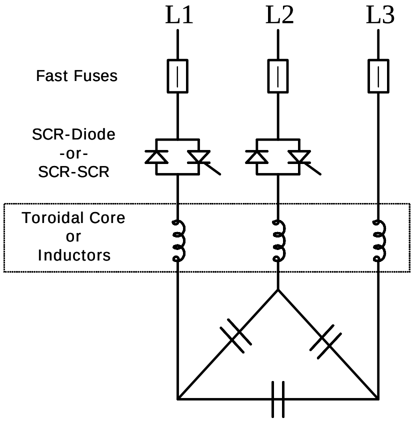
Figure 1:
Capacitor Switching Transient



A new class of electronic VAr compensation equipment, such as the Elspec Equalizer, uses power semiconductors and advanced microprocessors to monitor all three phases of the bus. The capacitors are switched electronically, rather than traditional mechanical contactors or fixed banks which, when used, sometimes resulted in over or under compensation. Elspec's system achieves compensation within typically 0.25 to 1 cycle, precisely compensating dynamic load fluctuations; This is achieved using DSP (Digital Signal Processor) Technology and utilizing Fast Fourier Transform Analysis, to provide accurate compensation on the main service (mains) 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; ideal for use with any DG installation supplying dynamic loads.

Another power quality issue of 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

Figure 2:
Electronically Switched Capacitor Diagram



supplies, and other highly prevalent devices which use 6 or 12-pulse rectifiers as part of the circuitry in the power supply and generate 5th and 7th, & 11th and 13th harmonics respectively.

In the presence of harmonics, traditional fixed banks of capacitors could contribute to a resonant condition, with resultant damage to the capacitors and other pieces of equipment. The addition of inductors to electronically switched capacitors permits de-tuning below the resonant frequency. The Elspec system 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 power factor control. VArs may be produced by changing the reference power factor 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 maintain stable frequency. (The ISO 8528-5 standard details recovery time, voltage dip and frequency deviation at block loads up to 25 per cent.) For large block loads, or for dynamic loads such as welding or the start up of large motors, electronic VAr compensation 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 turn key 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 (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 grid independent, VAr support would permit the startup of the many motors and chillers comprising the HVAC system.

During normal operation, a 1,750 kW natural gas engine generator operates in parallel with the utility. The use of two high efficiency electric chillers and other large motor loads, which degrade power factor, led to an evaluation of methods to improve the power factor 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 VAr compensation system provides increased capacity on the transformer.

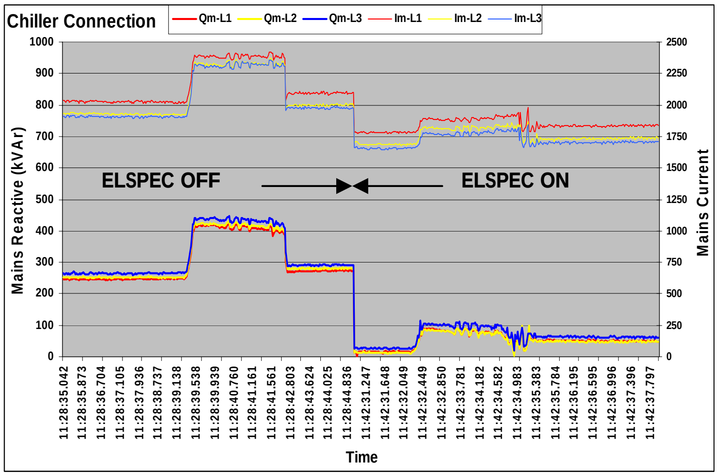
An Elspec EQUALIZER VAr compensation system was recommended. The unit's total output is 895 kVAr with a maximum current rating of 1077 amperes. The system is detuned to 245 HZ to avoid resonance with the fifth harmonic. There are 6 switching steps with each step providing 149 kVAr to provide for smooth compensation. A standard 6% inductor was specified to limit current inrush. A brief description of the unit's operation at the school in grid connect mode and its benefits follow:

Figure 3:
Two 15-Ton Chillers

When the chiller turns on, there is a correspondingly low power factor, a voltage drop on the bus, high current and a high reactive energy requirement. With the Elspec system operating, reactive energy is provided by the Elspec system resulting in stabilized voltage and current levels and a smoother load profile. Graph 1 below depicts the

Graph 1:

Effect of Chillers on Reactive Power & Current



effect of a single chiller at 90% capacity (approximately 129kW) cycling on and off with Elspec VAr compensation system off initially, and switched on (at the mid-point of the sampled period.)

With the VAr compensation system not running, base load is ~ 750kVAr at the main service but only 75kVAr with the Elspec system on. Dynamic kVAr load at chiller startup is reduced 75%, with an overall current reduction of nearly 250 Amps. This results in significantly less I^2R losses in the facility wiring.

Diesel Generators at an Automobile Plant

Another application of VAr compensation to supplement stand alone generator operation: A large automobile plant in India had a need to operate independent from the utility power supply during outages, while running a spot welding operation. This type of welding operation places stress on a facility's electrical system due to multiple simultaneous welding strikes occurring. Running on distributed generation is particularly challenging under these circumstances. The factory had installed five (5) 1250 kVA engine generators to meet production needs. Prior to the installation of an Equalizer VAr compensation system, significant voltage fluctuations resulted causing the plant to trip off line with frequent interruptions to production. After installation of an unbalanced real time Elspec Equalizer system, (consisting of three 600 kVAr units specified at 415 volts with a 14% reactor), operation resumed satisfactorily.

Wind Turbine Generator Applications

The efficiency of an inductive wind turbine is affected by a number of parameters: wind speed, location, site electrical system conditions, and significantly, the efficiency of its reactive power (VAr) compensation system.

Improper compensation will affect not only the efficiency of the generator but will create power quality issues on the site electrical system by causing excessive voltage drops and increased current draw potentially impacting 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 startup, 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 always been imported from the grid.

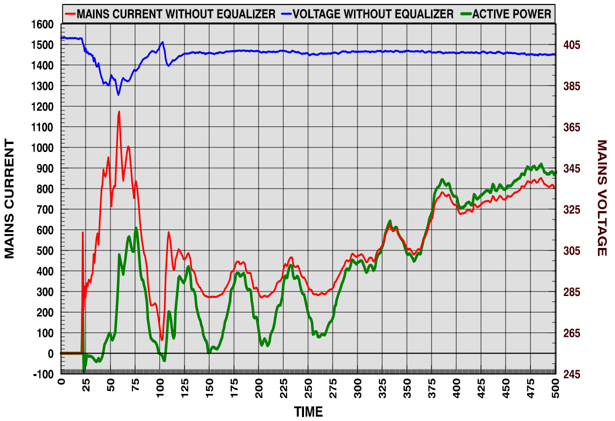
Figure 4:

Image from Mendota Hills Wind Farm - Illinois

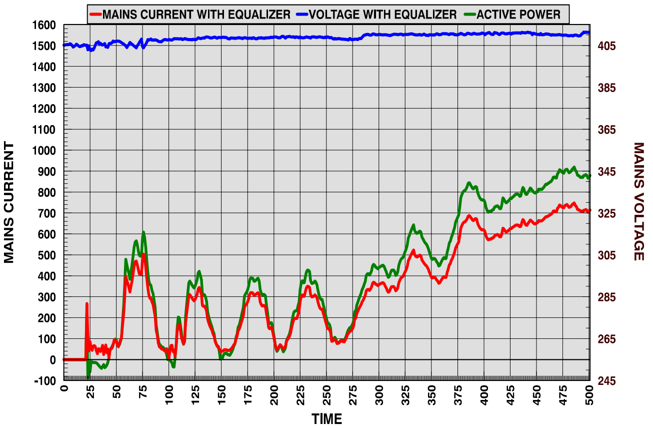
A typical inductive wind turbine generator's start up creates significant harmonic current distortion. For the 1.3 MW generator used in this example, current levels at the transformer reach values of nearly 1,200A and the generator's reactive consumption is at its peak, exceeding 1,200kVAr (Graph 2). The impact of this high reactive consumption on the supply transformer and subsequently the supply voltage is quite considerable. The voltage drops dramatically, which will cause unacceptable disturbances on the local utility network (grid), i.e. voltage flicker. This situation becomes increasingly 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 would be drastically lower, stabilizing the supply voltage. Consequently, voltage flicker disturbance would be limited, resulting in improved power quality on the grid.

Most wind turbines are equipped with conventional reactive power factor compensation (PFC) systems which use electromechanically switched capacitors. However, they are normally rated to offer only basic compensation. Typically, this rating is 25% of the true start-up reactive consumption requirements and they operate only after the turbine's start sequence has been completed and the wind turbine generator main contactor has closed. Alternatively, the Elspec Equalizer-W is designed to achieve complete power factor compensation on a cycle-by-cycle basis throughout the entire start-up and full operating range of the turbine.

Graph 2:
Typical Start-up Current & Voltage



Graph 3:
Start-up Current & Voltage w/ EQ-W



The speed at which this system works is evidenced by Graphs 2 and 3. Peak start-up current is reduced between 60 and 90% at various stages in the startup cycle, and the voltage drop associated with start-up is virtually eliminated. Please refer to APP NOTE – RTRPCWIND-0505-1 for further discussion of inductive wind turbine startup sequences.

Summary

Reciprocating Engines

Dynamic VAr compensation systems can supplement engine generators operating in parallel with the grid or in prime power mode to provide reactive power requirements and provide greater equipment utilization at a facility, increasing efficiency and reducing I^2R losses. Further, they can also accommodate increased nonlinear loads and provide harmonics filtration if required. They may be detuned to prevent resonance from developing and will stabilize voltage and current on the electrical bus during large motor load cycling. Practical benefits include diminished motor inrush and an option to eliminate soft starters on chillers with resultant cost savings.

Wind Turbines

VAr compensation systems utilizing electronic switching of capacitors are capable of reacting rapidly to reactive power fluctuations for near-instantaneous connection of all available compensation within less than one network cycle. The improvement in power quality on the network during initial start up and subsequent turbine operation is significant. This approach will also be very important as, under new regulations for grid interconnect, wind farms are required to remain 'on line' during various fault conditions and to support voltage recovery on the network.

A majority of wind farms are located in remote geographical areas. More often than not, utility networks in those same areas can sometimes be very weak and exhibit unstable voltage levels. Low-voltage compensation with the Equalizer-W Dynamic VAr compensation system at or near individual turbines is vitally important to keeping individual wind turbines on line and producing power for the grid.

Other Distributed Generation Applications

The use of dynamic VAr compensation systems to correct power factor is also suitable for use with other distributed generation equipment using inverter based power conversion systems, Micro turbines operating in parallel with the grid that require power factor correction at the point of common coupling (PCC) can benefit from rapid cycle-by-cycle compensation which results in improved power quality when supplying dynamic loads such as the start up of large chillers and other large motor loads.