Improving Power Factor Through Innovation:

An Alternative Solution for SCR-Controlled Transformer-Coupled Silicon Carbide Heating Elements

SCR power controllers operating on the transformer primary often control electric heating applications employing transformer-coupled Silicon Carbide (SiC) heating elements. Traditionally, designers must choose between two modes of operation: phase angle or zero voltage firing. But neither approach is ideal, as both present performance challenges.

A better solution combines the best aspects of both methods. With the advent of digital SCR technology, Control Concepts Inc. began developing a new hybrid firing mode: Zero Cross Transformer Mode, or ZCT Mode.

This innovation was thoroughly tested with an O'Brien & Gere/Denton TSI 48" rotary hearth furnace in a real-world application. The performance of ZCT mode was measurably superior to phase angle and zero-firing modes, as evidenced by reviewing the characteristics of these two traditional methods.

Phase Angle Control Mode

In phase angle control, the SCR is gated every half cycle by delaying the gating of the SCR sometime after crossing line voltage zero. Power is controlled on a sub-cycle basis (Figure 1).

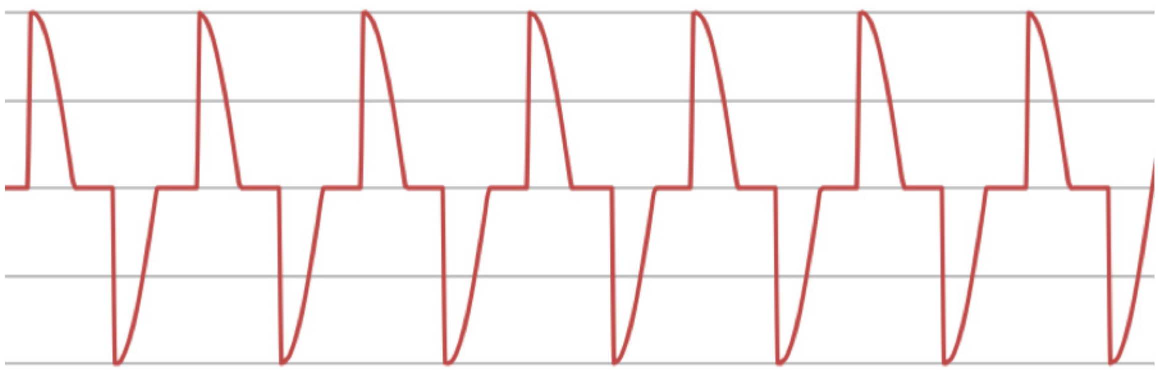


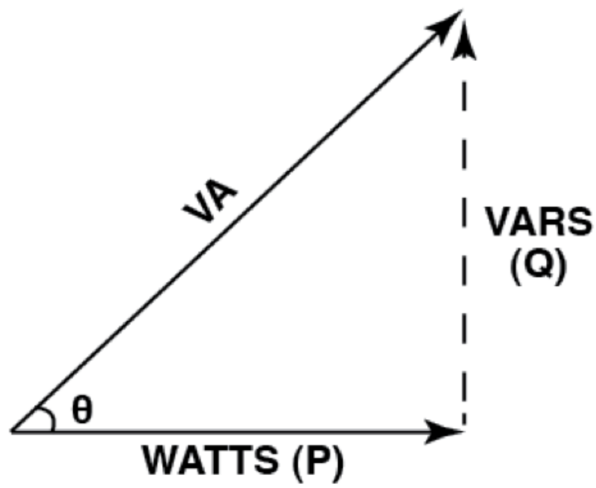
Figure 1: Phase Angle Control

Applying voltage every half cycle allows the voltage to be gradually increased to the transformer primary. This gradual turn on (typically one second or more) eliminates the possibility of forcing the transformer core into saturation. However, the phase angle waveform is distorted (chopped), so as the demand (% of full-scale rated current output of the SCR) decreases, the power factor will continue to decrease while the harmonic distortion increases. What is the resulting impact?

Power Factor Considerations

Power factor is the simple ratio of real power delivered at the load, Watts (KW) to the apparent power, Volt-Amps (KVA) of the supply circuit. It is given a dimensionless number ranging from 0 to 1. The lower the power factor, the higher the current required to deliver a given amount of power to the load. These higher currents require larger distribution system conductors and infrastructure - incurring higher initial system deployment costs. Higher currents also produce ongoing energy waste in the form of resistive heat loss and persistence of the unusable reactive power (VARs).

Additionally, electric utility providers must provide higher VAs to commercial operations with low power factor, and will typically assess substantial penalties in order to recuperate their higher cost of service delivery.



$$VA = E \cdot I$$

$$P = E \cdot I \cdot COS(\theta)$$

$$Q = E \cdot I \cdot SIN(\theta)$$

Figure 2: Power Triangle

Example:

When a resistive load is constant and the conduction angle is full (180 electrical degrees) the power factor is at unity (KVA = KW). In the event the conduction angle is less than 180° a degradation of the power factor occurs. When using phase angle control, portions of the sine wave are cut. In this situation a full sine wave of voltage is supplied to the SCR but only a portion of the voltage is applied to the load. Using Ohm's Law the required KVA is a factor of the line voltage times the load current. However the KW is determined by the load voltage times the load current. The apparent power factor is KW ÷ KVA. So if the applied voltage is 480 V and the load current 100A, the KVA = 48KVA. However, if the load voltage is 300V and the load current is 100A, the KW = 30KW.

The power factor is:

$$PF = \frac{KW}{KVA} = \frac{30KW}{48KVA} = 0.625\ PF$$

When power factor penalties are applied by the utility it is typically for a power factor less than 0.9. The utility provider will usually assess these penalties as part of the demand charge on the power bill. Cost saving are real but dependent on utility provider and the rate structure negotiated.

Harmonic Distortion Considerations

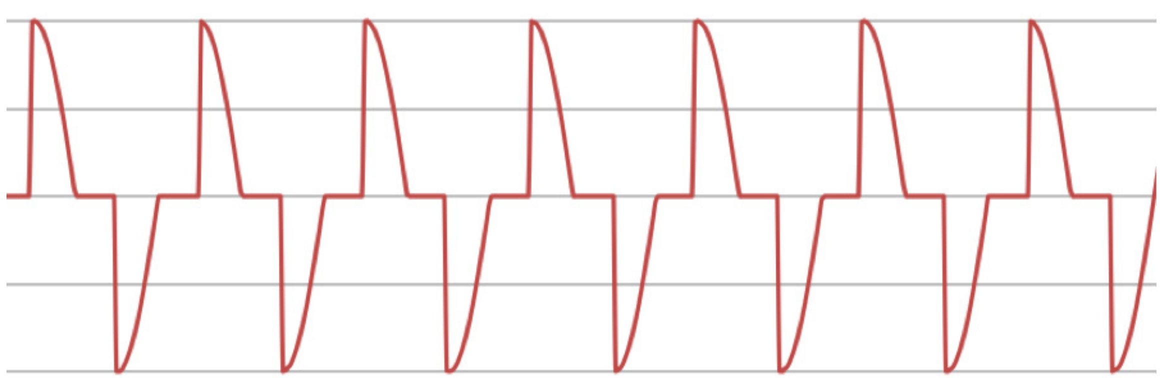
Harmonics are the higher frequency components of a waveform fundamental frequency (typically 50/60 Hz), caused primarily by any distortion of the pure sine wave. High harmonic content in the line can result in large induced currents. These currents can be destructive, causing overheating of supply transformers, overloading of neutral conductors and producing interference which adversely affects other sensitive electronic equipment.

Zero Voltage Firing

Considering the disadvantages, resulting additional costs and potential power factor penalties incurred with phase angle control, it may seem more intuitive to use a zero voltage fired SCR unit and eliminate the transformer altogether.

Inherently, zero voltage firing (zero-fired) mode offers several key advantages when compared with phase angle mode (Figure 3).

Figure 3: Zero Cross (above) vs Phase Angle (below)



As shown, in zero-fired mode the sine wave remains virtually undistorted and switching occurs at zero voltage. The resulting power factor is near unity and harmonic content is low.
Most zero-fired controllers have a variable time base. This time base is made up of two periods – an ON period and an OFF period. The unit is on for a number of AC cycles, and off for a number of cycles. Most furnace applications are very dynamic, and predetermining an off period is nearly impossible. A transformer is limited in the amount of voltage it can support, and not being able to limit the amount of voltage in the AC cycle, a typical zero voltage-fired SCR power controller will cause core saturation.
Silicon Carbide

Silicon Carbide is a variable resistance element and changes resistance with time and temperature. As power is applied and the heating cycle begins, the resistance change can be as much as 70%. Additionally there is as much as a 4:1 change in resistance over the life of the element. To maintain a required load power, the required load voltage is twice the requirement when the elements are new. Therefore, to maintain a constant power over a 4:1 resistance change, a 2:1 voltage change is required. Power being a product of both current and voltage, the current requirement for new elements is twice that of the aged elements. The required power control system must be sized for the worst-case conditions of both current and voltage.

A New Solution

Instantly applying full AC voltage to the primary of transformer can lead to core saturation and fuse blowing. Since there is no way of limiting the voltage in zero voltage fired mode, the possibility of core saturation is very high. Therefore, a true zero voltage fired unit is ineffective. We also know that while phase angle firing can eliminate saturation, it causes power factor and harmonic issues. The ideal solution, therefore, is to combine both features into one firing mode: Zero Cross Transformer Mode.

The key challenge driving this innovation is prevalent throughout industry – power quality improvement. The goal was clear: Develop a cost-effective solution to address power factor and harmonics issues without sacrificing performance, quality and reliability.

A digital power controller makes it possible to soft start to set the core flux and then switch to zero voltage fired for a period of time. (Figure 4) An intelligent unit can remember how voltage was applied on the last half cycle. Therefore we can expect the unit to turn on in the phase angle mode on the first half cycle of any on period. Furthermore we can set the number of cycles the ramp time will last (8 – 20 cycles). This adjustable cycle rate will allow operation in various types of transformers since not all transformer cores are the same. See Figure 4.

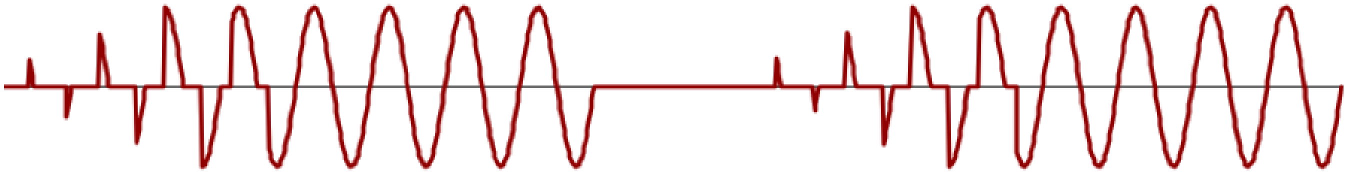


Figure 4: Zero Cross Transformer Mode

O’Brien & Gere/Denton TSI installed a rotary hearth furnace utilizing ZTC mode in a real world production facility - where power factor was an issue requiring attention. (Figure 5) The furnace design included a 68kW multi-tap transformer and six secondary connected SiC heating elements, operating at temperatures from 1500°F - 2350°F. During commissioning, the furnace was tested for uniformity and conformance to the specifications and met all requirements.

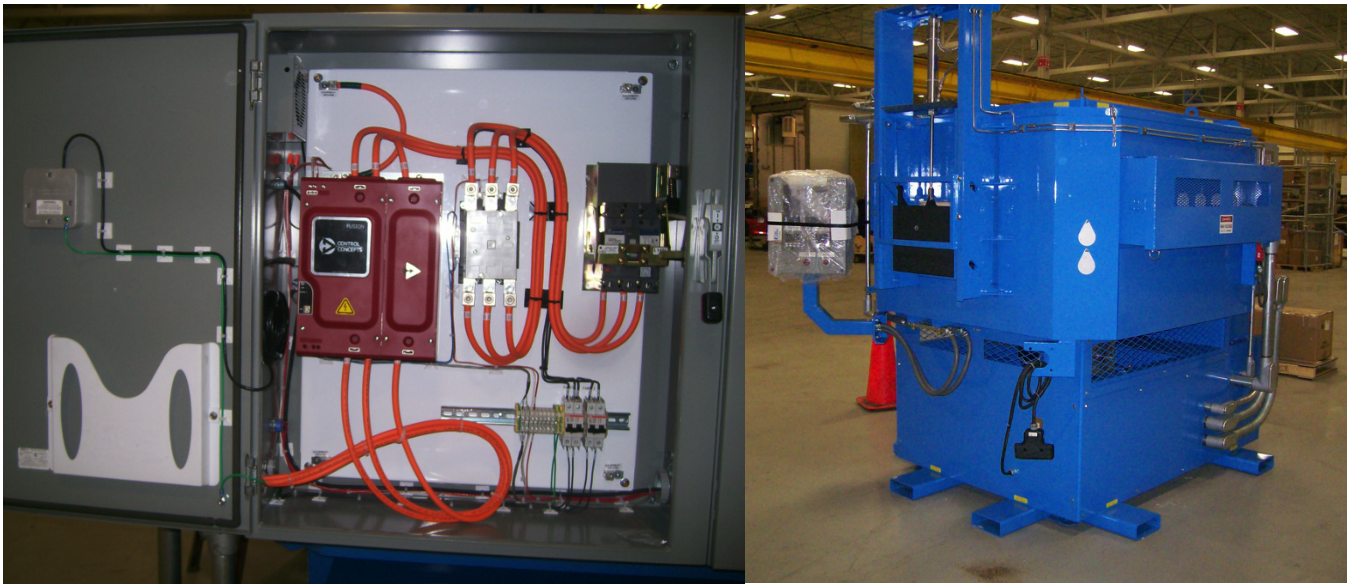


Figure 5: Rotary Hearth Furnace Setup

Advantages of ZCT Mode

• The combination of soft start phase angle and zero-cross firing modes results in a 0.90 power factor or greater with 50% or greater command signal.

• Because this is a firmware feature of a digital power controller, no additional hardware costs are needed to make a change to ZCT Mode.

• Limiting the number of cycles of phase angle control will also decrease the overall generation of destructive current harmonics in the system.

• The ability to set the number of phase angle cycles allows for operation of a wide range of transformers design

• This solution is energy-efficient and minimizes operation costs

In summary, this new mode of SCR control will help reduce power factor penalties and harmonic interference. The level of savings will be dependent on the site and the rate structure negated with the local utility provider. Operating at power factor of 0.92 or higher will definitely reduce the potential for power factor penalties charges by the utility provider. Reducing the amount of phase angle effect will also reduce the amount of destructive harmonics that are generated.