Spang Power Electronics

Technical Note

Zero Crossover Dynamic Power Synchronization Technology Overview

Background

Engineers have long recognized the power benefits of zero crossover (Figure 1) over phase angle (Figure 2) power control. **These benefits include the elimination of harmonic distortion and near unity power factor.** It is therefore always preferable to use zero crossover when the application permits.

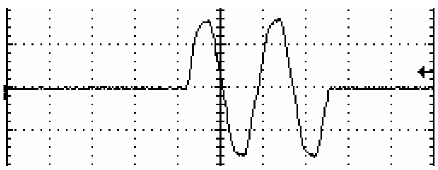

Figure 1. Zero Crossover Waveform (2% Firing)

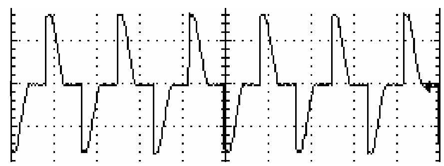

Figure 2. Phase Angle Waveform (50% Firing)

Because of the benefits, features were continually added to SCR controllers to allow them to overcome any application issues which prevent their zero cross application. **Two of the main application challenges for zero crossover control are "firing" into a transformer primary and mitigating voltage "flicker" or sag.** A standard analog zero crossover SCR controller cannot "fire" into the primary of the transformer. The transformer core will saturate and draw significant current from the source, causing the fuses to fail or the circuit breaker to open. A phase angle waveform or appropriately timed zero crossover waveform must be used to set the flux timing in the transformer core to prevent this from happening.

The latest digital SCR technology offered by Spang Power Electronics applies a hybrid phase angle and zero crossover technique. Figure 3 represents the phase angle start voltage waveform (phase to phase monitoring of a three-phase controller output). Once the transformer flux is set and the starting waveform is complete, the subsequent pulses utilize a small phase angle initialization to maintain the flux timing (Figure 4). Note that after the phase angle start is complete, the unit automatically switches to zero crossover firing. Due to the short phase angle duration, its negative impact on power factor and harmonic distortion are negligible.

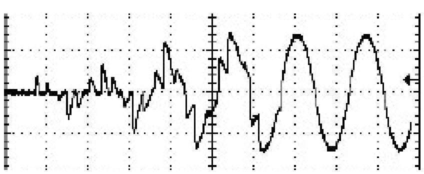

Figure 3. Phase Angle Start Voltage Waveform

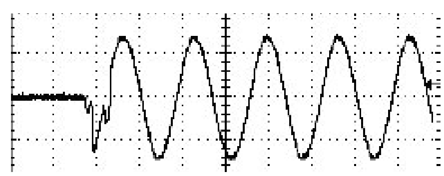

Figure 4. Repetitive Voltage Waveform

Using this technique, the Spang digital SCR controller works effectively in the zero crossover firing mode when coupled to a voltage matching transformer.

The second challenge is to mitigate voltage "flicker" or sag. **"Flicker" is seen by the dimming of lights in the plant.** When there is a high peak demand (a high current pulse) the source voltage drops. If the drop is of significant magnitude and of long enough duration, the lights in the plant "flicker" (they dim and return to full intensity). This condition may also cause problems with other voltage sensitive electrical equipment that is connected to the same source.

In Figure 5, we show the source power draw from two (2) zones each rated at 100 kW while each is "firing" at 50% duty cycle and there is no synchronization. Referencing a 100 cycle time base, we are showing the worst case condition when there is complete overlap of the firing time, i.e. both units are on at the same time. Note that 200 kW is drawn from the source for 50 cycles while 0 kW is drawn during the subsequent 50 cycles. At 50% duty cycle, each controller is fully on (full SCR conduction) for 50 cycles and then off for 50 cycles.

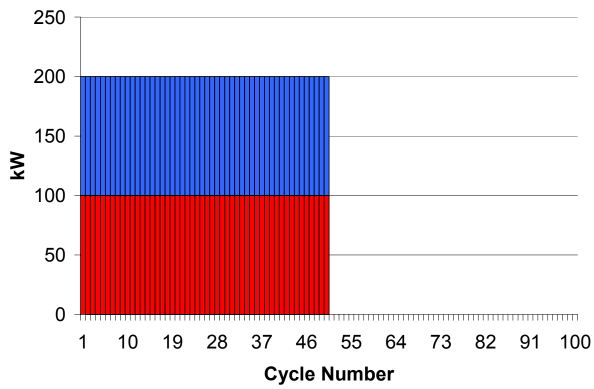

Figure 5. No Synchronization – 100% Overlap

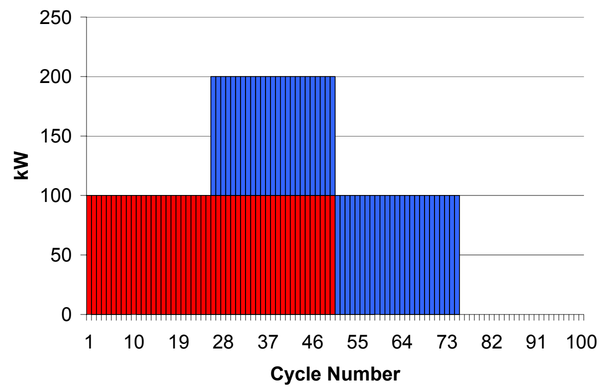

Figure 6. 50% Overlap

Figure 6 shows partial synchronization with 50% overlap. The peak power continues at 200 kW but with shorter duration. Figure 7 shows improved synchronization with only 10% overlap while Figure 8 shows the optimum condition with 0% overlap and full synchronization. With full synchronization, the peak power demand is reduced from 200 kW to 100 kW.

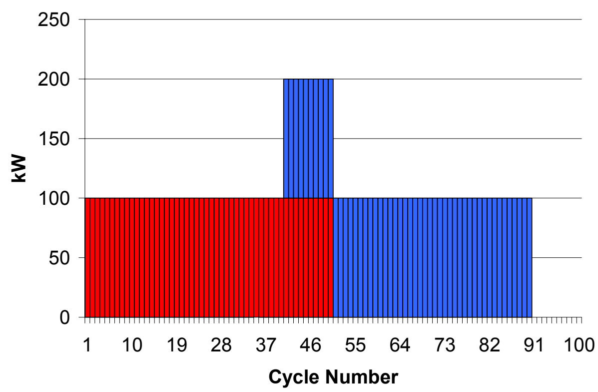

Figure 7. 10% Overlap

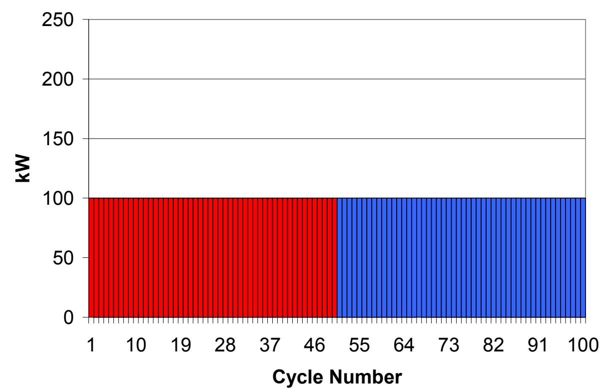

Figure 8. Synchronized – 0% Overlap

Synchronization of the zero crossover firing time reduces voltage "flicker" and associated problems with voltage sensitive electrical equipment.

Original analog SCR solutions were very primitive and used alternating phase rotations for the power connection (i.e. one controller was connected A-B-C and then the next B-C-A and so on) to reduce the likelihood of all units firing at one time. If all units were phased the same, experience had shown there was a natural tendency for the firing times to overlap. **With the advent of digital SCR controllers came the capability to provide more advanced synchronization.**

The first generation of synchronization in digital controllers was not ideal. Its primary purpose was to prevent all zones from firing at the same time and did not attempt to dynamically make corrections with the purpose of minimizing peak demand. This solution proved satisfactory for some applications, but not for all. In particular, generator fed applications required even further reduction and control of peak demand. With a generator, its circuit impedance is much greater than a typical distribution system. This means the voltage sag, the voltage drop at the generator, is much more significant for a given high current pulse (i.e. compared to a typical distribution system, the voltage drop at a generator associated with the same high current pulse will be much more severe). **A generator fed source is therefore much more susceptible to voltage "flicker".**

Based upon its 853 platform, Spang Power Electronics is offering active power synchronization with the latest generation of digital SCR controllers. **The solution dynamically changes individual unit firing time during operation to minimize voltage "flicker".**

Figure 9 and 10 show examples of a 12 zone and a 39 zone system with active power synchronization. Each block of a particular color represents a single zone's power contribution. As you see, the firing times and overlap are minimized. Both systems are fully synchronized.

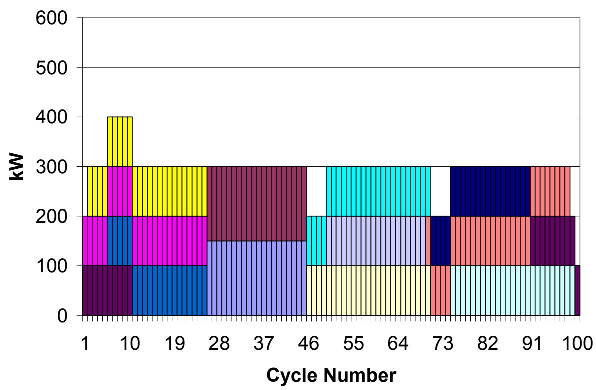

Figure 9. 12 Zone Example

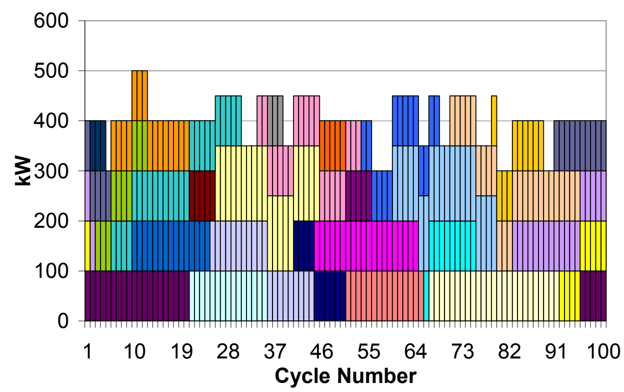

Figure 10. 39 Zone Example

Applications

Synchronization is applicable to any three-phase multi-zone heating application when applying zero crossover control and powered from a common source. Figure 11 represents a 7 zone example with 853 Digital SCR Power Controllers and voltage matching transformers. Note that synchronization may be applied in direct coupled applications (i.e. the heating elements are connected directly to the output of the SCR controller).

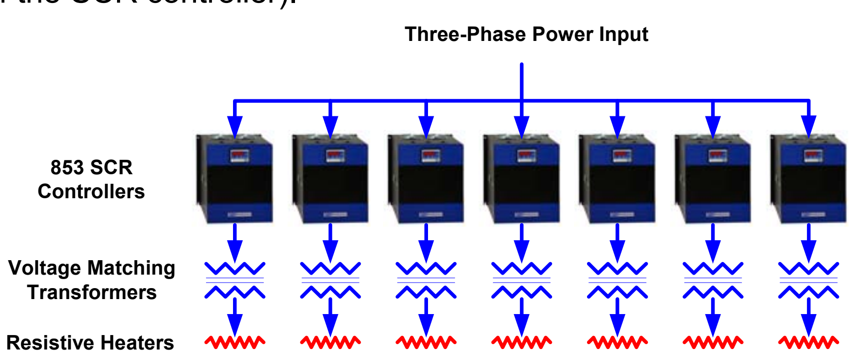

Figure 11. Typical Transformer Coupled Heating Application

The system shown in Figure 12 powers a 25 zone electric kiln. It includes 853 Digital SCR Power Controllers with power synchronization.

Figure 12. 25 Zone Electric Kiln Power Center (SiC Heating Elements)

Theory of Operation

To provide synchronization, we need to take control of the firing time of the individual SCR controller. We therefore need to understand its firing time relative to the firing time of all other units in the system. The preferred control solution for multi-zone systems with digital SCR controllers is to use network connectivity for control and monitoring. As shown in Figure 13, all controllers are connected to a common network. They receive their set points and provide feedback of their performance to the supervisory control system. Though possible to use this network for synchronization control, the preference is to use a separate dedicated connection (Figure 14).

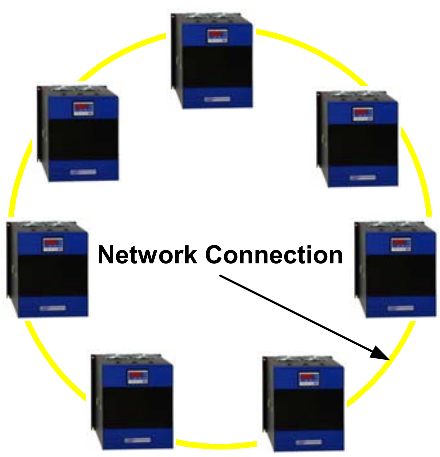

Figure 13. Network Connection

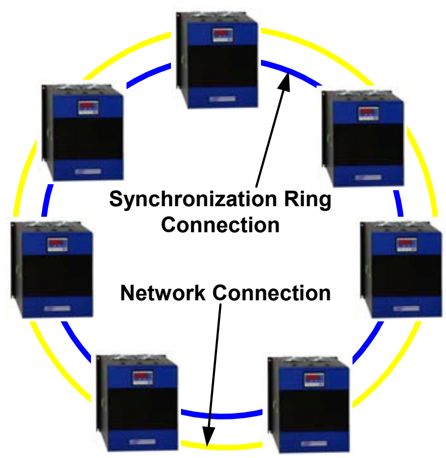

Figure 14. Network and Sync. Connection

With the Spang approach, the synchronization operates independent of the network. This allows a customer that does not use a network for control and monitoring to still apply synchronization. In addition, when there is a network and it fails, the synchronization algorithm continues to operate. It also functions when a single unit (or multiple units) is taken offline for service. When the unit is reinstalled, it will automatically synchronize with the rest of the controllers.

The physical connection between SCR controllers is a two-wire pair which carries an analog signal. Each unit is both transmitting and receiving information on a continuous basis. **Each SCR controller tracks total available power from all units, total actual power each cycle, and its own power contribution.** At the end of the unit's power cycle (from before, using a 100 cycle time base), it will analyze the data and automatically shift its pulse timing to minimize total peak power. The process is automatic and continuous, looking at the data, reviewing, and correcting as necessary at the end of every power cycle.

Figure 15 shows the simultaneous oscilloscope capture of the input current feeding seven (7) SCR controllers (top line) and the associated synchronization signal (bottom line) for a fully synchronized system with no overlap. As you see, when an individual unit is providing power, it is reporting it on the synchronization loop by putting out a signal of appropriate magnitude and duration proportional to its peak power and time contribution.

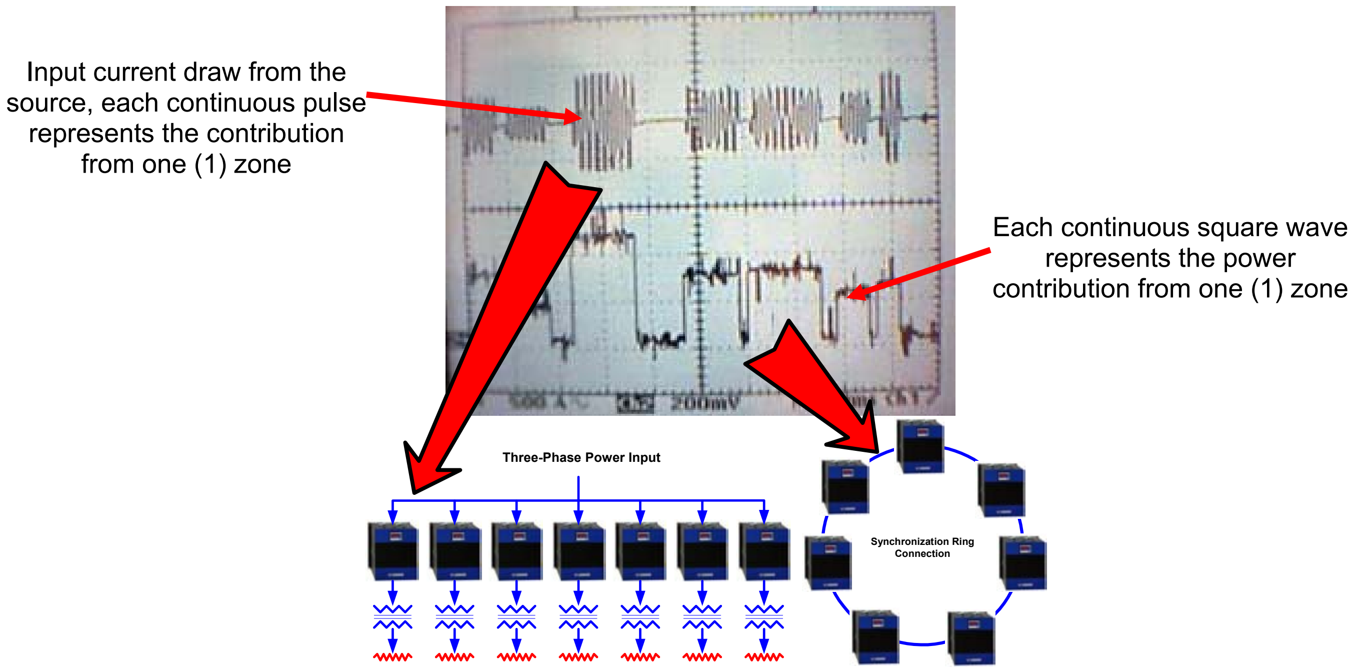

Figure 15. Oscilloscope Capture

When a given unit sees that it has collided with another, it makes a timing correction to minimize the peak demand. This process continues and makes corrections automatically over time. Figure 16 shows an example of the synchronization of a 39 zone system with all zones forced to initially fire simultaneously. Here, synchronization is achieved in less than 40 seconds.

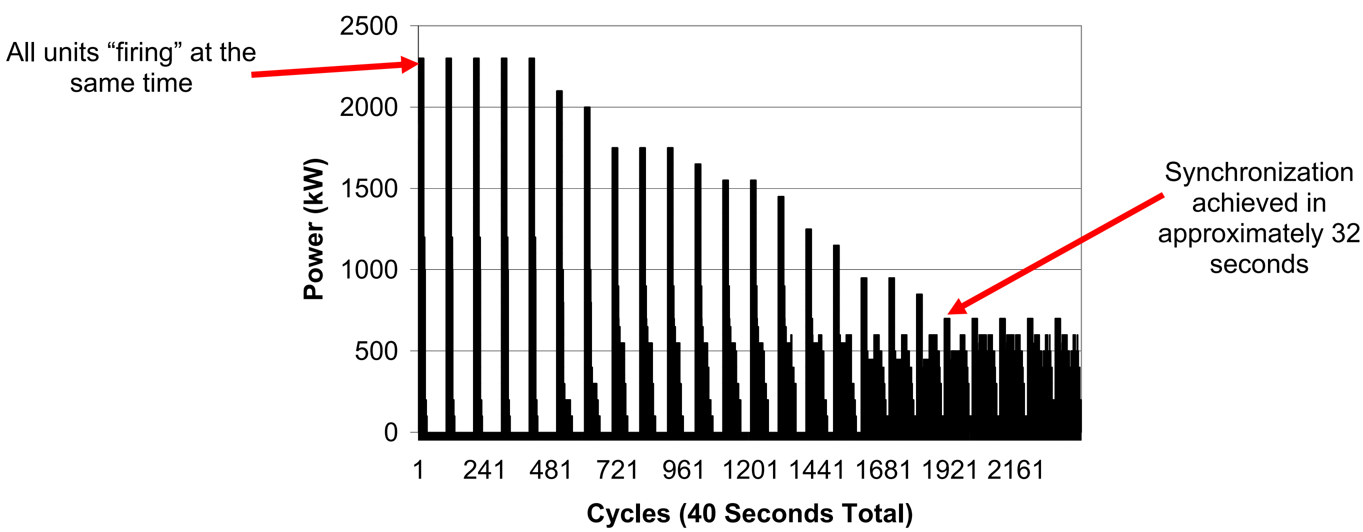

Figure 16. 39 Zone Synchronization Performance

Actual performance and synchronization time will vary based upon the number of connected zones to the synchronization ring, number of rings, initial firing time of each unit, and individual zone loading. **Please contact Spang Power Electronics to review your application and discuss the potential benefits of dynamic power synchronization.**