ABSTRACT

This paper compares electro-mechanical contactors and solid-state relays to SCR power controllers operating in a similar on-off manner. SCR power controllers deliver a number of advantages that can lead to lower costs and better process control.
ELECTRO-MECHANICAL CONTACTORS

An electro-mechanical contactor is a device that opens or closes a contact, allowing electricity to be switched fully on and fully off. An electrical control signal triggers the opening or closing of the contact or contacts.

In general, an electro-mechanical contactor is rated for a specific number of on-off cycles while in operation throughout its lifetime. This rating depends on the manufacturer and typically ranges from less than a million cycles at rated current and voltage to a few million cycles at rated current and voltage.

Table 1. Calculation of on-off cycles for one year at six days per week for 48 weeks’ operation and various process cycle times for contactor

<table>
<thead>
<tr>
<th>CONTACTOR</th>
<th>Cycle Time</th>
<th>Cycles Per</th>
<th>Six Days Per</th>
<th>48 Weeks Per</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seconds</td>
<td>Minute</td>
<td>Hour</td>
<td>24 Hours</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>120</td>
<td>2880</td>
<td>17,280</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>240</td>
<td>5760</td>
<td>34,560</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>360</td>
<td>8640</td>
<td>51,840</td>
</tr>
</tbody>
</table>

As shown in Table 1, for a process cycle time of 30 seconds, a mechanical contactor performs 829,440 on-off cycles per year. At a process cycle time of 10 seconds, a mechanical contactor performs 2,488,320 on-off cycles per year. Based on the manufacturer’s recommendation, the electro-mechanical contactor electrical contacts should be inspected and cleaned, and possibly repaired or replaced, after reaching the specified number of on-off operations.

SOLID-STATE RELAYS

A solid-state relay is an electronic switch that operates without the moving parts of an electro-mechanical relay. Because there are no moving parts, the life expectancy of the solid-state relay is greater. Typical cycle times are 2 to 5 seconds for reasonable solid-state relay life. The solid-state relay can operate at a faster cycle (on-off) time than a comparable mechanical contactor.

However, the solid-state relay has a higher contact resistance and is susceptible to damage from surge currents. It also has limited switching arrangements compared to an electro-mechanical contactor (typically a SPST contact).
Table 2. Calculation of on-off cycles for one year at six days per week for 48 weeks’ operation and various process cycle times for solid-state relay (Solid-state relays can switch load output faster than mechanical contactors.)

<table>
<thead>
<tr>
<th>SSR (SOLID STATE RELAY)</th>
<th>Cycle Time</th>
<th>Cycles Per</th>
<th>Six Days Per</th>
<th>48 Weeks Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seconds</td>
<td>Minute</td>
<td>Hour</td>
<td>24 HOURS</td>
</tr>
<tr>
<td>Cycle Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>30</td>
<td>1800</td>
<td>43,200</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>1200</td>
<td>28,800</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>15</td>
<td>900</td>
<td>21,600</td>
</tr>
</tbody>
</table>

SCR POWER CONTROL MODULES

The SCR power control module is designed to switch the power applied to its output load very quickly.

Table 3. Calculation of on-off cycles for one year at six days per week for 48 weeks’ operation and various process cycle times for SCR power control module

<table>
<thead>
<tr>
<th>SCR POWER CONTROL MODULE</th>
<th>Cycle Time</th>
<th>Cycles Per</th>
<th>Six Days Per</th>
<th>48 Weeks Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seconds</td>
<td>Minute</td>
<td>Hour</td>
<td>24 Hours</td>
</tr>
<tr>
<td>Cycle Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60</td>
<td>3600</td>
<td>86,400</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>30</td>
<td>1800</td>
<td>43,200</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>1200</td>
<td>28,800</td>
</tr>
</tbody>
</table>

Typical cycle times are 1 second, which means that the SCR will perform 24,883,200 operations in a year for the conditions stated.

Figure 1, below, compares the calculated total quantity of cycles of operation for the electro-mechanical relay, the solid-state relay (SSR), and the SCR over 48 weeks, operating six days per week.

Figure 1. Comparison of total cycles of operation
TYPICAL OPERATION: ON AND OFF CYCLING

The electro-mechanical contactor and solid-state relay both switch electricity to a load when signaled to do so. This means that both devices can turn the electrical power to the output load on and off at any point in a sinusoidal wave.

Figure 2. AC sinusoidal waveform showing different on-times in a cycle

In the U.S., electricity is provided at 60 cycles per second, or 60 Hz. When the power supplied to a device does not turn on or off at a zero crossover point in the sinusoidal waveform, voltage spikes occur on the sine wave and RFI and harmonics are generated. An arc also may occur with this type of random on and off operation.

Figure 3. AC waveforms showing effects of contact closing and opening at non-zero crossover

When in operation and turned completely off or completely on, both the contactor and solid-state relay devices operate efficiently (no disturbances when fully turned on or off). However, under normal process operating conditions, the generated harmonics can cause the sine wave provided by the power company to become distorted. This may cause difficulty for the power company’s measurement equipment, making it appear that the measured or required power is greater than the actual power used. This could increase power costs.

SCR POWER CONTROL MODULES

An SCR power control module is an electronic semiconductor device designed to efficiently regulate the power to an output load. It can switch the power applied to an output load very quickly (in milliseconds, for example) compared to a mechanical contactor or solid-state relay.

POWER CONSUMPTION, RFI, AND HARMONICS

Zero-cross operating mode enables SCRs to function comparably to contactors and solid-state relays, which operate by turning power fully on and fully off.

However, in zero-cross mode, the SCR turns the output on and off at the zero-cross point in the sinusoidal wave, which eliminates the potential RFI, harmonics, and arcing associated with contactors and solid-state relays.
Zero-Cross Point

Figure 4. Sinusoidal waveform zero-cross point

By eliminating the effects of the RFI and harmonics associated with contactors and solid-state relays, the SCR provides more consistent and efficient power regulation to the output load, thereby reducing potential harmful effects and minimizing power consumption.

UTILITY COST REDUCTION

The SCR’s ability to transition power to a load at the zero-cross point also helps reduce utility costs associated with “dirty power.” Dirty power, with power factors less than 1, generally incurs significant penalties from power companies. The SCR provides a positive effect on the power grid, which can reduce penalties for dirty power, and ultimately reduce utility costs.

CONTROL ACCURACY

The SCR power control module also provides more accurate control of the process compared to contactors and solid-state relays. It can turn on and off much more quickly. For example, for a 1 second time period for the control output, the SCR can switch on and off to provide fine control resolution.

If the output from the process controller were to demand 60% output, the SCR would be on for 0.6 seconds (60% of 1 second, or 36 cycles of 60 cycles) and off for 0.4 seconds (40% of 1 second, or 24 cycles of 60 cycles) for a 1-second time period.

An SCR power controller’s ability to turn on and off at the zero-cross point eliminates the potential RFI, harmonics, and arcing associated with contactors and solid-state relays.

Figure 5, to the right, provides a visual representation of typical cycle time periods for the SCR, solid-state relay (SSR), and electro-mechanical contactor, comparing each to a process cycle on-time of 60% and off-time of 40% based on 60 cycles per second (60 hertz). The SCR provides much finer control resolution compared to the SSR and electro-mechanical contactor.

Figure 5. Comparison of total cycles for typical device control time period
Figure 6. SCR power control module regulating process output

Figure 6 shows that the process signal input to the SCR can vary and the SCR process output maintains temperature at a stable value.

Compare this to a contactor that may be turning on and off for a 10 to 30 second time period, or to a solid-state relay turning on and off for a 2 to 5 second time period. In comparison, the SCR power control module greatly minimizes over-shoot and under-shoot in the controlled process.

The SCR power control module greatly minimizes over-shoot and under-shoot in the controlled process.

Figure 7. Contactor or solid-state relay regulating process output

In Figure 7, note that the process signal input to the contactor varies on and off and the process output (open or closed contact) shows some temperature regulation variation due to the cyclic nature of the on and off control output and time period.

Figure 7. Contactor or solid-state relay regulating process output

HEATER LIFETIME

The SCR power controller’s ability to provide finer control of the heating element or elements also can extend heater life. When the duration of time the heating element turns on and off is reduced, the element spends less time transitioning between hot (expanding) and cold (contracting). This maintains the heating element at a relatively even temperature while in operation and extends its life.

The SCR power controller’s ability to provide finer control of the heating element or elements can extend heater life.

COST EFFICIENCY

The SCR’s capacity to provide finer control leads to better overall equipment effectiveness (OEE) for the user. Additionally, better process control stability and extended heater life improve return on investment (ROI). Better control stability leads to less variation in the process, which helps optimize the process cycle and reduce the overall cycle cost. Furthermore, extended heater life directly results in the ability to process more cycles with the same equipment, which reduces overall cost of ownership (COO).
NOISE AND TRANSIENT RESISTANCE

Industrial power quality is not always ideal. Voltage line sags, interference from other equipment, and peak load situations can lead to false triggering, reset conditions, and varying output power. 

Advanced SCR power control modules incorporate digital and analog technologies to suppress the effects of poor line quality, including software and analog filters, optical isolation between the control and power sections, and configurable voltage and current alarms. Electro-mechanical contactors and solid-state relays do not account for poor line power quality.

Figure 8. Suppression of poor line quality effects by SCR power control module

Figure 8 shows stable SCR output despite poor incoming line power quality.

ACTIVE PROCESS MONITORING

The SCR monitors its own operation using voltage and current transformers to measure the real-time status of ongoing operation. This information is used to control the process via voltage, current, or power. These process values may be monitored by interfacing with external devices using either an analog output or via a field bus communication interface.

DIAGNOSTICS AND FAILURE DETECTION

The SCR self-monitors and turns off output power when a failure occurs. It also typically has LEDs to indicate fault conditions.

Electro-mechanical contactors can fail in one of two modes: either the failure can be a function of welded contacts (output power shorted on) or a function of open contacts (output power off). The contacts are more prone to fail in an open condition. Solid-state relay contacts tend to fail in a shorted power-on condition, which may lead to overheating of the heating elements and associated equipment.

Figure 9. Thyro-Family SCR power control module LED indicators and displays
OPTIMIZED POWER CONSUMPTION

Multiple SCR power control modules may be coordinated to optimize power consumption. This reduces the peak demand compared to multiple SCR power control modules operating at the same time without coordination.

Compared to uncoordinated operation of contactors and solid-state relays, the ability to coordinate and optimize the power consumption of SCR power control modules reduces overall operation costs.

Figure 10. Multiple SCRs operating without mains load optimization, worst case (left) vs. multiple SCRs operating with mains load optimization (right)

Figure 11, on page 9, shows the main load power demand produced without and with power consumption coordination. Note that coordination of power consumption reduces the overall power demanded. The Thyro-Power Manager provides static serial optimization of multiple SCRs. The dASM operation provides dynamic optimization of multiple SCR power control modules to reduce the mains load requirement.

The ability to coordinate and optimize the power consumption of SCR power control modules reduces overall operation costs.

COMMUNICATION CAPABILITY

Advanced SCR power control modules can communicate with other devices (computers, PLCs) using optional field bus protocols. This communication capability permits tightly coupled integration into a user’s overall process control scheme.

Standard communication protocols include:

- Ethernet/IP®
- Modbus® TCP
- Modbus® RTU
- Profibus®
- Profinet®
- DeviceNet®
- CANopen®
Dynamic Mains Load Optimization
Simplified Example with ASM Procedure (Seven SCRs)

Figure 11. Coordinated power consumption: Thyro-Power Manager and dASM (automatic synchronization for multiple power controllers)
SCR ADVANTAGES

SCR power controllers provide several advantages when compared to contactors and solid-state relays. These include:

› Elimination of RFI and harmonics
  • SCRs operate at the zero-cross point, eliminating RFI and harmonics associated with contactors and solid-state relays. Harmonics can lead to higher costs for power consumed. RFI can cause interference with other devices.

› Elimination of arcing
  • SCRs operate at the zero-cross point, eliminating potential arcing associated with mechanical contactors. Arcing can reduce the operating life of contacts.

› Process control accuracy and extended heater life
  • SCRs provide more accurate process control, which reduces power consumption and associated costs throughout a process cycle.
  • SCRs can extend the life of the heating elements, which reduces total cost of ownership for equipment.

› Extension of operating life
  • SCRs feature components and protective fuses designed to extend operating life, which reduces total cost of ownership for equipment compared to contactors and solid-state relays.
  • Electro-mechanical contactors and solid-state relays have a specified operating life for on-off operations. Generally, these devices or device components have to be replaced more often than an equivalent SCR power control module.

› Noise and transient resistance
  • SCRs typically have built-in digital and analog technologies to suppress the effects of poor power line quality.
  • SCRs prevent false triggering and have software and analog filters, as well as optical isolation between the power and control sections.

› Active process monitoring
  • SCRs typically have built-in voltage and current transformers to monitor the real-time operating condition of the device. The measured values are used to control process output and provide diagnostics.
  • SCRs typically can be configured to provide control of the connected load using voltage, current, or power.

› Diagnostics and failure mode
  • SCRs typically have built-in diagnostics for monitoring operating condition faults. They turn off the output power on failure and have voltage and current alarms.
  • The contactor may or may not turn off power on failure.
  • The solid-state relay generally does not turn off power on failure.

› Communication capabilities
  • SCRs have built-in communication capabilities that permit connection to optional field bus communication protocols, providing integration into plant control schemes.

› Power consumption optimization
  • Multiple SCRs may be coordinated and optimized to reduce peak demand for power consumption. This reduces costs for power consumption compared to contactors and solid-state relays, which cannot be coordinated.
CONCLUSION

The use of SCR power control modules in electric thermal heating applications offers several advantages compared to use of electro-mechanical contactors or solid-state relays. These advantages generally include:

› Elimination of harmonics and RFI
› Elimination of arcing potential across contacts
› Improved process control accuracy
› Extended heater life
› Noise and transient resistance
› Active process monitoring

These advantages can lead to lower cost of operation and total cost of ownership. Additional benefits can be realized with SCR features such as diagnostics, communication capability, and optimized power consumption for multiple SCRs.