

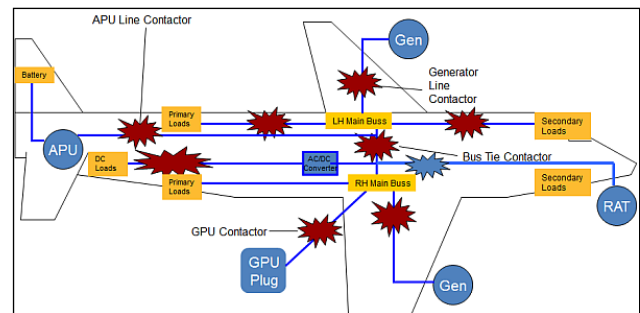
# CONTACTORS FOR AEROSPACE GROW SMARTER AND MORE CAPABLE

by: Karl Kitts, Director of Development Engineering – High Performance Relays, TE Connectivity

As a designer's primary choice to control high power circuits, contactors today offer more efficient operation and smarter operation to protect against overcurrent and faults. They are electrically controlled devices that use a low-power coil drive circuit to switch a higher power circuit. With the contactor located near the controlled load, this allows weight savings through use of smaller wiring sizes used for on/off coil control of the remote load. Contactors are a special high-power class of electrical relay designed to switch much higher currents and voltages. In a large commercial or military aircraft, contactors are used to control the different power sources, including engine-driven generators, auxiliary power units, batteries, external power, and ram air turbines. Power systems must not only accommodate the routine needs of flight, but also offer redundant backup power and emergency power.

Switching high currents and voltages can certainly produce design and endurance life challenges for power contactors. Current spikes and arcing can damage both contactors and connected devices. Designers have devised various methods over the years to protect the contactors and connected circuits. Protection can include external elements such as shunting resistors, diodes, and transorbs. Today, transient protection is increasingly built into the contactor. The growth of high-voltage DC and AC systems also presents challenges for the power distribution components. Similar to issues surrounding 42 VDC automotive systems, designers cannot assume existing legacy relays and contactors are suited for use in these newer power systems.

One of the most important trends today for military and aerospace contactors is building in more electronic intelligence to provide protection against abnormal events and to detect systems faults.



**Figure 1. Today's contactors bring smarter operation to power management.**

## SWaP is Critical

In aerospace and similar applications, designers are concerned with reducing SWaP—size, weight, and power consumption. Space is always at a premium, and weight savings translate in better fuel economy, longer flight times, and larger loads. Similarly, lowering power consumption throughout the power-generation and -distribution system can save weight and space. Considering a large commercial jet may now contain nearly 100 high-power contactors in the power distribution system, saving even 0.1 amp in control power for each device can be significant in overall power dissipation. Less power dissipation allows smaller power sources.

In recent years, the aerospace industry has been moving away from traditional 28 VDC and 120 V/400 Hz power systems to 240 VAC and 270/540 VDC systems. These changes were required in order to supply the ever-increasing electrical demand, while minimizing the impact of weight from larger power feeders. From a

power-management perspective, this move presents challenges in designing and applying contactors.

### The Challenges of Higher Voltages

How much energy must be absorbed during switching the contactor's main contacts? The switching energy common with opening of the main contacts may be less severe with conventional 120 VAC systems: by definition, the voltage drops to zero at regular intervals, lessening the magnitude of spikes and clearing them more quickly. At 240 VAC, however, the spacing of open contacts may not be sufficient to eliminate arcing re-strike as voltage escalates after zero current. One way around this is to use multiple contact sets in series. The downside of this approach is increased device size, weight, and heat generation.

In latest aerospace power systems, frequency is no longer held at 400 Hz. It varies from 350 to 800 Hz depending on engine speed. Designers of both contactors and power panels must carefully evaluate the affects that this wide frequency range has on device life and thermal performance.

The adoption of 270 VDC and 540 VDC, first into military and now commercial aviation, has forced dramatic design changes in power contactors. Existing 28 VDC designs are not suited for high-voltage switching because of their inability to generate adequate arc voltage for interruption—at least in a reasonable package size. To overcome these physical limitations, the contactor design must rely on such methods as arc splitting plates, runners, blow-out magnets and better internal switching atmospheres. A 540 VDC system is often split into positive and negative channels that must now be controlled either with 2x contactors or new 2-pole switching designs.



**Figure 2.** Even as contactors grow more intelligent in monitoring capabilities, they continue to evolve to meet SWaP goals.

### Reducing Required Power

One of the first areas where electronic controls were added to contactors was for economizing circuits to reduce power consumption in the coil drive. Most contactors are configured as normally open switches. The actuators within these contactors are driven by ampere turns of the magnetic coil and magnetic iron circuit. The magnetic field created by the coil is used to close the contacts. Relays, contactors, and solenoids all take considerably more power to start the actuator's motion to close the contacts than is required to hold them closed. For example, it may take 5 A to actuate a contactor, but less than 1 A to maintain the state—an 80 percent reduction in power. The economizer circuit is a method to provide 5 A only during pickup and then reduce coil power for holding contacts closed.

Two common methods used to economize power consumption are multiple coils and pulse-width modulation (PWM).

In early economized contactor designs, the actual transfer of power from pickup to hold windings was accomplished using mechanical limit switches. Once the actuator has transferred through most of its travel, a switch is tripped to reduce power. Limit switches have proven problematic for several reasons. The adjustment can be extremely critical for proper long-term contactor performance since the switch can be actuated too early or too late in the cycle. Since the switch turns off the high power winding coincidental to main contact closure, it may cause increased contact bouncing or chatter.

With the integration of electronic coil controls, the transfer timing of the coil power is no longer tied to actuator motion and a limit switch. It becomes possible to ensure the contact sets have fully transferred and are in a stable closed position before initiating the coil transfer. By thus controlling the timing of the transfer, reliability is significantly improved.

PWM uses ON-OFF coil pulses of different durations—or duty cycles—to control the average current delivered to a coil. Due to the coil inductance, the contactor is unaffected (no contact chatter or relaxation) during the coil OFF periods. PWM has the advantage of tolerating a range of voltage levels, but may cause radiated noise if not properly filtered. PWM also holds the ability to set the steady-state duty cycle based upon actual operating voltage. During low battery condition, the duty cycle ON time is increased to effectively create a constant current source for the contactor.

### Overload Protection

A common issue with power systems is the danger of overloads. Electrical faults can occur not only in the load equipment but also within an aircraft's entire power distribution and wiring systems. This has been well studied relative to aging aircraft and the effects of long-term environmental exposure on insulation systems. Protection includes detecting undervoltages in the generator, monitoring current levels and detecting leakage current.

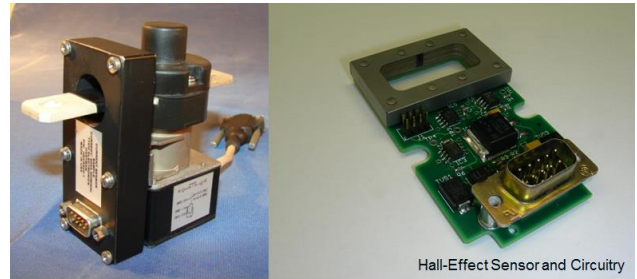
Many existing applications still rely on thermal trip elements using bimetal-based circuit breakers. While effective, these breakers have limited accuracy in the set trip point(s). They also cannot be in-service performance tested periodically. To overcome these deficiencies in overload protection, one option for the electrical systems engineer is electronic sensing integrated into the power contactors.

Electronic sensing provides more reliable sensing of overcurrents. These circuits generally provide at least twice the accuracy in trip settings over mechanical circuit breakers. Electronic sensing devices can also be exercised through built-in tests to simulate fault events to insure they will perform as expected if a system fault occurs.

A method to monitor running current through the contactor accurately is the first requirement for electronic overload protection. The simplest method is to use a precision resistor as a shunt and simply measure the voltage across it. The method is very accurate, but can generate considerable heat in high-current contactors. It also is less than desirable for mixing control circuits and 120 V/240 V sense lines for overall systems integrity. Care must be taken to isolate low-voltage circuits from high-voltage ones. Optical isolators are commonly used for this purpose.

A second method for monitoring current is a current transformer (CT). CTs are simple toroids placed around conductors. The magnetic field created by the feed through current in turn creates a secondary current in the CT. The current is proportional, but is much lower. A typical ratio of current to CT current is 500:1. CTs are simple to apply and accurate, but also heavy.

Hall-effect sensors are another common method of measuring the magnetic field created by the current. Hall-effect elements change a voltage output level based upon exposure to a magnetic field. This field is most commonly expressed across the Hall-effect sensor using a flux ring or collector surrounding the contactor's bus bar or output feeder. Not only are modern Hall-effect sensors programmable for output voltage and linearity, they also can allow bidirectional current sensing and AC sensing. TE advanced its Hall-effect current sensor with the addition of the math function circuitry to have to emulate the  $I^2T$  trip function of a thermal circuit breaker. Using the Hall-effect technology the device trip times are not affected by ambient temperatures like conventional thermal breakers. This device has an optional reverse current trip function that gives additional protection.



**Figure 3. Hall-effect sensors are flexible and accurate.**

Advantages of the Hall-effect sensor are:

- Isolation between primary and secondary circuits
- Works with direct or alternating current
- High accuracy
- High dynamic performance
- High overload capacities
- High reliability

Regardless of sensor type, supporting electronics is used to collect information from these sensors and make decisions on system configuration. In certain instances, the integrated electronics only communicates running conditions to other aircraft systems. This information can be very useful in decision-making for load shedding if a power source is lost. Aircraft loads are prioritized for criticality so that noncritical convenience loads are depowered in order to maintain flight-essential and other critical loads.

In addition to communicating circuit conditions, contactors with integrated sensing electronics can react independently to overload fault conditions. Overcurrent conditions can be measured and integrated versus time/duration to provide wiring protection much more accurately than bimetal circuit breakers. Similar to circuit breakers, trip times can be adjusted according to the severity of the fault. Lengthy trip times suffice for current levels just about normal, while massive faults require trip times of less than 0.05 second. The level of fault protection for smart contactors—i.e., those with electronic sensing—can even be adjusted by the user or application to tailor protection for each individual load. Such adjustments can be accomplished through connector pin programming, DIP switches, external resistor additions, or software coding. This allows the smart contactor to be reconfigured if the application warrants changes.

### Additional Fault Detection and Protection

While sensing overcurrents is generally the prime task required of a smart contactor, other faults can be sensed. These include:

- Loss of phase and phase rotation
- Differential feeder fault
- Ground fault
- Arc fault detection

**Phase Faults.** To protect motors, fans, and other devices using three-phase power, phases must remain synchronized to ensure the proper delivery of power. Phase faults stress the operated devices, shortening their lifetime, causing improper operation, and even bringing catastrophic failure. The two main phase faults are loss of phase and phase rotation. Both result in uneven, unbalanced delivery in power. When one of the phases is lost, delivered power is diminished since only two phases are delivering power. Phase rotation occurs when the phases are not properly synchronized at 120 degrees of separation.

The same techniques used to monitor current for overloads can be used to detect phase problems. By sensing and comparing current levels on each phase, any difference can be detected.

### Leakage Current Fault Protection

Sensing leakage currents and protecting against differential faults involves multiple current sensors along a length of wiring. Outputs of the sensors are compared to detect faults. Ground fault detection is a specialized protection scheme using only one common sensor to ensure all passed current is also returned from the load without leakage. This detection means has become commonplace on aircraft fuel pump applications to reduce risk for fuel vapor ignition.

Differential feeder fault protection is common in the aerospace industry. This is usually a high threshold protection to validate no current leakage on large-diameter power feeders. A typical setup includes a sensor at or even within the power generator and a second one at the main line contactor. If the sensed currents are different, a fault has occurred.

Ground faults can be monitored in two ways. One way is to check for current in the ground plane. The second is to use the information provided by the phase sensors. The sum of all three phases should be zero. If it does not sum to zero, a fault exists in the wiring or load.

### Arc Fault Detection

Arc fault detection is becoming more commonplace in circuit breakers and secondary solid-state power controllers (SSPCs). It has been demonstrated that existing protective devices are ineffective against sputtering arc faults. While current levels may not increase enough to trigger a hard fault, arc faults can generate unacceptable heat levels. Parallel arcing faults may ultimately progress to full overcurrent faults, while series arcs resulting from broken conductors or loose device terminals could generate tremendous heat well under traditional overcurrent trip curves. Detecting arc faults and even locating distances to a wiring fault is an emerging area for smart contactors.

### Beyond Electromechanical Contactors

While solid-state relays are common, the application of power semiconductors to contactors is relatively new. MOSFETs can

replace the power contacts, with the obvious advantage in improved reliability relative to no moving parts. Solid state power devices can extend the switching life of a contactor. Power contacts are subject to wear from both the mechanical mating and the effects of arcing. As contacts wear, the increased resistance across the connection means increased heat generation and end of life failures.

Solid-state relays require additional thermal management versus hard contact designs. While the absence of mechanical parts makes solid-state designs very reliable, the main failure mechanism now becomes heat. The devices must be protected from overheating. Beyond heat sink thermal management, multiple power transistors can be applied in parallel to keep currents well below the maximum rated levels. For aerospace applications, transistors are de-rated at 15 to 20 percent of datasheet current-carrying rating in order to manage thermal performance effectively.

### From Sensing to Prediction

Microcontroller-based electronic control allows more information about the state of the contactor to be gathered and analyzed. This information can be used to go beyond basic trip circuits in response to faults. It is one thing to sense a fault and shut down a component. More useful is to monitor operation in real time to identify trends and changes. This allows intelligent prediction of problems and flexible responses.

Current and voltage levels can provide real-time insight into the health of the contactor and of the overall electrical system. Information on running currents, temperature, and number of cycles can be used to predict the life cycle of the contactor. Operating the contactor at lower current levels can significantly increase the number of switching cycles. For example, a contactor can offer 50,000 switching cycles at its rated current. Operating it at 25 percent of rated current can double the cycle life to 100,000.

The collected data can also be used to monitor the system. For example, current draw during contact pickup reflect inrush currents to motors or pumps, yielding insight into bearing wear. The same information can indicate the need for lubrication or other maintenance. Changes over time in sensor data can also indicate faults in the wiring system.

Comparing initial operation at commissioning with changes over time is fundamental to understanding and predicting problems. While the output from a single contactor can yield useful data, information from multiple contactors and from other sensors in the wiring system can be combined into "big picture" analysis and prediction since it allows comparison of conditions throughout the system.

### Integrated Assemblies: Power Distribution Panels

As contactors become more sophisticated, they also become more complex. Many users are opting for custom-designed, application-

specific power panels, an example of one designed and built by TE is shown in Figure 4, as a plug-and-play solution to power management and distribution. These panels contain not only contactors or relays, but also the control electronics to provide advanced monitoring and control capabilities.



Figure 4. Custom power distribution panels provide an engineered solution for power distribution management.

Contactors design is evolving to provide enhanced and increasingly intelligent monitoring of conditions. Because they play a central role in power distribution management, the information obtained from sensors can be used not only for fault management, but also to monitor and analyze the health of the power system. In modern aircraft, analysis of trends is a key to ensuring long-term reliability and the ability to maintain systems in a timely and efficient manner.



### ABOUT THE AUTHOR

Karl Kitts serves as the Director of Development for High Performance Relays for the Global Aerospace, Defense, & Marine business unit of TE Connectivity. With more than 25 years' experience, his expertise is in high current MIL/AERO power distribution, electrical relays and power contactors, electronics circuit protection, HVDC relays, sensors and time delays, and solid state devices.

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