DESIGN GUIDE

ELECTRICAL CONNECTIONS

with Relays, Terminal Blocks, and Motor Starters

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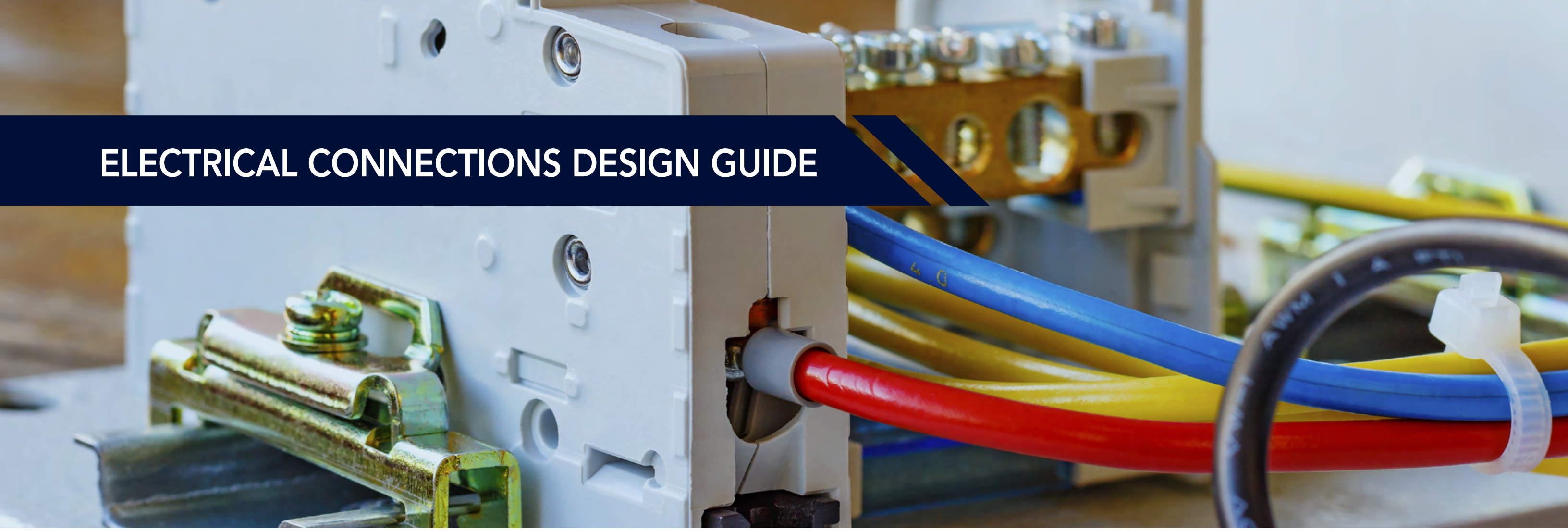
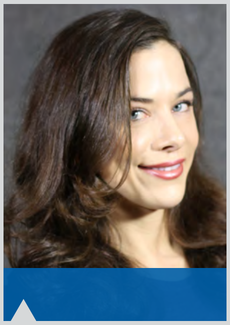


ELECTRICAL CONNECTIONS DESIGN GUIDE

Power and signal connectivity components include terminal blocks, relays, motor contactors, and motor starters. Use of these components endures and complements burgeoning technologies that integrate various connectivity and control functionalities into systems on a chip (SoCs), embedded single-board computers, and smart components for distributed control. What's more, the advent of embedded microprocessors has in some instances expanded the applications for terminal blocks, electromechanical relays, SSRs, and motor starters … imparting new capabilities for automated functions.

In this Design Guide, the editors of Design World detail the most common relay types and variations as well best practices for sizing, selection, and installation. Then we explain the various subtypes of terminal blocks — and what's more common on the market today. Finally, we compare various motor contactor and motor starter types and where each is most suitable.



LISA EITEL
Executive editor

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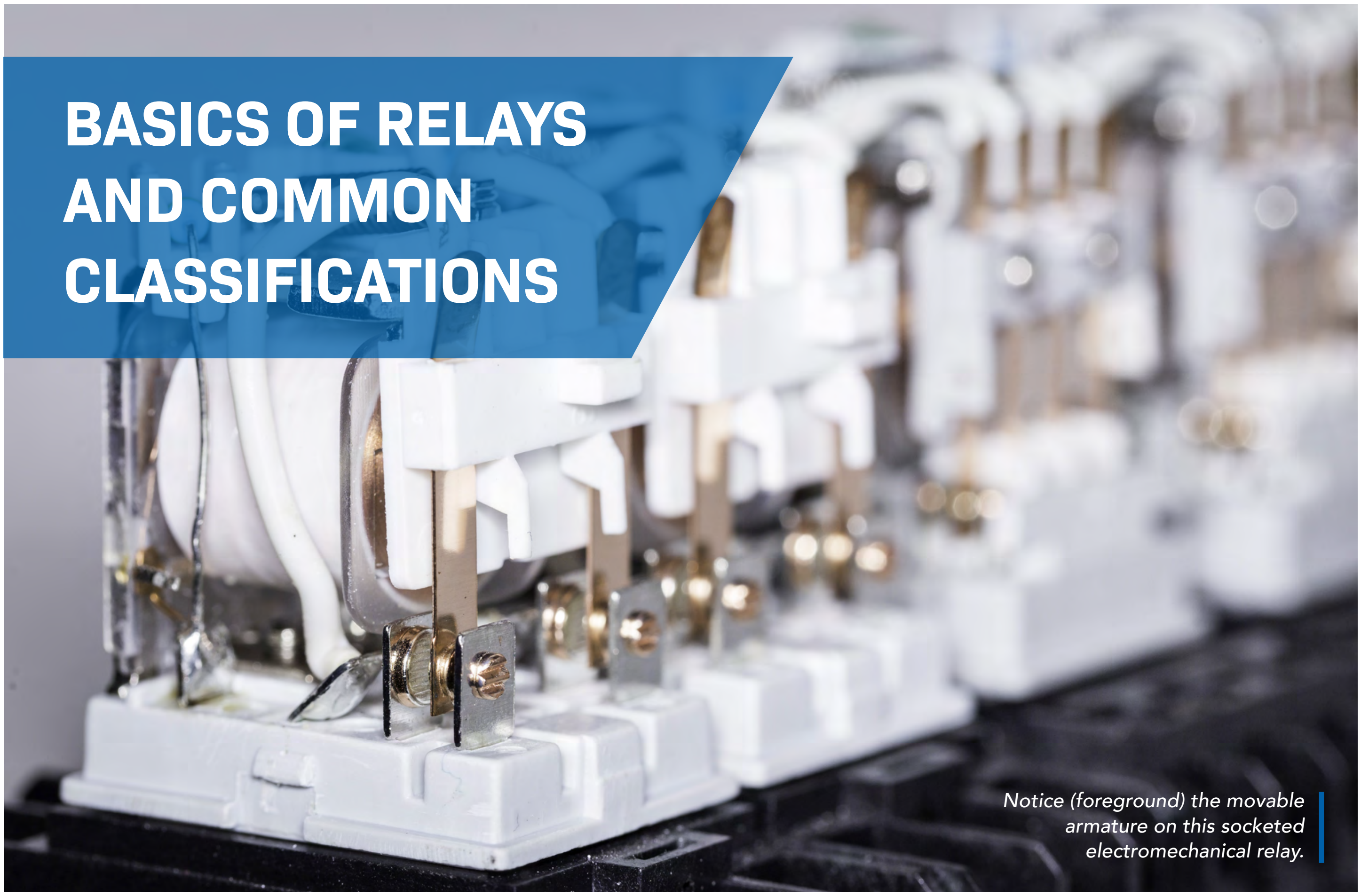
BASICS OF RELAYS AND COMMON CLASSIFICATIONS



Notice (foreground) the movable armature on this socketed electromechanical relay.

Relays are electronic devices that accept current or voltage signals in an input circuit as a prompt to switch open or close another circuit or pilot device. In this way, relays are switches that are controlled by some other input. The output is to trigger a predictable state change in the connected system.

Variations abound: Perhaps the most iconic relay design is the traditional socketed or "ice cube" format. This is a block-shaped relay having a clear plastic housing (for visual inspections of internal subcomponents) and an array of pins protruding from a base for plugging into a system requiring switching. But such ice-cube formats are only one of many for electromechanical relays, which we'll cover shortly. In fact, there are also a wide variety of solid-state relays (SSRs) for interlock and control functions on moving as well static operations. Traditional SSR formats include those with a classic "hockey puck" geometry and various "slice" shapes for DIN-rail mounting covered in this Design Guide's appendix. In fact, particularly thin designs have a 6-mm-thick slice shape that's fairly standard to other devices destined for tightly stacked DIN-rail installations. It's a format most common for relays integrated with logic circuits to support industrial automation.

Relays operate in industrial machines, plant equipment, and even consumer-grade vehicles and appliances employing electrical power and control signals. More specifically, relays are common in marine, off-shore, and off-highway designs; food processing, communications, and plants that process petroleum products; power-station and substation control panels; office automation equipment (such as printers) and building management systems; home appliances such as washing machines and refrigerators; industrial machinery, programmable controllers, and robotics for automation; and vending machines as well as other entertainment installations. Automotive and process control are other leading markets that make copious use of relays — and have prompted their evolution over the decades.

> *"ELECTROMECHANICAL RELAYS AT THEIR CORE HAVE CONTACTS THAT OPEN AND CLOSE A SWITCH IN RESPONSE TO INPUT VOLTAGE OR CURRENT SIGNALS ON AN INPUT COIL. A SIGNAL ON THAT COIL AND ITS ELECTROMAGNETIC EFFECT PROMPTS A RESPONSE FROM THE ATTACHED CIRCUIT. THEN THE OUTPUT CIRCUIT ACTIVATES A PRESET SYSTEM RESPONSE."*

To be clear, electromechanical relays at least don't typically exact direct control over power-consuming components beyond some small motors and solenoids; they're more commonly associated with control systems in automated designs. Refer to our discussion of contactors (which do in fact exact direct control over motors and other power-consuming components) for more on this.

Just as relay races in track-and-field athletic events involve the continuation of some action (in this case, the carrying of a baton)

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BASICS OF RELAYS AND COMMON CLASSIFICATIONS

so do industrial relays pass actions along in a sequence. So relays activated by a signal in one circuit (as from a machine-operator pushbutton) electromagnetically or electronically actuate another circuit (as in an electric motor on a high-voltage circuit).

MOST RELAYS FALL INTO ONE OF TWO CATEGORIES

➤ **Electromechanical relays** — which much of industry calls general-purpose replays, EMRs, mechanical relays, or simply relays — include those we briefly mention above. These are relays that work by transferring signals via the connection of mechanical contacts having moving elements that open and close the output circuit. Electromechanical relays often serve in systems to deliver simple current or voltage-based signals as well as on-off signals.

Note that the majority of relays in use today are these general-purpose (electromechanical) relays. Again, many manufacturers refer to electromechanical relays as simply *relays* — and solid-state relays as SSRs.

Where the term *relay* appears alone, it's usually same to assume that this refers to an electromechanical relay. However, in this Design Guide, we will use the relays' full names for clarity.

➤ **Solid-state relays** abbreviated SSRs are relays that transfer signals with contact-free electronic circuits sans the moving connections (and clicking sounds) of electromechanical relays. Sometimes called solid-state *switching devices*, SSRs employ semiconductors and electronics to trigger currents, voltages, or on-off signals. Refer to this Design Guide's section *Summary of solid-state relay characteristics and applications* for more information.

With no moving subcomponents, SSRs turn on and turn off faster than electromechanical relays. Some SSRs can exhibit residual electrical resistance as well as current leakage, though that's not usually an issue.

Of course, both relay types are governed by various industry and governmental standards. In wide use are NEMA Class A and B relay specifications. Relays designed to MIL-R-5757 specifications include those with contacts that can switch up to 10 A; MIL-R-6106 covers relays capable of switching to beyond that. Meanwhile the IEC classification system (primarily in IEC 61810, IEC 60050, and IEC-60255) defines the required performance of two relay types:

➤ The IEC defines all-or-nothing relays as those for which input is either within the operating range (to trigger action) or effectively zero. These operate (set) and release (reset) based on input sans time delay. In some cases, all-or-nothing relays serve as auxiliary relays —energized by another relay to provide some amount of time delay; higher-rated contacts; or multiple outputs from one given input. These take the form of elementary relays (to serve in safety applications and elsewhere) as well as time relays.

➤ The IEC defines measuring relays as those that operate (set) when a given quantity reaches a set value with some specified level of precision. For measuring relays, common parameters include measures of protections for interface equipment connected to controls, monitoring, and process subsystems.

This Altech Smart Relay from Altech Corp. runs simple logic, timing, counting, and real-time clock operations ... and is a suitable programmable control for simple automation involving building equipment, HVAC, and parking-lot lighting. Image courtesy Altech Corp.

COMPARING SOLENOIDS AND CONTACTORS
WITH ELECTROMECHANICAL RELAYS

For some the words *solenoid* and *relay* conjure visions of an ancient electromechanical world now replaced by all-electronic devices, smart motors, and more. That almost makes sense, as these two components in various forms have been with us for over 150 years. But don't be fooled: Both are still indispensable devices … and remain viable choices for the conversion of electrical energy to mechanical motion (in the case of solenoids) or where a signal must control the on-off path of one or more other signals (in the case of relays).

Let's compare these two electrical components — having very different uses but employing very similar physics.

What is a solenoid? In basic terms, a solenoid is a helically wound coil with a hollow center along its longitudinal axis. Within this coil there is a free-floating plunger of magnetic material that retracts or extends along that axis — with a head to one of the hollow's ends.

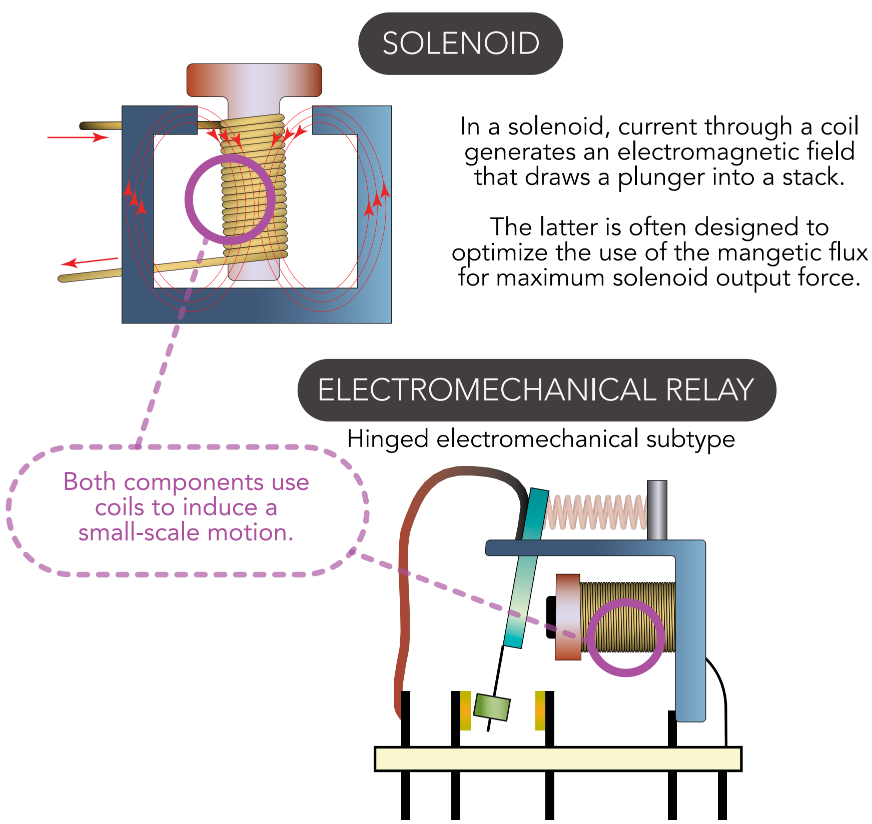
When the coil is energized by either an ac or dc current, the plunger is pulled to the center by the resultant magnetic field. When the current is off, a spring or other mechanism pulls the plunger back to its resting position.

Where are solenoids used? Solenoids excel in places needing sharp and quick linear motion over a limited range. Of course solenoids vary in size and power, but typical sizes range from one to six inches in length with linear motion of the same range. Depending on the wire turns and applied current, solenoids can apply sub-ounce to very large impact forces capable of punching holes in metal or forming rivet heads.

Among the many solenoid applications are the opening and closing of locks, motions on industrial machinery, and dispensing in vending machines … and anywhere else a machine design needs a solid linear stroke or punching action.

How is the solenoid's force determined? Solenoid output force is expressed by equations based on Ampere's Law. These define output in terms of number of turns N, armature cross-sectional area A, gap size g, air's magnetic permeability μO, and applied current i. Note that strength of the output force is proportional to the square of both the current and number of turns. More realistic equations use these parameters and account for coil fringing losses, coil imperfections, and other real-world issues.

Used in automated systems for many decades, solenoids and relays are still vital components — especially where versatility, ruggedness, ease of use, and flexibility are required for linear motion or circuit switching. In a solenoid, a magnetic field of an energized coil moves a captive metal plunger. When power is removed, the plunger returns to a neutral position. In contrast, an electromechanical relay has an armature which moves and closes (or opens) a contact circuit when the coil is energized and generates a magnetic field.



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COMPARING SOLENOIDS AND CONTACTORS WITH ELECTROMECHANICAL RELAYS

How does electrical circuitry drive a solenoid? Like most magnetic devices, the solenoid is a current-driven device — so is best supplied by a true current source. However, because many applications have a voltage source (rail) rather than a current source, solenoids are also specified in terms of their dc resistance … so a voltage source can be used as long as it can supply the needed current as determined by Ohms law.

Does it matter if a design engineer uses a current source or voltage source? Yes and no. Many successful solenoid designs use voltage sources capable of supplying the needed current. However, it may be hard to drive that current properly from the voltage source. That's because the solenoid's relatively high transient-current demand may cause the voltage source to "dip" as it tries to supply that current pulse — unless it's a stiff source with very low lead-wire resistance. that's why designs use a current source rather than a voltage source wherever possible.

Any other solenoid-drive issues? Most solenoids tend to use a relatively high amount of power —and they dissipate much of this power as heat. That means they run hot and can exhibit both short life and surrounding system degradation. Of course with pulse operation of a solenoid (as in the low duty-cycle situation of a vending machine) this may not be a problem. However, it can be an issue in high-volume high-rate applications on industrial production lines.

What are the other downsides of solenoids? In addition to their fast-transient and high-current requirements, they are difficult to use for precise operation of force or repeatability. That said, smart drivers along with position feedback via Hall-effect devices have greatly improved the capabilities of solenoids.

How to enhance and improve solenoid operation? There are two basic solenoid modes. In basic impact mode, the solenoid (upon energization) moves its plunger and impacts with force … and then is deenergized — as when opening a door. In the second mode, the solenoid is energized and held in that mode for a relatively long period — as when a door must be kept unlatched as people pass through.

Any use requiring that a solenoid be held in the energized position for more than a brief stroke will cause the generation of heat and the consumption of significant energy. After all, the amount of current required to hold a solenoid is far less than activation current. This is where smart drivers are useful — to activate solenoids at full current and then shift to a much lower hold current.

MORE ON SOLENOID SMART DRIVERS

While it's possible to drive a solenoid by simply connecting to a suitable voltage rail or current source, a *smart driver* can do much more.

From an electrical perspective, a solenoid is similar to a motor: Both are current-driven and act as highly inductive loads — so the driver requirements are similar as well. No wonder that many components used for motor-coil control (usually metal-oxide semiconductor field-effect transistors called MOSFETs) and their drivers work as solenoid drivers too. For example, certain power-saving solenoid-current controllers run off a 24-Vdc rail. These can serve as a true current source to controls the solenoid current during peak and hold modes — which in turn makes for lower power and thermal dissipation by using PWM drive control via an external MOSFET.

Such smart drivers also let engineers adjust peak current (and time at that current) as well as hold current. They can also enable automatic switchovers from peak-to-hold current mode at the end of the plunger stroke. Some smart drivers even accept an external Hall-effect sensor to track plunger position. Sensing in some cases can let a smart driver detect hard and soft fault conditions … such as shorted or open coils as well as an externally blocked or jammed plunger movement.

REED RELAYS FOR SWITCHING CONTACTS AND MORE

Reed relays are glass-encased contacting relays that excel in dusty and fumy settings. Various sources list reed relays as electromechanical relays (due to their electromagnetic operation and moving elements) while others list them as a subtype of SSRs (due to their widespread use in conjunction with solid-state devices). We categorize reed relays as a fully distinct relay class. During operation of the most common iteration — a normally-open (NO) arrangement — a magnetic field from an electromagnet or coil acts on a pair of closely placed flexible reeds. Ultimately the attractive force of the reeds' opposite polarity overcomes their stiffness and draws their tips (often gold-plated or of a highly conductive material) into contact. Upon removal of the input, the reeds return to their separated positions.

In fact, reed relays can incorporate reeds in various arrangements and quantities, though the latter is limited by the relays' coil size. Many coils can handle up to a dozen standard switches; for applications requiring more than that, relay coils can connect in parallel. Miniature reed relays are also available: These are surface-mount devices (SMDs) that fasten directly onto printed circuit boards (PCBs).

Reed relays are often used to switch starter motors and other industrial components.

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COMPARING SOLENOIDS AND CONTACTORS WITH ELECTROMECHANICAL RELAYS

Although such IC-based drivers require more external passive-support components than a simple power rail in series with the solenoid, they offer far superior performance.

Of course, there are many low-end applications (such as consumer-grade robotics and toys) for which a basic power-source loop sans electronics is adequate and appropriately cost effective.

HOW RELAYS COMPARE TO SOLENOIDS

Now let's consider the design of electromechanical relays. These share many electromagnetic characteristics with solenoids … but have a very different construction and functionality.

The design of an electromechanical relay uses a coil and current drive (or a voltage source) just as a solenoid does. However, the function of the relay is quite different. Despite the availability of alternatives for some applications such as the optical solid-state relay (SSR) and MEMS-based relays, the electromechanical relay is still a vital and versatile component for switching both ac -dc signals and power — and at low and high levels.

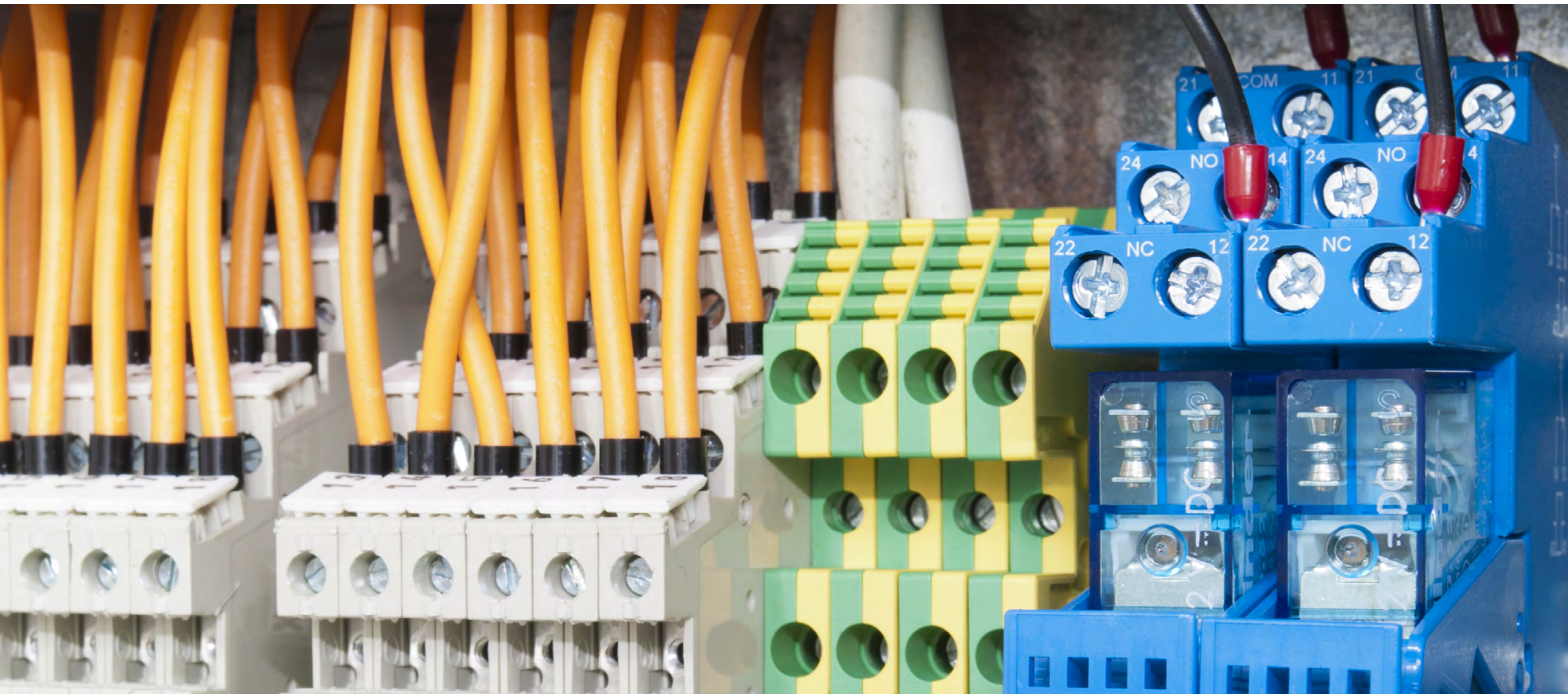
As already described, the function of a relay is to allow one signal to control the switching of another circuit, with complete electrical isolation and without any electrical contact between the two circuits.

The operating principle of a basic relay uses the energized coil of the solenoid. However, instead of moving a plunger in the core, it instead pulls in an armature— on which are one of more electrical contacts. As the movable armature pulls in, which then makes (or breaks) connection with a fixed contact, completing (or opening) a circuit path through the armature and contact. When the coil is de-energized, a spring pulls the armature back to the power-off position. Thus, the relay is an electrically controllable on-off switch.

ELECTROMECHANICAL-RELAY BENEFITS

Reasons abound for the unique and enduring utility of electromechanical relays — even with the availability of SSRs and MEMS relays.

• The coil circuit and the contact circuit are completely isolated from each other and can have very different voltage and current levels.



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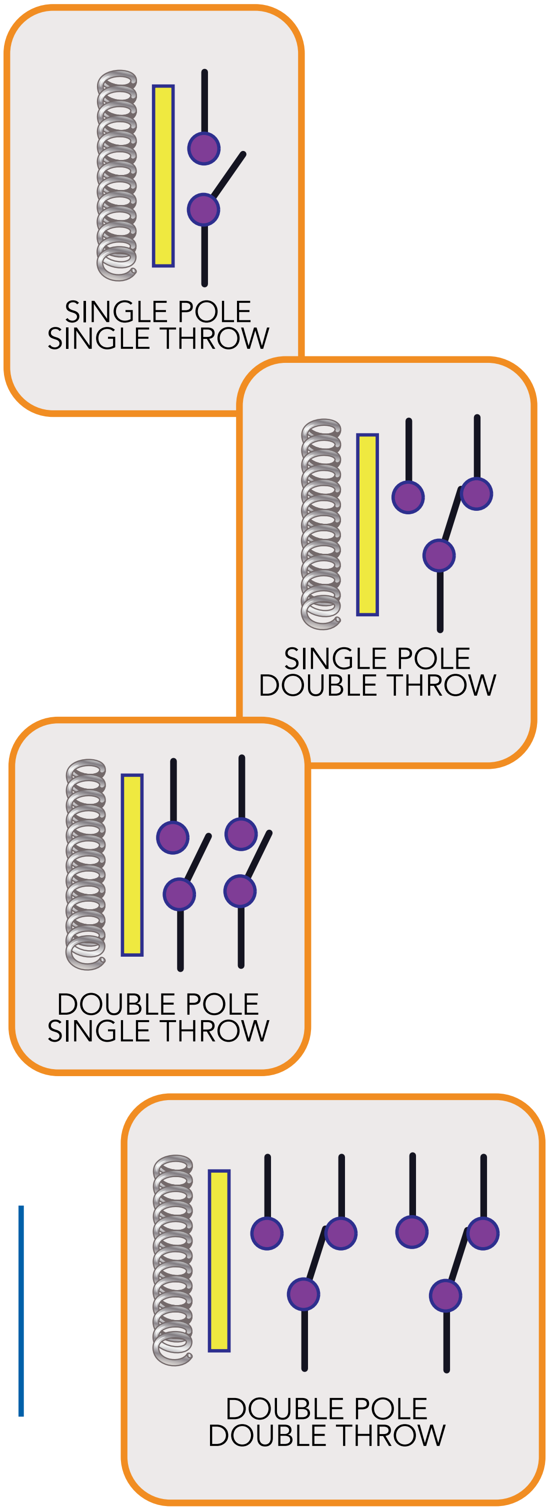
COMPARING SOLENOIDS AND CONTACTORS WITH ELECTROMECHANICAL RELAYS

- The electromechanical relay contact forms a basic switch closure … and current through it can be ac or dc — independent of the coil drive. Neither side of the closure is grounded or connected to circuit common, so the closure can be placed anywhere in a circuit
- An electromechanical relay can close a contact on activation (called normally open or NO) or it can open a contact (in normally closed or NC designs). Electromechanical relays can also do both using multiple contacts.
- Many relays control multiple NO and NC contacts — with three, four, or even more independent NO and NC contacts. These multiple contacts don't need to be carrying the same type and rating of loads … so some contacts can be for low-level signals while others can be for power.
- The contact circuit doesn't need to be live when the relay is activated — which is actually a necessity in some designs. That means the relay can be switched while the load circuit is off. This is called a *dry-contact* closure.
- Electromechanical relays are electrically and mechanically rugged and robust, and simple to troubleshoot. They can also withstand transients that would damage a solid-state equivalent.
- Electromechanical relays are commonly designed for coil currents from 10 mA up to a couple dozen amps, with contacts handling milliamps and a few volts to several orders of magnitude greater for both parameters.

Once an electromechanical relay is energized and the armature has moved, it only needs a weaker field to hold it in place; thus, the relay holding current is far less than the actuation current — typically about half. This is the same as with the solenoid, and the same or very similar circuit can be used as a solenoid driver or a relay driver. In addition, the relay load doesn't need to be fully known or defined as long as it's within the design limits; this is useful in cases where the load may have uncertain or hard-to-control characteristics.



Relay-contact configurations include single pole-single throw (SPST), single pole-double throw (SPDT), double pole-single throw (DPST), and double pole-double throw (DPDT).

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COMPARING SOLENOIDS AND CONTACTORS WITH ELECTROMECHANICAL RELAYS

A properly designed relay can use low-level voltage-current to switch a much higher voltage-current. In addition, relays are very easy to troubleshoot: All that's needed is an ohmmeter to measure coil continuity and dc resistance … and to measure the contact resistance when the relay is open and closed.

• Relays can also be used to switch RF signals, though these require unique internal construction.

A portion of this information originally appeared on Design World sister site Power Electronic Tips — here and here.

COMPARING RELAYS WITH CONTACTORS

Relays and contactors are electrical switches with the same basic operation — which is why some engineers consider contactors to be a subset of relays.

The difference between relays and contactors is where they're suitable for use: Relays most commonly act upon smaller circuits having ampacity of 20 A or less. In contrast, contactors act upon high-power circuits … directly switching circuits associated with high-current loads such as lights, large capacitors, and integral-horsepower electric motors — as detailed in this Design Guide's section on motor starters.

We've explained the construction of electromechanical relays already: Just like relays, contactors employ an electromagnetic coil for opening and closing an electrical circuit. However, with contactors, this coil is always on its own power supply. However, contactors have one or more pairs of NO three-phase inputs and outputs … and in some instances, auxiliary contacts that operate with the main contacts.

Many contactors used on electric motors (to establish and interrupt the power into the windings) also integrate thermal-overload protection at each winding. Low-resistance metal bands warm as the windings draw current. Upon detection of overheating, they trigger an NC contact (in series with the contactor's electromagnetic coil) to open … that in turn deenergizes the contactor — and cuts the motor off from power.

Contactor formats typically adhere to NEMA or IEC standards. The latter tend to be smaller for a given rating as well as less reliant on mass to dissipate heat from arcing — thanks to use of complementary contacts (and blowout coils) for electromagnetic arc quenching. Also integrated into the design of many contactors are arc chutes (closed spaces walled by parallel plates) for arc suppression and the extinguishing of arcs.

ELECTROMECHANICAL-RELAY DRAWBACKS

Electromechanical relays are well suited for some situations — and not for others.

They can be relatively slow, with switching speeds on the order of tens of milliseconds. This is unacceptable for those switching applications which need microsecond-range or faster speeds.

They will wear out — although a well-designed quality relay used within its design limits can last over a million cycles, that may not be enough.

Not only will the moving mechanical elements wear out, but the electrical contact surface plating will abrade from the repeated make-break action … eventually making poor or intermittent contact.

Unless they are sealed, contacts can accumulate dirt and may even corrode (which degrades contact-side performance).

They are also larger than SSR or MEMS counterparts and require current driven at relatively high levels — so can consume (and dissipate) significant power … especially when held in an energized mode.

Some of this content originally appeared on Design World sister site Power Electronic Tips here and here.

SUMMARY OF SOLID-STATE RELAY CHARACTERISTICS AND APPLICATIONS

Solid-state relays (SSRs) serve the same functions as electromechanical relays but are non-moving noncontact devices that can switch voltages to several hundred Vac for hundreds of thousands of cycles and beyond … which makes them useful for switching heating elements, motors, and transformers needing frequent and high-speed switching. In contrast with electromechanical relays, the subcomponents in an SSRs are entirely electronic:

1. An SSR's **input circuit** (like the coil of an electromechanical relay) connects to a system control. As voltage entering the SSR changes — 3 to 32 Vdc is common — it prompts the input circuit to act.

In one common variation, the circuit activates upon application of any in-range voltage exceeding the relay's pickup voltage value … and deactivates upon reduction of input to below the relay's dropout voltage value.

2. An SSR's **coupling** communicates energization and de-energization commands to the relay output — acting as the go-between between the input and output circuits.

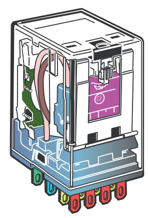
Note that this portion of an SSR is specially engineered to ensure the input circuit interfaces with the output circuit in a galvanically isolated way … so that high-power (output) load current is segregated by the relay's coupling section. That reliably prevents load current from flowing to the relay input — even during system failure. Various technologies are used for the coupling portion of an SSR:

The most common type, photocoupler SSRs, uses an LED or infrared light source on the input circuit to communicate with a photosensitive semiconductor on the output switch side.

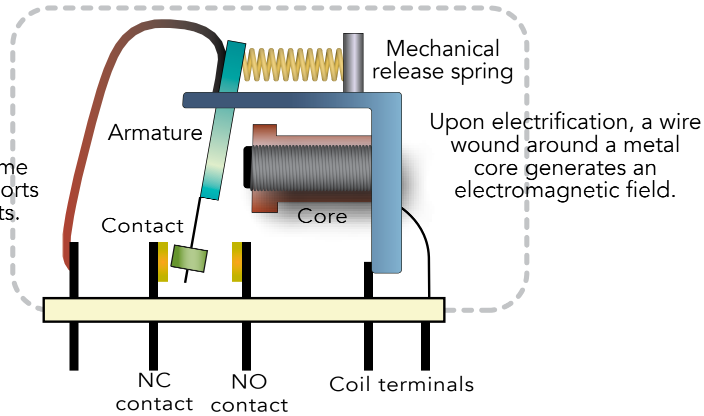
In contrast, transformer-coupled SSRs use a dc-ac converter to generate output that magnetically couples to the output via a low-power transformer.

ELECTROMECHANICAL RELAY

One electromechanical relay subtype — hinged type

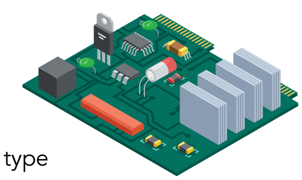


A ruggedized frame contains and supports the relay contents.



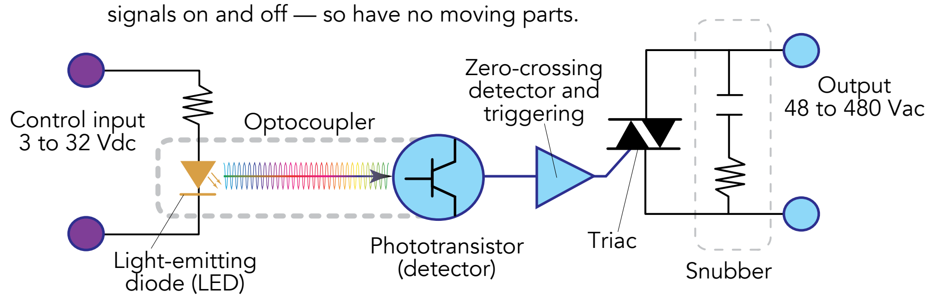
The electromagnetic field from the core causes the armature to pivot on its fulcrum and open and close the NC and NC contacts. An attached spring returns the armature to its original position.

SOLID-STATE RELAY (SSR)



One SSR subtype — photocoupler type

SSRs use electronic subcomonents to switch signals on and off — so have no moving parts.



Electromechanical relays and solid-state relays use different technologies to perform essentially the same function. The fast switching of SSRs makes them suitable for use on myriad high-power loads.

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SUMMARY OF SOLID-STATE RELAY CHARACTERISTICS AND APPLICATIONS

3. Next an **SSR's trigger or drive circuit** connects one of several designs taking the form of a:

- Silicon-controlled rectifier (SCR) for high-speed switching of (usually) short-duration "on" periods
- Back-to-back thyristor called a *triac* — short for triode for alternating current
- Metal-oxide semiconductor field-effect transistor (MOSFET) or Darlington transistor (for dc)
- Insulated-gate bipolar transistor (IGBT) for dc

Here, zero-switching operation — the most common for SSRs — as well as peak switching, dc switching, and instant-on switching are all options to tailor the relay action to the type of load the system drives. For example, analog switching uses a synchronizing circuit to make output voltage track input voltage — and allow a wide variety of possible output voltages within the SSR's allowable range. These excel in soft-start designs to drive electric motors.

4. Beyond that, an SSR's **output (power) circuit** connects to the load being controlled. Past the switch it may also include a snubber circuit (in some cases, a reverse-connected diode) or a zero-crossing detector to reduce spikes and transients and electromagnetic interference (EMI) during switching. That's an issue because SSRs switch load current through attached inductive loads — and (according to Faraday's law) current interruption induces voltage rise.

Any such rise across the SSR exceeding the maximum ratings may cause damage.

WHERE SSRs EXCEL

SSRs are compatible with a variety of control systems and are immune to magnetic noise; their solid-state nature means they mount in various orientations … and SSRs are impervious to heavy vibration. It's true some SSRs are more expensive than alternatives, but the most sophisticated can deliver exceptionally long life. Consider a few electric-motor applications of SSRs:

- On the motors of large conveyor belts or assembly lines with the potential to jam
- On industrial motor blowers for commercial ovens at risk of being overworked should a door be left ajar
- On motors subject to overcurrent conditions or incorrect starting currents
- On neglected motors and those attached to wearing mechanical components exhibiting excessive friction
- On general-purpose electric motors subject to high-temperature environments

Such motor-driven machinery may incorporate protective relays (electromechanical relays and SSRs) on their power supplies to both sense any such overheating and turn off the motor to prevent damage. The use of durable SSRs in such applications is widespread, because they have no moving parts to degrade life of accuracy … and in fact often outlast the equipment on which they are installed.

MEMS MECHANICAL SWITCHES COMPETE WITH SSRs

When microelectromechanical systems (MEMS) were first introduced in the 1980s, they were touted for their ability to subminiaturize electromechanical contacts. Built on silicon substrates using the same etching processes to make conventional ICs, MEMS structures work in inkjet printing heads, accelerometers, pressure sensors, and elsewhere. But they've yet to displace conventional mechanical switches … in part because MEMS switches' tiny contacts can't handle much current. Plus MEMS switches can exhibit arcing and heating that cuts switch life short.

But now, MEMS devices employing Digital-Micro-Switch (DMS) smart power relay technology could soon spur more use of MEMS-based power relays. These combine the benefits of solid-state and electromechanical relays. The DMS parallels a MOSFET with a MEMS switch to get zero-voltage switching. This reduces the switching energy across the contacts — which in turn boosts reliability under high voltage and current. The switch design also uses metal processing to boost the reliability of the cantilever beam holding one side of the contact — as well as the contact material itself. It makes for devices capable of three billion cycles and beyond. In fact, the power relay retains the galvanic isolation properties of traditional relays … and it can integrate into traditional semiconductor packages to provide other intelligent features. Read the full story at Design World sister site powerelectronictips.com.

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SUMMARY OF SOLID-STATE RELAY CHARACTERISTICS AND APPLICATIONS

MANAGING THE HEAT FROM SSRs

Semiconductor-based switches as found in SSRs generate non-negligible heat — and left unaddressed, this can present a risk of mechanical fatigue due to thermal cycling. Two solutions here are heat sinks and thermostats. Thermostat can be added to SSRs by design engineers (who assume the design of the thermal protection) or pre-integrated by the SSR manufacturer.

In some SSRs with pre-integrated thermostats, the SSR cuts off input circuit power when the temperature of the SSR itself goes beyond the specified maximum as determined by the application requirements. After a brief cooldown, power is automatically turned on again. Here, the SSR's thermostat senses the internal temperature of a mechanical interface with a metal plate at the mount for the internal power-switching device. If the heat exceeds the normal range, it sends a signal to the SSR to turn off the power.

This built-in thermal protection prevents overheating conditions by providing a trip before equipment damage can occur, thereby saving time and money.

For machine designers wanting to leverage this technology and save themselves the trouble of doing it themselves, it's first necessary to select the appropriate SSR for the load needing control. One key consideration is the application's ambient operating temperature, which factors into the best derating for ampacity. In other words, engineers must identify the maximum power rating, current rating, or voltage rating for which the SSR is rated — and then use less than those maximum ratings.

Other design considerations are the heatsink used and anticipated power dissipation.

SSRs benefiting from most from such built-in thermal protection include those on industrial ovens, commercial refrigeration systems, sterilization equipment, welding equipment, and conveyors in packaging, construction, and material handling.

Information about thermostats on SSRs originally appeared on Design World's sister site eeworldonline.com.

SGT three-phase solid-state relays and contactors made by celduc are available through altechcorp.com/solidstate.

WHEN TO USE A RELAY — OR A PLC — OR BOTH

Top design objectives for control installations include capability, reliability, and cost effectiveness. Many new and retrofitted control panels employ components such as PLCs and even industrial PCs (IPCs) and programmable automation controllers (PACs) for advanced connectivity and control. It's often appropriate to use these more complicated (and capable) options and remove or forgo electromechanical relays in the system. In other cases, machines that have simple architectures, fixed functions, or specialty requirements may derive benefit from connectivity and control primarily based on electromechanical relays and SSRs. In still other cases, hybrid approaches are best — to combine various technology types and leverage the benefits of today's controls and relays.

Let's consider the parameters that can factor into this engineering decision.

WHERE RELAYS ARE THE SUITABLE CHOICE

Relays are an enduring technology that is simple and efficient — and relay-based control excels at satisfying very specific design requirements. Oftentimes plant personnel and end users are familiar with or prefer their inclusion, and most industrial technicians can install them without issue. That's in contrast with other control options, which necessitate preconfiguration and advanced programming for proper commissioning.

Applications needing little troubleshooting of wired logic benefit from the use of traditional relays as a cost-effective choice. Simple diagnostics are possible with electromechanical relays sporting indicator LEDs (communicating the coil's electrical status) and mechanical flags (communicating contact status) for unambiguous information about the device. But elsewhere, advanced relays include diagnostics as well as communications with microprocessing power and the ability to connect to software. These are particularly useful in arrangements where relays interface with motors needing protection against the effects of ground faults, overloads, and other situations that can damage windings.

Further facilitating their application is the increasing convenience of ever-smaller relay footprints for both electromechanical relays and SSRs already discussed. Relay-design advances with optimized circuitry, efficiency, and heatsinks mean today's relays are much smaller than previous generations with the same mA or A switch rating. Even relays having the ice-cube format have in recent years seen advancement with embedded processing.

These increasingly compact form factors of smart relays complement their expanded functions. As mentioned earlier in this Design Guide, many such relays are now manufactured in 6-mm slice geometry for DIN-rail mounting, which (besides saving space) also eliminates the need for daisy-chain wiring schemes. In some instances, power bridges (to power multiple

(continued)

WHEN TO USE A RELAY — OR A PLC — OR BOTH

Altech Corp. offers a wide range of UL ground fault equipment protection (GFEP) devices.

A ground fault relay (GFL) branch circuit breaker combines a GFEP with a UL 489 circuit protector to eliminate the need for upstream circuit protection.

A UL 1053 ground gault (GF Series) sensing and relaying device provides residual current protection for circuits with loads to 63 A.

A UL 1077 ground gault relay (GFR Series) with overload protection serves as a GFEP relay and supplementary protector (RCBO).

relays) further simplify and ruggedize their installation. Another development for simpler relays are increasingly standardized sockets that accept insertion of relays and timers with various pole counts and voltage requirements.

Relays can unburden safety PLCs of alarm and response tasks, which is helpful where programming even modest design changes is a hassle. In fact, smart relays can be more suitable than certain controls on otherwise simple designs needing safety functions — for example, where safety PLCs are prohibitively expensive. The economy of relays (especially on designs needing only a few safety points) can allow safety functionalities that might otherwise be omitted. Here, single-channel relays and smart alarms are top choices for safety sans overcomplicated implementations.

In fact, where smart relays are configurable and assume safety functions (going beyond redundant electrical connections with processing capabilities) they've come to closely resemble small safety PLCs. Such configurable relays can have slightly less logic and configurability than PLCs but require less technician knowhow and software for programming.

In fact, several protective relays on the market today include data-processing power as well as advanced communications. These and other smart relays can include EtherNet/IP, CANopen, PROFIBUS, and other protocol communications for the transmission of data about relay-monitored devices.

IO-Link connectivity has had perhaps the most adoption in relays for monitoring functions … especially of single and three-phase voltage sources. IO-Link-ready relays impart continual access to variables as well as signal scaling — in the past something only possible with PLCs and higher-level controls. In short, signal *scaling* allows inbound and outbound relay communications for the output of system values and the input of new setpoints. Read more about the spread of IO-Link here and here.

Other configurable relays accepting SIM cards are capable of cellular communications to support M2M functions in remote settings. Such smart relays can transmit instructions and receive alerts even without a wireless network.

WHERE PLCs ARE THE SUITABLE CHOICE

Controls that take the form of PLCs or incorporate PLC functionalities continue to proliferate in operations needing coordinated system automation. PLCs also excel where logic functions must accommodate reconfigurable equipment — as for machinery involved in producing batch sizes down to one. Such controllers store in memory instantly accessible alternative routines. Case in point: New models of electric vehicles are released every year — requiring annual production-line retooling. Relay-based logic would necessitate physical rewiring and the addition of relay modules to make such changes. That's no issue where onsite personnel is familiar with the design (and may be fastest in some instances) but with no such technicians, PLCs and higher controls accept software-based parametric updates for quick turnaround of new automation routines.

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WHEN TO USE A RELAY — OR A PLC — OR BOTH

Many PLCs can also handle arrays of I/O nodes and the addition of high-density digital I/O to minimize control-rack size. PLCs impart diagnostic functions to identify failed I/O points requiring replacement — impossible with legacy relays. Plus add-on PLC cards can satisfy the need to supplement with devices exceeding the voltage and current ratings of existing I/O … and options abound to address field-device reactivity.

PLCs have also become increasingly cost-effective — in some instances becoming cost-competitive with relay-socket-connector setups of comparable capabilities. That's in large part because the cost of installation for the latter and the efforts of a technician required to hardwire relay-based systems.

Though we've touched on how some particularly capable smart relays are practically indistinguishable from simple PLCs, some relay logic is limited to simple Boolean control. So where designs go beyond very specific tasks, traditional relays at least necessitate the addition of counters and timing relays— and may not be able to execute all diagnostics required to keep an installation optimized. In contrast, even simple PLCs are capable of counting, timing, and diagnostics — as well as accepting reprogramming for applications that change.

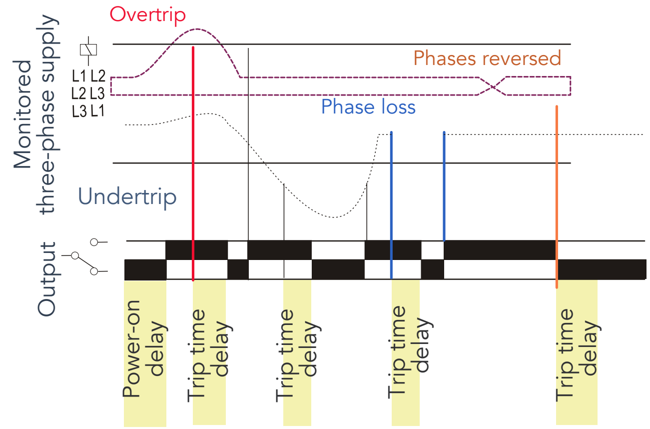
PLCs also facilitate the addition of HMIs for human-readable communication of cycle counts, system status, and faults. With PLCs now allowing technicians more accessibility (with laptops and smartphones) their use has become practical for more applications. In fact, today's most advanced controls can collect and analyze production floor data (as well as distilled data from edge devices with built-in processors) for full IIoT connectivity.

WHERE RELAYS COMPLEMENT OTHER CONTROLS

We've covered the situations where relays excel and those for which PLCs are most suitable. But a vast array of automated installations benefit from hybrid control architectures that integrate a combination of PLCs and relays —electromechanical relays and SSRs.

For example, PLCs benefit from the help of relays to switch and control high-current devices. After all, PLCs excel in commanding small electrical loads such as contactors, annunciators, safety indicators, and relay coils of low ampacity. In contrast, advanced relays can switch larger loads of several amps and beyond — associated with electric motors, valves, linear actuators, and other components. Where a particularly inductive field device threatens to damage controls with surge or inrush current (or voltage spikes) interposing relays can (serving as a sacrificial component) complement a PLC. SSRs in particular excel at isolating and protecting controls from

VOLTAGE PROTECTION RELAY TIMING



These are some functions that a relays can execute; adjustments to setpoints are made via rotary DIP switches on the face of the timer relay.

EMI — especially in designs that drive particularly inductive loads … and relays shield PLCs from high-voltage transients when loads are switched off. Of course, relays and PLCs used together must have electromagnetic compatibility.

Still other designs use SSRs or PLC digital output on points needing high-frequency switching because solid-state devices (with their theoretically infinite number of cycles) extend machine life in these situations. SSRs in particular are indispensable for commanding high-speed components in timing, sensing, and machine-vision functions.

> *PLCS CAN ALSO BENEFIT FROM THE HELP OF RELAYS TO CONVERT FIELD DEVICES' VARIOUS VOLTAGES FOR SIGNAL OUTPUTS TO ONE STANDARD (FOR EXAMPLE, 24 VDC) IF THAT'S ALL THE PLC ACCEPTS. CERTAIN SSRS CAN EVEN EXECUTE SIGNAL CONDITIONING ON THESE INPUTS IF THAT'S REQUIRED.*

During retrofits, portions of a design may accept a PLC upgrade while the rest of the installation continues to run off a relay panel. After all, replacing legacy relay systems with improved models can extend control-panel life. That may mean the swapping out of electromechanical relays with SSRs … because with automated diagnostics accessible through today's through Ethernet-based protocols in particular, SSRs can communicate when failures do occur.

(continued)

WHEN TO USE A RELAY — OR A PLC — OR BOTH

Elsewhere, relays complement various control and I/O combinations. That's why many high-density I/O components use relays to either convert voltage or amplify current to accessible values. Relays can complement high-density low-power digital I/O on PACs for some tasks run off traditional high-current equipment. Such hybrid installations are more common for retrofits … but no matter the installation phase, PAC communications and logic often work well with relay-based systems.

Other engineers pair relays and PLCs when output signals need addressing — typically around the system's PLC where high-ampacity components that the PLC can't handle. Some DIN-rail I/O modules are also designed to integrate with relays for safety — and relay on PLCs for the distributed control of field devices imparting IIoT functionality.

Of course, new designs for both electromechanical relays and SSRs have blurred lines between these subtypes — as well as those between SSRs and other controls. As mentioned, the most advanced programmable relays are often indistinguishable from micro PLCs for delivering configurability via ladder logic and other standard programming … so that relay logic and ladder logic aren't mutually exclusive.

Shown on this page are three components from the [Altech Corp. Smart Relay (ASR) product line](#).

***Top:** The ASR Smart Relay base module is programmable (with ladder programming) via an onboard keypad or through the supplier's ASR-Soft configuration software — an easy-to-use PC-based GUI for program generation, project simulation, and documentation. The base module has a backlit LCD screen for display and modification of preselected parameters related to function blocks as well as I/O status and other programming. The module allows programming of up to 16 timers, 16 counters, 16 time switches, 16 compare counters, 16 soft text messages, 64 auxiliary relays, and 12 analog comparators. The module allows eights digital inputs and four relay outputs as well as two 0-to-10-V analog inputs (in a 12-to-24-Vdc model) that also work as digital inputs. This base module also accepts connection of up to three extension modules for more I/O — up to 32 digital inputs and 16 relay outputs.*

***Middle:** The ASR communication module lets the programmable relay connect to a Modbus network through an RS-485 link.*

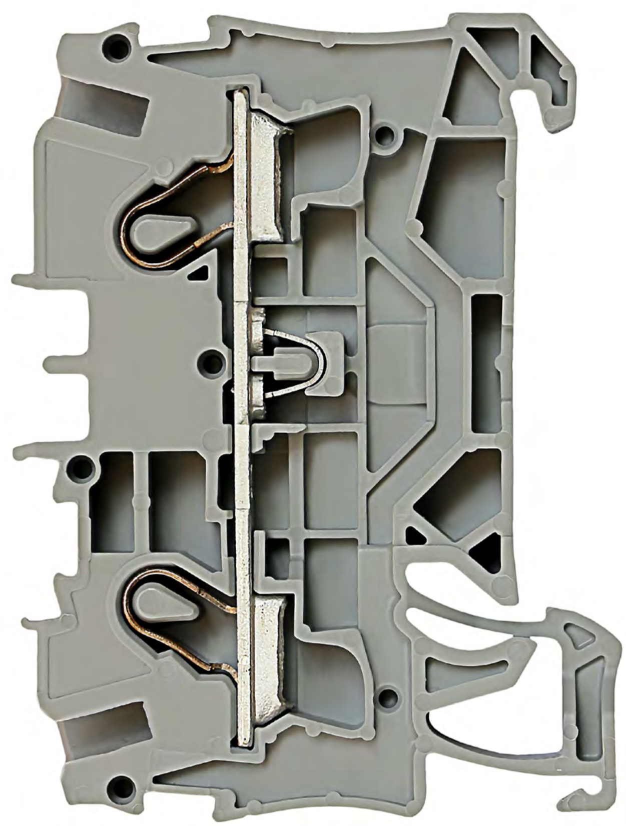
***Bottom:** ASR extension modules complement ASR base modules to increase I/O capacity; every extension module has eight digital inputs and four digital outputs. Connections are daisychained.*

BASICS OF TERMINAL BLOCKS AND THEIR VARIOUS SUBTYPES

Mounted on this DIN rail are terminal blocks and (in the blue housings) relays based on electromechanical action.

Terminal blocks are [one variety of connector component]() for joining sections of electronic circuits in industrial applications. They include electrically conductive assemblies having wire-securing receptacles — all encased in monolithic plastic housing. Some terminal blocks have contact pads or legs for connection to PCBs, but most are designed with their own housings for screwing onto machine frames, attaching to the sides of industrial electrical components, snapping into industrial rail and rack systems, or mounting to the inside walls of control-panel enclosures. Here we focus on the latter. Please refer to the appendix of this Design Guide for more information on the DIN rails onto which many terminal blocks mount. Also refer to Design World sister site [eeworldonline.com]() for more information on PCB terminal blocks — those that solder or otherwise mount to PCBs and connect thin-gage wires for low-voltage power and control applications between circuit-board components.

Housed terminal blocks are most suitable for semi-permanent and permanent connections of signals and power … accommodating wire and cable sizes from the delicate 16 American Wire Gauge (awg) to what would be the logical equivalent of -7.5 awg — a beefy circular mil of 600 kcmil or



This is a cutaway of a terminal block. Left are the two spring-loaded wire-captivation mechanisms for joining and securely holding wires in a circuit. Right are (top) hook and (bottom) latch geometries molded into the block body to allow DIN-rail mounting.

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BASICS OF TERMINAL BLOCKS AND THEIR VARIOUS SUBTYPES

MCM. Most all terminal-block designs provide reliable securing of wire as well as easy release of wire —to allow inspections, repairs, and replacement of wiring and attached components.

General-purpose terminal blocks (sometimes simply called electrical blocks or wire terminations) are broadly applicable in myriad applications as electrical-connection termination points. Other more specialized terminal blocks include:

- Terminal blocks for the transmission of I/O signals
- Terminal blocks for power distribution
- Terminal blocks for motor connections — including single-phase and three-phase motors for various industrial uses
- Terminal blocks to serve as *ground blocks* — designed specifically to make connection to ground)
- Terminal blocks to serve as fuse blocks — in which two wires make a connection to a fuse for circuit protection.

Unlike other connector options such as DIN cable connectors, pin headers, D-sub connectors, and industrial socket connectors, a single terminal block typically makes only one (single pole) wire connection to the electronic circuit at hand. That said, terminal blocks do come in multi-row banks for joining arrays of wires to circuits as needed.

Consider the special case of interface blocks. Also called **terminal block interfaces**, these are identifiable by their inclusion of two connector types … with one usually taking the form of a very long receptacle array to accept separate discrete wires. In fact, the job of an interface block is to connect an array of wires from a power component to pre-engineered cable (sporting a specialty connector) from a controller or other low-signal component. For example, one common interface might accept a 37-pin D-sub plug and connect it to a 38-position terminal block that holds the wires in their terminals with push-in contacts. Recall that the *D-subminiature connector* is named for its distinctive D-shaped metal plug shield … perhaps most familiar for its inclusion on older consumer-printer cable ends.

Terminal block interfaces abound for connecting various DIN headers as well as flat ribbon headers, IDC connections, and other industry-standard cable ends. Some safety-featured styles include dead-front wire receptacles that recess conducting elements into the plastic housing. Other styles have a stepped (tiered) design to save space and make it easier to access all wire receptacles even if one section of the block is already wired.

When selecting a terminal block, current ratings are paramount. Excessive current through a terminal block can induce overheating and failure. Voltage is usually less of an issue, but still a key terminal-block parameter: Excessive voltage (while rare) can induce dielectric breakdown and current leakage between adjacent blocks. A terminal block's published creepage (between terminals) and clearance (through-air distance) values affect voltage ratings as well.

The receptacles on terminal blocks must be large enough to accommodate the designs' cable gages. The wire type (single or multi-strand) in part dictates which terminal types are most suitable: Single-strand (single-core) wire is typically stiff enough to push aside the spring mechanism inside push-in connectors, whereas multi-strand wires are often used with screw terminals on terminal blocks.

MORE ON THE RECEPTACLES INSIDE TERMINAL BLOCKS

Wire-contacting elements inside terminal blocks are often a copper alloy having the same thermal-expansion coefficient as the wire they accommodate. This avoids problems associated with differing expansion rates as well as those associated with electrolytic reactions when dissimilar metals touch. Where a terminal block will likely accept insertion of both single-conductor wire and stranded wire, some manufacturers make the wire-contacting elements of copper beryllium.

Terminal blocks with **screw terminals** employ screws to secure cable and wire in place. Typically found on blocks handling moderate voltages and currents, these require that the technician insert wires into open receptacles and then use a screwdriver to tighten a small plate down onto the wire to hold it fast. Larger terminal blocks may insert-mold metal receptacle linings to make the wire contact even more reliable. Subtypes of screw terminals are strap-clamp contacts (which use a wire-clamping screw and strap assembly) and tubular contacts. The latter use a rectangular metal tubing pierced by a screw at each end. This is called a tubular screw contact when the screw's flat bottom holds inserted wire in place. It is called tubular clamp contact when a flat pressure plate on the screw end clamps the wire … which is a setup that's useful for finely stranded wire.

Terminal blocks with **barrier terminals** also employ screws to hold conducting wires and cables fast. However, these have multiple termination points for multiple cables — as well as small barriers between individual terminals.

Terminal blocks with **quick-connect contacts** employ the mating of simple female tabs that accept insertion of flat male blades soldered to the end of wire needing connection. This friction-based mating is common for thin-wire applications and those that see regular service or reconfiguration.

Terminal blocks with **push-in** or **push-fit contacts** (sometimes called spring-loaded contacts) have open receptacles to accept manual insertion of wire and cable. Then a flat-spring-loaded

(continued)

BASICS OF TERMINAL BLOCKS AND THEIR VARIOUS SUBTYPES

mechanism embedded at the root of each receptacle bites into the cable and traps it via mechanical wedge action against the receptacle's interior wall.

These push-in designs include pushers called release plungers (depressed with the use of a flathead screwdriver or more specialized poker tool) to temporarily hold back the spring-loaded mechanism if the wires loaded into the terminal block need to be removed for some reason. In some cases, these pushers are brightly colored — for easy identification and to make it easier for technicians to see where to apply screwdriver pressure.

Push-in contacts are increasingly common on terminal blocks that mount on DIN rails because they avoid issues associated with the overtightening of screws and often make the wiring of terminal blocks go faster.

Closely related to push-in contacts are **tension-clamp contacts**. A spring-loaded mechanism holds the wires in their receptacles … but the difference is that the spring takes an α shape inside the receptacle. That means it necessitates the use of release plungers (depressed with the use of a flathead screwdriver) for both removal *and insertion* of wire. Terminal blocks having receptacles made with this design are useful when reliability is a top design objective.

Pluggable terminal blocks have wire and cable input receptacles as expected — *as well as a male plug output to insert into a mating socket*. Such terminal blocks are indispensable for hot-swapping connections during inspection and service.

Besides selling components with these variants, terminal-block manufacturers allow for almost boundless customization. Just a few options include:

• Clear-plastic housing options and label sets (especially for terminal blocks that mount to DIN rail) to allow inspection, labeling, and organizing wire connections

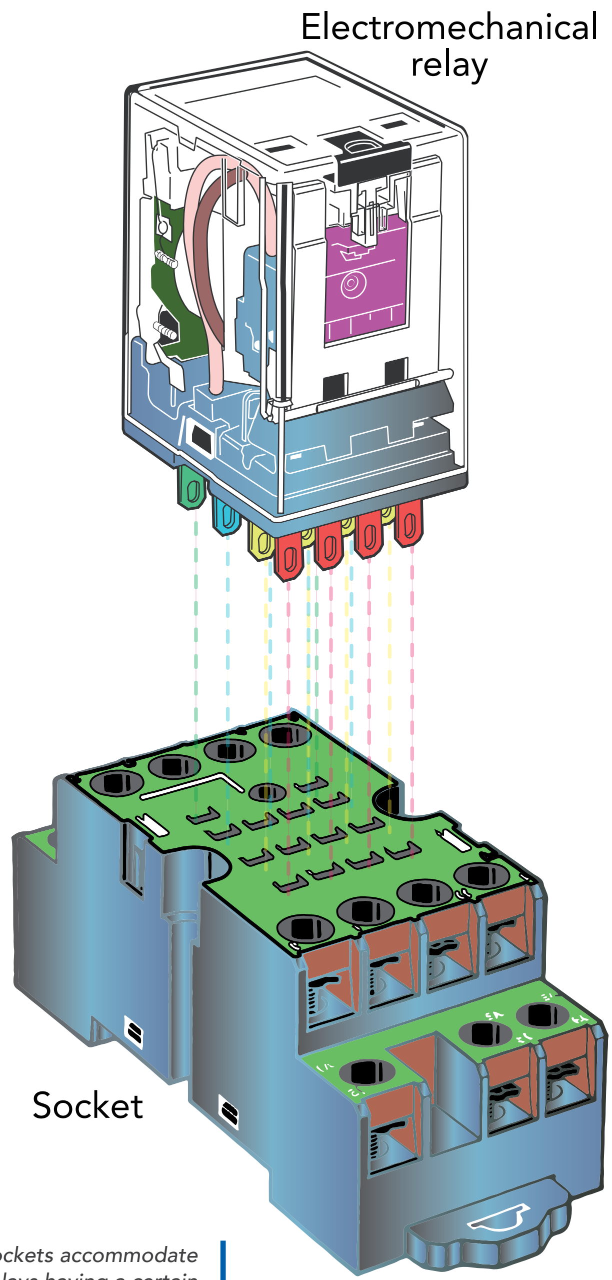
• Switch or disconnect formats (as in knife-disconnect terminal blocks) with a plastic-molded throw that lets operators move a blade connector (embedded inside the block) into or out of a circuit — for a quick way to disconnect the circuit

• Lights and complementary circuits for visual annunciation of connection status

• Jumper straps to link adjoining contacts as well as fanning strips to allow the concurrent connection of wire arrays

• Sockets on terminal blocks for fuses and disconnect elements (especially for the accommodation of ferrule fuses of various ampacity ratings) for surge suppression and voltage regulation

Sockets for the insertion of PCBs (to impart advanced functions)



Sockets accommodate relays having a certain number of connector blades. These assemblies allow quick replacement of the relay in case of failure.

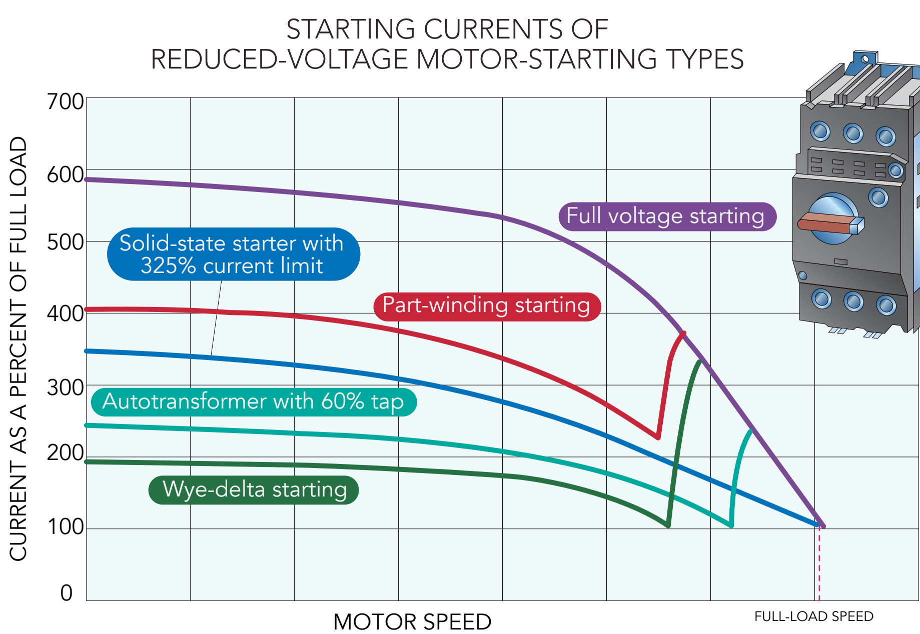
ALL ABOUT MOTOR STARTERS
(AND HOW THEY COMPARE TO CONTACTORS AND DRIVES)

Electric motors are absolutely essential to automating innumerable applications around the world. In most cases, the driving of motors — the supplying of electric power to them — requires some engineered system that must also be compatible with the motor's winding arrangement.

Because these motor-powering systems are often found employing or accompanying the other electrical control and connectivity devices already covered in this Design Guide, we'll now review their most common permutations. Additional information on motor drives having functions beyond motor starters can be found at motioncontroltips.com.

Only the simplest and smallest designs — usually with single-phase motors 5 hp or smaller or three-phase motors 15 hp or smaller — accept direct-on-line (also called across-the-line) connection to the electrical power source without risk of a motor overdraw and a line undervoltage condition. Three-phase motors driven this way can have windings connected in a simple wye (also called star) or delta configuration … and dual-voltage motors (convenient for how they can accept 230 V or 460 V input) have twin coil sets that can run in parallel or (for the higher voltage) in series.

Everywhere else, across-the-line motor starts present too many problems for the motor itself as well as systems attached to the motor — including detrimental electrical effects as well as excessive wear on mechanical power-transmission components. The design objectives of safety, productivity, and precision usually necessitate the use of more advanced motor-driving approaches.



Above: This [Altech Corp. manual motor starter (of the supplier's MMS series)]() is a three-pole self-protected Type E starter.

Left: Starting current is an important parameter in the proper sizing and pairing of motors and motor starters. Starting current from the motor starter must be sufficient to help the motor meet torque and acceleration requirements but mustn't cause excessive voltage drop on the electrical supply line.

(continued)

ALL ABOUT MOTOR STARTERS

(AND HOW THEY COMPARE TO CONTACTORS AND DRIVES)

Contactor image courtesy Altech Corp. Visit altechcorp.com/contactors for more information.

TERMINOLOGY GROUNDWORK: THE DIFFERENCE BETWEEN CONTACTORS AND MOTOR STARTERS

In a previous section of this Design Guide, we detailed how contactors and relays are distinct components — despite occasional industry usage of the terms that suggests otherwise. Contactors and motor starters are also distinct components. Here the terms are used interchangeably because their core is the same exact technology — a switch capable of handling high voltages.

The difference is that motor starters have one extra system or systems not found in contactors — *an overload relay of some type to cut voltage input* should that relay sense a motor-overload or thermally compromising condition due prolonged running overcurrent. Those designated as **self-protecting motor starters** also include short-circuit protection. Here again, precise use of terminology is key: Rather than using *short circuit* to refer to any electrical malfunction, it's only proper to use the term when discussing a sudden overcurrent arising from the flow of electrical power that has found some unintended path of travel. Short-circuit protection acts instantaneously to cut off the system from the power source.

Another difference between contactors and motor starters is related to how the two components are rated and specified. Contactors are generally classified by their voltage capacity. In contrast, motor starters are typically rated by their current capacity and the horsepower of the motors for which they're compatible … even while accommodating inrush current upon startup without nuisance tripping. That is usually done through a slight delay in relay tripping — as many motors (especially smaller motors) can reach full operating speed in just a few seconds.

Motor starting at its most basic level is classified as manual or automatic.

Manual starting includes hand-turned on-off switches that simply make or break the motor input circuit when activated by plant personnel. Some versions that qualify as true motor starters (as designated above) incorporate a thermal-overload relay to de-energize the motor if it becomes overheated.

In contrast, *automatically triggered motor starting* is sometimes called *magnetic starting* for the electromechanical contactors that are core to this design.

As with any electromechanical relay technology, these have stationary electromagnetic coils that (upon a command from a pushbutton, limit switch, timer, float switch, or other relay) force together two circuits. These circuits include input power contacts and a mating carrier that (once closed together) allow current flow into the motor windings. One variation on this design is a combination starter, which includes the magnetic action as well as some way of disconnecting electrical power when needed … either with a fuse, breaker, or motor circuit switch.

Wye-delta motor starting (one type of reduced-inrush system) sends full-line voltage the motor's wye windings during startup — though voltage across each motor winding is reduced by the inverse of the square root of three (57.7%) which is why this arrangement is sometimes (rather inexactly) called reduced-

(continued)

ALL ABOUT MOTOR STARTERS

(AND HOW THEY COMPARE TO CONTACTORS AND DRIVES)

voltage starting. Then a circuit (usually with a contactor for each phase, overload relay, timer, and mechanical interlock) switches the motor input to supply it full-line voltage into its delta windings.

Part-winding motor starting — used in conjunction with the specialty dual-voltage motors mentioned above — applies across-the-line voltage to only one part (half or two thirds) of the motor windings (typically nine or twelve) upon start. Then once a set time has passed or set voltage is detected, a relay or timer springs into action and commands that the rest of the windings be added and supplied power as well.

Acceleration may be irregular, but part-winding motor starting impedance has no effect on starting torque … and allows low-torque starts that are useful for pumps, fans, and blowers. Like wye-delta starting, part-winding starting is a type of reduced-inrush system and delivers a diminished full-line voltage upon motor startup — but doesn't technically qualify as reduced-voltage starting.

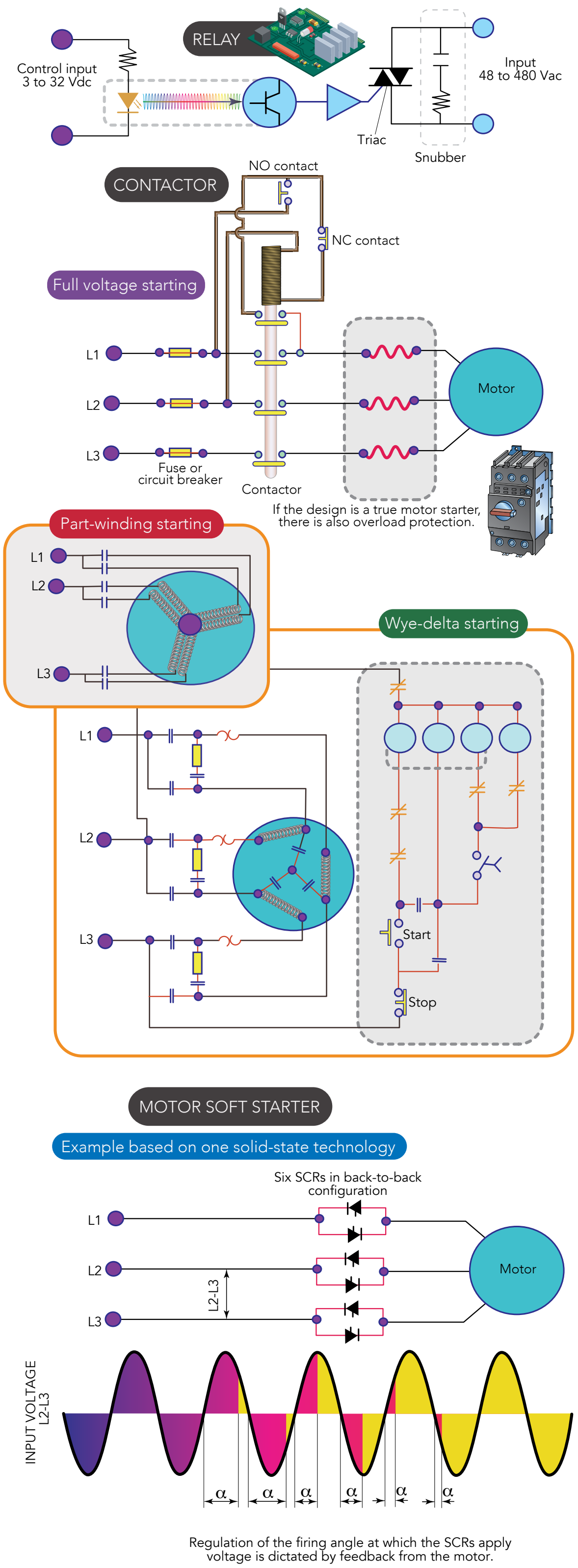
Full-voltage reversible starting leverages how induction motors change rotation direction upon reversal of any two power leads. Reversing starter systems simply incorporate a pair of mirrored contactors complemented by interlocking subcomponents to allow run-forward and run-reverse conditions. Quicker rotational-direction reversals can be made with plugging, which is the temporary powering of both circuits.

MORE CONTROLLABLE: REDUCED-VOLTAGE MOTOR STARTERS

Besides the family of full-voltage motor-starting options are reduced-voltage starters. Where machine axes require smooth non-jarring acceleration to full speed (to protect attached machine equipment or some attached load) reduced-voltage motor starters are essential. In fact, they're also useful in settings regulated by local power utilities that limit voltage fluctuations and current surges on power supplies during motor starting.

Reduced-voltage motor starters include four common subtypes.

1. Primary resistor motor starters are a cost-effective option that uses resistors and some number of contactors — with the latter dictating the number of starting voltage steps. These steps can be somewhat abrupt due to the circuit's low inductance. Though the resistors can be bulky and introduce inefficiency, this starter type delivers reliable motor-starting torque.



Circuit diagrams of sample variations of contactors, full-voltage motor starters, and soft starters show their differences and similarities.

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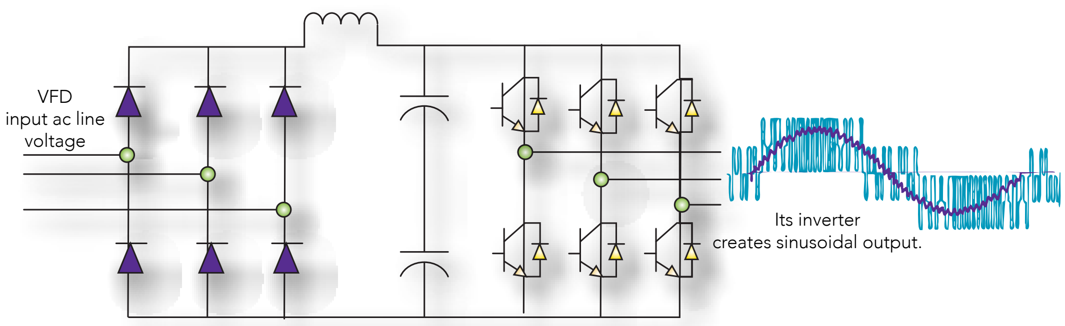
ALL ABOUT MOTOR STARTERS

(AND HOW THEY COMPARE TO CONTACTORS AND DRIVES)



2. Primary reactor motor starters are most common on large high-voltage motors. They employ a reactor (inductor) action in a circuit like that of a primary resistor motor starter. Relatively long smooth accelerations are possible (even to a dozen seconds or more) though additional system inductance can degrads overall efficiency — and a poor power factor degrades torque-generating current components and motor flux.

3. Autotransformer motor starters are relatively costly but useful where adjustable start torque is required. Autotransformer motor starters use a single-winding electrical transformer — with the latter being a passive electrical device for transferring electrical energy from one circuit to another.

More specifically, autotransformer starters employ a trio of electrical contactors on an autotransformer having selectable taps. That imparts stepped voltage starting for long smooth acceleration upon startup — even to a few dozen seconds. Start voltage can be 50% to 80% of line voltage for high start torques in applications where that (and not efficiency) is a leading design objective.

4. Soft starters employing solid-state semiconductor technology are capable of the most controllability out of all motor-starter options. They're also the gentlest on motors' internal subcomponents and attached power-transmission mechanisms. At their core, soft starters consist of various thyristor or SCR arrangements … so for example, some designs have a pair of thyristors on each of the three lines into the motor. Review this Design Guide's section on solid-state relays for the basics of this technology.

These switching devices work to control electrical power into the motor windings (as illustrated by the soft-starter diagram showing firing angles) while leveraging how motor voltage along with current and torque are low upon initial startup. Then they gradually raise voltage and torque according to a preset routine. Motor soft-starter programming dictates the exact parameters of the increase to set voltage.

Consider the operation of a representative SCR-based soft starter: Here a conducting (gated) SCR has a movable gate point … and adjusting back this speed value (called ramp time) causes an increase in voltage accumulation before the SCR switches on. Then once the motor windings reach full voltage, the SCR switches off.

One caveat: Excessive ramp time can make current exceed the motor's safety limits or prompt a current-limit safety cutoff.

Besides the benefits already mentioned, soft starters impart motor protection (even during phase imbalances during electric-utility brownouts) as well as the ability to soft stop. The latter is helpful where motors drive designs such as conveyors that involve inertias capable of shifting or breaking during transport.

Of course, variable frequency drives (VFDs) are another option for soft-start functionality. They provide the same controlled starting and stopping functions of a soft starter, albeit in a different way — by varying motor-input voltage frequency rather than voltage magnitude. Other VFDs advantages over soft starters include the ability to control motor speed over the entire operating range. VFDs can also deliver power for holding torque (full torque at zero speed) which is key in motor-driven applications such as cranes and elevators.

However, for some designs VFDs are overly costly and complicated. Reduced-voltage motor starters tend to be more suitable than VFDs where there's no gain in efficiency to be had from running the attached motor below its top speed rating.

APPENDIX: DIN RAILS AND THEIR USES

This is a sample of DIN rail with a module mounted to it — as well as an end clamp (also called an end plate) to prevent components from sliding off the rail end.

The Deutsches Institut fur Normung (DIN) is a German institute for standardization and a leading provider of technical standards worldwide. It is the organization which has (among other things) established the standard for uniform geometry and electrical connectivity regarding 35-mm DIN rails so ubiquitous in today's control panels and automation equipment.

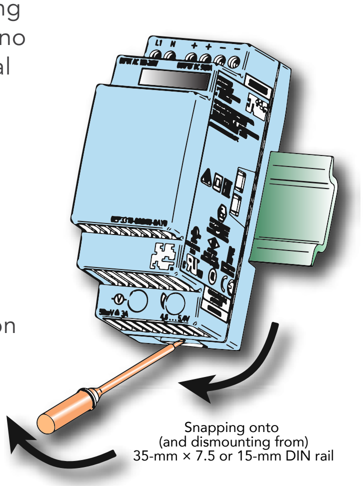
The ubiquitous nature of components for DIN-rail mounting makes this standard particularly helpful … especially when panel redesigns are in order. Here, a technician need only to unclamp components, slide them to their new locations, and reclamp them to the DIN rail. In addition, DIN rail prevents upside-down and other incorrect installation.

Altech Corp. PS-C120 (120-W) DIN-rail-mount power supplies as well as PS-C240 (240 W) and PS-C480 (480 W) models maximize energy efficiency. They serve as low to medium-wattage supplies offering high performance in a compact footprint.

Standard features include a built-in DC OK relay contact, active PFC function, and 100% full-load burn-in test. The power supplies are cooled by free air convection and incorporate multiple protections against short circuits, overload, overvoltage, and over temperature.

Why is DIN rail so ubiquitous? Well, reconsider the terminal blocks that were detailed earlier in this Design Guide — a component commonly found mounted onto such DIN rails. Terminal blocks meant for rail mounting are either DIN compliant or proprietary. The latter come in an array of formats, with geometries that are vendor specific — necessitating strict use of only the vendor's blocks and rail with no possible mixing and matching. In contrast, terminal blocks that comply with DIN requirements are in many instances interchangeable; they also tend to be smaller than proprietary blocks for a given electrical-power rating.

Note: Besides their differing rail and mount geometry, DIN and proprietary systems also have differing electrical connections. For example, DIN-style terminal blocks have a dead-front configuration — with recessed termination hardware in their plastic block housing to isolate electrically live parts … and minimize the risk of shock, even if connections on the block are live. In contrast, some proprietary terminal blocks have open electrical receptacles.



(continued)

APPENDIX: DIN RAILS AND THEIR USES

> *A TYPICAL DIN RAIL IN USE MIGHT ACCOMMODATE RELAY SOCKETS, CIRCUIT BREAKERS, TERMINAL BLOCKS, FUSES — AS WELL AS SMALL DRIVES, INDUSTRIAL-COMMUNICATION DEVICES, PLCS, OR OTHER CONTROLS.*

BASIC CONSTRUCTION AND VERSIONS OF DIN RAIL

DIN rail is made of straight extruded aluminum or cold-rolled steel tracks that are finished with either chrome or zinc plating. Slots in this rail allow installers to screw or both DIN rail to the inside walls of a control panel or other protected wall. Longitudinal bends in the DIN rail profile serve as shoulders upon which various components can clamp.

Several DIN-rail geometries exist … and in many cases, components for DIN-rail mounting are capable of clamping to a couple different styles of DIN rail.

DIN 1 or C DIN rail — so called for is C-shaped cross section — is for systems rated to 600 V. With a total face width of 35 mm, this is a particularly common variation. This rail's edges turn inward, so components attach to such rail by clip mechanisms that engage the inside channels of the rail tracks.

Note that some technicians nickname component attachments by key dimensions — so a terminal block with hardware to snap onto a 32-mm DIN 1 rail (having a lower lip 22.5-mm deep) may be called a 22.5-mm block for the depth of its lower latching mechanism.

G DIN rail — also called asymmetric rail for its extra bit of lip on one longitudinal edge — is also for systems rated to 600 V. In fact, this type of rail closely resembles C DIN rail … but with its deeper bottom lip, it's often used to hold particularly heavy components that need more mounting engagement. G-shaped rail for the orderly mounting of components is the oldest rack design, dating back to the 1920s … and predating the first DIN-rail standards by a couple decades.

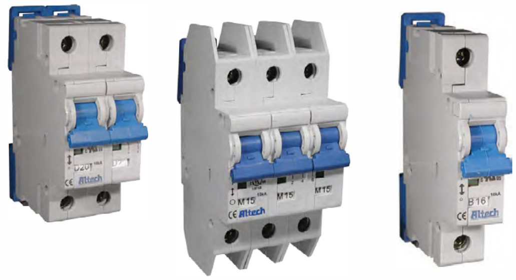
DIN2 or top-hat DIN rail — also called symmetric rail for the matching longitudinal bends of its brimmed-hat cross-sectional profile — is also for systems rated to 600 V. Its edges flare outward; components attach to such rail by wrapping clip mechanisms around these edges.

Mini DIN rail is for systems rated to 300 V. These are far less common than 35-mm DIN rail variations.

75-mm top-hat rail is yet another option for very large electrical and electronic components.

DIN rail provides a standard way of organizing and mounting breakers, terminal blocks, relays, drives, and other electric and electronic components. This is an industrial control panel with various power and control components mounted on large-format DIN rail.

Altech® TOP PRODUCTS for Control & Automation



1 Circuit Breaker Protection

- 2 lines of UL 489, UL 508 and UL 1077 available
- 1, 2 and 3 poles (4 poles upon request)
- Many trip characteristics
- UL1077 Recognized Supplementary Protectors
- On/OFF indicator window
- AC or DC UL489
- UL508 Manual Motor Controllers "Suitable as Motor Disconnect"

2 Terminal Blocks

- International Approvals UL, CSA, IEC, Lloyd, ATEX, IECEX, VDE, AEx
- Wide Range of Terminals and accessories
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- NEW Push-In blocks
- Power Distribution
- Disconnect & Test Terminals
- Space Saving Solutions
- Fuse Terminals
- High Current and High Voltage

E220514

3 Disconnect Switches

- Advanced switch technology
- Across the line, motor starting - up to 75hp/600V
- General Use Rating 16A to 150A/600V
- 10kA short circuit withstand rating
- UL 508 & UL 98
- Horsepower ratings
- Snap on auxiliary contacts
- DIN rail and panel mount
- Toggle switches
- Many types of Enclosed Switches

4 Industrial Enclosures

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- Broad range of sizes
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- Large selection of accessories
- Customization and imprinting service are available

5 Liquid Tight Strain Reliefs

PROTECTION IP54 RATING / PROTECTION IP67 RATING

- Full line of Standard and Industrial Series
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