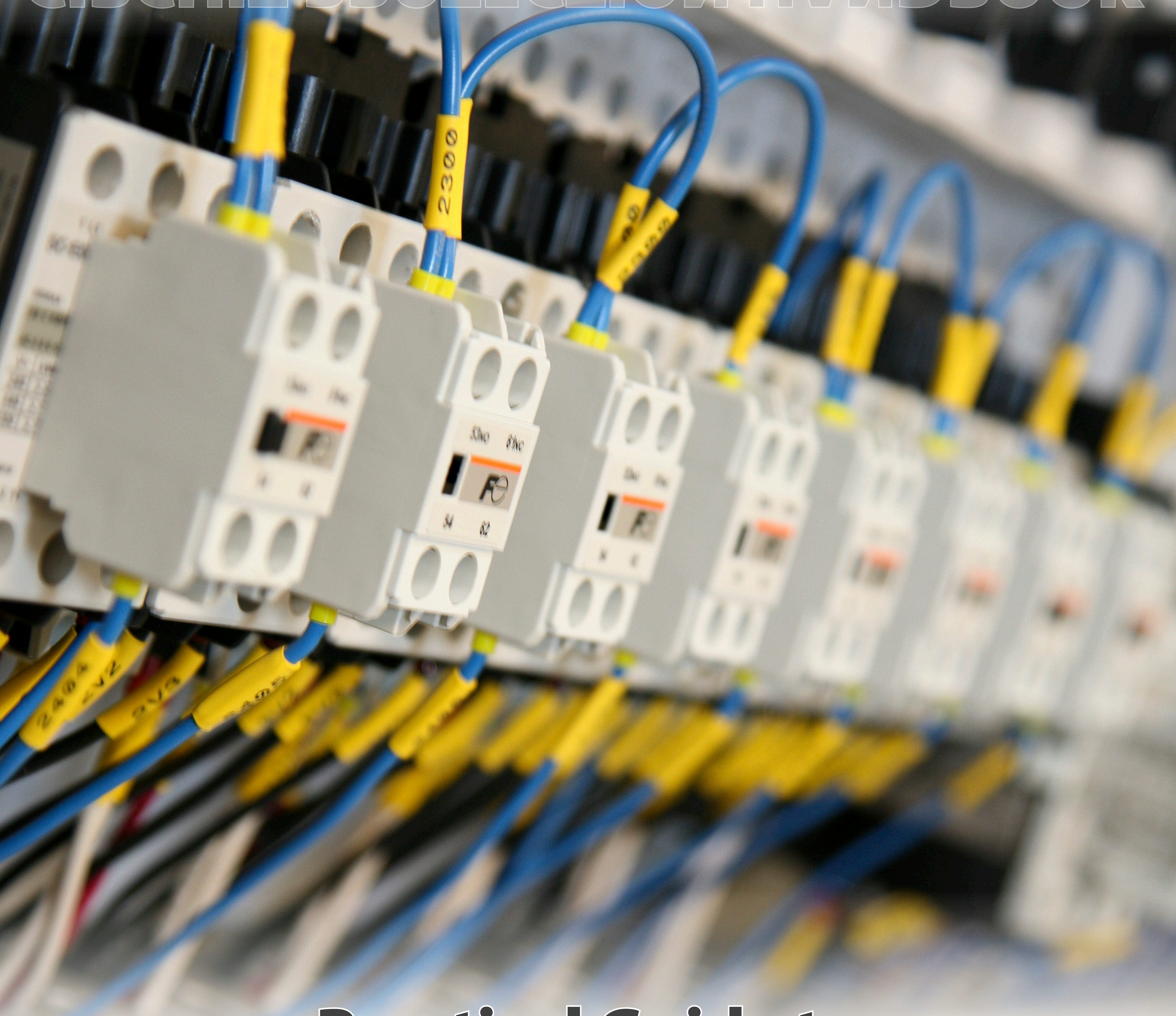
CIRCUIT PROTECTION HANDBOOK



Practical Guide to Electrical Circuit Protection

from AUTOMATIONDIRECT.com

ADC-001-CIRCUIT

Circuit Protection Handbook

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Electrical Circuit Protection Introduction

Almost every electrical or control panel created for residential, commercial, or industrial use includes at least one incoming power circuit, some amount of internal power distribution, and power or input/output circuits outgoing to field devices. Every electrical and control product and design incorporated into these panels must comply with applicable codes and standards, which dictate specific electrical circuit protection requirements.

Whether an electrical or control panel contains digital electronics, hardwired buttons/lights/relays, voltage conversion transformers, motor starters, variable frequency drives (VFDs), or any other of a multitude of devices, proper overcurrent circuit protection devices (OCPD) and designs are essential to guard against failures.

Accordingly, designers and engineers must familiarize themselves with and follow all applicable codes, standards, and design practices. This eBook is not a detailed explanation of these topics, but rather a high-level consideration of the issues, as well as a description of products and methods to help users create compliant, safe, and robust designs.

Codes and Standards

Because of the many hazards possible due to electrical circuit faults, numerous electrical codes and standards have been developed over the years to define how to avoid and handle faults.

Some of the most well-known codes and standards are:

- National Fire Protection Association (NFPA) 70 "National Electrical Code" (NEC)
- UL Solutions 508A "Standard for Industrial Control Panels"
- International Electrotechnical Commission (IEC) 61439 "Low-voltage switchgear and controlgear assemblies"

However, there are many others depending on the application, installation location, industry, and other criteria.

Design Basics

While this document does not address detailed electrical design practices, most electrical or control panel designers typically follow these steps:

- Select devices: Appropriate devices must be specified to accomplish the needed functionality.
  This includes components like relays, controllers, and motors, as well as the power supplies to operate them.
- Provide physical protection: Usually the devices are arranged in a protective enclosure, sized to house all components
  and address environmental issues, such as moisture or heat.
- Size overcurrent protection devices to adequately carry the electrical loads they will supply while protecting supplied elements.
- Size the conductors, including the terminal/distribution blocks to connect them.
- Verify short circuit current ratings for all protecive devices are appropriate.
- Repeat this design cycle as needed until all conditions are satisfied.

Common Failure Modes

Improper design can lead to electrical faults, but even a proper design can experience unexpected failure. Electrical faults can damage conductors and equipment, create costly outages and downtime, cause more extensive fires and problems, or even harm personnel.

Some of the most common failure modes are:

- Overload: When an unacceptably high electrical current flows.
- Short circuit fault: When current-carrying conductors (either both electrified, or one electrified and one neutral) are inadvertently connected.
- Ground fault: When an energized conductor is inadvertently connected to ground.

Overloads happen over a span of time measured in seconds to minutes. They can happen when a motor is too heavily loaded, or when other downstream equipment simply draws too much power. Faults can occur due to direct connection between conductors, or indirect connection via a medium like water or through degraded insulation, or even through the air as an arc. Every failure poses a varying degree of severity, such as excess heat, thermal damage, fire, or arc flash explosions.

Fault Current

Fault current is an extreme spike in current flow, much larger in magnitude than a simple overload condition, which occurs during a short circuit or ground fault. These faults, unlike overload conditions, occur in milliseconds and draw thousands of amps. An arc fault, which occurs through the air, is especially dangerous due to the light, heat, and rapidly expanding shockwave produced by the arc.

During a fault condition, an OCPD is exposed to extremely high currents and it must be able to withstand this fault current while reliably opening the circuit without failure. To achieve this, it requires an interrupting rating high enough to handle and prevent the maximum fault current from arcing through the device.

In recognition of this hazard, evaluating and calculating both the available fault current (AFC) and short circuit current rating (SCCR) for devices is a design requirement. Electrical circuit product data sheets include SCCRs—in addition to voltage, current, and other operational ratings—so designers can properly coordinate operation and select appropriate devices.

There are detailed processes for determining the SCCR rating of a panel or assembly of individual components. One such method, the “two sweep method”, is a common way to calculate a panel’s SCCR. This allows designers to properly protect their equipment

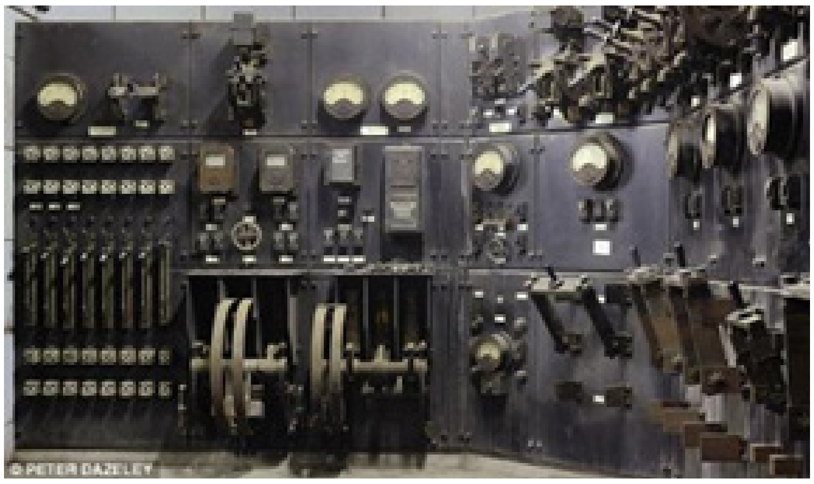
Disconnects and Distribution

Electrical power is measured in watts, consisting of current flowing at a voltage to perform work such as spinning a motor, operating electronics, and powering other loads like lighting and heating. Power is typically sourced from the electrical utility, but it can also come from a local fossil-fuel-based generator, solar array, battery, or other means.

Electrical power distribution generally runs from higher voltage/current supplies down to lower voltage/current utilization. Users need the ability to manually disconnect power sources from the loads they serve for purposes of normal operation and safety, and electrical systems need the ability to automatically disconnect power in the event of a problem.

Disconnects

The oldest disconnect switches look like props from a Frankenstein movie. Of course, over the years, safety equipment and protocols have evolved tremendously. As a result, modern devices provide far better protection for users and equipment.



Disconnects are available in several form factors with a variety of voltage/current ratings. When closed, disconnects pass power from a supply to a load; when open, they interrupt power between the supply and load. Most disconnects are rated to open under load (load break), but some are not, which must only be opened when the circuit is already de-energized upstream.

A basic disconnect is simply a non-fused open/close switch, while fused disconnects incorporate circuit protection. Additionally, circuit breakers can act as disconnects (fuses and circuit breakers will be discussed in subsequent chapters).

Many industrial disconnects are lockable, enabling users to switch off power, open the circuit, and lock the switch in this state for safer working conditions downstream. In fact, a common safety requirement is that a disconnecting means of some type, with lockout/tagout (LOTO) provisions, be installed within sight of the equipment it feeds. This helps users clearly and easily prevent the supply of electrical energy to equipment during maintenance and repairs, avoiding hazardous operation. Disconnects can also include provisions so their open/closed status can be monitored by a supervisory control system.

A disconnect is more than just a visible exterior handle; it also includes the physical device inside the enclosure where the conductors are connected, linked to the operating handle, and equipped with mechanical contacts that open or close to make or break the circuit. General categories include:

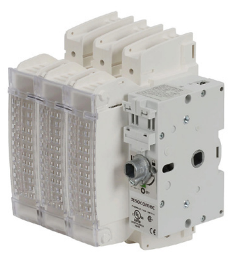
- Enclosed disconnects : These come in varying sizes, and can be small enough for location near a motor, or bigger for much larger loads.

- Motor disconnects : These are a specific type of enclosed disconnect, typically housed in a compact enclosure for installation near motor-driven or other localized loads. Both plug-and-cord and hardwired versions are available.

- Disconnect enclosures : Many control panel enclosures, whether wall- or floor-mount, are available with openings to accept a variety of standard disconnect handles, providing a convenient way for designers to create panels that can be de-energized entirely at once. Additionally, some devices allow the disconnect handle to be installed right through a door. These enclosures are often interlocked with the disconnect handle so that users cannot open the enclosure door unless the disconnect is de-energized.

- Non-fused disconnects : Non-fused disconnects do not include built-in overcurrent protection. Instead, they are installed downstream of an overcurrent protection device and provide a means for an operator or technician to manually open or close the circuit.

- Fused and circuit breaker disconnects : Many disconnects also use fuses, or a circuit breaker can be installed in a mechanism to make it operable as a disconnect from the front of a control panel.



- Manual transfer switches : This is a special category of disconnect, commonly used for selecting one of two power sources to carry a load. In these cases, the normal primary power source is commonly the utility, while the backup secondary power source could be a local generator.

Distribution

Within any electrical or control panel, the power distribution is generally handled by conductors connected to terminal blocks, distribution blocks, and other devices.

General categories include:

- Terminal blocks : Terminal blocks come in an astounding array of electrical capacities, physical sizes/configurations, and colors. Some incorporate multiple circuits, disconnects, circuit protection, indication, and other features. Many terminal blocks use screws to tighten the conductor in place, while newer screwless spring-tension designs provide faster installation and better performance, even in high-vibration environments.

- Power distribution blocks : Power distribution blocks, both open- and closed-style, provide a compact way to manage power wiring and accommodate the transition of one larger circuit to many smaller circuits.


- Wiring/routing: Many accessories are available to route, protect, splice, terminate, and identify conductors and distribution products.





Fuses

Fuses are the traditional overcurrent and overload protection method. They are available in a wide range of current/voltage ratings and operating characteristics, and are designed to open the electrical circuit under certain adverse conditions to protect downstream conductors and load, as well as the upstream supply.

Fuse Basics

Fuses are a relatively low-cost OCPD technology compared with other options. However, they are single-use devices, so when they operate or "blow", a qualified person or electrician must troubleshoot and address the problem, then replace the fuses.

Fuses are also thermal devices, carefully constructed with an internal metal conductor and filler materials. If the electrical current passing through a fuse is too high, the metal melts and arcs away, opening the circuit. They are excellent at rapidly opening a circuit during a fault condition and providing a high interrupting rating and current limiting properties.

The majority of fuses are dual-element fuses designed as the name implies with two types of elements. One specifically interrupts overloads that are lower in magnitude and develop over time. The other element is an extremely fast acting element that nterrupts fault currents. All of these responses can be interpreted and evaluated using the fuse's trip curves.

Designers must consider the nominal voltage and current ratings, the appropriate physical size, how much fault current must be interrupted in the event of a short circuit downstream, the ambient operating temperature, and other conditions and features. For industrial electrical and control panels, common fuse designations are Class CC, J, L, M, RK1, RK5, and T, along with small dimension electronic glass and ceramic fuses.

Fuse Operating Characteristics

Another key fuse consideration is the operating characteristic; that is, whether a fuse should be fast-acting or time-delay. Every fuse has a time versus current curve, representing how it will operate.

- Fast-acting: Fast-acting fuses are commonly used for electronic and other loads where large and sudden current changes are not anticipated. These fuses work quickly—on the order of much less than one second at 500% of the rated current—to protect downstream conductors and devices if there is a fault. As previously mentioned, they also help prevent overload damage to the supply. Semiconductor fuses are a form of very-fast-acting fuses, useful for electronics.

- Time-delay: Time-delay fuses, also known as slow-blow or dual-element fuses, are used for motor, transformer, and other feeder/branch loads that experience relatively large inrush currents for periods of time. These events often last several seconds until the current settles to the normal operating load. A fast-acting fuse would open under these normal starting conditions, which is not desirable, while time-delay fuses permit temporary overcurrent conditions for a defined period, as the name implies.

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Fuse Interrupting Ratings

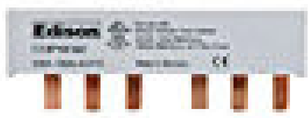
Fuses provide excellent short circuit current interrupting ratings, depending on the fuse type and holder. Smaller glass fuses can interrupt fault currents on the order of hundreds or thousands of amps, while larger fuses can interrupt 10kA, 100kA, or even larger fault currents.

Fuse Holders and Blocks

As noted in the previous chapter, a fused disconnect switch has provisions to accept properly sized fuses. When fuses need to be installed separately from the disconnecting means, then fuse holders and fuse blocks must be used. Some fuse holders and fuse blocks are not touch-safe, but many are designed as touch-safe or are available with covers.

- Fuse holders : Fuse holders come in a range of sizes and configurations, compatible with different types of fuses. They are available in single, fixed-multiple, and modular styles, depending on the need to protect single-conductor or multi-phase circuits. They usually mount on standard DIN rails, or they can be panel-mounted. These devices commonly enclose the current-carrying conductor portions to make them touch-safe. Options such as blown indication lights make it easier for personnel to troubleshoot blown fuses, and accessories like busbars speed up installation.





- Fuse blocks : Fuse blocks also come in a wide array of sizes and configurations. They are available in single, fixed-multiple, and modular styles, similar to fuse holders. However, fuse blocks are typically mounted directly on a panel, instead of on DIN rails. Fuse blocks may not be touch-safe, but they are often available with covers to protect personnel from the current-carrying parts. Some fuse blocks incorporate power distribution blocks, which can be useful for streamlining designs.



Molded Case Circuit Breakers (MCCBs)

Molded case circuit breakers (MCCBs) are automatic electrical devices, used to protect against overload and fault currents in power circuits. They have a higher initial cost than fused installations, but they are self-contained OCPDs. MCCBs operate automatically to open or "trip" due to fault conditions, and can be used as a disconnecting means. Additionally, MCCBs are not damaged or consumed in the event of a trip fault; they can be reset afterward, so they do not require replacement.

In North America, MCCBs are typically designed to comply with the UL 489 standard, "Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures," which establishes requirements for the safety, performance, and testing of these devices to ensure reliable short-circuit/overcurrent protection and safe operation in electrical systems.

MCCB Basics

There are several types of MCCBs, and they are available in various current-carrying frame sizes in 2-pole and 3-pole configurations. For example, a 100A frame size might be available with ten or more ampere ratings, ranging from 15A to 100A.

An MCCB operating mechanism is designed with multiple ways of tripping open. Upon opening, metallic contacts are separated, and this air gap prevents current from flowing through the device. The contacts are designed to be arc-resistant with low resistivity and anti-corrosion features, but these components wear over the device's lifecycle.

Arc chutes help extinguish arcs when the MCCB is opened under load. MCCBs may operate slower and provide a lower interrupting rating than fuses, but they deliver excellent and durable circuit protection in many applications.

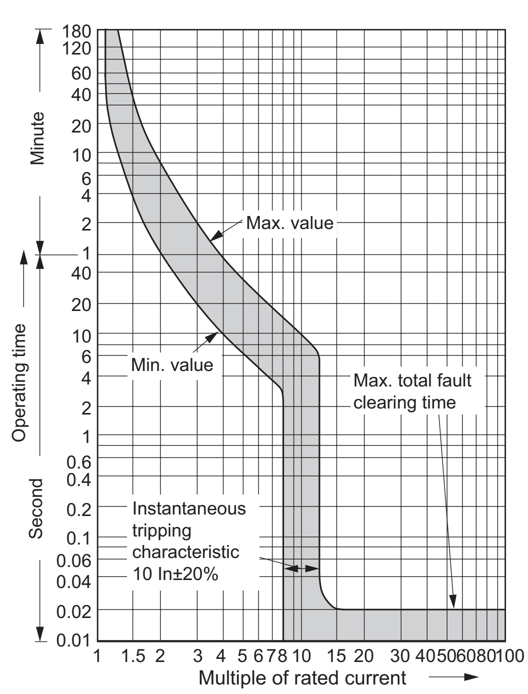
A user can manually operate the MCCB handle between UP/ON/CLOSED and DOWN/OFF/OPEN. A MCCB has a trip-free operating handle, which means even if the handle is held ON, the internal mechanism is still free to trip the MCCB to OFF. The handle also has a third middle position, which indicates a TRIP has occurred. After a TRIP, the user must cycle the MCCB to OFF before the handle can be moved to ON once again.

When a circuit breaker is switched to the ON position, the circuit is said to have undergone a MAKE operation. When it is switched OFF or automatically performs a TRIP action due to a fault, the circuit is said to have undergone a BREAK operation.

MCCB Operating Characteristics

MCCBs can provide overload and short circuit protection using different types of functionalities:

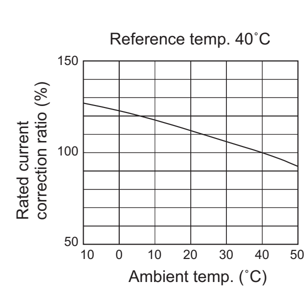
- Thermal trip (overload): An MCCB may use a physical bimetallic strip that heats up during moderate overload conditions and initiates a trip if too much current has flowed for too long. This is useful to accommodate brief overload currents of a few seconds at perhaps 500% or less of the rated current. However, if the load remains over the rated current threshold for too long, the MCCB trips.
- Magnetic trip (short circuit, instantaneous): An MCCB may incorporate a solenoid-based mechanism, which upon very high current flows, creates a magnetic force sufficient to trip the MCCB, providing short circuit protection.
- Electronic trip: Electronic trip MCCBs use a current sensor and a micro controller to measure the current and initiate overload and short circuit trips as needed. Electronic trip MCCBs can provide more accurate functionality than the electromagnetic-based thermal and magnetic trip units.
- Manual trip: A manual push-to-trip button on the face of the MCCB allows the user to activate the trip mechanism. It simulates a fault to test the breaker's internal operation and confirms that the breaker will open automatically under actual fault conditions, including activation of any connected alarm- or trip-indication contacts. Note that alarm- and trip-indication contacts are only activated by a manually- or fault-triggered trip, and not by manually switching the breaker OFF.
- Remote/shunt trip (SHT): A remote or shunt trip option allows a circuit breaker to be tripped remotely by an external control signal, without any physical contact or manual operation. The signal energizes the shunt trip coil, activating the internal trip mechanism to open the contacts and disconnect power. They are typically used to safely disconnect power during emergencies or fault conditions, such as activating an emergency power off (EPO) function, responding to fire alarms, or enabling controlled shutdowns to protect personnel and equipment.
- Undervoltage trip (UVT): An undervoltage trip is a protective feature that automatically trips a breaker to OFF when the supply voltage falls below a specified threshold. Its primary purpose is to prevent equipment from operating under low-voltage conditions, which can cause motors to overheat, controls to behave unpredictably, or sensitive devices to malfunction. When activated, the undervoltage trip triggers the breaker to open, and it remains tripped even if voltage is later restored, requiring a manual reset to resume operation. This ensures a controlled, deliberate restart and helps protect both equipment and personnel from potential hazards associated with unstable power.
- Adjustable trips: Some MCCBs have provisions for the user to adjust the trip functionality and more closely tailor the MCCB function for the application.
- Trip curves: MCCB device specification sheets include a detailed time versus current trip curve, indicating the overload and instantaneous operating characteristics of the device so designers can coordinate the protection.



Note: Instantaneous tripping = 10 x (rated current) ± 20%
In = rated current

Fuji Electric

BW400 (Current Range: 250 - 400A)



MCCB Interrupting Ratings

MCCBs provide good short circuit current interrupting ratings, although often less than what is possible with fuses. MCCBs are available with various ratings—such as 22kA, 30kA, 35kA, 50kA, or 65kA—so designers can select what best meets the requirements. Higher interrupting ratings generally come at a greater cost.

MCCB Accessories

To provide expansive design flexibility, there are many types of accessories available for MCCBs . Some examples are:

- Alarm contact (AL): An alarm contact is a small switch linked to the circuit breaker that indicates if the MCCB trips. This switch changes state whenever the breaker experiences a trip condition, whether by a manually- or fault-triggered trip (but not by being manually switched OFF). Note that an alarm contact only changes state in response to trip events, and otherwise remains inactive during normal ON and OFF operations of the breaker. It signals the breaker's trip status (without carrying the main current), and provides a way to specifically alert operators, and monitoring and control systems, that a trip has occurred, enabling timely response to protect equipment and ensure safety. This contact must be reset once the source of the trip is cleared.
- Auxiliary contact (AX): An auxiliary contact is a small switch linked to the circuit breaker to indicate if the MCCB is on or off. This switch changes state whenever the breaker opens or closes, whether manually switched or tripped. It signals the breaker's position status (without carrying the main current), and provides remote indication so monitoring and control systems can track the breaker's position at all times.
- Operating mechanisms: Various flange-mounted and rotary door-mount operating mechanisms and padlockable handles are available so that users can initiate control of an MCCB from the exterior of an enclosure, providing greater safety.
- Locking systems: Padlocking devices mountable directly on the MCCB provide another LOTO option.


Miniature Circuit Breakers (MCBs) and Supplementary Protectors

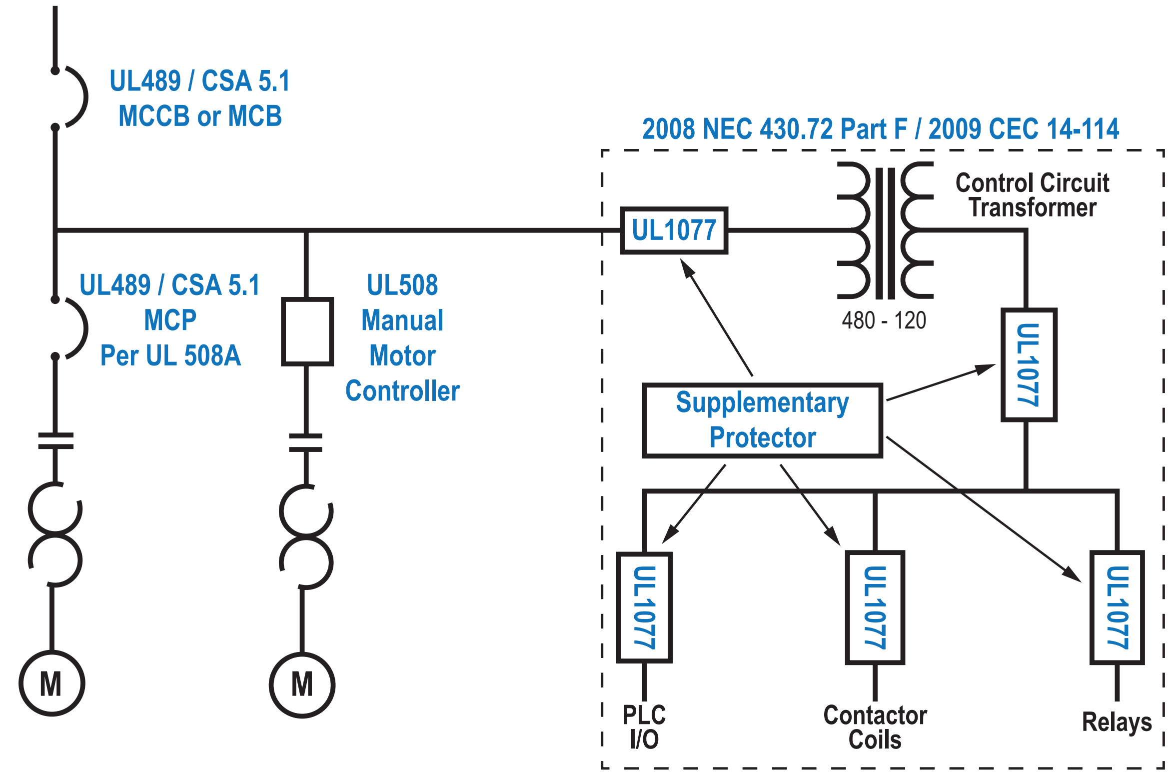
Miniature circuit breakers (MCBs) and supplementary protectors are automatic electrical overload and short circuit protective devices that look and operate much like MCCBs, but they are smaller and generally intended for control panel applications, as opposed to large electrical power distribution. There are some notable differences between MCBs and supplementary protectors.

Miniature Circuit Breaker Basics

In North America, MCBs are typically designed to comply with the UL 489 standard "Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures." Main and branch-circuit protection using circuit breakers must typically incorporate UL 489 compliant devices.

Supplementary Protector Basics

By contrast, supplementary protectors in North America are typically designed to comply with the UL 1077 standard "Supplementary Protectors for Use in Electrical Equipment." Supplementary protectors are subject to less stringent requirements and testing than UL 489 devices, and are therefore less expensive. In fact, supplementary protectors are even allowed to experience damage when used within normal rated conditions. As a result, supplementary protectors are intended to provide additional, albeit limited, protection beyond properly applied branch circuit overcurrent protection (which would usually be fuses or a UL 489 rated MCB upstream). Supplementary protectors have their place but are not permitted to replace a listed breaker or fuse.



Supplementary protectors are not to be used in feeder circuits or motor circuits. Use them only in applications where branch protection is already provided or is not required.

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MCB and Supplementary Protector Operating Characteristics

MCBs and supplementary protectors are commonly available in compact DIN-rail-mount form factors. However, accessories for mounting them on a flat backpanel are also often used.

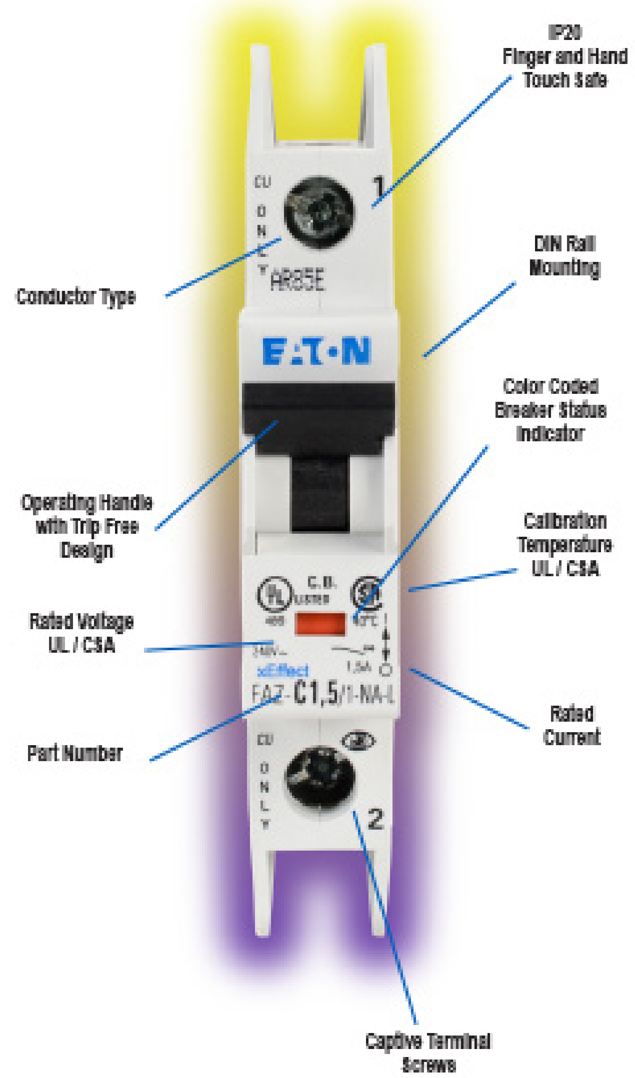
Electrically, these components are commonly available in 1-, 2-, or 3-pole configurations at 240 VAC, 277 VAC, or 480Y/277 VAC. The available ampere trip rating is under 100A, ranging in increments from 0.5A up to 63A.

These devices use thermal-magnetic overcurrent protection and are available with three standard levels of short circuit protection, characterized by fixed trip curves designated B, C, and D.

- B-curve: This operates at 3 to 5 times the rated current, and is typically used for resistive loads, such as heaters.
- C-curve: This operates at 5 to 10 times the rated current, and is typically used for small transformers, pilot devices, and similar low-inrush loads.
- D-curve: This operates at 10 to 20 times the rated current, and is typically for larger transformers, power supplies, or other highly inductive loads. These types of MCBs can withstand intermittent high inrush without nuisance trips.

Some MCBs are rated for switching duty (SWD), which means they are designed for long life, even if regularly used for switching loads such as lighting circuits on and off.

Because MCBs and supplementary protectors are intended to protect relatively low-amperage control panel circuits, they carry correspondingly sized interrupting ratings on the order of 5kA, 10kA, or 14kA.



MCB and Supplementary Protector Accessories

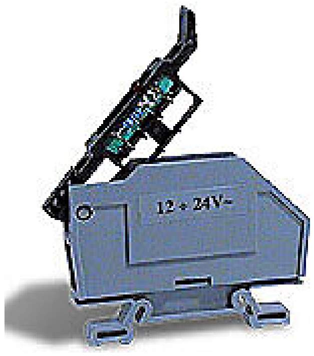
Much like larger MCCBs, MCBs and supplementary protectors have many accessories available to enhance their usage and integration. These include alarm switches, auxiliary switches, shunt trips, padlocking provisions, and bus bar systems.

Electronic Circuit Protection

Electrical circuit design principles are similar in both AC and DC voltage circuits. In fact, many OCPDs, including fuses and circuit breakers, carry ratings for use in either type of circuit.

For industrial electrical and control panels, many of the significant loads—such as motors, heating, and lighting—are supplied by 480, 277, 240, or 120 VAC using one or more phases. However, it has become popular for control circuitry to operate at 24 VDC (and sometimes 24 VAC in building automation applications). This is especially prevalent in control panels with programmable logic controllers (PLCs), other microcontroller devices, and digital instrumentation. Circuits operating at 24V are touch-safe for users to work around.

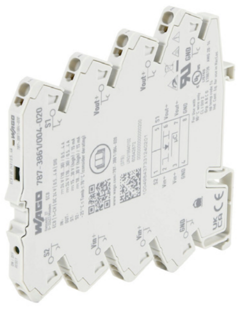
Even relatively low-current 24 VDC control circuits require OCPD protection, which can be provided using small fused switches or circuit breakers. This is often accomplished with a DIN-rail-mounted fused switch, or a terminal block with a small supplementary protector installed.



However, a newer and more capable class of OCPD for these types of circuits has been developed in recent years. Known as electronic circuit protection or electronic circuit breakers (ECBs) , ECBs are not UL 489 or UL 1077 rated, but they provide a flexible and beneficial way to incorporate selective load protection for lower power control circuits. UL 2367 standard “Solid State Overcurrent Protectors” is associated with ECBs. Note that UL 1077 is the standard for mechanical thermal-magnetic protectors, while UL 2367 is the standard for electronic-semiconductor protectors for low-voltage DC applications.

Electronic Circuit Protection Basics

Instead of using electromechanical thermal-magnetic technology, ECBs use current sensors and electronics to reliably recognize overloads and short circuits on an output, and then respond by opening the secondary circuit as needed. Using digital methods, ECBs can provide faster and more accurate response compared with physical methods. ECBs are available in DIN-rail-mount single-channel models (which can be bussed together on the incoming/primary side) or multi-channel formats.



Electronic Circuit Protection Advanced Capabilities

ECBs can be used in place of fuses or MCBs in many 24 VDC control circuit applications, providing many advantages and enabling more sophisticated protection and monitoring strategies, including:

- Local and remote operation: ECBs can be switched ON or OFF—and RESET—locally like a traditional device, but they often include an input to remotely perform these functions, usually coming from a PLC.
- Avoid power supply overloading: ECBs can prevent power supply overloading during system powerup by incorporating time-delayed secondary channel energization. This effectively staggers the energization of downstream devices to minimize current spikes.
- Enhanced local diagnostics: ECBs can indicate circuit operating states—such as on, off, overcurrent, overcurrent trip, malfunction, and more—using a multicolor steady-state or blinking LED.
- Fixed and adjustable outputs: ECBs are available with fixed output current settings, and some models allow adjustment of the output rating of each channel.

NEC Class 2 Considerations

ECBs can also help designers comply with and take advantage of NEC Class 2 requirements in North America. NEC Class 2 circuits are of such low voltage and current that they do not present fire or shock hazard to personnel. While they may not supply enough energy to be practical for motor starters or similar larger loads, they are ideally suited for low-power PLCs, human-machine interfaces (HMIs), and other intelligent digital devices.

Within UL 508A listed control panels, any NEC Class 2 circuits and components connected to them need not be evaluated further for UL compliance. These circuits typically use smaller conductors and other simplified circuitry, providing savings in materials and design effort.

A few other requirements for NEC Class 2 circuits include:

- Must not exceed 60 VDC (although 24 VDC is the most common industrial operating voltage).
- Load side maximum power is 100 VA, although fuses and circuit breakers are not acceptable for achieving this.
- The device supplying the NEC Class 2 circuit must be specifically UL listed as such.

ECB models listed for NEC Class 2 use generally provide one or more outputs at a nominal 24 VDC 3.8A. Designers are finding that using ECBs for industrial control panel power is an intelligent and efficient way to distribute bulk 24 VDC power.

Motor Power Circuit Protection

Motor power circuit protection requires special consideration. Electrical motors are inductive devices, and they can be connected to physical loads with significant inertial mass. Therefore, upon startup a motor draws significant inrush current—often up to 10 or 20 times the normal full load amps—which is also known as locked rotor current because electrically, a starting motor presents much like a motor that has been overloaded to the point of stalling.

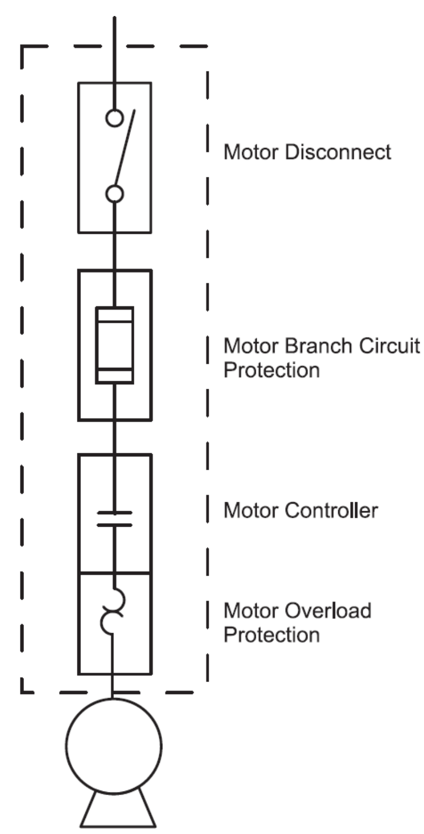
This normal starting condition can cause improperly applied OCPD devices to perform nuisance trip actions. However, if the OCPD device is sized large enough to accommodate the motor start, it may not provide suitable protection during mild overload conditions. Striking a balance between withstanding the brief but extreme overcurrent spike, while providing closely-sized protection for lower overload conditions, requires specific OCPD characteristics.

Motor Power Circuit Protection Basics

The most common approach for achieving standard across-the-line motor power circuit protection is a combination of a carefully selected short circuit protection device, a properly rated relay or contactor as the motor controller, and a dedicated overload relay. Note that NEC and IEC each identify varying approaches for applying motor power circuit protection.

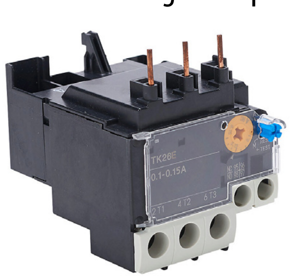
Here are some motor circuit protection options:

- Fuses: Fuses—typically the time delay type—can be used as the short circuit protective device. However, when sized sufficiently to supply the motor and protect the conductors, while avoiding nuisance trips during startup, they may not provide adequate protection against mild overload conditions that warrant a trip.
- MCCB: An MCCB can be used instead of fuses, but with the same caveats.
- Instantaneous trip motor circuit protector (MCP): An MCP is basically an MCCB but with only the instantaneous magnetic trip protection, and not the thermal overload protection. An MCP can be used to provide just the short circuit protection function, if it is used as part of a listed combination motor controller.
- IEC manual motor protector : IEC manual motor protectors provide an all-in-one motor control/protection solution, integrating control, disconnecting means, and circuit protection.



TYPES A - D COMBINATION STARTERS

- Motor overload relays : Motor overload relays are available in thermal magnetic and solid-state electronic versions, and they perform the same function as the overload component of an MCCB. The benefit of separately installed and dedicated motor overload relays is that they are specifically designed to monitor overload currents, due to either mechanical failures that cause a motor to work harder than rated, or to a phase loss. The motor overload components can be selected or adjusted to closely monitor these conditions and initiate an overload trip when needed, without being susceptible to nuisance trips due to inrush current during startup.



Motor Power Circuit Protection Advanced Capabilities

Three-phase motors present some additional electrical circuit protection challenges. For example, if the power phases are somehow reversed, the motor and load may operate within normal current parameters, but will be running backward. Or, if a single phase of a three-phase motor is lost during operation, the motor may continue to run but the remaining two phase conductors may or may not present an overload condition. Additionally, various undervoltage, overvoltage, or phase voltage imbalance conditions can exist without presenting a typical detectable overload condition, or it may take significant time to do so.

To more closely protect against these conditions, many designers choose to incorporate digital phase monitor relays as part of the motor control circuit. These devices connect with each of the three phase conductors, providing detection, indication, and control circuit trip control in the event of:

- Phase reversal
- Phase loss
- Phase unbalance
- Overvoltage
- Undervoltage

Ground Fault Protection

A ground fault is an electrical fault where an abnormal condition—such as failed conductor or motor winding insulation—or failed component allows some amount of current to travel to ground. A ground fault may not be enough to trigger short circuit or overcurrent protection, but it can still easily degrade device performance. This can potentially cause overheating which can lead to thermal damage, or present electrical shock safety risks to personnel.

To better protect against these conditions, designers can incorporate AC ground fault sensors into their power distribution and motor control circuits. These devices are available in varying sizes, providing an output which can be used for monitoring, to turn off a motor load, to initiate a shunt trip, or perform other actions.

The principle of operation is that all hot and neutral conductors in a given circuit should produce a zero-sum current. Any current leaking to ground causes an imbalance, resulting in a detectable net magnetic field. The ground fault sensor monitors the appropriate conductors and is sensitive enough to detect ground fault currents on the order of milliamps.

The trip setpoint is adjustable between 5mA (typical for personnel protection) and 10mA or 30mA (for applications where the primary concern is equipment protection).

Power Quality Protection

Modern electronics present additional electrical circuit challenges compared to simple devices such as motors and resistive electric heaters. Electronic power supplies and variable frequency drives (VFDs) can introduce electromagnetic interference (EMI) and radio frequency (RF) noise onto power circuits. In addition, external conditions such as lightning strikes can introduce surges into electrical power systems.

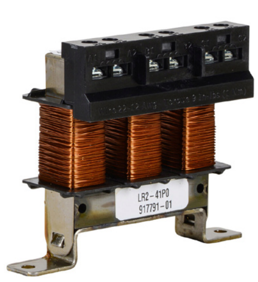
Simple devices may not be affected greatly by EMI/RF or surges, but some electronic devices are sensitive to these issues. Voltage sags, swells, spikes, and harmonics can all cause devices to operate improperly or fail outright.

For industrial electrical and control panels, there are two main categories of power quality protection devices to defend against these sorts of issues: power line filters and surge protective devices.

- Power line filters : Power line filters can be active electronic devices or passive ferrite toroids. They are generally installed where the power source enters the panel, and are available in a multitude of sizes and ratings to indicate and reduce the effect of EMI/RF noise.

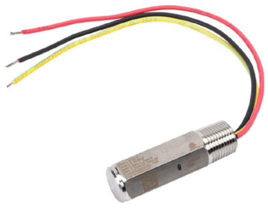
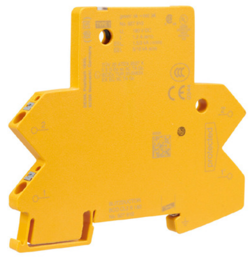


- Line/load reactors : Line/load reactors are a form of power line filters specifically designed for use with VFDs. Line reactors are installed on the input/source line of a VFD to protect the VFD from utility capacitor switching, and to reduce VFD-generated harmonics from travelling up to the power source. Conversely, load reactors are installed on the output/load to minimize reflected wave damage and effectively smooth the motor current waveform.



- Drive isolation transformers: Drive isolation transformers are designed to withstand the mechanical stresses, voltage distortions, and heating associated with motor drives. They offer all the benefits of a line reactor, with added reactance that helps reduce harmonics and minimize the effects of voltage and current distortion caused by variable speed drives. They also isolate the drive system from the power source. When the Wye-connected secondary is grounded, it blocks the transfer of common-mode noise and transients between the voltage source and the drive. Additionally, they help localize the effects of drive-induced ground currents and prevent them from flowing upstream to the power system.

• Surge protective devices : Surge protective devices, sometimes called surge suppressors, are designed to protect electrical equipment or installations from voltage spikes by blocking unwanted high voltages and keeping them below a safe threshold. Typical applications include AC power distribution, drive line filtering, and control panel protection. They are available in a variety of capacities and form factors, ranging from DIN rail mount to panel/conduit mount.

• Power monitoring : Power monitoring devices analyze power quality and harmonics, and can detect common power problems such as over- and under- voltages, over- and under-currents, troughs, outages, and more. These devices provide indication to users and monitoring and control systems, supplying crucial information needed to identify and prevent costly or wasteful electrical incidents or production downtime.