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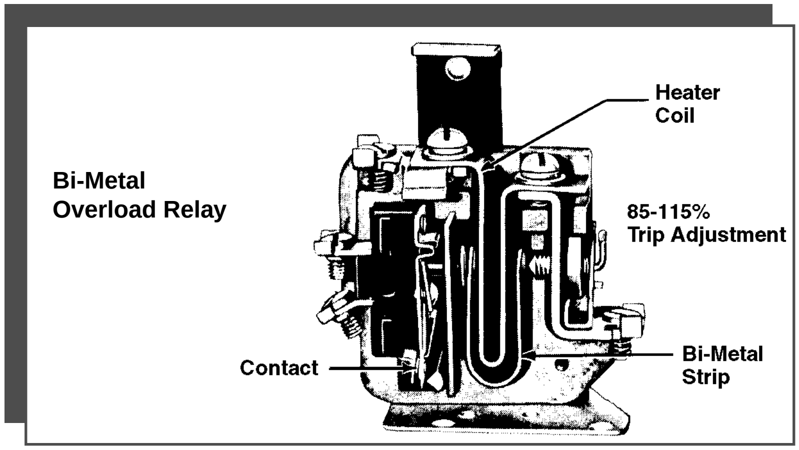
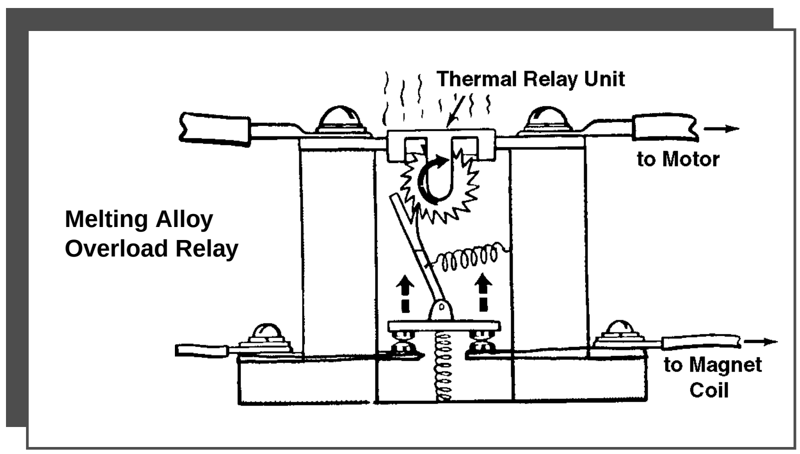
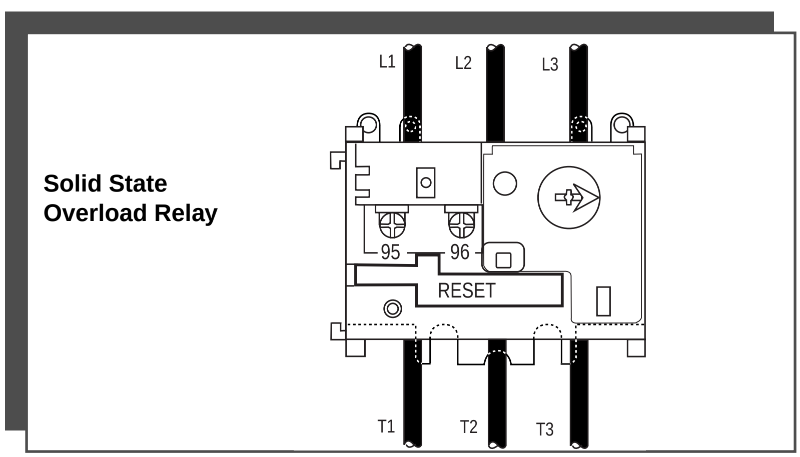
DEVELOPMENTS IN MOTOR PROTECTION
White Paper







INTRODUCTION

Electrical motors make up a large percentage of power system loads. Market demands for reduced downtime and increased productivity have compelled the motor control industry to evaluate motor protection technology continuously. Technology advancements now allow the motor control industry to offer several options for motor protection.

This paper briefly reviews traditional motor protection technologies and discusses the new, electronic motor protection options. After reading this paper, you should be able to understand the available technologies and how to choose the right solution for a given application. Important factors to consider in determining the appropriate overload protection include:

- Application requirements
- Cost per feature of a given technology
- Willingness and ability of all parts of the user's organization to embrace and implement the new technology.

MOTOR FAILURE AND PROTECTION

Motor failure may be the result of electrical or mechanical factors. A study commissioned by the Electrical Research Associates (ERA) of the United Kingdom in 1986 indicated the most common causes of motor failure are:

1.	Overload Relay	30%
2.	Contamination	18%
3.	Single Phasing	15%
4.	Bearing Failure	12%
5.	Aging (natural wear)	10%
6.	Rotor Fault	5%
7.	Miscellaneous	7%

Failure modes 1, 3, and 7 are attributable to electrical issues. Modes 2, 4, 5, and 6 are the result of mechanical (and some manufacturing) issues.

Historically, motor protection provided with the controller was only able to address the electrical causes of motor failure. These electrical issues account for at least 45% of the most common causes of motor failure. Motor branch circuits are protected against short circuits (instantaneous overload currents) and steady state or low level, sustained overload relays. In the U.S., this protection is provided by the short circuit protective device (SCPD) and the motor overload relay, when they are applied according to the National Electrical Code (NEC).

DASH POTS, MELTING ALLOY AND BI-METAL OVERLOAD RELAYS

The earliest form of electrical motor protection was a magnetic dash pot overload relay which used a moveable magnetic core inside a coil that carried motor phase current. The movement of the core was slowed by a piston working in an oil filled dash pot. Under a sustained motor current overload, the core moves slowly upwards and trips a set of contacts. The next technology was either melting alloy or bi-metal (there are conflicting reports as to which came first). In the U.S., Square D Company was the first to develop and introduce a melting alloy overload relay. The U.S. market quickly accepted the melting alloy technology, whereas Europe adopted the bi-metal technology.

In the melting alloy and bi-metal technologies, there is a heater "element" directly in the current path to protect against overload conditions. In NEMA rated bi-metal devices, the heater elements are interchangeable. In IEC bi-metal devices, these elements are dedicated. In either case, the element indirectly heats a bi-metal strip. Under an overload condition, the metal strip deflects and actuates the mechanism, tripping the device.

Melting alloy devices contain a heater winding which carries motor phase current and a eutectic alloy “patch” or “pot.” Under an overload condition, the heater winding causes the alloy to melt, allowing the trip mechanism to actuate.

One of the fundamental application differences between the melting alloy and bi-metal devices is that bi-metal devices are available in ambient compensated forms.

Only 5-10% of all installations require ambient compensation. Ambient compensated overload relays are designed for applications where the motor is in a constant ambient and the controller is in a varying ambient. The most common example is a down-hole pump motor application. The motor, in this case, is in a constant ambient (roughly 50 °F, depending on the level of the well) and the controller is up on the surface in a varying ambient. The ambient compensated thermal elements for this application are designed with a deflection that takes into account the varying ambient conditions at the controller.

Applications where the controller and the motor are in the same, varying ambient do not require compensation. Also, applications where the controller is at a constant temperature and the motor is in a varying ambient do not require compensation. In all cases, the melting alloy or bi-metal thermal units should be sized according to the motor Full-Load Amperes (FLA).

The fundamental difference between melting alloy and bi-metal devices is the design and operation of the trip mechanism. Most bi-metal overload relays employ an over-center trip mechanism. Melting alloy devices typically employ a directly actuated, ratchet mechanism.

Because 90-95% of all applications do not require ambient compensation, the choice of melting alloy or bi-metal is usually a matter of user preference, and not an absolute application requirement. In these cases, melting alloy or bi-metal overload relays work equally well.

NEMA style melting alloy and bi-metals require the customer to select the proper thermal units for adequate motor protection. Typically, customers stock replacement thermal units in case they are required to keep a machine running after a catastrophic fault. Heater selection procedures are often a source of error in the protection of motors using melting alloy and bi-metal technologies.

Regardless of the product style (NEMA or IEC), overload relays respond to overload relay conditions according to trip curves. These trip curves are defined by the class of protection required (see Table 1).

Table 1 Trip Classes

Class Designation[1]	Tripping Time
Class 10	10 Sec. or less
Class 20	20 Sec. or less
Class 30	30 Sec. or less

[1] Marking designation for tripping time at 600% of current element rating

IEC components are typically application rated. This means the controller is sized very close to its operational limit for a given application. IEC motors are also generally more application rated. For these reasons, Class 10 trip is most common on IEC applications. Because NEMA products are applied with more built-in excess capacity, the Class 20 trip is most common.

Figure 1 shows the three types of trip curves.

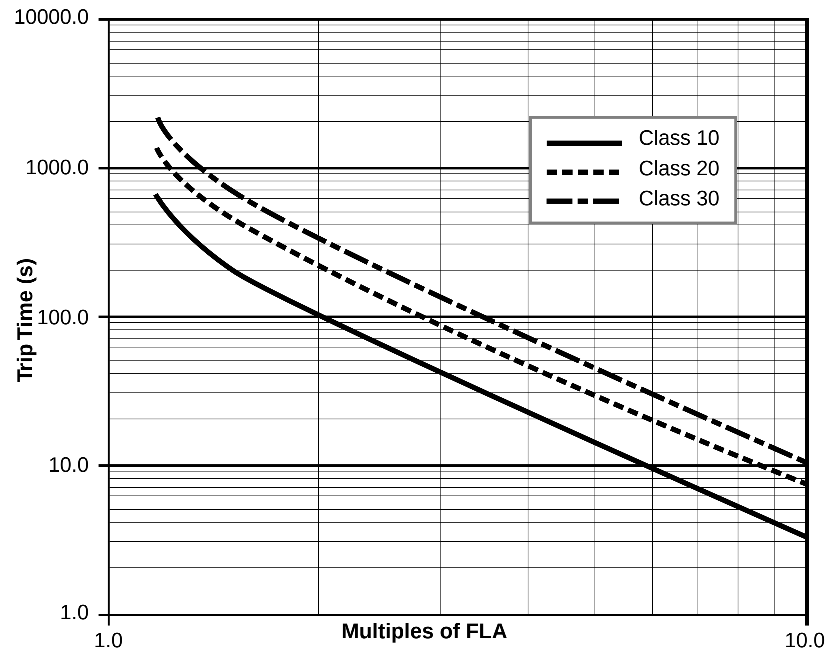


Figure 1 Typical Trip Curves

To protect the motor branch circuit against short circuits, overload relay protection must be coordinated with protection provided by the SCPD. The SCPD may be a fused switch or a circuit breaker. Figure 2 shows the critical point (I_c) in this coordination.

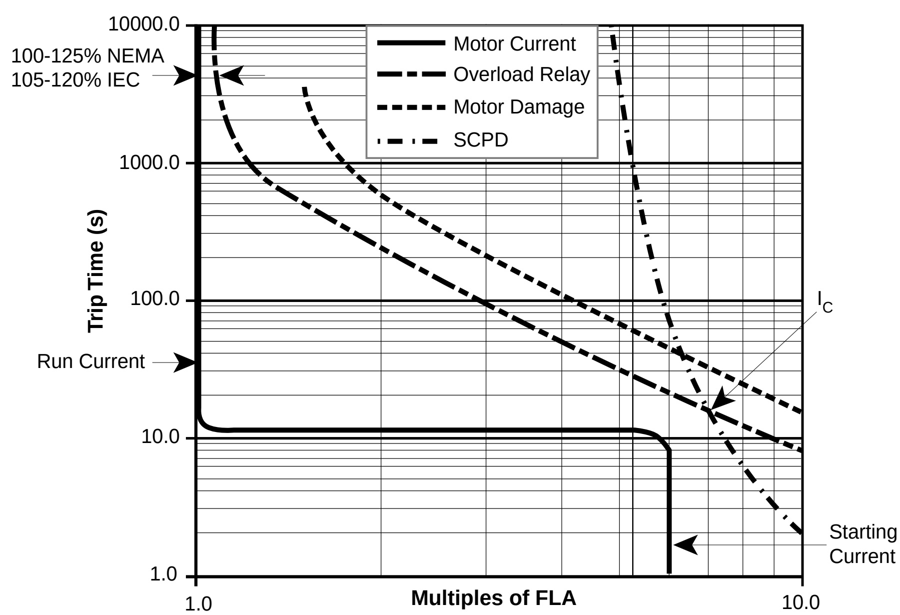


Figure 2 Typical Coordination Curves

At current values greater than I_c, the SCPD reacts quicker than the overload relay. At current values less than I_c, the overload relay reacts quicker. Articles 110 and 430 of the NEC provide guidance in the selection of the SCPD to facilitate coordination of the components of a motor branch circuit (i.e. location of point I_c).

Withstand Ratings

Equipment withstand ratings are linked to branch circuit protection. The same parameters that affect the trip point of a given protective device also contribute to how much (or how little) let-through energy the device may be exposed to and still function after the clearing of the fault. Withstand does not explicitly show up in Figures 1 or 2. Traditional melting alloy and bi-metal overload relays have been the "weak link" in motor branch circuit withstand ratings. Since these devices employ sensing elements directly in the current path, electrical faults leading to mechanical stresses are a concern. These devices typically contain small mechanical parts that can quickly become out-of-spec when exposed to let-through energy exceeding their withstand capability. If the coordinated protection for the circuit operates properly (and the SCPD protects the circuit), the motor and the controller will be protected. The withstand rating of a branch circuit must account for the withstandability of the lowest rated component in the circuit.

ELECTRONIC MOTOR PROTECTION

Developments in microprocessor and integrated circuit technology have led to the proliferation of electronic motor protection devices. Users have directly and indirectly influenced vendors to offer these products as a result of increased emphasis on reduced downtime, increased uptime and, in the case of microprocessors, the need for more information about a given process.

Electronic motor protection products currently offered may be split into three categories: low-end, mid-range, and high-end (see Table 2).

Table 2 Electronic Motor Protection Categories

	LOW-END	MID-RANGE	HIGH-END
FEATURES	• Self-Powered • Overload Current • Phase Loss • Phase Unbalance • Current Adjustment 3:1 • Permanent Tamper Guard • Power LED	• Separately Powered • Overload Current • Phase Loss • Phase Unbalance • Current Adjustment 5:1 • Tamper Guard/DIP Switches • Undercurrent • Overvoltage • Undervoltage • Ground Fault • Indicating LEDs: – Trip – Power – Dedicated - "Cause of Trip" • PTC/RTD Inputs • LCD Display Optional • Communication Optional	• Separately Powered • Overload Current • Phase Loss • Phase Unbalance • Current Adjustment Unlim. • Software Password/DIP Switches • Undercurrent • Overvoltage • Undervoltage • Ground Fault • Indicating LEDs: – Trip – Power – Dedicated - "Cause of Trip" • PTC/RTD Inputs • LCD Display - Local/Remote • Communication Std. • Programmable Inputs • Programmable Outputs • Programmable Function - Alarm/Trip By Function • Fault Logging/Trending
TYPICAL APPLICATION	0 - 100 A Low Voltage	100 - 300 A Low Voltage Medium Voltage	300 A and above Low Voltage Medium Voltage
SET-UP	• Set Trip Level • Connect Motor Leads	• Set Trip Level • External CTs • Control Power • Connect PTC/RTD • Set Switches/Dials	• External CTs • Control Power • Program Inputs/Outputs • Program Trips/Alarms • Connect PTC/RTD • Set Switches/Dials • Store Program Data/Hand Held Info.

Table 3 Price Comparison

	LOW-END	MID-RANGE	HIGH-END
TYPICAL PRICE	Typically <$100	$400 - $1000	$1600 - $2000
	• Basic Function — Melting Alloy + Thermal Units • (Extended Function — Slight Increment)	NEW GENERATIONS $800 - $1200	

The most important difference between the low-end and mid-range/high-end products is the inclusion of technology in the latter products that allow, at least in part, protection against certain mechanical causes of motor failure. Mid-range/high-end devices that accept Resistance Temperature Device (RTD) or Positive Temperature Coefficient (PTC) device inputs allow for protection against elevated bearing or winding temperature. These types of elevated temperatures are typically indicative of impending mechanical failure in the machine.

All three classes of electronic motor protection employ current transformers (CTs) to provide the signal level necessary for monitoring current values. These CTs may be built into the overload relay package or the customer may be required to purchase them separately and connect their output to the overload relay. The low-end products are intended to be “drop in” replacements or substitutes for melting alloy or bi-metal devices. In most cases, the customer will connect the motor leads directly to the load side of the contactor after passing these same leads through CT windows in the overload relay. Even if the low-end product allows the customer to connect the motor leads directly to the load side of the overload relay, there are still CTs internal to the device. The bus bars will pass through the CTs before being terminated on the load side of the contactor.

Mid-range and high-end devices may allow the customer to connect the phase currents directly to the overload relay up to a certain amperage (25 A, for example). Above this level, externally mounted CTs are required. Voltage monitoring in mid-range and high-end products is usually accomplished via the unit power voltage input. This control or power voltage is fed from one phase of the line power through a control power transformer. In this way, the overload relay device must contain the intelligence to perform the necessary calculations in order to monitor and protect the motor against undervoltage and overvoltage conditions.

All three classes of electronic motor protection devices are designed to function in accordance with the NEMA or IEC Trip Class characteristic curves. This is important, as the use of an electronic device does not alter the criteria for coordinated motor branch circuit protection (procedure for selecting the I_c point on curves). Some high-end devices allow more customized protection through “tailored” trip curve characteristics (i.e. a “Class 22” trip curve).

Trip classes for low-end devices are usually selected by catalog number. Trip classes for mid-range and high-end devices are usually selected by positioning DIP switches or through software set-up utilities.

The choice of motor protection technology can have an affect on the shape of the trip curve. This point has not previously been mentioned because melting alloy and bi-metal devices operate according to an I^2t function. Many electronic overload relays operate according to an I*t function. Figure 3 illustrates the different trip curve shapes resulting from the two defining functions. A device operating according to either function will respond to an instantaneous overload current in the same manner. Both defining functions also dictate that devices react in the same manner to a current six times the FLA of the motor. The difference in operation occurs in between these two "end points." For example, in Figure 3 where the current is at 200% of the motor FLA (i.e. 2 x on the graph). An I*t device will trip in approximately 80 seconds and an I^2t device will trip in approximately 200 seconds. In either case, the motor protection device provides adequate protection according to applicable NEMA, IEC, and other standards.

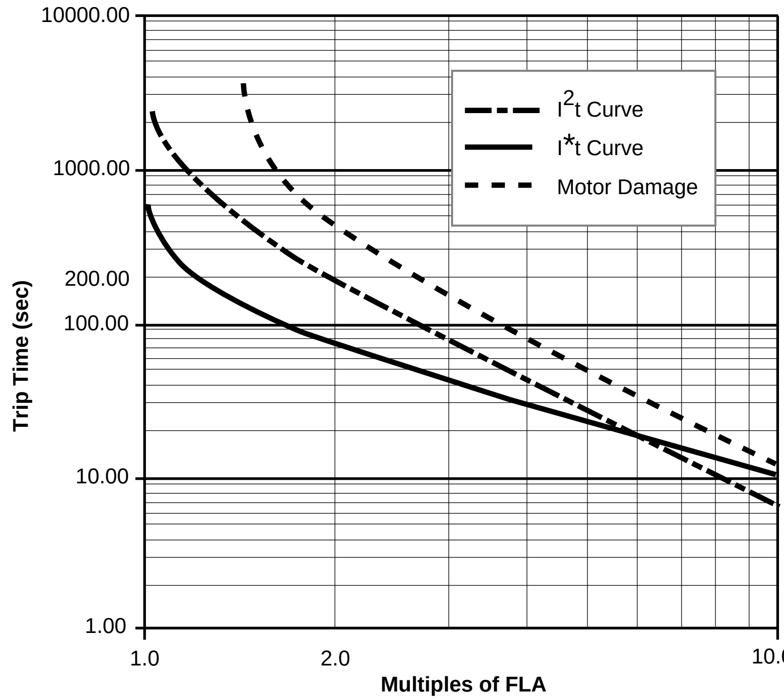


Figure 3 I^2t vs. I*t

The I^2t function allows the motor to operate closer to its thermal damage boundary. Although this may be true when compared to an I*t device, the trip characteristics of the I^2t device, as defined by NEMA and IEC standards, dictate that it react or trip far enough from the motor damage limit to prevent machine damage. After all, this is the function of a motor protection device. The "end points" for either the I^2t or I*t functions allow the user to adequately coordinate protection with the SCPD. There is only a minor difference in the trip times of the I^2t and I*t devices at the point of I_c on the curve.

TRUE RMS, PEAK DETECTION AND AVERAGING

Many customers will ask whether a given electronic motor protection device uses true RMS sensing for current detection. The answer is that most electronic motor protection devices DO NOT USE TRUE RMS sensing. However, they will typically employ another type of averaging scheme to sense currents.

In motor protection, the device employed should be more concerned with the thermal effect of the sensed current than the actual value of the current signal used to internally determine whether a trip should be initiated. If the device was intended for metering purposes, the accuracy of the current value would be critical and true RMS sensing would be merited.

Circuitry required to do true RMS sensing involves more components (sometimes substantially more) than the circuitry used for a less sophisticated averaging scheme. Therefore, true RMS sensing can be substantially more expensive. Simple averaging schemes can reduce the complexity of the device component “tree”. This can translate into enhanced reliability. In motor protection, reliability is key!

One important point should be made regarding peak detection schemes. Although these schemes may offer adequate protection for motors operating under balanced conditions, the introduction of harmonic distortion and other transients can cause undesirable performance. Typical averaging schemes employed in electronic motor protection devices offer at least a degree of harmonic insensitivity. This is an important consideration in the selection of a motor protection device because of the proliferation of non-linear loads on power systems.

SWITCHING TO ELECTRONIC MOTOR PROTECTION

There is a lot of flexibility in the selection of an electronic motor protection device. The level of sophistication chosen depends on the application requirements. In the U.S., the majority of all motors installed are less than 20 horsepower. Many would argue that more than 80% of all the motors installed in the U.S. are less than 10 horsepower. The average cost of an electromechanical motor controller could vary between $60 and $120.

In these cases, unless the application is a critical process, customers are typically reluctant to pay more for an electronic motor protection device than they would usually pay for an entire starter. Also, typical 10 hp, 480 V, 1800 rpm motors cost approximately $300-350 and are relatively inexpensive to rewind (approx. $200). Unless it is a critical process application, customers rarely spend more for the electronic protection than they do for the motor. As a result, the low-end device is usually the first choice for electronic protection.

Table 4 highlights some of the differentiating features of a typical low-end device, as compared to typical NEMA melting alloy and bi-metal and IEC bi-metal devices.

Table 4 Low-End Electronic vs. Traditional Overload Relays

FEATURE	NEMA		IEC	ELECTRONIC
	MELTING ALLOY	BI-METAL	BI-METAL	LOW-END
Three Phase	X	X	X	X
Self-Powered	X	X	X	X
Protection:				
Overload Current	X	X	X	X
Phase Loss		X	X	X
Phase Unbalance				X
Class 10	X	X	X	X
Class 20	X	X	X	X
Class 30	X	X	X	X or Optional
Mech. Latched Output	X	X	X	X
Selection	Therm. Units	Therm. Units	Amp Range	Amp Range
Manual/Auto Reset	Manual	MAN/AUTO	MAN/AUTO	MAN/AUTO or Optional
Remote Reset (Elec.)			Optional	Optional
Permanent Tamper Guard			Yes	Yes
DIN Rail Mounting			Yes	Optional or Yes
4 – 20 mADC output				Optional
Communication				Optional

There are some substantial advantages to using the low-end electronic device. The low-end device does not require thermal units. The customer does not have to exercise skill at the selection procedure nor is there a need to stock thermal units for repair or replacement. Not having to install thermal units can save from 20-30% of the installation time for a starter or separate overload relay, as compared to the traditional NEMA devices.

The low-end device, when operated within its operating temperature range, does not require ambient compensation. Only the level of current being drawn by the motor affects the trip of the device.

Low-end devices are typically available as part of a starter or as a separate component. This adds to the flexibility of their application and mounting. Some low end devices are designed to retrofit melting alloy or bi-metal devices from the same manufacturer. This flexibility provides the user a migration path to the new technology. Product selection and application are not dramatically different from the traditional melting alloy or bi-metal devices. The mounting and "look" are also similar to the traditional devices. Backward compatibility can also be useful if the decision is made to standardize on the new technology and the user wishes to upgrade the existing installed base.

Low-end devices that may be purchased as separate components may typically be mounted directly to a panel or on a DIN rail. This mounting flexibility enhances the attractiveness of the device. Low-end devices that are sold as separate components also provide a degree of modularity. If one piece of a starter fails, the customer only replaces that piece.

Most low-end devices have at least a 3:1 current adjustment range. This range is generally broad enough to cover the range of thermal units that are available for a given NEMA or IEC starter. An 18 A rated overload relay with a 3:1 current adjustment range may be used on any application with a motor FLA from 6 to 18 A.

The most important feature offered by a solid state overload relay is phase loss protection. While a phase loss causes a significant current increase in the remaining phases of the motor circuit, there is a major increase in rotor current that can cause motor damage.

The time it takes for a melting alloy device to trip is determined only by the level of current in the remaining phases. The majority of the motors installed (worldwide) are run at about 70% of their full load capability. In these situations, the phase loss condition may result in a level of current in the remaining phases just slightly above the actual FLA of the motor and, therefore, only slightly above the rating of the thermal unit. Therefore, it could take a substantial amount of time for the melting alloy device in this application to respond to the phase loss.

The bi-metal device offers a limited form of phase loss protection by means of a differential tripping mechanism where the device will trip somewhat faster when an overload is detected on only two of the phases. This device contrasts with a solid state overload relay with phase loss protection that would trip in less than three seconds and alert the user of a potential distribution system problem in advance of motor failure. Consequently, the problem does not have an opportunity to affect other equipment on the system.

The low-end device also provides phase unbalance protection where the device will trip if the current on any phase is 25% greater than the average of all three phases. Phase unbalances are typically caused by an unbalanced up-stream single phase load that can disturb phase voltages. Such a condition can similarly lead to excessive rotor currents and motor damage.

Another important aspect of the low-end electronic motor protection devices is that there is nothing directly in the current path of the circuit. Suppose there were a lightening strike on the distribution system that made its way to the motor branch circuit of the electronic device. The CTs in the low-end device would saturate and, in a sense, self-protect the overload relay. Although the low-end motor protection device is not a SCPD, by nature of its design, it is not directly exposed to large faults and the resulting mechanical forces that might exist. These faults, if severe, can have potentially undesirable effects on melting alloy or bi-metal devices.

The withstand rating of a controller may be slightly affected by the inclusion of low-end electronic motor protection devices. Since there are no thermal units in the circuit, the small amount of impedance they contribute to the circuit is absent. This loss of impedance typically only affects applications for very small motors where a circuit breaker SCPD is employed. If upgrading to electronic technology, the customer should consult the vendor regarding the use of the electronic device. Certain manufacturers have a catalog item to address the situation. It is a simple matter of adding an additional element of impedance (“Z” element) to the circuit. The Z element provides the same impedance that would have been present if a device requiring thermal units had been selected.

CONCLUSION

There are several advantages to using electronic motor protection as compared to using melting alloy or bi-metal devices. This is true even when considering a low-end electronic device. Even low-end devices provide high value feature enhancements for a very modest, if any, price increment. Low-end devices are typically priced the same as melting alloy devices plus thermal units. It has been shown that the mid-range and high-end devices offer features that allow the customer to protect against some of the more common mechanical causes of motor failure. The application and selection of electronic motor protection devices is very similar to the application and selection of melting alloy and bi-metal devices. As with any situation where there are several product technology solutions, all of which provide acceptable levels of protection, the customer must select the best technology and product for the application.

In the case of electronic motor protection, selection is based on:

- Application Requirements
- User Comfort with the Technology
- Product Features
- Product Cost

Any shift in technology is often viewed with some skepticism. Careful consideration is required when changing to a new technology or solution. The feature enhancements provided by electronic motor protection make the decision to change easier. However, melting alloy and bi-metal products will be available for the foreseeable future. Manufacturers will continue to support these products, which have been around for a long time and are installed worldwide.

Whether your customers have made the decision to change or stay with your current solution, encourage them to select a vendor who can adequately address their application and service needs. In today’s world, they must select a vendor with a product that is sold and supported around the world.

BIBLIOGRAPHY

1. ANSI/IEEE C37.94-1976, "An American National Standard-IEEE Guide for AC Motor Protection.
2. Earley, Mark W.,P.E., et al, National Electrical Code Handbook, copyright 1992, National Fire Protection Association, Quincy, Massachusetts, sixth edition, Articles 110 and 430.
3. National Electrical Manufacturers Association, NEMA Standards Publication No. ICS 2-1978 - "Standards For Industrial Control Devices, Controllers and Assemblies," copyright 1978.
4. Square D Company, Product Data Bulletin No. 9065PD9301, "Motor and Branch- Circuit Overload Protection, A Guide To Solving Problems," copyright 1994, Raleigh, North Carolina.
5. UL 508, "Standard For Industrial Control Equipment," copyright 1994, sixteenth edition, pgs. 118 - 167.
6. Square D Company, Product Data Bulletin No. 014BR9102, "Fundamentals of Motor Control–Basic Principles and Language of AC Motor Control," copyright 1991, Raleigh, North Carolina.

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