A Guide to Understanding: Short-Circuit Protection Devices, Overload Protection Devices, and Coordinated Protection

Rockwell Automation

Allen-Bradley

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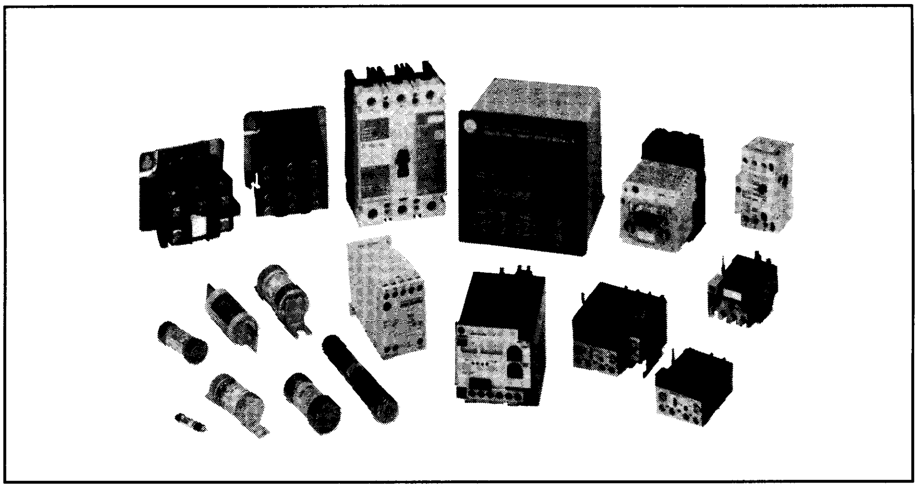


INTRODUCTION

In today's world of manufacturing, motors provide the majority of power that is used to convert raw materials into finished goods. In fact, over 50% of the work completed in today's manufacturing plant is completed by electric motors. It is estimated that this percentage will continue to increase for the foreseeable future. With this great percentage of manufacturing capability relying of electric motors, it is important to ensure that motors and their circuits are properly protected to provide maximum operating time and minimum downtime. Improperly protected motors/circuits in today's modern manufacturing plants can mean production downtime losses from hundreds of dollars to ten's of thousands of dollars per hour besides the cost of in-process material that can be destroyed. It is no wonder that over the last several years, an enormous amount of effort and resources has been utilized by control manufacturers in the development of improved and cost effective short-circuit protection and overload protection devices.

This paper will address many issues related to the proper understanding of short-circuit and overload protection devices and how to achieve "coordinated protection" for motors and their circuits

This paper will cover the following subjects:

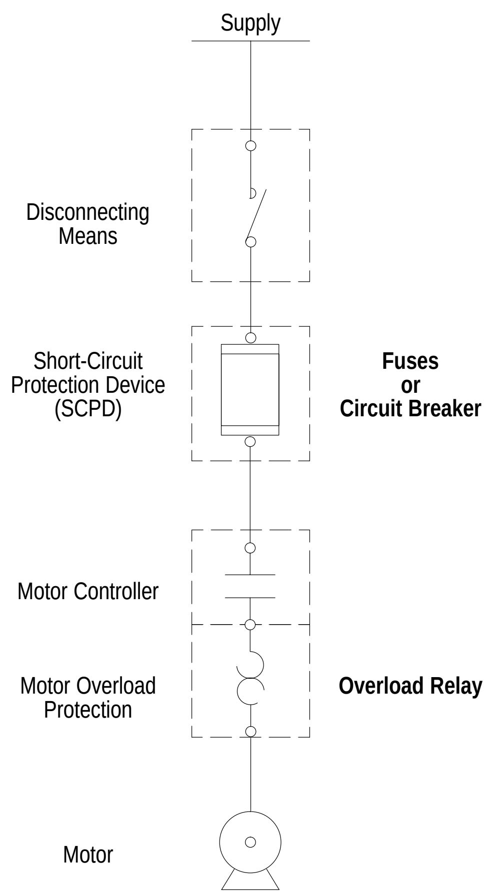
- Electrical code requirements
- Basics of short-circuit protection devices
  - Fuses
  - Circuit breakers
  - Type 2 Coordination
- Basics of overload protection devices
  - Eutectic alloy overload relays
  - Bimetal overload relays
  - Solid-state overload relays
- Advanced motor protection
- Coordinated motor circuit protection
- Life of a typical motor installation
- Terminology

CODE REQUIREMENTS

Whether you are designing motor circuits for use in North America, Europe, or any other part of the world, several basic requirement are typically specified for a motor circuit. In the U.S., the National Electrical Code (NEC) is followed as the basis for most electrical installations. In Canada, the Canadian Electrical Code (CEC) is followed, and in Europe, each country has it’s own electrical code requirements that must be met. Due to time and space limitations, we will address code issues in reference to the NEC unless otherwise stated.

Article 430 of the NEC describes the requirements for installations involving motors, motor circuits, and controllers. In Article 430, the requirements for motor branch circuit short-circuit, and ground fault protection and motor overload protection are specified. Figure 1 identifies the control and protection components required for a motor branch circuit.

Figure 1
NEC Article 430 – Motor Branch Circuit Requirements



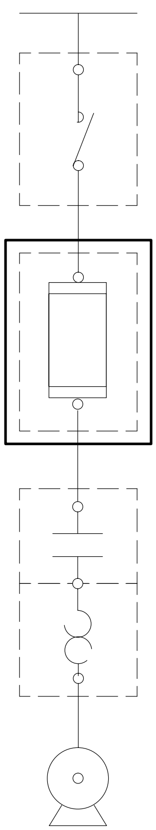
Now that we have identified the components required by code to provide motor brand protection, let’s take a closer look at the available types of short-circuit protection devices that will meet code requirements.

SHORT-CIRCUIT PROTECTION DEVICES

Short-circuit protection devices (SCPDs) can be classified into two groups; fuses and circuit breakers. The NEC further recognizes four types of fault protection devices and specifies their sizing limitations based on the type of motor that is used in the circuit.

- Non-time Delay Fuse
- Dual Element (Time Delay) Fuse
- Instantaneous Trip (Magnetic-only) Circuit Breaker
- Inverse Time (Thermal-magnetic) Circuit Breaker

This review of short-circuit protection devices will not attempt to endorse either circuit breakers or fuses since each type of device has its own strengths and weaknesses. Instead, we will provide a clear understanding of both types of SCPDs and let the application requirements determine which protective device will best meet customer needs.



FUSES

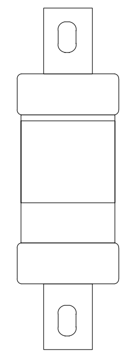
Fuses are over-current protective devices that are placed in an electrical circuit to protect the control components, wiring, insulation, and motor from damage caused by excessive current and associated heat. Overcurrents are considered any increase in continuous current above the normal operating current level.

In motor circuits, overcurrents are classified in two different categories. Motor overloads are any overcurrents up to or slightly above locked rotor current (6-8 times FLA). This range of overcurrent is protected by overload relay protection devices which will be discussed in more detail later. Short-circuit overcurrents are those produced by short-circuit or ground fault conditions with fault current levels in excess of 8 times FLA. In todays industrial facilities, short-circuit overcurrents can easily reach 50,000A. If the short-circuit overcurrents are not interrupted within fractions of a second, severe damage to the electrical installation can occur including motor damage, conductor and controller damage or even fires. In motor circuits, fuses best provide protection from damage caused by short–circuit currents.

Throughout the world, many different types of fuses are used for short-circuit protection in motor circuits. In North America, UL and CSA fuses are most commonly used. In other parts of the world, DIN (German) and BS88 (British) fuses are dominant. Even though the construction and fastening means are quite different (See Figure 2), all these fuses still perform the same essential function of short-circuit protection.

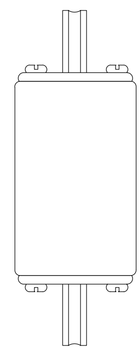
Figure 2
The World of Fuses

BS88 Fuses



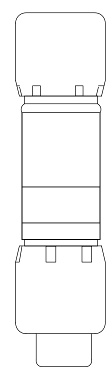
- IEC fuse type: Fuse-link for bolted connection
- Voltage rating: 660V AC
- Interrupting rating: 80,000A
- Standard cartridge sizes: A1, A2, A3, A4, B1, B2, B3, and B4
- Typical ampere ratings: 2–400A
- Construction: Blade type for bolted connection
- Where commonly used: United Kingdom, Australia, New Zealand, Asia, and Middle East

DIN Fuses



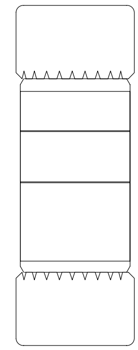
- IEC fuse type: Fuse-link with blade contacts
- Voltage rating: 660V AC
- Interrupting rating: 100,000A
- Standard cartridge sizes: 00, 0, 1, and 2
- Typical ampere ratings: 2–400A
- Construction: Blade type
- Where commonly used: Europe, South America, Middle East, and India

UL/CSA Fuses

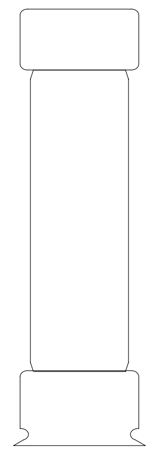


- Operation: Time-delay; Current-limiting
- UL fuse type: Class CC
- CSA fuse type: HRCI-MISC
- Voltage rating: 600V AC
- Interrupting rating: 200,000A
- Standard cartridge sizes: 30A
- Typical ampere ratings: 1–30A
- Construction: Ferrule type
- Where commonly used: North America

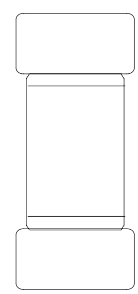
UL/CSA Fuses (cont.)



- Operation: Time-delay; Current-limiting
- UL fuse type: Class J
- CSA fuse type: HRCI-J
- Voltage rating: 600V AC
- Interrupting rating: 200,000A
- Standard cartridge sizes: 30A, 60A, 100A, 200A, 400A and 600A
- Typical ampere ratings: 1–600A
- Construction: 1–60A; Ferrule type 61–600A; Blade type for bolted connection
- Where commonly used: North America

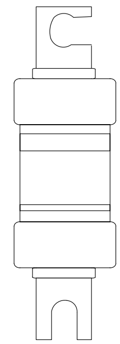


- Operation: Dual-element, Time-delay, Current-limiting
- UL fuse type: Class RK1, RK5
- CSA fuse type: HCR-R
- Voltage rating: 250 and 600V AC
- Interrupting rating: 200,000A
- Standard cartridge sizes: 30A, 60A, 100A, 200A, 400A and 600A
- Typical ampere ratings: 1/10–600A
- Construction: 1–60A Ferrule Rejection type; 61–600A; Blade type for wedge clamp connection
- Where commonly used: North America



- Operation: Fast-acting; Current-limiting
- UL fuse type: Class T
- CSA fuse type: HCR-T
- Voltage rating: 300 and 600V AC
- Interrupting rating: 200,000A
- Standard cartridge sizes: 30A, 60A, 100A, 200A, 400A, 600A, 800A, 1200A
- Typical ampere ratings: 1–1200A
- Construction: 1–60A; Ferrule type; 61–1200A; Blade type for bolted connection
- Where commonly used: North America

CSA Fuses



- CSA fuse type: HRCII-C
- Voltage rating: 600V AC
- Interrupting rating: 200,000A
- Standard cartridge sizes: 30A, 60A, 100A, 200A, and 400A
- Typical ampere ratings: 1–400A
- Construction: Blade type for bolted connection
- Where commonly used: Canada

Fuses are designed to meet specific standard performance requirements. In the case of UL and CSA fuses, specific characteristics such as current ratings, voltage rating, fuse dimensions, rejection features, withstand ratings, maximum I^2T and Ip current let-through limits, trip time parameters (time-delay) and more are specified in the standards.

Table A compares the performance requirements of various UL and CSA fuse classes. As you can see, different class fuses with similar current ratings can have significantly different results on I^2T and Ip let-through values.

Table A
Fuse Performance Requirements

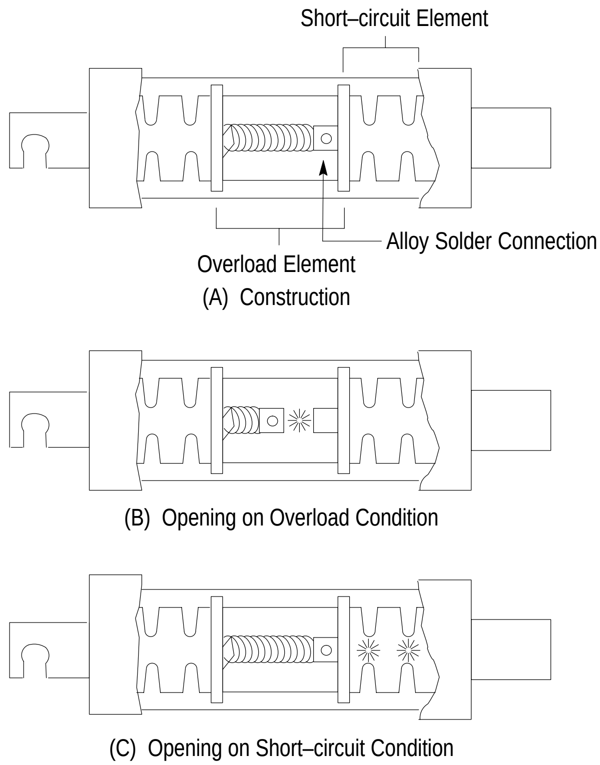
UL Fuse Performance Requirements per UL 198, 600 Volts, 100kA [1]			
Ampere Rating (A)	**UL Fuse Class**	**Max $I^2t \times 10^3$ (A^2-Sec.)**	**Max. Ip $\times 10^3$ (A)**
30	K5, RK5 K1, RK1 J T CC	50 10 7.0 7.0 7.0	11 10 7.5 7.5 7.5
60	K5, RK5 K1, RK1 J T	200 40 30 30	21 12 10 10
CSA Fuse Performance Requirements per CSA C22.2 No. 106 [1]			
Ampere Rating (A)	**CSA Fuse Class**	**Max $I^2t \times 10^3$ (A^2-Sec.)**	**Max. Ip $\times 10^3$ (A)**
30	HRCII-C HRCI-R HRCI-J HRCI-T	50 50 7 7	14 14 12 12
60	HRCII-C HRCI-R HRCI-J HRCI-T	200 200 30 30	26 26 16 16

[1] Fuses are tested on circuits with available fault currents between the threshold current of the fuse and 100,000 RMS symmetrical amperes.

FUSE MECHANICS

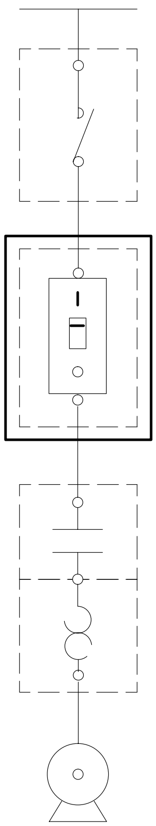
Figure 3 illustrates the typical operation of a dual element-time delay fuse. As its name indicates, “dual element” means that the fuse incorporates two separate current sensing elements arranged in a series configuration (A). The overload element opens when continuous overcurrent conditions exist (B). During an instantaneous short-circuit condition, the short-circuit element will open in multiple locations (C), interrupting the short-circuit an limiting the let-through I^2T and Ip within the limits specified by the fuse standard requirements.

Figure 3
Dual Element Time Delay Fuse



Several key benefits of using fuses for short-circuit protection includes:

- Low initial cost
- Current limiting
- High interrupting ratings
- Newer small dimension fuses (Class J & CC)
- Reliable operation



CIRCUIT BREAKERS

An increasingly popular method of providing short-circuit protection in motor circuits is with the use of circuit breakers. Circuit breakers have become very popular due to the fact that following a fault condition, circuit breakers can be easily reset once proper troubleshooting and maintenance procedures are completed. The ability to reset a circuit breaker following a fault condition, allows the manufacturing process to begin operation with minimal downtime.

There are many different types of circuit breakers on the market. In discussing the world of circuit breakers, we will concentrate on two groups of products. The first group will be UL/NEMA type molded case circuit breakers which are very popular in North America, and IEC type circuit breakers (motor circuit protectors) that are commonly used as short-circuit protection devices outside North America.

North American Circuit Breakers

The most commonly used circuit breakers in North America are referred to as "molded case circuit breakers" (MCCBs). These circuit breakers meet UL 489, CSA C22.2 No.5 and NEMA AB-1 standards requirements. These standards define circuit breaker characteristics such as ratings, performance, corrosion protection, electrical spacings, testing requirements, pass/fail criteria, insulating materials, current carrying parts, terminal wire capacities, etc. There are many different types of molded case circuit breakers including thermal-magnetic, magnetic-only, current-limiting, fused circuit breakers, and many more. This discussion will concentrate on thermal-magnetic and magnetic-only devices since they are the most popular type used in industry today.

Thermal–magnetic Circuit Breakers

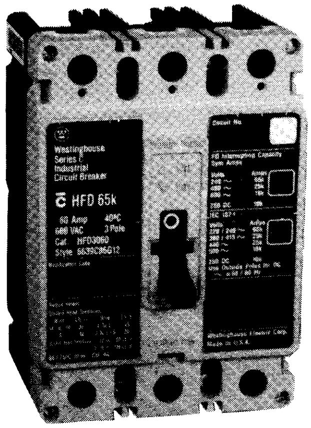
Thermal-magnetic (inverse time) circuit breakers provide both thermal (overcurrent) and magnetic (short-circuit) protection within a single device. For thermal overcurrent protection, thermal elements (bimetallic or electronic) are used to protect the circuit components from damage caused by continuous levels of high overcurrent. As current passes through the thermal elements, they will deflect until a trip point is reached, at which time the circuit breaker will trip, opening the motor circuit. The thermal action is also associated with the characteristic of "inverse time" since low overcurrents require longer trip times and high overcurrents result in shorter trip times.

For short-circuit protection, thermal-magnetic circuit breakers incorporate a magnetic trip element. During a short-circuit condition, the high fault current causes the magnetic trip element to release a latching mechanism, tripping the circuit breaker and opening the motor circuit.

Magnetic-only Circuit Breakers

Magnetic-only circuit breakers (also called "instantaneous trip" circuit breakers) differ from thermal-magnetic devices in that they only incorporate magnetic trip elements and no thermal elements. In motor circuits, the magnetic-only device is referred to as an MCP-motor circuit protector. This device must be used in combination with a separate overload relay which will provide overcurrent protection up to the locked rotor current of the motor.

Figure 4
North American Circuit Breakers



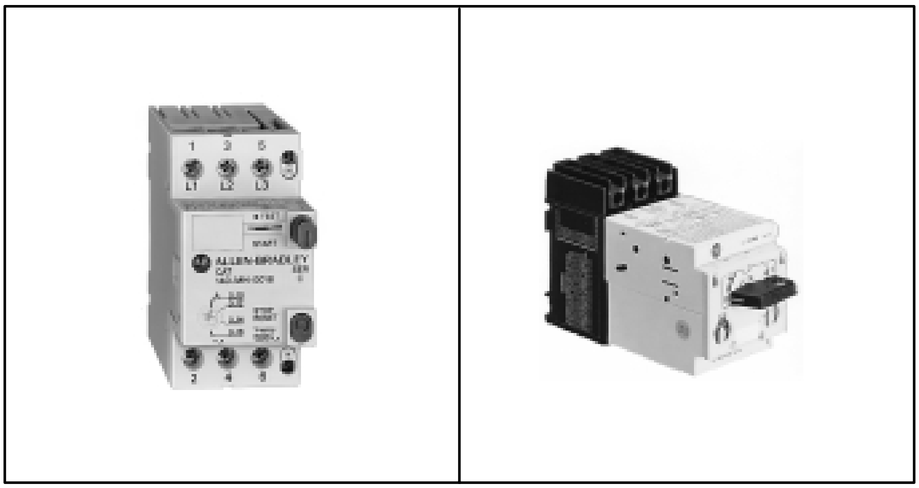
Several key benefits of using molded case type circuit breakers include:

- Can be reset after a fault occurs
- Visible trip indication
- External disconnection mechanisms available
- Some allow shunt trip and auxiliary contact options

International Circuit Breakers

Although North American type circuit breakers are used around the world, motor circuit protectors that meet IEC 947 requirements are most common outside North America. The IEC type circuit protector incorporates several functions within a single device including On-Off push buttons for local control and motor circuit isolation, adjustable bimetallic elements for overload protection, and magnetic trip elements for short-circuit protection. Since the IEC type circuit protectors do not meet the UL 489 molded case circuit breaker requirements, they cannot be used as a stand-alone short-circuit protection device as UL molded case circuit breakers or fuses in the U.S. or Canada.

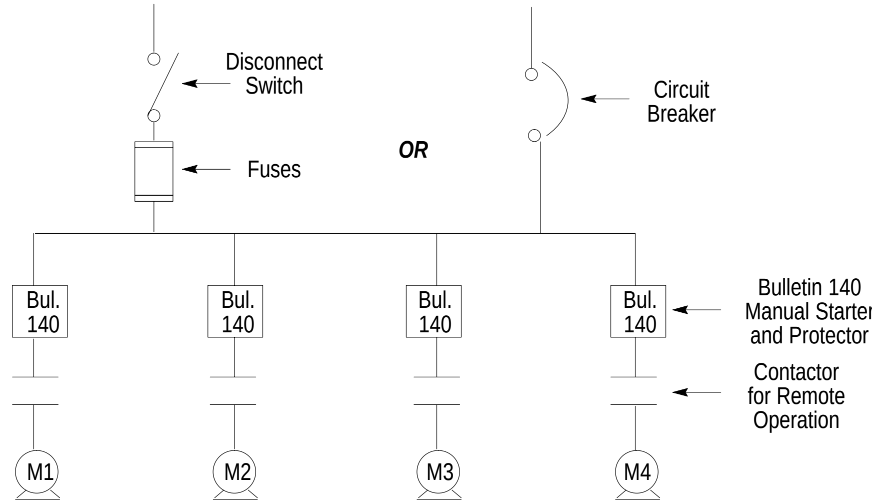
Figure 5
IEC Type Circuit Breakers



In the North American markets, the IEC motor circuit protectors have achieved what is called "group motor rating." This UL/CSA rating allows several motor circuits, each using an IEC motor circuit protector, to be protected with a single UL/CSA short-circuit protective device (Figure 6).

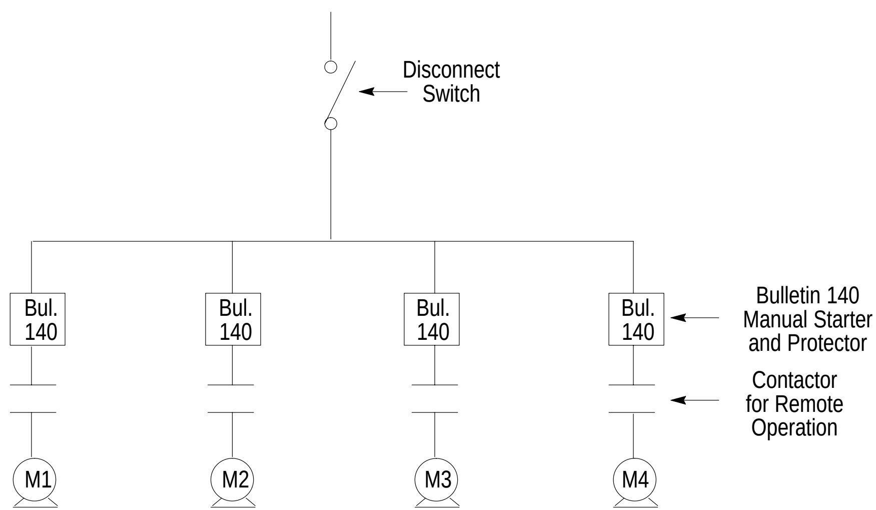
The elimination of individual motor circuit fuses or circuit breakers means significant panel size reduction. NEC Article 430-53 outlines the requirements for such installations.

Figure 6
North American "Group Motor Installation"



In international markets, the IEC motor circuit protectors are recognized and utilized as stand-alone short-circuit protection devices. Not until the available fault current exceeds the interrupting capability of the the motor circuit protector, do "back-up" short-circuit protection devices need to be used (Figure 7).

Figure 7
Motor Installations Outside North America



Several key benefits of using IEC circuit breakers include:

- Provide useful "group motor ratings" for North American applications
- Resetable after fault occurs
- Visible trip indication
- Overload protection
- Provide local On-Off and isolation

TYPE 2 COORDINATION

Type 2 Coordination is a term used to describe a level of protection that can be achieved by properly "coordinating" the selection of the short-circuit protection device with the withstand capability of the motor controller and overload protection device in the circuit. The concept of Type 2 Coordination originated from the IEC (International Electrotechnical Commission) standard 947-4-1. In this standard, two levels of short-circuit coordination are identified.

Type 1 Coordination is defined as follows:

"Under short-circuit conditions, the contactor or starter shall cause no danger to persons or installation and may not be suitable for further service without repair and replacement of parts."

In other words, contact welding is allowed in the contactor and overload burnout is acceptable. In either case, replacement of the control components are required.

Type 2 Coordination on the other hand, limits the effect of a short-circuit on the control components. Type 2 Coordination is defined as follows:

"Under short-circuit conditions, the contactor or starter shall cause no danger to persons or installation and shall be suitable for further use. The risk of contact welding is recognized, in which case the manufacturer shall indicate the measures to be taken in regard to the maintenance of the equipment."

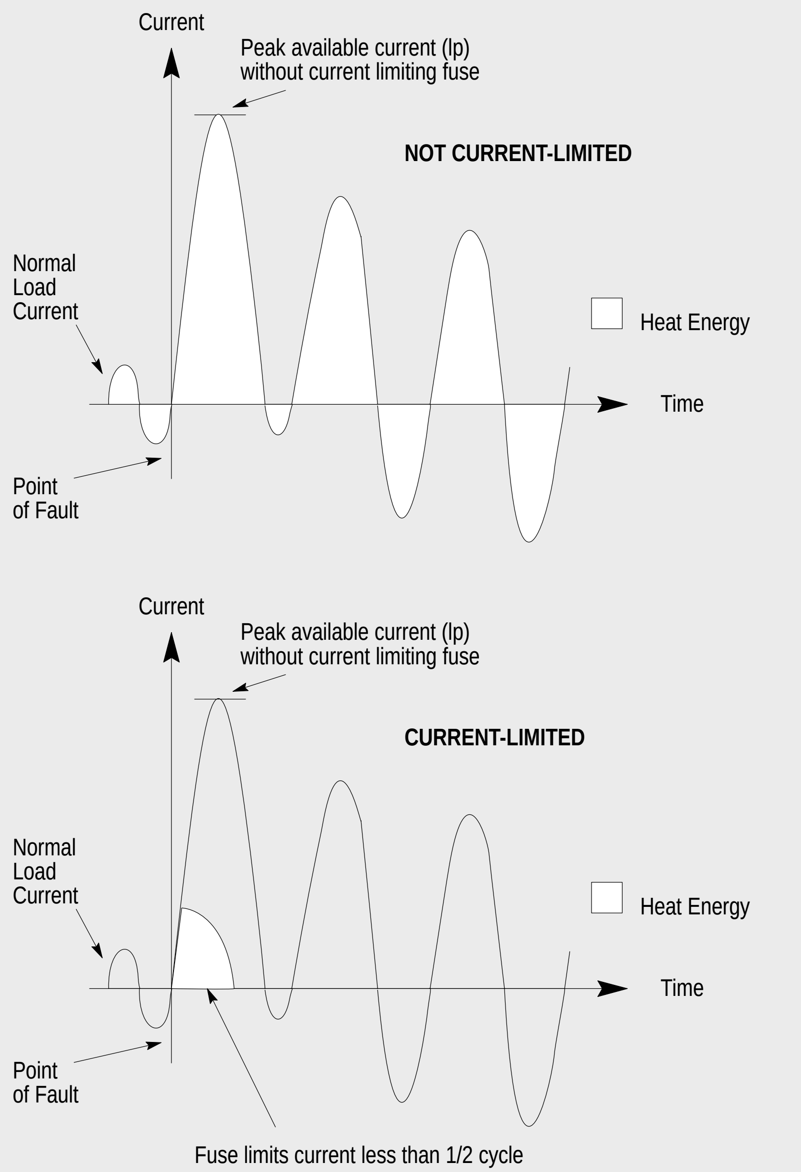
Figure 8 illustrates the results of a short-circuit if a motor branch circuit was protected by current limiting device vs. a circuit without a current limiting device. In circuits using a current limiting device, the let-through energy is limited to less than 1/2 cycle. This limited level of let-through energy allows the control components to survive a short-circuit and continue operation with little or no maintenance required.

In general, fuses have had much better current limiting capabilities than do circuit breakers, although some current limiting circuit breakers can provide Type 2 Coordination results. It is best to consult the control manufacturer for recommended short-circuit protection devices required to achieve Type 2 Coordination. Control manufacturers can provide component selection data (see Table B) that has already been proven during Type 2 testing programs. By following the manufacturers guidelines, you can be assured of achieving Type 2 Coordination in your motor branch circuit installation.

Benefits of Type 2 coordination include:

- Increased productivity and less down time
- Reduced component replacement costs
- Simple selection of SCPDs and motor circuit components with manufacturer supplied data

Figure 8
Let-through Heat and Current

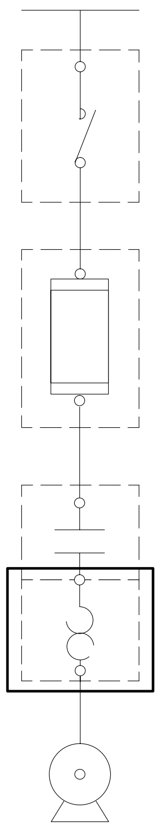


At the inception of a fault, a branch circuit can reach peak available current (Ip) without a current-limiting protector. The heat produced reaches temperatures that melt conductors as well as insulation, and the magnetic forces bend conductors and supports. When protected with a current-limiting fuse, however, the let-through current is only a fraction of Ip, usually opening the fuse in less than one-half cycle. Type 2 Coordination assures that no harm to people or damage to equipment results from short-circuit currents.

Table B
Manufacturer Fuse Recommendation for Type 2 Coordination

Motor Horsepower						Contactor	Overload Relay	UL Listed Time-delay Class J (CSA HRCI-J) Fuse			
Single Phase		Three-phase						Fuse Max. Amp. Rating	Cat. No.		
115V	230V	200V	230V	460V	575V	Basic Cat. No.	Cat. No.		Bussman	Gould-Shawmut	Littlefuse
—	—	—	—	1/2	3/4	100-A09	193-BSB16	2	LPJ-2	AJT2	JTD2
—	—	—	—	3/4	1	100-A09	193-BSB16	2	LPJ-2	AJT2	JTD2
—	1/10	—	1/2	1	—	100-A09	193-BSB22	3	LPJ-3	AJT3	JTD3
—	1/8	—	—	—	—	100-A09	193-BSB22	3	LPJ-3	AJT3	JTD3
—	1/6	1/2	—	1-1/2	1-1/2	100-A09	193-BSB30	6	LPJ-6	AJT6	JTD6
—	—	—	—	—	2	100-A09	193-BSB30	6	LPJ-6	AJT6	JTD6
1/10	1/4	3/4	3/4	2	—	100-A09	193-BSB42	6	LPJ-6	AJT6	JTD6
—	1/3	—	1	—	—	100-A09	193-BSB42	6	LPJ-6	AJT6	JTD6
1/8	—	—	—	—	3	100-A09	193-BSB50	6	LPJ-6	AJT6	JTD6
1/6	1/2	1	1-1/2	3	—	100-A09	193-BSB60	10	LPJ-10	AJT10	JTD10
1/4	3/4	1-1/2	2	5	5	100-A09	193-BSB80	10	LPJ-10	AJT10	JTD10
1/3	—	—	—	—	—	100-A09	193-BSB80	10	LPJ-10	AJT10	JTD10
—	1	2	—	—	7-1/2	100-A09	193-BSC10	15	LPJ-15	AJT15	JTD15
—	—	—	3	—	—	100-A12	193-BSC10	15	LPJ-15	AJT15	JTD15
1/2	1-1/2	3	—	7-1/2	10	100-A12	193-BSC15	20	LPJ-20	AJT20	JTD20
—	2	—	—	—	—	100-A12	193-BSC15	20	LPJ-20	AJT20	JTD20
3/4	—	—	5	10	—	100-A18	193-BSC15	20	LPJ-20	AJT20	JTD20
1	3	5	—	—	15	100-A18	193-BSC24	30	LPJ-30	AJT30	JTD30
1-1/2	—	—	7-1/2	15	20	100-A24	193-BSC24	30	LPJ-30	AJT30	JTD30
2	—	—	—	—	—	100-A24	193-BSC24	30	LPJ-30	AJT30	JTD30

By following manufacturer recommendation for maximum short-circuit protection device allowed, automatic Type 2 Coordination can be achieved.



MOTOR OVERLOAD PROTECTION

Overload relays are used in a motor circuit to protect motors and circuit conductors from damage caused by prolonged periods of overcurrent conditions. If motors are exposed to increased levels of continuous current and prolonged periods at locked rotor condition, damage to the motor and circuit conductors can occur.

Motors can be damaged or destroyed under any of the following conditions.

- Low or high supply voltage
- Phase unbalance
- Continuous excessive loading
- Single-phasing
- Jam or stall conditions
- Ground/earth faults
- Mechanical failures such as seized motor bearing or binding mechanical linkages

By selecting the proper type of overload relay with the appropriate functionality, the motor can be protected from damage caused by these conditions.

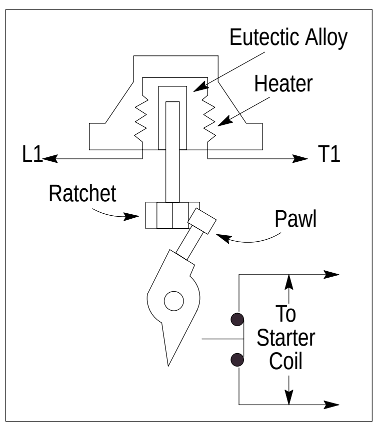
TYPES OF OVERLOAD RELAYS

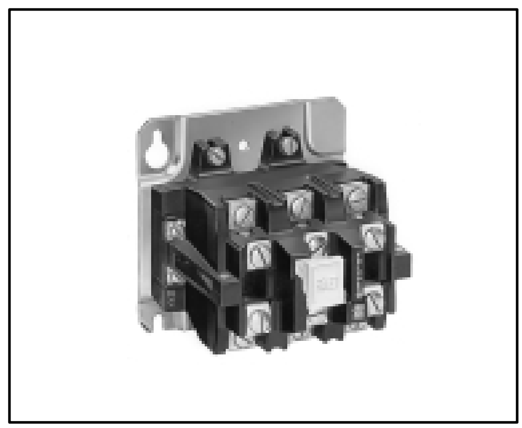
Today three basic types of overload relays are available: eutectic alloy, bimetal, and solid-state. Let's take a closer look at each type of overload relay and review the basic features of each.

Eutectic Alloy Overload Relays

Eutectic alloy overload relays are typically used with NEMA motor starters. These overload relays utilize a solder type alloy within heater elements. As current moves through the heater element, the solder is heated until a predetermined melting point (trip point) is reached. At the trip point, the solder is instantaneously changed from a solid to a liquid, allowing the ratchet mechanism to open a normally closed contact, dropping out the starter coil circuit, Figure 9.

Figure 9
NEMA Type Eutectic Alloy Overload Relay





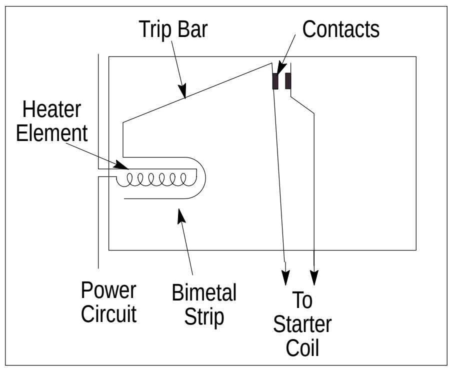
Key features of a eutectic alloy overload relay:

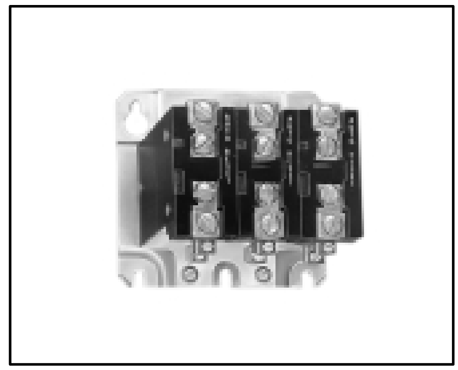
- Tamper-proof
- Not effected by nuisance tripping caused by vibration
- Manual reset only
- Single-phase "sensitive"
- Selectable trip classes 10, 20, 30

Bimetal Overload Relays

Two types of bimetal overload relays are available, NEMA and IEC. The NEMA type bimetal overload relay utilizes replaceable heater elements that indirectly heat bimetal strips. As the bimetal strips are heated, they flex towards a trip point, at which time a normally closed contact will open, dropping out the starter coil, Figure 10.

Figure 10
NEMA Type Bimetal Overload Relay





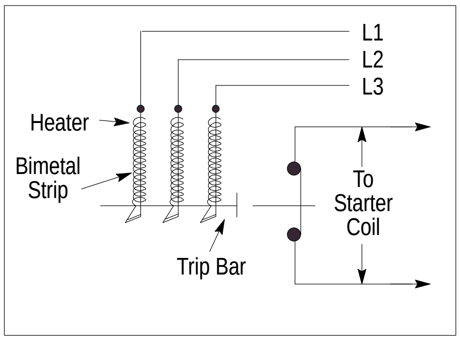
Key features of a NEMA type bimetal overload relay:

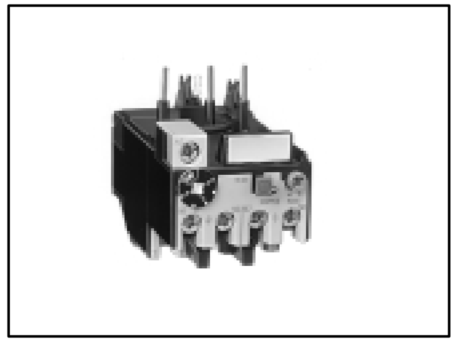
- Flexibility of changeable heater elements.
- Automatic reset
- Selectable trip classes 10, 20, 30
- Ambient temperature compensation
- Single-phase sensitive

Bimetal Overload Relays, Continued

IEC bimetal overload relays are similar to the NEMA devices except that the heater/bimetal are integral to the overload relay, Figure 11. To allow for added flexibility, the overload trip setting is adjustable over a range of motor full load current settings. The typical FLA setting range would be 1.0:1.5 (min. to max. setting). IEC bimetal overload relays are typically designed to Class 10 trip characteristics. This means that the overload relay will trip in less than 10 seconds at locked rotor current.

Figure 11
IEC Type Bimetal Overload Relay





Key features of an IEC type bimetal overload relay are:

- Manual or automatic reset
- Ambient temperature compensated
- Single-phase “sensitive”
- Wide current adjustment range (1:1.5)

Solid-state Overload Relays

Solid-state (electronic) overload relays are the newest and fastest growing type of overload protection devices. Until recently, solid-state overload relays were large, costly, and impractical for use on the vast majority of small motors used in industry today. With recent development in solid-state overload technology, the *cost* and *size* of the solid-state devices have been significantly reduced while the *functionality* has been greatly increased. The latest solid-state overload relay technology utilizes integral current transformers, application specific integrated circuits (ASIC), and/or microprocessors along with electromechanical design principles to produce a compact, high functionality overload protection solution. Available in either NEMA or IEC versions, the principle of operation is the same. As motor current passes through the integral current transformers, power is available to supply the integrated circuit. By monitoring the three-phase power, the ASIC can process current data, and activate a trip mechanism on overload conditions, opening a normally closed contact and dropping out the motor starter coil circuit, Figure 12.

Figure 12
Solid-state Overload Relay

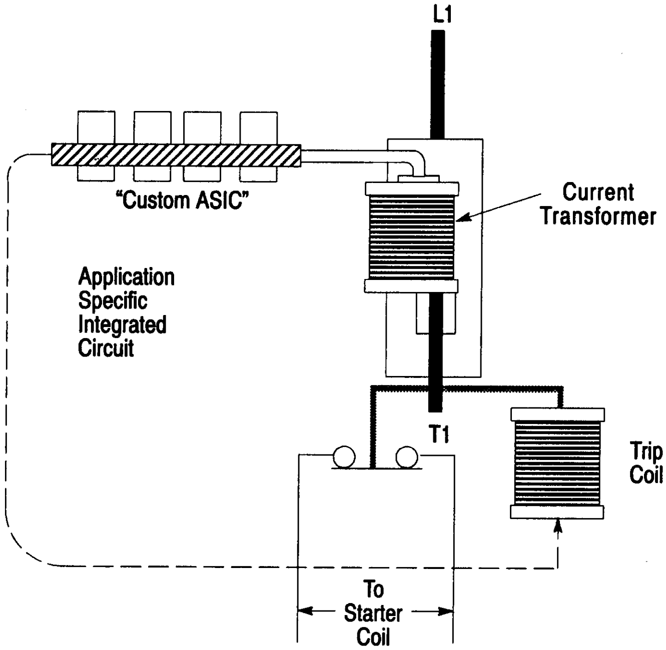
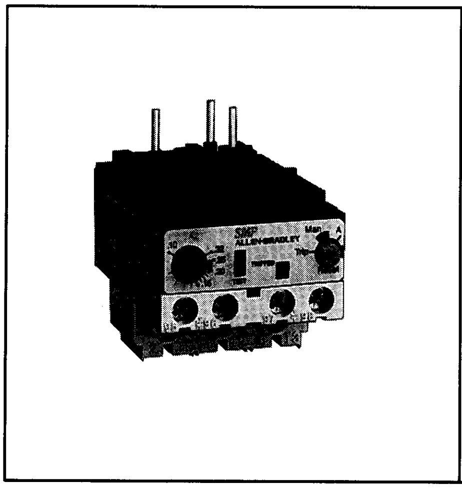
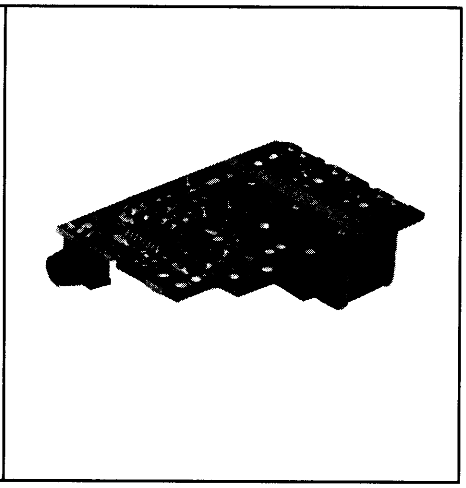


Figure 13
Solid-state Overload Relay and Application Specific Integrated Circuit (ASIC)





Key features of solid-state overload relays:

- Trip classes 10, 15, 20, 30
- Ambient temperature compensation
- Single-phase "protection"
- Manual or automatic reset
- Low power consumption (less heating and smaller panels)

ADVANCED MOTOR PROTECTION

As a result of integrating a microprocessor or an application specific integrated circuit (ASIC) as the brains of a solid-state overload relay, the opportunity to add advanced protective functionality to the overload relay becomes very practical.

Figure 14
Advanced Overload Protection Devices

Besides “basic” overload protection, advanced solid-state overload relay devices can offer additional functionality that previously would have required several additional protection devices to be used in the motor circuit. By consolidating many protective features into a single device, installation costs, component costs, panel size, and maintenance time can be significantly reduced while performance and efficiency of the system can be increased.

An additional benefit of solid-state devices is its ability to function via network communications. Through a communication network, vital motor information can be collected, processed and displayed in order to take corrective action prior to reaching fault conditions. Examples of data that can be obtained through the solid-state overload relay include:

- % Thermal capacity used (0–100%)
  How close is the motor to a trip condition (100%)?
- Phase unbalance
- Average current
- FLA settings
- Fault frequency
- Fault cause indication

Through triac outputs, control via a communication network can occur. Control functions include:

- Start/Stop
- Reset
- Restart limit

Table C
Advanced Solid-state vs. Traditional OLRs

Advanced Protection Feature	Solid-state OLRs	Traditional OLRs
• Jam/Stall protection selectable – I/O selectable	• Trips within .5 sec. at 400% of FLA setting	• Relays on overload trip curve response
• Ground (earth) fault protection selectable – I/O selectable	• Monitors phase vector angles Trips at lower level prior to fault level	• None – rely on SCPD
• Single-phase “protection”	• Trips within two sec. on fully loaded motor	• “Sensitive” to single-phase conditions Trips in 40 sec. or longer
• Trip setting accuracy	• Dip switch setting increased accuracy ±2.5%	• Potentiometer or heater elements: ±10%
• Repeat accuracy of trip setting	• Increased accuracy ±1%	• ±5–10%
• LED trip indication	• Fault cause indication – Jam/Stall – Ground earth fault – Improper setting – Communication loss – Test – Phase loss – Overload	• None
• Wide current adjustment range	• 3.2:1 and 5:1	• 1.6:1 and 1.1:1
• Low power requirement and low heat dissipation	• 150mW per device	• 6W or greater per device
• Trip classes 10, 15, 20, 30	• Selectable by DIP switch setting	• Dedicated components per trip class
• Network communications	• Control, data acquisition and fault cause indication • Control – Start/stop – Reset – Restart limit • Data acquisition – % thermal capacity used (trip warning) – Trip frequency – Phase unbalance – FLA trip setting – Average current • Fault cause indication (see above)	• None

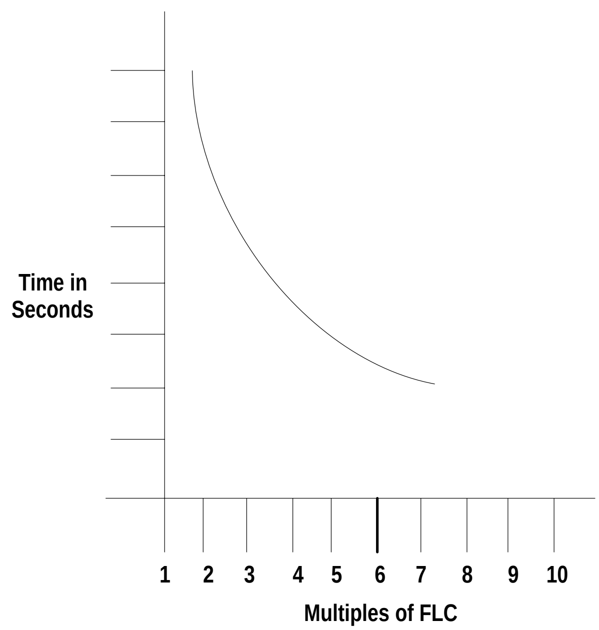
COORDINATED MOTOR CIRCUIT PROTECTION

Coordinated motor circuit protection for a branch circuit consists of providing a continuous level of damage protection from minor overloads through major short-circuit currents. Such protection provides benefits of reduced down time and replacement costs as well as greater safety.

The purpose of the overload protection in any branch circuit is to provide starting and running protection from overcurrents caused by such problems as binding bearings or jammed parts in the machine. These overcurrents range up to motor locked rotor current, usually about six times the motor full load current. Since locked rotor current is also initial starting current, overload protective devices require some designed in time delay in order to prevent nuisance tripping during start up.

The time/current curve of an overload protective device shows that the time to trip is inversely related to the magnitude of overload current.

Figure 15
Overload Response Curve

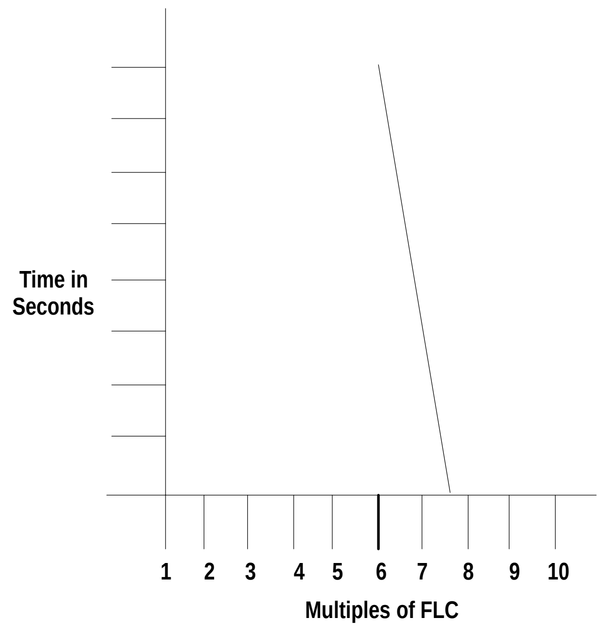


The purpose of the short-circuit protective device is to prevent higher levels of overcurrent from damaging components of the motor branch circuit. Short-circuit currents are considered to range from motor locked rotor current up to the maximum current available at the motor circuit

Short-circuit currents result from such problems as wiring errors, insulation breakdown, and accidental contact with the circuit by tools or other metal objects. Short-circuit protective devices must react quickly to minimize damage.

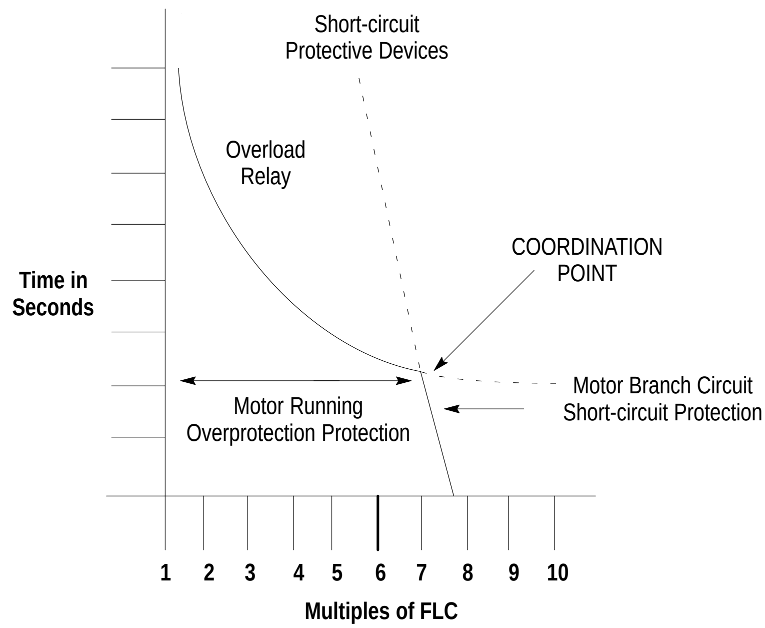
The time/current curve for a short-circuit protective device shows its trip timIt is also inversely related to current. You can see, however, that the slope of the curve is very steep.

Figure 16
Short-circuit Protective Device Responsive Curve



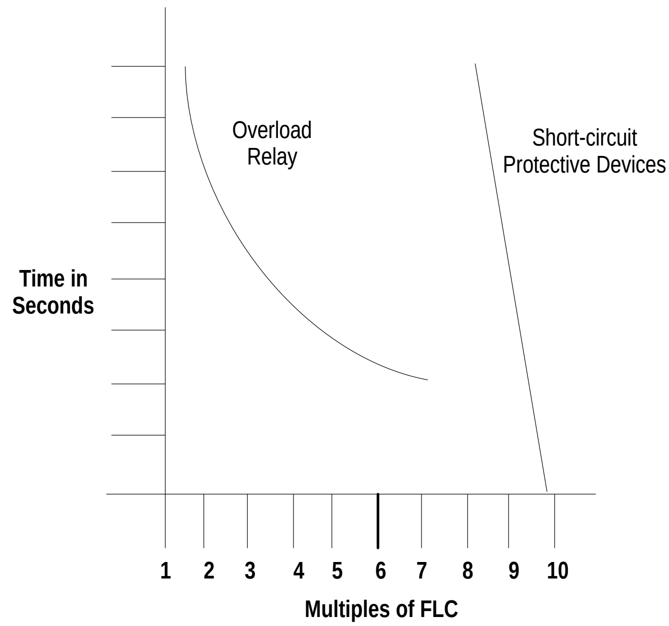
The National Electrical Code requires short-circuit and overload protection for the branch circuit. If these curves are overlaid we then have a time current curve that illustrates the behavior of the protective devices for all levels of current. If the curves intersect, the point of intersection is called “coordination point.” This point should be just above motor locked motor current (6–8 $\times$ FLC) for proper coordination. If the curves are properly coordinated, the short-circuit protective device will react to currents above the overload range, but will not trip if the overcurrent is in the overload range.

Figure 17
Coordinated Motor Circuit Protection



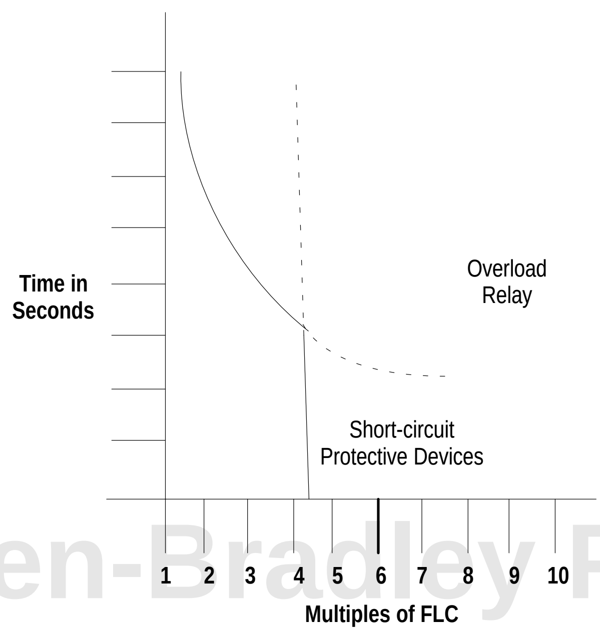
If, however, these curves do not intersect, or intersect well above the motor locked rotor current, the overload protective device will react to short-circuit currents in the gap between the overload range and short-circuit protection, and probably be damaged.

Figure 18
Protection Not Coordinated (Curves Do Not Intersect)



If the curves intersect in the overload range below the locked rotor current, the short-circuit protective device will nuisance trip on motor start-up.

Figure 19
Protection Not Coordinated (Curves intersect at less than locked rotor current)



LIFE OF A TYPICAL MOTOR INSTALLATION

Over the life of a typical motor installation, several different fault conditions can occur, from high level faults such as short-circuits or ground faults to low level faults such as overloads and jam conditions. When selecting motor circuit protection devices, several questions should be raised.

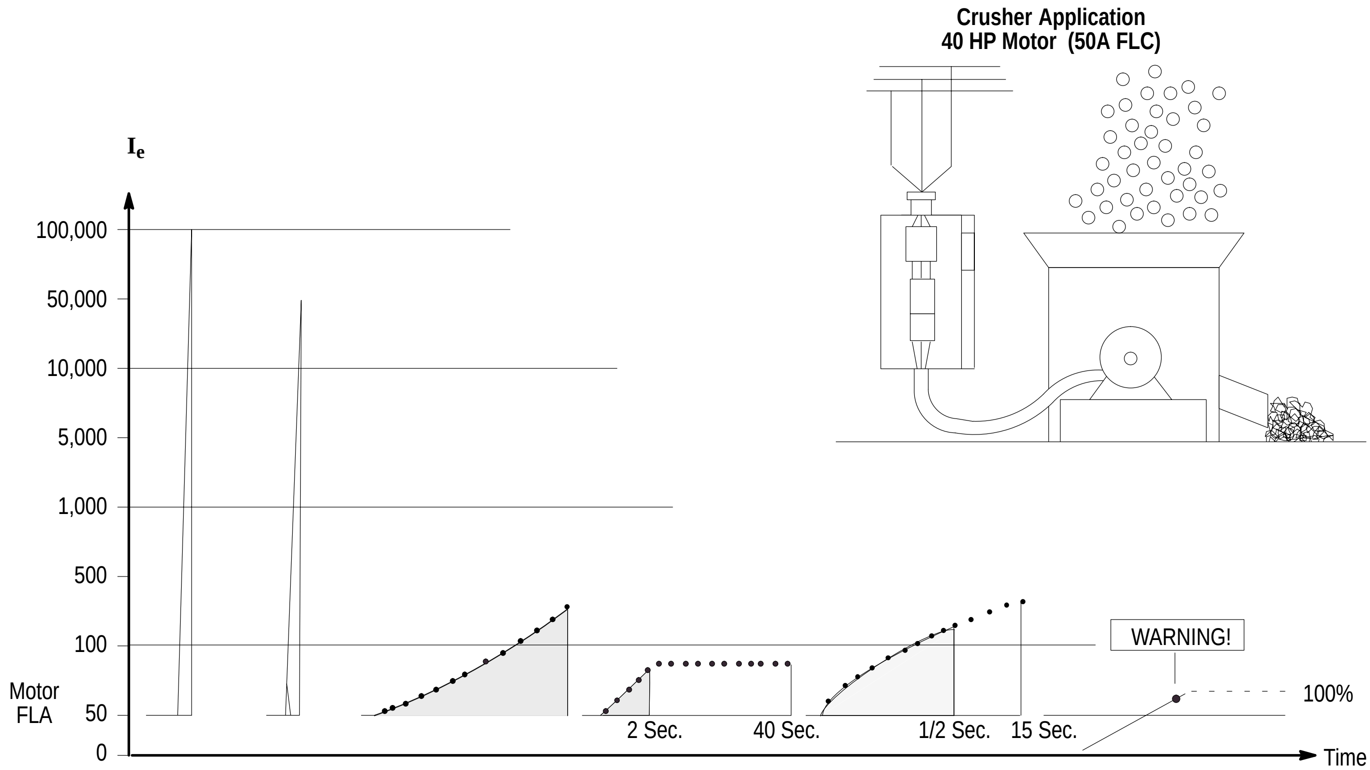
- Is the motor circuit critical to the manufacturing process?
- What is the “total cost” of downtime in the application?
- Is the application more susceptible to certain types of fault conditions?
- Is Type 2 Coordination important?
- Do I need to collect motor data and be warned of impending fault?
- Are fuses or circuit breakers preferred for short-circuit protection?

Dependent on the answers to these questions (and possibly many others), the process can begin to specify the type of products required to adequately protect the motor circuit. For less critical applications such as a fan or blower, where critical manufacturing processes or safety issues are not a consideration, meeting code requirements with fuses and a traditional overload relay may be the ideal solution. On the other hand, in a critical application, where the manufacturing process relies on a continuous flow of materials and downtime can be very costly, the best protection solution may require the following capabilities:

- Selecting a short-circuit protection device that provides Type 2 Coordination
- Selecting a solid-state overload device that provides:
  - Ground fault protection
  - Jam/Stall protection
  - Network communications to more closely monitor the motor data and application

By properly outlining the application requirements and selecting the appropriate protection components, the optimum implementation costs and motor circuit protection scheme can be developed to optimize the maximum life and performance of the motor and application.

Figure 20
Life of a 40 HP Motor



Fault Type	Short-Circuit	Ground/Earth	Overload	Phase Loss	Jam/Stall	Impending Trip
Protection Device Type	Fuses or Circuit Breakers					
			Traditional Overload Protection Devices		Responds with Overload Trip Curve	
		Trip Due to Low Level Ground Fault	Solid-state Overload Protection Devices			Advanced Protection via Network Communications ● % Thermal Capacity used ● Phase Unbalance ● Start-Stop-Reset Control ● Restart Limit
	High Level Faults		Low Level Faults			

“Coordinated“ Motor Circuit Protection Point

TERMINOLOGY

To help understand Coordinated Motor Circuit Protection, it is necessary to be familiar with the characteristics and definitions related to fuses, circuit breakers, overload relays, short-circuit, and overload protection.

- **Ampere Rating –** The continuous current carrying capability of a fuse or circuit breaker.
- **Ampere-squared Seconds (I^2t) –** An expression related to the thermal energy associated with current flow.
- **Available Fault Current –** The maximum possible short-circuit current that can flow in an unprotected circuit.
- **BS88 Fuse Designations –** British Standards Institute has defined basic physical specifications (size, mounting dimensions, labeling) and guidelines to fuse manufacturers for providing maximum let-through current and energy for fuses (in a standard format). Fuse designed to British Standards are described by their dimension (e.g., Al, A2, A3, A4, B1, etc.) and continuous current rating.
- **Circuit Breaker –** A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined overload current.
- **Clearing Time –** The total time measured from the beginning of the fault to the interruption of the circuit.
- **Current Limiting Circuit Breaker –** A circuit breaker that does not employ a fusible element and that when operating within its current limiting range, limits the let-through I^2t to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current.
- **Current Limiting Fuse –** A fuse which will limit both the magnitude and duration of current flow under short-circuit conditions. The available fault currents a fuse will clear in less than 1/2 cycle, thus limiting the actual magnitude of current flow.
- **DIN Fuse Designations –** DIN/VDE Standards specify physical specifications as well as classes of operation for fuses. The class of operation is identified by two or three letters (e.g., gL, aM, gTr). The gL fuse is a general purpose fuse with characteristics that are well suited for the protection of starters and associated wiring. These fuses are described by their dimension (e.g., 00, 0, 1, 2, 3 and 4) and continuous current rating.

- **Dual-element Time Delay Fuse –** A fuse of special design which utilizes two individual elements in series inside the the fuse casing. One element is a spring-actuated trigger assembly that operates that operates on sustained overloads, but which ignores momentary surges. The other element operates without intentional delay on currents of fault magnitude up to the interrupting rating of the fuse.
- **Fast-acting Fuse –** A fuse that opens very quickly on currents of fault magnitude. This type of fuse is designed with no intentional time-delay characteristics. Fast-acting fuses are commonly used to protect solid-state electronic devices.
- **Fuse –** An overcurrent protective device with a fusible link that operates to open the circuit on an overcurrent condition.
- **High Level Fault –** Short-circuit currents between the threshold current of a fuse that would be used for the branch circuit protection of a motor in a given application and the test current for the controller of that motor, per the short-circuit test of UL 508.
- **Interrupting Rating –** The maximum short-circuit current that an overcurrent protective device can safely open or clear.
- **Let-through Energy (I^2t) –** A measure of thermal energy developed within a circuit during the total clearing time of the fault current.
- **Low Level Fault –** Short-circuit currents that are less than the threshold current of a fuse that would be used for the branch circuit protection of a motor in a given application.
- **Overcurrent –** A condition existing in an electrical circuit when normal current is exceeded. Overcurrents occur in two distinctly separate forms – overloads and short-circuits.
- **Overload –** An overcurrent that exceeds the normal full-load current of a circuit.
- **Overload Current –** A level of current above the motor full load current, but generally not greater than six times the full load current. Overload currents are usually caused by overloading the motor and are restricted to the normal current path. These currents are typically detected by the overload relay.
- **Peak Let-through Current (*Ip*) –** The maximum instantaneous peak current passed through a short-circuit protective device when clearing a fault current of specified magnitude.
- **RMS Current –** The effective, root-mean square value of current, and the measure of its heating effect. The RMS value is calculated as the square root of the mean of the squares of all the instantaneous values of the current throughout one cycle. RMS alternating current is the value of an alternating current that produces the same heating effect as a given value of direct current.
- **Short-circuit Current –** Excessive current caused by insulation breakdown or wiring error. Short-circuit currents leave the normal current carrying path of the circuit, such as line-to-line or line-to-ground. Short-circuits are typically detected and cleared by the branch circuit protective devices.

- **Single-phasing –** The condition that exists when one phase of a three-phase power system opens. Single-phasing results in unbalanced currents and overheating in polyphase motors and other three-phase inductive devices. Proper selection of dual-element time-delay fuses and/or protective relays will help protect motors from damage during single-phasing conditions.
- **Threshold Current –** The magnitude of current a which an SCPD becomes current limiting.
- **Time-delay Fuse –** A fuse with a built-in time delay that allows temporary a harmless inrush currents to pass without opening, but is designed to open on sustained overloads and currents short-circuit magnitude.
- **UL Class of Fuse/CSA Fuse Designations –** Underwriters Laboratories and the Canadian Standard Association have developed basic physical specifications (size, rejection features, labeling) and electrical performance requirements (interrupting rating, maximum Ip and I^2t) for fuses with voltage ratings of 600 volts or less. If a fuse meets these requirements, it can be designated by a UL class of fuse or a CSA fuse designation. Typical UL fuse classes are K1, K5, RK1, RK5, J, T, and CC. Typical CSA fuse designations are HRCI-T HRCI-R, HRCI-J, and HRCII-C.
- **Voltage Rating –** The maximum value of system voltage in which a fuse can be used and safely interrupt an overcurrent. Exceeding the fuse voltage rating impairs its ability to clear an overload or short-circuit safely.

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Allen–Bradley offers a wide range of motor protection products that will help extend the life of your motor. These products are an integral part of the automation process and the life cycle.

Justify. If your application requires motor protection, choose any one of our solutions for increased productivity. These product lines offers many protective features such as detection of overload, short circuit and ground fault conditions. Analyze the complete line of motor protection products through customer training seminars, product demonstrations and literature.

Apply. Any one of the motor protection devices may be applied based upon your application and requirements. Many of these products work together to provide increased functionality.

Install. Integrate our products with new systems as well as existing systems. Traditional and solid–state protection is available. Our panel system solution reduces wiring and installation costs.

Operate. Striving for optimum productivity and monitoring motor faults constitute pro–active approaches to this phase.

Maintain. By protecting the motor from damage, our products help reduce downtime. Product features such as diagnostics and communications capability also reduce system maintenance.

Improve. Extending the life of your motor is the main benefit of our product line. As your needs change, we change with you by increasing the effectiveness of our products and monitoring market demands. Staying focused on product line improvements results in advanced product offerings such as the SMP™ Overload Relays and the Smart Motor Manager.

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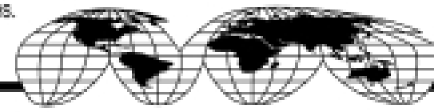

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