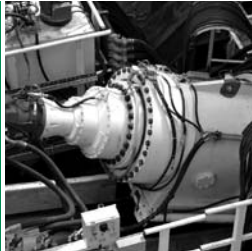




WHITE
PAPER



Expertise Applied | Answers Delivered

MOTOR PROTECTION

The Importance of Effective Motor and Motor Circuit Protection

TECHNICAL APPLICATION GUIDE

Introduction

The importance of effective motor and motor circuit protection cannot be over emphasized. Motors are consistently the largest single cause of industrial and commercial fires, and in today's highly automated commercial and industrial facilities, the failure of even one relatively minor motor may shut down an entire installation.

As a result, it is vitally important that there is at least a basic understanding of how motors and their related electrical systems can be properly protected. The purpose of this White Paper is to provide a more detailed discussion of the factors which must be considered when properly selecting and applying low voltage fuses, medium voltage fuses, and protection relays in electrical systems.



Descriptions and ratings of Littelfuse POWR-GARD® fuses and protection relays, along with application data, are located in the corresponding sections of the Littelfuse POWR-GARD Catalog. To download a copy visit www.littelfuse.com/catalogs.

For questions, contact our Technical Support and Engineering Services Group at **800-TEC-FUSE (800-832-3873)**. Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog.

Overcurrent Protection Fundamentals

Before we go further, let's briefly review some overcurrent protection basics and touch on the types of fuses typically used to protect the service entrance and feeder conductors within electrical systems.

Overcurrent Types and Effects

An overcurrent is any current that exceeds the ampere rating of conductors, equipment, or devices under conditions of use. The term "overcurrent" includes both overloads and short-circuits. For motor protection, we'll just discuss overloads.

Overloads

An overload is an overcurrent confined to normal current paths in which there is no insulation breakdown.

Sustained overloads are commonly caused by installing excessive equipment such as additional lighting fixtures

or too many motors. Sustained overloads are also caused by overloading mechanical equipment and by equipment breakdown such as failed bearings. If not disconnected within established time limits, sustained overloads eventually overheat circuit components, causing thermal damage to insulation and other system components.

Overcurrent protective devices must disconnect circuits and equipment experiencing continuous or sustained overloads before overheating occurs. Even moderate insulation overheating can seriously reduce the life of the components and/or equipment involved. For example, motors overloaded by just 15% may experience less than 50% of normal insulation life.

Temporary overloads occur frequently. Common causes include temporary equipment overloads such as a machine tool taking too deep of a cut, or simply the starting of an inductive load such as a motor. Since temporary overloads are by definition harmless, overcurrent protective devices should not open or clear the circuit.

It is important to realize that fuses selected must have sufficient time-delay to allow motors to start and temporary overloads to subside. However, should the overcurrent continue, fuses must then open before system components are damaged. Littelfuse POWR-PRO® and POWR-GARD™ time-delay fuses are designed to meet these types of protective needs. In general, time-delay fuses hold 500% of the rated current for a minimum of ten seconds, yet will still provide short-circuit protection by opening quickly on higher values of current.

Even though government-mandated high-efficiency motors and NEMA Design E motors have much higher locked rotor currents, POWR-PRO time-delay fuses such as the FLSR_ID, LLSRK_ID, or IDSR series have sufficient timedelay to permit motors to start when the fuses are properly selected in accordance with the NEC®.

Protecting Service Entrance and Feeder Conductors

Let's briefly review the types of fuses commonly used to provide the proper protection for motors and service entrance and feeder conductors within electrical systems. We'll start with applications above 600 amperes and then look at main services and feeders rated 600 amperes and below.

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601 through 6000 Amperes

Select POWR-PRO® KLPC series Class L fuses for AC circuits from 601 through 6000 amperes. The construction and operating characteristics of KLPC series fuses meet the toughest project specifications for Class L fuses. KLPC series fuses...

- Provide maximum time-delay and current-limitation.
- Have a 300,000 Ampere interrupting rating.
- Contain an "O-ring" seal to improve short-circuit performance.
- Contain fuse links that are 99% pure silver.

If the system has DC circuits, another choice is the POWR-PRO LDC series Class L fuses for both AC and DC circuits and available from 601 through 2000 amperes. LDC series fuses are the only Class L fuses which are UL Listed at both 600 Volts AC and DC. When facilities have a mix of large AC and DC circuits, standardizing on LDC series for all Class L fuse needs should be strongly considered. This helps reduce inventory and eliminates the possibility that an AC-only fuse will inadvertently be used in a DC circuit.

When conductors are selected in accordance with the NEC®, recommended fuse ratings for mains and feeders with combined motor and non-motor loads are:

- 150% of the largest motor full load current plus,
- 100% of all other motors full load currents plus,
- 125% of the continuous non-motor load plus,
- 100% of the non-continuous, non-motor load.

If the largest motor has a long acceleration time requiring branch circuit protection to be increased to 175-225% of full load current (FLA), it may be necessary to increase main and feeder fuse ratings to 175-225% of the largest motor FLA plus the other current values as indicated above. However, if conductor ampacity has been increased to provide spare capacity for future loads, fuse ratings may be increased to the ampacity of the conductors.

When standard fuse ratings do not match conductor ampacities, the next larger standard fuse ratings may be used only if they are rated less than 800 amperes. If fuse ratings are greater than 800 amperes, the next smallest ratings must be used. In addition to all standard ampere ratings, KLPC and LDC series fuses have many additional, intermediate ampere ratings. The additional ratings permit minimum downsizing of fuses which saves valuable conductor ampacity.

Main Services and Feeders 600 Amperes and Less

Several fuse series may be used for protecting main services and feeders under 600 amperes. Choices should be made based on the needs of the particular facility – some of which are discussed below with recommendations for fuses that meet those needs. The vast majority of electrical systems, especially those 600 amps and smaller, have available short-circuit currents less than 100,000 amperes. Class RK5 fuses have provided excellent protection for such circuits for many years. When fault currents exceed 100,000 amperes at the service entrance, a study should be made to determine if the additional current limitation provided by Class RK1 or Class J fuses is required.

POWR-PRO Class RK5, 600 Volt FLSR_ID series Indicator® fuses provide superior time-delay plus substantially better current limitation than required by UL Class RK5 standards. In addition, the patented indicating window on the fuse immediately shows which fuses are blown. This can significantly reduce a user's downtime.

POWR-PRO Class RK1, 250/600 Volt LLNRK / LLSRK / LLSRK_ID series time-delay fuses are the fuse of choice for circuits where fault currents exceed 100,000 amperes. The advanced design of the LLSRK series reduces short-circuit damage to both full-size NEMA and sensitive IEC motor controllers, and is capable of providing Type 2 "No Damage" protection to NEMA size motor starters. Together with the KLPC series fuses, the LLNRK / LLSRK series form the foundation of the POWR-PRO Fuse System of overcurrent protection, with the patented indicating window on the LLSRK_ID series providing blown fuse indication for the user.

POWR-PRO Class J, 600 Volt JTD_ID series time-delay fuses provide the amount of time-delay necessary for most applications and are substantially smaller than RK5 or RK1 fuses while providing current-limitation equal to that of comparable RK1 fuses. JTD_ID series fuses provide IEC Type 2 "No Damage" protection to both NEMA and IEC control components and motor controllers. When time-delay is required and space is the determining factor, JTD_ID time-delay Class J fuses provide the answer.

When conductors are selected in accordance with the NEC®, recommended fuse ratings for mains and feeders rated 1 to 600A with combined motor and non-motor loads are:

- 150% of the largest motor full load current plus,
- 100% of all other motors full load currents plus,
- 125% of the continuous non-motor load plus,
- 100% of the non-continuous, non-motor load.

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Motor Protection for Low Voltage Applications (600 Volts and below)

Motor Characteristics

Motors discussed herein are standard characteristic AC induction motors which cover about 80-85% of all motors used. Motors considered 'special purpose motors' are beyond the scope of this publication. Specific application information and protection requirements for these special purpose motors should be obtained directly from the motor manufacturers.

Horsepower Ratings

A motor's assigned horsepower rating indicates the work that it can perform under standard test conditions. This rating is the maximum horsepower load that the motor can drive over a long period of time without exceeding its rated temperature rise. However, a motor can develop far more horsepower than its rating, and if the overload does not last long enough to overheat the motor, then no damage occurs.

By design, a motor tries to rotate any load attached to it. If the load is too large, the motor will not be able to rotate, will overheat, and fail within a very short period of time. However, if the motor is able to start and run with an overload, excess heat will be generated. If the motor is not stopped or the overload removed, the excessive heat will gradually deteriorate the insulation and the motor will prematurely fail.

Motor RPM

The motor nameplate shows the rated speed of the motor in revolutions per minute (RPM) with rated full load attached. The no-load (synchronous) speed of the motor is somewhat higher and is a function of its design and the number of poles (windings). *Table 1* shows the relationship between the number of poles, the motor's no-load speed, and its full load speed as shown on a motor's nameplate. All nonsynchronous induction motors begin to slow down as the load increases. This is commonly referred to as "slip". As load increases, both the motor current and slip increase.

Table 1
Synchronous (No Load) Speed of Induction Motors vs Full Load Speed

Number of Poles	Synchronous (No Load) Speed (RPM)	Typical Full Load Speed Range (RPM)
2	3600	3450 – 3500
4	1800	1710 – 1760
8	900	855 – 880
12	600	520 – 610

Motor Running Current

Full Load Amperes (FLA or F.L.A.): A motor's rated full load amps (full load current) is the motor's running current when connected to a load equal to its horsepower rating. If the load exceeds the horsepower rating, current will exceed the FLA and the motor may overheat. The vast majority of motors are only partially loaded and as the load decreases, the motor current decreases.

Partially Loaded Motors: If a motor is not connected to any external load, it still requires a certain amount of current to turn the rotor. This is defined as the "no-load amps" or "no-load current". No-load current is a constant for any given motor and does not change with increases or decreases in the load. However, no-load current varies widely for different motor designs and horsepower ratings.

A motor's actual running current is the sum of its no-load current and load current. For all practical purposes, load current increases directly as the load increases. If a motor is loaded to only 50% of rated horsepower, then the actual load current will be approximately 50% of the full potential load current.

As an example...if a given motor's no-load current is 30% of FLA, its load current is 70% FLA ($100\% - 30\% = 70\%$). At 50% rated load, the load current would be about 35% FLA (one-half of 70%). Added to no-load current of 30%, a motor running current at 50% load will be about 65% FLA ($35\% \text{ load current} + 30\% \text{ no-load current} = 65\% \text{ motor running current}$).

If this same motor were 75% loaded, the motor running current would be about 83% FLA ($75\% \text{ of } 70\% \text{ load current is } 52.5\% \dots \text{plus } 30\% \text{ no-load current} = 82.5\% \text{ motor running current}$).

Motor starting currents: Per the simple laws of physics, when a motor is first energized a great deal of energy (or torque) is required to overcome the inertia of the motor and the load. Once the load is moving, it requires much less energy to keep it moving.

At the instant a motor is energized, motor current peaks at about 12 to 15 times the nameplate FLA. This is the current required to magnetize the motor windings. Within 1/2 to 3/4 cycles (0.008 to 0.0125 seconds) the full magnetic field is developed, and current decreases from 12 to 15 times FLA to roughly 4.5 to 8 times FLA. This is called the motor starting current and is also the current the motor will draw if it stops while energized – thus the term 'locked-rotor amps' or LRA.

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The exact value of LRA is determined by a motor's design and is shown on the motor nameplate by the NEMA design letter. Motors designed to start only low inertia loads have the lowest starting current. Motors with the same horsepower ratings but designed to start very high inertia loads such as large flywheels, hammer mills, etc., will have much higher starting currents. *Table 2* shows the starting current for various NEMA design motors.

As the motor speed increases from zero, current remains high until the motor reaches about 85-90% full speed. The current then begins to decrease until the motor reaches full speed for the attached load, at which point current decreases to normal running current.

Table 2
Starting Current (Amperes) for Various Types of Motor Designs

NEMA Code Letter	Locked Rotor KVA Per Hrspwr.	Maximum Locked Rotor Amps for NEMA Code Letter Motors					
		Single Phase		Three Phase			
		115V	230V	200V	230V	460V	575V
A	3.14	27.3	13.7	9.1	7.9	4.0	3.1
B	3.54	30.8	15.4	10.2	8.9	4.5	3.5
C	3.99	34.7	17.4	11.5	10.0	5.0	4.0
D	4.49	39.1	19.5	13.0	11.3	5.7	4.5
E	4.99	43.4	21.7	14.4	12.5	6.3	5.0
F	5.59	48.6	24.3	16.2	14.0	7.0	5.6
G	6.29	54.7	27.4	18.2	15.8	7.9	6.3
H	7.09	61.7	30.8	20.5	17.8	8.9	7.1
J	7.99	69.5	34.8	23.1	20.1	10.1	8.0
K	8.99	78.2	39.1	26.0	22.6	11.3	9.0
L	9.99	86.9	43.5	28.9	25.1	12.6	10.0
M	11.19	97.4	48.7	32.3	28.1	14.1	11.2
N	12.49	108.7	54.3	36.1	31.3	15.7	12.5
P	13.99	121.7	60.9	40.4	35.1	17.6	14.0
R	15.99	139.1	69.6	46.2	40.1	20.1	16.0
S	17.99	156.5	78.3	52.0	45.2	22.7	18.0
T	19.99	173.9	87.0	57.8	50.2	25.2	20.0
U	22.39	194.8	97.4	64.7	56.2	28.2	22.4
V	24.00	208.8	104.4	69.4	60.2	30.2	24.0

Single-phasing of Three-phase Motors

Three phase motors are designed to operate with three balanced phases. When one phase is missing, severe damage may occur if the motor is not rapidly de-energized. This lack of phase may be due to an open wire in a motor junction box, an open motor winding, a blown fuse, a burned contact in a motor controller, a defective circuit breaker, or numerous other conditions. The outcome of what happens when single-phasing occurs depends on the nature of the circuit.

There are several possibilities which must be examined to fully understand the problem:

When there is only one motor single-phased on a circuit...

If the motor is not running at the time and then tries to start while single-phased, it will not have sufficient available energy to overcome starting inertia and will stay in a locked rotor condition. The motor will draw full locked rotor current, and most overcurrent protection devices (fuses and circuit breakers) will open the circuit quick enough to prevent serious motor damage. In theory, if the motor is running at the time it is single-phased, then current in the remaining two legs increases to 1.73 times the current being drawn at that point. Single-phased motors, however, do not have the capability of developing full horsepower and torque so the motors may begin to slow down (or increased slip) depending on the amount of load. The motor is designed to operate at full speed, so the current increases as the slip increases.

A motor that is more than 80% fully loaded at the time of single-phasing will slow down quite rapidly and come to a stop. Current increases to locked rotor values, and the running overcurrent protection will de-energize the circuit in sufficient time to protect the motor from significant damage. A motor that is loaded to less than 50-60% load at the time of single-phasing will not slow down significantly while the current is still increasing to 173% of the current being drawn just prior to single-phasing. Since this is less than the motor's FLA, ordinary running overcurrent protection will not sense this as an abnormal condition and the motor will continue to run. When the motor does stop, it will obviously not restart again until the source of the single-phasing is eliminated. Fortunately, the extra heat generated under these single-phase conditions can usually be dissipated by the motor. Little damage is done, unless the single-phasing continues for an extended period of time. For added protection to large, expensive motors, (especially those used in applications over 600 volts), consideration should be given to the installation of single-phase detection or voltage imbalance relays.

It is the group of motors loaded from 55-60% through 80% that present the greatest challenge. When these motors are single-phased, they slow down but continue to rotate. As a result of the combination between single-phasing (173%) and the current increase that comes with slip increase, current in the energized legs actually increases to approximately 200 to 220% of current being drawn at the time the motor was single-phased. Since these currents may vary from slightly-less-than FLA to as much as 200% FLA, standard overcurrent protection may not provide adequate protection when sized in accordance with rated full load amps of the motor.

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The voltage imbalance in the circuit may also result in extra heat. This additional heat produces damage in excess of that produced by just the current alone. The best way of reducing this type of damage is to measure the actual current drawn by the motor under normal conditions, determine if there may be temporary overloads that need to be considered, and size overcurrent protection just large enough to permit the motor to run under normal conditions.

When there are several motors single-phased on a circuit...

When there is more than one motor on a circuit that is single-phased, the effects on motor current depend on both the relative size of the motors and whether the motors in the circuit are all three-phase motors or consist of a mix of three-phase and single-phase motors.

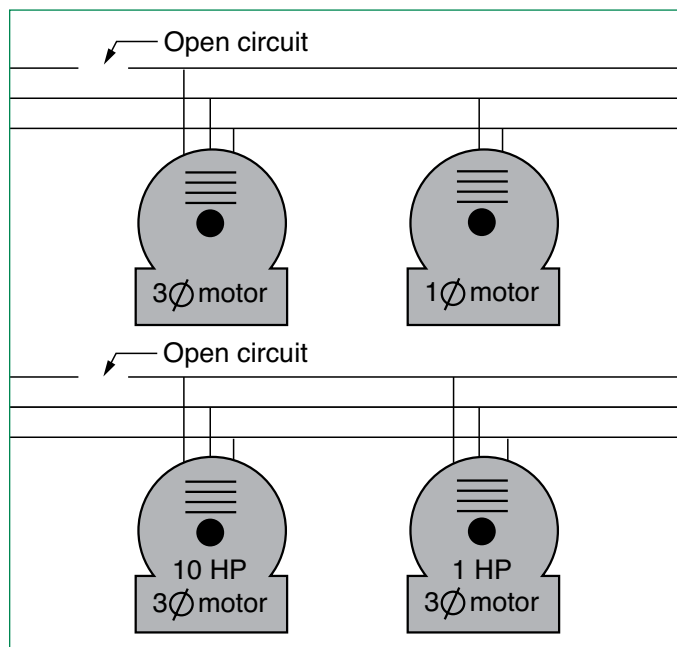


Figure 1

Figure 1 presents two such cases. The top circuit consists of one three-phase motor and one single-phase motor, with the three-phase motor loaded to 70% of full load. The feeder was then single-phased as shown by the open circuit marking. The currents in the three-phase motor increased to 52%, 120%, and 36% of full load current. At 120% current, it is questionable whether standard running overcurrent protection sized at 115% of rated FLA could provide protection from damage due to overload and voltage imbalance.

In comparison, when the lower circuit with the ten horsepower and one horsepower three-phase motors was single-phased, the smaller motor did little to affect the currents in the larger motor...but the one horsepower motor was in serious trouble. One of the currents was 140% of normal, while the other two currents were only slightly above the standard rating of running overcurrent protection.

When the ampere rating of a motor's running overcurrent protection is based on the motor's actual running current, adequate protection may be provided for such conditions. However, as is usually the case, if the ampere rating of a motor's running overcurrent protection is based on nameplate FLA and the motor is only partially loaded, the protective devices (overload relays and fuses) may not open in time to protect the motor because the current will not increase enough to operate the relays.

For these reasons and many others, it is strongly recommended that Littelfuse POWR-GARD™ dual-element fuses be properly sized per the recommended guidelines.

Protection Required by Motors

Since mains and feeders usually serve a mix of inductive and resistive loads, time-delay fuses provide significant advantages for a system's overcurrent protection. Even when there is no motor load, time-delay fuses reduce other nuisance outages caused by temporary overloads or switching surges. Available short-circuit current is generally highest at the main service disconnect such that adequate interrupting capacity and maximum current limitation are also desirable.

Motor Branch Circuits

Most motor circuits contain motor controllers (starters) which start and stop the motor, overload relays to provide motor running protection, and in some cases other relays to provide other types of protection. This white paper will review the protection provided by Motor Protection Relays later in this discussion.

Time-delay fuses should be considered a must for motor branch circuits. Motor starting currents and the possibility of temporary overloads and/or voltage surges would require oversizing of non-time delay fuses – often as much as 300% of the rated current. In such cases, only short-circuit protection is provided and because of the oversizing necessary, larger switches and enclosures are required. This is also true when motor control centers (MCCs) are involved. Properly selected time-delay fuses also provide back-up protection to the motor controllers for such conditions as single-phasing and unintentional contact welding.

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Recommended ratings of Class RK1 and RK5 time-delay fuses for motor branch circuits containing motor controllers with overload relays are as follows:

- For general purpose motors with a 1.15 service factor or 40°C rise, the fuses may generally be rated at 125% of the motor's FLA. When fuse ratings do not exactly match the motor's FLA, it is permissible to use the next larger standard fuse rating assuming it does not exceed the NEC® limitation of 175% of motor's FLA (per NEC Tables 430.248 through 430.250). Following these guidelines will provide optimum protection to the motor and the circuit involved.
- High efficiency motors and NEMA Design E motors have much higher efficiencies and require higher locked rotor currents in relation to FLA. Such motors require careful selection of both fuses and overload relays. In such circuits, it is recommended to size fuses at 150% of FLA, or the next smaller rating.

These recommendations should cover about 90% of all motor applications. For those motors with especially severe starting duty and long acceleration times, NEC® Table 430.52 permits time-delay fuses to be sized up to 175% of motor FLA. If 175% of motor FLA will not permit the motor to start, the fuse rating may be increased to a maximum of 225% of motor FLA.

Motor Protection Tables are included later in this white paper to help simplify the selection of Littelfuse POWR-GARD™ Class RK5, RK1, J, CC and CD fuses for motor running protection and motor branch short-circuit and ground-fault protection.

Motor Feeders 600A and Above with 100% Motor Load

Recommended fuses for motor protection applications rated above 600 amperes are the POWR-PRO® KLPC series. The recommended fuse ratings when conductors are selected in accordance with the NEC are 150% of the largest motor's full load current plus 100% of the full load current of the other motors. If the resulting required rating does not correspond with a KLPC ampere rating, it is permissible to use the next larger ampere rating.

Fuses for Mains and Feeders With No Motor Loads

The minimum fuse rating for mains and feeders without any motor load is 125% of the continuous load plus 100% of the non-continuous load.

Fusing Motor Control Centers (MCCs)

The same general considerations apply to protecting MCCs as they do to protecting mains and feeders. Use time-delay current-limiting fuses as outlined above to provide protection to the entire MCC including its buses and internal construction.

Feeders serving a MCC are sized the same as general purpose mains and feeders as many MCCs have both motor and non-motor loads. Non-motor loads may include fused switches that serve dry-type power transformers used for lighting panels, or feeders to distribution panels. MCC ampere ratings based on the MCC main buses usually exceed the load connected to the MCC. As a result, fuses feeding the MCC or located in a main switch within the MCC may be rated to protect the MCC buses as long as they meet the minimum size as determined above.

When Using AC Motor Protection Tables to Select Fuse Ratings...

The time-delay Class RK1 and RK5 fuse ratings recommended in these Tables are determined in accordance with and meet NEC® requirements for Motor Branch circuit and Short-Circuit Protection.

When Selecting Fuses for Motor Running Protection Based on Motor Horsepower...

Motor horsepower and motor Full Load Amperes (FLA) shown in these Tables are taken from NEC Tables 430.248 through 430.250 and cover standard speed AC motors with normal torque characteristics. Fuse ratings for motors with special characteristics may need to vary from given values.

- If motor running protection will be provided by the fuses, select fuse ratings for correct type of motor from Motor Protection Table Columns headed 'Without Overload Relays'.
- If overload relays will provide principal motor running protection, select fuse ratings for the correct type of motor from Motor Protection Table Columns headed 'Back-up Running Protection' or 'With Overload Relays'. Fuse ratings selected from these columns coordinate with most UL Class 10 and 20 overload relays which covers over 90% of typical motor applications.

When Selecting Fuses for Motor Running Protection Based on Motor Actual Full Load Currents...

Better protection is achieved when fuse ratings are based on a motor's actual FLA obtained from motor nameplates. Locate the motor nameplate FLA in the column appropriate for the type of motor and type of protection required. Then select the corresponding ampere rating of the fuse from the first column of that line.

Protection Tables - Class J, CC, and CD

Selection of Class RK5 Fuses (FLNR_ID / FLSR_ID / IDSR Series) or POWR-PRO® Class RK1 Fuses (LLNRK / LLSRK / LLSRK_ID Series) Based on Motor Horsepower

MOTOR HP	FULL LOAD AMPS	WITHOUT OVERLOAD RELAYS		WITH OVERLOAD RELAYS		SWITCH OR FUSE CLIP RATING
		S.F. = 1.15 OR MORE, TEMP RISE NOT OVER 40°C	S.F. = LESS THAN 1.15 OR TEMP RISE MORE THAN 40°C	S.F. = 1.15 OR MORE, TEMP RISE NOT OVER 40°C	S.F. = LESS THAN 1.15 OR TEMP RISE MORE THAN 40°C	
120 VOLT 1-PHASE MOTORS (120V CIRCUIT)						
1/8	4.4	5	5	5 ^{5/10}	5 ^{5/10}	30
1/4	5.8	7	6 ^{1/4}	7 ^{1/2}	7	30
1/2	7.2	9	8	9	9	30
3/4	9.8	12	10	15	12	30
1	13.8	15	15	17 ^{1/2}	17 ^{1/2}	30
1 1/2	16	20	17 ^{1/2}	20	20	30
2	20	25	20	25	25	30
2 1/2	24	30	25	30	30	30
230 VOLT 1-PHASE MOTORS (240V CIRCUIT)						
1/8	2.2	2 ^{1/2}	2 ^{1/2}	2 ^{5/10}	2 ^{5/10}	30
1/4	2.9	3 ^{1/2}	3 ^{3/10}	4	3 ^{3/10}	30
1/2	3.6	4 ^{1/2}	4	4 ^{1/2}	4 ^{1/2}	30
3/4	4.9	5 ^{5/10}	5 ^{5/10}	6 ^{1/4}	6	30
1	6.9	8	7 ^{1/2}	9	8	30
1 1/2	8	10	9	10	10	30
2	10	12	10	15	12	30
2 1/2	12	15	12	15	15	30
3	17	20	17 ^{1/2}	25	20	30
5	28	35	30*	35	35	60
7 1/2	40	50	45	50	50	60
10	50	60	50	70	60	60
200 VOLT 3-PHASE MOTORS (208V CIRCUIT)						
1/2	2.5	3	2 ^{5/10}	3 ^{3/10}	3	30
3/4	3.7	4 ^{1/2}	4	5	4 ^{1/2}	30
1	4.8	6	5 ^{5/10}	6 ^{1/4}	6	30
1 1/2	6.9	8	7 ^{1/2}	7 ^{1/2}	8	30
2	7.8	9	8	10	9	30
3	11	12	12	15	15	30
5	17.5	20	20	25	25	30
7 1/2	25.3	30*	25*	35	30*	60
10	32.2	40	35	45	40	60
15	48.3	60	50	70†	60	60
20	62.1	75	70	80	75	100
25	78.2	90	80	100	90	100
30	92	110	100*	125	110	200
40	120	150	125	150	150	200
50	150	175	150	200	175	200
60	177	200*	200*	225	225	400
75	221	250	250	300	300	400
100	285	350	300	400	350	400
125	359	400*	400*	450	450	600
150	414	500	450	600	500	600
230 VOLT 3-PHASE MOTORS (240V CIRCUIT)						
1/2	2.2	2 ^{5/10}	2 ^{1/2}	2 ^{5/10}	2 ^{5/10}	30
3/4	3.2	4	3 ^{1/2}	4	4	30
1	4.2	5	4 ^{1/2}	5 ^{5/10}	5	30
1 1/2	6.0	7 ^{1/2}	6 ^{1/4}	7 ^{1/2}	7 ^{1/2}	30
2	6.8	8	7 ^{1/2}	9	8	30
3	9.6	12	10	12	12	30
5	15.2	17 ^{1/2}	17 ^{1/2}	20	17 ^{1/2}	30
7 1/2	22	25	25	30	30	30
10	28	35	30*	35	35	60
15	42	50	45	60	50	60
20	54	60*	60*	70	70	100
25	68	80	75	90	80	100
30	80	100	90	100	100	100
40	104	125	110	150	125	200
50	130	150	150	175	150	200
60	154	175	175	200	200	200
75	192	225	200*	250	225	400
100	248	300	250	350	300	400
125	312	350	350	400	400	400
150	360	450	400*	450	450	600
200	480	600	500	600	600	600

MOTOR HP	FULL LOAD AMPS	WITHOUT OVERLOAD RELAYS		WITH OVERLOAD RELAYS		SWITCH OR FUSE CLIP RATING
		S.F. = 1.15 OR MORE, TEMP RISE NOT OVER 40°C	S.F. = LESS THAN 1.15 OR TEMP RISE MORE THAN 40°C	S.F. = 1.15 OR MORE, TEMP RISE NOT OVER 40°C	S.F. = LESS THAN 1.15 OR TEMP RISE MORE THAN 40°C	
460 VOLT 3-PHASE MOTORS (480V CIRCUIT)						
½	1.1	1⅓	1¼	1⅓	1⅓	30
¾	1.6	2	1⅝	2	2	30
1	2.1	2½	2¼	2⅝	2½	30
1½	3.0	3½	3⅔	4	3½	30
2	3.4	4	3½	4½	4	30
3	4.8	5⅝	5	6	5⅝	30
5	7.6	9	8	10	9	30
7½	11	12	12	15	15	30
10	14	17½	15	17½	17½	30
15	21	25	20	30	25	30
20	27	30*	30*	35	35	60
25	34	40	35	45	40	60
30	40	50	45	50	50	60
40	54	60*	60*	70	60*	100
50	65	80	70	90	75	100
60	77	90	80	100	90	100
75	96	110	110	125	125	200
100	124	150	125	175	150	200
125	156	175	175	200	200	200
150	180	225	200*	225	225	400
200	240	300	250	300	300	400
575 VOLT 3-PHASE MOTORS (600V CIRCUIT)						
½	0.9	1⅓	1	1⅓	1⅓	30
¾	1.3	1⅝	1⅓	1⅝	1⅝	30
1	1.7	2	1⅝	2¼	2	30
1½	2.4	3	2½	3	3	30
2	2.7	3⅔	2⅝	3½	3⅔	30
3	3.9	4½	4	5	4½	30
5	6.1	7½	7	8	7½	30
7½	9	10	10	12	12	30
10	11	12	12	15	15	30
15	17	20	17½	25	20	30
20	22	25	25	30	30	30
25	27	30*	30*	35	35	60
30	32	40	35	40	40	60
40	41	50	45	60	50	60
50	52	60	60	70†	60	60
60	62	75	70	80	75	100
75	77	90	80	100	90	100
100	99	110	110	125	125	200
125	125	150	125	175	150	200
150	144	175	150	200	175	200
200	192	225	200*	250	225	400

NOTES

S.F. = Motor Service Factor

* Fuse Reducers Required

† 100 Amp Switch Required

Protection Tables - Class J, CC, and CD

Selection of POWR-PRO® Class J Fuses (JTD_ID / JTD Series) Based on Motor Full Load Amps

MOTOR F.L.A.	JTD_ID / JTD AMPERE RATING	MOTOR F.L.A.	JTD_ID / JTD AMPERE RATING	MOTOR F.L.A.	JTD_ID / JTD AMPERE RATING
0.00 – 0.60	$\frac{8}{10}$	12.1 – 14.5	17 $\frac{1}{2}$	76.1 – 84.0	110
0.61 – 0.80	1	14.6 – 17.0	20	84.1 – 90.0	125
0.81 – 1.00	1 $\frac{1}{4}$	17.1 – 21.0	25	90.1 – 102	150
1.01 – 1.20	1 $\frac{1}{2}$	21.1 – 25.0	30	103 – 125	175
1.21 – 1.65	2	25.1 – 28.5	35	126 – 144	200
1.66 – 2.00	2 $\frac{1}{2}$	28.6 – 34.0	40	145 – 162	225
2.01 – 2.40	3	34.1 – 37.0	45	163 – 180	250
2.41 – 3.30	4	37.1 – 41.0	50	181 – 204	300
3.31 – 4.10	5	41.1 – 48.0	60	205 – 240	350
4.11 – 4.90	6	48.1 – 52.0	70	241 – 288	400
4.91 – 6.40	8	52.1 – 59.0	80	289 – 312	450
6.41 – 8.00	10	59.1 – 66.0	90	313 – 360	500
8.01 – 9.80	12	66.1 – 76.0	100	361 – 432	600
9.81 – 12.0	15				

NOTE: For severe motor starting conditions, fuses may be sized up to 225% motor F.L.A. (See NEC® Article 430.52 for Exceptions)

Selection of CCMR Time-Delay Fuses Based on Motor Full Load Amps

MOTOR FULL LOAD CURRENT (F.L.A.)						CCMR AMPERE RATING
FOR MOTORS WITH AN ACCELERATION TIME OF 2 SECONDS OR LESS		FOR MOTORS WITH AN ACCELERATION TIME OF 5 SECONDS OR LESS		FOR MOTORS WITH AN ACCELERATION TIME OF 8 SECONDS OR LESS		
MIN. F.L.A. (1)	MAX F.L.A. (3)	MIN. F.L.A. (1)	MAX F.L.A. (3)	MIN F.L.A. (2)	MAX F.L.A. (3)	
0.2	0.2	0.2	0.2	0.2	0.2	$\frac{3}{10}$
0.3	0.4	0.3	0.4	0.3	0.3	$\frac{1}{2}$
0.4	0.6	0.4	0.5	0.4	0.5	$\frac{8}{10}$
0.5	0.7	0.5	0.6	0.5	0.6	1
0.6	1.0	0.6	0.9	0.6	0.8	$1\frac{1}{4}$
0.8	1.1	0.8	1.0	0.7	0.9	$1\frac{1}{2}$
0.9	1.3	0.9	1.1	0.8	1.0	$1\frac{9}{10}$
1.1	1.4	1.1	1.2	0.9	1.1	2
1.2	2.1	1.2	2.1	1.2	1.8	$2\frac{1}{2}$
1.5	2.6	1.5	2.6	1.4	2.3	3
1.8	3.0	1.8	3.0	1.6	2.6	$3\frac{1}{2}$
2.1	3.4	2.1	3.2	1.8	2.8	4
2.3	3.9	2.3	3.3	2.0	2.8	$4\frac{1}{2}$
2.6	4.3	2.6	3.4	2.3	2.8	5
2.9	4.8	2.9	3.7	2.5	3.1	$5\frac{1}{10}$
3.3	5.2	3.3	4.0	2.7	3.4	6
3.5	5.4	3.5	4.1	2.8	3.5	$6\frac{1}{4}$
3.6	5.7	3.6	4.2	3.2	3.7	7
4.1	5.8	4.1	4.3	3.4	3.8	$7\frac{1}{2}$
4.3	6.2	4.3	4.6	3.6	4.2	8
4.6	6.9	4.6	5.2	4.0	4.5	9
5.2	7.7	5.2	5.8	4.5	4.9	10
5.8	8.9	5.8	6.6	5.4	5.5	12
6.9	10.0	6.9	7.7	6.7	6.7	15
8.9	13.5	8.9	10.0	6.8	9.0	20
11.5	15.8	11.2 (2)	11.8	9.0	11.0	25
14.3	17.8	13.4 (2)	13.4	10.0	15.0	30
20.7	23.3	16.1	17.9	15.6	15.9	35
23.7	26.7	18.4	20.5	17.8	18.2	40
26.6	30.0	20.7	23.1	20.0	20.4	45
30.0	33.3	23.0	25.6	22.3	22.7	50
35.5	40.0	27.6	30.1	26.7	27.3	60

1 Based on NEC requirement limiting the rating of time-delay fuses to 175% of motor F.L.A., or next higher rating.

2 Based on NEC exception permitting fuse rating to be increased, but not to exceed, 225% motor F.L.A., however per NEC Article 430.52 Class CC (0-30) fuses can now be sized up to 400% of motor F.L.A.

3 Based on Littelfuse CCMR time-delay characteristics.

NOTE: These values were calculated for motors with Locked Rotor Current (LRA), not exceeding the following values:

MOTOR F.L.A.	*LRA
0.00 – 1.00	850%
1.01 – 2.00	750%
2.01 – 10.0	650%
10.1 – 17.8	600%

*If motor LRA varies from these values, contact Littelfuse.

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Motor Protection for Medium Voltage Applications (above 600 Volts)

Introduction

Medium voltage fuses are applied quite differently than fuses rated 600 volts and less. The biggest difference is that medium voltage fuses are not intended to provide overload protection. They should only be applied in situations where it will not be required to open small overcurrents. Medium voltage fuses offer a much wider range of system voltages, thereby resulting in a correspondingly large number of fuse voltage ratings.

Descriptions and ratings of Littelfuse medium voltage fuses, along with some application data, are located in the Medium Voltage Fuse section of the Littelfuse POWR-GARD® Catalog.

To download a copy visit www.littelfuse.com/catalogs.



For questions, contact our Technical Support and Engineering Services Group at **800-TEC-FUSE (800-832-3873)**.

Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog.

The following is a more detailed discussion of factors which must be considered when properly selecting and applying medium voltage fuses in electrical systems.

What are Medium Voltage Fuses?

Littelfuse medium voltage fuses are silver-sand, non-expulsion design, current-limiting type devices. When properly applied, they are designed to carry their nominal current rating continuously without “fatigue failure.” This means that the fuse will not age, become brittle, or deteriorate under the most severe duty cycling.

When talking current-limiting medium voltage fuses, there are two basic types: general purpose and back-up. General purpose fuses have the ability to interrupt both large and small short-circuits down to currents which would cause the fuse to open within one hour. They are used to provide short-circuit protection for transformers, switchgear, and similar equipment.

Back-up fuses are designed to protect only against high fault currents, and must be used in series with equipment which provides the circuit’s required overload and low value short-circuit protection.

Medium Voltage (MV) “E-rated” fuses are considered general purpose fuses. Their mounting dimensions permit them to be installed in a wide variety of medium voltage switches, in pad-mounted transformers, and at other similar locations. “R-rated” MV fuses are specifically designed to provide short-circuit protection for medium voltage motor controllers and associated equipment.

Motor Protection

To properly select medium voltage fuses for motor protection, several factors should be considered. First, R-rated fuses are only intended for short-circuit protection and should be applied in conjunction with motor overload relays. An R-rated fuse does not have an ampere rating, and the “R” rating refers to the opening time of the fuse. R-rated fuses are designed to safely interrupt any current between their minimum and maximum interrupting ratings. When applying R-rated fuses, it is recommended to follow the fuse sizing guidelines established by the motor starter manufacturer.

When engineering an electrical system, time-current characteristic curves of the fuse and overload relay should be compared and analyzed to insure the overload relay opens before the fuse does during overload conditions. The following table is provided as a guideline for sizing medium voltage R-rated fuses.

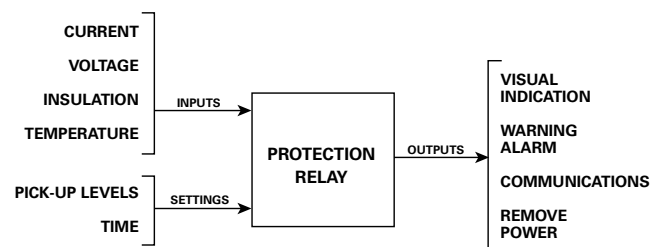
R-Rated Fuse Sizing Table

For Motors with an Acceleration of 10 Seconds		For Motors with an Acceleration of 3 Seconds	
Max.Motor FLA	R Rated Fuse	Max.Motor FLA	R Rated Fuse
28A	2R	32A	2R
40A	3R	45A	3R
55A	4R	65A	4R
80A	6R	95A	6R
125A	9R	140A	9R
165A	12R	190A	12R
250A	18R	280A	18R
330A	24R	360A	24R
500A	36R	550A	36R

Motor Protection for Relays

What is a Protection Relay?

A protection relay is a smart device that receives inputs, compares them to set points, and provides outputs. Inputs can be current, voltage, resistance, or temperature. Outputs can include visual feedback in the form of indicator lights and/or an alphanumeric display, communications, control warnings, alarms, and turning power off and on. A diagram is shown below.



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Protection relays can be either electromechanical or electronic/microprocessor-based. Electromechanical relays are an obsolete technology consisting of mechanical parts that require routine calibration to stay within intended tolerances. Microprocessor or electronic relays use digital technology to provide quick, reliable, accurate, and repeatable outputs. Using an electronic or microprocessor-based relay instead of an electromechanical design provides numerous advantages including improved accuracy, additional functions, reduced maintenance, smaller space requirements and reduced lifecycle costs.

Overview

Motors are a significant investment for any facility and often run critical processes. Motor protection relays are used to protect the windings in the stator from damage due to electrical faults and thermal overloads. Adequate motor protection not only prevents motor damage, but also ensures optimal process efficiency and minimal interruption. Cost recovery for protection is achieved by extending the life of the motor, preventing motor rewinds and reducing downtime.

Common Motor Problems

Overload and Overtemperature

Insulation breakdown is a common reason for motor failure. Windings in the motor are insulated with organic materials including epoxy and paper. Insulation degradation occurs when winding temperature exceeds its rating. The National Electrical Manufacturers Association (NEMA) states that the

time-to-failure of organic insulation is halved for each 8 to 10°C rise above the motor insulation class rating. This point is illustrated in *Figure 2*.

Solution: An I²t Thermal Model provides thermal-overload protection of motor windings during all phases of operation. By integrating the square of the current over time, a thermal model can predict motor temperature and react much quicker than embedded temperature devices. A thermal model takes into consideration the motor service factor, full-load current and class.

A dynamic thermal model adjusts the time-to-trip depending on how much motor thermal capacity has been used. *Figure 3* illustrates the adjustment in trip time for different current levels at different levels of used thermal capacity.

A dynamic thermal model allows conservative protection of a motor and allows operations to get the maximum work out of a motor without sacrificing available life. If the motor is hot (high % used thermal capacity) it will trip more rapidly during an overload than if the motor is cold (0% used thermal capacity). In the event of a stall condition when available motor torque is lower than the torque required by the load, the motor can be de-energized before it overheats.

Many old-technology electronic thermal overloads do not take into consideration the values of load current below the full-load current (FLA) pick-up value. Modern overload relays should model currents above and below the FLA pickup current to achieve maximum output of the motor and maximum life of insulation.

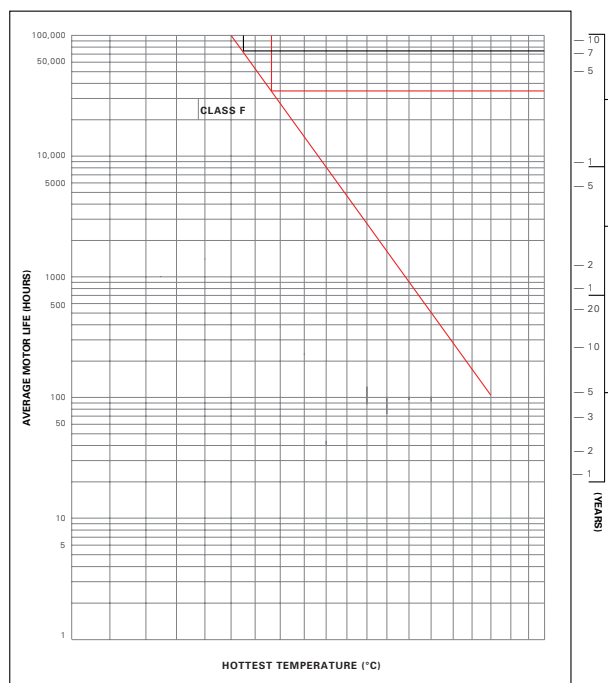


FIGURE 2

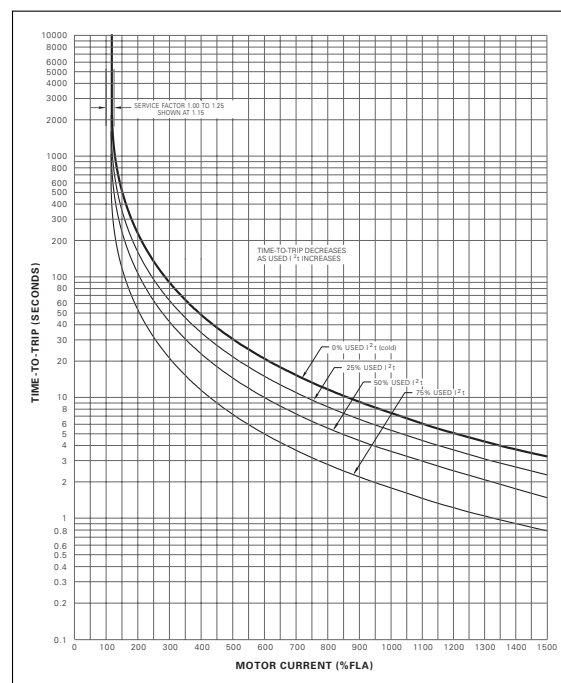


FIGURE 3

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On larger induction motors, blockage or loss of ventilation can cause motor hot spots that current-based protection cannot detect without the use of temperature sensors. Resistance temperature detectors (RTDs) are an inexpensive device installed between the stator windings during manufacturing and may be included on motor-end bearings. An RTD has a linear change in resistance over its rated temperature range. Using information from an RTD, motor protection relays can provide protection for loss-of-ventilation, loss-of-cooling, or high-ambient-temperature.

The RTD temperature reading can also be used as input to the thermal model to improve protection.

When hot-motor compensation is enabled, the maximum stator-RTD temperature is used to bias the thermal model by increasing used I_{2t} when the RTD temperature is greater than the thermal-model temperature.

Overcurrent, Jam and Undercurrent

Overcurrent faults (also referred to as short circuits) can cause catastrophic motor failures and fires. Overcurrents can be caused by phase-to-phase and phase-to-ground-to-phase faults.

A mechanical jam, such as a failed bearing or load, can cause locked-rotor current to be drawn by the motor, resulting in overheating.

Undercurrent protection is required by some codes as a safety measure. A water pump that cavitates can be dangerous. The water typically provides pump cooling, and without the cooling water, the case temperature can reach an extremely high value. If valves are opened under these conditions and cold water is allowed to reach red-hot metal parts, the resulting steam pressures can destroy the pump and pose a serious personnel hazard.

Solutions: A multifunction motor protection relay has multiple trip and alarm settings for current protection. Overcurrent protection is typically set above the locked rotor current and has a minimal delay time. Overcurrent protection may be used to trip a breaker instead of a starter due to the high fault levels involved. Jam protection is set below overcurrent and has a slightly longer delay time. Jam protection prevents motor heating that would otherwise lead to an overload trip and is enabled after the motor is running to avoid tripping on starting current. Undercurrent is set below full-load current to detect loss of load.

Under and Overvoltage

Overvoltages cause insulation stress and premature breakdown. Undervoltages, such as those caused by brownouts, can lead to increased motor heating. Torque developed by an electric motor changes as the square of the applied voltage. For example, a 10% reduction in voltage results in a 19% reduction in torque. If the motor load is not reduced, the motor will be overloaded.

Solution: Undervoltage and overvoltage protection are features found in a higher-end motor-protection relays. Voltage protection can be used proactively to inhibit a start.

Ground Faults

Ground faults are the most common type of fault and can lead to more serious problems. Ground-fault protection, described further in the Littelfuse Protection Relays Catalog (literature #PF-130) and on our Protection Relays website (www.littelfuse.com/protectionrelays), is also an important consideration when considering motor loads.

Solution: The motor protection relay should be able to detect low-level ground-fault current when used on a resistance-grounded system.

High Resistance Winding Faults

As a result of low magnitudes of current, winding-to-winding and winding-to-ground failures inside the motor are difficult to detect using the phase and ground-fault current transformers (CTs).

Solution: Differential protection in high-end, motor protection relays use multiple CTs to compare the amount of current entering and leaving the winding. If a difference in currents exists, then leakage is occurring. This sensitive protection is most commonly used on very large motors.

Current and Voltage Unbalance, Phase Loss, Phase Reverse

Older motor protection systems typically did not consider current unbalance, and today it is often overlooked. Unbalance increases negative-sequence current which causes additional rotor heating.

Phase loss is also referred to as single phasing. When a phase loss occurs, negative-sequence current is equal to the positive-sequence current and unbalance is 100%. In this condition, one motor winding attempts to do the work of three, inevitably leading to overheating.

Phase reversal causes the negative-sequence current and voltage to be greater than the positive-sequence current and voltage. Voltage-based protection is advantageous to prevent a start with an incorrect sequence. In some applications, attempting to spin the motor backwards will result in damage to the load. An example of this scenario is certain impeller designs in downhole pumps.

Solution: Modern motor protection relays use digital signal analysis to measure true-sequence components. These sequence components are used for thermal model calculations and take the extra heating into consideration. Voltage imbalance which drives current imbalance can be used as a start inhibitor. Sequence components are also used for calculating imbalance, phase loss and phase reversal.

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Motor Jogging

NEMA designed motors are rated for two starts from cold and one start from hot per hour. Motor jogging refers to excessive numbers of starts above these limits, and can cause overheating. The motor may not get up to full speed and as a result, the forced air cooling is not effective.

Solution: Since the thermal model accurately tracks the motor's used thermal capacity at all times including during starts and between starts, the starts-per-hour feature may not be required. It is included for compatibility with protection relays that do not have dynamic thermal-modeling capability.

Motor Protection and the NEC®

The NEC requires the motor be protected by overload devices against excessive heating due to overload and failure to start (NFPA 70 Article 430 Section III).

NFPA 70 Article 430, Part IV also specifies the use of devices to protect against overcurrents such as short circuits and grounds. Both of these NEC requirements and many additional functions can be achieved with the use of a multifunction motor-protection relay.

For motors larger than 1500 hp, NFPA 70 Article 430.32 (A)(4) requires the use of a protection device having embedded temperature detectors that cause current to the motor to be interrupted when the motor attains a temperature rise greater than marked on the nameplate in an ambient temperature of 40°C.

Generally speaking, the NEC defines minimum requirements and is intended to provide protection from fire. Protection relays can provide many enhancements to a facility above and beyond simple fire protection.

Communications

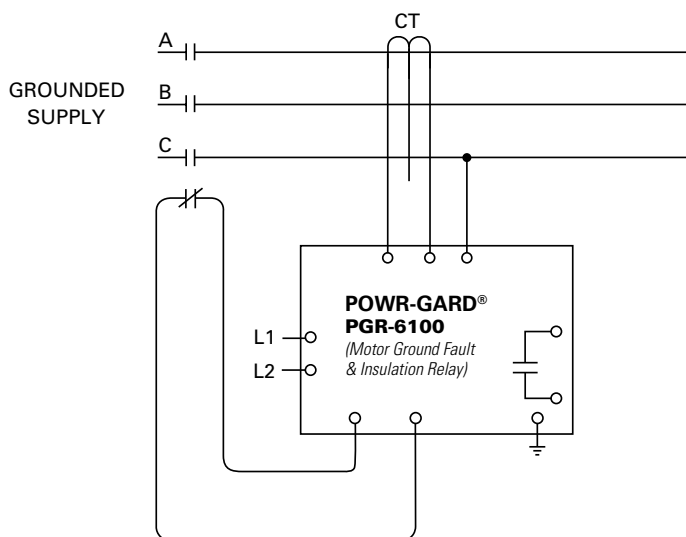
Network communications can be added to a motor protection relay to allow remote metering of currents, voltages and temperatures. Data logging is a useful feature for troubleshooting and comparing event sequences with process stages. Analysis of such information can often show operational issues that might not otherwise be apparent.

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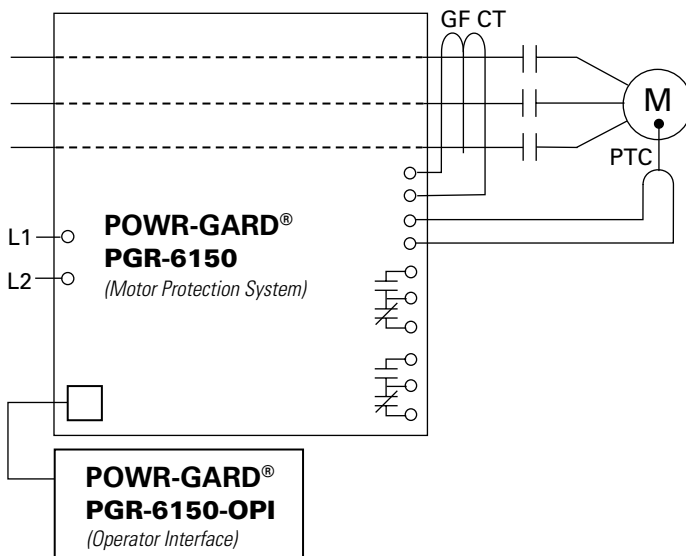
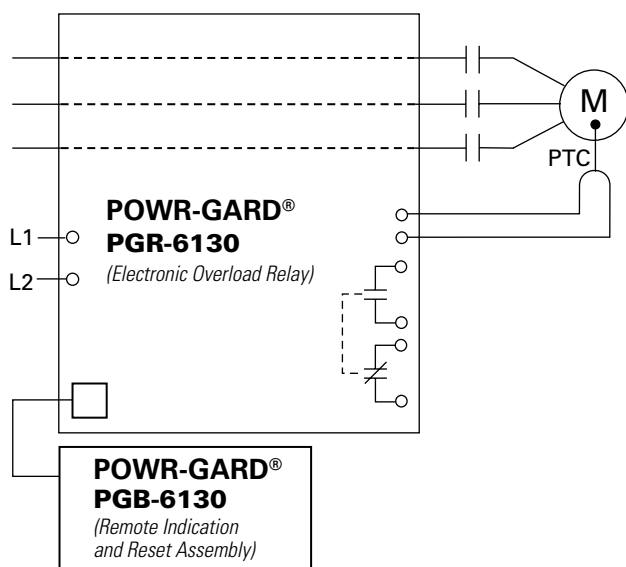


MOTOR PROTECTION

GROUND FAULT PROTECTION AND INSULATION MONITORING



MOTOR PROTECTION RELAYS

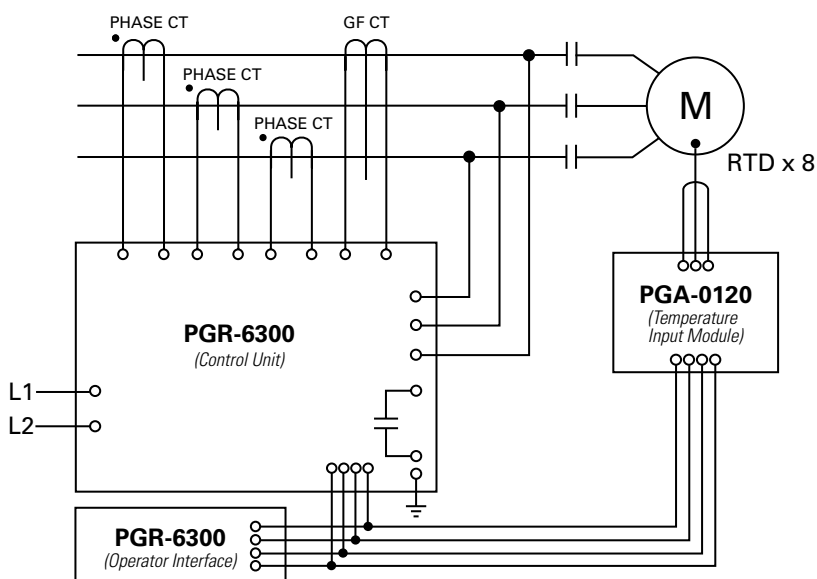
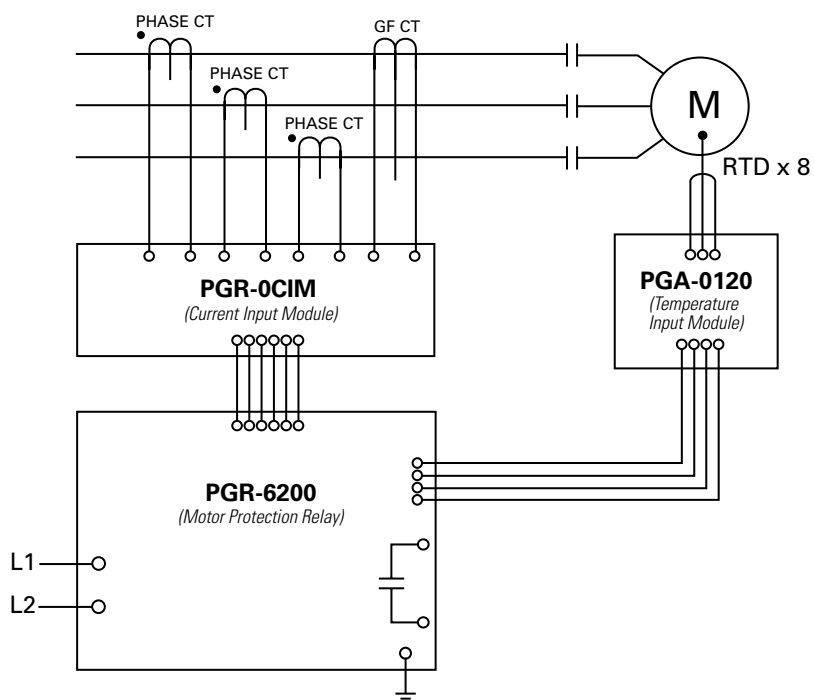


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MOTOR PROTECTION

MOTOR PROTECTION UNIT



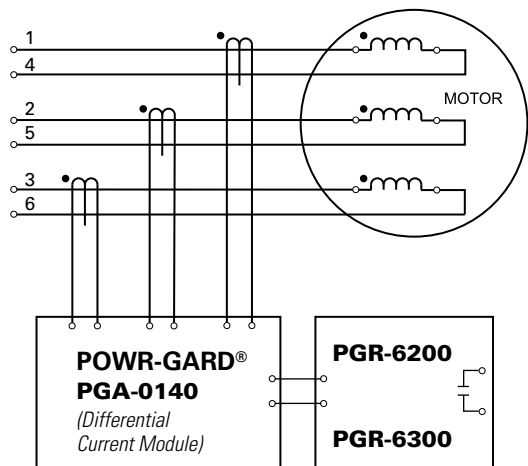
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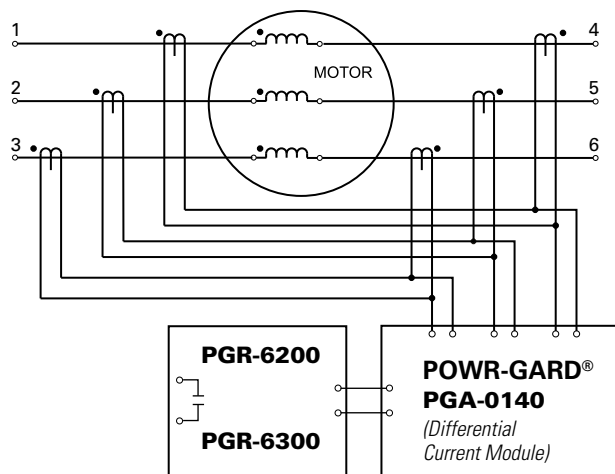
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MOTOR PROTECTION

MOTOR DIFFERENTIAL PROTECTION

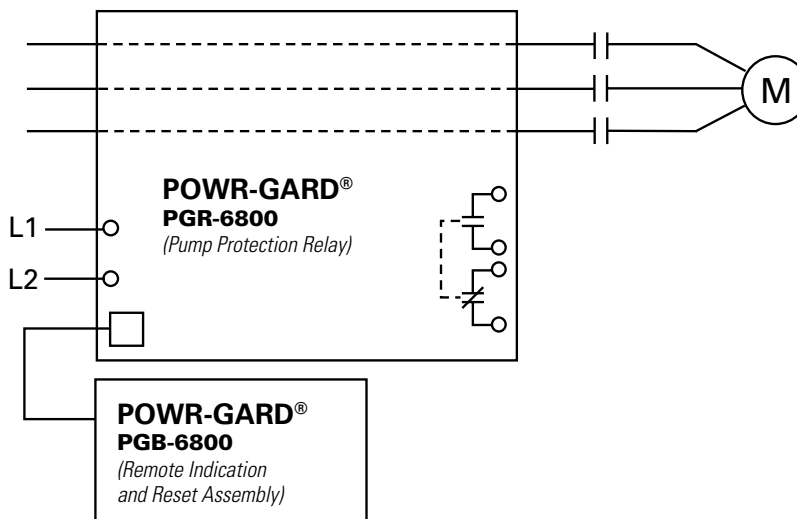


Core-Balance Connection



Summation Connection

PUMP PROTECTION RELAY



Additional technical information and application data for Littelfuse POWR-GARD® protection relays, fuses and other circuit protection and safety products can be found on www.littelfuse.com. For questions, contact our Technical Support Group (800-832-3873). Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog. To download a copy visit www.littelfuse.com/catalogs.