

ACHIEVING MAXIMUM BENEFITS WITH A FUSE PROTECTED MOTOR CONTROL CENTER

SYSTEM PROTECTION NOTE 2

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INTRODUCTION

Increasing concern for arc flash safety has grown to include both operators of electrical equipment as well as electrical workers. Internal arc faults can blow open doors of low voltage equipment including motor control centers (MCC) that have been properly installed^[1]. Should this occur when an operator is interacting with the equipment, the worker can very easily be exposed to the hazards of arc flash. MCC manufacturers have responded with 'arc resistant' low voltage MCCs that have been tested according to an IEEE standard^[2] to prove that the MCC contains the hazards of arc flash should an arc fault occur with the doors properly closed. Additionally, many companies are focusing efforts to get lower incident energy levels on equipment that has frequent worker interaction with the doors open. Many are seeking the lowest values that are economically feasible.

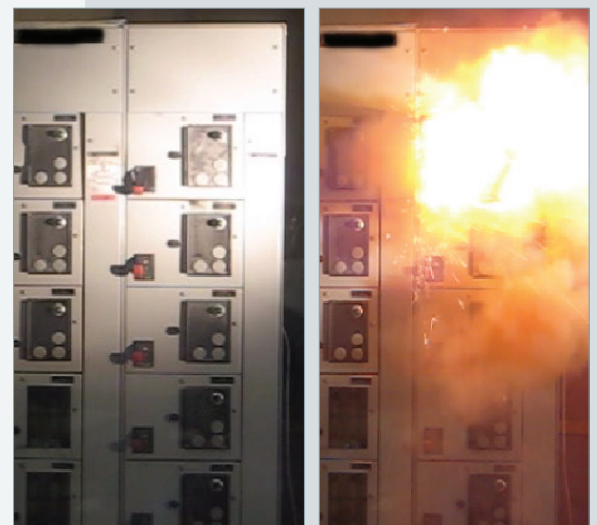
Maintaining continuity of power to critical loads requires a system view when deciding on overcurrent protective devices (OCPD) to protect against arc flash. Continuity of service requires that feeder OCPD allow MCC branch devices to clear faults within their zone of protection. If this requires that the upstream feeder OCPD has a delay added to its trip, incident energy levels at the downstream MCC will be increased. Thus, decisions about OCPD's within the MCC can indirectly affect the levels of incident energy at the MCC.

Since current limiting fuses can be coordinated within their short circuit region without any intentional delay, it is possible to dramatically limit the energy delivered to arcing faults without compromising continuity of service because of a short circuit event. Class J fuses can limit incident energy to well below the accepted 2nd degree burn threshold of 1.2 cal/cm². Properly sized fuses can also minimize damage to faulted equipment and provide the best protection of components in the fault path.

When possible, engineers should also consider future changes to the power system that could require changeout of all OCPD. Consideration should be given to the obsolescence of OCPD caused by the increased fault currents from future service expansions.

PROTECTION OBJECTIVES

- **Arc flash safety beyond target values of incident energy desired at the MCC**
- **Continuity of service requiring full coordination of all OCPD**
- **Optimum protection of equipment and components**
- **Long and reliable performance**



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Similarly, a conversion to high resistance grounding might also yield OCPD ratings inadequate. Finally, the reliability of the protection system over many years must be considered.

This paper provides an overview of the considerations necessary to achieve maximum benefits from a motor control center with branch circuit fuse protection. Particular emphasis is placed on the protection of workers, continuity of service and protection of equipment. Reference are provided throughout for more in depth information.

PROTECTION OBJECTIVES

In addition to selecting the proper fuse ratings, objectives should be defined for the following factors when selecting the type of OCPD for a MCC.

1. Arc flash safety beyond target values of incident energy desired at the MCC.
2. Continuity of service requiring full coordination of all OCPD.
3. Optimum protection of equipment and components.
4. Long and reliable performance.

Since the selection of the branch OCPD can affect the selection of the feeder or main OCPD, the evaluation of your options must include the performance of the feeder protective device with respect to these factors.

1. Arc Flash Safety

Electrical safety programs must ensure that all workers who interact with electrical equipment are protected from arc flash hazards to a level of risk acceptable to the organization. Arc resistant MCCs are a great option for minimizing the likelihood of operators being exposed to the arc flash hazard when interacting with the equipment when it is properly closed. An arc resistant MCCs rated with a A4BQ Class L main fuse should be very similar in construction to conventional MCCs and not have special venting requirements.^[2]

Even with an arc resistant MCC that will protect workers against arc flash hazards when the door is closed, consideration should be given to the required level of PPE worn by electrical workers who interact with the MCC while it is energized and the door open. An incident energy goal of less than 1 cal/cm² to reduce the risk of serious worker injury

can usually be obtained throughout the life of the MCC with proper selection of fuses.

2. Coordination and Continuity of Power

For optimal performance of the protection system, it is highly desirable that the feeder OCPD does not open for faults on any of the motor circuits. If it is possible for the main protective device to trip for faults downstream of a branch OCPD, then all loads powered by the MCC would be lost. This lack of coordination will not only result in more widespread outages but will cause increased difficulties in determining the location of the problem, increased time to restore power and processes, and the possibility that a worker may need to interact with an upstream device that may require higher rated PPE.

It is important to note that the OCPDs selected for the branch circuits of the MCC will limit your options with the feeder OCPD when coordination is desired. Intentional trip delays within the feeder OCPD to improve coordination with branch protective devices will raise incident energy to the entire MCC. These delays are not necessary with properly selected fuses.

It is also desirable that each branch short circuit protective device coordinates with the overload devices in its circuit. If the branch fuse is sized so as to allow time for the overload protection to clear overloads, it will be easier to troubleshoot and faster to restore equipment to service. Opening of the branch fuse would then be a clear indication of a fault on the circuit and the need to comply with the requirements 130.6(M) of NFPA 70E^[3].

3. Optimum Protection of Equipment and Components

Internal Faults. When an arc fault occurs within the MCC the amount of energy delivered to the fault can adversely impact the amount of effort required to return the equipment back to service after repairs. The greater the arc energy allowed by the feeder OCPD, the greater the damage and effort required to repair the equipment. If too much energy is transferred to the internal arc fault, extensive damage could occur and pose danger to nearby workers. Some researchers suggest limiting arc energies to less than 100kWs to ensure minimal damage that can be repaired in the field.^{[4][5]}

External Faults. When a fault occurs at a motor, large fault currents can flow through components of the

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MCC causing damage to vulnerable parts. Starters are particularly susceptible to damage of their contacts and overload elements. Most starters have been tested and certified to Type 2 (no damage) levels of protection with specific OCPDs (e.g. AJT Class J fuses).^[6]

Finally, the magnitude of energy allowed to downstream arc faults must be considered since it may have an effect on the ability to contain arc flash hazards from nearby workers. In a paper by Crawford et al on motor terminal box (MTB) explosions, the authors recommended Class RK1 current limiting fuses to reduce the arc energy at the MTB to the lowest level possible for worker safety^[7]. This also applies to local motor disconnects.

4. Long Reliable Life

System-wide increases in fault currents can obsolete equipment selections. Increases in available fault current may be caused by:

- A new utility supply transformer.
- Replacement of a transformer within the facility.
- Utility changes to the distribution system.
- Addition of a facility generator in parallel with the utility source.
- Addition of a facility tie bus for distribution reliability.

OCPDs may have adequate interrupting ratings when a system was originally commissioned; however, if changes to the power system increase fault currents they can become overdutied, unsafe and would need to be replaced. If fault currents increase to values greater than the Short Circuit Current Rating (SCCR) of the MCC, the entire equipment would need to be replaced.

Should a facility change to high impedance grounding, OCPDs will need to be fully rated devices since they may need to break full system voltage when clearing faults caused by two separate ground faults^[8]. Fuses have a full voltage rating and are UL tested as a single pole device. A 600 volt rated fuse is fully capable of safely opening any voltage up to a maximum of 600V within its interrupting rating. See^[9] for more details.

Increased system fault currents do not affect the key performance criteria of fuses that are discussed in this paper. For example:

- Following simple guidelines, coordination between fuses extends to 200kA^[10]
- Incident Energy calculations remain constant (and may decrease) for larger fault currents^[11]
- Type 2 protection of motor starters with fuses is typically valid for fault currents up to 100kA.^[6]
- Class J and L fuses are single pole rated at 600V and have ampere interrupting ratings (AIR) of 300kA.
- Fused protected MCC can have a SCCR of 100kA.

Fuses require minimal maintenance since they are calibrated at the factory. If a fuse opens it is replaced by a new, factory-calibrated fuse. By replacing all three fuses after a fault the likelihood that a fuse will open prematurely is greatly reduced.

MCC FUSE SELECTION BASICS

The key to obtaining all the goals identified above starts with selection of the branch circuit fuses. By optimizing the choice of AJT Class J time-delay fuses, the choices for fuses upstream can be more effective.

Since fuses are typically used in motor branch circuits with separate overload protection, their main purpose is to provide the short circuit protection for the circuit. Good engineering practice ensures that the following factors be considered when initially selecting a fuse for a motor circuit.

1. Compliance with NEC requirements
2. Characteristics of the motor current
3. Characteristics of the fuse
4. Desired component protection against expected fault current levels.
5. Coordination considerations
 - a. Coordination of branch fuse with the overload relay
 - b. Coordination between branch fuses and upstream feeder OCPD
6. Arc flash / arc fault considerations
 - a. MCC maximum incident energy
 - b. Arc flash considerations within each branch circuits
 - c. Minimizing damage from internal arc faults

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1. NEC Requirements

Article 430.52 specifies the maximum fuse ampere rating allowed for time-delay and non-time delay fuses. For example, table 430.52 allows for sizing of Time-Delay fuses up to 175% of motor full load amps (FLA) when a properly sized overload protection device is used. These limits ensure that the overload relay is not called upon to clear a low level fault beyond its interrupting capability.

2. Characteristics of the motor current

The ampere rating of the fuse should be selected so that it can be expected to have a long life under normal operations of the motor. Both the full load amps and starting current of the motor must be considered. Since the starting current will be greater than the ampere rating of the fuse, the magnitude and duration of this current must be considered so that fuse elements are not exposed to excessive heat cycles that could shorten their life. Fuse selection tables using full load amps, locked rotor amps and start times give the recommendations that ensure reliable operation. See ^[10] for more details and table 1 on page 7 for an example.

3. Characteristics of the fuse

Short Circuit Protection. As detailed in UL standards, current limiting fuses must clear a fault within their short circuit region in less than 1/2 cycle. Additionally, they must prevent (limit) the current from reaching the first peak of the prospective current as shown in Figure 2. Whereas any UL listed Time-Delay fuse can handle these basics, it is necessary to use the more current limiting Class J or Class RK1 fuses to obtain the maximum safety and protection benefits for fault currents. Since time-delay fuses have overload characteristics that better

matches motor starting current characteristics, they can be sized smaller than the non-time delay fuses. The smaller ampere ratings of the time delay fuses typically provide better short circuit protection for motor circuits and easier coordination with upstream OCPD.

The optimum fuse choice for new MCC branch circuits are AJT Class J Time Delay fuses. The superior current limitation requirements of this standard ensure that all of the short circuit protection benefits mentioned herein can be obtained. The unique dimensions of this fuse class, ensures that protection and reliability are not compromised by improper replacements.

For upgrading protection of existing fuse protected MCC, the A6D Class RK1 is the best option. This fuse class will provide comparable protection as the AJT. Since it uses the same overload element and has the same dimension as the less current limiting RK5 A6D fuses can easily be installed without changes to equipment.

4. Branch Circuit Protection Considerations

Starter Protection. For faults on the motor branch circuit, starters are exposed to very rapid heating of their contacts and overload elements which can cause damage to the device in less than 1 cycle. Additionally, electromagnetic forces from high fault currents can cause significant arcing damage within the starter by separating contacts during the fault. All major starter manufacturers have certified their conventional products to the Type 2 level of 'no damage' protection for fault currents as high as 100,000A when protected with Class J or Class RK1 fuses sized according to their selection charts. Sizes recommended for Class J Time Delay fuses in the Type 2 tables typically are adequate for addressing the requirements discussed above. See ^[6] for more details.

5. Coordination Considerations

Coordination with the Overload Relay. Fuses can be considered to be coordinated with the circuit's overload relay if they are sized so that the overload relay will clear all overcurrents up to and including the locked rotor amps of the motor. This can be accomplished if the time current characteristic of the fuse intersects that of the overload relay at a current value near 25% higher than the magnitude of the locked rotor current of the motor (see figure 1).

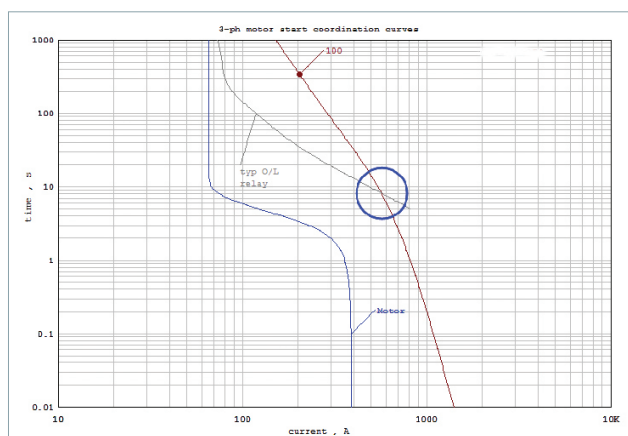


Figure 1: Intersection of fuse curve with OL curve at 550A; LRA is 400A

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The UL 248 standard requirement that Time-Delay fuses shall carry five times their ampere rating for 10 seconds, makes coordination with overload relays easy to obtain with Time-Delay fuses.

NFPA70E is clear when it comes to short circuits per section 130.6 (M). A qualified person must troubleshoot the circuit before it is re-energized [3]. When these devices are coordinated and the fuse opens, it is a good indication of a fault. On the other hand, if the circuit is cleared by the overload device, the circuit can easily be re-energized by resetting the overload with proper safety procedures.

Upstream Fuse/Branch Fuse. Complete selective coordination between a downstream AJT Class J fuse and an upstream A4BQ Class L fuse is possible for fault currents up to 200kA. That is, the main fuse will only open for faults on the bus between the main fuse and the line side of the branch fuses. To be selectively coordinated, the upstream fuse must pass the current waveform determined by the downstream fuse shown in figure 2 without melting its element. Lower let through currents by the downstream fuse as measured by I^2t , allow for smaller feeder fuses while maintaining coordination. Fuse coordination ratio charts are constructed to ensure that there is sufficient margin in the minimum ampere ratio to prevent damage to the upstream fuse.

When using Class J fuses, upstream fuses need to only have twice the ampere rating. For example an AJT400 would be fully coordinated with an upstream A4BQ800 for all fault currents up to 200kA [12].

Fuse with upstream non-current limiting circuit breaker. Selective coordination between a downstream fuse and an upstream non-current limiting feeder breaker is limited in the short circuit

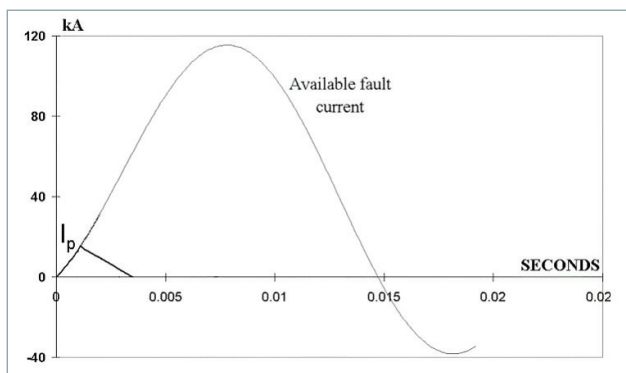


Figure 2: Current Limiting Waveform

region by the instantaneous pick up setting of the breaker and the degree of current limitation of the fuse. If the I_p shown in figure 2 is greater than that required to trip the instantaneous unit of the circuit breaker, selective co-ordination is lost. Fuses with lower I_p values provide coordination for wider ranges of fault currents. Designers need to evaluate the data in the let-through charts and the details of the instantaneous trip unit to ensure proper coordination. See [12] [13] for more details.

AJT Class J and A4BQ Class L fuses are the best choice for the lowest I_p values.

6. Arc Flash Considerations

MCC arc flash considerations. To get the minimal amount of incident energy at the MCC, it is important to ensure that the feeder fuse is operating in its short circuit region for arcing faults. That is, I_{arc} must be large enough to drive the fuse into current limitation. For example, the A4BQ800 will provide incident energies less than 1.2 cal/cm² for available fault currents between 16kA and 100kA. The AJT400 will have similar performance for fault currents between 5kA and 100kA. Consideration of available fault current should be part of the decision on the size of the MCC. For example, it might be beneficial to use two 800A MCCs instead of a single 1600A MCC to achieve optimal safety goals when fault currents are not sufficiently high.

The tripping characteristics of the upstream feeder overcurrent protection device will determine the incident energy at the MCC. As discussed above, using very current limiting Class J fuses in the MCC branches allows for faster opening times of the feeder OCPD for short circuits without compromising coordination. It is practical to select Class L feeder fuses to be fully coordinated with Class J branch fuses while still yielding incident energy calculations of less than 1.0 cal/cm² at the MCC when properly sized.

Since Class J fuses are the most current limiting fuse option for the branch fuse, designers have the greatest flexibility in selection of upstream protection of the MCC while preserving coordination and minimal arc flash energies.

Downstream arc flash considerations. Although infrequent, serious injuries have occurred for arc faults within motor terminal boxes. The energy delivered to an arc fault within the box will rapidly

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raise the pressure. Although internal pressures can be relieved into the motor, the common failure mode is to launch the cover away from the box posing a potential hazard to any nearby worker [7]. Since Class J fuses let through the lowest electrical energy, worker protection is greatly improved if the calculated arc fault current is greater than the fuse's threshold current. [11] Incident energies can be less than 0.5 cal/cm² at motor disconnects if the calculated I_{arc} is greater than current limiting threshold of the branch fuse. For example, with an AJT100, incident energy will be less than 0.5 cal/cm² if the available fault currents is greater than 2kA at the disconnect.

EXAMPLE

Steps to select fuses to accomplish MCC safety goals

By using the steps below, AJT and A4BQ fuses can be selected to accomplish all of the goals identified at the beginning of the paper. An example is provided to demonstrate the process.

1. Make a preliminary choice of MCC
 - a. Identify details of all expected motor loads to properly select the MCC.
 - b. Calculate the available fault current at the MCC with an initial selection of MCC bus size and feeder conductors
2. Select branch circuit fuses.
 - a. Select the optimum AJT Class J fuse for each branch to ensure coordination with the overload relays. Typically this is 140-160% of Full Load Amps (FLA) but could be larger with higher efficiency motors. For motor drives use the manufacturer's recommended size of Class J time delay fuse.
 - b. Review the starter manufacturer's information to confirm that the starters have Type 2 level of protection with the selected branch fuses.
3. Select main fuse
 - a. Identify the largest branch fuse selected for the motors that will be operated from the MCC.
 - b. Identify the smallest A4BQ Class L main fuse that will coordinate with the largest branch fuse for all fault currents. This is accomplished when the A4BQ ampere rating is twice that of the largest AJT branch fuse.

- c. Confirm that the A4BQ ampere rating complies with NEC requirements and system requirements.
 - d. Confirm that the incident energy at the MCC is under the target value.
4. Review the MCC manufacturer's information to confirm that the MCC is 'arc resistant' rated with the selected main fuse.

Step 1: In the circuit shown in figure 3, MCC 1 has 515A of motor load controlled by this center. With a preliminary selection of an 800A MCC and the appropriate feeder conductors, the estimated fault currents are shown on figure 3.

Step 2: Select the proper Class J fuse size for each motor from Table 1. Per the table's footnote, fuses from the center or right column will coordinate with typical Class 20 overload relays. Confirm that the selected fuse sizes meet starter protection objectives by checking with manufacturer's type 2 tables. For the fuses selected per table 1, several manufacturers provide starters that have been certified for Type 2 levels of short circuit protection.

Step 3: After selecting the proper Class J fuse for each motor from table 1, identify the fuse for the largest motor. With a code letter G and a motor start time of 2-5s, Table 1 suggests an AJT350 Class J time delay fuse for the 200hp motor. See [10] for more information on sizing fuses for motor circuits.

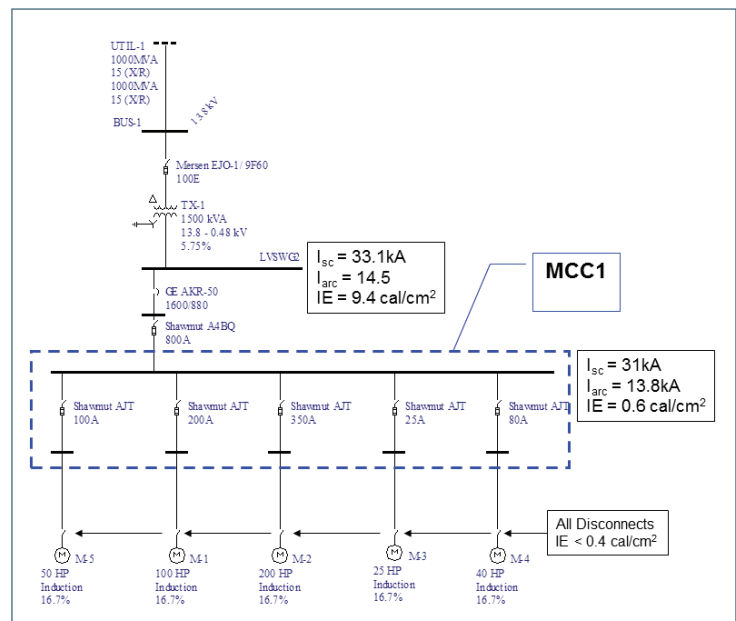


Figure 3: One-line diagram of MCC with motor sizes, class, IBF, Incident Energy, and fuses.

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Per the condensed coordination table 2, the A4BQ800 feeder fuse easily coordinates with the AJT350 for all fault currents up to 200kA with a coordination ratio greater than 2. The coordination plots for the fuse system shown in figure 4 have good separation for currents below threshold values. Likewise, all other fuses have a main/branch ratio greater than 2, and would be coordinated with the A4BQ800 for fault currents up to 200kA. Adjustments could be made to the upstream feeder breaker to get better separation.

In Figure 3, all 5 motors were fed with 200 feet of cable rated for the motors FLA. The arc flash calculations downstream of the MCC are less than 0.5 cal/cm² with the AJT fuses. By using the A4BQ800, the incident energy calculated on the main bus of the MCC is 0.6cal/cm². These calculations were done with a working distance of 18”.

Notice that with an instantaneous pick up of 11,200A for the feeder breaker shown in figure 4, the AJT350 will coordinate for faults up to 19kA. To assure coordination up to 31kA, the setting will need to be changed to greater than 13,200. See [12] and [13] for more information.

Step 4: Contact the MCC manufacturer or Mersen Technical Services to get information on MCCs that are

‘arc resistant’ per the manufacturer’s tests according to IEEE 37.20.7^[14] when protected with the appropriately sized A4BQ Class L fuse. With a ‘device limited’ design, installation requirements can be near to conventional MCCs. However, it is very important that you consult with the MCC manufacturer to ensure that you obtain the desired level of performance, since IEEE 37.20.7 is a test guide that includes recommended procedures.

Remember that the MCC is only ‘arc resistant’ with the door closed. Workers could be exposed to the full calculated incident energy should an arc flash occur while they were interacting with the MCC with the door open. By sizing the A4BQ so that it will be current limiting for the expected arc fault current, workers could be exposed to the lowest levels of arc flash energy.

TABLE 1. AJT FUSE SELECTION CHART FOR 480V MOTORS

Motor HP	Full Load Current	Minimum	Typical	Heavy Start
5	7.6	10	12	15
7 1/2	11	15	17 1/2	20
10	14	17 1/2	20	25
15	21	25	30	40
20	27	35	40	50
25	34	40	50	60
30	40	50	60	70
40	52	70	80	100
50	65	80	100	125
60	77	100	125	150
75	96	125	150	175
100	124	175	200	225
125	156	200	225	300
150	180	225	250	350
200	240	300	350	450
250	302	400	450	600
300	361	450	600	—

Typical sizes are recommended for most applications and will coordinate with NEMA Class 20 overload relays and starting times up to 5 seconds.

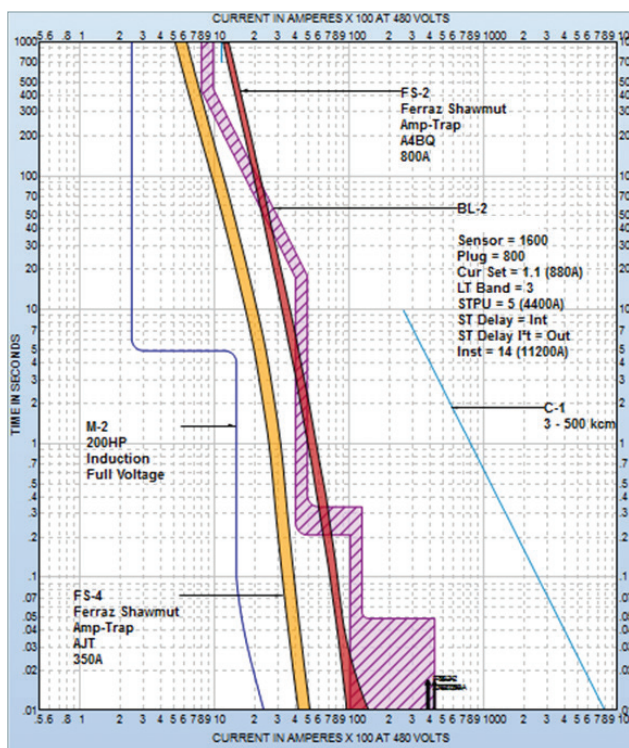


Figure 4: Time current curves for devices in the example of Figure 3.

TABLE 2. CONDENSED SELECTIVITY RATIO CHART - 480V

Branch Fuse	Main Fuse		
	A4BQ	AJT	A6D
A4BQ	2:1	2:1	2:1
AJT	2:1	2:1	2:1
A6D	2:1	2:1	2:1
TRS	4:1	4:1	4:1

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SUMMARY OF GUIDELINES

1. Use AJT (Class J) and A4BQ (Class L) fuses for lowest threshold currents and incident energy, maximum protection of equipment and lowest coordination ratios.
2. Select AJT branch fuse size to ensure coordination with the circuit's overload relay. This may be a size larger than normally used but will ensure coordination without compromising short circuit protection.
3. Specify device limited (fuse protected) 'arc resistant' MCCs to provide optimum protection for all workers that will interact with the MCC.
4. For low fault current applications consider two smaller MCC units to ensure feeder protection is in its short circuit range.

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ADDITIONAL RESOURCES

System Protection Note 1: Fuses vs. Circuit Breakers for Low Voltage Applications

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