CHAPTER 3

OVERCURRENT PROTECTIVE DEVICES

3-1. General

Design of power system protection requires the proper application motor of overload relays, fuses, circuit breakers, protective relays, and other special purpose overcurrent protective devices. This chapter provides detailed information about various protective devices, illustrates their time-current characteristics, and identifies information required to design coordinated power system protection.

3-2. Motor overload relays

a. Thermal overload relays. The most common overcurrent protective device is the thermal overload relay associated with motor starting contactors. In both low-voltage and medium-voltage motor circuits, thermal overload relays detect motor overcurrents by converting the current to heat via a resistive element. Thermal overload relays are simple, rugged, inexpensive, and provide very effective motor running overcurrent protection. Also, if the motor and overload element are located in the same ambient, the thermal overload relay is responsive to changes in ambient temperature. The relay trip current is reduced in a high ambient and increased in a low ambient. Typical time-current characteristic curves for thermal overload relays are shown in appendix C. The curves level off at about 10 to 20 times full-load current, since an upstream short-circuit device, such as a fuse or circuit breaker, will protect the motor circuit above these magnitudes of current. The thermal overload relay, therefore, combines with the short-circuit device to provide total overcurrent protection (overload and short-circuit) for the motor circuit.

(1) Melting alloy type overload relays, as the name implies, upon the circuit when heat is sufficient to melt a metallic alloy. These devices may be reset manually after a few minutes is allowed for the motor to cool and the alloy to solidify.

(2) Bimetallic type overload relays open the circuit when heat is sufficient to cause a bimetallic element to bend out of shape, thus parting a set of contacts. Bimetallic relays are normally used on automatic reset, although they can be used either manually or automatically.

(3) Standard, slow, and quick-trip (fast) relays are available. Standard units should be used for motor starting times up to about 7 seconds. Slow units should be used for motor starting times in the 8-12 second range, and fast units should be used on special-purpose motors, such as hermetically sealed and submersible pump motors which have very fast starting times.

(4) Ambient temperature — compensated overload relays should be used when the motor is located in a nearly-constant ambient and the thermal overload device is located in a varying ambient.

b. Magnetic current overload relays. Basically, magnetic current relays are solenoids. These relays operate magnetically in response to an overcurrent. When the relay operates, a plunger is pulled upward into the coil until it is stopped by an insulated trip pin which operates a set of contacts. Magnetic relays are unaffected by changes in ambient temperature. Magnetic current relays may be used to protect motors with long starting times or unusual duty cycles, but are not an alternative for thermal relays.

c. Information required for coordination. The following motor and relay information is required for a coordination study.

(1) Motor full-load ampers rating from the motor nameplate.

(2) Overload relay ampere rating selected in accordance with NFPA 70.

(3) Overload relay time-current characteristic curves.

(4) Motor locked rotor amperes and starting time.

(5) Locked rotor ampere damage time for medium-voltage motors.

3-3. Fuses

A fuse is a non-adjustable, direct acting, single-phase device that responds to both the magnitude and duration of current flowing through it. Fuses may be time delay or non-time delay, current-limiting or non-current-limiting, low-voltage or high-voltage. Fuse terminology and definitions are listed in the glossary. Underwriter's Laboratories (UL) further classifies low-voltage fuses as shown in table 3-1.

Table 3-1. UL fuse classifications

LOW-VOLTAGE FUSES (0–600V)	
Noncurrent Limiting	*Current Limiting*
PLUG FUSES	CLASS CC
CLASS H (Renewable)	CLASS T
CLASS H (Nonrenewable)	CLASS K (K-1, K-5)
	CLASS G
	CLASS J
	CLASS L
	CLASS R (RK-1, RK-5)

a. Nontime delay fuses. The Nontime delay fuse consists of a single type of fusible element, called a short-circuit element. Normal overloads and current surges often cause nuisance openings of this type of fuse. For this reason, substantial oversizing of these fuses is required when used in motor circuits. Therefore, Nontime delay fuses should be used only in circuits with noninductive loads such as service entrances and circuit breaker back-up protection.

b. Time delay fuses. The time delay fuse is constructed with two different types of fusible elements: overload and short-circuit. These elements are somewhat similar in operation to the thermal and magnetic elements of an inverse-time circuit breaker. The overload element will interrupt all overload currents, and the short-circuit element will open in response to short-circuit currents. The time delay fuse can be applied in circuits subject to normal overloads and current surges (e.g., motors, transformers, solenoids, etc.) without nuisance opening. Significant oversizing is not necessary.

c. UL classification. As shown in table 3-1, UL has established distinct classifications for low-voltage fuses. These classifications define certain operating characteristics associated with a particular fuse class. However, the fact that a fuse is classified, for example, as UL RK-5 does not mean that all of its operating characteristics are identical with those of other manufacturers' Class RK-5 fuses. Both time delay and Nontime delay fuses are classified as RK-5. Therefore, each type of RK-5 fuse will require different application procedures. UL classifications and time delay characteristics should always be specified along with current and voltage ratings for low-voltage fuses. This will eliminate any confusion on the Contractor's part and insure that the correct fuse is always provided. UL Class H fuses are tested for short-circuit ratings at 10,000 amperes symmetrical, and are, therefore, not current-limiting. UL Class K fuses are tested at 50,000, 100,000, or 200,000 amperes symmetrical, and are, therefore, current-limiting. However, Class K fuses are not labeled as current-limiting, because Class K fuses are interchangeable with UL Class H and NEMA Class H fuses. Therefore, Class H and Class K fuses should be avoided in favor of Class RK and Class L fuses. Rejection-type fuses and fuse holders prevent underrated fuses from inadvertently being installed.

d. Time-current characteristic curves. Fuse curves are available from various manufacturers. 'Typical fuse time-current characteristic curves are shown in appendix C. Medium-voltage and high-voltage fuses show an operating "band" while low-voltage fuses show an operating "line." The band associated with medium-voltage and high-voltage fuses graphically displays minimum melting time and total (or maximum) clearing time as a function of current magnitude.

e. Current-limitation. Current-limiting fuses are so fast acting that they are able to open the circuit and remove the short-circuit current well before it reaches peak value. Current-limiting fuses "limit" the peak short-circuit current to a value less than that available at the fault point and open in less than one-half cycle. To be effective, however, such fuses must be operated in their current-limiting range. Peak let-through charts, also called current-limiting effect curves, should be used to determine the effectiveness or degree of protection offered by current-limiting fuses. These curves plot instantaneous peak let-through current as a function of available RMS symmetrical short- circuit current.

f. Medium-voltage fuses. Medium-voltage fuses are either (1) distribution fuse cutouts or (2) power fuses. Distribution fuse cutouts are designed for pole or crossarm mounting and should be used primarily on distribution feeders and circuits. Power fuses have a higher dielectric strength than distribution fuse cutouts and should be used primarily in substations. The majority of medium-voltage fuses are used for applications within buildings, vaults, or enclosures. They are boric acid type fuses rated 4160—34.5kV or current-limiting fuses rated 2400V—34.5kV.

g. High-voltage fuses. Some medium-voltage fuses and all high-voltage fuses are rated for outdoor use only. These devices are boric acid type fuses rated 4160V—138kV, fiberlined expulsion fuses rated 7200V—l6lkV, or distribution fuse cutouts rated 4800V—138kV.

h. Current-limiting power fuses. Current-limiting power fuses include E-rated, C-rated, and R-rated fuses. E-rated, current-limiting, power fuses rated 100E and below open in 300 seconds at currents between 200 percent and 240 percent of their E-rating. Fuses rated greater than 100E open in 600 seconds at currents between 220 percent and 264 percent of their E-rating. C-rated, current-limiting power fuses open in 1000 seconds at currents between 170 percent and 240 percent of their C-rating. R-rated, current-limiting power fuses are suitable for use on medium-voltage motor controllers only. Generally, R-rated fuses open in 20 seconds at 100 times the R-rating.

I. Information required for coordination. The following fuse information is required for a coordination study:

(1) Fuse continuous current rating.

(2) Fuse time-current characteristic curves.

(3) Fuse interrupting-current rating.

(4) UL classification and time delay characteristics.

j. Fuse ratings. Standard voltage and current ratings for fuses can be found in appendix D.

3-4. Motor short-circuit protectors (MSCP)

Motor short-circuit protectors are current-limiting, fuse-like devices designed specifically for use in switch-type, combination motor controllers. UL considers MSCPs to be components of motor controllers rather than fuses. Therefore, MSCPs are marked by letter designations (A-Y) instead of ampere ratings and may not be used as fuses. MSCPs may be used in motor circuits provided the MSCP is part of a combination motor controller with overload relays and is sized not greater than 1,300 percent of motor FLA (NFPA 70). This relatively new arrangement (first recognized by NFPA 70-1971), provides short-circuit protection, overload protection, motor control, and disconnecting means all in one assembly. MSCPs provide excellent short-circuit protection for motor circuits as well as ease of selection. However, the limited number of manufacturers that can supply MSCPs has so far prohibited their use by the Government except for sole-source applications.

3-5. Circuit breakers

A circuit breaker is a device that allows automatic opening of a circuit in response to overcurrent, and also manual opening and closing of a circuit. Circuit breaker terminology and definitions are listed in the glossary. Low-voltage power circuit breakers have, for years, been equipped with electromechanical trip devices. Modern, solid-state devices, however, are rapidly replacing electromechanical trips. Solid-state trips are more accessible, easier to calibrate, and are virtually unaffected by vibration, temperature, altitude, and duty-cycle. Furthermore, solid-state devices are easy to coordinate, and provide closer, more improved protection over electromechanical units. Still, electromechanical units have their applications. Industrial plants with harsh environments, such as steel mills and ammunition plants, may demand the more rugged electromechanical devices. Today, molded-case circuit breakers are being equipped with solid-state trip units to obtain more complex tripping characteristics. Surface-mount, or integrated-circuit, technology is allowing very sophisticated molded-case circuit breakers to be constructed in small frame sizes. Most low-voltage power circuit breakers are also being equipped with solid-state trip units. New microprocessor-based circuit breakers are now available that offer true RMS current sensing. The increased use of switching-mode power supplies for computer systems and other harmonic-generating, non-linear loads created the need for true RMS sensing, which is a major advantage over peak-sensing trip units.

a. Low-voltage circuit breakers. Low-voltage circuit breakers are classified as molded-case circuit breakers or power circuit breakers. A molded-case circuit breaker is an integral unit enclosed in an insulated housing. A power circuit breaker is designed for use on circuits rated 1000 Vac and 3000 Vdc and below, excluding molded-case circuit breakers.

(1) Low-voltage circuit breaker trip units may be of the electromechanical (thermal-magnetic or mechanical dashpot) or solid-state electronic type. Low-voltage circuit breakers may include a number of trip unit characteristics. These characteristics are listed below and illustrated in figures 3-1 and 3-2. Typical circuit breaker time-current characteristic curves may be found in appendix C. Circuit breaker curves are represented as "bands." The bands indicate minimum and maximum operating times for specific overcurrents.

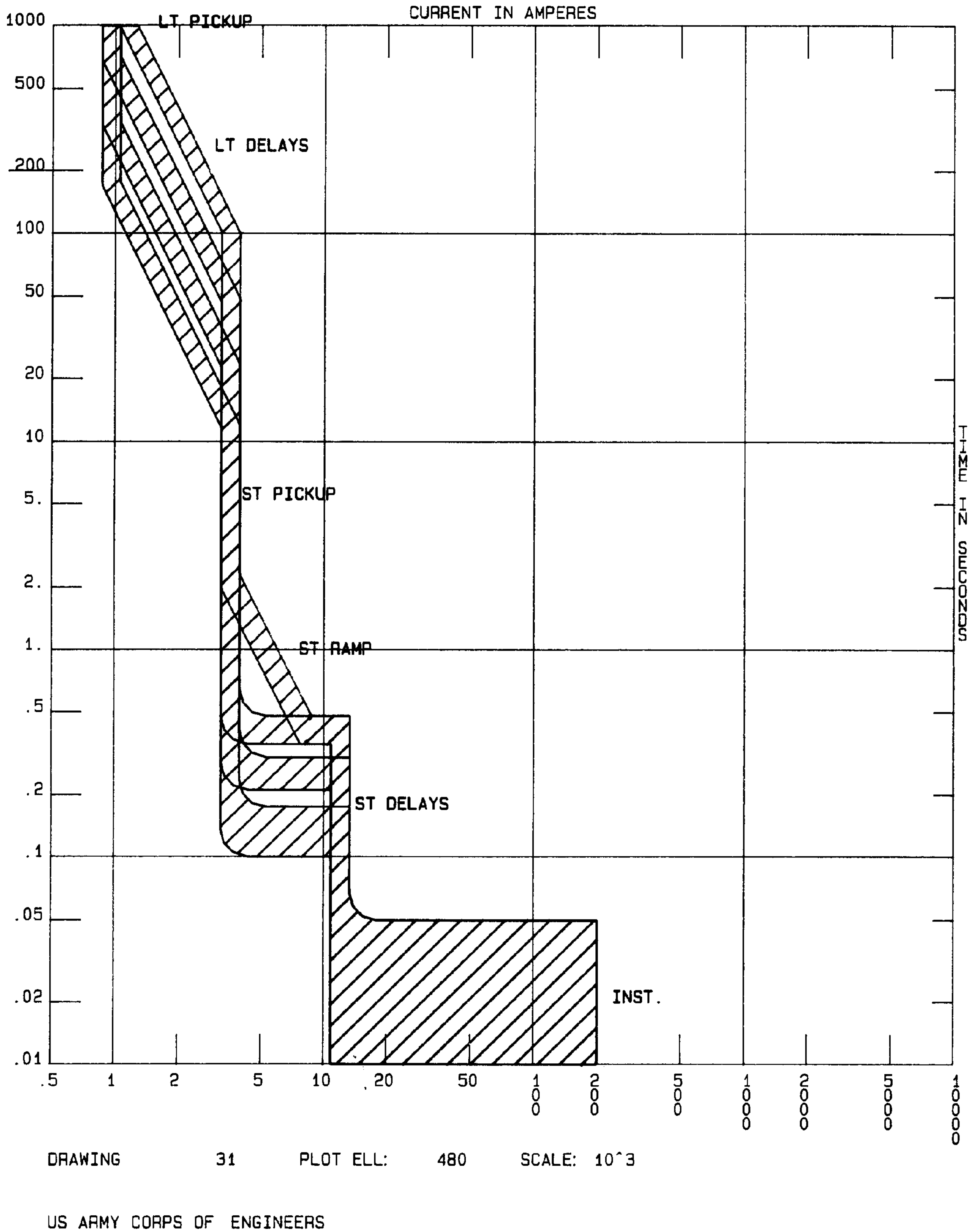

Figure 3-1. Solid-state circuit breaker characteristics.

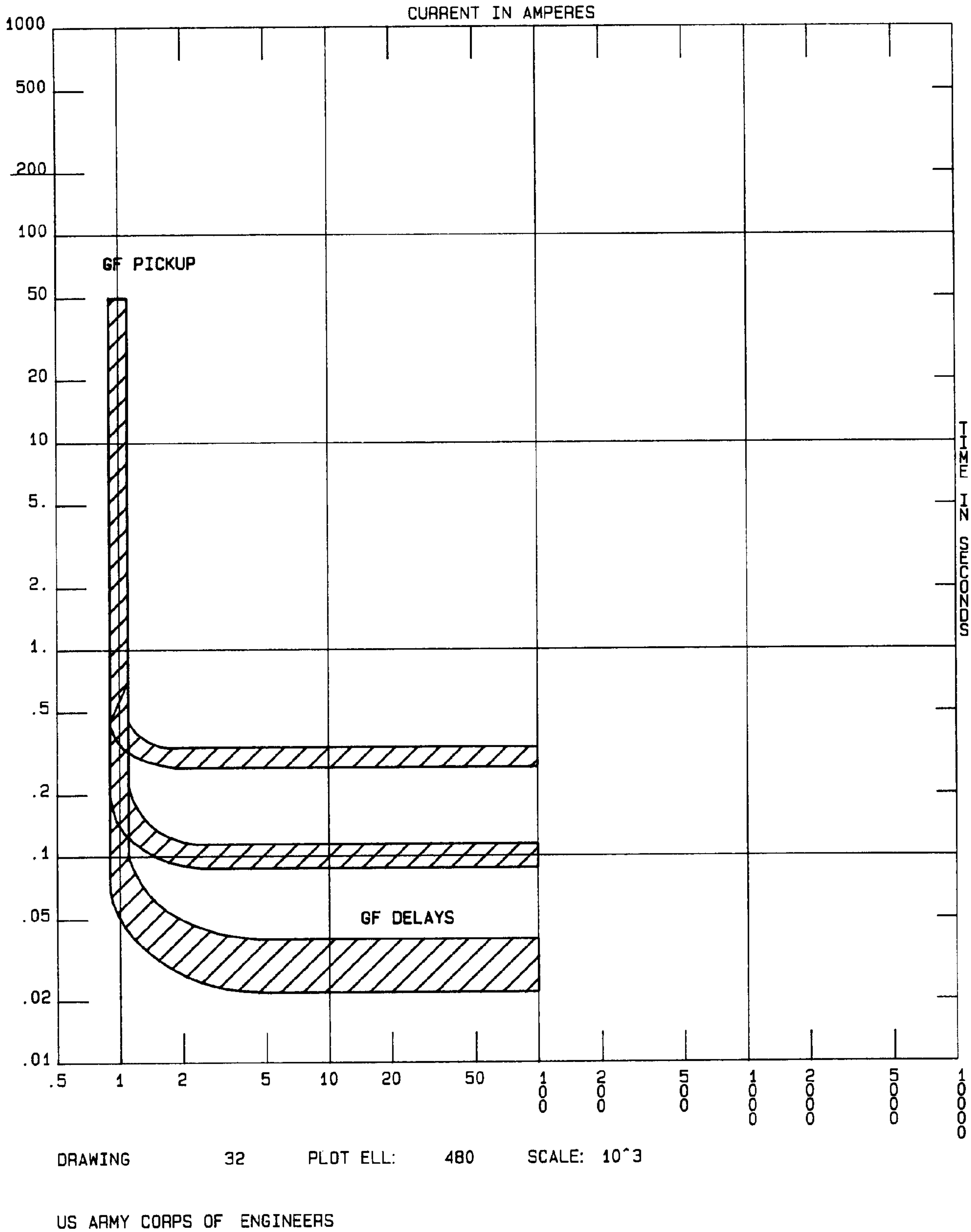

Figure 3-2. Solid state ground-fault characteristics.

(a) Long-time pick-up allows fine tuning of the continuous current rating. Typical settings range from 50 percent-100 percent of circuit breaker sensor current rating.

(b) Long-time delay varies the tripping time under sustained overcurrent and allows momentary overloads. Three to six bands are typically available.

(c) Short-time pick-up controls the amount of high-level current that can be carried for short periods of time without tripping and allows downstream devices to clear faults without tripping upstream devices. Typical settings range from 1.5 to 9 times long-time pick-up setting.

(d) Short-time delay is used with short-time pick-up to improve selectivity. It provides time delay to allow the circuit breaker to trip at the selected short-time pick-up current. Three bands (minimum, intermediate, and maximum) are typically available.

(e) Short-time I^2t switch introduces a ramp function into the short-time characteristic curve to improve coordination with downstream devices whose characteristic curves overlap the circuit breaker characteristic curve.

(f) Instantaneous pick-up establishes the tripping current level with no intentional time delay. Typical settings range from 1.5 to 9 times Long-time pick-up setting.

(g) Ground-fault pick-up establishes ground fault tripping current level and may incorporate the I^2t function. Ground-fault pick-up is typically adjustable from 20 percent to 100 percent of sensor rating. Ground-fault pick-up should never be set above 1200 A in accordance with NFPA 70.

(h) Ground-fault delay incorporates time delay for coordination. Three to six time delay bands are typically available. Ground-fault delay should not exceed one second for ground-fault currents greater than 3000 A in accordance with NFPA 70.

(2) Specifications should detail only those functions that are necessary on a particular project.

(a) The continuous current rating may be fixed or adjustable.

(b) Molded-case breakers with solid-state trips and power breakers normally have adjustable long-time and short-time functions.

(c) Power breakers may or may not have the instantaneous function.

(d) Most molded-case circuit breakers, especially in the smaller sizes, are not provided with long-time adjustments, short-time functions, or ground-fault functions.

(3) The inverse-time (or thermal-magnetic) circuit breaker contains a thermal and a magnetic element in series and is similar in operation to time delay fuses. This circuit breaker will trip thermally in response to overload currents and magnetically in response to short-circuit currents. Magnetic tripping is instantaneous while thermal tripping exhibits an inverse-time characteristic (i.e., the circuit breaker operating characteristics of time and current are inversely proportional). Inverse-time circuit breakers have three basic current ratings: trip rating, frame rating, and interrupting rating. Trip rating is the minimum continuous current magnitude required to trip the circuit breaker thermally. The frame rating identifies a particular group of circuit breakers and corresponds to the largest trip rating within the group. Each group consists of physically interchangeable circuit breakers with different trip ratings, as shown in table 3-2. Although NEMA recognizes other frame ratings in addition to those listed in table 3-2, these are the most common ones supplied by manufacturers. The interrupting rating describes the short-circuit withstand capability of a circuit breaker.

Table 3-2. Circuit breaker trip ratings

Frame rating (AF) (amperes)	*Trip ratings (AT) (amperes)*
100 AF	15–100 AT
225 AF	125–225 AT
400 AF	250–400 AT
1,000 AF	500–1,000 AT
2,000 AF	1,200–2,000 AT

(4) The instantaneous-trip circuit breaker is nothing more than an inverse-time circuit breaker with the thermal element removed and is similar in operation to the non-time delay fuse. This circuit breaker is often referred to by other names, such as, magnetic circuit breaker, magnetic-only circuit breaker, or motor circuit breaker. Instantaneous-trip circuit breakers may be used in motor circuits, but only if adjustable, and if part of a circuit breaker type, combination motor controller with overload relays. Such an arrangement is called a Motor Circuit Protector (MCP) and provides short-circuit protection (circuit breaker magnetic element), overload protection (overload relays), motor control, and disconnecting means all in one assembly. Instantaneous-trip circuit breakers have frame and interrupting ratings but do not have trip ratings. They do have an instantaneous current rating which, for motor circuits, must be adjustable

and not exceed 1,300 percent of the motor FLA (NFPA 70). MCPs provide excellent motor circuit protection and ease of specification, and should be considered for installations with numerous motors where MCCs would be specified.

(5) A current-limiting circuit breaker does not employ a fusible element. When operating within its current-limiting range, a current-limiting circuit breaker limits the let-through I^2t to a value less than the I^2t of the quarter cycle of the symmetrical current. Current-limiting circuit breakers employ single and double break contact arrangements as well as commutation systems to limit the let-through current to satisfy the fundamental definition of current-limitation without the use of the fuses. Current-limiting circuit breakers can be reset and service restored in the same manner as conventional circuit breakers even after clearing maximum level fault currents. Manufacturers of current-limiting circuit breakers publish peak let-through current (I_p) and energy (I^2t curves. The manufacturer should be contacted for specific application information.

(6) Integrally fused circuit breakers employ current limiters which are similar to conventional current-limiting fuses but are designed for specific performance with the circuit breaker. Integrally fused circuit breakers also include overload and low level fault protection. This protection is coordinated so that, unless a severe fault occurs, the current limiter is not affected and replacement is not required. Current limiters are generally located within the molded case circuit breaker frame. An interlock is provided which ensures the opening of the circuit breaker contacts before the limiter cover can be removed. Single phasing is eliminated by the simultaneous opening of all circuit breaker poles. Many circuit breakers employ mechanical interlocks to prohibit the circuit breaker from closing with a missing current limiter. The continuous ampere rating of integrally fused circuit breakers is selected in the same manner as for conventional circuit breakers. The selection of the individual limiters should be made in strict accordance with the manufacturer's published literature to achieve the desired level of circuit protection.

(7) A molded-case circuit breaker can be applied in a system where fault current may exceed its rating if it is connected in series on the load side of an acceptable molded-case circuit breaker. Such an application is called cascade system operation. The upstream breaker must be rated for maximum available fault current and both breakers must be tested and UL certified for a series rating. Cascade operation depends upon both breakers opening at the same time, and upon the fact that the upstream breaker will always open. Since molded-case circuit breaker contacts are designed to "blow open" on high short-circuit currents, failure of the upstream breaker to operate is not a concern. Since low-voltage power breakers are not designed to "blow open," power breakers should not be applied in cascade. Individual components within a cascade system should not be replaced since the entire system is UL approved. Individual components are not UL approved. Additionally, individual components should be from the same manufacturer as the cascade system. By virtue of the design, this approach does not pro- vide a coordinated system.

b. Medium-voltage circuit breakers. ANSI defines medium-voltage as 1000V or more, but less than 100kV. Switching a medium-voltage circuit involves either opening or closing a set of contacts mechanically. When closing the contacts, the applied mechanical force must be greater than the forces which oppose the closing action. An arc is created when the contacts are opened, which must be extinguished. Medium-voltage circuit breakers are classified according to the medium (oil, air, vacuum, or SF_6) in which their contacts are immersed. Normally, metal clad, drawout switchgear is used at medium-voltages up to 15kV. Air-magnetic, vacuum, and SF_6-filled-interrupter circuit breakers are available in drawout switchgear. Oil circuit breakers are used outdoors, as individual units, and thus are not available in drawout switchgear mounting.

(1) Medium-voltage air circuit breakers are either of the air-magnetic type or of the air-blast type. Due to cost and size restrictions, air-blast breakers are not normally used in medium-voltage drawout switchgear construction. In recent years, most medium-voltage drawout switchgear employed air-magnetic breakers. However, due to cost, size, and noise limitations, vacuum and SF_6 circuit breakers are replacing air circuit breakers in medium-voltage drawout switchgear.

(2) The contacts of vacuum circuit breakers are hermetically-sealed in a vacuum chamber or “bottle”. The vacuum in a new bottle should be about 10^{-8} Torr, and should be at least 10^{-4} Torr for proper operation. One Torr equals 760 millimeters of mercury. Vacuum interrupters are much smaller and quieter than air circuit breakers, and require no arc chutes. Vacuum circuit breakers in drawout switchgear mounting are available in a variety of continuous current and MVA ratings at 5kV to 15kV.

(3) Sulfur hexaflouride, SF_6, is a nonflammable, nontoxic, colorless, and odorless gas, which has long been used in high-voltage circuit breakers. Now, SF_6-filled-interrupter circuit breakers are

available in drawout switchgear for 5kV and 15kV applications. Like vacuum interrupters, the circuit breaker contacts are immersed in a hermetically-sealed bottle filled with SF_6 gas. SF_6 circuit breakers in drawout switchgear mounting are available in a variety of continuous current and MVA ratings.

c. EMI/RFI considerations. With today's increasing use of sensitive, solid-state devices, the effects of Electro-Magnetic Interference (EMI) and Radio-Frequency Interference (RFI) must be considered. Solid-state devices, due to their many advantages, are rapidly replacing the rugged electromechanical devices previously used. One disadvantage of solid-state devices, however, is their sensitivity to power source anomalies and electrostatic and electromagnetic fields. Recent developments in the design and packaging of solid-state devices have incorporated effective shielding techniques. However, the designer must still evaluate the environment and ensure that additional shielding is not required. Equipment and devices must comply with MIL-STD-461.

d. In formation needed for coordination. The following circuit breaker information is required for a coordination study:

(1) Circuit breaker continuous current and frame rating.

(2) Circuit breaker interrupting rating.

(3) Circuit breaker time-current characteristic curves.

e. Circuit breaker ratings. Standard voltage and current ratings for circuit breakers may be found in appendix D. To meet UL requirements, molded case circuit breakers are designed, built and calibrated for use in a 40 degrees C (104 degrees F) ambient temperature. Time-current characteristic trip curves are drawn from actual test data. When applied at ambient temperatures other than 40 degrees C, frequencies other than 60 Hz, or other extreme conditions, the circuit performance characteristics of the breaker may be affected. In these cases, the current carrying capacity and/or trip characteristics of the breaker may vary. Therefore, the breaker must be rerated.

(1) Since thermal-magnetic circuit breakers are temperature sensitive devices, their rated continuous current carrying capacity is based on a UL specified 40 degrees C (104 degrees F) calibration temperature. When applied at temperatures other than 40 degrees C it is necessary to determine the breaker's actual current carrying capacity under those conditions. By properly applying manufacturer' s ambient rerating curves, a circuit breaker's current carrying capacity at various temperatures can be predicted.

(2) Application of thermal-magnetic circuit breakers at frequencies above 60 Hz requires that special consideration be given to the effects of high frequency on the circuit breaker characteristics. Thermal and magnetic operation must be treated separately.

(a) At frequencies below 60 Hz the thermal rerating of thermal-magnetic circuit breakers is negligible. However, at frequencies above 60 Hz, thermal rerating may be required. One of the most common higher frequency applications is at 400 Hz. Manufacturer's rerating curves are available.

(b) At frequencies above 60 Hz, tests indicate that it takes more current to magnetically trip a circuit breaker than is required at 60 Hz. At frequencies above 60 Hz, the interrupting capacity of thermal-magnetic breakers is less than the 60 Hz interrupting capacity.

(3) When applying thermal-magnetic circuit breakers at high altitudes, both current and voltage adjustments are required. Current rerating is required because of the reduced cooling effects of the thinner air present in high altitude applications. Voltage rerating is necessary because of the reduced dielectric strength of the air. Refer to ANSI C37-13 and ANSI C37-14 for specific rerating factors to be applied at various altitudes.

(4) Trip curves provide complete time-current characteristics of circuit breakers when applied on an ac systems only. When applying thermal-magnetic circuit breakers on dc systems, the circuit breaker's thermal characteristics normally remain unchanged, but the manufacturer should be consulted to be certain. The magnetic portion of the curve, on the other hand, requires a multiplier to determine an equivalent dc trip range. This is necessary because time-current curves are drawn using RMS values of ac current, while dc current is measured in peak amperes. Additionally, the X/R ratio of the system as seen by the circuit breaker will affect its dc rating. When a circuit breaker opens a dc circuit, the inductance in the system will try to make the current continue to flow across the open circuit breaker contacts. This action results in the circuit breaker having to be derated. Furthermore, some circuit breakers require the ac waveform to pass through a current zero to open the circuit. Since dc does not have current zeros, the circuit breaker must be derated. For dc applications the manufacturer should be contacted for derating requirements.

f. System X/R ratio. Normally, the system X/R ratio need not be considered when applying circuit breakers. Circuit breakers are tested to cover most applications. There are several specific applications, however, where high system X/R ratios may push short-circuit currents to 80 percent of the short-circuit current rating of standard circuit breakers. These applications are listed below.

(1) Local generation greater than 500kVA at circuit breaker voltage.

(2) Dry-type transformers, 1.0 MVA and above.

(3) All transformer types, 2.5 MVA and above.

(4) Network systems.

(5) Transformers with impedances greater than values listed in the ANSI C57 series.

(6) Current-limiting reactors in source circuits at circuit breaker voltage.

(7) Current-limiting busway in source circuits at circuit breaker voltage.

If the system X/R ratio is known, multiplying factors from various references can be used to determine the circuit breaker short-circuit current rating. If the system X/R ratio is unknown, the maximum X/R ratio of 20 may be assumed and the appropriate multiplying factor used.

g. Circuit breaker application. Molded-case circuit breakers, power circuit breakers, and insulated-case circuit breakers should be applied as follows:

(1) Molded-case circuit breakers have traditionally been used in panelboards or loadcenters where they were fixed-mounted and accessible. Low-voltage power circuit breakers, on the other hand, were traditionally used in industrial plants and installed in metal-enclosed assemblies. All power circuit breakers are now of the drawout-type construction, mounted in metalclad switch-gear. Therefore, molded-case breakers should be used in fixed mountings, and power breakers should be used where drawout mountings are employed.

(2) Since power breakers were traditionally used in metal-enclosed assemblies, they were rated for 100 percent continuous duty within the assembly. On the other hand, molded case breakers were traditionally used in open air. When used in a metal enclosure, molded-case breakers had to be derated to 80 percent of continuous rating. Molded-case breakers are now available at 100 percent rating when installed in an enclosure.

(3) Power breakers have traditionally been applied where selectivity was very important, thus requiring high short-time ratings to allow downstream devices to clear the fault. Molded-case breakers were, instead, designed for very fast operations. Fast opening contacts under high short-circuit current conditions resulted in molded-case breakers having higher interrupting ratings than power breakers.

(4) An insulated-case circuit breaker is somewhat of a hybrid circuit breaker which incorporates advantages of both the molded-case and power circuit breaker. However, an insulated-case breaker is not a power breaker, and should not be applied as such. Insulated-case breakers are not designed and tested to the same standards as power breakers. An insulated-case breaker is essentially a higher capability molded-case breaker. All commercially available insulated-case breakers are 100 percent rated.

(5) Molded-case or insulated-case breakers should be used in noncritical, small load applications with high interrupting requirements. Power breakers should be used in critical applications where continuity of service is a requirement. For overlapping applications, designer judgment should be based on factors discussed in this TM. Refer to table 3-3 * for circuit breaker application comparisons.

Table 3-3. Circuit breaker application comparisons

	Low voltage power circuit breaker	*Molded-case circuit breaker*
Critical loads	X	
Noncritical loads		X
Selectivity critical	X	
Selectivity not critical		X
Repetitive duty	X	
Nonrepetitive duty		X
Extended life critical	X	
Extended life not critical		X
Interrupting rating at 480 V		
Up to 65kA without fuses	X	X
Up to 150kA without fuses		X
Up to 200kA with integral fuses.	X	
Systems with large X/R ratio	X	
High short-time capability	X	
High current inrush applications.	X	

3-6. Protective relays

Protective relays are classified according to their function, and there are a wide variety of protective relays available. The overcurrent relay, for example, monitors current and operates when the current magnitude exceeds a preset value.

*Adapted from Application Considerations from Circuit Breakers-Choosing the Right Type for Specific Applications by S.H. Telander, Consulting-Specifying Engineer Magazine, July, 1987.

a. Overcurrent relay. The most common relay for short-circuit protection is the overcurrent relay. These relays are much more sophisticated than the simple thermal overload relays discussed previously for motor applications, and have a wide range of adjustments available. Electromagnetic attraction relays may be ac or dc devices and are used for instantaneous tripping. Electromagnetic induction relays are ac only devices. Electromagnetic attraction and induction relays, like all electromechanical devices, are simple, rugged, reliable, and have been used successfully for years. However, solid-state electronic relays are rapidly replacing the electromechanical types. Solid-state relays require less panel space and exhibit better dynamic performance and seismic-withstand capability. Additionally, solid-state overcurrent relays are faster, have more precisely-defined operating characteristics, and exhibit no significant overtravel. As in the case of circuit breakers, electromechanical relays will continue to find applications in harsh environments. Overcurrent relays have a variety of tap and time dial settings. Typical relay ratings are shown in appendix D, and typical over-current relay time-current characteristic curves are shown in appendix C.

b. Relay device function numbers. Protective relays have been assigned function numbers by IEEE that are used extensively to specify protective relays. A partial list of relay function numbers is included in appendix E.

c. Instrument transformers. Protective relays will always be associated with medium-voltage and high-voltage circuits, involving large current magnitudes. Therefore, current transformers (CT) are required to isolate the relay from line voltages and to transform the line current to a level matching the relay rating. CTs are normally rated 5A on the secondary with a primary rating corresponding to the requirements of the system. Potential or voltage transformers (VT) are single-phase devices, usually rated 120V on the secondary with primary rating matched to the system voltage.

(1) CT burden is the load connected to the secondary terminals. Burden may be expressed as volt-amperes and power factor at a specified current, or it may be expressed as impedance. The burden differentiates the CT load from the primary circuit load.

(2) Residually-connected CTs and core-balanced CTs are illustrated in chapter 5. Residually-connected CTs are widely used in medium-voltage systems, while core-balanced CT's form the basis of several low-voltage ground-fault protective schemes. Relays connected to core-balance CTs can be made very sensitive. However, core-balanced CTs are subject to saturation from unbalanced inrush currents or through faults not involving ground. High magnitude short-circuit currents may also saturate core-balance CTs thus preventing relay operation.

d. EMI/RFI With today's increasing use of sensitive, solid-state devices, the effects of Electro-Magnetic Interference (EMI) and Radio-Frequency Interference (RFI) must be considered. Solid-state devices, due to their many advantages, are rapidly replacing the rugged electromechanical devices previously used. One disadvantage of solid-state devices, however, is their sensitivity to power source anomalies and electrostatic and electromagnetic fields. Recent developments in the design and packaging of solid-state devices have incorporated effective shielding techniques. However, the designer must still evaluate the environment and ensure that additional shielding is not required. Equipment and devices must comply with MIL-STD-461.

e. New developments. Microprocessor-based relays are also becoming available which provide multiple relay functions as well as metering, fault event recording, and self-testing in a single enclosure. This system requires fewer connections and less panel space than individual relays and associated peripherals.

3-7 Automatic reclosing devices

Automatic reclosing schemes should not be applied where the load being protected is a transformer or cable, since faults in these types of loads are usually not transient in nature. Automatic reclosing schemes applied to permanent faults in transformer or cable loads may result in equipment damage and personnel hazards. Additionally, automatic reclosing schemes should be guarded against in motor circuits. If the system voltage is restored out of phase, the motor windings, shaft, and drive couplings may be damaged. Furthermore, reclosers should be applied only on aerial distribution systems.