

IEEE Guide for Motor Operated Valve (MOV) Motor Application, Protection, Control, and Testing in Nuclear Power Generating Stations

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Abstract: Motors used to drive valve operators in nuclear power generating stations are discussed. Guidelines to evaluate the adequacy of motors used to drive valve operators; to provide recommendations for motor application; and to provide methods for protection, control, and testing of motors used for valve operation are presented.

Keywords: generating stations, motor application, motor control, motor protection, motors, motor testing, nuclear power, nuclear power generating stations, valve operation, valve operators, valves

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Introduction

(This introduction is not a part of IEEE Std 1290-1996, IEEE Guide for Motor Operated Valve (MOV) Motor Application, Protection, Control, and Testing in Nuclear Power Generating Stations.)

Motor operated valves (MOVs) have historically presented both electrical and mechanical problems to the engineering community. Since a complete evaluation of MOV applications requires both electrical and mechanical disciplines, no one existing document covers MOVs in a comprehensive manner. As a result, MOV applications are evaluated using a wide array of existing standards and other documents. Thus, it is difficult to assemble all the supporting material to address all issues relating to MOVs and valve actuator motors (VAMs).

This guide provides references to other published documents as applicable. This guide presents issues and suggestions for consideration in the application, protection, control, and testing of VAMs. It specifically attempts to cover topics not found in existing IEEE or other easily accessible documents. This guidance is an accumulation of recommendations and suggested solutions to problems based on experience.

The reader is cautioned to use this guide in conjunction with applicable IEEE documents and new solutions to VAM problems that are evolving continually. Due to the dynamic nature of issues concerning MOVs, this document cannot be all-inclusive, and the user should search for information and solutions beyond this document.

Limit and torque switch settings have also presented problems to the engineering community. Their settings are dependent upon many complex factors. Guidance for setting these devices is outside the scope of this document, but this will be considered for a future revision.

This guide is presented in a logical progression of topics, their interrelationships, and their complexities.

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IEEE Guide for Motor Operated Valve (MOV) Motor Application, Protection, Control, and Testing in Nuclear Power Generating Stations

1. Overview

1.1 Scope

This guide applies to motors used to drive valve operators in nuclear power generating stations.

1.2 Purpose

This guide presents guidelines to evaluate the adequacy of motors used to drive valve operators; to provide recommendations for motor application; and to provide methods for protection, control, and testing of motors used for valve operation.

2. References

This guide shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

ICEA P32-382 (Reaff 1992), Short-Circuit Characteristics of Insulated Cables.¹

IEEE Std 43-1974 (Reaff 1991) , IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).²

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

IEEE Std 112-1991, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators (ANSI).

¹ICEA publications are available from ICEA, P.O. Box 411, South Yarmouth, MA 02664, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 113-1985, IEEE Guide on Test Procedures for DC Machines (ANSI).

IEEE Std 118-1978 (Reaff 1992), IEEE Standard Test Code for Resistance Measurement.

IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.³

IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book) (ANSI).

IEEE Std 382-1985, IEEE Standard for Qualification for Actuators for Power Operated Valve Assemblies with Safety-Related Functions for Nuclear Power Plants (ANSI).

IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10 000 hp) (ANSI).

IEEE Std 603-1991, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations (ANSI).

IEEE Std 741-1990, IEEE Standard Criteria for the Protection of Class IE Power Systems and Equipment in Nuclear Power Generating Stations.

IEEE Std C37.2-1991, IEEE Standard Electrical Power System Device Function Numbers (ANSI).

NEMA ICS 2-1993, Starters, Contactors and Overload Relays, Rated not More Than 2000 Volts AC or 750 Volts DC (sections 321–327).⁴

NEMA MG 1-1993, Motors and Generators.

NEMA ST 1-1988, Specialty Transformers (Except General-Purpose Type).

3. Definitions

3.1 duty cycle of a VAM: The number of consecutive valve strokes required for the intended service of the valve. Plant operation or testing may require successive stroking of the VAM.

3.2 duty cycle time of a VAM: The time for one stroke multiplied by the duty cycle.

3.3 inrush current: The rapid change of current with respect to time upon motor energization. Inrush current is dependent upon the voltage impressed across the motor terminals and the motor inductance by the relationship $V = L \, di/dt$.

3.4 locked rotor torque: The torque output capability of the VAM at zero speed and rated voltage and frequency.

3.5 nonlocking gear train: A power transmission gear train design that allows the power train to back-drive whenever the primary driving force is removed.

³IEEE Std 119-1974 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁴NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209, USA.

3.6 overload: Operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated ampacity, which, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault such as a short circuit or ground fault is not an overload.

3.7 position seating: A control scheme that uses the limit switch as the primary control for operation of a VAM. The limit switch controls the VAM by interrupting power to the motor contactor when the valve actuator has completed a predetermined number of revolutions.

3.8 rated locked rotor current: The steady-state current taken from the line with the rotor locked and with rated voltage and rated frequency applied to the motor.

3.9 rated start torque: A conservative value established by the manufacturer for motor torque at the locked rotor (zero speed) condition, taking into account uncertainties in the manufacturing process. It can exceed 20% less than locked rotor torque.

3.10 self-locking gear train: A power transmission gear train designed such that the power train will hold its position and not back-drive whenever the primary driving force is removed. A valve actuator with a self-locking gear train will hold the valve in its last position when the VAM is de-energized.

3.11 start current: The current taken from the line when the motor is producing rated start torque at rated voltage and frequency.

3.12 time rating of a VAM: The maximum amount of time the motor can be operated at rated running load without exceeding the allowable temperature rise for the insulation class being used.

3.13 torque seating: A control scheme that uses the torque switch as the primary control for operation of the VAM. The torque switch controls the VAM by interrupting power to the motor contactor when the valve actuator output torque exceeds a predetermined value.

3.14 total motor temperature: The motor temperature rise plus the ambient temperature.

3.15 valve stroke: Complete travel of a valve from either fully open to fully closed position or vice-versa.

3.16 VAM: valve actuator motor.

4. Motor applications

Valve actuator motors have a unique design that can result in significantly different operating characteristics than NEMA Design B motors. Continuous duty motors, such as NEMA Design B Motors, are rated in horsepower, which implies a constant torque. VAMs are neither continuous duty nor constant torque at rated speed. They can be characterized as short duty time, high starting torque motors.

4.1 Thermal considerations

The motor thermal endurance margin is a function of the load on the motor, the duration of the load, the applied voltage, and the ambient temperature. An increase in the load, an increase in the duration of the load, or an increase in the ambient temperature will result in a decrease in the thermal endurance margin of the motor.

For example, rated run torque is typically 20% of the start torque rating of the motor. There are disparities between vendors in the use of the run torque term that make it impossible to establish a universal definition. A motor rated for 10 ft·lbf (14 N·m) start torque and a 15 min time rating can typically be run continuously

at a load of 2 ft·lbf (2.7 N·m) or less for up to 15 min in the rated ambient temperature at rated voltage and frequency without exceeding the design temperature limits of the motor. If the motor is run at more than 20% of the start torque rating, the temperature will rise more quickly. Since the temperature will approach the motor design limits faster at this higher torque loading, the result is a shorter allowable operating time. A longer time rating can be obtained by using a higher class insulation, a lower ambient temperature, or a larger start torque rated motor, which reduces the percentage of the running load.

A longer operating time requires similar considerations. The requirement for several full-stroke consecutive operations should be conservatively treated as a continuous operating time, since this scheme does not allow time for the motor to cool down between operations.

Jogging duty is more severe and shall be considered, when applicable. Required run torques, starting frequency, operating times, and temperature limitations of the motor insulation shall all be considered for the proper application of the duty cycle of a VAM.

4.2 Voltage considerations

Voltage at the VAM terminals shall be determined for all design basis conditions at the time of VAM required operation. The minimum and maximum source voltage is derived from a plant-specific voltage study, including any effects of the VAM starting. The effect of high and low voltage on motor torque is discussed in 4.3.

4.2.1 AC motors

4.2.1.1 Source voltage

Some of the conditions that should be considered are as follows:

- a) Starting of large loads with resultant voltage dips
- b) Separation from the offsite power supply, starting of the diesel generators, and sequencing of large load blocks that contain MOVs
- c) Degraded grid voltage

4.2.1.2 Voltage drops

When calculating the terminal voltage at the VAM, all impedances in the circuit shall be included in the calculation. The impedance of thermal overload heaters shall be considered and may be 30 Ω or more for small heaters. It is also necessary to consider the effect of high ambient temperature on circuit components during certain plant operating and transient conditions. The impedance of the circuit breaker, contactor, and containment penetration assemblies are typically negligible.

4.2.1.3 Effect of locked rotor power factor

The high starting torque design of VAMs requires a high rotor resistance, which results in an elevated locked rotor power factor. Unlike induction motors, which may have typical locked rotor power factors of 0.2 to 0.4, VAMs may have starting power factors as high as 0.60 to 0.95. Data should be obtained from specific motor manufacturers. These high locked rotor power factors can have a significant effect on motor terminal voltage at starting conditions. See [B1].⁵

⁵ The numbers in brackets preceded by the letter B correspond to those of the bibliography in clause 8.

4.2.1.4 Source frequency

Significant frequency deviations (sustained high or low frequency) can cause motor overheating. Historically, frequency has not been a concern for VAMs because the power sources are highly frequency stable. If a VAM is powered from a source that could produce significant frequency variations (greater than a few percent) over a period of several seconds, the effect of those variations shall be considered in the design. Sources that could produce significant frequency deviations include motor-generator sets, diesel generators, and static inverters.

4.2.2 DC motors

4.2.2.1 Source voltage

The voltage drop analysis should consider dc system characteristics, such as battery end of life (fully aged), ambient temperature, battery equalizing charge voltage, voltage dip during starting of large loads, and where the MOV operates in the battery duty cycle. It should be noted that operation at reduced voltage may cause a change in actuator speed. Appendix B to IEEE Std 741-1990⁶ provides an example showing a method for estimating the change in stroke time due to reduced voltage.

4.2.2.2 Voltage drops

All resistances shall be included when calculating the terminal voltage at the VAM. For shunt wound or permanent magnet field motors, circuit resistance is proportional to twice the resistance corresponding to the single conductor length for the starter-to-motor cable conductor. Compound wound motors supplied by a reversing starter have both the armature and series field connections cabled to the starter, and total circuit resistance is proportional to four times the resistance of length of the cable from the starter to the motor. Note that the shunt winding cable conductors may be a different size than the armature or series field conductors. The effects of a starting resistor shall be considered.

It is also necessary to consider the elevated resistance of cable that is in a high ambient temperature. For motors that may be required to start in a high ambient temperature, it is necessary to consider the effect of the ambient temperature on the cable and motor resistance when evaluating the torque output of the motor.

The resistance of the thermal overload heater shall be included. It can be 30 Ω or more for small heater sizes. If two thermal overload heaters are used, the resistance of both shall be used to obtain the total circuit resistance. The resistance of the circuit breaker, contactor, carbon brushes, and containment penetration assembly are typically negligible in relation to the thermal overload.

4.3 Motor torque

Motor temperature and terminal voltage affect torque output [B1]. Some motors may be required to start after being exposed to elevated ambient temperatures for several hours. It is prudent to evaluate the minimum available motor torque at the highest motor temperature and minimum voltage.

This internal temperature should be based on worst-case operating conditions. For valves that may be required to stroke more than once in succession, a temperature rise obtained from the motor performance curve should be added to the motor ambient temperature to account for the internal heat generated during the preceding strokes. For operations in changing ambient conditions, the thermal lag of the motor should be considered. High temperature fluid in pipes may provide a localized ambient temperature rise.

⁶Information about references can be found in clause 2.

The distinction between rated start torque and locked rotor torque is an important factor in valve actuator motor application. Locked rotor torque is, by definition, the torque the motor produces at zero speed at rated voltage and frequency. Because variations in the manufacturing process allow some tolerance in the VAM resistance and inductance, and because all motors are not typically tested during the manufacturing process unless this was specified by the purchaser, a specific locked rotor torque for a specific VAM may be unavailable. The manufacturer therefore determines a rated start torque that it will guarantee. This rated start torque is usually a rather conservative value. For example, a motor that has a locked rotor torque design value of 342 ft·lbf (464 N·m) has a rated start torque of 300 ft·lbf (407 N·m).

If the user has no other data available on a specific motor, he or she has to use the rated start torque value in the calculation to determine the torque margin. If the user is able to perform testing, he or she will usually find more torque capability than would be given by the rated start torque value. This testing can be in the form of dynamometer testing at the plant of the manufacturer or user, or other testing where the motor current and voltage can be measured and the motor torque at zero speed determined by a thrust or torque measuring device. There are a number of diagnostic systems presently available to measure actuator thrust and torque. It is beyond the scope of this guide to discuss methods for determining motor torque from these diagnostic systems. In general, the locked rotor torque capability of the motor itself shall be determined, not the effect of rotational inertia of the actuator components. Where the output torque of the motor is assumed to be greater than the rated starting torque of the motor, each of the parameters (such as power factor, locked rotor current, and locked rotor torque) in the equation to estimate the output of the VAM shall be determined by testing the specific VAM being evaluated.

For applications where the hammerblow feature of the motor operator has been supplied, the VAM would start unloaded, thus requiring less voltage to start and drawing locked rotor current for a few milliseconds before actuating the hammer blow feature. Therefore, the VAM is only required to supply the torque associated with seating or unseating the valve while the motor is operating above zero speed. The current associated with this torque can be as much as 50% less than the locked rotor current. The voltage requirement for the unloaded motor would be expected to be reduced; however, this should be confirmed with the valve actuator supplier. The user may use this torque and current value in his or her analysis. The cases where the hammerblow feature could be negated are valves that have nonlocking gear sets with the valve position maintained by motor brakes, or valves that have last been seated by manual action. However, plant procedures generally require stroking the valve electrically after any manual manipulations.

The first torque margin calculation example in annex A for each motor type (ac and dc) is for the case where no other data is available and the calculation is done using rated start torque. The second example is done using torque and current values obtained from actual motor tests.

Under the abnormal conditions of actuator stall, motor locked rotor torque at elevated voltage may exceed the actuator limits. Since the actuator has to operate at reduced voltage where motor torque output is less, reducing motor size may not be a viable option. Actuators are normally capable of surviving at least a one-time stall condition in excess of rated torque or thrust. If the actuator is the limiting component, this one-time allowance might be considered for the case of a stalled motor. A weak link analysis of the MOV assembly would then be performed. This would identify components likely to be damaged by excessive torque/thrust. The components may be in the actuator or valve. These components could be examined by appropriate nondestructive examination techniques following the overtorquing incident. Spares should also be ordered for the weak link components. Thus, if an overtorque incident occurred, spares would be available for any required parts replacement. These techniques impact mitigating techniques only.

4.3.1 AC motor torque evaluation

Both voltage and temperature impact the starting torque. They may be considered independently. Examples of ac motor torque evaluation are found in annex A. The motor output torque is typically proportional to the per unit terminal voltage raised to the power of 2.0 or 2.2 [B1].

Determining the effect of temperature on starting torque requires knowledge of the appropriate motor constants. As valve actuator motors are not NEMA Design A, B, C, or D motors, these motor constants cannot readily be derived from typical motor tests using IEEE Std 112-1991. In addition, the alloys used in the rotor bars and end rings vary with motor frame size and manufacturer, and the effect of temperature on secondary resistance cannot be determined unless the alloy is known. The locked rotor torque versus the winding temperature data for each ac motor type shall be obtained from the manufacturer. When using this data, it is important to use total motor temperature. The effects of elevated temperature and reduced voltage may be calculated in accordance with the guidance from the manufacturer as shown in the examples found in annex A.

After the motor torque at the anticipated worst-case voltage and temperature is determined, it should be compared with the motor torque requirement of the valve actuator, and there should be a reasonable margin between them. The motor torque requirements of the valve actuator will normally take into consideration valve size and type, valve stem thread characteristics, valve seat area, differential pressure, unit gear ratios, and other applicable factors. Motor terminal voltages below 70% of rated may result in a nonlinear torque relationship, and testing or data from the vendor should be used.

4.3.2 DC motor torque evaluation

For dc valve actuator motors, the relationship between the torque and current is approximately linear and is shown by the motor speed torque curve, which is provided as part of the motor data sheet. For the starting condition, the motor is modeled as a fixed resistance whose value, R_m , is:

$$R_m = \text{Rated Voltage} \div \text{Locked Rotor Current} \quad (1)$$

In the case where no other data is available, locked rotor current may be determined from the motor torque curve at the rated start torque value. However, if actual test data is available, it would be preferable to use the test data.

This value of motor resistance shall be corrected based on the postulated motor internal temperature just prior to motor starting. Once the maximum and minimum starting currents have been calculated, maximum and minimum torques can be determined by utilizing the motor speed torque curve. Motor terminal voltages below 70% of rated may result in a nonlinear torque relationship, and the actuator vendor should be consulted (note that some testing has been performed to 25% of rated voltage, which found that a linear relationship of torque to voltage exists) [B7]. Examples of dc motor torque evaluation are found in annex A.

5. Protection

In general, protection schemes shall consider the design function of the VAM and its ability to perform this function. The protection scheme shall also consider the protection of the VAM. However, protection cannot always be designed to enable the valve to perform this design function and to protect the valve actuator. When this occurs, VAM protection should be established to encompass one of the following options:

- a) Protect the VAM at the expense of its design function to ensure that later VAM operation is possible. However, protection should not be provided that infringes on the design basis safety function of the VAM.
- b) Provide as much VAM protection as possible without limiting its chances of accomplishing its design function. Providing limited VAM protection may allow undetected VAM degradation.

Protection can be provided by various types and combinations of devices. This guide discusses thermal overload relays (5.1); fuses (5.2); thermal contacts (5.3); resistance temperature detector (RTD)—resistors (5.4);

molded case circuit breakers (5.5); and dc VAM surge protection (5.6). This guide is concerned with only VAM coordination with upstream power sources.

As VAMs frequently have not been fuse protected, this guide provides some detail on fuse application (see annex B).

5.1 Thermal overload relays

Thermal overload relays protect VAMs from harmful overload conditions that may result in motor operation beyond the thermal limit of the operator.

A properly sized thermal overload relay will both ensure motor protection and allow motor operation for the entire design duty cycle. Setting a thermal overload relay to operate at a time/current point greater than the equivalent resultant thermal capability of the motor does not improve the starting reliability of the motor. If a motor is unable to provide adequate torque to move a valve at the beginning of the stroke, simply allowing the motor to continue to draw locked rotor current will not result in valve motion. Torque output will decrease as the motor heats up. Oversizing thermal overload relays does not result in expanded valve reliability, but rather in motor degradation whenever the motor is called upon to provide torque in excess of its capability [B2].

VAMs shall be protected against operating conditions in which the design limits of the motor are exceeded in order to ensure that MOV function is maintained.

Motor protection is normally provided through the use of thermal overload relays. Block 1 of figure 1 represents the overload section of the control scheme. The function of the thermal overload relay is to protect the motor from overloading. This protection is normally provided throughout the entire opening and closing operation of the valve. U.S. Regulatory Guide 1.106 [B13] and NUREG-1296 [B8] discuss overload protection for MOVs. This protection is significant when the torque switch is bypassed in the control circuitry.

- a) Advantages
 - 1) Capable of resetting after trip and re-using
 - 2) Testable
 - 3) Many ambient compensated sizes available for ease of coordination with other protective devices, especially for smaller loads
- b) Disadvantages
 - 1) Contains mechanical moving parts
 - 2) When thermal-magnetic breakers are used, difficult to coordinate for high impedance faults
 - 3) Additional circuit impedance
 - 4) Not designed nor rated for fault currents

Appendix B of IEEE Std 741-1990 provides typical sizing methodology for thermal overload relays. Electronic overload protection may be considered for new designs. However, such equipment is considered emerging technology and is beyond the scope of this guide.

5.2 Fuses

Fuse selection for the protection of VAMs should consider five factors:

- Protection for an overload condition. Operation should be allowed over the duration of the duty cycle time but within the thermal limit of the VAM and the cable.
- Protection during a stall (locked rotor) condition within the thermal limit of the VAM.
- Allowance for motor starting current to pass without interruption.

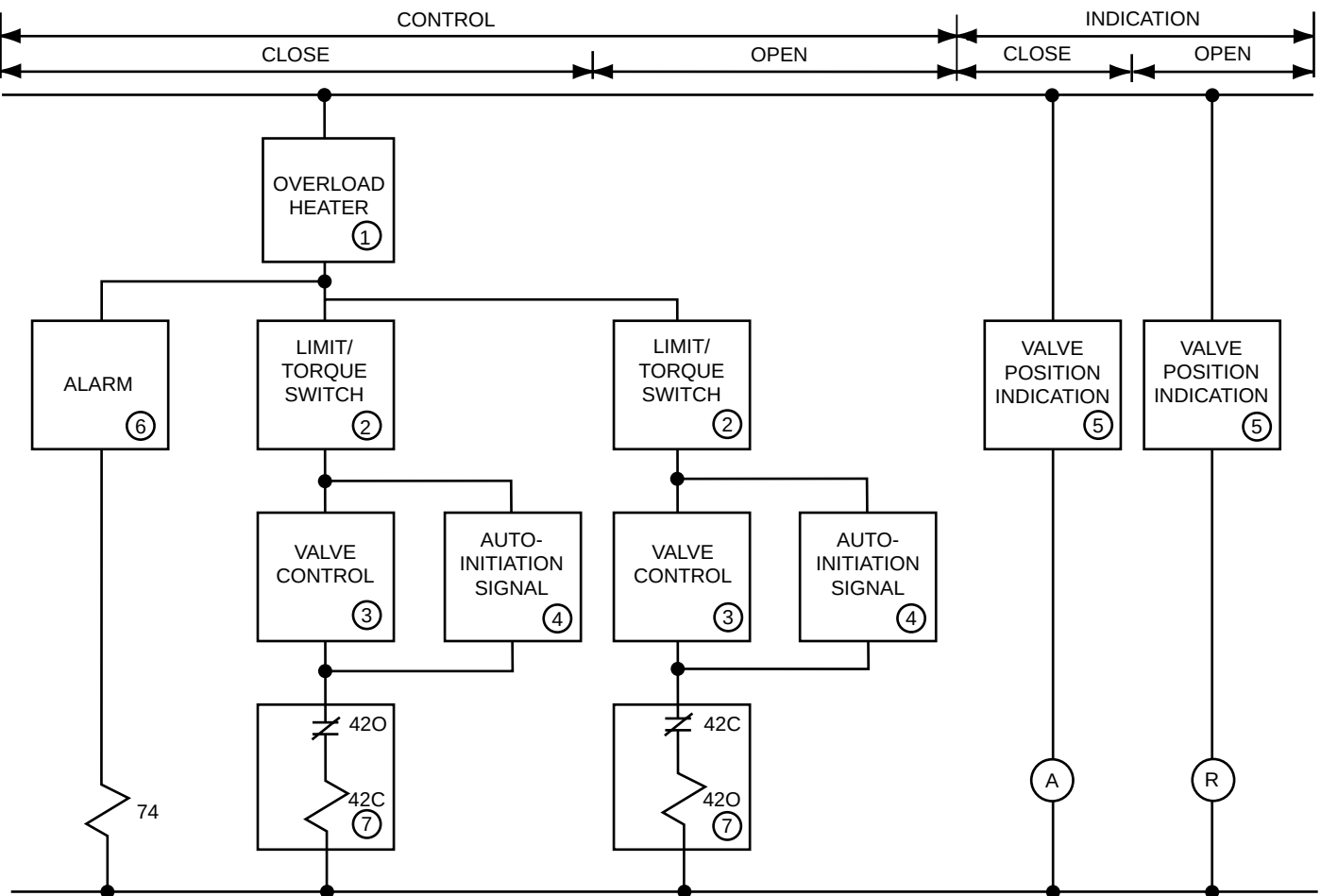


Figure 1—Block diagram for typical MOV control scheme

- Cable and containment penetration limits.
- Interrupting rating equals or exceeds requirements for type of circuit (ac or dc).

These requirements can be met by the use of time delay (UL Listed-Class RK-5) type fuses (see IEEE Std 242-1986).

a) Advantages

- 1) Fuses are typically available with third-party independent validation to provide interrupting capability of up to 200 000 A rms ac and 20 000 A dc in a small compact device.
- 2) Many sizes are available, allowing ease of coordination with other protective devices, especially for smaller loads.
- 3) There are no moving mechanical parts.
- 4) Some types of fuses have low resistance.
- 5) Both fault and overload protection are provided in one device.

b) Disadvantages

- 1) Cannot be reset, but has to be replaced.
- 2) It is possible to lose a single line phase (single phasing).
- 3) Cannot be nondestructively tested for its melt point characteristics that include arcing time to clear.

5.2.1 Fuse selection methodology

In order for the fuse to be sized, information regarding the VAM's rated nominal current, locked rotor current, duty cycle/jogging, temperature effects, and the stroke (operating) time of the associated valve is required. A combination of informational sources may include

- a) Motor performance curves
- b) Nameplate information
- c) Diagnostic test result
- d) In-Service Testing (IST) results
- e) Stroke time calculation

These sources are discussed in more detail in IEEE Std 741-1990.

5.2.1.1 Selection for ac VAMs

5.2.1.1.1 Protection for single phasing

The probability of losing a single phase (single phasing) exists when fused switches are utilized in the valve control circuit. In the common application where the control power transformer (CPT) is across two of the three phases, the probability of single-phase operation is limited to one phase. Consideration should be given to detecting a blown fuse condition utilizing a blown fuse indicator or a loss of voltage relay to detect a blown fuse (see figure 2). The benefits gained by the use of any detection scheme should be evaluated relative to the circuit complexity and feasibility of qualification to IEEE Std 323-1974 and IEEE Std 344-1975.

5.2.1.1.2 Ambient temperature effects

Time delay fuse ratings are typically based on an ambient temperature of 25 °C. Higher or lower ambient temperatures about the fuse (within a panel, MCC, etc.) effect the continuous current-carrying capacity and melting (clearing) time of a fuse. Figure 3 is a representative plot of these characteristics for a time delay fuse; actual characteristics may vary between fuse types and manufacturers.

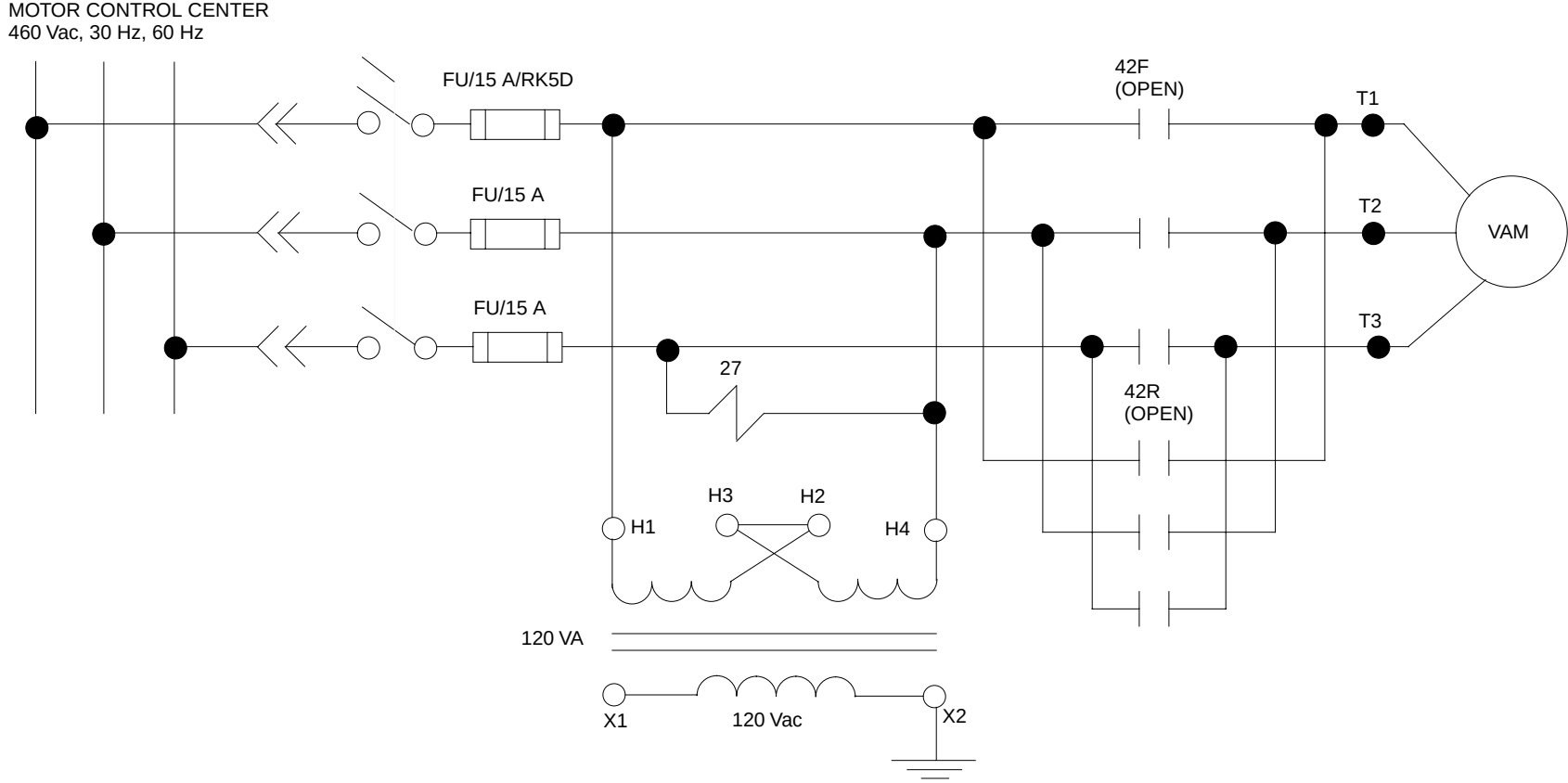


Figure 2—Typical fusing scheme

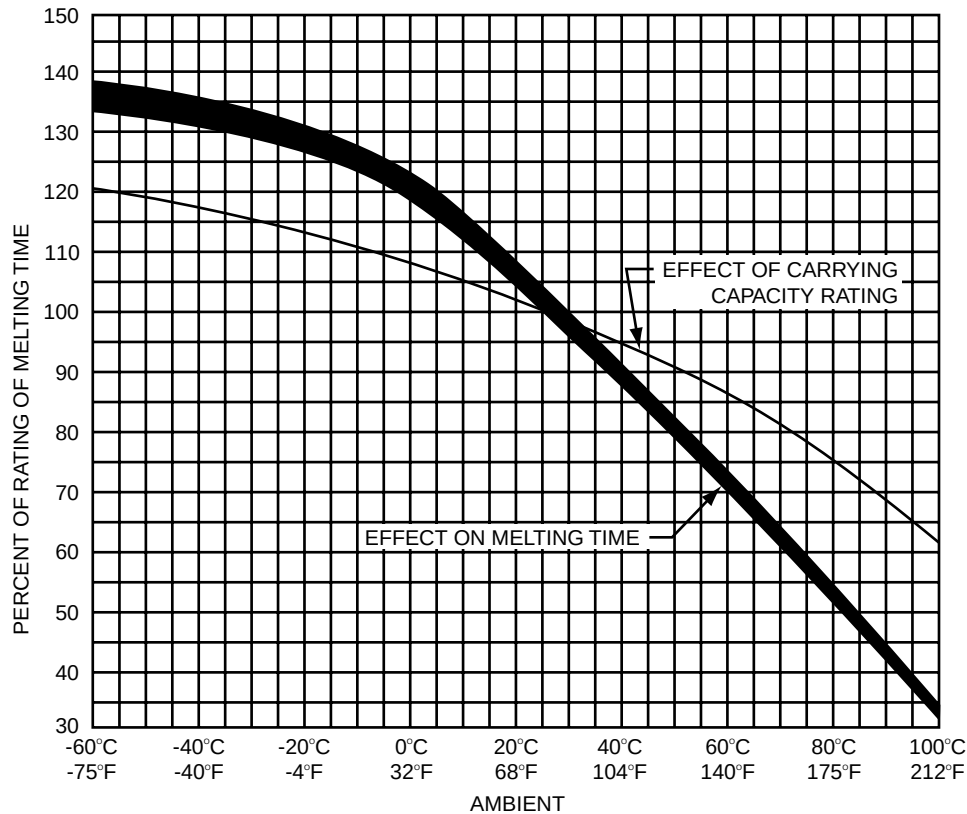


Figure 3—Effect of ambient temperature on operating characteristics of fuses

5.2.1.1.3 Correction for voltage variation

AC VAMs are sensitive to voltage variations. As voltage increases, running load current increases. The same relationship exists for locked rotor current [B1]. This relationship is further discussed in IEEE Std 741-1990. This greater current should be taken into account since the melt point of the fuse may be reached. Fuse sizing should consider the highest design base voltage that is expected.

As an example, if the VAM terminal voltage is 506 Vac, or 110% of rated 460 Vac, then the locked rotor current increases from 16 A to 18 A (see figure 4). This causes two effects:

- Current through the fuse increases, which decreases the melt time when the current is typically above 125% of the fuse rating.
- Heat input to motor insulation increases (proportional to the square of the current), which decreases the locked rotor withstand time.

The heat input to the motor insulation can be represented by I^2t for a short time period. At locked rotor, the maximum heat input a 10 ft·lbf (14 N·m) start motor can withstand at rated voltage without damage is: $(16 \text{ A})^2 \text{ locked rotor} \times (15 \text{ s})$ to 85° [From figure 4] = (3840) A·s. At a locked rotor current of 18 A, the with-

stand time is $t = 3840/(18)^2 = 11.8$ s. The fuse should be selected to protect the motor by melting before this new withstand time.

A low VAM terminal voltage of 414 Vac or 90% of rated 460 Vac will cause locked rotor current (16 A) to decrease to 15 A (see the table in figure 4). The fuse selected should not have any adverse effects on motor insulation temperature rise capability time due to a slightly longer melt time. High voltage along with high fuse temperature is the worst-case scenario for the MOV to perform its intended function. The melt time of the fuse is multiplied by the corresponding percent relative to the ambient MCC temperature as determined from figure 3.

5.2.1.2 Selection for dc VAMs

DC VAM fuse selection should be performed in the same manner as described for ac VAMs and in annex B.

The exceptions are that single phasing need not be considered and that terminal voltage variations effect dc VAMs as follows:

- a) *Locked rotor current:* The magnitude of the locked rotor current varies in direct proportion to the terminal voltage at a given temperature. This effect should be considered in the selection of the fuse. Typically, the locked rotor current quoted by the vendor is for the armature.
- b) *Voltage variation:* Voltage variations have an insignificant effect on the motor current during dc VAM stroking, which has an effect on the stroke time due to the change in valve speed. This results in either a shorter stroke time for higher voltage, or a longer stroke time for lower voltage. As the variation in current is negligible, higher voltages do not compromise the thermal time-current capability of the VAM and, as such, have no effect on selection of the fuse. However, lower voltage may result in longer operating time and, thus, have the potential to result in spurious operation of the fuse, if it is not properly selected.

The time delay fuses chosen will usually have an ac rating. The fuse manufacturer shall be consulted to determine the dc fuse ratings. Fuse ratings for fuses used in dc systems shall envelope maximum and minimum system voltage for all operating conditions having an interrupting rating equal to or greater than expected available fault or short-circuit current. Ratings for ac or dc application should be based on national consensus methods.

5.3 Thermal contacts

The thermal contact is one type of thermal protector that can guard electric motors from overtemperature conditions. When the temperature limit of the thermal contact is exceeded, deflection of a bimetallic strip occurs. This deflection causes a contact to open and switch off the motor current. In order to protect the motor, the thermal contacts shall be installed at the critical/limiting locations for temperature in the motor. For example, if the winding is critical, then a contact should be installed in each winding.

- a) *Advantages*
 - 1) The temperature is measured directly at the point where thermal damage is a concern. Therefore, environmental factors such as temperature, dust, insulation, and air density are not significant factors when protecting the motor. Thermal contacts allow maximum protection while minimizing the chances of inadvertent protection.
 - 2) The protection is independent from the load. The protection and operating times are not a concern. Varying torque loads are also not a concern since the thermal contacts are activated by temperature and not current.
 - 3) No additional impedance is added to the motor power feeder circuits.

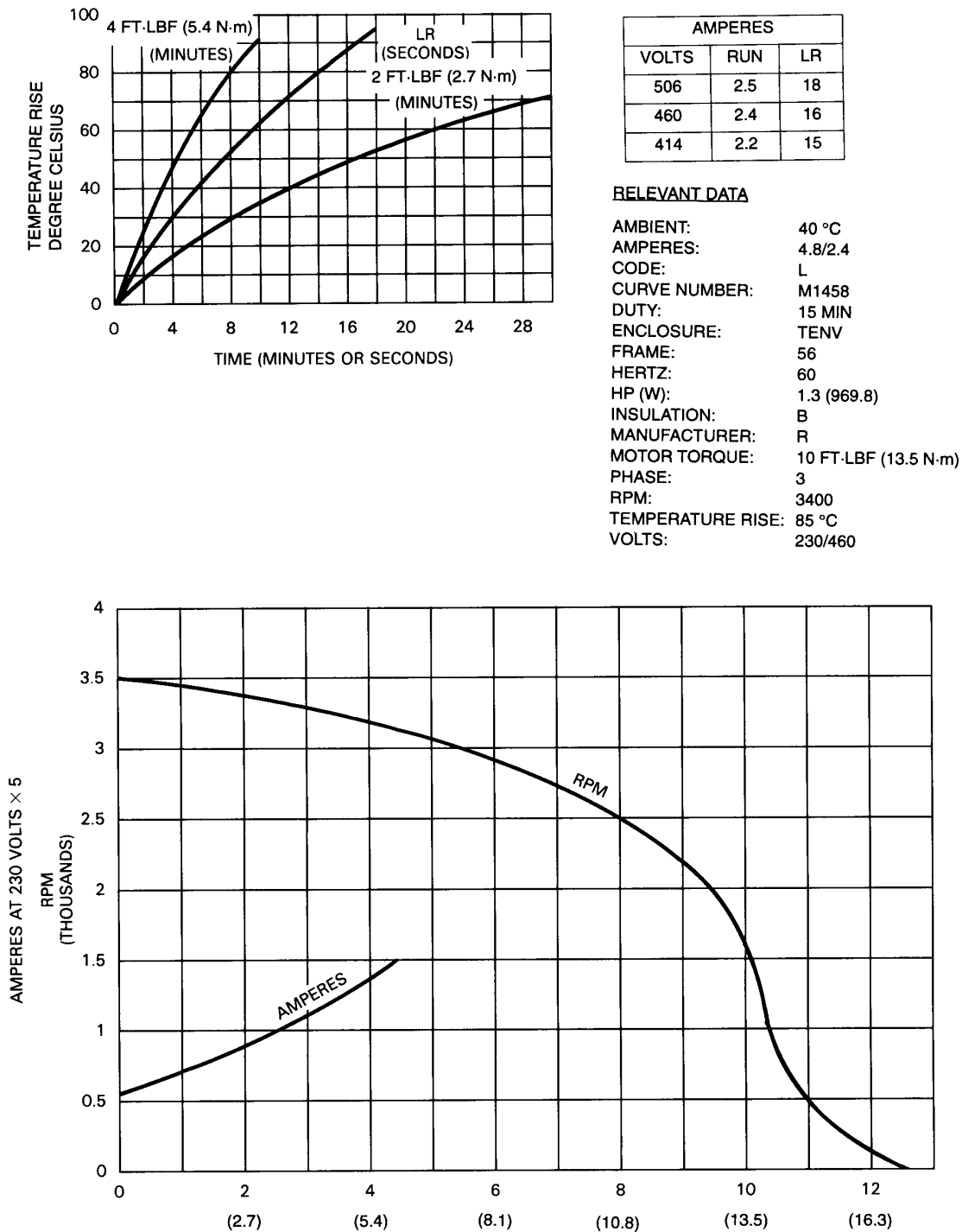


Figure 4—AC motor performance curves

- 4) Automatic reset; no operator action is required.
- 5) Reset time is dependent on ambient temperature and will vary from VAM to VAM.
- 6) Repeatability may not be adequate for high temperature applications.
- b) Disadvantages
 - 1) Two additional wires have to be installed and considered in the control circuit voltage analysis.
 - 2) There is no practical testing method to ensure that the contacts are functioning properly when testing is required.
 - 3) Rotor critical motors cannot be protected by thermal contacts in the stator.
 - 4) *Automatic reset*—A change in plant operability status at an unknown time and without operator knowledge is possible and may have major (safety) system implications. A further evaluation of the automatic reset feature has to be performed and consideration given to providing indication (alarm) of the change in operability status to the operator.
 - 5) Thermal contacts are supplied by the VAM supplier and are mounted permanently in the VAM motor. The VAM supplier should provide thermal contacts that protect the motor under all conditions. Typical temperature ratings of thermal contacts are 150 °C for motors with Class F insulation.

5.4 Resistance temperature detector (RTD)—resistors

Use of RTDs for protection is similar to thermal contacts and has the same advantages and disadvantages except that RTDs require control circuitry that can detect a resistance change. One disadvantage of the thermal contact that is overcome with the use of RTDs is that the RTD resistance can be measured with a high degree of confidence that the RTD is operating satisfactorily. Therefore, testing is not a concern and in fact can be done continuously if the proper controls are specified.

RTDs are temperature-dependent resistors that by definition change their resistance as the temperature changes. This resistance change has to be monitored by control equipment. When a resistance change consistent with the protection requirement is observed, the control circuitry interrupts power to the motor before damage occurs.

5.5 Molded case circuit breakers

Thermal-magnetic and magnetic-only circuit breaker selection for the short-circuit fault protection of the VAM circuit should consider

- a) Magnitude of the motor full load current rating
- b) Magnitude of the motor locked rotor current rating
- c) Magnitude of the available short-circuit current

5.5.1 Magnetic-only circuit breakers

- a) Advantages
 - 1) Many sizes are available in a given frame size for ease of coordination with other protective devices, especially for small motor ratings.
 - 2) They provide fault current interrupting capability.

- 3) They are available with adjustable trip setting ranging from three to ten times the circuit breaker trip rating.
 - 4) Faults as low as 10 to 20 times motor full load current can be cleared in a matter of a cycle or two, thus limiting damage to the motor and interconnecting circuitry.
 - 5) They provide circuit breaker convenience and are resettable.
- b) Disadvantages
- 1) They provide only short-circuit protection for the motor and motor circuit. Motor overload and locked rotor protection have to be provided by other protective devices within the controller. A thermal overload relay is required for complete VAM protection.

5.5.1.1 Magnetic-only circuit breaker sizing/trip setting methodology

Continuous current rating of the magnetic-only circuit breaker should be selected on the basis of the recommendations of the circuit breaker manufacturer. The continuous current rating is chosen to be greater than 120% of motor full load current rating. This allows additional margin for heating effects.

The magnetic-only circuit breaker reacts to current waveforms within the first cycle. To account for the effects of manufacturing tolerances ($\pm 20\%$), system asymmetry (50%), and overvoltages (10%), a trip setting equal to approximately two times the motor nominal locked rotor current should be used. Similarly, the trip setting for dc application could equal approximately 150% of the motor nominal locked rotor current, as system asymmetry is not a consideration.

5.5.2 Thermal-magnetic circuit breakers

Thermal-magnetic circuit breakers combine the overload and instantaneous functions within a single device. Modern circuit breakers are designed and calibrated for ambient temperatures for operation at full nameplate trip rating.

- a) Advantages
 - 1) Provide breaker convenience
 - 2) Testable
- b) Disadvantages
 - 1) The smallest typical thermal-magnetic breaker is rated at 15 A. A significant portion of installed and available VAMs have full load current ratings of less than 15 A.
 - 2) A thermal overload relay is required to be coordinated for complete VAM protection.
 - 3) They are not available with adjustable trip settings.

5.5.2.1 Thermal-magnetic circuit breaker sizing methodology

The continuous current rating of the thermal-magnetic circuit breaker should be selected on the basis of the recommendations of the circuit breaker manufacturer. Modern circuit breakers are designed and calibrated for ambient temperatures for operation at full nameplate trip rating. In general, the circuit breaker trip rating is chosen to be greater than 120% of the motor full load current rating. Higher trip ratings may be required to ensure coordination between breaker and motor thermal overload relay.

5.6 DC VAM surge protection

A discharge resistor or metal-oxide varistor should be used for dc VAMs to absorb the energy when the shunt field circuit is opened quickly. The device is placed in the circuit in parallel with the shunt field and should be sized sufficiently to dissipate the power.

DC VAM designs do not require the use of starting resistors to protect the motor. However, 150 ft·lbf (203 N·m) and larger dc VAMs can have very high locked rotor currents, and it may be beneficial to use starting resistors to protect the reversing contactor or some other limiting component. Starting resistors should either allow for a current draw of at least five times the full load current or use a time delay relay to drop the starting resistor out before the VAM becomes mechanically loaded.

NOTE—Starting resistors reduce the voltage to the motor and subsequent motor torque.

6. Control

This clause includes considerations to be addressed in designing an MOV control circuit. A typical control circuit has been depicted in a block diagram layout in figure 1. Each block represents an individual portion of the control scheme that will be discussed in detail in the following subclauses. This clause provides suggestions for integrating the individual blocks into a complete control circuit such that the MOV can perform the required function for its application. EPRI NP-6660-D [B5] also provides guidance for selecting control, protection, and alarm functions that are consistent with typical MOV applications.

The first step in designing a control circuit is to obtain the specific system design requirements. The MOV system requirement data sheet (figure 5) can be used to document the valve functional requirements needed to develop the control circuit. The design of a control scheme is based on the valve application, system design requirements, valve design and type (including design limits), vendor requirements, and limitations of control devices.

Subclauses 6.1 through 6.6 provide a brief description of each block in figure 1 of the control logic, including advantages, disadvantages, and design considerations for each. This description, in combination with the MOV system requirements documented in figure 5, gives the parameters necessary to select a control configuration appropriate for the MOV control circuit.

Protection can be provided by various types of devices. For examples of these devices, see clause 5.

6.1 Thermal overloads (TOLs)

Sizing criteria developed in IEEE Std 741-1990 provides detailed guidance to ensure proper sizing. Block 1 of figure 1 represents the TOL section of the control scheme. The design options discussed in the following subclauses are provided for the use of TOLs.

6.1.1 Continuous protection

Detail A of figure 6 depicts a general TOL configuration for continuous motor protection for the intended service. This option is most desirable, since it provides continuous motor protection.

- a) Advantages
 - 1) Continuous overload protection will de-energize the control circuit in case of a sustained overcurrent. The motor will be protected so that the valve can be stroked again after the TOL is reset.
- b) Disadvantages
 - 1) De-energization of the control circuit due to an inadvertent TOL heater actuation could potentially interrupt valve travel before the desired position is achieved.
 - 2) Dependent upon TOL placement in the control circuit, protection for hot shorts in the control circuit may not be provided (see 6.10).