# Desensitizing Electric Motor Controls

Introduction.   This note is not meant to be a complete discussion of this topic; it is only an attempt to explain some basic operating issues that appear frequently. This note will only cover alternating current induction motors operating at voltages under 600 volts, and full-voltage starters. Subjects covered will include: starting, stopping, overload and overcurrent protection. Subjects not covered include: reversing, changing speed, jogging, plugging, sequence control, and reduced voltage starting. See references at the end for further information, or contact motor controller manufacturers' representative.

In addition to providing a general description of operating issues, this paper makes particular note of nuisance tripping issues. A common cause of nuisance tripping is a sag in the supply voltage. Refer to our other Power Note on sags titled: Short Duration Voltage Sags can Cause Disruptions.

Motor control is a broad term that means anything from a simple toggle switch to a complex system with components such as relays, timers, switches, and pushbuttons. When motor control equipment is selected and installed, many factors must be considered to insure that the control will function properly for the motor and the machine for which it is selected. The term *motor starter* is often used in the electrical industry and means practically the same thing as "controller." Strictly speaking, a motor starter is the simplest form of controller and is capable of starting and stopping the motor and providing it with overload protection. The NEC also requires a disconnect means and over-current protection for a motor installation.

Essential Motor Controller Functions

| Power Source | → | Disconnect Point | → | Start/Stop | → | Short Circuit Protection | → | Over Current Protection | → | Motor |
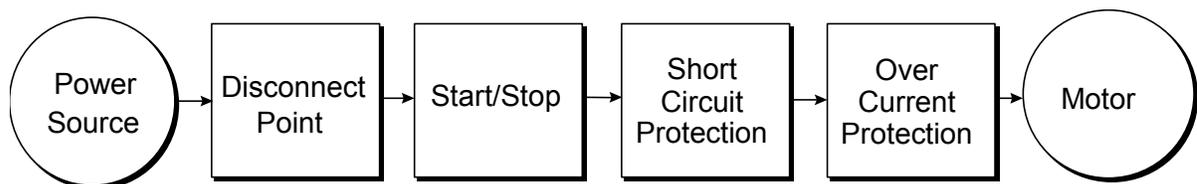
Purpose of controller.   The major factors to be considered when selecting and installing motor control components for use with a particular machine application are:

starting, stopping, reversing, running, speed control, safety of operator, protection from damage and maintenance of starting equipment.

Starting.   The motor may be started by connecting it directly across the source of voltage. Slow and gradual starting may be required, not only to protect the machine, but also to insure that the line current inrush on starting is not too great for the power company's system. The frequency of starting a motor is another factor affecting the controller and the motor. Very frequent starting can cause thermal overload due to high starting currents. National Electrical Manufacturers Association (NEMA) standards require that the starter size be derated if the frequency of starting, jogging, or plugging is more than 5 times per minute.

Stopping.   Most controllers allow motors to coast to a standstill. Some impose braking action when the machine must stop quickly.

Reversing.   Controllers can be required to change the direction of rotation of machines automatically or at the command of an operator.

Running.   The maintaining of desired operational speeds and characteristics is a prime purpose and function of controllers. They protect motors, operators, machines, and material while running with many different types of safety circuits and devices. The particular application of each motor and control installation must be considered to determine what protective features are required to be installed and maintained. Every motor needs overload protection for a variety of reasons. The supply voltage may decrease and cause the motor to pull excessive current. One phase of the supply voltage may fail and cause the motor to overheat if it continues to run. The motor itself could experience a winding insulation failure. The bearings may fail in the motor or the driven machinery. Wiring connections could become loose or the ambient temperature may increase to a very high level and cause overheating. There are many reasons that necessitate overcurrent protection.

Speed Control.   Some controllers can maintain very precise speeds or vary according to the needs of the industrial processes.

Manual starters.   A manual full-voltage starter is a motor controller whose contact mechanism is operated manually by a mechanical linkage from a toggle handle or push-button. A thermal unit and direct-acting overload mechanism provides motor running overload protection.

Manual starters are used mostly on small machine tools, fans, and blowers, pumps, compressors, and conveyors. They are lowest in cost of all motor starters; they have a simple mechanism, and provide quiet operation with no AC magnet hum.

The contacts, however, remain closed and the lever stays in the "on" position in the event of a power failure, causing the motor to restart automatically when the power returns. Therefore, low-voltage protection and low-voltage release are not possible with these manually operated starters. However, this action is an advantage when the starter is applied to motors that should run continuously.

There are three general size categories: 1) fractional-horsepower manual starters control and provide overload protection of motors of one horsepower or less; 2) manual motor-starting switches providing on-off control only for motors up to 10hp, no over-load protection, and 3) integral-horsepower manual starter with overload relays. These come in sizes up to 5hp, single phase and 10hp, three phase. These can have an optional low-voltage protection for protection against automatic restart after power failure. This is accomplished with a continuous-duty electrical solenoid which is energized whenever the line-side voltage is present and the start button is pressed. Typical applications are where a machine operator safety could be in jeopardy.

Thermal overload units are widely used on both the fractional and integral horsepower manual starters for protection of motors from sustained electrical overcurrents that could result from overloading of the driven machine or from excessively low line voltage.

Heater elements which are closely calibrated to the full load current of the motor are used on the solder-pot and the thermobimetallic types of overload relays.

Magnetic controllers. Magnetic motor controllers use electromagnetic energy for closing switches. The electromagnet consists of a coil of wire placed on an iron core. When current flows through the coil, the iron of the magnet becomes magnetized, attracting an iron bar called the armature. An interruption of the current flow through the coil of wire causes the armature to drop out due to the presence of an air gap in the magnetic circuit.

Line-voltage magnetic motor starters are electromechanical devices that provide a safe, convenient, and economical means of starting and stopping motors, and have the advantage of being controlled remotely. The great bulk of motor controllers sold are of this type.

In the construction of a magnetic controller, the armature is mechanically connected to a set of contacts, so that when the armature moves to its closed position, the contacts also close. When the coil has been energized and the armature has moved to the closed position, the controller is said to be "picked up" and the armature "seated" or "sealed in." (*See Figure 1*)

LINE "L" AND LOAD "T" TERMINALS

L1   L2   L3

STATIONARY
CONTACTS

MOVABLE
CONTACTS

T1   T2   T3

PRESSURE
SPRINGS

INSULATED CONTACT
MOUNTING (MOVABLE)

SOLENOID COIL

COIL TERMINALS

MAGNET
SHADING
COILS

STATIONARY
ELECTRO-
MAGNET

MOVING ARMATURE
OR PLUNGER

L1   L2   L3

"L" = LINE VOLTAGE

"T" = LOAD (MOTOR)

NORMALLY
OPEN
CONTACTS

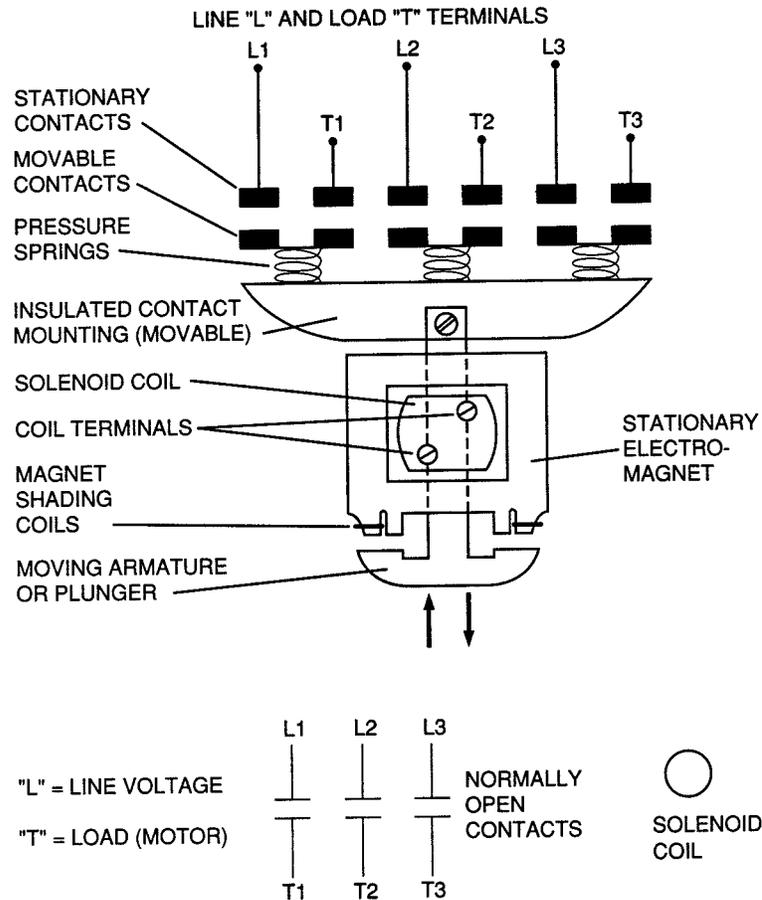SOLENOID
COIL

T1   T2   T3

**Figure 1.   Three-pole, solenoid-operated magnetic switch contactor
and electrical wiring symbols.**

NEMA standards require that the magnetic switch operates properly at varying
control voltages from a high of 110% to a low of 85% of the rated coil voltage.

PQ Note: Any voltage below 85% of nominal then, could result in a drop out.

Contact surfaces are a machined silver alloy. If they appear burned or have any
non-uniform surface appearance, you need to replace them and investigate the
cause immediately, otherwise overheating will quickly cause failure.

Overload protection. Overload protection for an electric motor is necessary to
prevent burnout and to ensure maximum operating life. Electric motors will, if
permitted, operate at an output of more than rated capacity. Conditions of motor

overload may be caused by an overload on driven machinery, by low line voltage, excessive voltage unbalance, or by an open line in a polyphase system, which results in single-phase operation. Under any condition of overload, a motor draws excessive current that causes overheating. Since motor winding insulation deteriorates when subjected to overheating, there are established limits on motor operating temperatures. To protect a motor from overheating, overload relays are employed on a motor control to limit the amount of current drawn. This is overload protection, or running protection.

In situations where the motor must operate in high ambient temperature condition, manufacturers have optional higher temperature rated models. The IEEE standard 117 establishes a temperature classification for insulation systems (see table below). The temperature classification indicates the maximum (hot-spot) temperature at which the insulation system can be operated for normal expected service life. Obviously, the higher the rating, the higher the cost.

Insulation System		Temperature Classification	
Class A	Class 105	105°C	221°F
Class European	Class 120	120°C	248°F
Class B	Class 130	130°C	266°F
Class F	Class 155	155°C	311°F
Class H	Class 180	180°C	356°F
Class N	Class 200	200°C	392°F

The overload relay does not provide short circuit protection. This is the function of overcurrent protective equipment like fuses and circuit breakers, generally located in the disconnecting switch enclosure.

The ideal overload protection for a motor is an element with current-sensing properties very similar to the heating curve of the motor *(Figure 2)* which would act to open the motor circuit when full-load current is exceeded. The operation of the protective device should be such that the motor is allowed to carry harmless over-loads but is quickly removed from the line when an overload has persisted too long.
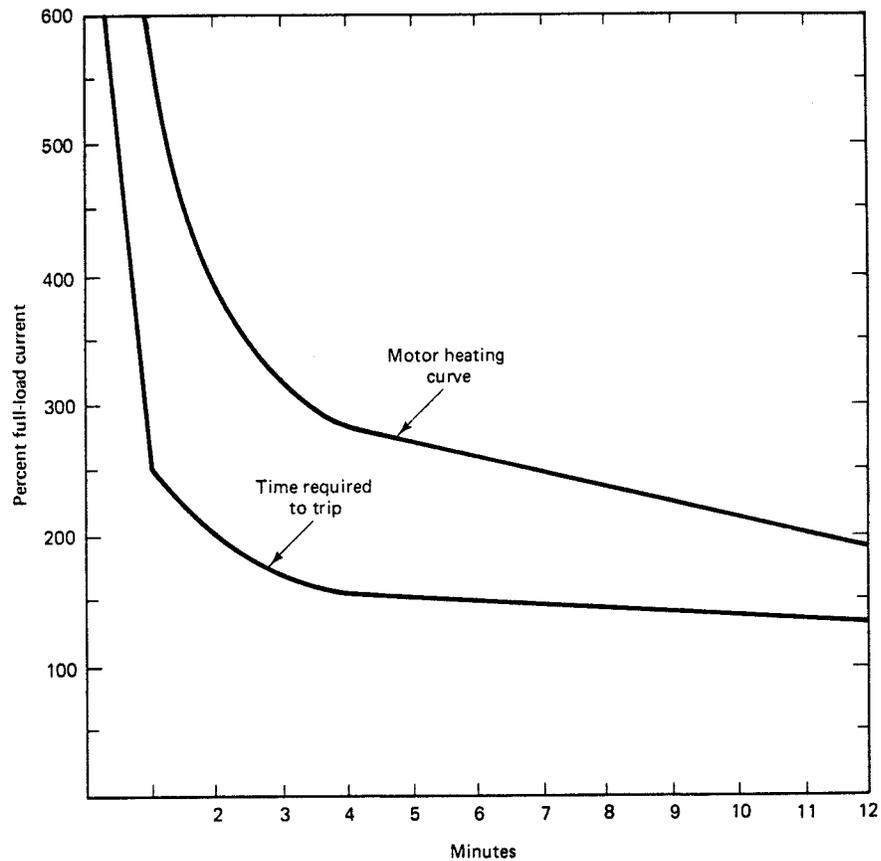
Figure 2. Motor and relay heating curves.

Single-element fuses are not designed to provide overload protection. Their basic function is to protect against short circuits (overcurrent protection). Motors draw a high inrush current when starting and conventional single-element fuses have no way of distinguishing between this temporary and harmless inrush current and a damaging overload. Such fuses, chosen on the basis of motor full-load current, would "blow" every time the motor is started. On the other hand, if a fuse were chosen large enough to pass the starting or inrush current, it would not protect the motor against small, harmful overloads that might occur later. Dual-element or time-delay fuses can provide motor overload protection but suffer the disadvantage of being nonrenewable and must be replaced.

The *overload relay* is the heart of motor protection. It has inverse-trip-time characteristics, permitting it to hold in during the accelerating period (when inrush current is drawn), yet providing protection on small overloads above the full-load current when the motor is running. Unlike dual-element fuses, overload relays are renewable and can withstand repeated trip and reset cycles without need of

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replacement. Overload relays cannot, however, take the place of overcurrent protection equipment.

The overload relay consists of a current-sensing unit connected in the line to the motor, plus a mechanism, actuated by the sensing unit, which serves, directly or indirectly, to break the circuit. In a manual starter, an overload trips a mechanical latch, causing the starter contacts to open and disconnect the motor from the line. In magnetic starters, an overload opens a set of contacts within the overload relay itself. These contacts are wired in series with the starter coil in the control circuit of the magnetic starter. Breaking the coil circuit causes the starter contacts to open, disconnecting the motor from the line.

Overload relays can be classified as being thermal, magnetic, or electronic. Magnetic overload relays react only to current excesses and are not affected by temperature. As the name implies, thermal overload relays rely on the rising temperatures caused by the overload current to trip the overload mechanism. Thermal overload relays can be further subdivided into two types: melting alloy and bimetallic.

Electronic or solid-state overload relays, provide the combination of high-speed trip, adjustability, and ease of installation. They can be ideal in many precise applications.

The melting-alloy assembly of heater element (overload relay) and solder pot is shown in *Figure 3*. Excessive overload motor current passes through the heater element, thereby melting a eutectic alloy solder pot. The ratchet wheel will then be allowed to turn in the molten pool, and a tripping action of the starter control circuit results, stopping the motor. A cooling-off period is required to allow the solder pot to "freeze" before the overload relay assembly can be reset and motor service restored.
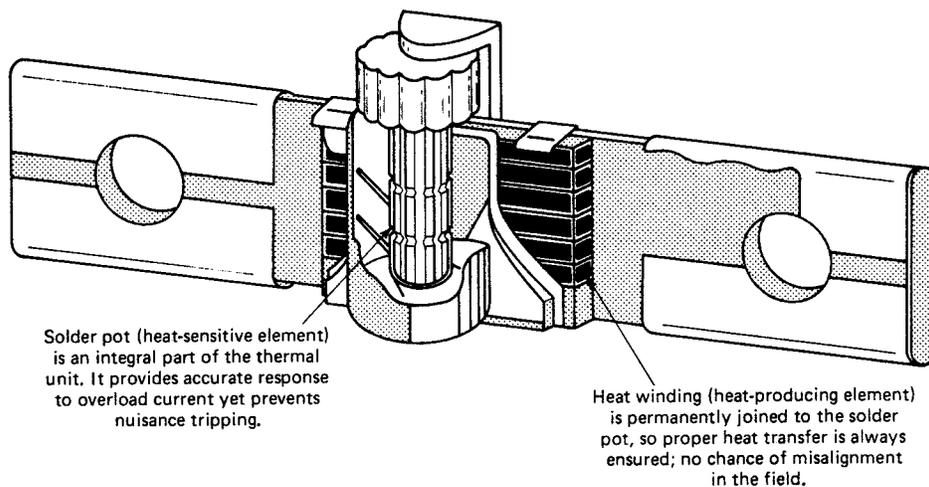

Figure 3.

Melting-alloy thermal overload relay.

Solder pot (heat-sensitive element) is an integral part of the thermal unit. It provides accurate response to overload current yet prevents nuisance tripping.

Heat winding (heat-producing element) is permanently joined to the solder pot, so proper heat transfer is always ensured; no chance of misalignment in the field.
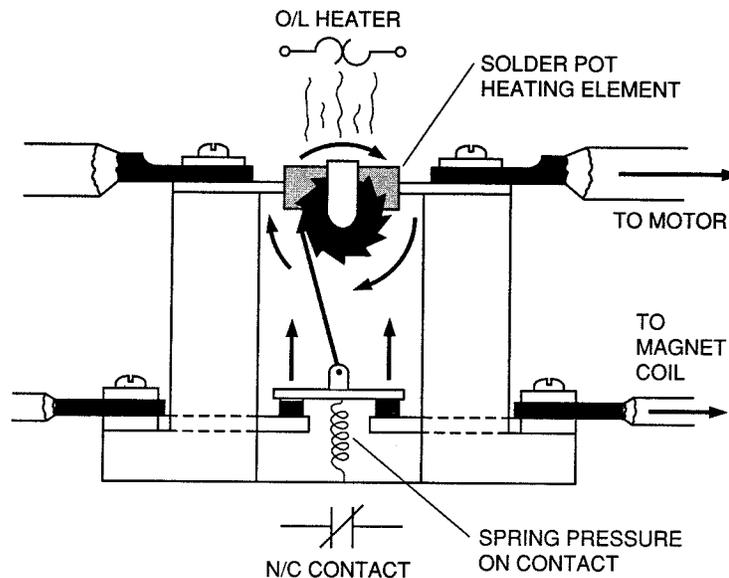
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Figure 4. Melting-alloy thermal overload relay. Spring pushes contact open as heat melts alloy allowing ratchet wheel to turn freely. Note electrical symbols for overload heater and normally closed control contact.

Melting-alloy thermal units are interchangeable and of one-piece construction, which ensures a constant relationship between the heater element and solder pot and allows factory calibration, making them virtually tamperproof in the field.

These important features are not possible with any other type of overload relay construction. A wide selection of these interchangeable thermal units is available to give exact overload protection of any full-load current to a motor. The various motor controller manufacturers publish tables that list motor horsepower (1/3 to 900) by nominal voltages (115-575) and NEMA starter sizes 00 through 8. Usually they have columns that list the continuous current ratings and the service limit current rating. The ultimate trip current of over-current (overload) relays or other motor protective devices shall not exceed the service-limit current ratings of the controller.

The units are easily mounted into the overload relay assembly and held in place with two screws. Being in series with the motor circuit, the motor will not operate without these heating elements installed in the starter.

Bimetallic overload relays are designed specifically for two general types of application. One application is where it is desirable to reset automatically for remote locations. They can be adjusted within a bandwidth of +/-15% of the nominal trip current. The second application is where the motor is located at a constant temperature but the controller is located separately in a varying temperature. If the controller senses a high temperature but the motor ambient temperature is adequate, this can result in needless nuisance tripping.

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When selecting thermal overload relays, the following must be considered: 1) motor full-load current, 2) motor starting characteristics, and 3) difference in ambient temperature between motor and controller.

Magnetic overload relays have a very broad adjustment range and are used in special cases where the motor has a long accelerating time or unusual duty cycle.

Combination Starters. The circuit breakers and fuses of the motor feeders and branch circuits are normally selected for overcurrent, short-circuit, or ground fault protection. With minor exceptions, the National Electric Code (NEC) requires that every motor have a disconnect means. A combination starter, consists of an across-the-line starter and a disconnect means wired together in a common enclosure. Combination starters may have a blade-type disconnect switch, either fusible or nonfusible, or a thermal-magnetic trip circuit breaker.

Contactors. Magnetic contactors are electromagnetically operated switches that provide a safe and convenient means for connecting and interrupting branch circuits. The principal difference between a contactor and a motor starter is that the contactor does not contain overload relays. Contactors are used in combination with pilot control devices to switch lighting and heating loads and to control AC motors in those cases where overload protection is provided separately.

Control relays. A relay is an electromagnetic device whose contacts are used in control circuits of magnetic starters, contactors, solenoids, timers, and other relays. They are generally used to amplify the contact capability or multiply the switching functions of a pilot device.

A condition may exist in which the voltage rating or current rating of a pilot device, such as a temperature switch, is too low to permit its direct use in a starter control circuit operating at a higher voltage or current level. In this application, the coil of the interposing relay and the pilot device are wired to a control source of an acceptable level. The relay contact, with its higher voltage or current rating, is then used to control operation of the starter.

Instantaneous trip current relays are used to take a motor off the line as soon as a predetermined load condition is reached. They should be considered as a special purpose relay. For example, when a blockage of material on a woodworking machine causes a sudden high current, an instantaneous trip relay can cut off the motor quickly.

Phase Failure and Reversal Relays. In many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire to a motor breaks while the motor is running, the motor will continue to operate on single phase but will experience serious overheating. To protect motors against these conditions, phase

failure and reversal relays are used. To prevent *nuisance dropouts* it is necessary to provide for a time delay of five or so cycles. Some solid state relays also include voltage unbalance trip. Again, this requires a time delay of 15 cycles *to avoid nuisance tripping*. For large motors, current transformers are used for the input to a special motor protector module that can include the following protection: solid state overload, phase loss, phase reversal, and instantaneous fault protection.

Time-delay, low voltage release relay. There is a possibility of injury to an operator or damage to machinery when the power suddenly resumes after a prolonged voltage failure. Therefore, it is desirable to provide some means of preventing motors from restarting in such cases. One method of preventing motor restart is known as low-voltage protection or three-wire control. This requires that an operator must manually push a start button to restart the motor. There may be cases where it is desirable for the motor to be able to restart if the loss of power is momentary or partial and there will not be danger to the operator or to the machinery. Actually, in some cases, damage to the process may be reduced by allowing an automatic restart. One solution to this problem is to use a time-delay, low voltage release device. When this device is used with a magnetic starter and a momentary contact push-button station, the motor is automatically reconnected to the power lines after a momentary or partial voltage failure if short duration. If the voltage failure exceeds the time-delay setting of the low-voltage release device, or if the stop button is pressed, the motor will not restart automatically; it must be restarted by pressing the start button. This device provides operator protection and can eliminate the inconvenience of a loss of production time where momentary or partial voltage failures are common. And what is a *partial voltage failure* but a SAG, the most common power anomaly.

The time-delay, low voltage release device has two critical components. The first is an energy storage device, a electrolytic capacitor, to maintain the magnetic energy in the control relay coil. The second is a timer function to control the time delay between 2 to 4 seconds, generally.

PQ Note: This optional relay may provide a solution to nuisance tripping due to a sag in the supply voltage.

Programmable controllers. Programmable controllers may be used in place of conventional controls; they include relays offering faster startup, decreased startup costs, quick program changes, fast troubleshooting, and up-to-date schematic diagram printouts.

Control Circuit Transformers. Low-voltage control circuit transformers (class 2) are used extensively in control circuits to obtain a lower voltage than is available from the power supply. For example, many control circuits operate at 24volts, and normally 120 volts is the lowest voltage used in any electrical system for building construction. Typically, they are limited in capacity to 75VA.

Electrical Codes and Standards. Electrical control equipment is designed to meet the provisions of the National Electrical Code (NEC), articles 430, 440, and 500. The NEC governs the selection of the proper sizes of conductors, starting fuses, circuit breakers, and disconnect switches for specific system requirements. NEC Article 430-31 specifically states that overload device for continuous duty motors rated more than one horsepower shall be selected to trip or rated at no more than 125% of motor nameplate full-current rating. Also since early 70's it has been required to protect all three phases on three-phase motors, not just two. OSHA requires an environment free from recognized hazards likely to cause serious harm. Standards established by the National Electrical Manufacturers Association (NEMA) assist users in the proper selection of control equipment. NEMA standards provide practical information concerning the construction, testing, performance, and manufacture of motor control devices, such as starters, relays and contactors. One of the organizations which actually test for conformity to national codes and standards in Underwriters Laboratories (UL).

Electricity Basics. PG&E does not use tap changing transformers for individual services. PG&E regulates the service voltage by tap changers in substation transformers, line regulators and line capacitors. PG&E regulates voltage for large segments of each feeder. Variable line regulation is required due to changes in customer load.

Electrical System Protection and Coordination*.* The objectives of electrical system protection and coordination are to prevent injury to personnel, to minimize damage to the system components, and to limit the extent and duration of service interruption. Interrupting devices should have *adequate interrupting capability* and energized parts should be sufficiently enclosed or isolated so as not to expose personnel to explosion, fire, arcing, or shock.

The principal abnormalities to protect against are short circuits and overloads. In the case of short circuits, a major concern is the available short circuit current. It is very important that all line connected equipment be rated for the available short circuit current from the utility and internally from other motors and generators. The electrical design engineer or electrical contractor is responsible to perform a fault current calculation so that the *withstand rating* for all equipment is properly rated. Typical values range from 10,000 to 100,000 amps. Naturally the cost for the higher rated equipment increases with it's current capacity.

Electric Motors, general specifications. Any study of electric motor controls should include a brief review of some electric motor principles and terms. Manufacturers provide *style numbers* on the motor nameplate and in the written specifications to identify that particular motor in contrast to all others. They also use a *serial data code* to identify the month and year of manufacture. *Frame sizes* are used to specify the shaft height and motor mounting dimensions. A *service factor* (SF) is a multiplier that when applied to the rated horsepower, indicates a permissible

horsepower loading that may be carried continuously. For integral horsepower motors, it is common to specify a service factor of 1.15. *Phase* indicates whether the motor has been designed for single or three phase operation. *Degree C ambient* is the air temperature immediately surrounding the motor. Forty degrees Celsius is the NEMA maximum ambient temperature (104 degrees Fahrenheit). *Insulation class* is chosen to ensure that the motor will perform at the rated horsepower and service factor load, (see table on page 5, typical is Class F.)   *Horsepower* defines the rated output capacity of the motor. It is based on breakdown torque, which is the maximum torque that a motor will develop without an abrupt drop in speed. Revolutions per minute (*Rpm)*, is the approximate full-load speed. The speed of the motor is determined by the number of poles in the winding. A two-pole motor runs at an approximate speed of 3450 rpm. A four-pole motor runs at an approximate speed of 1725 rpm. *Amperes* is given in full load condition. In North America, we are all on *60 Hertz frequency*. This is determined by the speed of the generators. The *KVA code letter* is defined by NEMA standards to designate the locked rotor kilovolt-amperes (kVA) per horsepower of a motor. It relates to starting current and selection of fuse or circuit breaker size. *Housing* designates the type of motor enclosure. The most common types are open and enclosed.

There are four NEMA design types listed in the following table. The most typical is design B.

Table 1. NEMA Design types for polyphase motors

NEMA Design	Starting Torque	Starting Current	Breakdown Torque	Full-Load Slip
A	Normal	Normal	High	Low, <5%
B	Normal	Low	Medium	Low, <5%
C	High	Low	Normal	Low, <5%
D	Very high	Low	-------	High, >5%

Maintenance of Motor Starters. Although the exact details of a preventative maintenance program will vary with the conditions of the applications, the following general points should apply to almost all conditions:

1. Everything possible must be done for the safety of personnel.

2. Initial installation should be tested and proved satisfactory before it is accepted. Apparatus should be easily accessible for inspection and repair.

3. An adequate supply of correct renewal parts must be available.

4. Enclosures should be chosen with respect to the operating conditions.

5. Controllers should be kept clean and dry.

6. Contacts that are worn thin or badly burned and pitted should be replaced. Replacement should be by pairs, maintaining correct contact pressures.

7. Contacts should be kept clean. Contact shape should not be changed by rough filling or grinding.

8. Contacts and all connections should be kept tight.

9. Contactor or relay bearings should not be oiled but should be kept clean and with no friction in the moving parts.

10. Coils should be operated at rated voltage. Both overvoltage and undervoltage conditions are undesirable.

11. Arc-rupturing parts should be kept in good condition and in correct operating positions.

12. Frayed and worn shunts should be replaced.

13. All dashpots should be kept clean and all oil dashpots should have the correct oil in them.

14. Conditions that cause excessive temperatures should be corrected. Temperatures should be measured if in doubt about overheating.

15. Undesirable grounds on all circuits should be watched for and eliminated.

References

A. Complete Handbook of Electric Motor Controls, John E. Traister, Second Edition, 1994, The Fairmont Press, Inc.

B. Electric Motor Control, Walter N. Alerich, Fifth Edition, 1993, Delmar Publishers, Inc.

C. IEEE Std 242-1986, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

D. ANSI/NFPA 70-1999, National Electrical Code, NEC.