

American National Standard

guide for induction motor protection

ANSI/IEEE C37.92-1969



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American National Standard Guide for Induction Motor Protection

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**Switchgear Committee of the
IEEE Power Engineering Society**

Approved March 14, 1968

IEEE Standards Committee

Secretariat

**Edison Electric Institute
Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

Approved January 28, 1972

American National Standards Institute

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Foreword

(This Foreword is not a part of American National Standard Guide for Induction Motor Protection, C37.92-1972 (IEEE Std 288-1969)).

Following the publication of this standard by IEEE in 1969, the document was reviewed by the C37 Subcommittee on Protective Relays and forwarded to American National Standards Committee C37, Power Switchgear, for approval as an American National Standard.

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ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge and have conducted experimental work on which many of the IEEE publications are based.

This publication was prepared by the Motor Protection Subcommittee of the Power Systems Relaying Committee of the IEEE Power Group. The Subcommittee is indebted to its members, both past and present, who, as members of the Power Systems Relaying Committee and other liaison Committees and Groups, gave so willingly of their time and knowledge. The membership of the Subcommittee was:

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IEEE Guide for

INDUCTION MOTOR PROTECTION

I. INTRODUCTION

A. General Format. The application guide for relay protection of squirrel-cage and wound-rotor induction motors presents a review of the generally accepted forms of motor protection and summarizes the use of relays and devices, singly and in combination, to enable the reader to properly select the necessary equipment to obtain adequate motor protection. The Guide is prepared primarily for the protection of three-phase integral-horse-power motors and refers to single- or two-phase motors only in special instances and only where specifically indicated. It is especially useful where the motor installation is sufficiently important, due to either its size or the consequences of motor malfunction, to justify specific design of the protective system. It also provides the information necessary to judge whether there are safety or economic reasons for such a specific design.

This Guide is not a Standard and does not purport to detail the protective requirements of all motors in every situation. Its recommendation is of a general nature designed to cover the usual or typical motor installation. Sufficient background of material on objectives, application, and setting philosophy is presented, however, to enable the reader to evaluate the need for various forms of protection and to select and properly apply suitable protective equipment for most situations.

Section II, Motor Protection Requirements, presents a brief description of the damaging effect on a motor of abnormal voltage, current, temperature, and incorrect operating conditions or procedures. A clear understanding of the electric and mechanical response of a motor to these abnormalities will greatly assist the reader in evaluating the need for and the means of obtaining adequate motor protection for any specific situation.

Section III, Motor Protection Specifications, presents detailed recommendations in a series of tables and diagrams showing good engineering practice. The tables and diagrams are classified according to type of switching, nominal source voltage, and motor or circuit rating; they show the combination of devices normally applied for the associated protective function.

Section IV, Setting and Adjustment of Protection Devices, presents a discussion of the various factors which must be considered in determining the settings of each relay or device. Whenever it is applicable a discussion is given on the desirability of using a device to actuate an alarm or a trip.

B. Interrupting Devices. Since the protective device generally provides only for the detection of an abnormality, it is necessary to consider the interrupting device in selecting the overall protective package. Although a detailed review of such devices is beyond the scope of the

Guide a summary of their application and limitations is essential. Fault protection for motor feeder circuits can be provided by the interrupting ability of the following devices:

- (a) fuses,
- (b) molded-case circuit breakers,
- (c) low-voltage power circuit breakers,
- (d) high-voltage power circuit breakers,
- (e) contactors.

1. Fuses. Fuses are the simplest of all protective devices, combining both the detecting element and the interrupting medium. Age or atmospheric conditions will usually have little effect on the protective characteristic of a fuse. Any such effect will cause the fuse to open earlier. Fuses require practically no maintenance.

For most applications, fuse ratings of about 150 to 400 percent of motor full-load current are usually required in order to allow the motor to start. The National Electrical Code (NEC) requires that branch circuit protection not exceed four times motor full-load current. Fuses selected in this manner provide short-circuit protection for most phase and ground faults at operating speeds dictated by the fuse time-current curves. Fuses of those ratings cannot provide overload protection. Multiple-element fuses with special time-delay characteristics rated at 125 percent motor full-load current may be used for motor overload protection. Detailed application guides for types of fuses are given in Section IV.

2. Molded-Case Circuit Breakers. Molded-case circuit breakers are frequently used in combination with motor starters. The starter with overload elements serves as the contactor and overload device while the molded-case breaker provides the fault protection and the branch circuit disconnecting means. The circuit breaker provides fault protection for the motor, its starter, and the circuit conductors. Motor voltage rating must be 575 volts or less.

Molded-case circuit breakers with either thermal magnetic (time and instantaneous) trips or solely with magnetic (instantaneous) trips may be applied. Adjustable magnetic trips usually provide better motor fault protection. For best fault protection the magnetic trips are set to trip on as low a value of current as possible but still not trip on motor starting currents. The application of molded-case circuit breakers for overload as well as fault protection is not recommended unless the molded-case breaker is provided with a special thermal trip suitable for this use.

3. Low-Voltage Power Circuit Breakers. Unlike molded-case breakers, low-voltage power circuit breakers are often used as the sole device for all disconnecting

fault protection, starting, and overload protection functions for a motor. The protective devices used with these breakers differ from those used with molded-case breakers in several respects. Their tripping characteristics differ in curve shape; they have field adjustable pickup settings and can be equipped with various time bands. Motor voltage rating must be 575 volts or less.

Low-voltage power circuit breakers can be obtained with integrally mounted current-limiting fuses for increased interrupting ability while still retaining three-phase tripping.

The circuit breaker series tripping device can be supplemented by adding separate protective relays for additional protection. When close protection or coordination is required it is necessary to use protective relays exclusively.

4. High-Voltage Power Circuit Breakers. High-voltage power circuit breakers are often used as the sole device for all disconnecting, fault protection, starting, and overload protection functions for a motor. The protective devices are separate relays supplied through instrument transformers. Power circuit breakers with protective relays are often used to provide backup fault protection and disconnecting means for a group of high-voltage NEMA class E-2 starters.

5. Contactors. Air-break and oil-immersed contactors are primarily designed for starting and overload protection. The contactor must be capable of interrupting locked-rotor current. Certain designs have high fault-interrupting capabilities and can be used as the fault protective device within their ratings. Examples are the NEMA class C and class E-1 controllers.

C. Effect of Control Equipment. Protection from extreme low line voltage or complete loss of line voltage is an inherent feature of alternating-current motor controllers of the non-latched-in type. These devices are not designed to release at any specific level of voltage. This protection is available because the line switches or contactors are maintained closed by a potential taken directly from the motor line or from a control transformer. The line contactors will close on 85 percent or less of line voltage and open if the voltage is decreased to a point somewhat less than the pickup voltage. This dropout point is usually 50 to 70 percent voltage for alternating-current contactors with alternating-current coils. If a severe voltage dip or a complete loss in line voltage should occur while the motor is running, the line contactor will drop open.

When "three-wire control" circuits are used, as in Figure 1 the contactor circuit is maintained through an auxiliary control contact in parallel with the start pushbutton. If the contactor should open due to low line voltage, the coil circuit is broken by the auxiliary control contact and the motor cannot restart until the start button is operated. This type of protection is referred to as *three-wire control with undervoltage protection*.

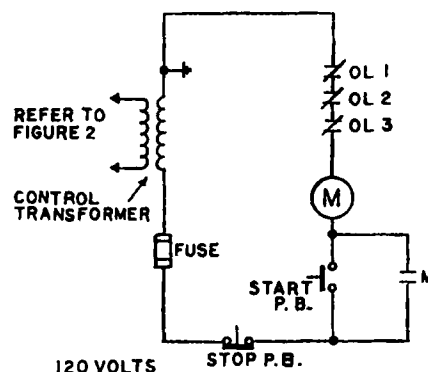


Figure 1. Three-Wire Control Circuit with Undervoltage Protection.

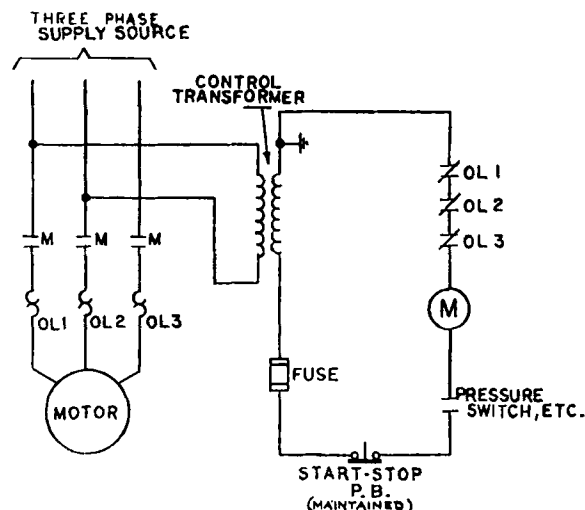


Figure 2. Two-Wire Control Circuit with Undervoltage Release.

If the auxiliary control contact (M) is omitted and the start-stop pushbutton replaced with a knife switch, pressure switch, or other type of maintained contact device, the "two-wire control" circuit of Figure 2 results. With this scheme, the line contactor will open on low or no-line voltage to shut down the motor, but the motor will automatically restart when sufficient voltage is restored to close the line contactor. This arrangement is referred to as *two-wire control with undervoltage release*. The two-wire control arrangement has the disadvantage that several motors on the same power system would attempt to restart simultaneously after a voltage outage. Normally, such a strain placed on a system may drag the voltage down to the point where the motor would never be able to accelerate to full speed. Also unexpected automatic starting after restoration of voltage may be a safety hazard.

When two-wire control is required, overload relays with automatic reset features should not be used. Under such a condition, an overload would cause the overload relays to shut down the motor, but the motor would be restarted when the relays had reset. This cycle could continue until the motor is damaged. Standard controllers will provide either low-voltage protection or low-voltage release, de-

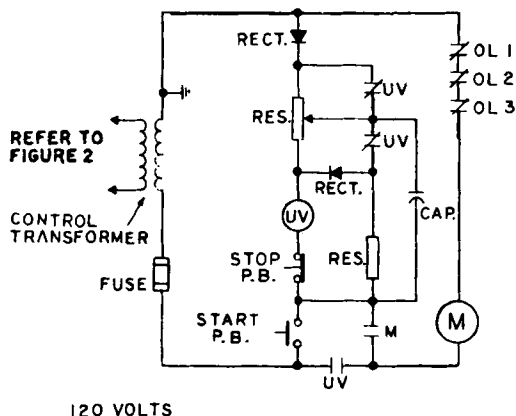


Figure 3. Three-Wire Control Circuit with Time-Delay Under-voltage Protection.

pending upon which of the initiating circuits is used.

A third arrangement, which combines features of two-wire and three-wire control, is referred to as *time-delay undervoltage protection*. A typical arrangement is shown in Figure 3 and consists of a time-delay relay UV which maintains a sealing contact for a definite period so that the motor will restart if the line voltage has been restored before the expiration of the time delay. If the voltage is not restored by that time, the motor cannot start until the start pushbutton is operated. The purpose of this type of protection is to permit continued motor operation after voltage dips or failures of short duration. With the circuit shown, while the sealing contact of UV is maintained closed for a definite period after a voltage failure, it drops out instantly if the stop button is operated.

II. MOTOR PROTECTION REQUIREMENTS

A. Thermal Protection

1. **General.** Motor life may be reduced or terminated by numerous causes; e.g., moisture, excessive dielectric stress, mechanical damage, and thermal damage to the insulation. Of these, thermal damage is the most common.

The insulation system of a motor is subject to deterioration, with age, of its physical and dielectric properties. This, like other chemical activity, is hastened by an elevation of the temperature. The effect of temperature on motor life has been the subject of repeated studies, and it is generally accepted that the life of an insulation system is approximately halved for each 10°C elevation of winding temperature. The half-life temperature rise may lie between 7° and 12°C for practical systems.

In practice, dielectric breakdown is usually the result of some electric surge, moisture condition, or mechanical displacement of the conductor at the time of failure. Regardless of the reason for the failure, the effect of excessive temperature is to reduce the ability of the insulation materials to withstand mechanical or electric abuse.

The temperature level at which an insulation system should be protected is subject to engineering judgment and applicable codes. Since temperature and life are

inversely related, it is possible to derive more output at the expense of shorter life.

In all cases of abnormal operation which result in overtemperature, time is an important factor. The heat storage capacity of an induction motor is relatively large; thus slight overloading for short periods of time will not result in damaging temperature excursions, because the extra heat is stored in the mass of the conductor, core, and structural members. Under abnormal conditions, such as locked-rotor, temperatures that are damaging to the insulation may be reached in seconds *because of the high current density*. Also, at high rates of rise there is insufficient time for the heat to be transmitted from the conductor to the more massive parts of the motor, and the heat storage capacity will appear to be small.

In general, the principal heat loss in an induction machine is proportional to the current squared. Overtemperature from this cause can be prevented by sensing line-current magnitude and interrupting power when the current value is excessive. Since motors require and can stand an excessive current for a short time during starting, some time delay must be incorporated in the current-sensing device.

With motors that are used in essential or critical service, such as fire pumps or boiler-feed pumps, it is often desirable that the operator be given time to correct an overload condition before a motor is stopped. Such service may require the motor to run with an overload condition for hours or days in situations in which the overload does not exceed the breakdown torque rating of the motor. In such cases, the cost of reduced motor life, due to the overload conditions, is offset by the expense and damage which would result from a service interruption.

2. **Inadequate Ventilation.** Should an induction motor operate without ventilation even with no load on the motor, the temperature rise may become excessive and the temperature will increase until a destructive value is reached. This situation can occur when the ventilation passages and/or filters become blocked by foreign matter such as lint, dirt, insects, snow, ice, and other materials. Loss of ventilation can be detected by air flow, air pressure, or temperature sensing devices which may sound an alarm or shut down the motor. These devices should not be necessary if a suitable maintenance program is adopted.

Such instances as reversing, accelerating duty, jogging or positioning, reduced-frequency operation, or low-speed operation of wound-rotor motor or multispeed squirrel-cage motor result in reduced ventilation. These conditions also result in a higher than normal temperature rise and allowance for them must be made in the motor application.

3. **Unusual Ambient Conditions.** When motors are installed at high altitude, the effectiveness of the ventilation is reduced because of the lower air density. This results in a higher than normal temperature rise and must

be considered when specifying or selecting the protective relay setting.

When the ventilating medium increases in temperature, the motor winding temperature increases by an equal amount. Therefore, when operation is planned under varying ambient temperature, care must be exercised to match the protective-device characteristics to the motor. Special consideration should be given to settings when the motor and relay are subject to different ambient temperatures. (See Section II-7c.) Excessive motor temperature may result if the discharge air is misdirected so as to reenter the inlet ports. This can be caused by installing motors:

- (a) too close to a wall,
- (b) too close to each other so the discharge airstreams buffet each other (with discharge air ducts too close to the inlet—assuming the motors are moveable).

Motors located in direct sunlight during a hot summer day, in certain areas of furnace or boiler rooms, or in an industrial plant adjacent to heating devices, will also be subjected to high ambient temperatures. Motors designed for special applications, such as canned motors on submersible pumps which have their rotor in the path of the fluid being pumped, involve unusual ambient conditions which require special consideration in setting thermal devices. This also applies to fuse elements and thermal devices which are located in oil-immersed starting equipment.

4. Frequent Starts or Jogging. It is important to allow time for the motor to cool between successive starts. The heat energy developed in the rotor winding during startup equals the kinetic energy imparted to the rotating parts. The heat energy developed in the motor's stator winding may be less than or equal to or more than that in the rotor winding. The ratio is proportional to the ratio of the respective resistances, which varies from design to design. If the running period is short, very little of the heat is carried away by the cooling air. Repeated starts, therefore, have the effect of increasing the temperature and enough time must be provided to allow this heat to be dissipated. Repeated starts must be matched to the machine-cooling characteristic at standstill to prevent restarting before the windings are cool enough to accept the starting energy and remain within a reasonable temperature.

Standard induction motors rated 200 horsepower and larger are capable of two starts in succession, coasting to rest between starts, with the motor initially at ambient temperature. They are capable of one start with the motor initially at a temperature not exceeding its rated-load operating temperature. These capabilities assume that the rotational inertia parameter (identified by NEMA by WK^2) of the load, the load torque during acceleration, the applied voltage, and the method of starting are all within the values for which the motor was designed. A table of normal WK^2 of connected load for various motor

horsepower and speed ratings is given in NEMA Standard MG1-1967.

5. National Electrical Code (NEC) Requirements for Motor Protective Devices. The NEC specifies that overcurrent devices and thermal protectors must "protect the motors, the motor control apparatus, and branch-circuit conductors against excessive heating due to motor overloads." By definition, "Overload in electric apparatus is an operating overcurrent which, when it persists for a sufficient length of time, would cause damage or dangerous overheating of the apparatus. It does not include short circuits or ground faults."

This requires the motor running overcurrent protection to supervise the maximum continuous motor current. The National Electrical Code (NEC), 1965 specifies trip ratings for overcurrent devices. Modifications are permitted in NEC-1965 for a maximum of 140 percent of the full-load current rating of sealed (hermetic type) refrigeration compressor motors and motors marked to have a temperature rise not over 40°C, and not higher than 130 percent of full-load current rating for all other motors.

Thermal protectors integral with the motor (NEC specifies these devices shall be approved for use with the motors which they protect) should also supervise the maximum continuous motor current if the branch-circuit conductors, the motor control apparatus, and the protected system are to be properly coordinated in keeping with the intent of the NEC; otherwise separate overload protection devices are needed to protect the branch-circuit conductors and the motor control apparatus.

In motors of one horsepower or less with thermal protectors applied on the basis of preventing dangerous overheating of the motor due to overload or failure to start, as interpreted by Underwriters' Laboratories, Inc., the trip current is invariably within the rating of the motor-branch-circuit conductors and control apparatus selected in accordance with the NEC. Thermal protectors for these smaller motors generally interrupt the motor current directly.

In motors over one horsepower with thermal protectors "approved" in terms of the NEC Article 430-31 (1965), it should be expected that the protector will trip at current levels which will protect the minimum conductors allowed by the Code. This is important because on some ratings of integral-horsepower motors the continuous current corresponding to maximum allowable motor-winding temperature may exceed the rating of the branch-circuit conductors and/or control apparatus selected on the basis of horsepower. In these instances, thermal protection to meet the limitations of percent of motor full-load amperes would need to be applied on the basis of a lower winding temperature. It is, therefore, necessary to know the basis of the thermal protection installed in the motor and its approval status so that proper selection can be made of the motor-branch-circuit conductors and control apparatus. Thermal protective devices or overload relays for larger motors generally operate to trip the motor

contactor or circuit breaker which in turn interrupts the motor current.

6. Internally and/or Frame-Mounted Protective Devices.

(a) Three basic types of protective devices. Motor protection devices in this category are usually called thermal protectors. They are also known as inherent overheating protective devices. There are three basic types of these devices in current use to provide a wide range of characteristics to match the differing needs of the various types of electric motors from the small fractional-horsepower shaded-pole up through integral-horsepower polyphase sizes. The three types are 1) devices sensing motor temperature only, 2) devices sensing both motor temperature and current, and 3) devices sensing both motor temperature and its rate of change. All of these are designed to be built into the motor and to be installed by the motor manufacturer.

Although each of these three types incorporates a thermal element as its operating means, each responds in a distinct manner to motor winding temperature and offers specialized capabilities of application and use.

As a group, they differ from thermal overload relays which also use a thermal element but are designed to sense motor temperature as a function of motor current and, depending on type of relay used, compensated or uncompensated as a function of relay ambient.

(b) Motor-winding temperature limiting. Inherent protection devices are intended to limit motor-winding temperature to a predetermined value during abnormal motor operating conditions. For properly selected and applied devices, this is accomplished without interfering with maximum planned motor loading. At the same time, maximum desired temperature and current values must not be exceeded to avoid premature motor insulation failure and to keep from exceeding the maximum current ratings of the motor-branch-circuit conductors and motor control apparatus.

Maximum temperature limits are determined by the insulation system and expected motor life. Commonly used values are specified in the Underwriters' Laboratories requirements for thermal protectors.

This approach to protection is related to the fact that motor rating has as its basis maximum allowable winding temperature. It should be noted that disconnect devices, conductors, and controllers are selected on the basis of horsepower and current. This equipment, when based on horsepower, may be a limiting factor in the circuit when inherent protectors permit higher loads than indicated by the motor-rated horsepower or current. Adequate protection of this equipment must then be provided by other means or the equipment must be uprated accordingly.

Abnormal conditions which can result in overheating include overload, stalling and failure to start, high ambient temperature, restricted motor ventilation, high or low line voltage or frequency, mechanical failure of the driven load, improper installation, failure of start switch or

capacitor in single-phase motors, and unbalanced line voltage or single phasing in three-phase motors. Current sensing alone will not limit insulation temperature to a safe value for all these abnormal conditions. Temperature sensing is also needed to provide protection for conditions such as blocked ventilation, high ambient temperature, jogging, and reduced speed. .

The temperature-sensing capability of inherent protection devices is dependent on their location. Their location is in the motor windings or within or on the motor frame in such a manner that the device temperature is subject to changes in proportion to winding temperature.

(c) Devices sensing motor temperature only. Devices of this type are generally called thermostats or temperature detectors. They consist of a thermal element and circuit-interrupting means. The element is calibrated for circuit interrupting at a fixed temperature value and is usually automatically reset upon cooling after operation to shut down the motor or to initiate a signal. These devices are usually pilot circuit types connected electrically in the pilot or control circuit of the magnetic motor controller which controls the motor line current.

When the controller is provided with some form of three-wire control, the motor will shut down after tripping of the thermostat and require restarting manually by the pushbutton station. If the controller is provided with some form of two-wire control, resetting of the thermostat will automatically cause power to be reapplied to the motor. Manual restarting of the motor must be used where specified by safety requirements or where personnel hazard or damage may result because of an unexpected restarting of the motor. As pilot-circuit devices, thermostats and temperature detectors may be used through large integral-horsepower motor sizes. The 1965 edition of the National Electrical Code recognizes embedded temperature detectors for running overcurrent protection for motors larger than 1500 horsepower. Various thermal elements are used including bimetal snap-acting elements, resistance coils, semiconductor materials such as thermistors of either negative or positive temperature coefficient, and liquid- or gas-filled assemblies.

Operation of the various types depends upon the transfer of heat from the motor winding to the thermal element. Since heat flow is involved, the temperature difference between the thermal element and the winding is related to the rate of temperature change and increases with the winding heating rate for a given element mass and installation.

For running overload conditions, the rate of temperature change of the winding is generally slow and the temperature difference between the winding and thermal element is a minimum. Here thermal element temperature varies directly with winding temperature. When the winding temperature raises the element to its operating temperature, the motor is shut down. For stalled rotor, the rate of increase in winding temperature depends on the motor design. Thus, thermostats provide stalled-rotor