PLEASE NOTE:

Electrical equipment should be serviced only by qualified electrical maintenance personnel, and this document should not be viewed as sufficient instruction for those who are not otherwise qualified to operate, service or maintain the equipment discussed. Although reasonable care has been taken to provide accurate and authoritative information in this document, no responsibility is assumed by Square D for any consequences arising out of the use of this material.
# Table of Contents

Introduction......................................................................................... 1
Purpose .............................................................................................. 1
Reference Material ........................................................................... 1
Use as a Troubleshooting Guide ......................................................... 1
Scope ................................................................................................. 1

National Electrical Code ...................................................................... 2
Use of NEC ....................................................................................... 2
Nema Standards ............................................................................... 2
UL508 .............................................................................................. 3

Objectives of Overload Protection ..................................................... 3
Safety .............................................................................................. 3
Economy ........................................................................................... 3

Temporary Problems .......................................................................... 3
Frequent Resetting ........................................................................... 3

Overload Protection Compared with Short-Circuit Protection ............. 3
Combined Overload and Short-Circuit Protection ................................. 4
Location of Protective Devices ......................................................... 4

Types of Overload Relays .................................................................. 4

Thermal Overload Relays .................................................................. 4
Thermal Modeling ............................................................................. 5
Resetting .......................................................................................... 5
Types of Thermal Overload Relays ..................................................... 5

Melting Alloy Overload Relays .......................................................... 6
Hand Reset ....................................................................................... 6
Trip Class .......................................................................................... 7

Bimetallic Overload Relays ................................................................. 7
Trip Current Adjustment .................................................................... 7
Automatic Reset ................................................................................ 7
Ambient Temperature Compensation ................................................ 7

European Overload Relays ................................................................. 8

Magnetic Current Relays .................................................................... 8
Time Delay ........................................................................................ 9
Trip Current Adjustment .................................................................... 9
Instantaneous Trip Overload Relays .................................................. 9

Causes of Motor Failure ...................................................................... 9
Insulation ......................................................................................... 9
Voltage Surges ................................................................................ 9
Mechanical Damage ......................................................................... 10
Chemical Deterioration .................................................................... 10
High Temperature ............................................................................ 10
Solutions .......................................................................................... 10
Diagnosis of Motor Failures .............................................................. 10

Mechanical Overloads ....................................................................... 10
Misapplication of Service Factor ....................................................... 10
High Inertia Loads ............................................................................ 11
Duty Cycle ....................................................................................... 11

Voltage Variation .............................................................................. 11
Undervoltage ................................................................. 11
Overvoltage ............................................................... 11
Frequency Variation .................................................... 11
Phase Loss .................................................................... 12
Phase Unbalance ......................................................... 12
  Cause of Phase Unbalance ........................................ 13
  Rural Open-Delta Systems ....................................... 13
  Phase Converters ................................................... 13
Application of Overload Relays ..................................... 14
  General Application of Thermal Overload Relays ....... 14
    Ambient Temperature ............................................ 14
    Ambient Temperature Sensitivity ......................... 14
    Ambient Temperature Compensation .................. 15
    Ambient Temperature and the NEC ..................... 16
    Temperature Rise Within the Enclosure ............... 16
OEM Applications .......................................................... 17
Long Accelerating Times .............................................. 17
  Overload Relay Time-Current Characteristics ............ 17
  Estimating Trip Time Requirement For Acceleration .... 17
  Shunting During Starting Period, Manual Start ......... 18
  Shunting During Starting Period, Automatic Start ..... 18
General Application of Magnetic Current Relays .......... 18
  Magnetic Overload Relays ....................................... 19
  Underload Relays .................................................. 19
  Instantaneous Trip ................................................ 19
Operating Overload Relays With Current Transformers .... 20
  Saturable Current Transformers ............................. 20
Location of Overload Relay Control Circuit Contacts ....... 20
Troubleshooting Overload Relay Trips ....................... 22
  General ............................................................... 22
  Troubleshooting Procedure .................................... 22

Appendix A

Estimating Overload Trip Time .................................. A1
  General ............................................................... A1
  Calculation Method .............................................. A1

Appendix B

Calculation of Rms Currents ...................................... B1

Appendix C

Driving Overload Relays with Current Transformers ....... C1
  Accuracy and Burden of Current Transformers:
  Product Data Bulletin EI-9 .................................... C4
    Power Transformer vs. Instrument Transformer ....... C4
    More Terms ...................................................... C4
    National Standards Define Accuracy .................... C5
Appendix D

National Electrical Code
Article 430, Part C .................................................. D1
Motor and Branch-Circuit Overload Protection ...................... D1
430-31, General ....................................................... D1
430-32, Continuous-Duty Motors .................................. D1
430-33, Intermittent and Similar Duty .............................. D3
430-34, Selection of Overload Relay ............................... D3
430-35, Shunting During Starting Period .......................... D3
430-36, Fuses .......................................................... D4
430.37, Devices Other than Fuses .................................. D4
430-38, Number of Conductors Opened by Overload Device ..... D5
430-39, Motor Controller as Overload Protection ............... D5
430-40, Thermal Cutouts and Overload Relays ..................... D5
430-42, Motors on General-Purpose Branch Circuits .......... D5
430-43, Automatic Restarting ....................................... D6
430-44, Orderly Shutdown .......................................... D6

Appendix E

NEMA - PART ICS 2-222 ............................................. E1
Overload Relays ....................................................... E1
2-222.01 Definitions ............................................... E1
Ambient Temperature Compensated (Thermal Overload Relay) E1
Ambient Temperature Sensitivity (Overload Relay) .............. E1
Current Element (Overload Relay) ................................ E1
Current Rating (Overload Relay) .................................. E1
Heater Element (Thermal Overload Relay) ......................... E1
Limit of Self Protection (Overload Relay) ......................... E1
Overload Relay ........................................................ E1
Thermal Overload Relay ............................................. E1
Time-Current Characteristics (Overload Relay) ................... E2
Trip Free (Overload Relay) .......................................... E2
Ultimate Current (Overload Relay) ................................ E2
General Information and Features ................................ E2
ICS 2-222.05 Time-Current Characteristics ....................... E2
ICS 2-222.06 Overload Relay Class Designation ................. E2
ICS 2-222.07 Limit of Self Protection ............................ E2
ICS 2-222.08 Ambient Temperature Sensitivity ................... E2
ICS 2-222.09 Resetting ............................................. E3
Ratings ................................................................. E3
ICS 2-222.20 Current Rating ....................................... E3
ICS 2-222 21 Control-Circuit Contact Ratings ................................E4
Design Tests & Performance .................................................E4
ICS 2-222 40 ...........................................................................E4
   .01 Test Conditions ...............................................................E4
   .02 Test Connections .............................................................E4
   .03 Test Procedure ...............................................................E5
   .04 Performance ....................................................................E5
ICS 2-222 41 ...........................................................................E6
   .01 Test Condition ...............................................................E6
   .02 Test Procedure ...............................................................E6
   .03 Test Connections .............................................................E6
   .04 Performance ....................................................................E6
ICS 2-222 42 ...........................................................................E6
   .01 Test Conditions ...............................................................E6
   .02 Test Connections .............................................................E6
   .03 Test Procedure ...............................................................E6
   .04 Performance ....................................................................E6
ICS 2-222.43 ...........................................................................E6
ICS 2-222.44 ...........................................................................E6
Manufacturing ...........................................................................E7
ICS 2-222.60 ...........................................................................E7
ICS 2-222.61 ...........................................................................E7
Application ..............................................................................E7
ICS 2-222.80 ...........................................................................E7
ICS 2-222.81 ...........................................................................E7
ICS 2-222.82 ...........................................................................E7
ICS 2-222.83 ...........................................................................E7
ICS 2-222.84 ...........................................................................E7
ICS 2-222.85 ...........................................................................E8
ICS 2-222.86 ...........................................................................E8
   .01 General ..........................................................................E8
   .02 High Level Fault-Current Protection ................................E8
   .03 Limit of Self Protection ....................................................E8
   .04 Operating Overloads .......................................................E8
ICS 2-222.87 ...........................................................................E8
ICS 2-222.88 ...........................................................................E8

Appendix F

UL 508 .......................................................................................F1
25.0 Overload-Relay Calibration Test .........................................F1
   General .................................................................................F1
   Calibration ............................................................................F1
   Marking .................................................................................F2
   Details ..................................................................................F2
Appendix G

Nema Motor and Generator Standard MG-1 Excerpts .................. G1
Test and Performance-AC ............................................. G1
  MG 1-12.43 .......................................................... G1
  MG 1-12.45.a ....................................................... G1
  MG 1-12.46 .......................................................... G1
  MG 1-12.50 .......................................................... G2
Application Data ....................................................... G3
  MG 1-14.30 .......................................................... G3
  MG 1-14.31 .......................................................... G4
  MG 1-14.32 .......................................................... G4
  MG 1-14.33 .......................................................... G5
  MG 1-14.34 .......................................................... G5
Bibliography .......................................................... G6
List of Figures

Figure 1: Thermal Overload Relay Parts Within a Motor Circuit ..........4
Figure 2: Overload Relay Trip Curve versus Motor Heating Curve .... 5
Figure 3: Schematic View of Melting Alloy Overload Relay .......... 6
Figure 4: Melting Alloy Thermal Unit ........................................ 6
Figure 5: Schematic View of Bimetallic Overload Relay .............. 7
Figure 6: Schematic View of Magnetic Current Relay .................. 8
Figure 7: Three-Phase Motor Fed by Wye-Delta Transformer ....... 12
Figure 8: Three-Phase System with Single-Phase Load .............. 13
Figure 9: Rural Open-Delta System ......................................... 13
Figure 10: Effect of Ambient Temperature Upon Trip Current ...... 14
Figure 11: Ambient Temperature Correction Curve .................... 15
Figure 12: Submersible Pump with Controller above Ground ....... 15
Figure 13: Hammer Mill / Conveyor Circuit .............................. 19
Figure 14: FVNR Three-Wire Control Circuit — Contact Location ... 21
Figure 15: Two-Speed Three-Wire Control Circuit - Contact Location .... 21

Appendix A
Figure 1: Ambient Temperature Correction Curve .................... A2
Figure 2: Time-Current Characteristics of Class 10, 20 & 30 ......... A3

Appendix B
Figure 1: Formula for Calculating Root-Mean-Square (rms) .......... B1
Figure 2: Time-Current Characteristics of a Overload Relay .......... B3

Appendix C
Figure 1: Power Transformer (4 Turn Primary /2-Turn Secondary) ... C1
Figure 2: Relationship Between Flux Density & Magnetizing Force C2
Figure 3: Typical Application of a Power Transformer ............... C3

Product Data Bulletin EI-9
Figure 1: Concentric Parallelogram ....................................... C4
Figure 2: Typical Current Transformer Circuit ......................... C6
Figure 3: Standard Ratios & VARs = .058 ................................ C7
Figure 4: Resistance Per 100’ of Copper Wire ......................... C7
Figure 5: Typical Excitation Curves ....................................... C8
Figure 6: Typical Accuracy Curve ......................................... C9

Appendix E
Figure 1: 2-222-1 Overload Relay Time-Current Characteristics .......... E3
Figure 2: 2-222-2 Schematic Diagram of Test Connections .......... E5

Appendix G
Figure 1: 14.1 Derating Factor Due to Unbalanced Voltage ........... G5
List of Tables

Table 1: Effect of Phase Loss Conditions upon Line Currents .................12

Appendix A
Table 1: Required Trip Time of an Overload Relay ..........................A1

Appendix B
Table 1: RMS Values at Various Time Periods ...............................B2

Appendix C
Table 1: Metering Accuracy and Burden .......................................C5
Table 2: Current Transformer and Burden .................................C10

Appendix D
Table 1: 430-37 — Overload Units ...........................................D4

Appendix F
Table 1: 51.1 Designations for Trip Time at 600% of Current Rating ..........F2

Appendix G
Table 1: Torque Characteristics and Inertia Value ..........................G2
INTRODUCTION

Purpose

The purpose of this bulletin is to serve as a guide in solving problems having to do with overload protection in motor branch circuits. It includes discussions of the standards which guide and govern overload protection, the objectives of overload protection, types of overload relays, causes of motor failure and application of overload relays. It also includes a guide for troubleshooting when an overload relay trips. In addition, appendices are included which describe in detail the calculations required to solve almost any problem having to do with overload protection.

Reference Material

Pertinent sections of the National Electrical Code® (1984), UL 508 and NEMA Standards are copied in this bulletin. No attempt at updating this material will necessarily be made, and therefore, current issues of those documents should be referred to if detailed information is important.

Use as a Troubleshooting Guide

To use this bulletin as a troubleshooting guide, it is suggested that the reader start out in “TROUBLESHOOTING OVERLOAD RELAY TRIPS” on page 22. Whenever instructions are not self evident, they are followed by a reference (e.g., to a paragraph in this bulletin or an item in the bibliography). These references lead the reader to the shortest possible explanation of the instruction. Further explanation appears either in following paragraphs or in the form of additional reference numbers.

To simplify discussions, certain types of motors and branch circuits are excluded from this bulletin. The scope of this bulletin is defined in detail below.

Scope

In order to keep this bulletin precise without being complicated by qualifications and exceptions, the scope of discussion is somewhat restricted. These restrictions do not apply to the great majority of motor applications. In the few cases where they do apply, the additional information to make this bulletin useful should be easy to find. As a result, discussions in this bulletin are restricted to the following:

1. Induction motors
2. 600 V or less
3. Permanently installed on an individual motor branch circuit
4. With thermal or magnetic overload relays

Discussions will not cover:

1. Inherently protected motors
2. Impedance limited motors
3. Fire pump motors
4. Air conditioning and refrigeration motors covered by Article 440 in the NEC
5. Motors which are part of an approved assembly that does not normally subject the motor to overloads and have a protective device integral with the motor that protects the motor against damage due to failure to start
6. Synchronous motors
7. DC motors
8. Installations not covered by NEC® Article 430 on page D-1.
The National Electrical Code (NEC) is sponsored by the National Fire Protection Association (NFPA) and states as its purpose the practical safeguarding of persons and property from hazards arising from the use of electricity. The NEC further states that it contains provisions considered necessary for safety, but not necessarily efficiency, convenience, or adequacy for good service or future expansion of electrical use. Some interpret this to mean that the NEC concerns itself with only the minimum requirements for a safe electrical installation.

Use of NEC

An often ignored statement in the NEC is that it is not intended as a design specification nor as an instruction manual for untrained persons. To use the NEC as a guide for overload protection, the whole of article 430 part C must be considered. This is an extremely cumbersome task. When a specific motor branch circuit is considered, only a small portion of part C applies and determining whether a specific motor branch circuit meets the NEC becomes relatively simple. As an example, a copy of article 430 part C is presented in Appendix D on page D-1. The sections of part C in italic does not apply to this paper because of its limited scope. Although this paper deals with a great majority of industrial motor applications, almost half of part C has been eliminated.

After an electrical installation has been completely designed, use the NEC to determine whether the design meets minimum safety requirements.

NEMA STANDARDS

The National Electrical Manufacturers Association is a group of electrical manufacturers organized to standardize electrical products so users may apply these products with greater ease and safety. These standards are not laws. Rather, they are mutually agreed upon objectives developed by members.

National Electrical Code® and NEC® are Registered Trademarks of the National Fire Protection Association, Inc., Quincy, MA.

Appendix E on page E-1 contains a copy of NEMA, Part ICS 2-222, Overload Relays. If used as reference in an important matter, obtain an up-to-date version of part ICS 2-222.

A relatively new addition to part ICS 2-222 is ICS 2-222.02, Class Designations. These designations give a relative idea of the trip time of an overload relay at locked rotor conditions and in the past, have been referred to as quick, standard or slow trip. Using class designation numbers opens the way for greater definition in the future. For example, if motor designs become more specialized according to their applications, Class 5 or Class 15 overload relays may be required.

A point which may require change in the future appears in ICS 2-222.40.3 (c) (2) and (3) (Appendix E on page E-1). At present, this test procedure calls for testing a three-phase overload relay with only two current elements connected. This is done as a safety measure since some overload relay designs may take longer to trip with only two current elements connected than with three. With the advent of European style overload relays (page 8) in the American NEMA rated device market, this situation will change. Most European style thermal overload relays are designed to be more sensitive if one current element runs cold. This provides a faster trip during phase loss conditions. Because of this a European style overload relay should be tested with three current elements connected in order to prove that it meets Class 10 requirements under normal conditions. Refer to “European Overload Relays” on page 8.
The section of UL 508 dealing with overload relays is continually changing. A copy is provided in Appendix E on page E-1. If used as a reference in important matters, obtain an up-to-date copy.

The sections of UL 508 dealing with overload relays follow a similar pattern to that of NEMA standards with two important exceptions:

1. The limits established in UL 508 are not recommendations but definite requirements if a product is to be listed by UL.
2. Many test requirements listed in UL 508 as well as test results are much more detailed than in NEMA standards. Test procedures are very specific in terms of wire sizes, ratings of short-circuit protective devices used in conjunction with the overload relay and allowable damage resulting from the test. These requirements are established to ensure that the overload relay functions in conjunction with the rest of the motor branch circuit in accordance with the intent of the requirements of the National Electrical Code.

**OBJECTIVES OF OVERLOAD PROTECTION**

**Safety**

The primary objective of overload protection is to protect the motor, the motor controller and the motor branch circuit conductors against excessive heating due to motor overloads and failure to start. (Appendix D, 430-31 on page D-1). If such a condition is allowed to persist for a sufficient length of time, dangerous overheating and/or damage may result. Under these circumstances, a properly functioning overload relay automatically causes the motor to be deenergized.

**Economy**

As well as safety, economic benefits are provided by overload protection. The most obvious benefit is the overload relay can prevent the expense of replacing or rewinding a burned-out motor. In addition, an overload relay can prolong motor life, allow the maximum safe utilization of the motor and minimize down time.

**Temporary Problems**

In many cases, the cause of an overload relay tripping is a temporary, easily correctable problem. An undervoltage condition, a phase loss, a machine blockage or a dry bearing in a machine could cause the overload relay to trip. It is preferable to correct these problems immediately rather than having to replace the motor and/or rebuild the machine as well.

**Frequent Resetting**

The cause of an overload relay tripping should be determined before resetting the relay. Most overload relays are designed so that they cannot be reset immediately; this allows the motor time to cool. Motor damage usually occurs if repeated resets are attempted without correcting the cause of the overload relay tripping.

**Overload Protection Compared with Short-Circuit Protection**

In a motor branch circuit, the same three items (motor, conductors and motor controller) are required by the NEC to be given two types of protection:

1. Motor and branch circuit overload protection.

The former is applied to prevent excessive heating due to motor overloads and failure to start. The latter is applied to prevent damage due to short-circuits or grounds.
Overload protection is intended to deal with currents ranging from motor full-load current to locked-rotor current (10 x full-load current). These currents always travel within the branch circuit conductors, motor windings and current paths within the motor controller.

Short-circuit or ground-fault currents are currents which travel at least partly through paths other than those intended for carrying the motor current. These currents can reach values much higher than 10 x full-load current.

Combined Overload and Short-Circuit Protection

The NEC allows a single device to provide both overload protection and short-circuit protection if the requirements of both functions are met by that device. Usually, fuses are used for such applications.

Location of Protective Devices

Overload protective devices (thermal units, heaters, fuses etc.) are intended to deal with currents flowing in normal motor circuit paths, therefore one device is required in each phase of a polyphase circuit. Because the same current must appear in both lines to the motor, one overload protective device is required in a single-phase circuit, regardless of the voltage. Short-circuit protective devices are intended to deal with currents that leave the normal current paths in the motor circuit, therefore one device is required in each conductor capable of supplying current (ungrounded conductor).

In the case of most single-phase, 120 V circuits, one line is grounded and as a result, only one short-circuit protective device is required. In the case of a single-phase 240 V circuit, two lines are capable of supplying current and as a result, two short-circuit protective devices are required. In a three-phase, three-wire system with one conductor grounded, only two short-circuit protective devices are required, but three overload protective devices are required.

TYPES OF OVERLOAD RELAYS

Thermal Overload Relays

Thermal overload relays are operated by heat derived from the motor line current and proportional to the square of that current. The heat generated is used to trip open the contacts of a manual contactor or to open an integral normally closed contact in series with a magnetic contactor coil. This deenergizes the motor in case of overcurrent.

![Diagram of Motor Circuit with Overload Relay](image)

**Figure 1** Location of Thermal Overload Relay Parts Within a Motor Circuit
Thermal Modeling

The object of the design of a thermal overload relay is to produce a thermal model of a motor. Heat in a motor is generated by $I^2R$ losses in the motor windings and iron losses in the rotor and stator. A detailed discussion of how this heat is generated and distributed throughout the motor is very complex, but is not required. The net result of all factors influencing motor heating can be combined and displayed in terms of a time-current curve showing the ability of a motor to withstand damage due to heat. Figure 2 shows a typical motor withstand curve superimposed upon an optimum overload relay trip curve. At any current, the overload relay holds as long as possible without allowing the motor to sustain damage.

![Motor Heating Curve]

**Figure 2** Overload Relay Trip Curve Superimposed upon Motor Heating Curve

Resetting

When a thermal overload relay has tripped, it cannot be reset until it has cooled to some degree. Ideally, the cooling time of the overload relay should be sufficient to allow the motor to cool to the point where it can withstand another start. This is seldom true because the mass of the motor is usually much greater than that of the overload relay.

⚠️ **CAUTION**

**POSSIBLE EQUIPMENT DAMAGE.**

*Motor damage will occur if repeated resets are attempted without correcting the cause of overload relay tripping.*

Failure to observe this precaution will result in product damage.

Types of Thermal Overload Relays

Thermal overload relays are subdivided into two types according to the means by which they convert heat into the mechanical activity of opening the overload relay contacts. These two types are: melting alloy overload relays and bimetallic overload relays, described in the following sections.
Melting Alloy Overload Relays

The control-circuit contacts of a melting alloy overload relay are closed against spring force when the reset button is depressed. The energy stored in the contact spring at the time of reset is retained by a pawl which engages a ratchet wheel. The ratchet wheel would normally be free to rotate within the solder pot, but it is held in a fixed position by a eutectic alloy (solder) at the time of assembly.

![Schematic View of Melting Alloy Overload Relay](image)

Figure 3  Schematic View of Melting Alloy Overload Relay

Mounted adjacent to the solder pot is a resistance element which carries the motor line current. This resistance element generates heat (I^2R) which is proportional to the square of the motor current and the resistance value of the element. When the motor line current reaches its limiting value, the heat produced by the resistance element is sufficient to melt the solder and free the ratchet wheel with respect to the solder pot. The force of the compressed contact spring against the pawl causes the ratchet wheel to turn and releases the contacts, which open.

![Melting Alloy Thermal Unit](image)

Figure 4  Melting Alloy Thermal Unit

Hand Reset

A melting alloy overload relay must be reset by hand and this allows for the storage of a large amount of energy in the contact spring. The ready availability of this stored energy greatly eases the design constraints upon the rest of the overload relay and makes for a highly accurate and reliable device as compared to one which must obtain its operating force from the motor line current.
Trip Class

The time-current characteristics of the melting alloy overload relay are dependent upon the design of the thermal unit (ratchet, solder pot, resistance element assembly). By changing the mass of the solder pot and/or the rate of heat transfer between the resistance element and the solder pot, the time-current characteristics of the thermal unit can be changed. This allows for using a standard overload relay block with a variety of thermal units to provide either Class 10 (quick trip), Class 20 (standard trip), or Class 30 (slow trip) overload protection.

Bimetallic Overload Relays

In a bimetallic overload relay, a resistance element or heater is placed in series with the motor line. This heater is located near, or attached to, a bimetallic element which deflects in proportion to its temperature.

Deflection of the bimetal trips a set of contacts which are wired in series with the contactor coil and will cause the motor to be deenergized if its line current exceeds a critical value. When the motor is deenergized, the bimetal slowly cools and returns to its initial shape allowing the overload relay contacts to be reset, or to reset automatically if this feature is provided. Refer to “Automatic Reset” below.

![Image of a bimetallic overload relay]

Figure 5  Schematic View of Bimetallic Overload Relay

Trip Current Adjustment

Bimetallic overload relays are normally provided with an adjustment which allows the nominal tripping current to be adjusted plus or minus 15%.

Automatic Reset

A major advantage of bimetallic overload relays over the melting alloy type is that they can be made to reset automatically. In remote applications or applications where the controller is difficult to reach, automatic reset can be very desirable, but care must be taken that personnel cannot be injured by an unexpected restart of a motor or machine. For this reason, automatic reset should be used only in conjunction with three-wire control or in applications which are only accessible to trained personnel. Bimetallic overload relays are normally manufactured so that they can be set for either hand or automatic reset.

Ambient Temperature Compensation

Another feature offered by some bimetallic overload relays is ambient temperature compensation. In an ambient temperature-compensated overload relay, a compensating bimetal is employed which is affected only by ambient temperature and not by heat due to motor current. This compensating bimetal is arranged mechanically so that it cancels the effect of ambient temperature upon the other bimetals in the overload relay. This allows the overload relay to maintain a constant tripping current regardless of the ambient temperature in which it is placed.
**European Overload Relays**

Bimetallic overload relays produced by European manufacturers are becoming increasingly common in the American market. Although they are not all exactly alike, they have many features in common which are distinctly different from most bimetallic overload relays produced by American control manufacturers at this time. The features referred to are as follows:

1. Class 10 tripping characteristics
2. Directly heated bimetals
3. Adjustable trip current
4. Ambient temperature compensation
5. Phase loss sensitivity

Features 1 and 2 go hand in hand. In order to accomplish a Class 10 tripping characteristic, the heaters in these overload relays are wound directly on the bimetals. In some designs a portion of the motor current is conducted by the bimetal itself. This allows for a quick transfer of heat to the bimetal. Feature 3 is a result of features 1 and 2. Since the heaters are an integral part of the overload relay, the tripping current cannot be changed by changing heaters. Rather, the base tripping current of each overload relay is made adjustable upward by approximately 50%. Phase loss sensitivity refers to a characteristic which causes these overload relays to trip faster if one of the bimetals runs cold due to loss of current.

**Magnetic Current Relays**

Magnetic current relays are basically solenoids. They are designed to have a relatively low resistance and impedance so they can be placed in series with a load without noticeably dropping the load voltage or affecting the load current. Thus, when a magnetic current relay is connected in series with a load, the applied voltage and impedance of the load determine the load current and the magnetic current relay reacts to the current as desired depending upon the application. When the relay picks up, a plunger is drawn upward into the coil until it stops against an insulated trip pin, which operates a set of contacts.

![Schematic View of Magnetic Current Relay](image)

**Figure 6 Schematic View of Magnetic Current Relay**
The nature of the design of magnetic current relays is such that their impedance increases as their current range decreases. Although many magnetic current relays are used in motor branch circuits, this is not the exclusive intent of their design.

It is possible to find magnetic current relays with current ranges so low and impedances so high that they would drop too much voltage for satisfactory operation in a motor circuit. This should be considered when selecting magnetic current relays for small motors (1 hp or less, 3-phase; 1/3 hp or less, 1-phase).

**Time Delay**

An inverse time-current characteristic is accomplished by fastening a piston to the bottom of the plunger. The piston is suspended in a cup (dashpot) filled with oil. When the magnetic force, due to current, becomes sufficiently great to lift the plunger, the upward motion is retarded by the oil in the dashpot, which must pass through small holes in the piston to allow the plunger to move. The time delay is adjustable in set increments by exposing different numbers and/or sizes of holes through which the oil can pass.

**Trip Current Adjustment**

The trip current can be adjusted by changing the air gap between the plunger and the pole piece. This is done by threading the plunger up or down upon a threaded stud.

**Instantaneous Trip Overload Relays**

Another version of a magnetic current relay uses no dashpot oil and as a result, trips without time delay when its trip current is reached.

**CAUSES OF MOTOR FAILURE**

Before attempting a discussion of the causes of motor failure, it is important to emphasize two ideas:

1. All motors will ultimately fail and most motors fail due to an insulation breakdown.
2. The events surrounding the insulation breakdown (fuse melting, circuit breaker tripping, overload relay tripping, smoke or flame) are usually results rather than causes of the insulation breakdown.

Motor insulation has a definite design life. Even if a motor is never abused, its insulation eventually deteriorates and break down, resulting in a short-circuit or a ground fault. If motor insulation is subjected to a temperature higher than rated for prolonged periods, the design life is seriously reduced. It is a good approximation to say that the insulation life used up by a motor operating for a given time period at a given temperature is doubled for every 10°C increase in that temperature. For example, if a motor operating with a winding temperature of 110°C used up 8 hours of life expectancy in a given time period, the same motor operating with a 120°C winding temperature would use up 16 hours of life expectancy in the same time period.

When a motor fails due to an insulation breakdown, it is important to determine what caused the insulation to break down. The answer to this question could be old age or one or more of the occurrences described in the following sections:

**Voltage Surges**

A voltage surge beyond the insulation rating can instantly destroy a motor. Voltage surges could be the result of lightning or electrical switching within the plant. Refer to “BIBLIOGRAPHY”, Item 1 on page G-6.
Mechanical Damage

Mechanical damage to insulation can result from motion between conductors in the motor winding or motion between a conductor and an adjacent insulator or part of the motor frame. The cause of the motion could be mechanical vibration due to the motor mounting, the nature of the load or the coupling between the motor and the load. Motion could also result from mechanical forces due to current surges through conductors.

Chemical Deterioration

Chemical deterioration of the insulation could range from normal aging of the insulation, which is a chemical process, to a direct attack from corrosive compounds brought into contact with the windings either with the ventilating air or from the surroundings in which the motor is used. This includes such materials as cutting or cooling fluids, grease or lubricating oil, which frequently finds its way into the motor as a result of excessive lubrication.

High Temperature

The primary causes for motor insulation operating at higher than rated temperature are:

1. Loss or reduction of ventilation
2. High ambient temperature
3. Excess current

Solutions

High ambient temperature and excess current can be handled by overload relays. All of the other above listed causes of motor failure must be handled on an individual basis.

Voltage surges can be handled by surge protectors. Mechanical damage, chemical deterioration or loss of ventilation must be handled by preventive measures in the design or installation stage of an application or by a continuing maintenance program.

Diagnosis of Motor Failures

As stated at the outset, establishment of the fact that insulation breakdown resulted in a motor failure is very little help. Any of the previously mentioned causes may result in the insulation breakdown. If a recurrence of the problem is to be prevented, a careful analysis must be made to determine the cause of the final breakdown.

Mechanical Overloads

If a 25 hp load is applied to a 20 hp motor and the motor is able to start the load, the motor continues to run. It adjusts to the excessive load by running at greater than normal slip and higher than rated current. Without the intervention of overload protection, premature damage results. Mechanical overloads can occur inadvertently in a properly designed installation. For example, a dry bearing in a motor or machine effectively increases the load on the motor. Opening a door in duct work supplied by a blower increases the load on the blower. A dull or broken cutter in a screw machine increases the load on the motor.

Misapplication of Service Factor

A situation similar to that described above may occur if a service factor load is applied to a motor and all of the service factor conditions (voltage, frequency and ambient temperature) are not met.
For example, a 10 hp motor with a 1.15 service factor can be operated continuously at 11.5 hp without exceeding the temperature rating of the insulation in the motor. If the ambient temperature exceeds 40°C, the temperature rating of the insulation is exceeded. The same is true if the motor is operated at a voltage or frequency other than that specified on the motor nameplate.

High Inertia Loads

If the inertia of the load is beyond the design limitation of the motor, the motor may be subject to injurious heating during every start period. Normally this does not occur with a Class 10 or 20 overload relay installed (nuisance tripping would result), but it could occur if a user employed a special arrangement to produce a long trip time at locked-rotor current without considering the motor's accelerating capacity. Refer to “Shunting During Starting Period, Manual Start” on page 18 and Automatic Start also on page 18.

Duty Cycle

If a motor is subjected to frequent starting, plugging, jogging or other excessive duty cycle, frequent recurrences of locked-rotor current can produce an overall rms value of motor current greater than rated full-load current. If this occurs, the motor heats according to the rms value and damage could result. Refer to Appendix B, “CALCULATION OF RMS CURRENTS” on page B -1.

Voltage Variation

NEMA standards require that an induction motor operate successfully at rated load and frequency with a voltage variation 110% of rated voltage. Performance of the motor throughout this voltage variation will not necessarily meet the standards set for operation at rated voltage. Refer to “BIBLIOGRAPHY”, Item 1 on page G -6.

Undervoltage

As motor excitation decreases, the field is weakened. This results in an increase in slip with a resultant increase in current and temperature. The increase in temperature due to current ($I^2R$) is somewhat counterbalanced by a decrease in temperature due to iron losses, but this makes overload protection more conservative in the case of an overload relay, which responds to current. Refer to “BIBLIOGRAPHY”, Item 1 on page G -6.

Overvoltage

As motor excitation is increased, iron losses increase with a resultant temperature increase. In addition to this, the current increases as the iron goes into saturation. This adds an $I^2R$ component to the motor's temperature increase. In this case, a current sensitive overload relay will not respond to the increase in temperature due to the iron losses and tends towards risk instead of being conservative. In a case where serious overvoltage is expected on a regular basis, a separate overvoltage relay may be warranted. Refer to “BIBLIOGRAPHY”, Item 1 on page G -6.

Frequency Variation

NEMA standards require that an induction motor operate successfully at rated load and voltage with a frequency variation 15% of rated frequency. A combined variation in voltage and frequency of 110% (sum of absolute values) of the rated values is allowed. Variations above rated frequency are rarely encountered and within reasonable limits would not harm a motor. Variations below rated frequency could be expected in the case of a small generating plant operating at or slightly over its capacity. A reduction in frequency results in a decrease in speed and an increase in cur-
rent and torque. At normal voltage, this could be expected to cause a motor to overheat, but if the reduction in frequency is accompanied by a proportional reduction in voltage, the motor current remains essentially constant and no ill effects will result. Refer to “BIBLIOGRAPHY”, Item 1 on page G-6.

**Phase Loss**

Table 1 shows the approximate effect upon line currents resulting from possible phase loss conditions. With one thermal unit per phase, if the motor is running at full-load current, normal overload protection produces a trip for all phase loss conditions. If a motor is running lightly loaded at the time of the phase loss, however, the increased line current could still fall within the tripping current of the overload relay. This could cause serious problems. Refer to “Phase Unbalance” on this page. If an application were such that the motor continually ran lightly loaded, overload protection could be selected based upon the actual current thus removing this problem. If the load varies, the only way to ensure protection against loss of phase is to provide a separate device designed for that purpose.

**Table 1  Effect of Phase Loss Conditions upon Line Currents**

<table>
<thead>
<tr>
<th>Status of Power Supply</th>
<th>Possible Event</th>
<th>Reaction of Motor to Event</th>
<th>Resultant Line Currents</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Phase Loss</td>
<td>Motor is Started</td>
<td>Runs Normally</td>
<td>FLA, FLA, FLA</td>
</tr>
<tr>
<td></td>
<td>Start is Attempted With Excessive Load</td>
<td>Does Not Start</td>
<td>LRA, LRA, LRA</td>
</tr>
<tr>
<td>Primary Phase Loss</td>
<td>Start Attempted During Phase Loss</td>
<td>Does Not Start</td>
<td>.5 LRA, .5 LRA, LRA</td>
</tr>
<tr>
<td>(F1, F2 or F3 Open)*</td>
<td>Phase Loss Occurs While Running</td>
<td>Continues to Run</td>
<td>1.15 FLA, 1.15 FLA, 2.3 FLA</td>
</tr>
<tr>
<td>Secondary Phase Loss</td>
<td>Start Attempted During Phase Loss</td>
<td>Does Not Start</td>
<td>.87 LRA, .87 LRA, 0</td>
</tr>
<tr>
<td>(F4, F5 or F6 Open)*</td>
<td>Phase Loss Occurs While Running</td>
<td>Continues to Run</td>
<td>1.73 FLA, 1.73 FLA, 0</td>
</tr>
</tbody>
</table>

* See Figure 7

**Figure 7  Three-Phase Motor Fed by Wye-Delta Transformer**

**Phase Unbalance**

The effect of unbalanced phase voltages upon induction motor performance can be serious. A complete analysis of the problem would be too involved to present here, but much has been written on the subject and it is summarized in NEMA Motor and Generator standards MG1-14.34, Rev. No. 7, July, 1982, Appendix G on G-1.
Causes of Phase Unbalance

Probably the most common cause of phase unbalance is the practice of connecting single-phase loads on individual phases of a three-phase system. If these loads are not distributed in a balanced manner or if they are not all energized at the same time, they will produce different voltage drops on individual transformer secondaries and phase conductors according to the total current drawn on each phase. Conditions like this can and should be corrected within the plant. An open phase in the distribution system down stream from a plant has the effect of a large single-phase load on the system. This can unbalance the phase voltages in upstream plants. Protection against such an occurrence can only be provided by a device designed to detect phase unbalance. Refer to "BIBLIOGRAPHY", Item 1 on page G -6.

Rural Open-Delta Systems

In some rural areas, utilities supply both single-phase and three-phase loads by supplying an open-delta system. In such a system, two transformers are supplied whose voltages are 120° out of phase. The transformer secondaries are connected in series and single-phase loads are connected to one secondary while three-phase loads are connected to the two outside terminals and the common terminal between the two secondaries. Since the secondaries are 120° out of phase, the third phase appears across the outside terminals. Such a system inherently tends to be unbalanced unless the load is constant because two of the phases have only their own internal impedance while the third phase has the internal impedance of both of the other phases.

Phase Converters

A variety of phase conversion devices are available on the market which allow three-phase motors to be used on single-phase systems. Some of the converters are rotary and some are static and use capacitors to produce the phase displacement required to operate a three-phase motor. These converters have a strong tendency to be unbalanced and when used, the manufacturer should be consulted about motor derating requirements. Refer to "BIBLIOGRAPHY", Item 1 on page G -6.
Whether melting alloy or bimetallic, a thermal overload relay has a critical temperature at which the heat sensing element will cause the overload relay to trip. This critical temperature is made up of several components as follows:

1. Ambient temperature (the temperature around the outside of the enclosure).
2. Temperature rise within the enclosure.
3. Temperature due to motor current through the resistance element in the overload relay.

![Diagram](image)

**Figure 10  Effect of Ambient Temperature Upon Trip Current**

**Ambient Temperature**

If the ambient temperature of the motor and the overload relay are the same, a normal selection of thermal unit or heater produces satisfactory motor protection regardless of the ambient. In low ambient temperatures, the component of the critical temperature due to the ambient temperature is reduced allowing for a larger than usual component due to motor current. Although this results in a higher tripping current, the motor can withstand a higher current due to the low ambient temperature. If the ambient temperature is high, the overload relay trips at a lower current as required for a motor in a high ambient temperature.

**Ambient Temperature Sensitivity**

The characteristic just described is known as ambient temperature sensitivity. It is shown graphically in Figure 11, which displays the change (M) in trip current resulting from changes in the ambient temperature above and below the rating temperature of 40°C.
Figure 11    Ambient Temperature Correction Curve

If the motor and the controller are in different but constant ambients, it is desirable to modify the current limit of the motor according to the motor’s ambient temperature and select thermal units or heaters based upon the modified current limit.

Ambient Temperature Compensation

If the overload relay is in a variable ambient temperature and the motor is in a constant ambient temperature, an ambient temperature compensated overload relay can provide advantages. The motor has a fixed current limit and the overload relay tripping current remains constant regardless of changes in ambient temperature. The classic example of such an application is a pump motor located in a well, where the temperature is constant, whose controller is out of doors above ground, where the temperature changes with the weather.

Figure 12    Submersible Pump with Controller above Ground

Many users employ ambient temperature-compensated overload relays in less clear-cut applications such as overload relays mounted in motor control centers where cubicle temperatures vary according to how many cubicles are energized and producing heat. Sometimes this is done even though the motor is not in a strictly constant ambient temperature, probably because compensation allows users to establish a fixed protection level in which they have confidence.
In its discussion of Motor and Branch-Circuit Overload Protection, the NEC does not mention ambient temperature. As already pointed out, ambient temperature is one of the components of the critical temperature of thermal overload relays. Why does the NEC not discuss ambient temperature? Since no explanation is given in the NEC, we can only derive an explanation by examining NEC limits.

The NEC will allow for actual motor currents of 125% and 115% of full-load current for motors with 1.15-1.25 and 1.0 service factors respectively. These limits can be extended to 140% and 130% by selecting the next higher rated thermal unit if the proper size will not allow the motor to start or carry the load. To simplify discussion, let us consider a 1.15 S.F. motor and the 140% limit (Appendix D, 430-32 (a) (I) on page D-1 & 430-34 on page D-3).

A strict interpretation of the NEC requires all electrical equipment to be used within its rated temperature. When evaluating a worst case, consider a 40°C motor in a 40°C ambient temperature and an overload relay in a 0°C ambient temperature. Both devices are at opposite extremes of their ambient temperature application range, such that the motor is most vulnerable to overheating and the overload relay produces its highest tripping current.

Under these circumstances, the overload relay tripping current is 136% of normal (M = 1.36, Refer to Figure 11 on page 15). Since normal thermal unit selection could produce a tripping current as high as 125% of FLA, tripping current in this case could be as high as 1.36 x 125 or 170% of FLA and be within NEC requirements. This situation does not provide good motor protection when overload thermal units are selected to the NEC limits. Note, however, that Part C of Article 430 (Appendix D on page D-1) only addresses “excessive heating due to motor overloads and failure to start” and does not consider many of the other potential problems discussed in this bulletin.

If the motor is in a 0°C and the controller in a 40°C ambient temperature, the overload relay trips within 125% of FLA. The motor will probably be able to operate beyond this limit due to its low ambient temperature, but the only "legal" opportunity to take advantage of this margin is if nuisance tripping occurs. If nuisance tripping occurs, the new limit of tripping current is that of the next larger size thermal unit, as long as it did not exceed 140% of motor full-load current. Refer to (Appendix D, 430-34 on page D-3).

The problems discussed in the preceding paragraphs are best handled by controlling the ambient or moving the motors or overload relay to eliminate the problem.

The temperature rise within the enclosure of the overload relay depends upon the size of the enclosure and the heat dissipation of all parts within the enclosure. Magnets, coils, transformers, current carrying parts and the thermal units all contribute heat. This is taken into consideration in the manufacturer’s instructions for selecting thermal units, but these recommendations are based upon the assumption that power wiring of the proper size are used and that all connections are clean and properly torqued down. Improper wire size, loose or dirty connections or the addition of heat generating equipment to an enclosure all affect the tripping current of an overload relay.
OEM Applications

When an OEM purchases a starter or overload relay, they usually purchase an open device and receive with that device an instruction sheet which includes two thermal unit selection tables, one for a small enclosure and one for a large. Instructions as to which selection table should be used are based upon the volume of the enclosure. This is a safe procedure, but if it should turn out that the OEM has a large enclosure which contains many heat-generating devices (relays, transformers, contactors etc.), nuisance tripping could result. In such a case, an adjustment to the original thermal unit selection can be estimated based on the temperature inside of the enclosure but it is almost impossible to be precise. The enclosure temperature can reach the critical temperature of the overload relay as a result of heat which is conducted, convected and/or radiated. A thermometer measuring inside temperature might absorb less radiated heat than the overload relay and produce a discrepancy. If precision is desired or if UL listing is required for the completed product, testing may be necessary to determine and verify the tripping current of the overload relay in the particular application.

Long Accelerating Times

Some applications such as large fans, compressors or centrifuges tend to have long accelerating times. A Class 30 (slow trip) overload relay supports an accelerating time of about 12 seconds, as opposed to about 7 seconds for a Class 20 (standard trip). Magnetic overload relays can handle accelerating times of approximately 45 seconds. Other methods are also available for handling long accelerating times. Refer to "Shunting During Starting Period, Manual Start" on page 18, "Automatic Start" on page 18 and "Saturable Current Transformers" on page 20.

Overload Relay Time-Current Characteristics

Overload relay time-current characteristics can be used to coordinate the fuses or circuit breaker in a motor branch circuit with the overload relay. They can also be used to estimate the trip time of an overload relay and the ability of the overload relay to allow a motor to start without tripping when the accelerating time is long.

Estimating Trip Time Requirement For Acceleration

While an AC squirrel-cage motor is accelerating, the current drawn by that motor remains essentially constant at locked rotor until the motor reaches about 80% of full speed. At this point, the current drops rapidly to a value determined by the load. It is acceptable to consider this a step function, where the current remains at locked-rotor value throughout the accelerating time and then drops instantly to its run value determined by the load.

While the motor is accelerating and drawing locked-rotor current, the thermal units are heating at a rapid pace, but normally they do not achieve a temperature high enough to cause the overload relay to trip. When the motor current subsides from locked rotor to run current, the heater winding cannot cool down instantaneously, and heat continues to be transmitted to the heat sensing element for a short time. Because of this, it is not unusual for the overload relay to trip as a result of a long accelerating time after the motor is up to speed.

A good rule of thumb to prevent nuisance tripping due to long accelerating time is to provide a trip time at locked-rotor current equal to 150% of the accelerating time. Refer to Appendix A, "ESTIMATING OVERLOAD TRIP TIME" on page A-1.

Another method of handling the problem discussed in the previous paragraphs is to calculate the rms value of the motor current during and after acceleration and
plot the rms values on the trip curve of the overload relay in question. Refer to Appendix B, “CALCULATION OF RMS CURRENTS” on page B -1. If the rms curve does not intersect the trip curve, there should be no nuisance tripping.

If the curves do intersect but barely, there is a chance that the overload relay will not trip because the calculation of rms current neglects variations in heat loss. In such a case an actual trial is advisable.

Shunting During Starting Period, Manual Start

If an application is nonautomatically started, the NEC permits the overload protection to be shunted or cut out of the circuit during the starting period of the motor. This is only allowed if the device which cuts out the overload protection cannot be left in the starting position and if the short-circuit protection is operative during the starting period of the motor.

If allowed, shunting the overloads during the starting period has an advantage over providing an overload relay with a longer trip time. For example, if an overload relay has a 45 second trip time at locked-rotor current, the overload relay can also produce a trip time nearly that long if the machine jams after a long running period (shortened slightly due to preheating from the running current). Although the motor may be capable of withstanding locked-rotor current through a 45 second period of acceleration, it is likely that it may not withstand 45 seconds drawing locked-rotor current while standing still. There can be a considerable difference between a motor's allowable accelerating time from a cold start and its allowable accelerating time from a hot start. There can also be a considerable difference between a motor's withstand time while it is coming up to speed and its withstand time standing still without the benefit of ventilation.

Shunting During Starting Period, Automatic Start

If an application with a long accelerating time is automatically started, two separate overload relays can be used in series:

One overload relay having a normal, fast or even instantaneous trip time at locked-rotor current which would be shunted out during accelerating time and another overload relay with a long trip time at locked-rotor current which would allow the motor to come up to speed. After the motor is up to speed, the shunt can be removed from the quick trip overload relay.

Another method of handling long accelerating time in an automatically started application has been allowed as of the 1984 NEC (Appendix D, 430-35(b) on page D -3). This method allows for shunting out the overload relay during the starting period if a device capable of sensing motor rotation is used to prevent shunting the overload relay when the motor fails to start and to limit the shunting time to less than the locked-rotor time rating of the motor. It also provides for shut down and manual re-start if the motor fails to start. The equipment used to achieve these ends must be UL listed or equivalent.

General Application of Magnetic Current Relays

Magnetic current relays come in three versions; overload, underload and instantaneous trip.
Magnetic Overload Relays

Magnetic overload relays differ from thermal overload relays in that they are current sensitive devices and their tripping current is not affected by temperature. Their tripping time, however, can be affected by temperature, depending upon the viscosity of the dashpot oil as well as the size of the opening through which the oil can pass. If a magnetic overload relay is to be applied in a varying ambient temperature, a silicone dashpot oil can be used. The viscosity of silicone oil is much less affected by temperature change than that of mineral oil normally used.

Underload Relays

Underload relays, which reset on a slight decrease in current from their trip value, are a special version of magnetic overload relays. This characteristic can be used to advantage in applications where loss of output is a hazard or a serious problem. For example, an underload relay can be used to produce an alarm if a well ran dry because when the pump loses its prime, the pump motor current decreases and the underload relay detects the decrease in current. Likewise an underload relay can be used to detect a broken belt between a fan and its motor because the motor current decreases when it loses its load. Trip and reset actions are quite fast due to low viscosity dashpot oil normally used.

Another common application of underload relays makes use of both the trip point and the reset point of the relay. An example of such an application is a hammer mill fed by a conveyor. The coil of the underload relay is placed in series with the hammer mill motor and set to trip in the vicinity of motor full-load current (a brief time delay prevents the relay from picking up during motor acceleration). The normally closed contacts of the underload relay are placed in the control circuit of the conveyor motor starter. While the hammer mill is running at less than full load, the conveyor automatically feeds the hammer mill at a rate slightly faster than it can accommodate.

![Hammer Mill / Conveyor Circuit](image)

**Figure 13  Hammer Mill / Conveyor Circuit**

When the hammer mill reaches full load, the underload relay will pick up and its normally closed contacts open, stopping the conveyor. As the hammer mill disposes of ground material, its motor load current decreases to about 90% of full load at which point the underload relay drops out and reenergizes the conveyor motor. This system allows the hammer mill to operate automatically within the region of its highest efficiency.

Instantaneous Trip

Magnetic current relays are also available in an instantaneous trip version. Instantaneous trip relays are normally used in applications where mechanical overloads
are expected to occur with relative frequency, such as rock crushers or grain augers, and it is undesirable to allow the motor to repeatedly heat through the locked-rotor trip time. Since motor current is related to mechanical loading, an instantaneous trip relay may also be used to limit mechanical loading in a machine to prevent breakage. An instantaneous trip relay could be used on a winch motor to prevent cable breakage, or in a bale to control the force of the ram upon the bale.

Operating Overload Relays With Current Transformers

In many applications such as medium and high voltage or high current starters, it is desirable to operate a low current, low voltage overload relay in the secondary circuit of a current transformer. This has advantages in economy and in the variety of overload relay types. If this is the case, take care to ensure the current transformer has the capacity to handle the power requirements of the overload relay. Thermal overload relays usually have a considerably higher resistance than meter current coils for which current transformers are usually used. Because of this, current transformers with greater iron cross sectional area are often required to prevent saturation of the current transformer. Refer to Appendix C, “DRIVING OVERLOAD RELAYS WITH CURRENT TRANSFORMERS” on page C-1.

Saturable Current Transformers

As a current transformer is driven into saturation, it becomes inaccurate because the increase in the secondary current ceases to be proportional to the increase in primary current. This characteristic can be used to advantage in applications where the accelerating time is too long for the trip time of the overload relay. If the current transformer is chosen so that it saturates somewhere between full-load current and locked-rotor current, the secondary current at locked rotor appears to be a smaller multiple of full-load current than the primary. This inaccuracy produces a longer trip time at locked-rotor current. Refer to Appendix C, “DRIVING OVERLOAD RELAYS WITH CURRENT TRANSFORMERS” on page C-1.

If a current transformer is deliberately chosen to produce an abnormal trip time, great care must be taken to ensure that the motor has the capacity to withstand the resulting locked-rotor trip time.

Location of Overload Relay Control Circuit Contacts

Figure 14 shows the location of the overload relay control circuit contacts as they appear in NEMA standards. As the diagram is shown, the location of the overload relay contact is not important. Frequently, however, L2 is grounded. When this is the case and the overload contacts are on the left-hand side of the coil, an accidental ground in the coil could weld the overload relay contact, leaving the overload relay disabled after the coil is replaced. This could happen without anyone being aware of it and create a hazardous situation.
Figure 14  FVNR Three-Wire Control Circuit — Location of Contacts

In the circuit shown above, it is that a ground between the coil and the overload contact on the right-hand side of the starter coil could effectively disable the overload relay. However, because the wire between the starter coil and the overload relay contact is a short, factory-installed, well protected wire, it is extremely unlikely that such a ground would occur.

In the case of a reversing, multispeed, part-winding or reduced voltage starter refer to Figure 15, the only choices for the location of the overload relay contact are on the right-hand side of the starter coils or on the right or immediate left hand side of the stop button. In such a case, the push buttons are often remote, with wire running through conduit. This greatly increases the likelihood of a short-circuit, which could weld the overload relay contacts if they are in the vicinity of the stop button. This could cause the same problem mentioned in the previous paragraph.

Figure 15  Two-Speed Three-Wire Control Circuit — Location of Contacts

When overload relay contacts are on the right hand side of the coil and L2 is grounded, a ground between the coil and the overload relay contact could start the motor if two-wire control is employed. The likelihood of a ground in this wire is very small however. With two-wire control, an unexpected start must always be considered a possibility and as a result, this wiring scheme is considered relatively unhazardous.
TROUBLESHOOTING
OVERLOAD RELAY
TRIPS

General

The tripping of an overload relay should be regarded as an indication of a problem with the motor, its electrical supply or its load. Before resetting the overload relay, the user should give some consideration to what the problem is. Refer to “Temporary Problems” on page 3. If tripping persists, motor currents, ambient temperatures, accelerating time etc. should be measured and studied to determine the cause of tripping. Refer to “Frequent Resetting” on page 3. If proper methods are applied, the problem is usually solved and corrected.

In many instances, users do not have the experience or knowledge to apply proper methods to determine the cause of an overload relay tripping and for this reason, the following procedure is provided. The suggested steps assume the user has reason to suspect the overload relay and they are arranged for simplicity rather than a logical order. Review the entire list before beginning an investigation.

Troubleshooting
Procedure

1. Check thermal unit selection.
2. Check for loose or dirty connections in vicinity of thermal units and/or overload relay. Refer to “Temperature Rise Within the Enclosure” on page 16.
3. Measure current in all lines to motor. If current varies, a recording ammeter may be required.
4. Estimate trip current in terms of existing ambient temperature. Refer to Appendix A, “ESTIMATING OVERLOAD TRIP TIME” on page A -1. If application is a special controller, heat producing equipment in vicinity of overload relay should be considered as a possible cause. Refer to “Temperature Rise Within the Enclosure” on page 16.
5. Check accelerating time if trips are associated with starting. Refer to Appendix A, “ESTIMATING OVERLOAD TRIP TIME” on page A -1.
6. Check rms current in terms of duty cycle. Refer to Appendix B, “CALCULATION OF RMS CURRENTS” on page B -1.
ESTIMATING OVERLOAD TRIP TIME

General

Due to overload relay problems or the desirability of the in-plant testing of overload relays, customers occasionally request information on how to evaluate overload relay performance in terms of trip currents and/or trip times. This bulletin outlines overload relay requirements, the calculation of trip current ratings, the adjustment of trip current ratings for ambient other than 40°C and the estimation of trip time for any particular current.

When a motor is to be protected by a separate overload device that is responsive to motor current, the National Electrical Code defines the limit of protection in terms of the percentages of motor full-load current rating as follows:

- Motors with a marked service factor not less than 1.15 — 125%
- Motors with a marked temperature rise not over 40°C — 125%
- All other Motors — 115%

Nothing is said in the National Electrical Code about the time in which the overload relay must trip.

NEMA and UL establish the required tripping time of an overload relay in terms of maximum time at various percentages of the current element rating or tripping current. (In Square D terminology, this is the trip current rating of the thermal unit or heater). The trip times are specified in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Required Trip Time of an Overload Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Trip Current Rating</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>600</td>
</tr>
</tbody>
</table>

The above times are specified for tests at an ambient temperature of 40°C.

The performance of an overload relay can be checked by establishing that it meets all of the criteria listed above. It is not recommended that the ultimate trip time be checked because this would be extremely time consuming (as much as 4 hours per trip); and if thermal units are properly selected, the selection ensures that the trip current rating is within the limits defined by the National Electrical Code. This performance is ensured because Square D thermal units are UL approved when used in conjunction with Square D starters.

Calculation Method

Use the following procedure to estimate trip time at any given current:

1. **Calculate The Trip Current Rating** — Trip current rating is a nominal value which approximates the minimum current to trip an overload relay in an ambient temperature outside of the enclosure of 40°C (104°F). In all selection tables, except Class 8198, the trip current rating is 1.25 times the minimum full-load current shown for the thermal unit selected. For Class 8198, the trip current rating is 1.15 times the minimum full-load current. This applies to bimetallic overload relays with the trip adjustment set at 100%.
Appendix A - Estimating Overload Trip Time

Procedure:

- Use the selection table for the specific controller involved.
- Find the minimum motor full-load current listed for the thermal unit in question.
- Multiply that current by 1.25 (1.15 for Class 8198). The result is the trip current rating.

Example 1 — Determine the thermal unit selection and trip current rating for thermal units in a Class 8536 Type SCG-3 Size 1 magnetic starter used to control a three-phase, 1.15 service factor motor with a full load current of 17.0 A, where the motor and controller are both located in a 40°C (104°F) ambient temperature.

- The proper selection is B32.
- The minimum motor full-load current is 16.0 A (The range shown in the selection tables is 16-17.5).
- Trip current rating is 16.0 x 1.25 = 20.0 A.

2. **If Ambient Temperature Is Not 40°C Adjust Trip Current Rating For Actual Ambient** — Ambient temperature is the temperature surrounding the starter enclosure. Normal temperature rise inside the enclosure has been taken into account in preparing the thermal unit selection tables.

Procedure:

- Find multiplier M from Figure 1 corresponding to ambient temperature.
- Multiply trip current rating at 40°C by M.

![Figure 1 Ambient Temperature Correction Curve](image)

Example 2 — Determine the trip current for the motor and controller in Example 1, except the controller is in a 30°C (86°F) ambient temperature. From the curve in Figure 1, the multiplier M is 1.1 at 30°C. Approximate Trip Current is 16.0 x 1.25 x 1.1 = 22 A

3. **Divide Current At Which Trip Time Estimate Is Desired By Trip Current Rating.**

4. **Use Multiple Obtained In Step 3 To Find Trip Time From Approximate Time Current Characteristics (Figure 2).**
Example 3— Determine trip time at locked rotor current for the motor in Example 1 & 2. (LRA = 6 x 17 = 102 A).

- Multiple of trip current rating is 102 + 22 = 4.64.
- Approximate trip time would be 11 sec. (Class 10), 20 sec. (Class 20) or 33 sec. (Class 30)

Figure 2  Approximate Time-Current Characteristics of Class 10, 20 & 30

Results obtained by this method are approximate for a cold start. If a test is repeated the second trip will be considerably shorter than the first unless a very long time is allowed between trials (on the order of hours). If more accurate results are desired, time-current characteristics of specific overload relays in specific enclosures can be obtained by contacting Milwaukee GIC Marketing Headquarters.
CALCULATION OF RMS CURRENTS

The following is a method for estimating whether or not an overload relay will hold during a given accelerating time. Please note that the results will be approximate, useful only as an aid to judgement.

Heat produced by current flow through a resistor is proportional to the square of the current and the value of the resistor ($I^2R$). If $R$ is considered constant and the current changes in a repetitive cycle, the average heat produced is proportional to the average of the individual $I^2t$-time increments throughout the cycle. If heat losses are assumed to be constant, the heat-producing constant current equivalent of the various currents throughout the cycle is the square root of this average $I^2t$. The heat-producing equivalent current (rms or root-mean-square) can be calculated using the formula [I] refers to Figure 1.

\[
I_{\text{rms}} = \sqrt{\frac{I_1^2t_1 + I_2^2t_2 + \ldots + I_n^2t_n}{t_1 + t_2 + \ldots + t_n}} \tag{1}
\]

![Figure 1](image)

**Figure 1** Formula for Calculating Root-Mean-Square (rms)

Example 1 — A motor has a full-load current of 6 A and a locked-rotor current of 36 A. Its operating cycle is:

☑ 5 sec accelerating time, 30 sec run time, and 90 sec off time

Will a properly selected thermal overload relay trip?

☐ Answer:

\[
I_{\text{rms}} = \sqrt{\frac{(36^2 \times 5) + (6^2 \times 30)}{5 + 30 + 90}} = 7.8
\]

Since 7.8 is about 130% of 6, the overload should eventually trip because a properly selected overload should produce a protection level within 125%.

Example 2 — A motor has an accelerating time of 12 sec, a full-load current of 1 A and a locked-rotor current of 6 A. Figure 2 shows the time-current characteristic of the overload relay in question.

Will the overload relay nuisance trip?
Answer — Assuming that the trip current rating of a properly selected overload relay is about 125% of full load, the locked rotor and full-load current can be plotted on the overload relay time-current characteristic (1/1.25 = 0.8 and 6/1.25 = 4.8) in multiples of trip current rating (solid line A).

It would be incorrect to stop here and assume that the overload relay would not trip because line A does not intersect the overload relay time-current characteristic. The rms value must now be calculated for different time periods and plotted on the characteristic. Table 1 was developed by calculating rms values using equation [1] for time periods from 12 to 1000 seconds. The rms value of the motor current runs almost tangent to the average time-current curve, and as a result, it is questionable whether the overload relay will hold.

<table>
<thead>
<tr>
<th>Time Period (Sec)</th>
<th>$I_1$</th>
<th>$I_2$</th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$I_{rms}$</th>
<th>$I_{rms}/1.25$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 12</td>
<td>6</td>
<td>—</td>
<td>12</td>
<td>—</td>
<td>6</td>
<td>4.8</td>
</tr>
<tr>
<td>0 to 20</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>4.69</td>
<td>3.75</td>
</tr>
<tr>
<td>0 to 30</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>18</td>
<td>3.87</td>
<td>3.1</td>
</tr>
<tr>
<td>0 to 60</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>48</td>
<td>2.828</td>
<td>2.26</td>
</tr>
<tr>
<td>0 to 100</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>88</td>
<td>2.28</td>
<td>1.8</td>
</tr>
<tr>
<td>0 to 200</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>188</td>
<td>1.76</td>
<td>1.4</td>
</tr>
<tr>
<td>0 to 500</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>488</td>
<td>1.36</td>
<td>1.09</td>
</tr>
<tr>
<td>0 to 1000</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>988</td>
<td>1.19</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Figure 2  Time-Current Characteristics of an Overload Relay
DRIVING OVERLOAD RELAYS WITH CURRENT TRANSFORMERS

Current transformers are normally used in metering applications driving ammeters or wattmeter current coils. They follow the same natural laws as those which govern voltage transformers, but because of their special applications, they have special design considerations and a language all their own. These differences between power transformers and current transformers are discussed and clarified in “ACCURACY AND BURDEN OF CURRENT TRANSFORMERS Product Data Bulletin EI-9” on page C-4. EI-9 discusses accuracy and burden of current transformers in terms of metering and relaying applications, but there are some aspects of driving an overload relay with a current transformer which are not covered in either of these applications.

For example, if a current transformer is used to drive an overload relay simply to increase the operating current range of the overload relay in question, the selection of the current transformer must ensure that both locked rotor and full-load current are reproduced faithfully in the secondary according to the turns ratio of the current transformer. In some applications, however, current transformers are deliberately selected so they will saturate somewhere between full-load current and locked-rotor current and as a result, produce a longer than normal trip at locked-rotor current. To understand such applications, it is helpful to make a comparison between power transformers and current transformers.

![Power Transformer (Four Turn Primary / Two-Turn Secondary)]

Figure 1 shows a power transformer with a four-turn primary connected to a supply voltage \( V \) and a two-turn secondary connected to a load resistor \( R \). With no load on the secondary \( (R = \infty) \), a primary current \( I_p \) will flow, which establishes a flux \( \Phi \). This flux links both the primary and secondary turns. The flux, following Lenz’s law, induces an emf, which acts to oppose the change which caused it. The back emf is almost equal to the applied primary voltage and as a result, a very small magnetizing current flows in the primary. Since the secondary is an open circuit, no current flows in the secondary although a secondary voltage is induced because the secondary turns are linked by the same flux that links the primary turns. Since the primary has four turns and the secondary has two turns, the secondary voltage is half of the primary voltage.

If the secondary resistance is dropped from infinity to some real value, secondary current begins to flow and (according to Lenz’s law) produces a flux which opposes the flux that caused the current flow. This tends to reduce the flux in the core, but a reduction of the flux in the core tends to reduce the back emf, allowing more current to flow from the primary supply and maintaining the flux in the core at its original level. When a transformer is properly designed, the flux in the core remains constant as long as the transformer is operated within its design limitations. The ratio of the primary current to the secondary current is also proportional to the ratio of the secondary turns to the primary turns. This results in a situation where the net current through the window of the transformer core is always the magnetizing current.
The conclusions in the previous paragraph were based upon an assumption best described by referring to Figure 2, showing the relationship between flux density resulting from magnetizing force when current carrying conductors are wound around a piece of iron as shown in Figure 1. Previous discussions were based upon the assumption of operation within point A on the curve shown in Figure 2. As a result, an increase in current always produced a proportional increase in flux density. If the primary voltage of the transformer in Figure 1 increased beyond its design limitation, it would begin to operate beyond point A in Figure 2 and further increase in primary current would no longer result in a proportional increase in the core flux density. As a result, the back emf would not increase proportionally and the input current and output voltage wave forms would become badly distorted. With this in mind, we can compare the major difference between the application of a power transformer and a current transformer.

Figure 3(a) shows a schematic diagram for a typical application of a power transformer. Figure 3(b) shows a typical current transformer application. It can be seen that the power transformer is readily able to draw more or less primary current from the supply as required by the secondary load. The primary current of the current transformer, however, is controlled by the load whose current is being monitored by the current transformer. If the load (primary) current in Figure 3(b) increases and is unable to produce a corresponding increase in the secondary current (R is too high), the flux increase resulting from the increase in primary current is not counterbalanced by a corresponding opposing flux which should result from a corresponding increase in secondary current and the operation of the current transformer core will be pushed beyond point A in Figure 2. This results in saturation of the core.
For example, if a 500:5 current transformer is operating with a shorted secondary, 500 A in the primary should produce 5 A in the secondary. Actually, the secondary current is slightly less than 5 A because a very small part of the primary current is used in magnetizing the core. The 100-turn secondary (500:5 = 100:1) with almost 5 A in each turn almost cancels the magnetizing force due to 500 A in the one-turn primary. If the secondary circuit is opened, the secondary current becomes zero and the total 500 A primary current (uncancelled) becomes magnetizing current. This saturates the core, which is designed for a magnetizing current probably within 0.5 A.
ACCURACY AND BURDEN OF CURRENT TRANSFORMERS
Product Data Bulletin EI-9

Power Transformer vs. Instrument Transformer

The differences between power transformers and current transformers are clarified here in this reprint of Product Data Bulletin EI-9, released out of Square D, Clearwater.

Although current transformers follow the same physical laws as power transformers the relationship is not always apparent. This is, in part, probably due to the different terminology used in describing current transformers. For example, the "burden" of an instrument transformer is the equivalent of the "load" on a power transformer.

In a power transformer, the term "regulation" means the change in voltage ratio (or internal voltage drop) with respect to change in load. Regulation is customarily expressed as a percentage below the no-load voltage. When relating to a current transformer, its "metering accuracy" class is expressed in terms of the change in ratio (related to the nameplate ratio) and the phase angle of the secondary current (with respect to the primary current).

Just as "load" and "regulation" in a power transformer are interdependent, so is "burden" and "accuracy" in a current transformer. One term of either pair is meaningless without the other.

More Terms

The burden of a current transformer is expressed in volt-amperes (VA) or, more commonly, in ohms impedance. The formula $VA = I^2Z$ expresses the relationship of the two terms.

![Concentric Parallelogram](image)

**Figure 1** Concentric Parallelogram

The burden is the total impedance of the device(s), (e.g. meter, relay coil, etc.) connected to the secondary terminals including the impedance of the connecting leads.

In current transformers, the determination of the accuracy class is a composite of the ratio correction factor and the phase angle. The method of combining these two characteristics is graphically described by a parallelogram as shown in Figure 1. Concentric parallelograms are established for accuracy classes of 0.3, 0.6, 1.2, and 2.4, with the limits of the 0.3 parallelogram coinciding with a ratio correction factor of 0.3% (1.003 and .997) for each accuracy class.

The ratio correction factor (RCF) is the factor by which the measured secondary amperes must be multiplied to obtain the true secondary current. The error is the amount the ratio correction factor deviates from the (errorless) factor 1.
The national standards relating to instrument transformers is the American National Standards Institute (ANSI) Specification C57.13. The metering accuracy classes standardized by ANSI are 0.3, 0.6, and 1.2. The transformer is tested for ratio and phase angle at 100% of the nameplate current rating and the point derived is plotted on the parallelogram having as its abscissa the phase angle and as its ordinate the ratio correction factor. Similarly, a point derived by testing the transformer at 10% of the nameplate current rating is also plotted. A current transformer is then said to be in the 0.3 accuracy class (at a specified burden) if its 100% point is inside the 0.3 parallelogram and its 10% point is within the 0.6 parallelogram. A transformer having its 100% point within the 0.6 parallelogram and its 10% point within the 1.2 parallelogram is said to be in the 0.6 accuracy class at the specified burden. Similarly, to conform to the 1.2 accuracy class the 100% and the 10% points must be within the 1.2 and the 2.4 parallelograms respectively.

Besides the standardization of the accuracy classes, ANSI has standardized burdens for the purpose of accuracy ratings. This makes possible comparison of transformer ratings of different makes. The standard metering burdens are 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, and 8.0 ohms. It is customary for manufacturers to rate their current transformers in terms of ANSI standard burdens and metering accuracy classes.

ANSI Standard C57.13 standardizes the method in which the metering accuracy and burden shall be written, for example; "0.3B2.0". This term signifies that the transformer accuracy is within the 0.3 metering accuracy class when connected to a burden of 2 ohms. The term 0.6B1.0 indicates an accuracy in the 0.6 class when connected to a 1 ohm burden. If the latter transformer, for example, had a nameplate ratio of 500:5, then at 500 A (nominal rating) the maximum ratio error is 0.3% and 10% nominal rating (or 50 A), the maximum error is 0.6% — all at a 1 ohm burden. It is normal for a current transformer to have more than one accuracy rating, for example, see Table 1. The 500:5 A ratio has a ratio which would be written as follows: 0.3B0.1, B0.2; 0.6B0.5, B1.0; 1.2B2.0.

The EI catalog shows current transformer ratings in tabular form as shown. The standard burdens from 0.1 ohm through 2.0 ohms appear at the head of the columns. The applicable metering accuracy classes corresponding to each of these burdens is shown opposite each transformer ratio.

### Table 1 Metering Accuracy and Burden

<table>
<thead>
<tr>
<th>Catalog Number (without brackets)</th>
<th>Current Rating (amperes)</th>
<th>ANSI Accuracy Classification - 60 Hz Metering Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B-O.1</td>
<td>B-O.2</td>
</tr>
<tr>
<td>65-151</td>
<td>150:5</td>
<td>1.2</td>
</tr>
<tr>
<td>65-201</td>
<td>200:5</td>
<td>1.2</td>
</tr>
<tr>
<td>65-251</td>
<td>250:5</td>
<td>0.6</td>
</tr>
<tr>
<td>65-301</td>
<td>300:5</td>
<td>0.3</td>
</tr>
<tr>
<td>65-401</td>
<td>400:5</td>
<td>0.3</td>
</tr>
<tr>
<td>65-501</td>
<td>500:5</td>
<td>0.3</td>
</tr>
<tr>
<td>65-601</td>
<td>600:5</td>
<td>0.3</td>
</tr>
<tr>
<td>65-751</td>
<td>750:5</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Proper Selection

The proper selection of a current transformer for a particular application, is no less important than the selection of a power transformer. All too often, however, this matter receives insufficient attention, often resulting in a current transformer with too great an error, in some cases unable to support its burden or, the opposite extreme, one that is oversize and more expensive than the application demands.

When a current transformer is used for revenue metering, accuracy is usually mandatory. Various Public Service Commissions throughout the country generally require 0.3 metering accuracy class for that purpose.

In most other applications, accuracy is a matter of common sense. For example, a current transformer supplying a switchboard instrument, which has a maximum error of 1%, should be in the 0.3 accuracy class at the burden of the meter. If the burden is a 2% or 3% accuracy class panel meter, it would seem inconsistent to pay a premium for accuracy in the current transformer greater than 1.2% class.

Ordinarily the price of a current transformer increases with an increase in accuracy assuming no change in burden. The reverse is also true. Consequently, a careful analysis of the burden and accuracy of the current transformer can assure both satisfactory performance and economy.

Calculating Metering Accuracy from Excitation Curves

The tabular accuracies given above are for standardized (per ANSI) burdens. The tables permit a quick approximation of the accuracy for most purposes. If a more precise value of accuracy is needed, refer to the excitation curves where the exciting current, \( I_e \), is plotted against secondary voltage, \( E_s \).

The transformer ratio error expressed as a percentage becomes:

\[
\% (\text{RE}) = \frac{I_e \times 100}{I_s}
\]

This method is applicable when the error does not exceed approximately 10%. Above that value, the wave form of the secondary current may be distorted due to saturation of the core and the reliability of the result becomes questionable.

In order to use the curves to determine \( I_e \), it is first necessary to calculate \( E_s \).

![Typical Current Transformer Circuit](image)

**Figure 2** Typical Current Transformer Circuit

Referring to a typical current transformer circuit, Figure 2, the voltage \( E_s \) must force the secondary current \( I_s \) through the entire circuit consisting of the secondary winding and the burden, including the interconnecting leads. This voltage \( E_s = I_s Z_c \) where \( Z_c = R_s + R_b + j(X_s + X_b) \). Refer to Current Transformer and Burden on page C - 10.
In a toroidal design, \( X_s \) is small and can be ignored. Further, the burden impedance may simply be added arithmetically to the secondary resistance, i.e. \( Z_c = R_s + Z_b \). This abbreviated method is commonly used in calculating the circuit impedance and results in a calculated error slightly greater than the actual error.

The resistance of the secondary winding \( R_s \) is listed in the catalog for a given current transformer under the heading of “DC R-ohms”. \( Z_b \) is commonly referred to as “Burden” and must be obtained from the catalog information of the connected devices added to the resistance of the interconnecting leads. Combining \( E_s = I_s Z_c \) with \( Z_c = R_s + Z_b \) results in \( E_s = I_s (R_s + Z_b) \). The excitation curve for the current transformer in question may now be entered to determine \( I_s \), the exciting current.

<table>
<thead>
<tr>
<th>Catalog Number (Without Brackets)</th>
<th>Current Rating (Amperes)</th>
<th>VA-60 Hz</th>
<th>VA-400 HZ</th>
<th>DCR Ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>5N101</td>
<td>100:5</td>
<td>2.0</td>
<td>4.0</td>
<td>.016</td>
</tr>
<tr>
<td>5N151</td>
<td>150:5</td>
<td>2.5</td>
<td>5.0</td>
<td>.023</td>
</tr>
<tr>
<td>5N201</td>
<td>200:5</td>
<td>5.0</td>
<td>12.5</td>
<td>.031</td>
</tr>
<tr>
<td>5N251</td>
<td>250:5</td>
<td>5.0</td>
<td>12.5</td>
<td>.035</td>
</tr>
<tr>
<td>5N301</td>
<td>300:5</td>
<td>5.0</td>
<td>12.5</td>
<td>.058</td>
</tr>
<tr>
<td>5N401</td>
<td>400:5</td>
<td>12.5</td>
<td>25.0</td>
<td>.091</td>
</tr>
<tr>
<td>5N501</td>
<td>500:5</td>
<td>12.5</td>
<td>25.0</td>
<td>.111</td>
</tr>
<tr>
<td>5N601</td>
<td>600:5</td>
<td>25.0</td>
<td>50.0</td>
<td>.168</td>
</tr>
</tbody>
</table>

**Figure 3**  
*Standard Ratios & VA*  
\[ R_s = .058 \]  

**Example:**  
Type: 5N  
Ratio: 300:5  
Catalog Number: 5N-301  

\( I_p = \) Primary Current: 240 A (Given for some particular application)

To calculate the burden:

\[ .083 \text{ ohms (ammeter from Cat. Sec. D-1)} \]
\[ .359 \text{ ohms (214 ft. of #12 wire - Figure 4)} \]

\[ External \text{ Burden } Z_b = .442 \text{ ohms} \]

\[ Internal \text{ Burden } R_s = .058 \text{ ohms (from Figure 3 or Cat. Sec. A-1)} \]

\[ Z_c = R_s + Z_b = .5 \text{ ohms} \]

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>#8</th>
<th>#10</th>
<th>#12</th>
<th>#14</th>
</tr>
</thead>
<tbody>
<tr>
<td>ohms/100'</td>
<td>0.0659</td>
<td>0.106</td>
<td>0.168</td>
<td>0.268</td>
</tr>
</tbody>
</table>

**Figure 4**  
*Resistance Per 100' of Copper Wire*
To calculate the accuracy:

The transformation ratio \( K_n = \frac{300}{5} = 60 \)

With 240 A in the primary, the secondary current, \( I_s \) is 240 + 60 = 4 A

\[ E_s = I_s Z_c \]
\[ = 4 \times .5 = 2 \text{ V} \]

Referring to Figure 3, we see that at 2 V the exciting current \( I_e \) = .04 A

\[ \% (\text{RE}) = \frac{I_e \times 100}{I_s} = \frac{.04 \times 100}{4} = 1\% \]

Figure 5 Typical Excitation Curves

The two factors which influence accuracy the most in a toroidal current transformer, are \( R_s \) and \( I_e \). To improve the accuracy, \( R_s \) can be reduced by increasing the wire size or \( I_e \) can be reduced by decreasing the flux density (i.e. increasing the cross sectional area of the core). However, the latter has two opposing factors, (1) the mean length turn of the winding increases thus increasing \( R_s \) and (2) the core weight increases. Since the exciting current is a function of flux density and core weight, any change in the core size becomes a compromise of these factors. It now becomes apparent that accuracy improvement will increase the cost.

Figure 6 shows the typical behavior of a current transformer at multiples of rated currents.
Relaying Accuracy

Previously, only metering accuracy has been discussed. Relaying accuracy defines the accuracy of the current transformers in another way — on the basis of voltage.

Since a transformer used for relaying may operate at many times its nameplate rating (for very brief intervals), the ANSI accuracy is based on 20 times the rated secondary current. The relay accuracy defines the maximum voltage attainable, without saturation (and hence without large errors), under these conditions.

The ratio error must not exceed 10% when supporting a standard burden at 20 times nominal current and the error, also, may not exceed 10% at 1 to 20 times nominal ratio, while supporting a lesser burden.

The ANSI relaying accuracy strictly refers to current transformers with a nominal 5 A secondary, hence at 20 x nominal, the secondary current is 100 A. When this current flows through the standard burdens \( E_s = 100 \times Z_b \). The following values are obtained:

\[
\text{Standard Burden} = \begin{array}{cccccccc}
0.1 & 0.2 & 0.5 & 1.0 & 2.0 & 4.0 & 8.0 \\
\end{array}
\]

\( E_s = \begin{array}{cccccccc}
10 & 20 & 50 & 100 & 200 & 400 & 800 \\
\end{array} \) (from ANSI)

The characteristics of a transformer having low leakage reactance (e.g. toroidal transformers) may be accurately calculated within the range and the accuracy designation has the prefix “C”. To determine the accuracy of transformers having a high leakage reactance, they must be tested at various points and the prefix “T” is used in defining the accuracy.

Consequently, the accuracy of a low reactance transformer is given in one of the following ways: C10, C20, C50, C100, C200, C400 or C800. Likewise, a high reactance current transformer has one of the following ratings T10, T20... T800.

The phase angle of the secondary current, with respect to the primary, is rarely of importance in relaying applications.
A current transformer operates on the ampere-turn balance principle, i.e. \( N_p I_p = N_s I_c + N_s I_s \)

\[
\begin{align*}
H_1 & \quad H_2 = \text{Primary Terminal} \\
I_p & = \text{Primary Current} \\
N_p & \quad N_s = \text{Number of primary and secondary turns respectively} \\
K_h & = \text{Transformation Ratio} = \frac{\text{Rated Primary Amperes}}{\text{Rated Secondary Amperes}}
\end{align*}
\]

### Table 2: Current Transformer and Burden

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description of Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_p ) = Resistance of primary winding referred to the secondary</td>
<td>Very low in EI Xfmr.s. Highest in low ratio, wound types. In window and bar types so low it can be ignored.</td>
</tr>
<tr>
<td>( X_p ) = Reactance of primary winding referred to the secondary</td>
<td>Very low in all EI transformers. Toroidal transformers with fully distributed windings have negligible ( X_p ).</td>
</tr>
<tr>
<td>( I_{fe} ) = In-phase component of exciting current</td>
<td>The vectorial sum of ( I_{fe} ) and ( I_m ) is the exciting current. This is in a shunt circuit and is not transformed. This current represents the error except where ( R_p ) and ( X_p ) are a significant factor.</td>
</tr>
<tr>
<td>( I_e ) = Exciting current referred to the secondary</td>
<td></td>
</tr>
<tr>
<td>( I_m ) = Quadrature component of exciting current</td>
<td></td>
</tr>
<tr>
<td>( Z_e ) = Impedance of exciting branch</td>
<td></td>
</tr>
<tr>
<td>( R_s ) = Resistance of secondary winding in ohms</td>
<td>This is an important factor and must be known in order to calculate the accuracy. ( R_s ) is given in the EI catalog section A1.</td>
</tr>
<tr>
<td>( Z_s ) = Impedance of secondary winding in ohms</td>
<td>The vectorial sum of ( R_s ) and ( X_s ).</td>
</tr>
<tr>
<td>( X_s ) = Reactance of secondary winding in ohms</td>
<td>Negligible in all toroidal transformers where the secondary winding is fully distributed around the core. This includes Catalog Sections A2, A3, B2, B3 and C1 and most models in Section A1.</td>
</tr>
<tr>
<td>( X_1 ) &amp; ( X_2 ) = Secondary terminals</td>
<td></td>
</tr>
<tr>
<td>( E_s ) = Secondary Voltage</td>
<td>This value changes as ( I_p ) changes. In an ideal transformer this would be a linear relationship. In actual practice it is nearly linear until the core approaches saturation.</td>
</tr>
<tr>
<td>( I_s ) = Secondary current</td>
<td></td>
</tr>
<tr>
<td>( R_b ) = Resistance of burden in ohms</td>
<td>The burden of a current transformer is the total impedance of the device(s) connected to the secondary terminals including the impedance of the connecting leads.</td>
</tr>
<tr>
<td>( Z_b ) = Impedance of the burden (</td>
<td>R_b + jX_b</td>
</tr>
<tr>
<td>( X_b ) = Reactance of burden in ohms</td>
<td></td>
</tr>
<tr>
<td>( Z_c ) = Total secondary circuit impedance</td>
<td></td>
</tr>
</tbody>
</table>
NATIONAL ELECTRICAL
CODE
ARTICLE 430, PART C
Motor and Branch-Circuit
Overload Protection

430-31, General

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Part C specifies overload devices intended to protect motors, motor-control apparatus, and motor branch-circuit conductors against excessive heating due to motor overloads and failure to start.

Overload in electrical 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.

These provisions shall not be interpreted as requiring over-load protection where it might introduce additional or increased hazards, as in the case of fire pumps.


(FPN) See Example No. 8, Chapter 9 of the NFPA publication.

430-32, Continuous-Duty Motors

(a) More than 1 Horsepower. — Each continuous-duty motor rated more than 1 hp shall be protected against overload by one of the following means:

(1) A separate overload device that is responsive to motor current. — This device shall be selected to trip or rated at no more than the following percent of the motor nameplate full-load current rating.

Motors with a marked service factor not less than 1.15 — 125%
Motors with a marked temperature rise not over 40°C — 125%
All other motors — 115%

Modification of this value shall be permitted as provided in “430-34. Selection of Overload Relay” on page D-3.

For a multispeed motor, each winding connection shall be considered separately.

Where a separate motor overload device is so connected that it does not carry the total current designated on the motor nameplate, such as for wye-delta starting, the proper percentage of nameplate current applying to the selection or setting of the overload device shall be clearly designated on the equipment, or the manufacturer’s selection table shall take this into account.

1. A thermal protector integral with the motor, approved for use with the motor it protects on the basis that it will prevent dangerous overheating of the motor due to overload and failure to start. The ultimate trip current of a thermally protected motor shall not exceed the following percentage of motor full-load current given in Tables 430-148, 430-149, and 430-150.

Motor full-load current not exceeding 9 A — 170%
Motor full-load current 9.1 to and including 20 A — 156%
Motor full-load current greater than 20 A — 140%

1. Material in italic does not apply to this Bulletin. Refer to “Use of NEC” on page 2.
If the motor current-interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it shall be so arranged that the opening of the control circuit will result in interruption of current to the motor.

(3) A protective device integral with a motor that will protect the motor against damage due to failure to start shall be permitted if the motor is part of an approved assembly that does not normally subject the motor to overloads.

(4) For motors larger than 1500 horsepower, a protective device having embedded temperature detectors that cause current to the motor to be interrupted when the motor attains a temperature rise greater than marked on the nameplate in an ambient of 40°C.

(b) One Horsepower or less, Nonautomatically Started.

(1) Each continuous-duty motor rated at 1hp or less that is not permanently installed, is nonautomatically started and is within sight from the controller location shall be permitted to be protected against overload by the branch circuit, short circuit and ground-fault protective device. This branch circuit protective device can not be larger than that specified in Part D of Article 430.

Exception: Any such motor shall be permitted on a nominal 120 V branch circuit protected at not over 20 A.

(2) Any such motor that is not in sight from the controller location shall be protected as specified in Section 430-32, Part C. Any motor rated at 1 hp or less that is permanently installed shall be protected in accordance with Section 430-32(c).

(c) One Horsepower or Less, Automatically Started. — Any motor of 1 hp or less that is started automatically shall be protected against overload by one of the following means:

(1) A separate overload device that is responsive to motor current. — This device shall be selected to trip or rated at no more than the following percentage of the motor nameplate full-load current rating.

Motors with a marked service factor not less than 1.15 — 125%
Motors with a marked temperature rise not over 40°C — 125%
All other motors — 115%

For a multispeed motor, each winding connection shall be considered separately. Modification of this value shall be permitted as provided in Section 430-34.

(2) A thermal protector integral with the motor, approved for use with the motor which it protects on the basis that it will prevent dangerous overheating of the motor due to overload and failure to start. Where the motor current interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it shall be so arranged that the opening of the control circuit will result in interruption of current to the motor.

(3) A protective device integral with a motor that will protect against damage due to failure to start shall be permitted: (1) if the motor is part of an approved assembly that does not normally subject the motor to overloads, or (2) if the assembly is also equipped with other safety controls (such as the safety combustion controls on a domestic oil burner) that protect the motor against damage due to failure to start.
Where the assembly has safety controls that protect the motor, it shall be so indicated on the nameplate of the assembly where it will be visible after installation.

(4) In case the impedance of the motor windings is sufficient to prevent overheating due to failure to start, the motor shall be permitted to be protected as specified in (b)(1) for manually started motors if the motor is part of an approved assembly in which the motor will limit itself so that it will not be dangerously overheated.

(FPN): Many alternating current motors of less than 1/20 hp, such as clock motors, series motors, etc. and also some larger motors such as torque motors come within this classification. It does not include split-phase motors having automatic switches that disconnect the starting windings.

(d) Wound-Rotor Secondaries. — The secondary circuits of wound-rotor alternating current motors, including conductors, controllers, resistors, etc., shall be permitted to be protected against overload by the motor-overload device.

430-33. Intermittent and Similar Duty

A motor used for a condition of service that is inherently short-time, intermittent, periodic or varying duty, as illustrated by Table 430-22(a) — Exception, shall be permitted to be protected against overload by the branch circuit, short-circuit and ground-fault protective device, provided the protective device rating or setting does not exceed that specified in Table 430-152.

Any motor application shall be considered to be for continuous duty unless the nature of the apparatus it drives is such that the motor cannot operate continuously with load under any condition of use.

430-34. Selection of Overload Relay

Where the overload relay selected in accordance with Section 430-32(a)(1) and (c) (i) is not sufficient to start the motor or to carry the load, the next higher size overload relay shall be permitted to be used provided the trip current of the overload relay does not exceed the following percentage of motor full-load current rating.

- Motors with marked service factor not less than 1.15 — 140%
- Motors with a marked temperature rise not over 40°C — 140%
- All other motors — 130%

If not shunted during the starting period of the motor as provided in Section 430-35, the overload device shall have sufficient time delay to permit the motor to start and accelerate its load.

430-35. Shunting During Starting Period

(a) Nonautomatically Started — For a nonautomatically started motor the overload protection shall be permitted to be shunted or cut out of the circuit during the starting period of the motor if the device by which the overload protection is shunted or cut out cannot be left in the starting position and if fuses or inverse time circuit breakers rated or set at not over 400% of the full-load current of the motor are so located in the circuit as to be operative during the starting period of the motor.

(b) Automatically Started — The motor overload protection shall not be shunted or cut out during the starting period if the motor is automatically started.
Exception: The motor overload protection shall be permitted to be shunted or cut out during the starting period on an automatically started motor where:

1. The motor starting period exceeds the time delay of available motor overload protective devices.
2. Listed means are provided to:
   a. Sense motor rotation and to automatically prevent the shunting or cutout in the event that the motor fails to start
   b. Limit the time of overload protection shunting or cutout to less than the locked rotor time rating of the protected motor
   c. Provide for shutdown and manual restart if motor running condition is not reached.

430-36. Fuses

In Which Conductor — Where fuses are used for motor overload protection, a fuse shall be inserted in each ungrounded conductor.

A fuse shall also be inserted in the grounded conductor if the supply system is 3-wire, 3-phase AC with one conductor grounded.

430.37. Devices Other than Fuses

In Which Conductor — Where devices other than fuses are used for motor overload protection, Table 5, (430-37) shall govern the minimum allowable number and location of overload units such as trip coils, relays or thermal cutouts.

### Table 1 "430-37" OVERLOAD UNITS

<table>
<thead>
<tr>
<th>Kind of Motor</th>
<th>Supply System</th>
<th>Number and Location of Overload Units, such as Trip Coils, Relays, or Thermal Cutouts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-phase AC or DC</td>
<td>2-wire, 1-phase AC or DC ungrounded</td>
<td>1 in either conductor</td>
</tr>
<tr>
<td>1-phase AC or DC</td>
<td>2-wire, 1 phase AC or DC, one conductor grounded</td>
<td>1 in ungrounded conductor</td>
</tr>
<tr>
<td>1-phase AC or DC</td>
<td>3-wire, 1-phase AC or DC, grounded-neutral</td>
<td>1 in either ungrounded conductor</td>
</tr>
<tr>
<td>2-phase AC</td>
<td>3-wire, 2-phase AC, ungrounded</td>
<td>2, one in each phase</td>
</tr>
<tr>
<td>2-phase AC</td>
<td>3-wire, 2-phase AC, one conductor grounded</td>
<td>2 in ungrounded conductor</td>
</tr>
<tr>
<td>2-phase AC</td>
<td>4-wire, 2-phase AC, grounded or ungrounded</td>
<td>2, one per phase in ungrounded conductors</td>
</tr>
<tr>
<td>2-phase AC</td>
<td>5-wire, 2-phase AC, grounded neutral or ungrounded</td>
<td>2, one per phase in any ungrounded phase wire</td>
</tr>
<tr>
<td>3-phase AC</td>
<td>Any 3-phase</td>
<td>3, one in each phase*</td>
</tr>
</tbody>
</table>

* Exception: Where protected by other approved means.
430-38. Number of Conductor Opened by Overload Device

Motor overload devices other than fuses, thermal cutouts, or thermal protectors shall simultaneously open a sufficient number of ungrounded conductors to interrupt current flow to the motor.

430-39. Motor Controller as Overload Protection

A motor controller shall also be permitted to serve as an overload device if the number of overload units complies with Table 430-37 on previous page and if these units are operative in both the starting and running position in the case of a direct-current motor and in the running position in the case of an alternating current motor.

430-40. Thermal Cutouts and Overload Relays

Thermal cutouts, overload relays, and other devices for motor overload protection that are not capable of opening short circuits shall be protected by fuses or circuit breakers with ratings or settings in accordance with Section 430-52.

Exception No. 1: Where approved for group installation and marked to indicate the maximum size of fuse or inverse time circuit breaker by which they must be protected.

Exception No. 2: The fuse or circuit breakers ampere rating shall be permitted to be marked on the nameplate of approved equipment in which the thermal cutout or overload relay is used.

(FPN): For instantaneous trip circuit breakers or motor short-circuit protectors, see Section 430-52.

430-42. Motors on General-Purpose Branch Circuits

Overload protection for motors used on general-purpose branch circuits as permitted in Article 210 shall be provided as specified in (a), (b), (c), and (d) below.

(a) Not Over 1 Horsepower — One or more motors without individual overload protection shall be permitted to be connected to a general-purpose branch circuit only where the installation complies with the limiting conditions specified in Section 430-53(a) (1) and (a) (2).

(b) Over 1 Horsepower — Motors of larger ratings than specified in Section 430-53(a) shall be permitted to be connected to general-purpose branch circuits only where each motor is protected by overload protection selected to protect the motor as specified in Section 430-32. Both the controller and the motor overload device shall be approved for group installation with the short circuit and ground fault protective device selected in accordance with Section 430-53.

(c) Cord- and Plug- Connected — Where a motor is connected to a branch circuit by means of an attachment plug and receptacle, with the individual overload protection omitted as provided in (a) above, the rating of the attachment plug and receptacle shall not exceed 15 A at 125 V or 10 A at 250 V. Where individual overload protection is required as provided in (b) above for a motor or motor-operated appliance that is attached to the branch circuit through an attachment plug and receptacle, the overload device shall be an integral part of the motor or of the appliance. The rating of the attachment plug and receptacle shall determine the rating of the circuit to which the motor may be connected, as provided in Article 210.

(d) Time Delay — The branch circuit, short circuit and ground fault protective device protecting a circuit to which a motor or motor-operated appliance is connected shall have sufficient time delay to permit the motor to start and accelerate its load.
430-43. Automatic Restarting

A motor overload device that can restart a motor automatically after overload tripping shall not be installed unless approved for use with the motor it protects. A motor that can restart automatically after shutdown shall not be installed if its automatic restarting can result in injury to persons.

430-44. Orderly Shutdown

If immediate automatic shutdown of a motor by a motor overload protective device(s) would introduce additional or increased hazard(s) to a person(s) and continued motor operation is necessary for safe shutdown of equipment or process, a motor overload sensing device(s) conforming with the provisions of Part C of this article shall be permitted to be connected to a supervised alarm instead of causing immediate interruption of the motor circuit, so that corrective action or an orderly shutdown can be initiated.
NEMA - PART ICS 2-222

Overload Relays

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Part ICS 2-222 covers overload relays which may be separate or combined with contactors used in industrial control applications.

Part ICS 2-125 applies to this part unless otherwise specified. The definitions and standards of NEMA Standards Publication No. ICS 1 also apply to this part.

2-222.01 Definitions

Ambient Temperature Compensated (Thermal Overload Relay)

Ambient temperature compensated is a qualifying term applied to a thermal overload relay to indicate that its ultimate current remains essentially unchanged over a designated range of ambient temperatures.

Ambient Temperature Sensitivity (Overload Relay)

The ambient temperature sensitivity of an overload relay is an expression of performance which defines the variations in its ultimate current over a designated range of ambient temperature.

Current Element (Overload Relay)

A current element is the part of an overload relay that determines the value of current which causes the relay to function (trip). Current elements of thermal overload relays are referred to as heater elements.

Current Rating (Overload Relay)

The current rating of an overload relay is the minimum value of continuously applied current which is expected to cause all like relays to function (trip) under designated conditions. This value, for an individual relay, may be equal to or exceed its ultimate current under these conditions.

Heater Element (Thermal Overload Relay)

A heater element is the part of a thermal overload relay that is intended to produce heat when conducting current. Heater elements are sometimes referred to as heaters, thermal units, current elements, or heating elements.

Limit of Self Protection (Overload Relay)

The limit of self protection of an overload relay is the maximum current value that the relay can respond to without sustaining damage that will impair its function.

Overload Relay

An overload relay is an over-current relay which functions at a predetermined value of over-current to: provide a signal or to cause disconnection of the load from the power supply, or both.

An overload relay is intended to protect the motor branch-circuit conductors, the motor control apparatus and the motor(s) against over current. It does not necessarily protect itself.

Thermal Overload Relay

A thermal overload relay is an overload relay that functions (trips) by means of a thermally responsive system.
Time-Current Characteristics (Overload Relay)

The time-current characteristic of an overload relay is an expression of performance which defines its operating time at various multiples of its current rating.

Trip Free (Overload Relay)

Trip free is a qualifying term applied to an overload relay to indicate that its function is independent of and non-avoidable by the manual reset means.

Ultimate Current (Overload Relay)

The ultimate current of an overload relay is the minimum value of continuously applied current that will cause the relay to function (trip).

General Information and Features

ICS 2-222.05 Time-Current Characteristics

The time-current characteristics of an overload relay at 40°C are preferably expressed as the maximum operating times in seconds under the designated conditions associated with the current rating, at current values corresponding to multiples of the current rating. Curves such as minimum operating times may also be shown. All curves shall be identified. The time-current curve shall not be shown beyond the limit of self protection.

The preferred method for displaying these performance curves shall be time in seconds as ordinate and multiples of current rating as abscissa, plotted on a full logarithmic coordinate format as shown in the example in Figure 2-222-1 on the following page.

ICS 2-222.06 Overload Relay Class Designation

When an overload relay is classified by time-current characteristics, it shall be designated by a class number indicating the maximum time in seconds at which it will function (trip) when carrying a current equal to 600% of its current rating. A Class 20 relay will function (trip) in 20 seconds or less, and a Class 30 relay will function in 30 seconds or less.

A Class 10 relay will function (trip) in 10 seconds or less.
A Class 15 relay will function (trip) in 15 seconds or less.

ICS 2-222.07 Limit of Self Protection

The limit of self protection of an overload relay at 40°C shall be expressed by the assigned whole-number multiple of its current rating.

An overload relay should not be subjected to these current levels frequently.

ICS 2-222.08 Ambient Temperature Sensitivity

The ambient temperature sensitivity of an overload relay shall be expressed as the percentage change in ultimate current per 10°C, between 40°C and a specified lower or higher ambient temperature limit.

Specific values at ambient temperatures below or above the reference temperature of 40°C are derived from the ambient temperature correction curve of the overload relay.

The range of ambient temperatures qualifying the expression may be outside the application limits for continuous duty operation and are only intended to provide the information necessary to predict the performance that can be expected under intermittent or abnormal operating conditions.

Due to the close relationship which exists between the ultimate current at 40°C and the current rating, the ambient temperature sensitivity factor may be applied to the current rating to determine the approximate ultimate current at other ambient temperatures.
ICS 2-222.09 Resetting

Overload relays shall be capable of being reset. Resetting may be accomplished by an integral automatic function or by manual operation. Overload relays shall be of the trip-free type.

Ratings

ICS 2-222.20 Current Rating

The current rating of an overload relay shall be expressed in amperes at an ambient temperature of 40°C.

Figure 1 2-222-1 Overload Relay Time-Current Characteristics - Example
An overload relay may have different current ratings when used as an open type device, or when mounted in an enclosure, or when used in combination with other equipment within a similar enclosure. The ambient temperature of 40°C for current rating assignment of enclosed devices shall refer to the measured temperature of the air which surrounds the enclosure.

**ICS 2-222 21 Control-Circuit Contact Ratings**

The rating of the contacts of overload relays which operate in a control circuit shall be in accordance with Table 2-125-1 for the alternating-current contacts and/or Table 2-125-2 for direct-current contacts.

**Design Tests & Performance**

**ICS 2-222 40**

**.01 Test Conditions**

Verification Test for Current Rating and Time-Current Characteristics —

A. Test shall be conducted in an ambient temperature of 40°C ± 1°C. The overload relay shall be allowed to reach thermal equilibrium with the specified ambient temperature before proceeding with each test.

B. Tests shall be conducted in a manner which simulates the intended service conditions: this includes the designated conditions for the assignment of the current rating, that is, whether the relay is a separate device or a part of a motor controller and whether it is open or enclosed.

C. Relays designated as “ambient temperature compensated” shall be tested in ambient temperatures of 25°C and 50°C, as well as 40°C.

D. The power source shall be single-phase 60 Hz with means for maintaining a sine wave current of an essentially constant rms value.

E. Current measurements shall be accurate within 1% of the measured value.

**.02 Test Connections**

A. Conductors for Relays Marked for Full-Load Current — Conductors for the external wiring to the overload relay (or associated equipment), considered to be user connections, shall have a minimum length of 4 feet per terminal. The wire shall be of the smallest size having an ampacity of at least 125% of the maximum motor full-load current listing for the overload relay. The wire shall be selected from the 60°C column of Tables in Article 310 of the National Electrical Code for motor full-load currents of 100 A or less and from the 75°C column for motor full-load currents greater than 100 A, unless otherwise specified.

B. Conductors for Relays Marked with Current Rating — Conductors for the external wiring to the overload relay (or associated equipment) considered to be user connections, shall have a minimum length of 4 feet per terminal. The wire shall be the smallest size having an ampacity at least equal to the current rating of the relay. The wire shall be selected from the 60°C column of Tables in Article 310 of the National Electrical Code for current ratings of 125 A or less and from the 75°C column for current ratings greater than 125 A, unless otherwise specified.

C. Schematic Diagram — The wiring shall be in accordance with the typical schematic diagram shown in Figure 2-222-2 on next page.

D. Control Circuit — To avoid possible damage to the relay, it is recommended that the test circuit be arranged so as to assure the disconnection of the current source when the overload relay functions (trips). (This sub-paragraph is approved as Authorized Engineering Information.)
.03 Test Procedure

A. A single-pole relay with one current element shall be tested with that element at 100, 200 and 600% of the relay’s current rating.

![Diagram of Test Connections](image)

**Figure 2  2-222-2 Schematic Diagram of Test Connections**

B. Two single-pole relays, each with its own individual trip mechanism, or a two-pole relay with two current elements and a single trip mechanism intended for polyphase circuits, shall be tested at:

1. 100% of the relay’s current rating with two current elements connected.
2. 200% of the relay’s current rating with one current element connected.
3. 600% of the relay’s current rating with one current element connected.

C. Three single-pole relays, each with its own individual trip mechanism, or a three-pole relay with three current elements and a single trip mechanism, intended for three-phase circuits, shall be tested at:

1. 100% of the relay’s current rating with three current elements connected.
2. 200% of the relay’s current setting with two current elements connected.
3. 600% of the relay’s current rating with two current elements connected.

D. An adjustable relay with interchangeable current elements and means for adjustment in percentage of its current rating shall be set at the 100% mark on the adjustment scale and subjected to the test described in (a), (b) or (c) depending on the intended application and number of relays involved. In addition, an adjustable relay shall be tested at its high and low adjustment points, such as the 120 and 80% marks at 200% of its current rating to determine that the time of operation will be longer and shorter, respectively, than the operating time when the relay is subjected to the same test with the adjustment set at the 100% mark on the adjustment scale.

E. An adjustable relay arranged to cover several current ratings (trip currents) shall be tested at 100, 200 and 600% at its minimum, mid-point and maximum current ratings.

.04 Performance

A. When tested at 100% of its current rating, the relay shall function (trip) ultimately.

B. When tested at 200% of its current rating, the relay shall function (trip) in not more than 8 minutes.

C. When tested at 600% of its current rating, the relay shall function (trip) in not more than 10 seconds for a Class 10 relay, 20 seconds for a Class 20 relay and 30 seconds for a Class 30 relay.
ICS 2-222.41
01 Test Condition
Verification Test for Limit of Self Protection — Test conditions shall be the same as those specified in ICS 2-222.40.01 except that ambient temperature compensated relays may be tested at 40°C only.

02 Test Procedure
A single test shall be conducted for the limit of self protection assigned to an overload relay.

The magnitude of the test current (self-protection limit current) is determined by multiplying the current rating of the overload relay by the multiplier assigned as its limit of self protection.

03 Test Connections
Test connections shall be the same as those specified in ICS 2-222.40.02.

The test circuit shall be arranged to assure that tripping of the load relay will immediately cause the relay to be disconnected from the current source.

04 Performance
When tested at its self-protection limit current, an overload relay shall function (trip) without sustaining damage that will impair its performance. An overload relay which has been subjected to this test shall be considered to conform to the requirements of this standard if it can subsequently be shown that it meets the requirements of the design test for current rating described in ICS 2-222.40.

ICS 2-222.42
01 Test Conditions
Verification Test for Ambient Temperature Sensitivity — Test conditions shall be the same as those specified in ICS 2-222.40.01, except that tests shall be conducted at 40°C and other ambient temperatures.

02 Test Connections
Test conditions shall be the same as those specified in ICS 2-222.40.02.

03 Test Procedure
The ultimate currents shall be determined at the ambient temperatures under consideration.

04 Performance
When the ultimate currents are determined in this manner, the ambient temperature sensitivity of the overload relay shall not exceed the designated value.

ICS 2-222.43
Short-Time Capability — A new overload relay shall be capable of meeting the short-time capability requirements for controllers shown in Part ICS 2-321.

ICS 2-222.44
Control-Circuit Contacts — The contacts of overload relays which operate in a control circuit shall perform in accordance with Part ICS 2-125.
Identification of Thermal Overload Relay Using Interchangeable Heater Element—
Interchangeable heater elements shall bear identification which is visible after the
apparatus is installed and wired. Information relating the identification to the com-
plete device shall be furnished and shall include:

A. The current rating or the assigned motor full-load current or range of currents.

B. Instructions for converting motor full-load current to the relay current rating
when the information is provided in terms of motor full-load current.

C. Recommendations for high level fault-current protection where such protec-
tion is not included with the equipment and where the requirements are more
restrictive than those of the National Electrical Code.

D. Overload relay class if other than Class 20.

E. Range of adjustment if adjustment is provided.

Identification of Overload Relays Using Fixed or Non-interchangeable Current El-
ements — These relays shall meet all of the requirements of ICS 2-222.60 except
that the identification may be marked on the overload relay.

General Guide — The current rating and the performance characteristics provide
useful information for application purposes. This information makes it possible to
predict the performance of the overload relay over a wide range of operating over-
loads and ambient temperatures.

Current Rating and Time-Current Characteristics — The current rating and time-
current characteristics of an overload relay should be coordinated with the thermal
capabilities, at an ambient temperature of 40°C of the components which it is in-
tended to protect in accordance with the National Electrical Code.

Limit of Self Protection — The current corresponding to the limit of self protection
of an overload relay should be greater than the locked-rotor current of the motor
which it is intended to protect.

Ambient Temperature Sensitivity — The ambient temperature sensitivity provides
the means to modify the selection of overload relays to accommodate a difference
in ambient temperatures between the overload relay and motor that may exist on
some applications.

Cautions on the Use of Automatic Reset — Automatic reset of overload relays is a con-
vvenience in many installations and a necessity in some. However, the use of automatic
reset should be considered only if: (a) the motor circuit will remain open when the over-
load relay contacts reclose, or (b) automatic restarting will not create a hazard.

An automatic-reset overload relay does not necessarily provide protection against over-
heating of a motor and its branch-circuit components from a persisting overload condi-
tion that causes repetitive tripping and resetting of the relay. It may be necessary to
provide means for delaying motor restarting or limiting the number of trip-reset cycles.
ICS 2-222.85
Polyphase Motors Under Single-Phase Operating Conditions — Overload protection which is provided by over current units having current elements in each phase of a polyphase motor and which provides protection under polyphase operating overloads may not provide the same degree of protection when the same motor is operating under single-phase conditions.

ICS 2-222.86
.01 General
Coordination with High Level Fault-Current Protection — Proper coordination is necessary between the overload relay and the branch circuit, high-level-fault-current protective device to meet specified damage levels.

.02 High Level Fault-Current Protection
An overload relay should be protected against high level fault-currents by a device of a type and rating in accordance with ICS 2-222.60(c).

.03 Limit of Self Protection
At the current value corresponding to the self-protection limit of the overload relay, the fault-clearing time of the branch circuit, high level fault-current protective device should not exceed the operating time of the overload relay. When this comparison is based on mean values, a margin for safety should be allowed to account for possible variations in operating times.

.04 Operating Overloads
At operating overloads it is desirable for the overload relay to function (trip) before the branch circuit, high level fault-current protective device can open the circuit. It may not be possible to obtain this degree of coordination with all types of branch-circuit over-current devices.

ICS 2-222.87
Application with Current Transformers — The current rating and the performance characteristics of an interconnected current transformer and overload relay combination will not necessarily be the same as those of the overload relay alone and shall be determined in the primary circuit of the current transformer.

ICS 2-222.88
Control-Circuit Contact Rating — The control-circuit contact rating of an overload relay should be related to the performance characteristics of the component(s) used in the particular control-circuit arrangement.
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25.0 Overload-Relay Calibration Test
General
Calibration

Paragraph 25.1 — An overload relay, or industrial control equipment incorporating an overload relay shall comply with the requirements in paragraphs 25.2-25.10.

Paragraph 25.2 — When tested at an ambient temperature of 40°C (104°F), an overload relay shall operate:
A. Ultimately at 100% of the current-element rating (tripping current);
B. Within 8 minutes at 200% of the current-element rating; and
C. Within 20 seconds at 600% of the current-element rating, or when marked in accordance with paragraph 51.19 not exceeding the time in seconds at 600% of the current-element rating specified in the marking.

Paragraph 25.3 — An overload relay mounted in a starter or other enclosure is to be tested with the enclosure in the 40°C (104°F) ambient.

Paragraph 25.4 — An adjustable overload relay is to be set at the 100% mark on the calibration scale and subjected to the tests specified in paragraph 25.2. The relay is also to be tested carrying a current of 200% of the current-element rating, at the high and low points of the operating range — such as 120 and 80% of the element rating — to determine that the times of operation will be consistently longer and shorter, respectively, than the operating time at the 100% setting.

Paragraph 25.5 — If the adjustment of an adjustable relay is arranged to cover several ampere ratings — tripping currents — the relay shall perform in accordance with the requirements in paragraph 25.2 for each separate rating.

Paragraph 25.6 — An ambient-compensated overload relay or a starter provided with an ambient-compensated overload relay shall perform acceptably when subjected to the tests specified in paragraph 25.2 in ambient temperatures of 25, 40, and 50°C (77, 104, and 122°F).

Paragraph 25.7 — The overload relay or a starter provided with an overload relay is to be tested with 4 feet (1.22 m) of wire attached to each field-wiring terminal. The wire is to be the smallest size having an ampacity of at least 125% of the maximum full load motor current rating of the current element. The wire size is to be determined in accordance with Table 23.3 based on the wire temperature rating marked on the equipment. The type of insulation is not specified. If the terminal will not receive that size of wire, or if the device is marked in accordance with paragraph 17.9 to limit the size of wires, the maximum allowable wire size is to be used.
Paragraph 25.8 — The overload relay or relays in a starter employing two current elements for polyphase use are to be calibrated with only one current element in the circuit during 600 and 200% tests to cover single-phasing and with two current elements in the circuit during 100% tests. The relay or relays in a polyphase starter employing three current elements are to be calibrated with two current elements in the circuit during 600 and 200% tests and with three current elements in the circuit during 100% tests.

Paragraph 25.1-25.8 from page 34 dated December 23, 1983.

Paragraph 25.9 — The overload relay in a starter employing one current element for single-phase use is to be calibrated with one current element in the circuit during all tests. The overload relay or relays in a starter employing two current elements for single-phase use are to be calibrated with two current elements in the circuit during all tests.

Paragraph 25.10 — A separate overload relay—one not furnished as part of a starter—having two or more current elements is to be calibrated with one element in the circuit during all tests unless provided with marking to indicate other connection.

Paragraph 25.9 & 25.10 from page 35 dated December 22, 1983.

Paragraph 51.19 — With reference to item C of paragraph 25.2, an overload relay or the controller with which an overload relay is used, shall be marked to indicate the relay class designation in accordance with Table 1 (51.1).

Table 1 51.1 Marking Designation for Tripping Time at 600% of Current Element Rating

<table>
<thead>
<tr>
<th>Class Designation ¹</th>
<th>Tripping Time, Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 10</td>
<td>10</td>
</tr>
<tr>
<td>Class 20 ²</td>
<td>20</td>
</tr>
<tr>
<td>Class 30</td>
<td>30</td>
</tr>
</tbody>
</table>

¹ Class designations in excess of 30 may be used, with the tripping time in seconds equal to the numerical class marking.

² Marking optional

Paragraph 51.20 — Marking of overload relays required by paragraph 51.19 may be provided on the current element table that is provided on or with the product.

Paragraph 51.19 & 51.20 from page 75 dated December 23, 1983.

Paragraph 51.31 — An overload relay or industrial control equipment incorporating an overload relay shall be marked with the word “WARNING” and the following or the equivalent “To provide continued protection against a risk of fire and electric shock, the complete overload relay must be replaced if burnout of the current element occurs.”

Paragraph 51.32 — The ampere rating—tripping current—of an overload relay shall be marked on the relay if a noninterchangeable element is employed.
Exception: The tripping current may be marked on a table furnished with the relay if (1) the relay is marked with a code designation, and (2) the tripping current is specified for the code designation of the relay.

Paragraph 51.33 — The outside ambient temperature — 40°C (104°F) on which the rating of an overload relay is based shall be marked along with the tripping current.

Exception: An ambient-compensated overload relay need not be so marked.

Paragraph 51.34 — For an overload relay designed to accommodate current elements of the interchangeable type, each element shall be marked with the ampere rating—tripping current — of the relay, or shall bear a code marking as described in paragraphs 51.35-51.37.

Paragraph 51.35 — If code markings are employed on the current elements, the complete device shall be furnished with a table that shall include a column giving full load motor-running currents, with an explanation of the protection afforded, such as 115 or 125%; a column giving the corresponding code markings that appear on the elements; and a column giving ampere ratings—tripping currents—for the complete device corresponding to the various elements available, or an explanation as to how the tripping currents may be determined.

Paragraph 51.31—51.35 from page 76 dated December 22, 1983.

Paragraph 51.36 — The table referred to in the exception to paragraph 51.32 and in paragraph 51.35 shall include a current element rated for use at the maximum marked rating of the associated controller. If an ampere rating is provided as a part of the marking on the controller, the over current relay rating shall be equal to or greater than the ampere ratings.

Paragraph 51.37 — The table referred to in the exception to paragraph 51.32 and in paragraph 51.35 shall not include a current element or overload relay that is not intended to be used with the associated controller.

**Exception No. 1:** A table may cover more than one size of starter or may cover the use of one, two or three over current relays or heater elements when that table is clearly marked to indicate the limits of its use.

**Exception No. 2:** A resistance- or autotransformer-type controller, a combination controller, or a similar device intended for limited horsepower rating may be provided with a table covering the elements furnished as if the limiting feature were not present.

Paragraph 51.38 — A combination manual-automatic-reset overload relay shall be provided with marking to indicate the setting of the relay in either the manual or automatic position.

Paragraph 51.39 — Industrial control equipment employing an automatically reset overload relay and a wiring diagram indicating two-wire control shall be marked to indicate that a motor connected to the circuit may start automatically when the relay is in the automatically reset position.

Paragraph 51.36—51.39 from page 76A dated December 23, 1983.

Paragraph 51.40 — The table referred to in paragraphs 51.32-51.38 shall be permanently secured to enclosed equipment and shall be furnished with open types.

Paragraph 51.40 from page 77 dated December 23, 1983.
Test and Performance-AC

Variations from Rated Voltage and Rated Frequency —

A. RUNNING — Alternating-current motors shall operate successfully under running conditions at rated load with a variation in the voltage or the frequency up to the following:

1. Plus or minus 10% of rated voltage, with rated frequency for induction motors.
2. Plus or minus 6% of rated voltage, with rated frequency for universal motors.
3. Plus or minus 5% of rated frequency, with rated voltage.
4. A combined variation in voltage and frequency of 10% (sum of absolute values) of the rated values, provided the frequency variation does not exceed plus or minus 5% of rated frequency and the voltage variation of universal motors (except fan motors) does not exceed plus or minus 6% of rated voltage.

Performance within these voltage and frequency variations will not necessarily be in accordance with the standards established for operating at rated voltage and frequency.

B. STARTING — Integral horsepower motors shall start and accelerate to running speed, a load which has a torque characteristic and an inertia value not exceeding that listed in MG1-12.50 with the voltage and frequency variations specified in paragraph A.

The limiting values of voltage and frequency under which a motor will successfully start and accelerate to running speed depend on the margin between the speed-torque curve of the motor at rated voltage, frequency and the speed-torque curve of the load under starting conditions. Since the torque developed by the motor at any speed is approximately proportional to the square of the voltage and inversely proportional to the square of the frequency, it is generally desirable to determine what voltage and frequency variations will actually occur at each installation, taking into account any voltage drop resulting from the starting current drawn by the motor. This information and the torque requirements of the driven machine define the motor-speed-torque curve, at rated voltage and frequency which is adequate for the application.

Voltage Unbalance — Alternating-current polyphase motors shall operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1%. Performance will not necessarily be the same as when the motor is operating with a balanced voltage at the motor terminals. (See MG 1-14.34.)

Variation from Rated Speed — The variation from the nameplate or published data speed of alternating current, single-phase and polyphase, integral horsepower motors shall not exceed 20% of the difference between synchronous speed and rated speed when measured at rated voltage, frequency and load and with an ambient temperature of 25°C.
MG 1-12.50

A. Squirrel-cage induction motors having horsepower ratings given in paragraph D of MG 1-10.32 with performance characteristics in accordance with Part 12* shall be capable of accelerating without injurious heating load Wk\(^2\) referred to the motor shaft, equal to or less than the values listed in the following table under these conditions:

1. Applied voltage and frequency in accordance with MG 1-12.43.
2. During the accelerating period, the connected load torque is equal to or less than a torque which varies as the square of the speed and is equal to 100% of rated load torque at rated speed.
3. Two starts in succession (coasting to rest between starts) with the motor initially at the ambient temperature or one start with the motor initially at a temperature not exceeding its rated load operating temperature.

B. If the starting conditions are other than those stated in paragraph A, the motor manufacturer should be consulted.

C. When additional starts are required, it is recommended that none be made until all conditions affecting operation have been thoroughly investigated and the apparatus examined for evidence of excessive heating. It should be recognized that the number of starts should be kept to a minimum since the life of the motor is affected by the number of start.

Table 1  Torque Characteristics and Inertia Value

<table>
<thead>
<tr>
<th>Speed, Rpm</th>
<th>3600</th>
<th>1800</th>
<th>1200</th>
<th>900</th>
<th>720</th>
<th>600</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<tr>
<td>1</td>
<td>5.8</td>
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<td>31</td>
<td>53</td>
<td>82</td>
<td>118</td>
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<tr>
<td>1 1/2</td>
<td>1.8</td>
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<td>242</td>
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<tr>
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<td>8.3</td>
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<td>104</td>
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<td>4508</td>
<td>7750</td>
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</tr>
</tbody>
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*Part 12 is a reference to a specific section in the document.
Table 1  Torque Characteristics and Inertia Value (Continued)

<table>
<thead>
<tr>
<th>Hp</th>
<th>3600</th>
<th>1800</th>
<th>1200</th>
<th>900</th>
<th>720</th>
<th>600</th>
<th>514</th>
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</thead>
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<td></td>
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<td>1880</td>
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<td>...</td>
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</tbody>
</table>

Application Data

MG 1-14.30

Effects of Variation of Voltage and Frequency on the Performance of Induction Motors —

A. Induction motors are at times operated on circuits of voltage or frequency other than those for which the motors are rated. Under such conditions, the performance of the motor will vary from the rating. The following is a brief statement of some operating results caused by small variations of voltage and frequency and is indicative of the general character of changes produced by such variation in operating conditions.

B. With a 10% increase or decrease in voltage from that given on the nameplate, the heating at rated horsepower load may increase. Such operation for extended periods of time may accelerate the deterioration of the insulation system.

C. In a motor of normal characteristics at full rated horsepower load, a 10% increase of voltage above that given on the nameplate would usually result in a decided lowering in power factor. A 10% decrease of voltage below that given on the nameplate would usually given an increase in power factor.

D. The locked rotor and breakdown torque will be proportional to the square of the voltage applied.

E. An increase of 10% in voltage will result in a decrease of slip of about 17%, while a reduction of 10% will increase the slip about 21%. Thus, if the slip at rated voltage were 5%, it would be increased to 6.05% if the voltage were reduced 10%.

F. A frequency higher than the rated frequency usually improves the power factor but decreases locked-rotor torque and increases the speed, friction and windage loss. At a frequency lower than the rated frequency, the speed is decreased, locked-rotor torque is increased and power factor is decreased. For certain kinds of motor load, such as in textile mills, close frequency regulation is essential.

G. If variations in both voltage and frequency occur simultaneously, the effects will be superimposed. Thus, if the voltage is high and the frequency low, the locked-rotor torque will be very greatly increased, but the power factor will be decreased and the temperature rise increased with normal load.

H. The foregoing facts apply particularly to general-purpose motors. They may not always be true in connection will special-purpose motors built for a particular purpose, or as applied to very small motors.
Effects of Voltages over 600 V on the Performance of Low Voltage Motors — Polyphase motors are regularly built for voltage ratings of 575 V or less (see MG 1-10.30) and are expected to operate satisfactorily with a voltage variation of ± 10%. This means that motors of this insulation level may be successfully applied up to an operating voltage of 635 V.

Based on motor manufacturers’ high-potential tests and performance in the field, it has been found that where utilization voltages exceed 635 V, the safety factor of the insulation has been reduced to a level inconsistent with good engineering procedure.

In view of the foregoing, motors of this insulation level should not be applied to power systems either with or without grounded neutral where the utilization voltage exceeds 635 V, regardless of the motor connection employed.

However, there are some definite-purpose motors that are intended for operation on a grounded 830 V system. Such motors are suitable for 460 V operation when delta is connected and for 796 V operation when wye is connected with the neutral of the system connection is solidly grounded.

Operation of General-purpose Alternating-current Polyphase, 2, 4, 6 & 8-pole, 60 Hz & Integral-horsepower Induction Motors Operated on 50 Hz — While general-purpose alternating current polyphase, 2, 4, 6 and 8-pole, 60 Hz integral-horsepower induction motors are not designed to operate at their 60 Hz ratings on 50 Hz circuits, they are capable of being operated satisfactorily on 50 Hz circuits if their voltage and horsepower ratings are appropriately reduced. When such 60 Hz motors are operated on 50 Hz circuits, the applied voltage at 50 Hz should be reduced to 5/6 of the 60 Hz voltage rating of the motor and the horsepower load at 50 Hz should be reduced at 5/6 of the 60 Hz horsepower rating of the motor.

When a 60 Hz motor is operated on 50 Hz at 5/6 of the 60 Hz voltage and horsepower ratings, the other performance characteristics for 50 Hz operation are as follows:

A. SPEED — The synchronous speed will be 5/6 of the 60 Hz synchronous speed and the slip will be 6/5 of the 60 Hz slip.

B. TORQUES — The rated load torque in pound-feet will be approximately the same as the 60 Hz rated load torque in pound-feet.
The locked rotor and breakdown torques in pound-feet of 50 Hz motors will be approximately the same as the 60 Hz locked rotor and breakdown torques in pound-feet.

C. LOCKED-ROTOR CURRENT — The locked-rotor current (amperes) will be approximately 5% less than the 60 Hz locked-rotor current (amperes). The Code letter appearing on the motor nameplate to indicate locked rotor kVA per horsepower applies only to the 60 Hz rating of the motor.

D. SERVICE FACTOR — The service factor will be 1.0.

E. TEMPERATURE RISE — The temperature rise will not exceed 90°C. (See MG 1-14.30.)
Operation of 230 V Induction Motors on 208 V Systems — Induction motors intended for operation on 208 V systems should be rated 208 or 200 V.

Operation of a motor rated 230 V on a 208 V system is not recommended because utilization voltages are commonly encountered below the minus 10% tolerance on the voltage rating for which the motor is designed. Such operation will generally result in excessive overheating and serious reduction in torques.

Effects of Unbalanced Voltages on the Performance of Polyphase Induction Motors — When the line voltages applied to a polyphase induction motor are not equal, unbalanced currents in the stator windings will result. A small percentage voltage unbalance will result in a much larger percentage current unbalance. Consequently, the temperature rise of the motor operating at a particular load and percentage voltage unbalance will be greater than for the motor operating under the same conditions with balanced voltages.

Voltages preferably should be evenly balanced as closely as can be read on a voltmeter. Should voltages be unbalanced, the rated horsepower of the motor should be multiplied by the factor shown in Figure 1 (14.1) to reduce the possibility of damage to the motor. Operation of the motor above a 5% voltage unbalance condition is not recommended.

When the derating curve of Figure 14.1 is applied for operation on unbalanced voltages the selection and setting of the overload device should take into account the combination of the derating factor applied to the motor and the increase in current resulting from the unbalanced voltages. This is a complex problem involving the variation in motor current as a function of load and voltage unbalance in addition to the characteristics of the overload device relative to \( I_{\text{maximum}} \) or \( I_{\text{average}} \). In the absence of specific information it is recommended that overload devices be selected and/or adjusted at the minimum value that does not result in tripping for the derating factor and voltage unbalance that applies. When unbalanced voltages are anticipated it is recommended that the overload devices be selected so as to be responsive to \( I_{\text{maximum}} \) in preference to overload devices responsive \( I_{\text{average}} \).

![Figure 1](image)

**Figure 1** 14.1 Integral Horsepower Motors Derating Factor Due to Unbalanced Voltage

A. **EFFECT ON PERFORMANCE-GENERAL** — The effect of unbalanced voltages on polyphase induction motors is equivalent to the introduction of a “negative sequence voltage” having a rotation opposite to that occurring with balanced voltages. This negative sequence voltage produces in the air gap a
flux rotating against the rotation of the rotor, tending to produce high currents. A small negative sequence voltage may produce in the windings currents considerably in excess of those present under balanced voltage conditions.

B. UNBALANCE DEFINED — The voltage unbalance (or negative sequence voltage) in percent may be defined as follows:

\[
\text{Percent Voltage Unbalance} = 100 \times \frac{\text{Maximum voltage deviation from average voltage}}{\text{Average voltage}}
\]

Example — With voltages of 220, 215 and 210, the average is 215, the maximum deviation from the average is 5, and the percent unbalance is
\[
100 \times \frac{5}{215} = 2.3\%
\]

C. TORQUES — The locked-rotor torque and breakdown torque are decreased when the voltage is unbalanced. If the voltage unbalance would be extremely severe, the torques might not be adequate for the application.

D. FULL-LOAD SPEED — The full-load speed is reduced slightly when the motor operates at unbalanced voltages.

E. CURRENTS — The locked-rotor current will be unbalanced to the same degree that the voltages are unbalanced but the locked rotor kVA will increase only slightly.

The currents at normal operating speed with unbalanced voltages will be greatly unbalanced in the order or approximately 6 to 10 times the voltage unbalance.

**BIBLIOGRAPHY**


<table>
<thead>
<tr>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>accelerating time 17, 18</td>
</tr>
<tr>
<td>accuracy C4</td>
</tr>
<tr>
<td>adjustable relay E5</td>
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</tr>
<tr>
<td>Alternating-current Polyphase G4</td>
</tr>
<tr>
<td>ambient temperature 15, F1</td>
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<tr>
<td>compensation 8</td>
</tr>
<tr>
<td>Sensitivity E6, E7</td>
</tr>
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<td>Automatic Reset E7</td>
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<td>correction factor C4</td>
</tr>
<tr>
<td>corrosive compounds 10</td>
</tr>
<tr>
<td>critical temperature 14</td>
</tr>
<tr>
<td>Current Rating Characteristics E7</td>
</tr>
<tr>
<td>current sensitive devices 19</td>
</tr>
<tr>
<td>current transformer 20, C1, E8</td>
</tr>
<tr>
<td>current-element F1</td>
</tr>
<tr>
<td>CURRENT G6</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>dashpot 9</td>
</tr>
<tr>
<td>definitions and standards E1</td>
</tr>
<tr>
<td>Directly heated bimets 8</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>enclosure 16</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>flux C1</td>
</tr>
<tr>
<td>full-load current rating A1</td>
</tr>
<tr>
<td>FULL-LOAD SPEED G6</td>
</tr>
<tr>
<td>fuses D4</td>
</tr>
<tr>
<td>Fault-Current Protection E8</td>
</tr>
<tr>
<td>G</td>
</tr>
<tr>
<td>ground-fault currents 4</td>
</tr>
<tr>
<td>H</td>
</tr>
<tr>
<td>hammer mill motor 19</td>
</tr>
<tr>
<td>heat dissipation 16</td>
</tr>
<tr>
<td>heat sensing element 14</td>
</tr>
<tr>
<td>heater winding 17</td>
</tr>
<tr>
<td>heating D1</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>instantaneous trip 20</td>
</tr>
<tr>
<td>insulation breakdown 9</td>
</tr>
<tr>
<td>insulation life 9</td>
</tr>
<tr>
<td>integral automatic function E3</td>
</tr>
<tr>
<td>inverse time-current 9</td>
</tr>
<tr>
<td>interchangeable current 9</td>
</tr>
<tr>
<td>elements E5</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>Limit of Self Protection E7</td>
</tr>
<tr>
<td>line currents 12</td>
</tr>
<tr>
<td>load C4</td>
</tr>
<tr>
<td>locked-rotor current 17, G4</td>
</tr>
<tr>
<td>loss of output 19</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>magnetizing current C1</td>
</tr>
<tr>
<td>manual operation E3</td>
</tr>
<tr>
<td>mechanical forces 10</td>
</tr>
<tr>
<td>melting alloy 6</td>
</tr>
<tr>
<td>metering accuracy classes C5</td>
</tr>
<tr>
<td>motor heating 5</td>
</tr>
<tr>
<td>Motors and Generators G1</td>
</tr>
<tr>
<td>multispeed motor D1</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>National Electrical Code D1</td>
</tr>
<tr>
<td>NEMA E1</td>
</tr>
<tr>
<td>nominal tripping current 7</td>
</tr>
<tr>
<td>nonautomatically start D3</td>
</tr>
<tr>
<td>nuisance tripping 11</td>
</tr>
<tr>
<td>Number of Starts G2</td>
</tr>
<tr>
<td>O</td>
</tr>
<tr>
<td>open-delta 13</td>
</tr>
<tr>
<td>overload devices D1, D2</td>
</tr>
<tr>
<td>overload protection 3</td>
</tr>
<tr>
<td>OVERLOAD UNITS D4</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>PERFORMANCE G5</td>
</tr>
<tr>
<td>Variation of Voltage G3</td>
</tr>
<tr>
<td>Variation of frequency G3</td>
</tr>
<tr>
<td>Volatages over 600 V G4</td>
</tr>
<tr>
<td>phase angle C4</td>
</tr>
<tr>
<td>phase conversion 13</td>
</tr>
<tr>
<td>Phase loss sensitivity 8</td>
</tr>
<tr>
<td>phase voltages 13</td>
</tr>
<tr>
<td>Polyphase Motors E8</td>
</tr>
<tr>
<td>power transformer C1</td>
</tr>
<tr>
<td>primary current C1</td>
</tr>
</tbody>
</table>

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**R**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>regulation</td>
<td>C4</td>
</tr>
<tr>
<td>required tripping time</td>
<td>A1</td>
</tr>
<tr>
<td>resistance element</td>
<td>7</td>
</tr>
<tr>
<td>rms value</td>
<td>B1, B2</td>
</tr>
<tr>
<td>RUNNING</td>
<td>G1</td>
</tr>
</tbody>
</table>

**U**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ultimate currents</td>
<td>E6</td>
</tr>
<tr>
<td>UNBALANCE DEFINED</td>
<td>G6</td>
</tr>
<tr>
<td>Unbalanced Voltages</td>
<td>G5</td>
</tr>
<tr>
<td>Underwriters Laboratories Inc. F1</td>
<td></td>
</tr>
<tr>
<td>user connections</td>
<td>E4</td>
</tr>
</tbody>
</table>

**S**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>saturation</td>
<td>11</td>
</tr>
<tr>
<td>secondary current</td>
<td>C1</td>
</tr>
<tr>
<td>self-protection limit current</td>
<td>E6</td>
</tr>
<tr>
<td>sensing device(s)</td>
<td>D6</td>
</tr>
<tr>
<td>SERVICE FACTOR</td>
<td>G4</td>
</tr>
<tr>
<td>Short-circuit currents</td>
<td>4</td>
</tr>
<tr>
<td>short-circuit protection</td>
<td>3</td>
</tr>
<tr>
<td>Short-Time Capability</td>
<td>E6</td>
</tr>
<tr>
<td>single-phase</td>
<td>13</td>
</tr>
<tr>
<td>Single-Phase Operating</td>
<td>E8</td>
</tr>
<tr>
<td>single-phase circuits</td>
<td>4</td>
</tr>
<tr>
<td>SPEED</td>
<td>G4</td>
</tr>
<tr>
<td>standardized burdens</td>
<td>C5</td>
</tr>
<tr>
<td>STARTING</td>
<td>G1</td>
</tr>
<tr>
<td>starting period</td>
<td>18</td>
</tr>
</tbody>
</table>

**V**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation from Rated Speed</td>
<td>G1</td>
</tr>
<tr>
<td>ventilation</td>
<td>10</td>
</tr>
<tr>
<td>Verification Test</td>
<td>E4</td>
</tr>
<tr>
<td>Current Rating</td>
<td>E4</td>
</tr>
<tr>
<td>Voltage Unbalance</td>
<td>G1</td>
</tr>
</tbody>
</table>

**T**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPERATURE RISE</td>
<td>G4</td>
</tr>
<tr>
<td>thermal unit</td>
<td>7</td>
</tr>
<tr>
<td>thermal unit selection</td>
<td>17</td>
</tr>
<tr>
<td>three-phase</td>
<td>13</td>
</tr>
<tr>
<td>three-phase, three-wire</td>
<td>4</td>
</tr>
<tr>
<td>three-wire control</td>
<td>7</td>
</tr>
<tr>
<td>time-current characteristics</td>
<td>7, 17, E2, E7</td>
</tr>
<tr>
<td>TORQUES</td>
<td>G4, G6</td>
</tr>
<tr>
<td>Trip current rating</td>
<td>A1</td>
</tr>
<tr>
<td>trip curve</td>
<td>5</td>
</tr>
<tr>
<td>tripping characteristics</td>
<td>8</td>
</tr>
<tr>
<td>tripping current</td>
<td>16, F1</td>
</tr>
</tbody>
</table>