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REPORT SUMMARY

Protective Relay Maintenance and Application Guide

Protective relays are decision-making elements in the protection scheme for electrical power systems. A strong test and maintenance program will keep protective relays in a high state of readiness and help utilities avoid equipment damage and prolonged downtime. This guide provides recommended practices for maintenance and testing of these relays.

BACKGROUND Protective relays monitor circuit conditions and initiate protective action when an undesired condition is detected. Protective relaying serves many functions including isolating faulted circuits or equipment from the remainder of the system so the system can continue to function, limiting damage to faulted equipment, minimizing the possibility of fire or damage to adjacent equipment, and minimizing hazards to personnel. When required to operate because of a faulted or undesirable condition, it is imperative that protective relays function correctly. A strong maintenance and test program will ensure protective relays respond properly to normal and abnormal conditions.

OBJECTIVES

- To provide practical and cost-effective guidance for implementing a protective relay maintenance program.
- To provide techniques for evaluating and trending relay performance.

APPROACH EPRI's Nuclear Maintenance Applications Center reviewed protective relay types and specific applications of these components in power generating station protective schemes, especially those schemes used in nuclear power plants. To ascertain current maintenance and testing practices for protective relays, data was gathered from industry databases, power generating stations, and relay manufacturers.

RESULTS This guide provides a general overview of protective relays and reviews a typical protective relay operating sequence. It familiarizes readers with the key components and subassemblies used in electromechanical protective relays and reviews fundamental operating principles. The guide discusses protective relay design and construction features, the various types of protective relays that are available, and protective relaying design and application concepts .

The guide presents protective relay degradation, reliability, and failure information so as to establish a baseline from which recommended maintenance practices can be linked to a degradation mechanism or failure mode. Also provided is an overview of recommended mechanical inspection, checks, electrical tests, and calibrations.

INTEREST CATEGORIES

Nuclear plant operations and maintenance
Plant electrical systems and equipment
Engineering and technical support
Power system planning and engineering

KEYWORDS

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Protective Relay Maintenance and Application Guide

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Prepared by
EDAN ENGINEERING CORPORATION
900 Washington Street, Suite 830
Vancouver, WA 98660

Principal Investigators
Eddie L. Davis
Daniel L. Funk

Prepared for
Nuclear Maintenance Applications Center
1300 Harris Boulevard
Charlotte, North Carolina 28262

Operated by
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
Wayne E. Johnson

Nuclear Power Division

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Abstract

Protective relaying is an integral part of any electrical power system. The fundamental objective of system protection is to quickly isolate a problem so that unaffected portions of the system can continue to function. Under normal conditions, protective relays remain idle and serve no active function. However, when required to operate because of a faulted or undesirable condition, it is imperative that the relays function correctly. Failure of a protective relay to contain and isolate an electrical problem can have severe plant-wide repercussions. When an expected protective function does not occur, the end result of an electrical abnormality may be catastrophic equipment damage and prolonged downtime instead of localized minor damage. Another point of concern is undesired operation of a protective relay during normal plant conditions or tolerable transients. Inadvertent relay operation can result m unnecessary system or plant downtime. A strong maintenance and test program will help ensure protective relays respond properly to normal and abnormal conditions.

NMAC has created this guide to provide practical and cost-effective guidance for implementing a successful protective relay maintenance program and to eliminate ambiguity over which inspections and tests to conduct under different circumstances. It is difficult to find clear guidance on which inspections and tests to conduct within defined maintenance categories for protective relays. This guide contains technical information applicable to electromechanical protective relays in use at power generating stations. A description of protective relay operating principles, construction, applications, degradation mechanisms, and failure modes is provided in addition to maintenance recommendations. A key topic addressed in this guide is optimization of test intervals. One possible method for evaluating relay performance data in support of optimizing maintenance intervals is presented. Recent industry studies and surveys indicate that a general consensus now exists that protective relays have, in the past, been over-tested and that most utilities are reducing their test frequency. Over-testing will result in further escalation of operating and maintenance costs (which is already an industry-wide concern) and unnecessarily increases the potential for equipment damage.

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Table of Contents

Table of Contents (cont.)

Table of Contents (cont.)

Table of Contents (cont.)

Table of Contents (cont.)

5.0 Power Plant Protection System Design 5-1

6.0 Protective Relay Degradation and Failure Modes 6-1

Table of Contents (cont.)

Table of Contents (cont.)

Table of Contents (cont.)

Table of Contents (cont.)

10.0 Data Trending and Test Intervals 10-1

11.0 Relay Maintenance Program Guidelines and Considerations 11-1

Table of Contents (cont.)

List of Figures

List of Figures (cont.)

List of Figures (cont.)

List of Tables

1.0 Introduction

Protective relays have a reputation for providing reliable service for many years. Nonetheless, protective relays are delicate instruments that are susceptible to degradation mechanisms that affect performance. Failure of a protective relay to contain and isolate an electrical problem can have severe plant-wide repercussions. When an expected protective action does not occur, the end result of an electrical abnormality may be catastrophic equipment damage and prolonged downtime instead of localized minor damage. Because of the severe consequences of a failure, protective relays should be maintained in a high state of readiness.

1.1 Background Information

Protective relaying is an integral part of any electrical power system. The fundamental objective of system protection is to quickly isolate a problem so that the unaffected portions of a system can continue to function. Protective relays are the decision-making device in the protection scheme. They monitor circuit conditions and initiate protective action when an undesired condition is detected. Protective relays work in concert with sensing devices and control devices to accomplish their function. Protective relaying is applied for several reasons:

- To isolate faulted circuits or equipment from the remainder of the system so the system can continue to function
- To limit damage to faulted equipment
- To minimize the possibility of fire or catastrophic damage to adjacent equipment
- To minimize hazards to personnel

Under normal power system operation, protective relays remain idle and serve no active function. However, when required to operate because of a faulted or undesirable condition, it is imperative that the relays function correctly. Another point of concern is undesired operation of a protective relay during normal plant conditions or tolerable transients. Inadvertent relay operation can result in unnecessary system or plant downtime. A strong maintenance and test program will help ensure protective relays respond properly to normal and abnormal conditions.

An effective maintenance program for protective relays accomplishes two primary goals:

- It provides a high degree of confidence that the electrical power protection system will respond to abnormal conditions as designed. Periodic assurance that protective relays are in an operable status is particularly important since relay malfunctions are generally not detectable during routine operation.
- It preserves the relays and helps counteract normal and abnormal in-service deterioration that can affect relay performance over time. Even under normal conditions, electrical, mechanical, thermal, and environmental stresses are continually at work, slowly but predictably degrading the relays. Routine preventive maintenance helps curb the deterioration process and prolong useful service life, thereby reducing the probability of failure or degraded performance.

1.2 Purpose

The purpose of this guide is to provide practical and cost-effective guidance for implementing a successful protective relay maintenance program. A strong emphasis is placed on understanding protective relay construction, application, operation, degradation mechanisms, and failure modes. The philosophy of this guide is that a solid grasp of these fundamentals will enable maintenance personnel to develop and implement a more successful maintenance program.

This guide attempts to present recommended maintenance practices in a logical, straightforward manner and to eliminate ambiguity over which inspections and tests to conduct under different circumstances. It is difficult to find clear guidance on which inspections and tests to conduct within the defined maintenance categories for protective relays. Most existing literature tends to focus on the specifics of how to conduct a certain inspection or test. When, and under what circumstances, should testing be conducted is typically delegated to the user.

A key topic addressed in the guide is optimization of test intervals. One possible method for evaluating relay performance data in support of optimizing maintenance intervals is presented. Recent industry studies and surveys indicate that a general consensus now exists that protective relays have, in the past, been over-tested and that most utilities are reducing their test frequency. Manufacturers guidance has become less prescriptive and provides considerable latitude with regard to test intervals. Over-testing should be avoided for two reasons:

- Valuable resources are expended on maintenance that may not measurably improve plant safety, reliability, or efficiency. Other maintenance that is more beneficial to the plant may inappropriately receive a lower priority. Furthermore, escalation in operating and maintenance (O&M) costs at nuclear plants is an industry-wide concern. Excessive maintenance contributes to high O&M costs and should be avoided.
- Protective relays are delicate instruments that require considerable expertise to test properly. Each time a relay is removed from service and tested, the potential exists for adjustment errors or equipment damage. Over-testing increases the risk of errors or damage without a justifiable improvement in reliability. Some utilities have actually experienced an improvement in relay performance after extending test intervals because of the reduction in personnel-related problems.

Information presented in this guide will benefit individuals responsible for: protective relay maintenance, electrical system training, system reliability, maintenance planning and scheduling, reliability centered maintenance, and maintenance procedures.

The recommended inspections and checks are based on industry guidance, applicable standards, manufacturer recommendations, regulatory documents, and industry experience. Many different types and models of protective relays are in service. Consequently, the specific recommendations of this guide may not fully address unique requirements of a particular make and model of protective relay; conversely, some recommendations may not apply. For this reason, the manufacturer's literature should always be reviewed to confirm intended maintenance practices.

1.3 Scope

The recommended practices presented here pertain primarily to electromechanical protective relays. However, the recommendations are, in general, applicable to single-function solid-state relays used at nuclear plants (e.g., undervoltage and frequency relays). Maintenance activities for multi-function, microprocessor-controlled protective relays are not within the scope of this guide. These complicated programmable relays are usually applied to high-voltage transmission lines and are not typically used for generating plant protection.

1.4 Organization

Section 1 provides an introduction to the guide and highlights the key aspects of protective relay maintenance.

Section 2 provides a general overview of protective relays and is intended to set the stage for more detailed information presented later in the guide. A typical protective relay operating sequence is reviewed to provide a more intuitive understanding of how a protective relay works. This section also covers relay classification, designation, and terminology in considerable detail. Functional designations and terminology can be confusing because of overlapping and sometimes conflicting reference standards. The information presented here should help clarify any points of confusion or potential ambiguity.

Section 3 familiarizes readers with the key components and subassemblies used in electromechanical protective relays, and reviews the operating principles upon which they work. Although many different types of protective relays exist, they share similarities in design and operation. Typical design and construction features are covered in this section.

Section 4 builds on the fundamentals presented in Section 3 and discusses the many different types of protective relays that are available. This section is intended to familiarize readers with protective relay applications and to review the fundamental operating principles of these devices. Protective relays most often used at power generating plants are emphasized.

Section 5 describes design and application concepts used in protective relaying. By understanding the general design philosophy and approach, the importance of correctly performed maintenance can be better appreciated.

Section 6 presents protective relay degradation, reliability, and failure information. The primary purpose of this information is to establish a baseline from which recommended maintenance practices can be linked to a degradation mechanism or a failure mode.

Section 7 provides an overview of recommended maintenance practices for protective relays. The information contained in this section is intended to provide a framework, or baseline, for establishing a successful protective relay maintenance program. Section 7 stresses that application and service conditions for protective relays vary too widely to simply prescribe a single, inflexible maintenance program for all facilities.

Section 8 provides information on recommended mechanical inspections and checks and Section 9 provides information on recommended electrical tests and calibrations. This information is intended to help plants establish and/or refine their protective relay maintenance practices, consistent with their overall maintenance objectives. The emphasis of these sections is how to perform each inspection and check and what each inspection and check accomplishes. The procedures sections are intended to capture the essence of each recommended inspection and check, and to provide a general sequence or flowpath. The information presented here should be supplemented with manufacturer- and plant-specific information to create actual field procedures.

Section 10 addresses methods for evaluating relay performance to help determine appropriate test intervals. Analysis techniques for statistically analyzing and trending historic test data are presented. Trending test data can provide a means of quantitatively assessing relay performance and drift characteristics and can provide a technical basis for extending test intervals. Overcurrent and undervoltage relays are particularly well suited for the type of trending analyses discussed in this section. Cases in which trending is not appropriate are also discussed.

Section 11 covers general information pertaining to protective relay maintenance. This section is intended to suggest factors worthy of consideration when developing or refining maintenance practices for protective relays.

Appendix A lists references for the guide. A glossary of terms is contained in Appendix B.

Appendix C provides an overview of the most important industry standards relating to protective relays. The appendix serves as a good road map for researching specific areas of interest.

Appendix D contains a list of electrical equipment device function numbers. Device function numbers are used extensively in documents relating to relay design, application, and testing.

1.5 Summary

This guide provides recommended practices for maintenance and testing of protective relays used in electrical power systems. The guide's primary focus is nuclear generating stations; however, the information presented is generally applicable to all protective relay applications.

Protective relay maintenance programs should recognize the excellent track record of performance for electromechanical protective relays. It is the general consensus of the industry that protective relays have historically been overtested. Nuclear plants are encouraged to review the performance of their protective relays and evaluate the feasibility of extending test intervals when appropriate. Suggestions on how to approach extension of test intervals are contained in this guide. The optimum test and maintenance interval is achieved when the desired level of reliability is maintained with the least expenditure of resources.

2.0 Protective Relay Description

Protective relays are the decision-making element in the protection scheme for electrical power systems. They monitor circuit conditions and initiate protective action when an undesired condition is detected. Protective relays work in concert with sensing and control devices to accomplish their function.

Under normal power system operation, a protective relay remains idle and serves no active function. However, when required to operate because of a faulted or undesirable condition, the relay must function correctly. Failure of a protective relay can result in devastating equipment damage and prolonged downtime. A strong test and maintenance program is crucial to maintaining protective relays in a high state of readiness. Fortunately, protective relays have proven to be very reliable.

Section 2 provides a general overview of protective relays and is intended to set the stage for more detailed information presented later in the guide. A typical protective relay operating sequence is reviewed to provide a more intuitive understanding of how a protective relay accomplishes its design function.

This section also covers relay classification, designation, and terminology in considerable detail. Functional designations and terminology can be confusing because of overlapping and sometimes conflicting reference standards. The information presented here should help clarify any points of confusion or potential ambiguity.

2.1 Purpose of Protective Relaying

Protective relaying is an integral part of any electrical power system. The fundamental objective of system protection is to quickly isolate a problem so that the unaffected portions of the system can continue to function. The flip side of this objective is that the protection system should not interrupt power for acceptable operating conditions, including tolerable transients.

Protective relaying is applied for several reasons:

- To isolate faulted circuits or equipment from the remainder of the system so the system can continue to function
- To isolate portions of the system during abnormal conditions so the remainder of the system can continue to function
- To limit damage to faulted equipment
- To minimize the possibility of fire or catastrophic damage to adjacent equipment
- To minimize hazards to personnel

2.2 General Overview

The functions performed by protective relays can be accomplished using electromechanical or solid-state devices. Originally, all protective relays were electromechanical devices. It is not uncommon for a 50 year old electromechanical relay to still be in service - truly a testament to their reliability and endurance. Solid-state designs have been available for many years and are becoming common. However, their integration into power system protection has not been rapid.

At power plants, a majority of the protective relays in service are still electromechanical devices. This is especially true for nuclear plants, the majority of which were designed in the 1960s or 1970s. For this reason, electromechanical protective relays are stressed in this guide. Solid-state designs are covered only to the extent applicable to power plants.

2.2.1 Electromechanical Construction

Electromechanical protective relays contain discrete components mounted to a chassis that fits inside a protective case. Figure 2-1 shows a variety of electromechanical protective relays. A typical protective relay housed inside its case with the cover installed is shown in Figure 2-2. The relays are generally flush mounted on a switchboard panel. Connections to external circuits are accomplished via permanent wiring to the relay case. The chassis is designed to slip in and out without disturbing the case or external connections, thus allowing easy removal for testing and maintenance.

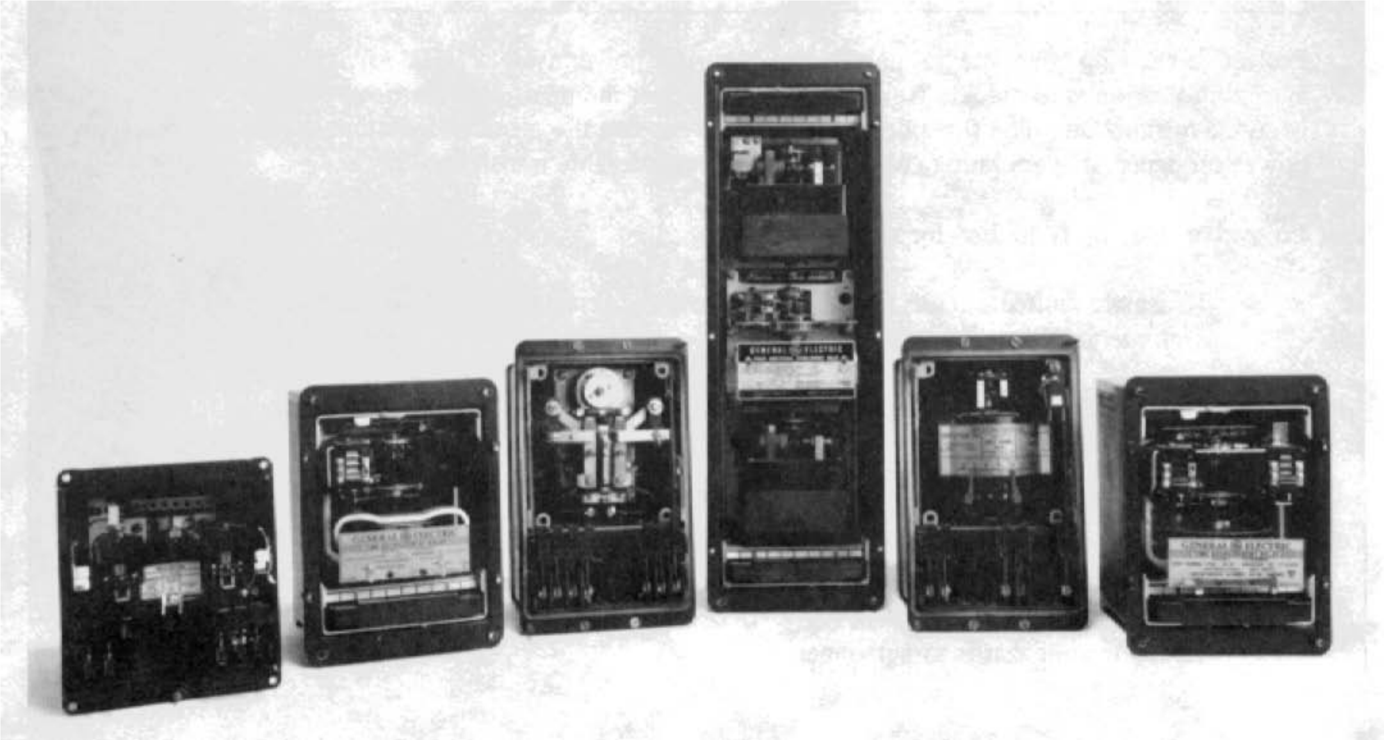


Figure 2-1
Electromechanical Protective Relays

Figure 2-2
Typical Electromechanical Protective Relay

2.2.2 Solid-State Construction

In the past, utilities were extremely cautious m their application of solid-state protective relays and, if used at all, they were typically limited to backup protection. Two factors contributed to the slow acceptance of solid state protective relays: 1) their lack of a substantial track record for application in a high-current, high-voltage environment and 2) the long track record of reliable service from electromechanical relays. As solid-state protective relays have built a track record of performance, they have become more widely accepted and now find application in many new designs and upgrades to older systems. At nuclear plants, solid-state protective relays are most often used for undervoltage and underfrequency protection.

Solid-state protective relays consist of integrated circuits and components mounted on printed circuit boards, which in turn are mounted in a protective housing. Larger, more complex solid-state protective relays are usually rack-mounted. Smaller, simpler units are generally case-mounted much like an electromechanical relay. Figure 2-3 shows a typical rack-mounted solid-state relay and Figure 24 shows a case-mounted unit. Solid-state relays are particularly advantageous when accuracy, speed, sensitivity, or complex decision making is required. The sophistication possible with solid-state designs makes them particularly well suited for complex applications involving long distance, high voltage transmission lines. Many new state-of-the-art designs also contain self diagnostic capabilities.

Figure 2-3
Rack-Mounted Solid-State Relay
(Courtesy Schweitzer Engineering Laboratories, Inc.)

Figure 2-4
Case-Mounted Solid-State Relay
(Courtesy General Electric Company)

2.2.3 Power System Protection Circuit Operation

A typical power system protection scheme includes sensing elements, a decision making device, and control (or actuation) equipment. Instrument transformers are the most common sensing elements used in power system protection. They measure current or voltage at strategic points in the system and provide an output signal to the relay proportional to the measured electrical quantity. The protective relay is the decision making device; it monitors the input signals and initiates protective action when predefined system conditions are reached. Control circuits respond to the relay's signal for protective action and carry out the function defined by the control circuit logic, usually to trip one or more circuit breakers. Once actuated, the circuit breakers open to isolate the affected part of the system. Figure 2-5 shows a simplified functional diagram of a typical protective relay circuit.

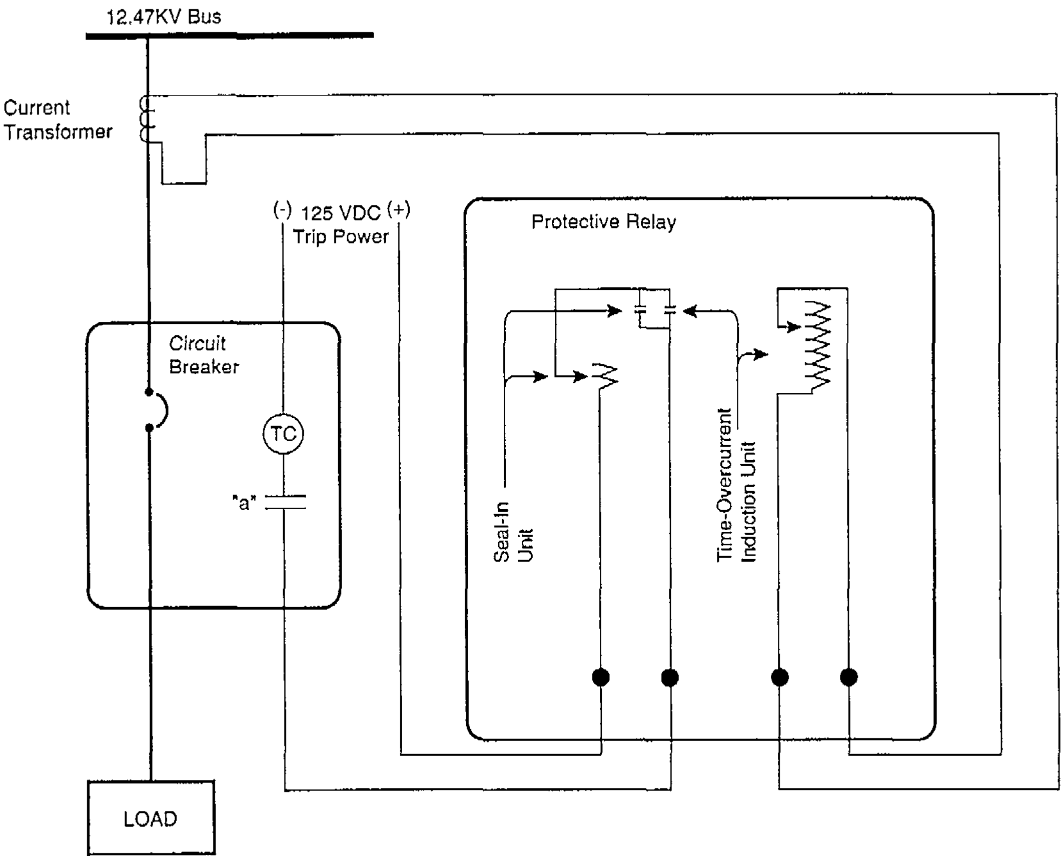


Figure 2-5
Protective Relay Functional Diagram

An example of a protective action sequence is helpful in understanding how a power system protection circuit functions. Assume the configuration depicted in Figure 2-5 is used for time-overcurrent protection. During normal conditions:

- The circuit breaker is closed and normal current is flowing through the 12.47 KV ac line. Since the circuit breaker is closed, the "a" contact (breaker position) is also closed.
- The current transformer is monitoring the line current and is providing a secondary current signal to the time-overcurrent protective relay.
- For normal conditions, the secondary current signal is below the pickup point of the relay's time-overcurrent unit. Thus, the main relay contact (i.e., the contact actuated by the time-overcurrent unit) is open. The contactor switch (also called a seal-in unit) is deenergized and its contact is also open.
- The circuit breaker's trip coil is deenergized since the main relay contacts and contactor switch are open.

If a fault occurs on the 12.47 KV ac line, the protective relay circuit responds as follows:

- The secondary current signal provided to the protective relay by the instrument transformer increases proportionally to the faulted line current. Once the current signal exceeds the pickup point of the relay's time-overcurrent unit, it picks up and rotates in the close direction. After a prescribed time delay corresponding to the magnitude of current, the time-overcurrent unit closes the main relay contacts.

- When the main relay contacts close, dc current flows through the control circuit, energizing the contactor switch and the circuit breaker trip coil. The contactor switch closes and seals in its contact, thus bypassing the main relay contact. The contactor switch will remain sealed in until after the breaker opens completely.

> *NOTE: The purpose of the contactor switch is to prevent delicate parts of tile relay from carrying large currents and to prevent the relay's main contacts from interrupting the circuit breaker trip coil current. Operation of the contactor switch is covered in greater detail in Section 3.2.6.*

- Energization of the trip coil initiates breaker action. As the breaker opens, the fault current rapidly decreases, causing the main relay contacts to open. Although the main relay contacts are open, current still flows through the dc control circuit because of the contactor switch.

- Once the circuit breaker is fully open, the "a" contact opens, thereby deenergizing the trip coil and contactor switch.

The above overview provides a brief description of protective relays and their function within a power system protection circuit. Relay construction, principles of operation, and applications are discussed in more detail in the following sections.

2.3 Relay Classifications

The scope of this guide is limited to protective relays. A clear understanding of exactly what devices are considered protective relays is important to assure maximum benefit of the information presented in the guide and to avoid misapplication of this information to relays or devices that are not, by strict definition, protective relays. A general overview of relay classifications and classification methods is presented to give readers the background information necessary to distinguish protective relays from other types of relays and devices.

There are numerous ways to classify relays. Relay terminology can be confusing because of the diversity of devices and applications. Although some differences exist between various groups and organizations, the classification methods and categories of relays used for electrical power systems are fairly consistent. ANSI/IEEE C37.90, *IEEE Standard Relays and Relay Systems Associated with Electrical Power Apparatus* and ANSI/IEEE C37.100, *IEEE Standard Definitions for Power Switchgear* serve as standard references for relay classification and terminology.

The most common methods used to classify relays are by:

- Function
- Input source
- Operating principle
- Performance characteristics

The following sections discuss relay classification and nomenclature in more detail.

2.3.1 Classification by Function

Functional classifications stem from the function that a relay provides in a power system. There are five general categories of relays as defined below.

Protective Relay: A protective relay functions to detect defective lines or equipment, or other power system conditions of an abnormal or dangerous nature, and to initiate appropriate control circuit action. It can be used to initiate switching operations or actuate an alarm. A protective relay is further classified according to its input quantities, operating principle, or performance characteristics. Examples of protective relays are:

- Overcurrent relays
- Undervoltage relays
- Differential relays
- Reverse sequence relays

Auxiliary Relay: An auxiliary relay provides a specific, or secondary, function to assist another relay or control device in performing a general function. Typical functions performed by an auxiliary relay include circuit seal-in, time delay, control signals or lights, and contact multiplication. Examples of auxiliary relays are:

- Control relays
- Time delay relays
- Lockout relays
- Trip and close relays

Monitoring Relay: A monitoring relay functions to verify that system or control circuit conditions conform to prescribed limits. Examples of monitoring relays are:

- Alarm relays
- Fault detector relays
- Network phasing relays
- Verification relays
- Synchronism check relays

Monitoring relays often provide a permissive function for various power system operations, such as paralleling across a circuit breaker. However, monitoring relays are not used to initiate protective functions during a fault.

Regulating Relay: A regulating relay responds to normal changes in system operating conditions and functions to control system parameters (e.g., voltage, power) within specified operating limits. A regulating relay is further classified according to its input quantities, operating principle, or performance characteristics. Regulating relays are typically used to control transformer tap changers and generator governors.

Programming: Relay A programming relay functions to establish or detect electrical sequences. Typical functions performed by a programming relay include reposing and synchronizing. Examples of programming relays are:

- Accelerating relays
- Phase selector relays
- Reclosing relays
- Synchronizing relays
- Initiating relays

Protective and auxiliary relays make up the majority of relays used in power system applications. These two classifications of relays are commonly described in technical documents and literature. Special-function relays falling within the monitoring, regulating, and programming classifications tend to be referred to by their specific function, and are not generally thought of as belonging to a broader functional category. For example, a synchronizing relay is a type of programming relay; however, it is seldom thought of in these terms. Thus, these three broader classifications tend not to be used extensively in practice.

This guide covers protective relays. From the definitions provided above, it is evident that protective relays constantly monitor power system conditions and only influence system operation when an abnormal or undesirable condition is detected. Once a protective relay detects an abnormal condition and initiates protective action, auxiliary relays and other control devices carry out the specific functions associated with the protective action.

2.3.2 Classification by Input

Protective relays may be identified by the input parameter monitored. Examples include:

- Current relays
- Voltage relays
- Power relays
- Temperature relays
- Pressure relays

Classification by input alone is not common. More often, a qualifying term is added to the input parameter (e.g., undervoltage, overvoltage, reverse power, overcurrent), thereby classifying the relay on a performance basis. Classification by performance characteristics is discussed in Section 2.3.4.

2.3.3 Classification by Operating Principle

Protective relays can be described in terms of their operating principle. This method of classification provides insight into the basic design features of a relay and is most useful for discussing hardware. However, classification by operating principle provides limited information about a relay's intended application or function. Examples include:

- Electromagnetic relays
- Solid-state relays
- Harmonic-restraint relays
- Electromechanical relays
- Percent-differential relays
- Sudden-pressure relays
- Thermal relays

2.3.4 Classification by Performance Characteristics

A protective relay's performance characteristics is a commonly used method to identify relays. Performance characteristics represent the specific function provided by the relay. Examples include:

- High-speed differential relays
- Directional-overcurrent relays
- Reverse-power relays
- Impedance relays
- Mho relays
- Overcurrent relays
- Undervoltage relays
- Phase-balance relays
- Reactance relays
- Frequency relays
- Overload relays

Additional terms are sometimes used to describe in more detail a relay's exact performance characteristics. As an example, an overcurrent relay that is designed to actuate with no intentional delay is referred to as an instantaneous overcurrent relay. If the relay can be programmed with an intentional time delay, it is called a time-overcurrent relay.

2.3.5 Relay Terminology

In addition to classifying relays, many terms exist to fully describe a relay's function, performance, operation, construction, or application. In most cases, these terms are self explanatory. However, the specialty area of protective relaying does have its own "language" that includes unique terminology. Readers of this guide should have a good working-level understanding of relay terminology. Appendix B contains a glossary of common relay terms. If additional help is needed regarding relay classifications or relay terminology, readers are encouraged to review ANSI/IEEE C37.90, *IEEE Standard Relays and Relay Systems Associated with Electrical Power Apparatus* and ANSI/IEEE C37.100, *IEEE Standard Definitions for Power Switchgear.*

2.4 Device Function Numbers

Device function numbers identify the specific function performed by various types of power system equipment. The use of device function numbers standardizes the way equipment and devices are represented on engineering documents (e.g., drawings, specifications, connection diagrams, instruction books). Maintenance personnel involved with testing protective relays need to be familiar with device function numbers to effectively use technical documents associated with electrical power systems.

2.4.1 General Description

The specific protective function performed by a protective relay is indicated by its device function number. The device function number usually correlates with the relay's performance characteristics classification. For example, 51 is the designation for an ac time overcurrent relay and 27 is the designation for an undervoltage relay. Essentially, the device function number matches a relay's performance characteristics to the function performed.

Device function numbers are applied to a wide variety of power system electrical devices. Table 2-1 lists the device function numbers for commonly used protective relays. Appendix D contains a comprehensive list of all device function numbers and a description of each. ANSI/IEEE C37.2, *IEEE Standard Electrical Power System Device Function Numbers* serves as the standard reference for device function numbers.

2.4.2 Suffixes

A device function number may include a letter suffix. A suffix provides additional information about:

- Auxiliary equipment associated with the device
- Distinguishing features or characteristics of the device
- Conditions that describe the use of the device

A suffix letter may have more than one meaning, depending on the convention chosen by the designer. For this reason, care should be used when interpreting device function numbers that contain a suffix. If ambiguity exists regarding the meaning of a suffix, ANSI/IEEE C37.2, *IEEE Standard Electrical Power System Device Function Numbers is* a good reference to help with an interpretation. Table 2-2 lists common suffixes used in conjunction with protective relay device function numbers.

Table 2-1

Commonly Used Protective Relay Device Function Numbers

Relay Device Function Number	Protective Function	Amplifying Information
21	Distance	
25	Synchronizing	Synchronism or synchronizing check
27	Undervoltage	
32	Directional power	Reverse power
40	Loss of excitation	Field relay
46	Phase balance	Current phase balance or negative sequence current
47	Phase sequence voltage	Reverse phase voltage
49	Thermal	Thermal overload
50	Instantaneous overcurrent	
51	Time-overcurrent	
59	Overvoltage	
60	Voltage balance	Between two circuits
63	Pressure	Sudden pressure for transformers
67	Directional overcurrent	
81	Frequency	Generally underfrequency
86	Lockout	
87	Differential	

Table 2-2
Commonly Used Suffix Letters

Suffix Letter	Relay Application	Amplifying Information
A	Alarm only or automatic	
B	Bus protection	
G	Ground-fault protection or generator protection	System neutral type
GS	Ground-fault protection	Toroidal or ground sensor type
L	Line protection	
M	Motor protection	
N	Ground-fault protection	Relay coil connected in residual CT circuit
T	Transformer protection	
V	Voltage	
U	Unit protection	Generator and transformer

3.0 Basic Construction and Operating Principles

Protective relays are capable of monitoring numerous electrical quantities and can detect a wide variety of complex power system conditions. This diverse capability is accomplished by using a surprisingly limited number of engineering principles. Electromechanical protective relays operate on one of two basic principles: electromagnetic attraction or electromagnetic induction. Multiple function relays or relays designed to monitor particularly complex situations may rely on a combination of the two fundamental principles to achieve the desired electrical characteristics. Solid-state relays use various semi-conductor components (e.g., diodes, transistors, and thyristors) along with resistors and capacitors to create logic units with the desired attributes.

The primary objective of Section 3 is to familiarize readers with the key components and subassemblies used in electromechanical protective relays, and to review the operating principles upon which they work. Although many different types of protective relays exist, they share similarities in design and operation. Typical design and construction features are covered in this section. Section 4 builds on the fundamentals presented here and discusses the various types of protective relays used for power plant protection.

3.1 Electrical Subassemblies

A protective relay is comprised of one or more individual electrical subassemblies or units. These units are critical to relay operation since they perform the decision making functions. The basic construction and operating principles for the most common types of decision making units are presented in the following sections.

Descriptions of the electrical subassemblies provided here concentrate on how the subassemblies themselves work. Section 3.2 provides more insight into how the different subassemblies, along with other components, are packaged together and function as an integral unit.

3.1.1 Electromagnetic Attraction Units

Devices operated by electromagnetic attraction use an electromagnet to attract a plunger or hinged armature when the unit is energized with a current or voltage of sufficient magnitude. The principle of electromagnetic attraction is valid for either ac or dc circuits. Three different types of electromagnetic attraction units are commonly used:

- Plunger (or solenoid) devices
- Hinged armature (or clapper) devices
- Polar devices

Electromagnetic attraction units are instantaneous devices and are used in applications in which no intentional delay is desired. Typical operating times range from 5 ms to 50 ms. Once the device has picked up, it may not drop out (reset) until the applied voltage or current drops below approximately 60%. Some applications cannot tolerate such a low dropout and use a modified design to achieve dropout at 90% to 95%.

3.1.1.1 Plunger Devices

A representative illustration of a typical plunger type unit is shown m Figure 3-1. The unit is effectively a solenoid; it consists of a center core (plunger) surrounded by a cylindrical coil that is housed in a magnetic frame. A moving contact is attached to the plunger. When current or voltage is applied to the coil, magnetic flux is produced. The magnetic flux generates a force on the plunger that, when sufficiently strong, draws the plunger upward into the coil. Movement of the plunger operates a set of contacts. The force necessary to produce movement of the plunger is proportional to the square of the current in the coil. The minimum value of current or voltage that will cause the plunger to move and operate the contacts establishes the unit's pickup point.

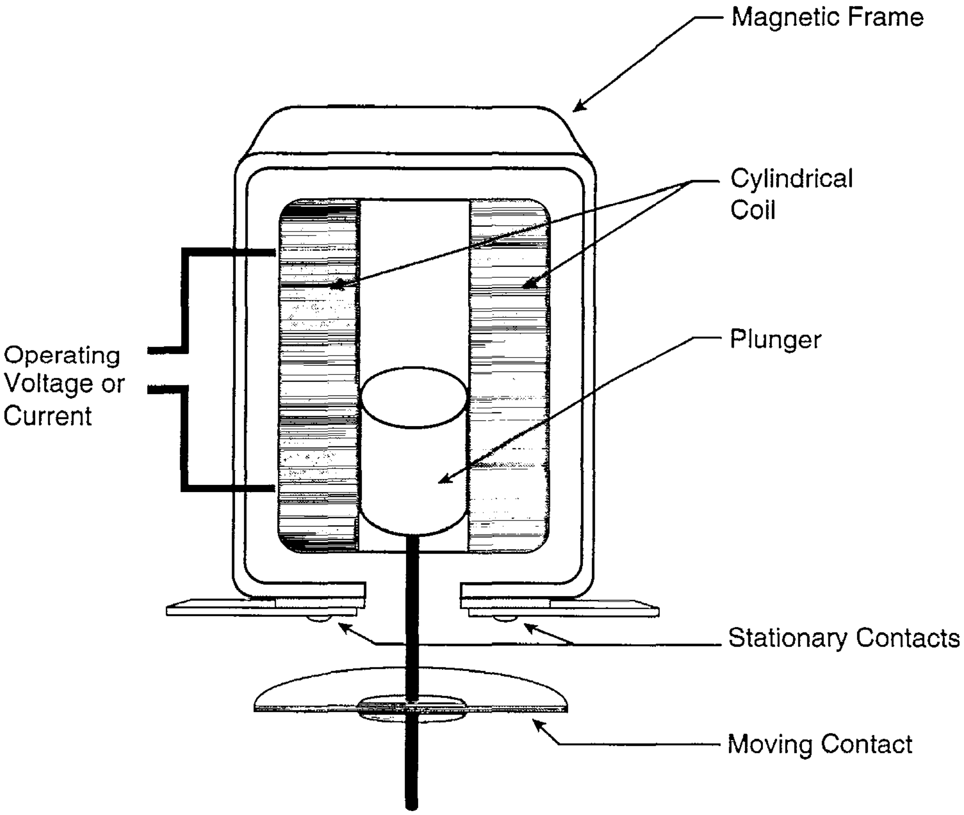


Figure 3-1
Plunger Unit

The pickup point of the device is usually adjustable and is altered by changing the initial deenergized position of the plunger with respect to the coil or by changing the degree of coupling between the plunger and coil.

Common applications for plunger type units are:

- Instantaneous overcurrent protection
- Instantaneous underpower protection
- Instantaneous undervoltage and overvoltage protection

3.1.1.2 Hinged Armature Devices

A representative illustration of a typical hinged armature, or clapper, type unit is shown in Figure 3-2. The unit contains an electromagnet (fixed core surrounded by a coil) and an armature that houses movable contacts. The armature is hinged at one end and is spring restrained in the deenergized position. When current or voltage is applied to the coil, a magnetic field is created by the electromagnet that attracts the armature towards the core, thereby opening or closing a set of contacts. Similar to a plunger type unit: (1) the force necessary to produce movement of the armature is proportional to the square of the current in the coil, and (2) the minimum value of current or voltage that will cause the plunger to move and operate the contacts establishes the unit's pickup point.

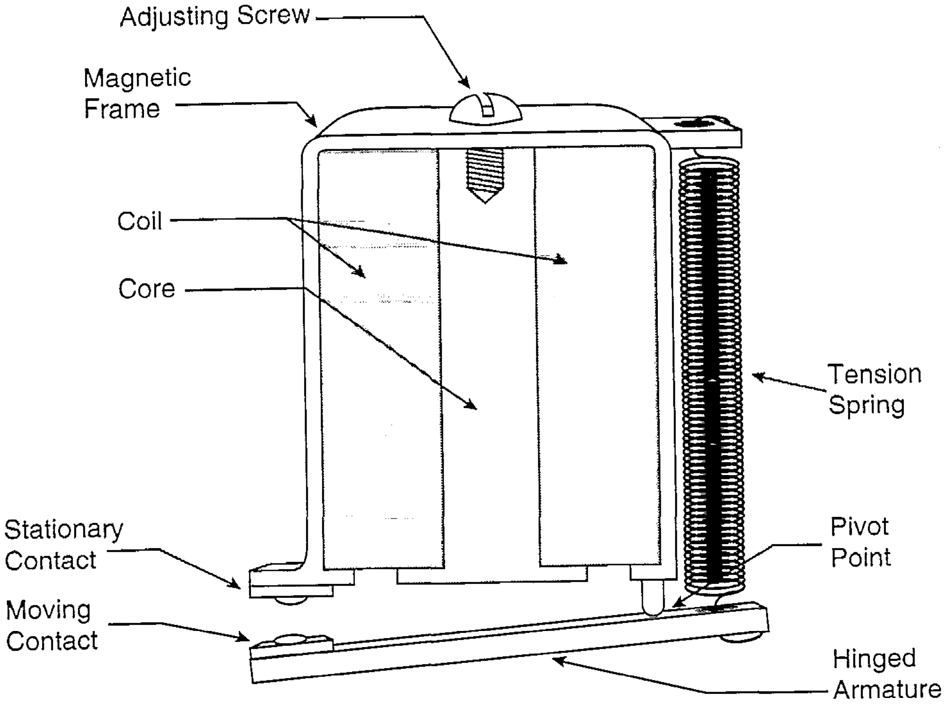


Figure 3-2
Hinged Armature Unit

Some types of hinged armature units are sometimes referred to as "telephone relays". The term originated several decades ago when this type of relay was used extensively in telephone exchange systems. Although not used in this application any longer (most telephone relays today are solid-state switching devices), the term has remained popular for this type of relay. Many manufacturers of protective relays continue to refer to these devices as telephone relays.

The pickup point of a hinged armature unit is usually adjustable and is altered by changing the air gap between the armature and the core or by changing the applied force of the restraint spring. The pickup and dropout setpoints of a hinged armature unit are less accurate than those of a plunger unit.

Hinged armature units are used more extensively than plunger units. Common applications for hinged armature units are-

- Contact multiplication (telephone relay)
- Instantaneous overcurrent protection
- Seal in or contactor switching

3.1.1.3 Polar Devices

A representative illustration of a typical polar unit is shown m Figure 3-3. The unit is constructed with a coil that surrounds a hinged armature. The coil and armature are located in the center of a permanent magnet. Current flowing through the coil magnetizes the armature, causing it to be attracted to the opposite pole of the permanent magnet. The direction of current flow determines the polarity of the armature, and consequently, the position of the moving contacts. Polar devices operate on a dc signal. Thus, when used in an ac circuit, the signal must be rectified. A full wave diode bridge is often used to rectify ac signals.

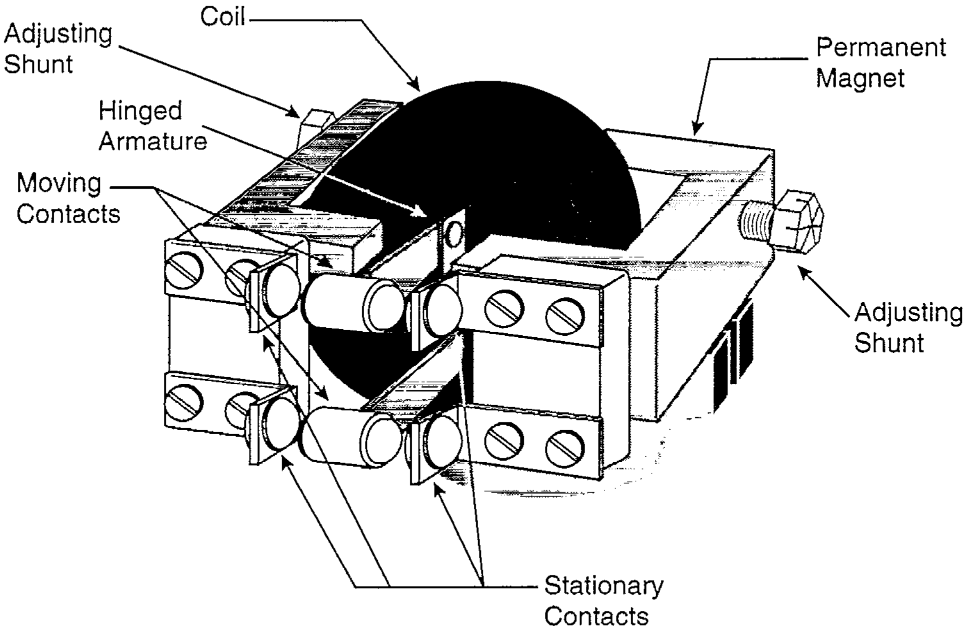


Figure 3-3
Polar Unit

Figure 3-4(a) shows a polar unit in the deenergized state; the armature is floating in the center and the moving contact is not touching the left-side or right-side stationary contact. Figure 3-4(b) shows the unit energized with a signal polarity that closes the left-side contacts. Figure 3-4(c) shows the unit energized with a signal of the opposite polarity.

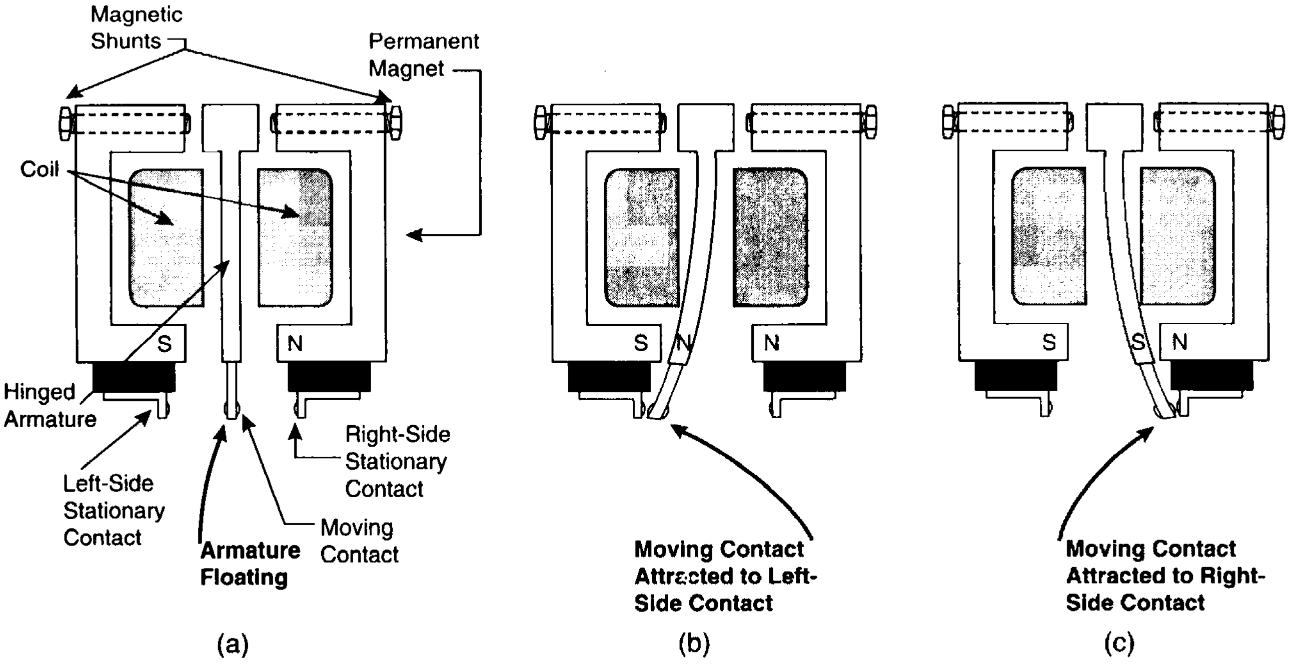


Figure 3-4
Polar Unit Operation

The magnetic shunts shown in Figure 34 can be adjusted to place a bias on the armature. Adjusting the shunts unbalances the armature air gaps, causing some magnetic flux to shunt though the armature. The armature is polarized by the flux shunted through it, even through the coil is not energized. Polarization of the armature places a constant bias in the system that attracts the armature towards one of the two poles. The amount of bias placed on the armature establishes the pickup point of the relay and also defines the "normally open" and "normally closed" contacts.

A polar unit adjusted to maintain a left bias would appear as shown in Figure 3-4(b) when deenergized. For this case, the left-side contact is "normally closed" and the right-side contact is "normally open". When current is passed through the coil in a direction that reinforces the bias, the contacts will not change position. When current of sufficient magnitude to overcome the bias flows in the opposite direction, the unit picks up and the contacts change state as shown in Figure 3-4(c).

It is evident that polar units have the ability to sense direction. Many of the applications for this type of device make use of this feature. Polar devices are very sensitive and are capable of high speed operation. They are also extremely efficient in comparison to a plunger or hinged armature type unit, which results in a low burden to the associated instrument transformer. A low burden is desirable to ensure accurate signal reproduction on the secondary side of instrument transformers.

Common applications for polar units are:

- Differential protection
- Pilot wire protection
- Phase angle measuring
- Directional monitoring

3.1.2 Electromagnetic Induction Units

Assemblies that operate on the principle of electromagnetic induction are the most commonly used units for protective relays. Electromagnetic induction devices are actually split-phase induction motors that contain contacts. Rotational force is developed in a moveable element (the rotor) as a result of the interaction between electromagnetic fluxes and induced eddy currents in the rotor. Electromagnetic induction units are usually characterized by the configuration of the rotor element. The principle of electromagnetic induction is only valid for ac circuits. Two different types of electromagnetic induction units are commonly used:

- Induction disk devices
- Induction cylinder (or induction cup) devices

3.1.2.1 Induction Force

Induction units take advantage of forces generated when a magnetic flux passes through a nonmagnetic, conductive element. Figure 3-5 shows the relationship between flux, current, and force in a rotor element pierced by two fluxes. Each flux induces a voltage around itself, causing current to flow. These induced currents, called eddy currents, interact with the magnetic flux of each other to produce force. The basic principle of operation is that current in the presence of a magnetic field produces force.

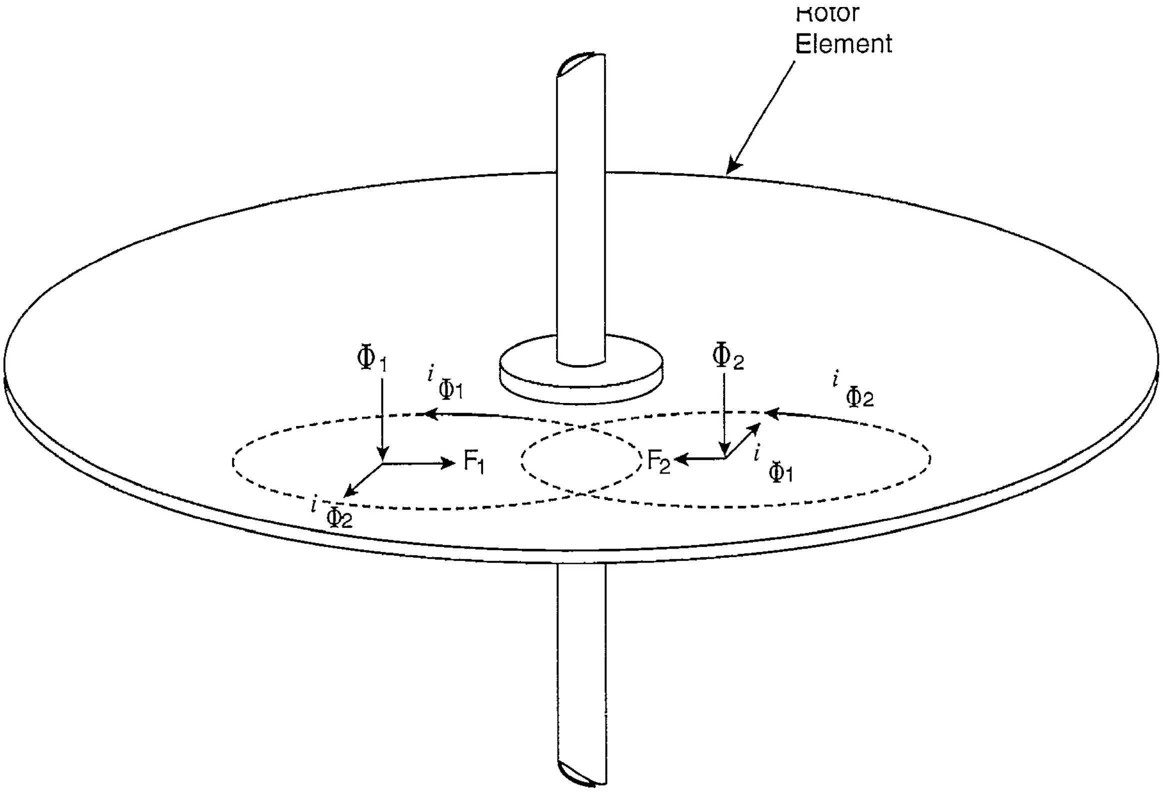


Figure 3-5
Electromagnetic Induction Force

The net force exerted on the rotor is expressed by the following mathematical relationship:

$\mathbf{F \propto \Phi_1\Phi_2 Sin\ \theta}$, where: Φ_1 is the first flux piercing the rotor
Φ_2 is the second flux piercing the rotor
θ is the phase angle between the two fluxes

Several observations are apparent from the above equation:

- The net force on the rotor is zero when the fluxes are in phase (θ = O) since Sin (0°) = O.
- The maximum force on the rotor is derived when the fluxes are 90° out of phase (θ = 90°) since Sin (90°) = 1. This concept is important for understanding maximum torque angles, which are discussed later in the guide.
- The direction of force depends on which flux is leading and which is lagging. This characteristic allows directional control of the rotor element.
- If either of the two fluxes is zero, no net force is produced regardless of the magnitude of the other flux.

3.1.2.2 Induction Disk Devices

Figure 3-6 shows a typical induction disk unit. The induction disk element consists of a nonmagnetic conductive disk (usually aluminum) that is mounted to a rotating shaft. The disk element, which acts as a rotor, is restrained by a precision spiral spring in the deenergized position. The disk element also houses the moving contact. The disk is free to rotate between the pole faces of an electromagnet. The key to producing rotational torque in the disk is based on the interaction between two magnetic fluxes in the disk and the resultant force produced by the fluxes as discussed in the previous section. Two different configurations will be discussed.

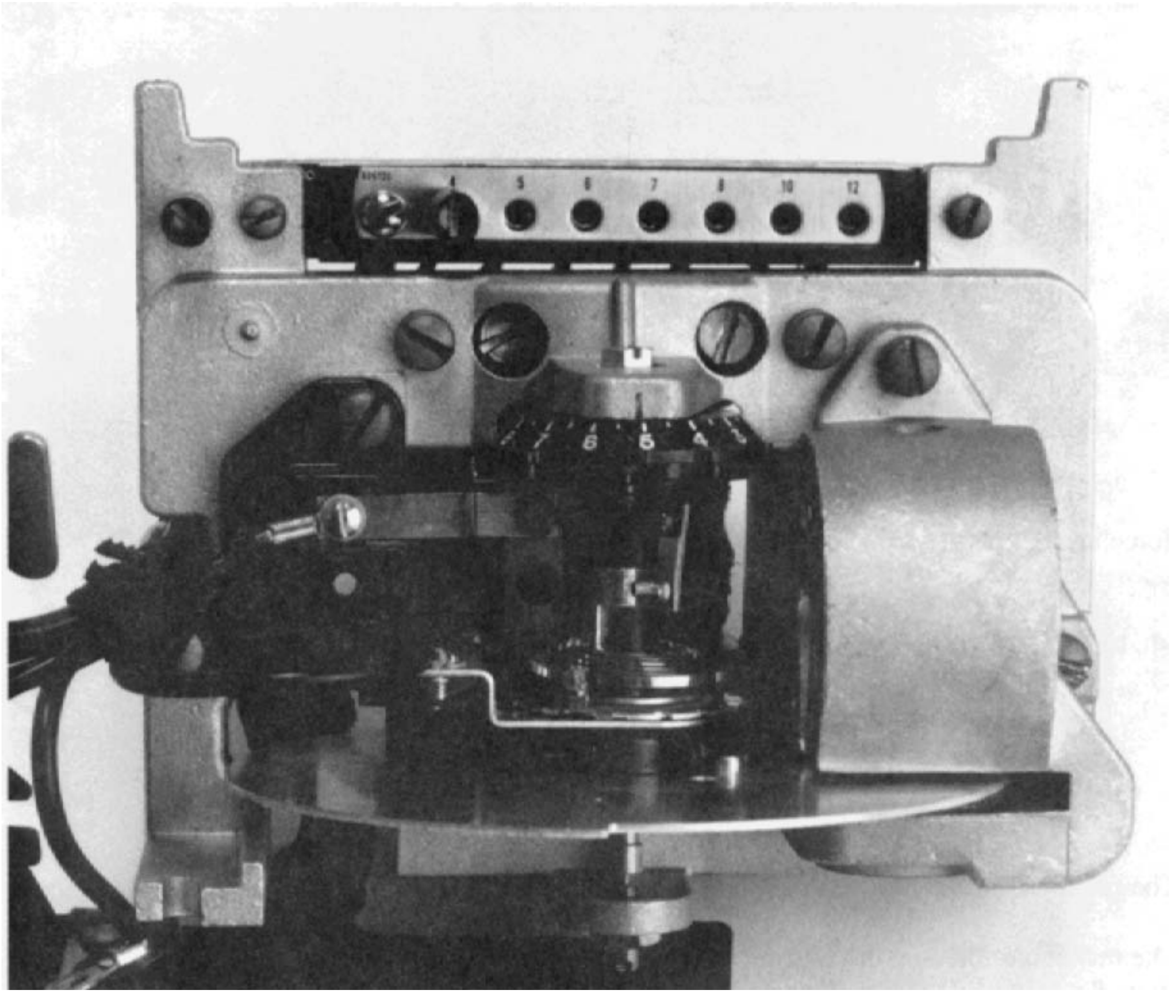
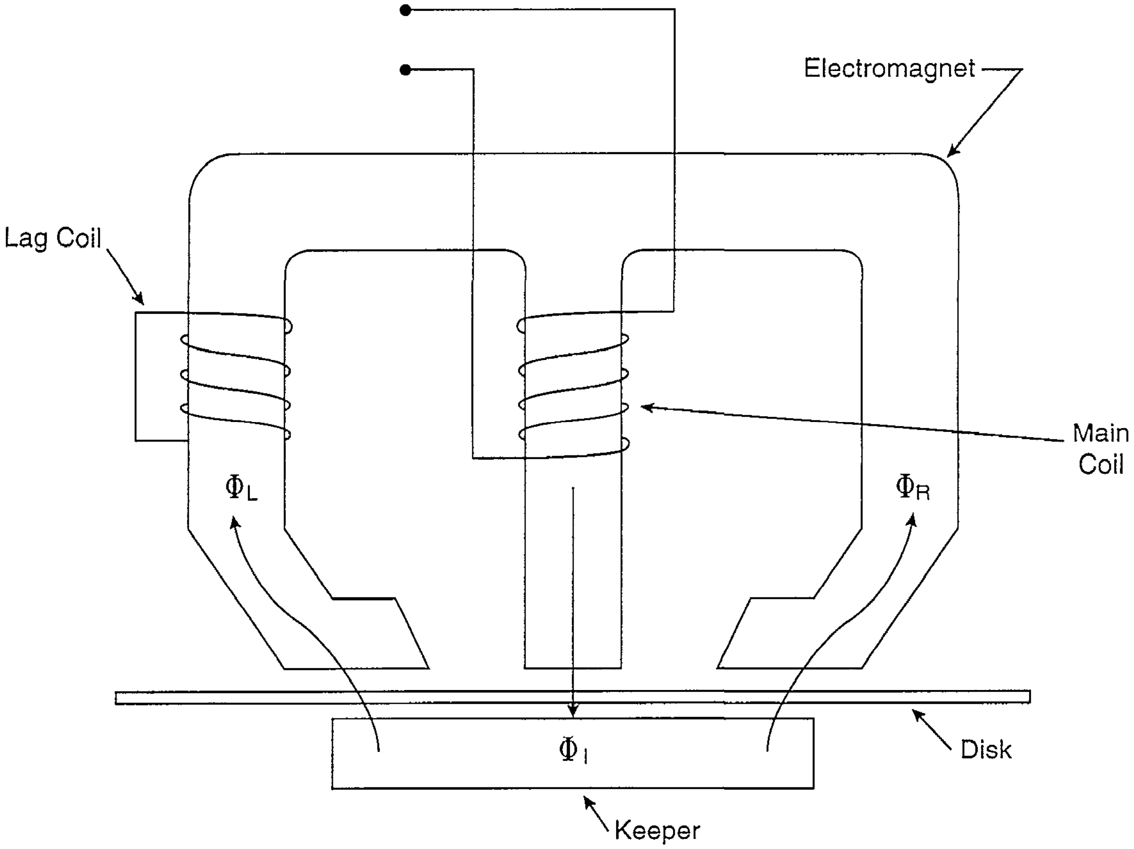


Figure 3-6
Typical Induction Disk Unit

Figure 3-7 represents a lag coil induction disk unit. The purpose of the lag coil (also caned a shading coil) is to produce an out of phase flux that lags the main flux. The unit is constructed using an E-shaped electromagnet and keeper. When current or voltage is applied to the main coil, a magnetic field is produced that passes through the air gap and disk to the keeper. The flux is effectively split in the keeper and returns through both of the outside legs of the electromagnet. The lag coil induces a phase shift m the flux returning through the leg to which it is attached. Thus, the lag coil creates a non-zero phase angle between the fluxes piercing the disk. Consider again the force equation - θ must be a non-zero value to produce a net force on the disk. The combined effect of the main and lag coils produces a net force on the disk. When the magnitude of this force is greater than the pickup value of the unit, the disk rotates. Without the lag coil, $\theta = 0$ and the sum of the forces created in the disk would cancel each other. In this case, the disk would not rotate regardless of the magnitude of the applied signal. The pickup point of the relay is that current or voltage necessary to overcome the friction of the rotating disk and the restraint applied by the spring. The pick up point is adjustable using a series of discrete tap settings for the input signal.



Φ_I → Induced flux

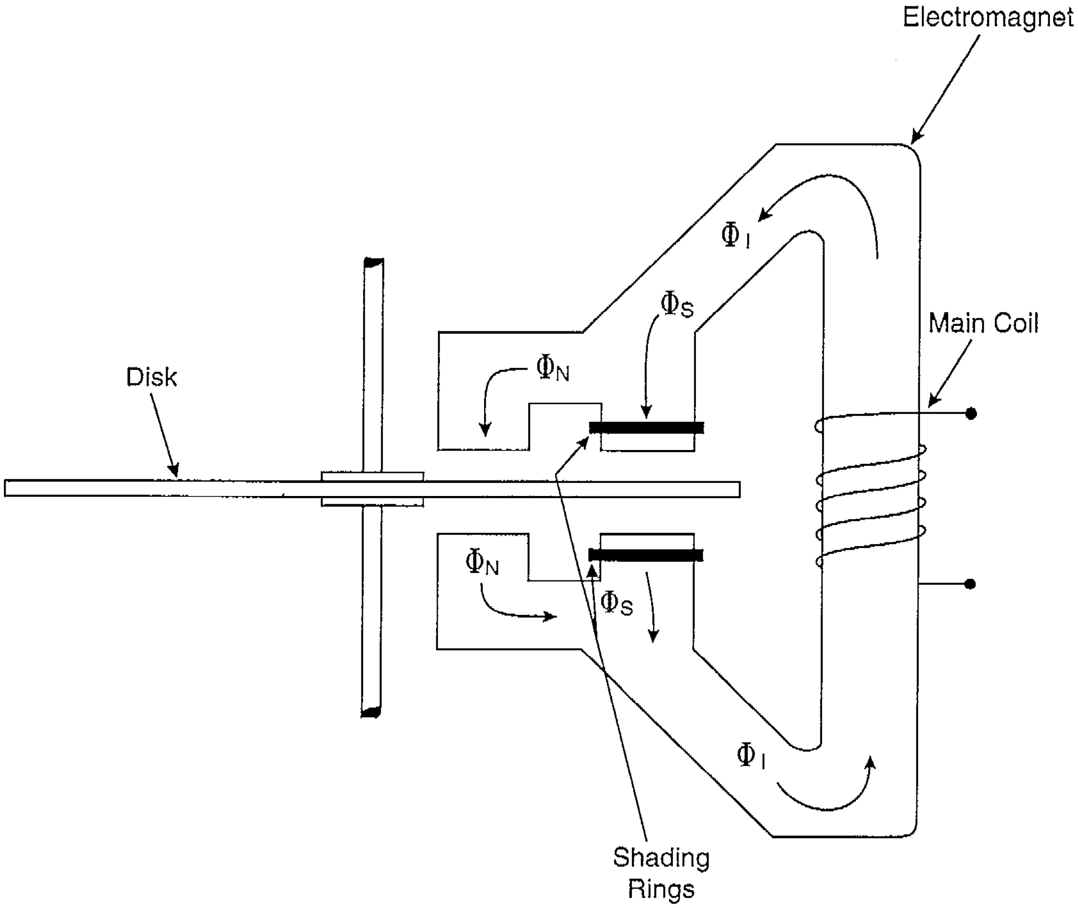
Φ_R → Flux returning through right leg of "E" magnet

Φ_L → Flux returning through left leg of "E" magnet

Note: Φ_L undergoes a phase shift due to the lag coil

Figure 3-7
Lag Coil Induction Disk Unit

Figure 3-8 illustrates an induction unit that uses a shaded pole to produce out-of-phase flux. For this type of unit, a single electromagnet with two sets of poles is used to split the flux. One of the sets of poles contains a shading ring, which induces a phase shift in the flux passing through it. Thus, two out-of-phase fluxes pierce the disk, resulting in a net force on the disk. Note that for both the lag coil unit and shaded pole unit only a single input voltage or current is needed to produce rotational force. The construction of the device serves to split the incoming signal and create the phase angle relationship necessary to produce motion in the disk.



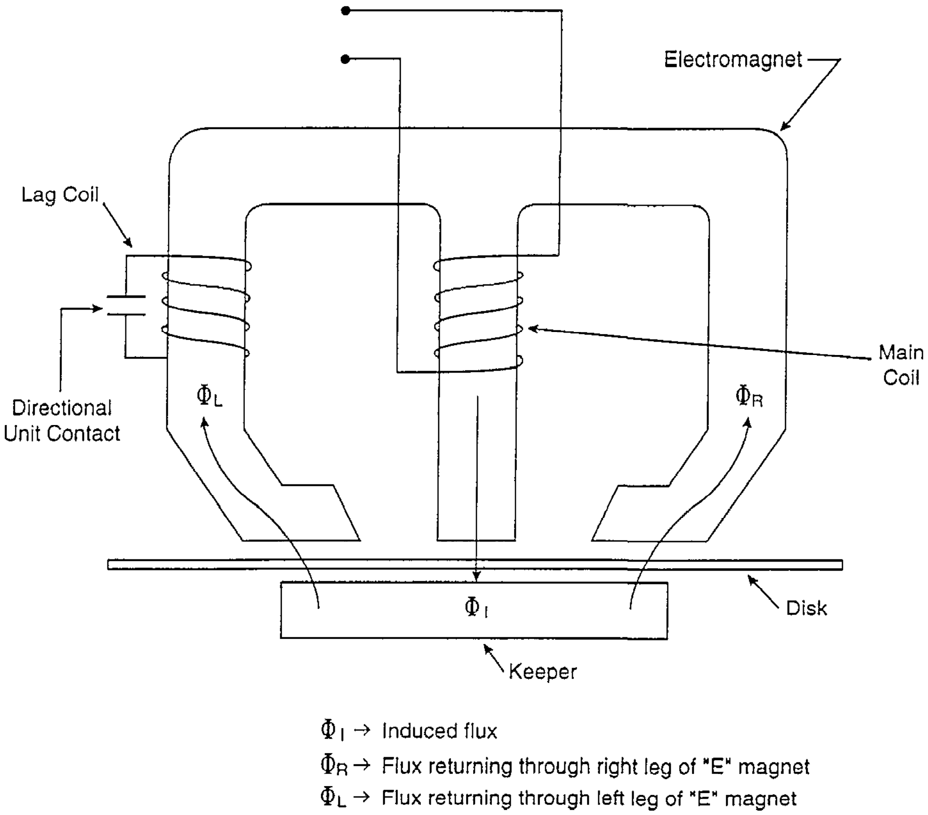
Φ_I → Induced flux
Φ_N → Flux shunted through non-shaded pole of electromagnet
Φ_S → Flux shunted through shaded pole of electromagnet

Note: Φ_S undergoes a phase shift due to the shading rings

Figure 3-8
Shaded Pole Induction Disk Unit

An induction disk unit serves as a time delay device and exhibits inverse-time characteristics. That is, the disk will rotate more rapidly for a larger applied signal. The initial position of the disk determines the amount of rotation necessary to actuate the contacts. Thus, the initial position also affects the timing characteristics of the device. The initial position is set by the unit's time dial; adjustment of the time dial allows the user to coordinate the tripping characteristics of the unit with other protective relays in the power system. Coordination of protective relays is discussed in greater detail in Section 5.

There are many alternate versions of the induction disk unit. The units discussed here operate on a single current or voltage input signal, and the direction of rotation is always the same since the physical construction of the unit fixes the phase angle between the split fluxes. For a lag coil or shading coil to function properly, its windings must be short circuited together. If the windings of the coil are connected via contacts from another relay unit, e.g., a directional unit, the coil may be used to provide additional control features. When the coil is short-circuited by closed contacts, it functions as designed and torque is produced in the disk. If the contacts are open, the coil is effectively removed from the circuit and no phase shift is induced in the flux passing through the coil. Without a phase shift in one of the fluxes, no net force is produced in the disk. This concept is illustrated in Figure 3-9.



Note: ϕ_L undergoes a phase shift only when the directional unit contact is closed and the lag coil is shorted. When the lag coil is open circuited by the directional contact, no phase shift occurs and the net force produced on the disk is zero, regardless of the magnitude.

Figure 3-9
Induction Disk Unit With Directional Control

Another variation of the induction disk unit is to replace the lag or shading coil with a coil receiving a second input voltage or current. Thus, the magnetic fluxes produced in the disk actually come from two separate input signals rather than from a single input signal that is split. Units with this construction are useful in monitoring power, phase angle relationships, and direction.

Induction disk units are widely used in protective relays; common applications include:

- Time overcurrent protection
- Undervoltage and overvoltage protection
- Directional overcurrent protection
- Differential protection
- Current balance detection
- Overpower and reverse power protection
- Synchronism check

3.1.2.3 Induction Cylinder Devices

Induction cylinder units, sometimes called induction cup units, contain a rotating cup or cylinder between the salient poles of an electromagnet. Induction cylinder units resemble a salient pole induction motor in appearance. Figure 3-10 illustrates a typical induction cylinder unit. The inner core of the unit is stationary and only the cylinder surrounding the core is free to rotate in the annular air gap between the poles and inner core. Movement of the cylinder actuates a set of contacts. The cylinder is usually made of aluminum.

Operating torque applied to the cylinder is a function of the magnitude of the two magnetic fields produced by the inputs and the phase angle between the inputs. Movement of the cylinder is initiated when the torque produced by the input signals overcomes the restraining spring torque and friction.

Different combinations of input quantities are used to achieve different functional characteristics. Induction cylinder units are often used for monitoring the direction of current flow. This is accomplished by applying a reference voltage or current signal to one set of poles. This reference signal is called the "polarizing quantity" and is the reference against which the phase angle of the other signal is compared. The second set of poles is supplied with a current signal. When current flows in one direction (presumably the normal direction), the angle between the polarizing quantity and current signal is such that the torque reinforces the restraining spring torque and no motion results. However, when the direction of current flow is reversed, torque is applied to the cylinder in the opposite direction, causing the cylinder to rotate and actuate the contacts.

Induction cylinder units are very sensitive and operate at high speed. Thus, they are used in applications where no intentional time delay is desired. In contrast, recall that induction disk units exhibit time delay characteristics.

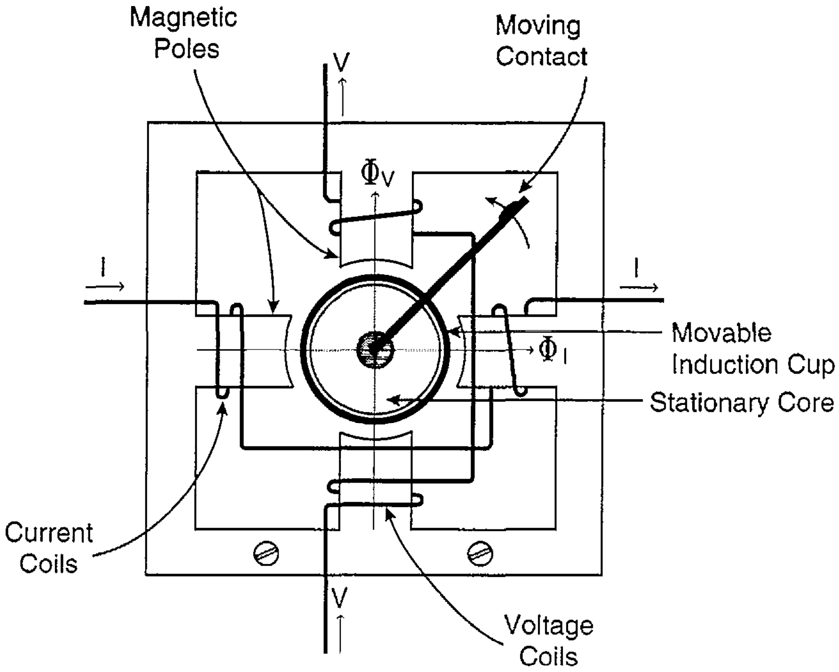


Figure 3-10
Induction Cylinder Unit

3.1.3 Coil Construction for Monitoring Voltage or Current

Both electromagnetic attraction and electromagnetic induction units make use of coils and electromagnets for sensing the incoming voltage or current signal. The coils are constructed to be sensitive to either voltage or current, depending on the application. A coil sensitive to current is wound with few turns of heavy wire. A coil sensitive to voltage contains many turns of fine wire.

A current sensitive coil is connected to the secondary of a current transformer and a voltage coil is connected to the secondary of a voltage transformer.

3.2 Electromechanical Protective Relay Construction

Electromechanical protective relays consist of discrete components and subassemblies mounted to a chassis that fits inside a protective case. The main functional components are the electrical subassemblies that were discussed in Section 3.1. Figure 3-11 shows the main structural parts of a typical electromechanical protective relay.

As previously discussed, the electrical subassemblies inside a protective relay vary depending on the type of relay and function to be performed. The following sections discuss the individual components of an overcurrent relay with both inverse-time and instantaneous overcurrent elements (a protective relay widely used at power plants). This type of relay is useful for explaining relay construction because it has a variety of different electrical subassemblies. Other types of protective relays will not have the same electrical subassemblies; however, the general relay configuration and functional interrelationships between components is valid for all electromechanical protective relays. Section 4 discusses the function and operation of other types of protective relays used at power plants.

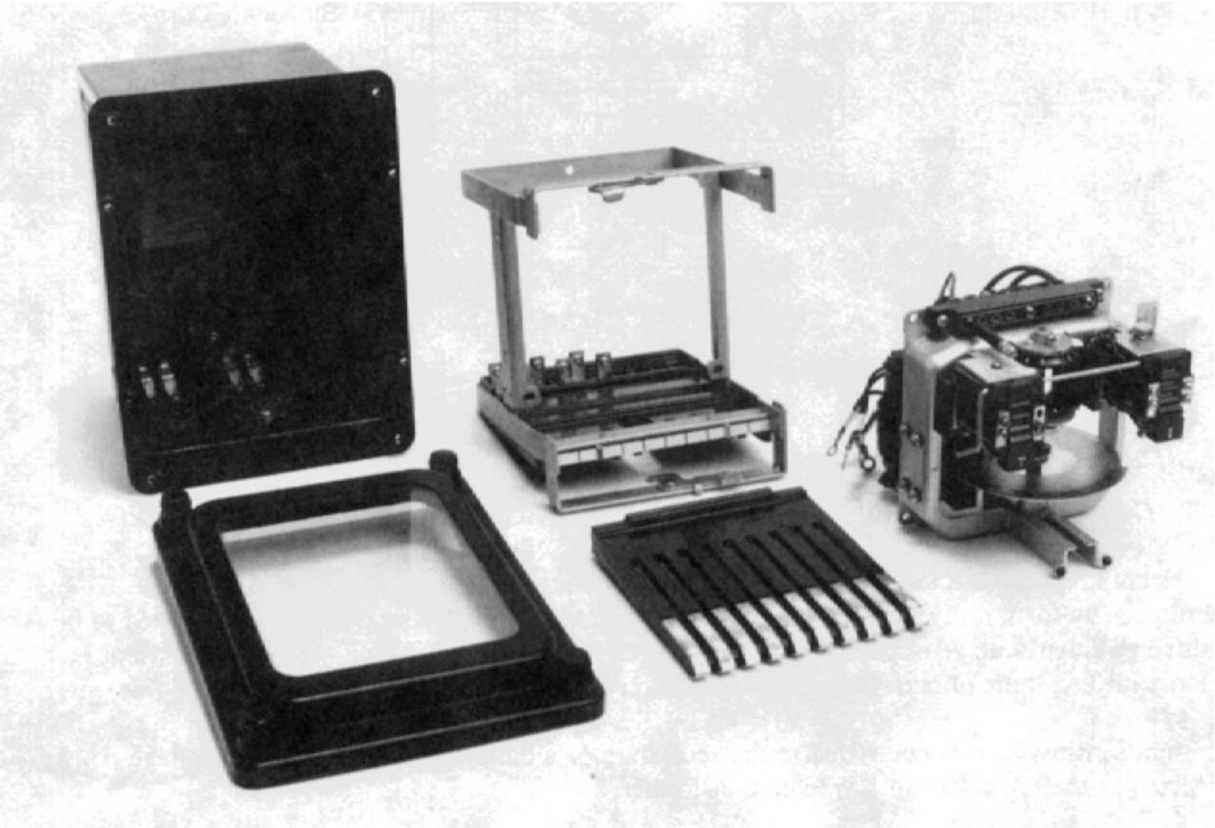


Figure 3-11
Main Structural Parts of an Electromechanical Protective Relay

3.2.1 Case

The case is fabricated from steel and is designed for flush or semi-flush mounting to a switchboard panel. The case is the main structural component and houses the functional parts of the relay; most cases used in power plant applications are of a dust proof design.

Terminals for connection to external circuits are located on the back of the case. The terminals are hard wired to contact fingers or knife-blade type disconnect switches located inside the case. The fingers or switches are mounted to a rigid insulating plastic block for electrical integrity. The contact fingers or switches serve as the normal means of connecting and disconnecting internal relay circuits to external circuits. Figure 3-12 shows a relay case with its contact fingers visible.

NOTE: General Electric models use contact fingers and a connection plug arrangement. Westinghouse models (now built by ABB Power T&D Company) use knife blade disconnect switches.

Figure 3-12
Relay Case With Contact Fingers Visible

Many protective relays require connection to a current transformer (CT). A current transformer may be severely damaged or destroyed if its secondary is open circuited with the primary still energized. To avoid inadvertent damage to CTs, protective relay cases are designed so that the CT circuit is automatically shorted with a shorting bar or shorting tabs when the device is removed from service.

3.2.2 Chassis

The chassis, or cradle, is the mounting platform for all of the functional components of a relay. The chassis is a steel cradle that slips in and out of the relay case. When in service, the chassis is locked in place with hinged locking clips. It is designed as a drawout unit that is easily removed for bench testing or maintenance.

The electrical subassemblies are hardwired to contacts on the chassis assembly. The contacts are firmly mounted to an insulated block, similar in arrangement to that used for the case-side contacts. Figure 3-13 shows a typical relay chassis.

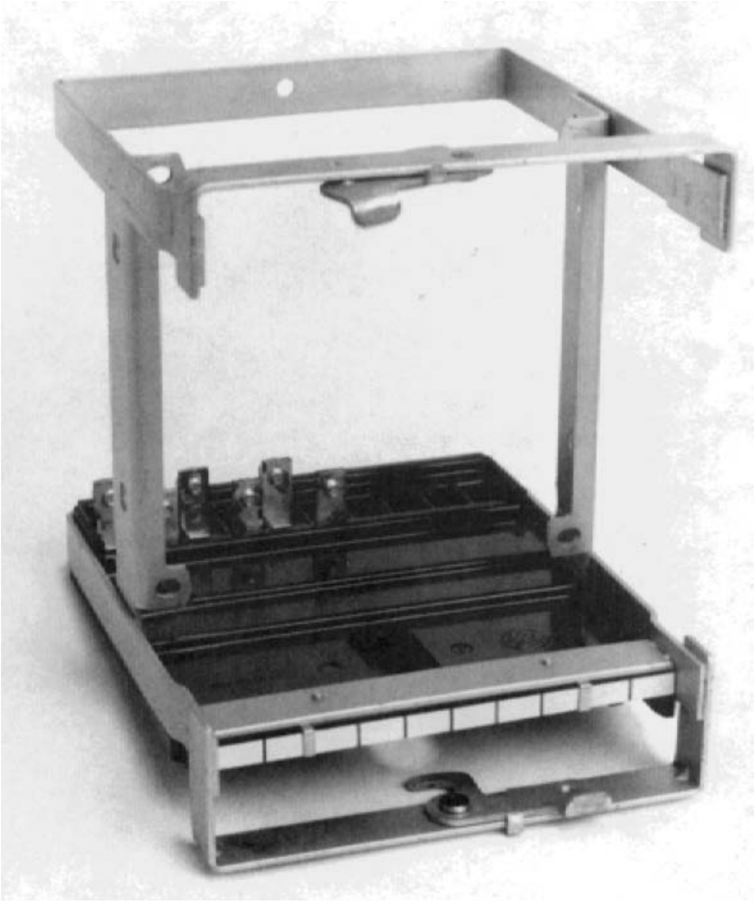


Figure 3-13
Typical Relay Chassis

3.2.3 Connecting Plug and Disconnect Switches

A connecting plug is used for relays that have finger-type contacts on the case and chassis. The plug is made of hard plastic and is effectively a removable contact block that, when installed, makes contact with the fingers on both the case and chassis.

Withdrawal of the connecting plug removes the relay from service. Even if the chassis assembly remains locked in place inside the case, no electrical connection exists between the external circuits and the electrical units of the relay once the plug is removed.

The contact fingers on the case, chassis, and plug are usually silver plated to ensure good electrical contact. A close look at the contact fingers on the chassis reveals that some are shorter than others. The short fingers are associated with the relay's trip circuit. As the connecting plug is removed, these contacts open before the other contacts, thereby ensuring the trip circuit is deenergized before any other circuits are disconnected. Figure 3-14 shows a connecting plug.

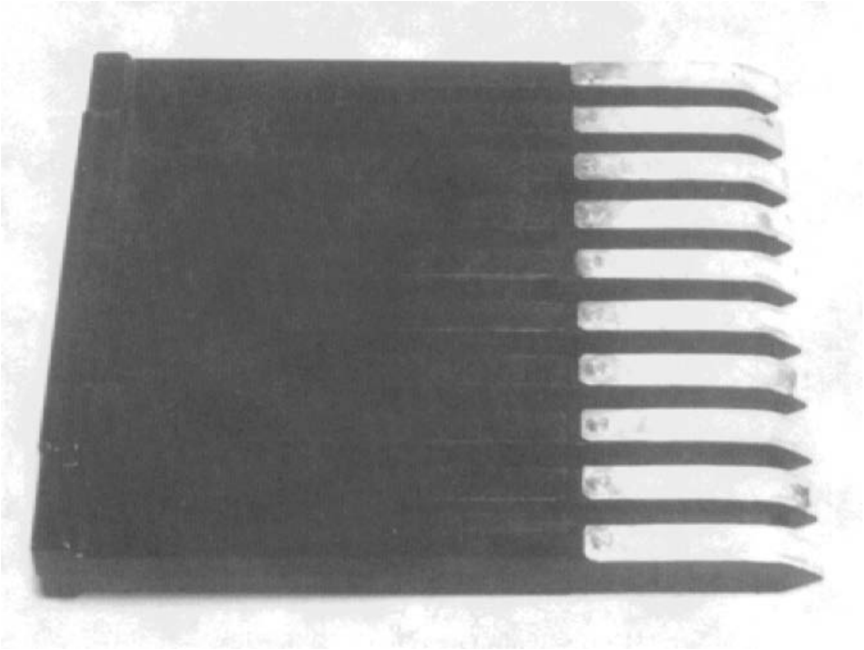


Figure 3-14
Connecting Plug

Relays that use disconnecting switches to establish electrical continuity between case and chassis do not need a connecting plug. The knife blades located on the case are closed into the receiving jaws mounted on the chassis. For this connection system, the disconnect switches are generally opened in a specific sequence to ensure the trip circuit is deactivated before any other circuits are disconnected. Figure 3-15 shows a protective relay configured with knife-blade disconnect switches.

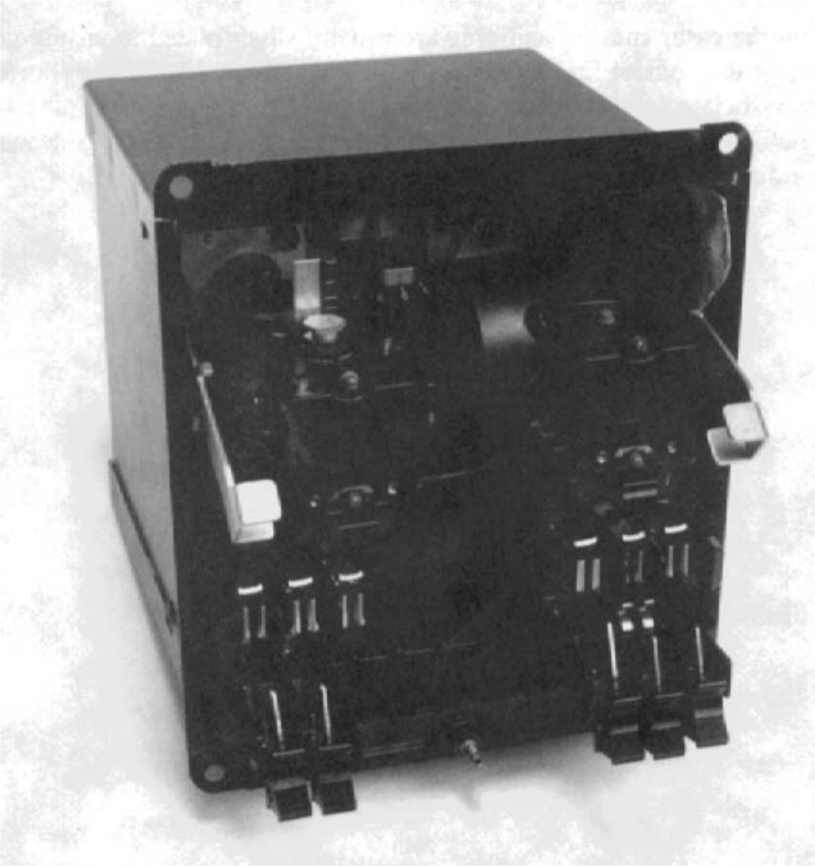


Figure 3-15
Knife-Blade Disconnect Switches

3.2.4 Cover

The cover is made of steel or hard plastic and is attached to the case with knurled knob bolts. The cover generally contains a glass insert through which some of the relay's internal components are visible. A thorough visual inspection of the relay is not practical simply by looking through the glass cover. The primary purpose of the glass cover is to allow easy verification of relay target positions (i.e., whether or not a relay has been actuated or not). The cover is typically lined with a gasket to prevent dust intrusion into the relay.

3.2.5 Time-Overcurrent Induction Disk Unit

The time-overcurrent induction disk unit works on the principle of electromagnetic induction as described in Section 3.1.2.2; it exhibits adjustable inverse-time operating characteristics. The operating time is a function of the applied current; the greater the current the quicker the operating time. A time-overcurrent induction disk unit is shown in Figure 3-16.

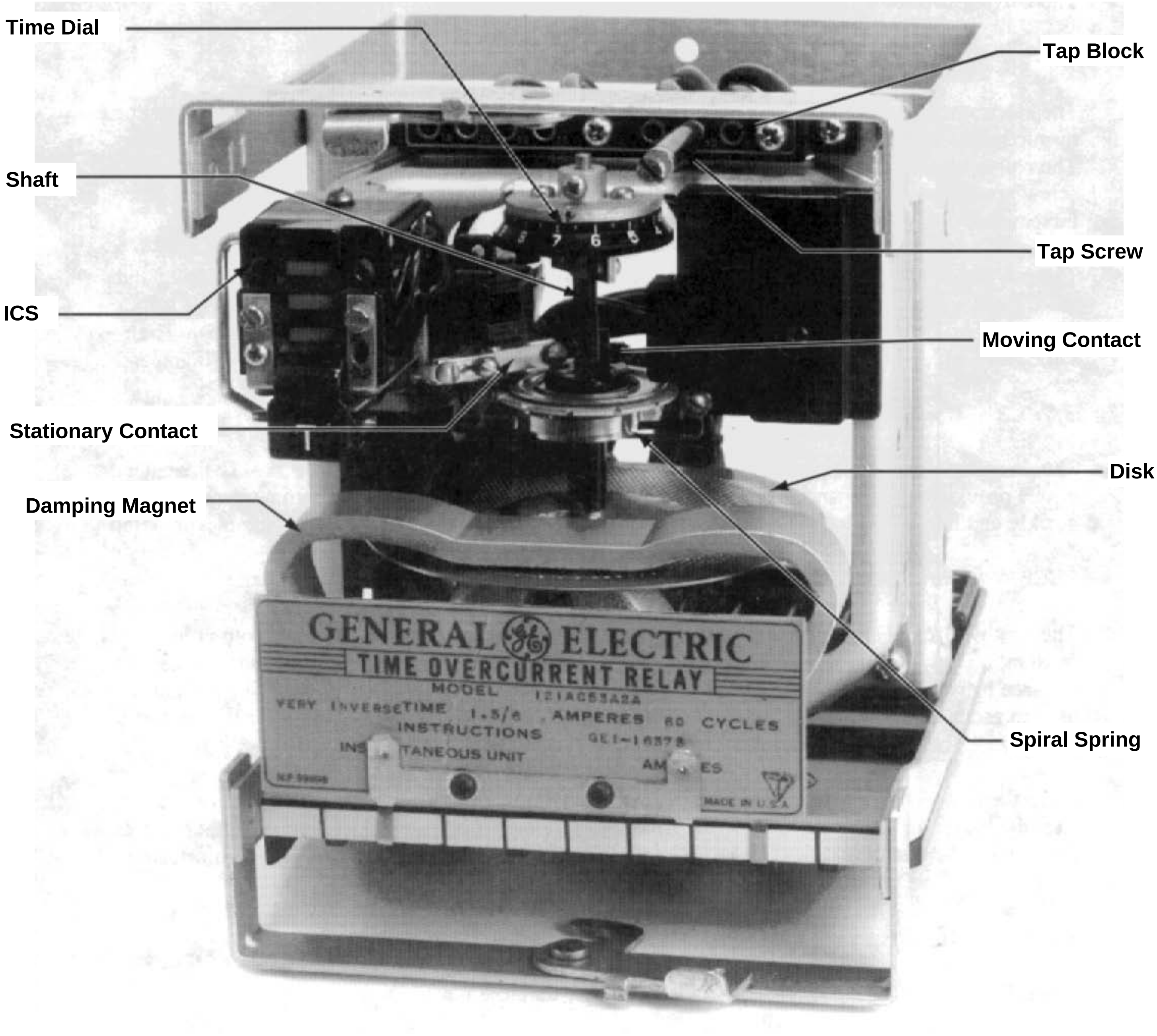


Figure 3-16
Time-Overcurrent Induction Disk Unit

3.2.5.1 Disk and Shaft Assembly

Major components of the disk and shaft assembly are shown in Figure 3-16. The disk itself is conductive, nonmagnetic, thin, and spiral in shape. The disk must be conductive to allow eddy currents to flow. It cannot be magnetic; otherwise, it would be attracted to the electromagnet. Disks are made of aluminum (the disk for some older relays may be made of copper). A disk's spiral shape ensures uniform pickup over its full adjustment range. The disk is connected to an insulated shaft that pivots between a jewel bearing and top pin. The design provides very low rotational friction. The moving contact is connected to the shaft.

3.2.5.2 Electromagnet

The electromagnet of an induction disk unit converts the current signal from the CT to a proportional magnetic flux that is induced in the disk. The coil of the electromagnet is designed to sense current. The coil is tapped at different locations to provide adjustable pickup points. A tap block and tap screw are used to select the current value at which the relay picks up. The tap settings are in discrete increments; different coils may be used to provide different tap ranges.

The magnitude of line current that will cause the relay to pickup is a function of the tap setting and the CT ratio. For example, a CT with a ratio of 400/5 connected to a time-overcurrent unit with a tap setting of 3.0 amperes will pick up when line current exceeds 240 amperes (3 x 400/5). The same relay with its tap setting changed to 8.0 amperes will pick up at a line current of 640 amperes.

3.2.5.3 Damping Magnet

The damping magnet is a permanent magnet that provides counter torque to the disk. The counter torque provides stability and repeatability to disk rotation. It prevents the disk from operating too quickly and minimizes inertial rotation of the disk once current has dropped below the pickup point.

3.2.5.4 Time Dial

The disk will rotate at a constant angular speed if the applied current exceeds the pickup point and is constant. Thus, the time necessary for the disk to rotate and close the contacts depends on the initial distance between the stationary and moving contacts for a given level of current. The time dial is used to establish the initial position of the moving contact by providing a backstop for the contact to rest upon. The moving contact is held in place against the backstop by a spiral spring.

Since the time dial does not affect the rate at which the disk rotates for a given current, it does not alter the basic time-current characteristic curve of the relay. Increasing the time dial setting increases the distance between the contacts and therefore increases the amount of time necessary to actuate the relay.

3.2.5.5 Spiral Spring

The delicate spiral spring is made of a copper alloy. Its three functions are to:

- Provide restraint torque on the disk assembly. The restraint torque applied by the spring determines the minimum amount of force necessary to rotate the disk. The spring is used to calibrate the pickup point once a tap setting is selected.

- Provide negative torque to reset the disk against the time dial backstop after the relay has operated.

- Provide a temporary current path for the dc tripping current when the relay's contacts are first actuated and before the contactor switch has closed. If the spiral spring carries the tripping current for a prolonged period of time, it will overheat. Overheating can anneal the spring and change its restraint characteristics.

3.2.6 Indicating Contactor Switch

A contactor switch that includes an integral operations indicator (also called a target or flag) is referred to as an indicating contactor switch (ICS). An ICS unit is shown in Figure 3-16.

An ICS unit provides three functions:

- It shunts tripping current away from the induction disk unit's delicate spiral spring. As discussed in the previous section, the spiral spring is not intended to carry full tripping current for an extended period of time.

- It seals in the trip signal until the circuit breaker's auxiliary position contact ("a" contact) interrupts the signal. This action ensures the main relay contacts do not inadvertently attempt to interrupt the tripping signal. The main contacts are not designed to interrupt full tripping current.

- It provides a visible target that indicates the ICS has operated and the tripping circuit has been actuated. The target must be manually reset.

ICS units are generally a hinged armature design. The contacts of an ICS are connected in parallel with a relay's main induction disk contacts and are normally rated for 30 amperes. Thus, the contacts are designed to handle the heavy trip current. An ICS coil is usually configured with two taps: 0.2 amperes and 2.0 amperes. The larger tap setting is used when the relay actuates the trip coil of a circuit breaker directly. The smaller tap setting is used when the relay actuates an auxiliary relay, thereby avoiding the heavy trip current.

When an ICS is energized and picks up, its contacts operate and seal-in the trip signal until the circuit is opened by the circuit breaker's auxiliary position contact. Actuation of the ICS contacts also sets a visible flag, or target, that indicates the unit has operated.

Some relays do not contain induction disk units and thus do not need a contactor switch. However, it may still be desirable to know if the relay has operated. In this case, a target unit or operations indicator is used instead of a combined seal-in and indicating unit. A target unit operates virtually the same as a seal-in unit except it only sets a flag when energized; it does not operate seal-in contacts.

3.2.7 Instantaneous Overcurrent Unit

Instantaneous overcurrent units are plunger or hinged armature devices that operate immediately (no intentional time delay) upon detecting a predetermined level of fault current. The pickup point of instantaneous units is adjustable. Similar to ICSs, most instantaneous units are configured with a target to indicate when the unit has operated. Figure 3-17 shows a hinged armature type instantaneous overcurrent unit.

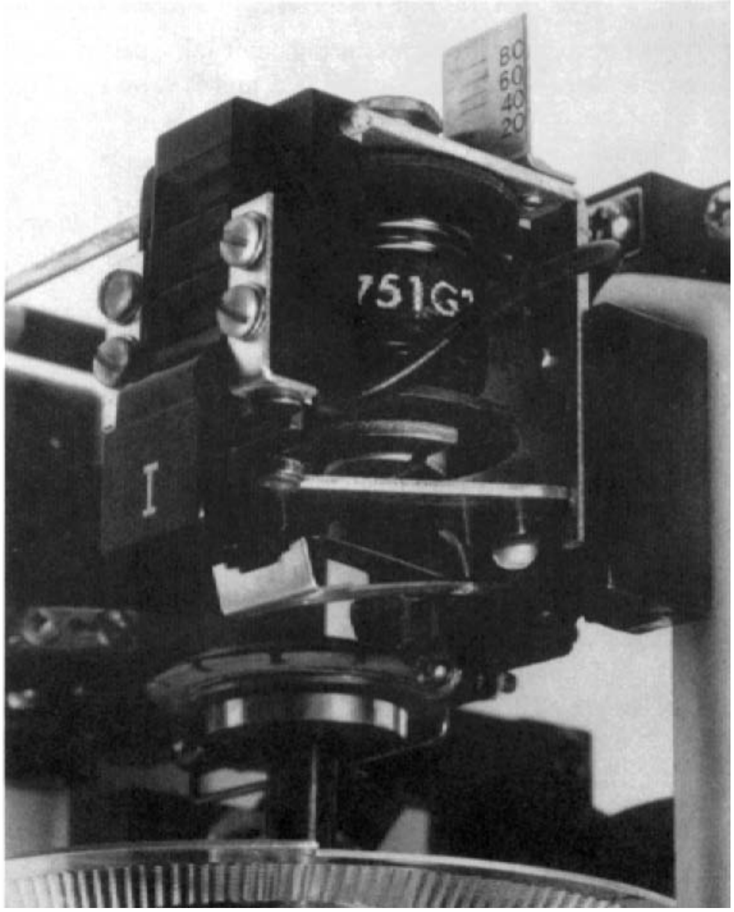


Figure 3-17
Instantaneous Overcurrent Unit

3.2.8 Integrated Operation

The integrated operation of an overcurrent relay containing both inverse-time and instantaneous trip units is discussed in this section. Figure 3-18 illustrates an overcurrent unit with all external connections and will be used to facilitate the discussion of integrated operation.

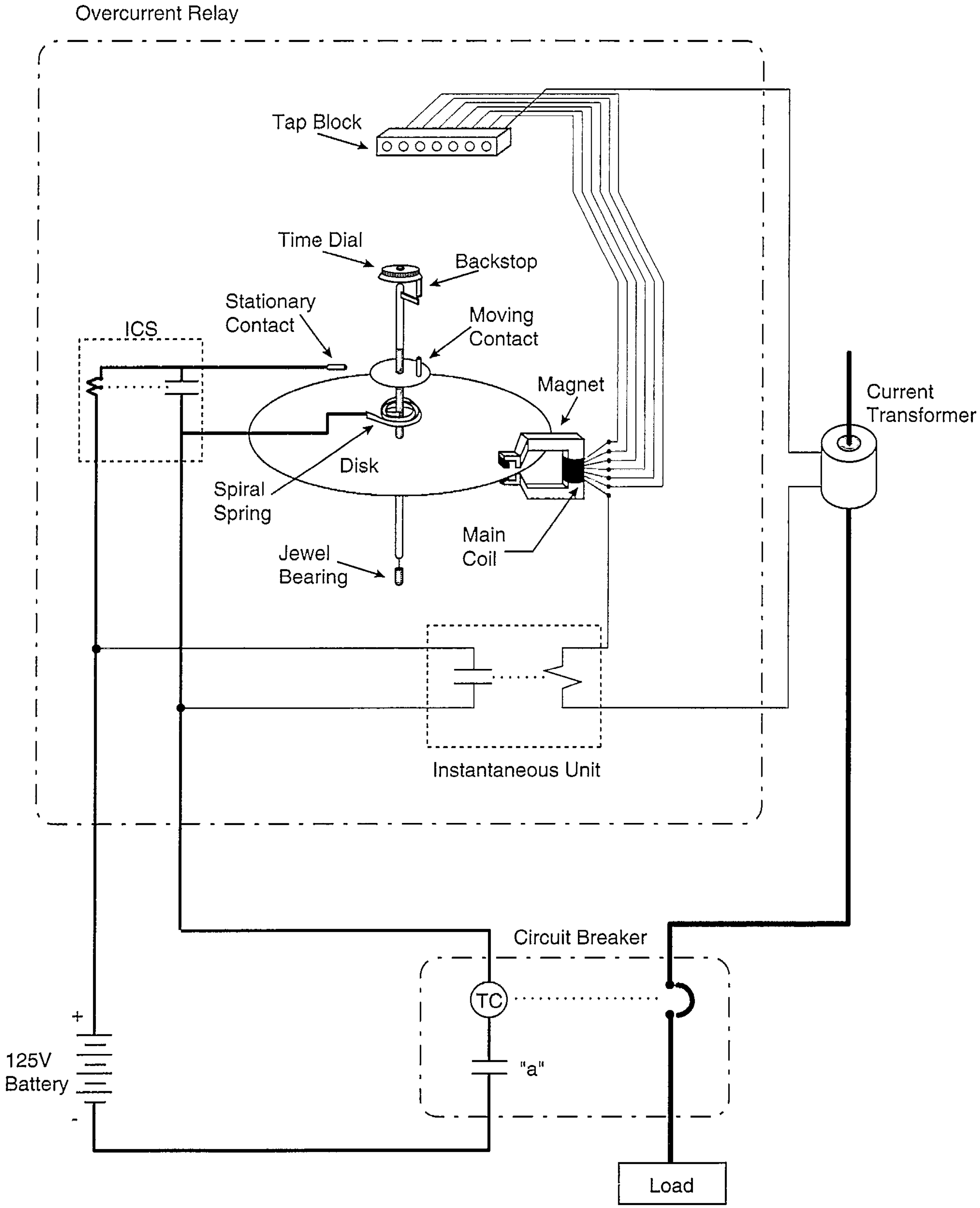


Figure 3-18
Overcurrent Protective Relay Integrated Operation

For discussion purposes assume the unit shown in Figure 3-18 operates with the following parameters:

Primary System Voltage:	12,470 volts
Normal Full Load Line Current:	102 amperes
CT Turns Ratio:	200/5
Pickup Point:	120 amperes (line current)
Relay Tap Setting:	3 amperes (118% of full load current)
Relay Time Dial Setting:	6.5
Instantaneous Trip Setting:	960 amperes (line current)
Instantaneous Unit Pickup:	24 amperes (secondary current)
Tripping Power:	125 volts dc
ICS Tap Setting:	2.0 amperes

3.2.8.1 Normal Operation

During normal operation, the CT is sensing line current and providing a secondary current signal to the relay in proportion to the CT's turns ratio. The CT, with a 200/5 ratio, is sensing a line current of 102 amperes and providing a secondary current signal of 2.55 amperes [102 x (5/200)] to the relay.

Since the relay current, 2.55 amperes, is less than the pickup point (i.e., the tap setting), the restraint spring holds the disk in the reset position against the backstop and the main contacts are open. The CT is also providing a current signal to the instantaneous trip unit, which is in series with the induction unit coil. Because the normal relay current of 2.55 amperes is well below the instantaneous pickup, the instantaneous unit's contacts are also open.

With the main induction unit contacts and instantaneous unit contacts both open, the tripping circuit is deenergized and the ICS contacts are open.

The circuit breaker is closed so its "a" position contacts are also closed.

3.2.8.2 Overload or Low-Level Fault

Assume the circuit is now subjected to a heavy overload of 200%. This results in a primary line current of 204 amperes and a secondary current of 5.10 [204 x (5/200)] amperes. The secondary current is still below the instantaneous setting so the instantaneous unit remains idle. However, the overload current is above the induction unit pickup point, thus the magnetic flux from the main coil induces a force in the induction disk greater than the restraint force exerted by the spiral spring. The disk begins to rotate the moving contact toward the stationary contact. The amount of rotation, or travel, is determined by the time dial setting. When the disk completes its travel and brings the moving contact and stationary contact together, a current flow path is established for the tripping circuit.

With the main induction unit contacts closed, dc tripping current is allowed to flow through the ICS coil, the main contacts, the disk stem (conducting portion), the spiral spring, the circuit breaker trip coil, and the circuit breaker "a" position contacts. As soon as dc current flowing through the trip circuit exceeds the ICS tap setting of 2.0 amperes, the ICS coil (which is an electromagnetic attraction device) generates sufficient force to move the hinged armature and close the seal-in contacts. Once the seal-in contacts are closed, a majority of the tripping current is shunted through the seal-in contacts and away from the induction unit components. During this time, the trip coil is energizing to trip the circuit breaker. The operations indicator is actuated concurrently with the seal-in contacts.

As the circuit breaker begins to open, line current falls rapidly causing the secondary current in the relay to also decrease. When current has fallen to approximately 60% - 70% of tap value the induction unit will begin to reset, thereby opening the main induction unit contacts. The seal-in unit will remain picked up so that the main contacts do not interrupt the current. The trip circuit is opened when the breaker's "a" position contacts open, reflecting the circuit breaker's open position. The seal-in contact is the last contact in the trip circuit to open (the ICS coil has a low dropout).

Subsequent to the protective action, the circuit breaker is open, relay current is zero, the relay induction unit is reset, and the ICS is deenergized. The ICS target indicates that a protective action occurred. The target must be manually reset.

3.2.5.5 High-Level Fault

Assume a fault occurs at the load causing a short circuit current of 1,900 amperes. A line current of 1,900 amperes causes a secondary current of 47.5 amperes [1,900 x (5/200)] to flow from the CT to the relay. The secondary current is well above the induction unit tap setting so the induction disk picks up and starts to rotate. However, before the induction disk completes its travel, the instantaneous unit initiates a trip. The 47.5 amperes is above the instantaneous unit's pickup setting of 24 amperes.

The high magnitude current causes the instantaneous unit's coil to energize and close its contacts with no intentional time delay. When the contacts close, continuity is established for the dc tripping circuit. Current flows through the trip coil, the instantaneous unit contacts, and the circuit breaker "a" position contacts. Note from Figure 3-19 that current does not flow through the ICS or induction unit contacts. The instantaneous unit's target is actuated simultaneously to indicate that a protective function has occurred. The circuit breaker opens as described previously.

Subsequent to the protective action, the circuit breaker is open, relay current is zero, the instantaneous unit is deenergized, the relay induction unit is reset, and the ICS is deenergized. The instantaneous unit's target indicates that a protective action occurred. The target must be manually reset.

3.3 Design Requirements

Several aspects of relay design and construction are standardized, regardless of the function of the protective relay. The following sections discuss some of the more important design considerations.

3.3.1 Service Conditions

Relays are designed to operate in a typical industrial environment. Relay designs conforming to applicable industrial standards are suitable for operation at ambient temperatures from -20°C (4°F) to +55°C (131°F). The ambient temperature in this case is the air temperature immediately surrounding the relay case or enclosure and is not simply the prevailing ambient temperature of the general area. Relays are designed for proper operation at altitudes of 5,000 feet and below. Altitude affects the operation of electrical contacts.

Other environmental or service conditions, if excessive, can affect proper relay operation. Potentially adverse factors include:

- Fumes and vapors
- Excessive moisture or dripping water
- Excessive dust or dirt
- Steam or extremely high humidity
- Explosive mixtures of dust or gas
- Salt air
- Abnormal shock, vibration, or seismic events (see Section 3.3.3.5 for seismic testing)
- Sudden temperature changes
- Gil vapor
- Extreme voltage variations

The above adverse conditions may require special construction or operating restrictions. Potentially adverse service conditions - for which the relay may not be designed - should be taken into consideration when specifying a relay for a particular application.

3.3.2 Ratings

Protective relays contain sensitive electrical components that are designed to operate at specific values of voltage and current. Standard voltage and current ratings for protective relays are shown in Table 3-1.

Table 3-1
Standard Voltage and Current Ratings for Protective Relays

Voltage (ac)	Voltage (dc)	Current (A)
120	24	1
240	48	5
480	125	
	250	

The operating coils of a protective relay typically determine the relay's rating. As a minimum, the maximum design voltage or current for the relay must equal the relay's rating. The maximum design rating is the value at which the relay is designed to be energized continuously without exceeding the allowable temperature rise (55°C) for the class of insulation associated with the relay coils. Many relays are designed to carry current in excess of the rated current.

Additional requirements apply for some types of voltage-operated relays. Protective relays that are energized continuously by ac voltage must be designed to operate without damage at voltages 10% above the rated voltage. Auxiliary relay circuits with dc voltage ratings must have a maximum design voltage of:

- 28 volts for a 24 volt system
- 56 volts for a 48 volt system
- 140 volts for a 125 volt system
- 280 volts for a 250 volt system

These ratings apply to the portions of a protective relay that are directly connected to the trip circuit of a circuit breaker operated by dc control power.

The contacts of a protective relay that are used to energize the trip coil of a circuit breaker must be designed to carry 30 amperes for at least 2000 operations if the relay is to meet industry standards. Since contacts in this category are usually bypassed by a seal-in unit once the circuit is energized, the contacts are only required to carry 30 amps momentarily and are not required to interrupt the current.

3.3.3 Design Testing

Design testing is performed to validate that a particular relay's design, construction, and materials perform as expected and are adequate for use in the intended application.

3.3.3.1 Dielectric Testing

Dielectric testing is performed to ensure adequate insulation resistance between circuits, between circuits and ground (relay frame), and across open contacts. Relays must withstand a low frequency test voltage of twice rated voltage plus 1000 volts rms or 1500 volts rms, whichever is larger. The test duration is 60 seconds.

Full strength dielectric testing is not recommended once a relay is in service. The normal convention is to use 75% of the full strength test values for field testing.

3.3.3.2 Surge Withstand Capability

When solid-state relays entered the market, concerns arose over their ability to withstand credible surges and the need for standardized surge testing became evident. In response, standardized surge tests were developed to ensure adequate surge withstand capability (SWC) of protective relay systems. SWC testing is a design test and is not usually performed on all production units or by users.

SWC testing includes two tests, an oscillatory waveform test and a fast transient test. The oscillatory waveform is a high frequency, decaying waveform between 2.5 KV and 3.0 KV. The oscillatory test waveform is representative of surges measured on actual systems. The fast transient waveform is a unidirectional wave with an extremely rapid rise time to a crest voltage between 4 KV and 5 KV. The fast transient test simulates surges caused by interruption of inductive devices. The test was only recently standardized. Thus, older relay designs most likely were not subjected to this type of surge testing.

3.3.3.3 Radiated Electromagnetic Interference

The electromagnetic fields produced by portable communications devices can affect the proper operation of semi-conductor devices. For this reason, solid-state protective relays are tested to ascertain their susceptibility to electromagnetic fields in the radio frequency domain.

3.3.3.4 Qualification for Class 1E Applications

Rigorous qualification testing is performed on protective relays designed for use in nuclear plant Class ME systems. Qualification testing demonstrates the design adequacy of equipment under normal conditions, abnormal conditions, during a design basis event, and subsequent to a design basis event. Qualification testing for protective relays usually does not include environmental qualification because relays are not generally located in harsh environments.

A protective relay test program consists of aging, performance and seismic evaluations. Significant aging mechanisms evaluated include time and temperature effects, operating cycles, and radiation. Other aging mechanisms are not considered significant for expected applications. Seismic evaluation of electromechanical relays is generally of greatest concern because of the potential for contact chatter during a seismic event.

3.3.3.5 Seismic Testing

Seismic testing of protective relays is required for Class 1E applications at nuclear plants. However, in locations particularly susceptible to earthquakes, seismic testing is often specified for critical protective relay applications as an additional precaution.

4.0 Types of Protective Relays - Application and Operation

Many different types of protective relays are available. Section 4 is intended to familiarize readers with protective relay applications and to review the fundamental operating principles of these devices. Protective relays most often used at power generating plants are emphasized.

4.1 Distance Relays (21)

4.1.1 Applications

4.1.1.1 Primary and Backup Line Protection

Distance relays are used to provide primary and backup fault protection for transmission lines. Transmission line protection is quite involved and requires considerable expertise to optimize both protection and system continuity. The reach (reach is a term used to describe the electrical range of the relay) of each distance relay is carefully selected to achieve the desired level of primary and backup protection for overlapping zones of protection.

4.1.1.2 Generator Phase Fault Backup Protection

Distance relays are frequently used on generators larger than about 100 MVA to provide backup protection for the generator against a system fault that is not cleared by other system protective devices. For this application, the distance relay is set with a reach that extends through the unit transformer and out into the first zone of the transmission system. The relay is coordinated with switchyard and transmission line primary distance relays so that it affords every opportunity for the primary protective relays to clear a system fault without unduly risking generator damage.

4.1.2 Principles of Operation

Distance relays monitor the voltage and current of a line to determine the effective impedance or admittance of the line. Distance relays respond to system impedance and not to the magnitude of current. This feature allows a distance relay to discriminate against faults outside of its zone of protection, unlike an overcurrent relay. The most commonly used distance relay is the mho-type relay.

A mho distance relay measures complex admittance of the protected line. The measured admittance is compared to the relay's operating characteristics and a protective action is initiated if the admittance falls within predefined limits. The operating characteristics of the relay are represented by a circle on an R - X diagram (resistance - reactance diagram). A typical characteristic diagram for a mho relay is shown in Figure 4-1. Three attributes characterize a mho circle; these attributes are:

1. Offset: The distance from the origin of the R - X axis to the closest point on the circumference of the characteristic circle. Note that offset is not the distance between the R - X origin and the center of the circle.

2. Reach: The maximum impedance the relay will detect along the angle of maximum torque. The reach of a distance relay determines the maximum distance down the transmission line that the relay is programmed to sense (i.e., a fault beyond the relay's reach will not cause relay operation).

3. Angle of Maximum Torque: The angle that the mho circle diameter makes with the R - X axis.

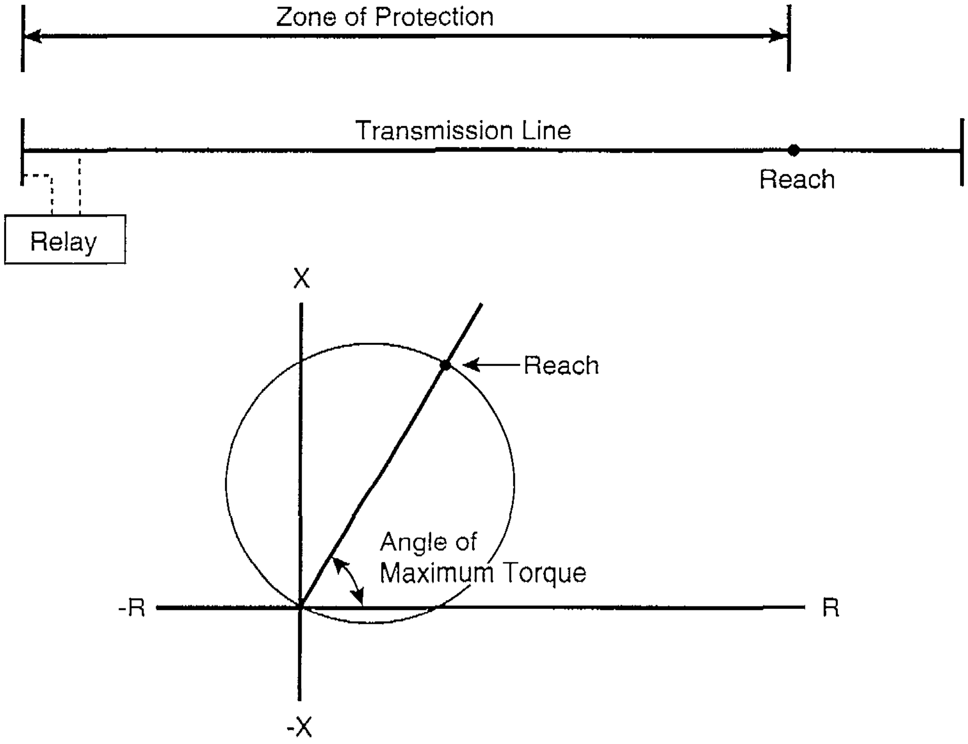


Figure 4-1
Mho Relay Operating Characteristics

An in-zone fault yields a system complex impedance that falls within the operating circle shown on Figure 4-1. A fault beyond a fixed distance results in an impedance outside of the circle. The maximum distance from the relay that will cause a relay operation is determined by the relay's reach. The center of the mho circle is in the first quadrant, with the circumference of the circle crossing the origin of the R - X axis. This property of the relay gives it directional characteristics since a fault anywhere behind the relay results in a system complex impedance that falls in the third quadrant of the diagram, which is outside of the operating circle. Notice that the relay depicted in Figure 4-1 has zero offset since the circumference of the mho circle passes through the R - X axis. The relay is most sensitive at its angle of maximum torque.

Distance relays are used extensively for protection of transmission lines. Their use at power plants is generally limited to backup protection of the main generator. Distance relays are the most complex type of protective relay. A complete discussion of transmission line protective relays is beyond the scope of this guide.

4.2 Synchronizing and Synchronism Check Relays (25)

4.2.1 Applications

4.2.1.1 Connecting a Generator to the Power Grid

Improper synchronizing of a generator to the power system grid can damage the generator and/or the prime mover. To avoid damaging the generator unit when placing it on line, synchronizing relays are used to ensure that frequency and phase angle are properly matched before connecting the generator to the system. Synchronizing relays automatically perform this function and initiate a signal to close the breaker at the right instant in time.

Synchronizing relays or high-speed synchronizing check relays can be configured to supervise bringing a generator on line manually. In this capacity, the relay serves as a permissive and only allows the generator's circuit breaker to close when frequency and phase angle are within prescribed limits. Slow-speed induction-type synchronizing check relays are not recommended for large generators because their accuracy is not compatible with the small angular window for these machines.

4.2.1.2 Paralleling Two Power Sources

Synchronizing and synchronism check relays are used to connect two or more power sources to a common bus, e.g., energizing a main transmission switchyard bus from two main feeders. Because of their limited accuracy, synchronism check relays are typically reserved for applications in which the likelihood is small that the two sources of power are not in synchronism.

4.2.2 Principles of Operation

Synchronism check relays contain an induction disk unit equipped with operate and restraint coils. The relay functions similar to a directional relay in that it measures the magnitude of and static phase angle between two applied signals - voltage signals in the case of synchronism relays. If the angle is within limits and the magnitude of both voltages is sufficient, an operating force is applied to the disk and it rotates in the close direction. After a time delay, the relay's contacts close allowing the two monitored circuits to be paralleled. If phase angle or voltage magnitude are not within limits, restraint force is applied to the disk and paralleling is inhibited.

Maximum torque is applied to the disk at zero angle. Maximum restraint occurs when the voltages are 180° out of phase. The operating characteristics of a synchronism check relay are shown in Figure 4-2. The angle of maximum torque, i.e., zero phase angle, is represented at the 90° position on the characteristic diagram. With both signals at rated voltage, the relay depicted in Figure 4-2 will close its contacts at a maximum phase angle of 20°. If the magnitude of voltage is either too high or too low the relay will not operate, even if the phase angle is within limits.

Synchronizing relays operate similar to synchronism check relays. However, synchronizing relays monitor the phase angle in a dynamic sense. If the frequency difference between the two measured voltages is too large, the time dial will never complete its travel before the phase angle falls outside acceptable limits.

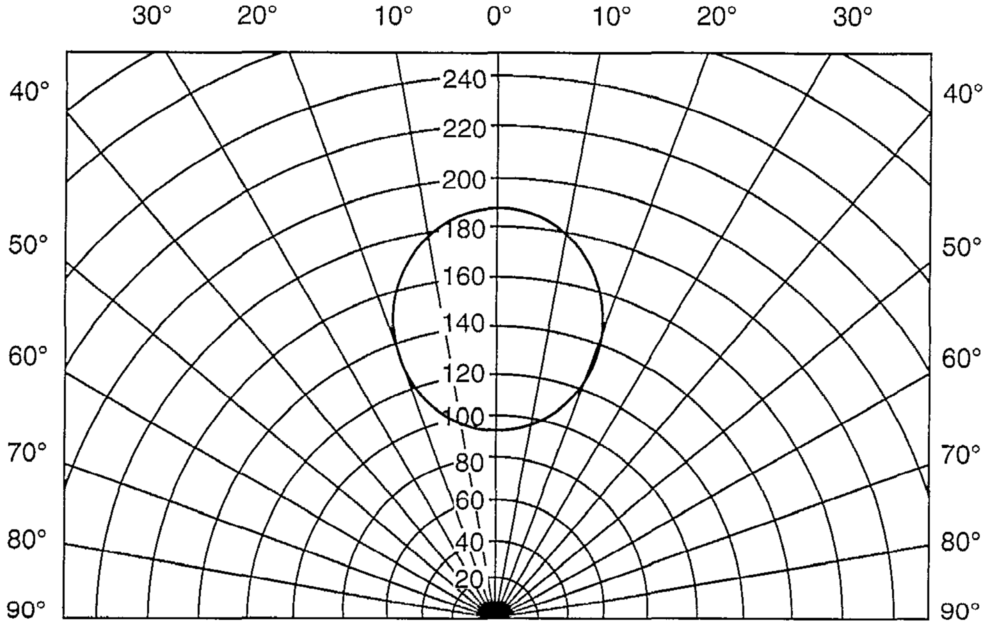


Figure 4-2
Synchronism Check Relay Operating Characteristics

4.3 Undervoltage Relays (27)

4.3.1 Applications

4.3.1.1 Motor and Bus Undervoltage Protection

Undervoltage relays protect induction motors and large synchronous motors against low-voltages that can cause an overcurrent condition. Undervoltage trips for motors generally include some time delay. Momentary undervoltage conditions are not damaging to motors and do not require protective action. However, an excessive transient undervoltage condition or loss of power may cause a motor to stall, potentially damaging the motor. Time-undervoltage relays are set to dropout when voltage falls below the expected minimum transient voltage for the bus, usually 75% to 80%. The ability of a motor to reaccelerate under load is also a consideration in determining the dropout setpoint. The relays will trip the motor after a short time delay. A motor overload resulting from an undervoltage condition will eventually cause the motor's time-overcurrent relays to actuate; however, an undervoltage relay can detect and respond to the undesirable condition much sooner, thereby minimizing the possibility of motor damage.

A second function performed by undervoltage relays is to disconnect motors from a deenergized bus to prevent them from automatically restarting when power returns to the bus. The cumulative inrush caused by several motors attempting to start at once may overburden the bus, possibly causing the bus to trip again on overcurrent or undervoltage.

In addition to transient and loss of power undervoltage protection, nuclear plants must also protect against a sustained undervoltage condition (degraded grid voltage) that is above the transient undervoltage relay setpoint. A degraded grid voltage at nuclear plants is of concern for two reasons:

- An undervoltage condition at the medium-voltage buses will result in a similar undervoltage condition at 480-volt and 120-volt buses and distribution panels. This condition may result in a voltage too low to assure proper operation of 480-volt and 120-volt safety-related equipment.
- Safety-related motors may be subjected to an overload condition because of the degraded voltage (a motor under a constant load will draw more current when voltage is decreased). An overcurrent condition, if allowed to persist, can deteriorate a motor's insulation, possibly affecting its qualified life.

To protect against a degraded grid condition, nuclear plants have additional time-undervoltage relays set to actuate at approximately 90%. If the degraded grid condition lasts for a specified period of time, usually one minute or less, the safety-related motors are tripped and a transfer to the emergency diesel generators (EDGs) is initiated for the Class IE electrical distribution system.

4.3.1.2 Source Transfer Scheme

Undervoltage relays are used to transfer loads from a normal power source to a backup or emergency power source upon a loss of normal power. The most critical application at nuclear plants is the undervoltage transfer scheme for the Class WE distribution system. Upon detecting an unacceptable condition, undervoltage relays initiate an orderly transfer of all safety-related loads to the plant's EDGs. This transfer scheme is quite elaborate and involves divorcing the Class ME system from off-site power, automatic start of the EDGs, tripping of large motors, and automatic sequencing to restart vital equipment.

4.3.1.3 Permissive Functions

Instantaneous undervoltage relays are used to block certain actions when voltage is below the dropout setting. For example, an inverter may not allow transfer to an alternate source if the voltage of the alternate source is inadequate.

4.3.2 Principles of Operation

Undervoltage relays with inverse-time characteristics are constructed very similar to time-overcurrent relays. There are two primary differences between them. First, the main coil of an overcurrent relay is designed to sense current whereas the main coil of a voltage relay is designed to sense voltage. Second, for an undervoltage relay, the spiral spring provides contact-closing torque and the magnetic flux produced in the main coil provides contact-opening torque. The opposite is true for an overcurrent relay.

When the voltage applied to an undervoltage relay is above the relay's dropout point, the magnetic flux produced by the main coil generates sufficient force in the induction disk to overcome the force of the spiral spring, thereby causing the relay contacts to open. When the applied voltage falls below the setpoint, the flux-induced force is not adequate to overcome the force of the spiral spring and the induction disk begins to rotate in the close direction. After a predetermined time, as established by the time dial setting, the relay contacts close.

The dropout point of an undervoltage relay is determined by discrete tap settings. The operating time is continuously adjustable by means of the time dial setting.

Instantaneous undervoltage units are generally a hinged armature device designed to operate on dc voltage. The ac input signal is converted to dc by a rectifying circuit in the relay. At normal voltages, the armature is normally picked up. When voltage falls below the dropout point, the magnetic force created by the coil is not sufficient to overcome the restraint spring force and the contacts open.

4.4 Directional Power Relays (32)

4.4.1 Applications

4.4.1.1 Source Power Flow Control

Industrial plants that normally operate with on-site generators paralleled to a utility supply may include a reverse power relay in the utility feeder to detect when on-site generators are supplying power back into the utility power system.

4.4.1.2 Generator Anti-motoring

Directional power relays are used to provide anti-motoring protection for synchronous generators. Generator motoring results when the prime mover loses its energy source but the generator remains connected to the power system. The relay detects power flow in the reverse direction, that is, real power flow into the generator instead of out of the generator. Upon detecting reverse power flow, the relay trips the generator and prime mover (turbine, diesel engine, or gas engine).

Reverse power protection is actually for the prime mover and not the generator. When power flows into the generator, the generator draws real power from the system and effectively becomes a motor that tries to drive the prime mover. This operating condition can severely damage steam turbine and engine prime movers. Generator motoring causes steam turbines to overheat due to inadequate steam cooling. Engine generators may suffer mechanical stresses and may even catch fire under severe reverse power conditions.

4.4.1.3 Reverse Power Flow

Some protection schemes for large transmission substations include reverse power relays to detect line-to-ground faults on the primary side of substation transformers. A primary side transformer fault that is inside the upstream isolation device will cause the upstream device to open but will not isolate the transformer on the secondary side. The reverse power relay is actuated when the transformer becomes energized from the secondary side and power flows back through the transformer into the fault.

4.4.2 Principles of Operation

Directional, or reverse power relays measure the direction and magnitude of power flow. When power is flowing in the trip direction and is above a predetermined level, the relay operates. Pickup of a directional power relay is a function of voltage, current, and phase angle.

Directional power relays operate similar to watthour meters. An induction disk unit is used to provide programmable time-delay tripping for reverse power protection. The induction unit contains separate current and voltage coils that induce flux in the disk. Torque is developed in the disk based on the interaction of the fluxes produced from the coils. The voltage signal is used as a reference value for the relay since its magnitude is relatively constant. In this case, the relay is said to be voltage polarized. The power sensed by the relay now becomes a function of current magnitude and phase angle. Typical operating characteristics for a directional power relay are shown in Figure 4-3.

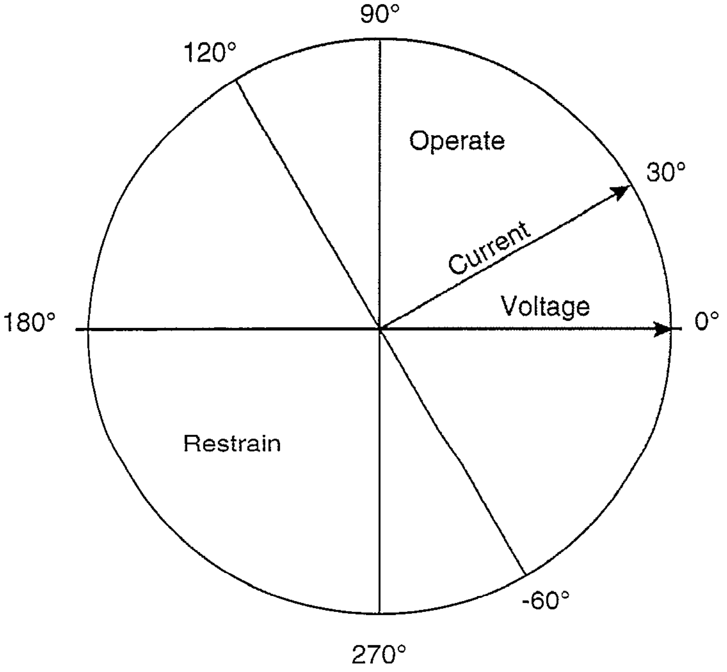


Figure 4-3
Directional Power Relay Operating Characteristics

The phase angle between voltage and current at which the relay is most sensitive is called the angle of maximum torque. At this angle, the least amount of current is needed to pick up the relay. For the unit depicted in Figure 4-3, the angle of maximum torque is 30° (current leading voltage). When the phase angle is between 120° and -60°, the unit will operate if total measured power is above the established pickup value. When the phase angle is outside the operate range, a restraining force will be exerted on the disk by the coils. Maximum restraint will occur at a phase angle 180° from the angle of maximum torque. The angles at which the relay transitions from operate to restraint are called the zero torque angles because no torque is applied to the relay in either the operate or restraint direction.

When very sensitive detection is needed, an induction cylinder unit is used in lieu of an induction disk unit to sense the direction of power flow. The principles of operation for this type of unit are the same as described above. However, the sensitive induction cylinder is used to control an induction disk unit. The induction disk unit provides a means of obtaining a time delay response. System voltage is used to provide the motive force for the induction disk unit.

4.5 Loss of Excitation (Field) Relays (40)

4.5.1 Applications

Loss of excitation, or field, relays are used to protect generators and, in some cases, very large synchronous motors. A synchronous generator tends to operate as an induction generator when excitation is lost or is insufficient. Under these conditions, the generator obtains its excitation from the system. This situation causes two significant problems: the rotor overheats from induced current and the reactive power flowing from the system to the generator can cause severe system instability.

4.5.2 Principles of Operation

A loss of excitation relay is no more than a mho-type distance relay with its operating characteristics modified to detect a voltage-current relationship indicative of a loss of excitation. The mho circle for a loss of field relay is shown in Figure 4-4. During normal operation, a generator exhibits an overall reactive impedance and operates in the first quadrant of the R - X diagram. When excitation is lost, the measured impedance rotates to the fourth quadrant as shown in Figure 4-4.

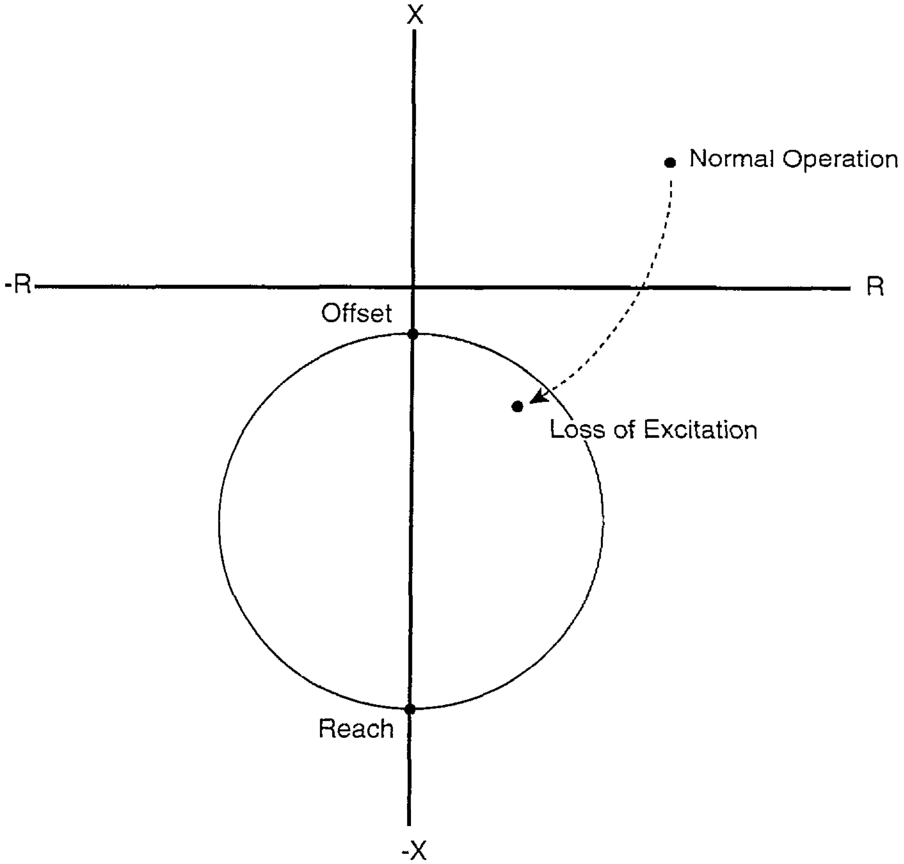


Figure 4-4
Loss of Field Relay Operating Characteristics

4.6 Phase-Balance Current Relays (46)

4.6.1 Applications

4.6.1.1 Motor Protection

Phase-balance current relays or negative-sequence current relays are used to protect large synchronous or induction motors against overheating caused by negative sequence current. Unbalanced phase voltages or currents cause negative sequence currents to flow in the motor stator windings. Unbalanced conditions can result from an open phase in the motor branch circuit, a single-phase fault, an unbalanced load, shorted stator windings, or phase-to-phase voltage variations (generally resulting from a single-phase system fault).

Negative sequence phase currents cause a flux that rotates opposite to the rotor, producing large rotor currents at double frequency (120 Hz). The relatively high resistance of the rotor to the induced 120-Hz current results in substantial heat generation in the rotor. A phase voltage imbalance can produce large negative sequence currents.

4.6.1.2 Generator Protection

Generators are susceptible to rotor damage from unbalanced conditions just like motors. Unbalanced currents in the stator windings induce double frequency currents in the rotor that cause rotor overheating. A negative sequence overcurrent relay is used to protect against potentially damaging imbalances. Unbalanced loads, unbalanced system faults, an open phase, or other unsymmetrical system conditions can result in unbalanced generator phase voltages.

4.6.2 Principles of Operation

Phase-balance current relays make use of induction units to compare relative magnitudes of phase current. Depending on make and model, two or three induction units are used to compare the phase currents.

The induction units are designed with two coils. Each coil applies a force on the disk in proportion to the input current and in opposite directions to each other. When the currents become unbalanced, the force on the disk also becomes unbalanced and the disk rotates. The rate at which the disk rotates is proportional to the degree of unbalance.

Some current balance relays are designed so that the electromagnets have unequal turns. This design feature gives the relay a slope characteristic in which the current imbalance must exceed a certain percent before the disk rotates. Other current balance relays make use of dual stationary contacts and a single moving contact. Under balanced conditions, the moving contact floats in a neutral position. When an imbalance occurs, the disk rotates in one direction or the other, ultimately closing the right-side or left-side contacts.

4.7 Phase-Sequence Voltage Relays (47)

4.7.1 Applications

Phase-sequence or negative-sequence voltage relays represent another option for protecting against unbalanced phase conditions for ac motors. Phase imbalances can result in rotor overheating, as discussed in Section 4.6.1. Phase-sequence voltage relays provide sensitive protection against system-related voltage imbalances. They are most often used to prevent starting large motors with one phase missing or with reverse-phase sequence.

4.7.2 Principles of Operation

Phase-sequence voltage relays detect reverse phase sequence and single phasing. Most units also provide normal undervoltage protection. The principles employed to obtain these operating characteristics vary between make and model. Two common constructions are described here.

In a balanced system with normal phase rotation, only positive sequence voltages are produced. If phase rotation is reversed or an unbalanced condition occurs, negative sequence voltages develop. One common construction is designed to detect these negative sequence voltages. A negative-sequence filter is supplied with three phase voltage. The output of the filter is applied to a polar unit via a full wave rectifier. The polar unit controls a voltage sensitive induction disk unit by means of a normally closed contact in the induction disk circuit. Normal operation produces no negative-sequence voltages, thus the output of the filter applied to the polar unit is zero. The polar unit is deenergized and the normally closed contact in series with the induction disk unit is closed. Sensing normal voltage, the induction disk unit is picked up. Two conditions will cause the relay to operate - undervoltage or unbalance. If voltage decreases to an abnormal level, the relay will function exactly like an undervoltage relay and the induction unit will drop out in accordance with its inverse-time characteristics. If an unbalanced condition develops, the negative-sequence filter produces a signal that is applied to the polar unit. If the magnitude of negative sequence voltage is above the unit's pickup setting, the polar unit is energized and opens the normally closed contact in the induction disk circuit. The open contact in the induction disk circuit removes the voltage signal from the induction disk, causing the induction unit to drop out. The force of the spiral spring will rotate the induction disk to close its contacts.

Another common construction detects unbalanced or undervoltage conditions by monitoring the effective area of the voltage triangle produced by the three phase voltages. Undervoltage or unbalance will affect the area of the triangle. An induction disk unit is configured with two voltage-sensitive coils; each coil circuit contains a series capacitor that produces a phase shift. The torque produced by the coils is proportional to the area of the voltage triangle. The relay operates when the area of the triangle reaches a predetermined value. The relay is not sensitive to what condition actually reduced the area, whether it be a loss of one phase, undervoltage of all three phases, or reverse phase sequence.

4.8 Thermal Relays (49)

4.8.1 Applications

4.8.1.1 Motor Protection

Thermal relays, or thermal overloads, are used in conjunction with time-overcurrent relays to protect large motors over their entire thermal limit curve. Thermal overloads monitor stator temperature and provide good long-time overload detection. However, they are seldom relied upon to protect against excessive rotor heating or locked rotor conditions. Heat transfer from the rotor to stator is not fast enough to provide a reasonable level of protection against excessive rotor temperatures.

Thermal overloads afford protection against light to medium overloads that are not an acute problem requiring immediate action. For this reason, the overloads are often configured to initiate an alarm rather than a trip. The decision to alarm or trip is a design tradeoff between operational continuity and motor protection. The more frequent approach is to alarm the overload condition and give operators a chance to correct the problem.

Because of the diversity and accuracy available with overcurrent relays, it is increasingly common to see a combination of time-overcurrent relays used to provide overload protection instead of thermal units.

4.8.1.2 Transformer Protection

Thermal overload protection is used on medium and large size transformers to detect overheating that can cause insulation damage and shorten the transformer's life. Similar to motor thermal protection, the relays are often used for alarm only to allow operators time to correct the problem. More elaborate schemes may have two settings, one for alarm and one for trip.

4.8.1.3 Generator Protection

Thermal overload protection can be used to protect generators from overheating conditions in a manner similar to that discussed for motors.

4.8.2 Principles of Operation

The replica-type overload relay is described here. The relay consists of a shaft-mounted thermostatic metal spring and heating elements. The thermostatic spring and heating elements are contained within an enclosure such that heat from the heating elements is transferred to the thermostatic spring. The heating elements are connected to a CT and generate heat in proportion to the sensed current. When the thermostatic spring is heated, it causes the shaft to rotate and close a set of contacts. The heating characteristics of the thermal unit are designed to approximate the heating characteristics of the protected equipment, hence the term replica relay.

Sophisticated, multi-function temperature and protection devices are frequently used in newer designs to protect critical motors.

4.9 Time-Overcurrent and Instantaneous Overcurrent Relays (50/51)

4.9.1 Applications

4.9.1.1 Generator Protection

Time-overcurrent relays are sometimes used as backup protection for generator ground faults. Primary protection against generator ground faults is provided by a time-overvoltage relay as discussed in Section 4.10.

Voltage controlled overcurrent relays are generally used to provide backup protection for small generators against external system faults. The relay prevents generator damage for a system fault that is not promptly cleared by primary switchyard and transmission line protective relays. A distance relay is generally used to provide this backup protection for medium and large size generators, as discussed in Section 4.1.

4.9.1.2 Motor Protection

Instantaneous overcurrent relays are used to provide phase fault and ground fault protection for both induction and synchronous motors that operate at medium-voltage levels (2.3 KV to 13.8 KV).

Time-overcurrent relays are used to provide protection against heavy overloads and locked-rotor conditions. Depending on the size of the motor and the motor thermal limit characteristics, time-overcurrent relays may also be used in lieu of thermal overloads to protect against light and medium (long time) overloads.

Instantaneous and time-overcurrent units are often packaged as a single overcurrent protective relay. A combined device number of 50/51 is used to designate this type of relay.

4.9.1.3 Transformer Protection

Instantaneous and time-overcurrent relays are used for primary phase and ground fault protection of transformers when differential protection is not provided. This generally applies to smaller unit auxiliary, station service, and secondary distribution transformers. Differential relays provide better protection against transformer faults than do overcurrent relays; however, the cost of differential protection is not always justified for smaller transformers. Overcurrent relays are often used for backup protection of large (10 MVA and above) transformers that use differential relays for primary protection.

Time-overcurrent relays are used to provide overload and through fault protection of transformers. Through fault protection of a transformer should be coordinated with downstream protective devices and should only clear a through fault when transformer damage is imminent. Transformer overload protection is required to prevent temperature excursions that can damage insulation.

4.9.1.4 Bus and Distribution Equipment Protection

Overcurrent relays are used almost exclusively to provide fault and overload protection for medium-voltage plant distribution equipment. Relay settings must be selected to protect equipment and coordinate with both upstream and downstream protective devices.

4.9.1.5 Line Protection

Instantaneous and time-overcurrent relays are used along with distance relays to protect transmission and distribution lines.

4.9.2 Principles of Operation

Overcurrent relays use an induction disk unit to obtain time-overcurrent protection and a hinged-armature or plunger-type unit for instantaneous tripping. A detailed description of overcurrent relay operating characteristics is provided in Section 3.2.8.

4.10 Overvoltage Relays (59)

4.10.1 Applications

4.10.1.1 Bus Overvoltage Protection

Overvoltage relays are used to provide overvoltage protection for buses and equipment that are intolerant of high voltage conditions. Frequently, the relay functions as a permissive or is used to actuate an alarm.

4.10.1.2 Generator Ground-Fault Protection

Virtually all large generators are high impedance grounded via a transformer with a secondary side resistive load. A time-overvoltage relay is connected in parallel with the secondary side resistor. The relay actuates when voltage is developed across the resistor as a result of ground current flowing in the generator neutral.

4.10.2 Principles of Operation

Overvoltage relay construction is very similar to overcurrent relay construction. The significant difference between the two types of relays is that the main coil of an overcurrent relay is designed to sense current whereas the main coil of a voltage relay is designed to sense voltage.

When the voltage applied to an overvoltage relay is above the relay's pickup point, the magnetic flux produced by the main coil generates sufficient force in the induction disk to overcome the restraint force of the spiral spring. At this point, the induction disk rotates in the close direction. After a predetermined time, as established by the time dial setting, the relay contacts close.

The pickup point of an overvoltage relay is determined by discrete tap settings. The operating time is continuously adjustable by means of the time dial setting.

4.11 Voltage Balance Relays (60)

4.11.1 Applications

Voltage balance relays are used to monitor the availability of voltage transformers (VTs) associated with generator protection and control circuits. If a VT fuse opens or a VT fails, the false low-voltage signal will cause improper operation of the generator regulator, synchronizing circuits, or protective relays that are fed from the faulty VT.

A voltage balance relay either blocks the operation of protective relays or shifts the regulator from automatic to manual, depending on which VT circuit failed. An alarm generally accompanies operation of the voltage balance relay.

Voltage balance relays are also used to protect three-phase motors from damage that may occur in the event of single phase operation. Relays designed for this application are very sensitive and can detect small imbalances in voltage.

4.11.2 Principles of Operation

Voltage balance relays designed to protect against VT failure are configured to receive three-phase voltage from two sets of VTs. Each voltage source produces an operating torque on an induction cylinder unit. When the voltages are balanced, the net torque applied to the induction cylinder is zero. If an imbalance develops, the net torque is no longer zero and the induction unit rotates to actuate a set of contacts. The relay is configured with two sets of contacts, the right-side contacts and the left-side contacts. A problem with one input signal causes the relay to rotate in a direction that closes the right-side contacts. A problem with the other signal causes rotation in the opposite direction and closes the left-side contacts. Operation of the induction unit contacts causes an internal auxiliary relay to pick up.

Voltage balance relays used for motor protection are supplied a three-phase voltage signal from one set of VTs. Each phase voltage is applied to a common network that detects an unbalanced condition by monitoring for the presence of negative sequence voltage. The magnitude of negative sequence voltage is proportional to the unbalance in the line. The relay is connected so that any negative sequence voltage is applied across the operating coil of the relay. The relay operates if the magnitude of negative sequence voltage exceeds the pickup threshold.

4.12 Pressure Relays (63)

4.12.1 Applications

Transformers greater than 500 KVA are equipped with a sensitive pressure switch that detects a sudden change in gas pressure within the transformer. These protective devices offer very sensitive protection against internal transformer faults and thus supplement differential protection. Although not a protective relay in the classical sense, these devices are part of the overall protection scheme and are briefly discussed here for completeness.

4.12.2 Principles of Operation

Pressure relays contain a pressure sensing element that responds to a sudden increase in the internal pressure of a transformer. Arcing caused by a turn-to-turn or phase-to-ground fault causes a rapid increase in the internal pressure of the faulted transformer. Sudden pressure relays are generally provided as an integral part of the transformer.

4.13 Directional Overcurrent Relays (67)

4.13.1 Applications

4.13.1.1 Distribution Network Protection

Directional overcurrent protection is desirable for distribution line networks where directional selectivity during faults is necessary to achieve coordinated tripping.

4.13.1.2 Generator and Transformer Protection

Sensitive high-speed ground fault protection for generators and transformers can be obtained using directional overcurrent relays. The relay is connected to the system so that it effectively provides differential protection.

4.13.2 Principles of Operation

Directional overcurrent relays are designed to operate on overcurrent conditions only when power flow is in a specified direction. This allows the relays to discriminate between faults ahead of or behind the relay. The direction of power flow is determined by measuring the phase angle between voltage and current. The phase angle is dependent upon the direction of current flow in relation to the monitored voltage.

A directional overcurrent relay is a conventional overcurrent relay with a directional control element. A controlling contact from the directional unit is connected in the shading coil circuit of the overcurrent induction disk unit. When the contact is open, no current flows in the shading coil and no phase shift is produced in the flux applied to the disk. As discussed in Section 3.1.2.2, without a split-phase signal, disk rotation is inhibited regardless of the magnitude of the applied current signal. When the directional unit contacts are closed, the relay behaves exactly like a regular overcurrent relay. A directional overcurrent relay operates only when two criteria are satisfied: an overcurrent condition exists and power flow is in the tripping direction.

The directional unit is an induction cylinder supplied with a voltage and current signal. When the phase angle between voltage and current is within a specified range, the directional unit operates. When the phase angle falls outside the range, the unit restrains. Voltage is used as the reference signal and is referred to as the polarizing voltage. The windings of the induction cylinder are such that the cylinder rotates in one direction when current has the same direction as the reference voltage and in the opposite direction when current is flowing in the opposite direction as the reference voltage. Figure 4-5 shows the operating characteristics of a typical directional unit. The unit represented in the figure will operate when current leads voltage up to 150° and lags voltage up to 30°. The two angles at which the unit shifts from operate to restraint are called the zero torque angles because neither operate or restraint torque is applied to the cylinder at these points. Maximum operating torque will be exerted on the cylinder when current leads voltage by 60°.

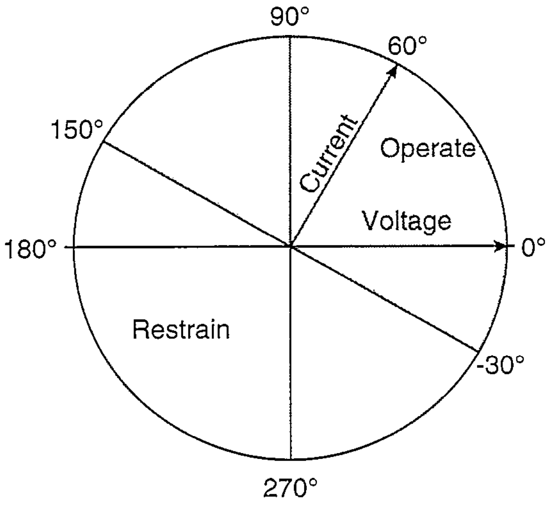


Figure 4-5
Directional Unit Operating Characteristics

4.14 Frequency Relays (81)

4.14.1 Applications

4.14.1.1 Underfrequency Protection

Underfrequency relays are used to protect generators from a prolonged underfrequency condition typically arising from a system-level overload. A system-level overload exists when the combined system generating capacity is not sufficient to keep up with the system load. The primary protection for this condition is load shedding, either carried out by automatic programs or by manual action of load dispatch personnel.

4.14.1.2 Overfrequency Protection

Overfrequency relays are sometimes used to provide overfrequency protection for generators. An overfrequency condition generally results after a severe load rejection. Overfrequency protection is not as critical as underfrequency protection because operators have it within their control to bring frequency back to an acceptable level. On the other hand, generating plant operators usually do not have control of system overloads and load shedding.

4.14.2 Principles of Operation

Electromagnetic frequency relays use either an induction disk unit or an induction cylinder unit to sense abnormal frequency. Both types of units rely on the same operating principle, however, induction cylinder units are quicker and more accurate.

The electromagnets and poles of the induction unit are configured such that two magnetic fluxes act on the disk or cylinder. A frequency-sensitive network acts on the input signal to create a phase displacement between the two fluxes in proportion to the signal frequency. The greater the frequency deviation the greater will be the angular displacement and applied force. Some units are constructed to discriminate between normal and abnormal frequency based on impedance changes in the frequency-sensitive network. The change in impedance resulting from a change in frequency is used to regulate the flow of current to the different driving coils where the flux is produced.

The frequency-sensitive network is connected to produce contact-closing torque for either a low or high frequency, depending on the application. The frequency-sensitive network generally consists of a capacitor and adjustable resistor. The resistor is adjusted to obtain the desired pickup setting.

Solid-state frequency relays are used extensively at power plants. They are relatively simple in construction and offer good accuracy and reliability.

4.15 Lockout Relays (86)

4.15.1 Applications

Lockout relays are not actually protective relays; however, they are used in conjunction with protective relays and are briefly discussed here for completeness. A lockout relay is a high speed, manual or electrically reset auxiliary relay that is used to provide contact multiplication. It responds to a trip signal provided by a protective relay to trip and lockout several breakers at once. A typical bus fault protection scheme may include a bus differential relay that sends a trip signal to a lockout relay, which in turn initiates a trip of all source and feeder breakers to isolate the faulted bus. Following a protective action, the lockout relay must be reset before any of the affected circuit breakers can be closed.

4.15.2 Principles of Operation

Lockout relays are usually hinged armature type devices designed for high speed operation (approximately 1 cycle). They contain between two and 16 sets of electrically isolated contacts. Lockout relays are often configured with a target to indicate that the relay has operated.

4.16 Differential Relays (87)

4.16.1 Applications

4.16.1.1 Transformer Protection

Differential protection is preferred for transformers over 10 MVA. The differential scheme is set up to detect faults within the transformer's zone of protection. Since differential relays operate on the net difference of current flowing into and out of the zone of protection, transformer differential relays should not actuate on a through fault, i.e., a fault on a downstream feeder outside of the transformer's zone of protection.

Differential relays used for transformer protection are generally percent differential relays with harmonic restraint. A straight differential relay operates on an absolute value of current and is not best suited for transformer protection. Since some relay current mismatch will always exist because of different CT ratios, CT characteristics, transformer tap settings, and relay taps, it is difficult to set the relay for good low-level fault sensitivity and also maintain an adequate margin against inadvertent tripping during heavy through faults. In contrast, percent differential relays actuate when the ratio of compared currents exceeds a certain percentage. These relays offer greater sensitivity to low-level transformer faults and minimize the likelihood of inadvertent trips during heavy through faults.

When energized, transformers have a substantial magnetizing inrush current. This presents a problem when differential protection is applied because the differential relay sees the inrush as an internal transformer fault. To overcome this problem, harmonic restraint units are added to transformer differential relays. Transformers exhibit a pronounced second harmonic when energized. Harmonic units incorporate a filter network that detects this second harmonic. When the harmonic is present, the harmonic unit restrains the relay from operating. In this manner, undesirable trips are avoided during energization of the transformer. On smaller distribution transformers, the inrush current may not be severe enough to require harmonic restraint. In these cases, percent differential protection is adequate.

4.16.1.2 Generator and Unit Protection

High speed differential relays are used to provide generator protection against three-phase and phase-to-phase faults in the generator's stator windings. Percent differential relays are used for generator protection for the same reason they are used on transformers - they provide good sensitivity at light loads and are relatively immune to undesired trips during heavy external overloads. A fault in the stator windings can produce high and very destructive fault currents. Thus, the objective of differential protection is to remove the equipment from service as fast as possible.

Large generating plants are most often arranged with the generator and main transformer connected to the power system grid as a unit. When configured in this manner, the generator is said to be unit connected. For unit connected generators, the transformer differential relays are configured to include the generator within their zone of protection since the generator must be tripped on a main transformer fault anyway. This setup provides backup protection against generator stator faults.

4.16.1.3 Motor Protection

Differential relays are employed when quick and accurate protection against faults is desired. This type of protection is usually reserved for large, expensive motors. Differential protection has advantages over conventional overcurrent protection. Differential relays provide sensitive fault current detection and are not prone to false tripping during motor starting or external faults.

4.16.1.4 Bus Protection

Various types of differential protection schemes are used for phase- and ground-fault protection of buses. Bus differential protection is generally reserved for substation and switchyard buses, it is not frequently used for protection of in-plant distribution switchgear below 750 MVA.

4.16.2 Principles of Operation

A differential relay measures the amount of current entering and leaving its zone of protection. Figure 4-6 illustrates the concept of how a differential relay works. The CTs are connected to the relay such that no current will flow through the operating coil if the currents are balanced (current entering the zone is equal to current leaving the zone). However, if a fault occurs within the zone, the measured currents will be different, causing a differential current to flow through the operating coil. If the differential current is above the relay's pickup point, the relay initiates a protective action.

Differential relays of this type are very sensitive to imbalances and are prone to undesirable trips on normal imbalances or through faults. As an example, assume the pickup value for the operating coil is .30 amperes and that a 4% mismatch exists between I_1 and I_2 due to minor circuit differences. If, under normal load conditions I_1 = 4.80 amperes, a 4% mismatch results in I_2 = 4.99 amperes and I_o = 19 amperes (4.99 - 4.80). The differential current of 19 amperes is less than the pickup value so the relay is deenergized under normal full load conditions. Now assume a through fault occurs that results in a fault current equal to 400% rated current. For this condition, I_1 = 19.2 amperes, I_2 = 19.96 amperes, and 1_o = .76 amperes. Since the differential current of .76 amperes is above the pickup value of .30 amperes, the relay will operate and cause an undesired trip for the through fault.

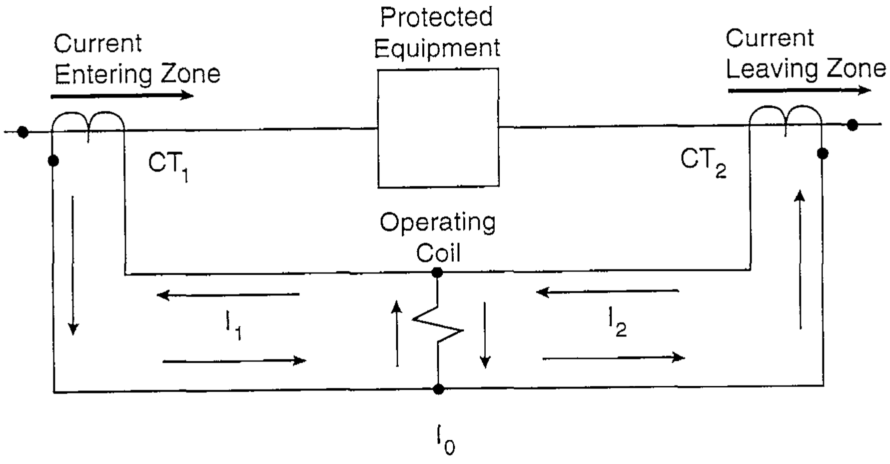


Figure 4-6
Differential Relay Scheme

To provide better immunity to undesirable tripping, most differential relays are designed with restraint coils in addition to an operate coil. The restraint coils desensitize the relay to through faults while allowing good in-zone sensitivity. A relay of this design is called a percent differential relay and has slope characteristics. Figure 4-7 illustrates the percent differential design.

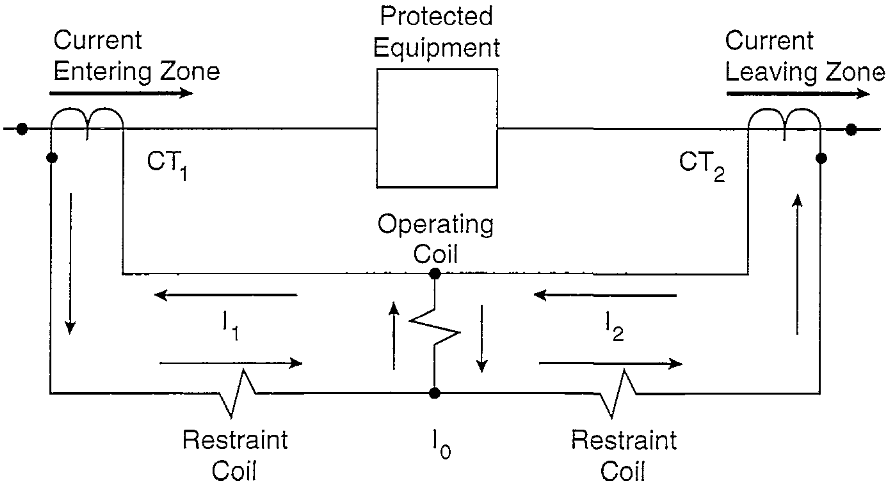


Figure 4-7
Percent Differential Relay Scheme

A percent differential relay is characterized by its slope. Slope is defined as the ratio of operate current to restraint current that will cause the relay to actuate. The restraint coils provide a contact opening force and the operate coil provides a contact closing force. The relay will operate when the ratio of operate current to restraint current exceeds the specified slope.

Assume a differential relay with a 10% slope is used for the example given above. The normal unbalance of the system is 4% so the relay will not operate under normal full load conditions. Nor will it operate during a high-current through fault since the percent unbalance remains 4%, regardless of the magnitude of the fault current.

Percent differential relays are constructed with an induction disk unit that contains the restraint and operate coils. When the amount of imbalance in the circuit is less than the specified slope, the restraint coils provide a proportionately larger force on the disk than does the operate coil, regardless of the absolute value of current passing through the coils. When the degree of imbalance exceeds the slope, the force generated by the operate coil exceeds the restraint force and the relay operates. Percent differential relays allow for a certain amount of normal imbalance in the protection circuit without sacrificing sensitivity to in-zone faults.

4.17 Pilot Wire Relays (87L)

4.17.1 Applications

Pilot wire differential relays are used to protect short and medium length transmission and distribution lines. Conventional differential protection is not practical for transmission or distribution line fault protection because of the distances required to bring CT and circuit breaker leads together.

Pilot wire differential protection may be employed at generating stations between the unit step up transformer and the station switchyard if they are separated by a significant distance, usually greater than 2,000 feet.

4.17.2 Principles of Operation

Pilot wire relays operate on the differential principle. Identical relays are installed at each end of the protected line. The relays are connected to each other via a pilot wire. The pilot wire serves as a means of information exchange between the two relays and allows the current entering the zone to be compared to current leaving the zone at both relays. A fault within the zone of protection will be detected by both relays. Pilot wire protection allows for rapid isolation at both ends of a faulted line. As with all differential schemes, immunity against undesired trips during through faults is high.

5.0 Power Plant Protection System Design

System protection has often been compared to insurance. As long as everything works well, it provides no tangible benefit. However, if a fault occurs, the system protection is responsible for minimizing the extent of the affected area, the amount of property damage, and the possibility of personnel injury. Just as with an insurance policy, the cost of protection should be compared to the cost and consequences of system failures.

Section 5 describes design and application concepts used in protective relaying. By understanding the general design philosophy and approach, the importance of correctly performed maintenance can be better appreciated.

5.1 Protection System Design Philosophy

5.1.1 Performance Objectives

The purpose of protective relaying is to initiate the prompt removal from service of any component of a power system when it suffers a short circuit or operates abnormally in a manner that might interfere with the effective operation of the rest of the system. The ideal protective relay accomplishes the following:

- Promptly removes from service faulted components with as little disruption as possible to the rest of the system.
- Performs no action in response to anticipated system transients or tolerable, but abnormal, conditions .

When a fault occurs within a system, the primary protective relays closest to the fault should act promptly to isolate the fault. Depending on the design and function, backup relays farther from the fault may begin to operate but should not actually initiate any tripping functions as long as the primary relays function properly. If the primary relays fail to isolate the faulted condition, the backup relays should complete their operation to isolate the fault.

5.1.2 Ideal Relay Characteristics

Protective relays do not prevent abnormal occurrences or failures within the power system. Instead, protective relays respond to conditions indicative of a system or equipment problem. In other words, these relays do not anticipate problems; they respond to problems once the abnormal condition has been recognized. In general, the ideal protective relay would have the following design characteristics:

- Maximum reliability The relay will actuate only on equipment or system conditions indicative of a problem, spurious relay actuation or actuation in response to tolerable transients will not occur.
- Maximum speed. The relay will detect equipment or system faults and perform its protective function as fast as possible.

- Selectivity. Only the faulted equipment will be removed from service by the protective function; minimum system disruption occurs as a result of relay actuation.
- Simplicity. The relay protection scheme will be designed as simply as possible.
- Low Cost. The above design characteristics will be achieved at the lowest possible cost.

To some degree, the above design attributes are mutually exclusive. For example, maximum speed of relay operation invariably involves some level of compromise with relay reliability - the faster the relay operation, the more likely it may be that the relay mistakes an expected transient for a system fault. The following sections describe these desired relay characteristics in more detail.

5.1.2.1 Reliability

Protective relay reliability is described in two ways:

- The relay must operate correctly in response to a system problem (dependability).
- The relay must not operate incorrectly during normal system operation (security).

Dependability is defined as the degree of certainty that a relay or relay system will operate correctly. Security is defined as the degree of certainty that a relay or relay system will not operate inadvertently. In more direct terms, dependability is a measure of the ability of the protective relay to perform correctly when required and security is its ability to avoid unnecessary operation during normal system conditions or in response to system faults outside its zone of protection. Dependability and security cannot be fully achieved simultaneously. Increasing relay dependability tends to reduce relay security, and increasing relay security tends to decrease relay dependability. Balancing these two system needs while also anticipating the many possible unusual system configurations requires considerable expertise and is as much an art as it is a science.

Dependability is relatively easy to verify. Relay testing can determine that the relay responds correctly when defined setpoints are exceeded. Thus, given that the system fault conditions for which the relay must actuate are understood, the reliability of the relay to perform its design function can be verified by periodic testing.

Security can be more difficult to verify for a relay. Anticipating all of the possible system configurations that may exist during normal operation for which the relay must not actuate can be difficult for a complex system. Fortunately, nuclear plants tend to have a relatively simple radial design in which the zones of protection are well understood.

5.1.2.2 Speed of Operation

Protective relays do not anticipate and prevent faults; they respond to system electrical parameters and actuate upon detection of electrical levels indicative of system faults or problems. The ideal goal is to isolate any faulted equipment as rapidly as possible to:

- Minimize or prevent equipment damage
- Minimize the possibility of other protective relays responding to the fault in a manner that isolates a larger portion of the power system

Unfortunately, higher speed is usually achievable by higher protection system cost and lower system security. Time duration is usually the best method of distinguishing between normal system transients and system faults - the faster the relay operation, the more likely it is that the relay will respond unnecessarily to a tolerable transient.

5.1.2.3 Selectivity

Protective relays in power plants are designed so that the relay closest to the fault or intolerable disturbance responds first to isolate the fault. The relay closest to the fault is primarily responsible for removing the fault as soon as possible, thereby deenergizing as little of the system as required. If the primary protection fails, backup protection may then respond to clear the fault. This principle of operation is termed selectivity and is a fundamental design requirement to minimize the amount of the system deenergized in response to a faulted condition. Section 5.4 discusses selectivity in more detail.

5.1.2.4 Simplicity

The protection system design should not be more complex than is necessary to implement the protection objectives for the system. Each added component adds to the system cost as well as ongoing maintenance costs. Furthermore, each added component may detract from the overall system dependability and security. The system design should be optimized to balance all goals.

5.1.2. 5 Cost Considerations

Engineering normally consists of the creation of an adequate technical design at the lowest reasonable cost. For protective relaying, minimum initial costs may be achieved at the expense of lower system reliability or higher maintenance costs. In particular, a lower system reliability that fails to prevent damage to critical equipment can easily outweigh the savings realized by a cheaper protection system design. The goal should be to establish a reasonable system design and then determine how costs can be reduced while still assuring a high level of reliability.

5.2 Protection System Design Approach

5.2.1 Zones of Protection

The general design approach of protective relaying is to divide the electrical power system into zones that can each be protected with the minimum possible disruption to the rest of the system. The concept of protective zones applies to protective relaying regardless of whether the system to be protected is a major transmission and distribution system or a single power plant. In either case, a fault or intolerable transient should be disconnected from the system with as little impact as possible to the unaffected portion of the system.

A typical power system is separated into the following zones:

- Generators
- Transformers
- Buses
- Cables and transmission lines
- Motors

A portion of a power system identifying typical zones of protection is shown in Figure 5-1. The dashed lines indicate the zones of protection into which this simple power system has been divided. Each zone contains one or more power system components in addition to the circuit breakers located at the zone boundaries.

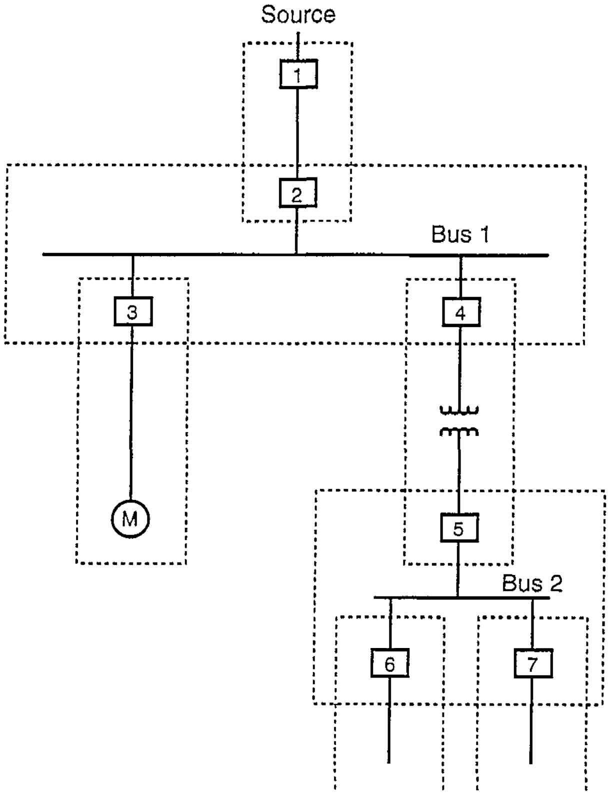


Figure 5-1
Typical Electrical System With Zones of Protection Shown

Zones of protection are defined around circuit breaker locations. A general design philosophy is that a fault within a given zone should cause the tripping of all circuit breakers at the zone boundary and no tripping of circuit breakers outside the faulted zone. Notice in Figure 5-1 that zones of protection are overlapped to avoid the possibility of any unprotected areas in the power system. However, the area of overlap is usually minimized as much as possible since a fault in the overlap region would result in the isolation of two zones.

5.2.2 Primary and Backup Protection

The zones of protection principle described in the previous section is an example of primary protection in which a faulted zone is isolated to remove the fault. Backup protection is the second line of defense and functions to clear the fault in the event that the primary protection fails to operate properly. Depending on the design and function, backup relays farther from the fault may begin to operate but should not actually initiate any tripping functions as long as the primary relays function properly. If the primary relays fail to isolate the faulted condition, then the backup relays should complete their operation to isolate the fault.

Note that failure of primary protection does not only mean that a protective relay failed. Primary protection may fail to isolate a fault due to a failure of any of several devices:

- Protective relays
- Instrument transformers
- Tripping circuit
- Circuit breaker
- Tripping circuit voltage supply

Upon failure of the primary protection, the available backup protection acts to isolate the fault. The method used to distinguish whether or not the primary protection has failed is usually based on time; after a selected time delay during which the primary protection should have isolated the fault, the backup protection will complete its protective response. In a power plant, the actuation of backup relaying will often involve the isolation of multiple zones of protection. For example, an entire load center may be isolated once the backup protection actuates to isolate a motor fault.

In general, backup protection is applied mainly for short circuit protection. Since short circuits are the most common form of power system failure, backup protection is of greatest value for overcurrent relaying. A typical backup protection scheme is shown in Figure 5-2. For a fault on the motor, Breaker 2 should open to clear the fault. In the event that Breaker 2 fails to open, the protective relaying associated with Breaker 1 should operate to isolate the fault. Notice that Breaker 1 is not the desired breaker to open in this case; Breaker 2 should have opened. However, when Breaker 2 failed to open, the backup protection then deenergized the entire load center to isolate the fault.

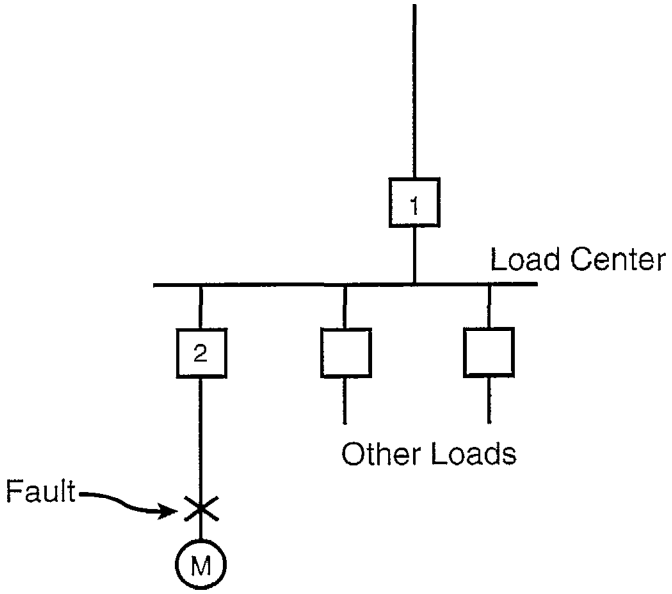


Figure 5-2
Short Circuit Backup Protection

5.2.3 Nuclear Plant Protection Design Criteria

Nuclear plants are typically designed with a radial design in which one bus feeds the next bus or set of buses. Cross-connections between buses or multiple simultaneous power feeds to a bus are not usually allowed by the design. This approach to the electrical system layout simplifies the protective relaying design for nuclear plants.

The principles of electrical system protection are the same regardless of whether the protected system is a nuclear plant or an industrial facility. ANSI/IEEE 141, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants* and ANSI/IEEE 242, *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* provide basic design criteria applicable to any protection system.

ANSI/IEEE 308, *IEEE Standard Criteria for Class HE Power Systems for Nuclear Power Generating Stations*, establishes the design criteria for Class WE systems within a nuclear plant. Protection system design, test, and surveillance criteria for the Class IE system are described in ANSI/IEEE 741, *IEEE Standard Criteria for the Protection of Class ME Power Systems and Equipment in Nuclear Generating Stations.* ANSI/IEEE 741 essentially functions as an umbrella standard by referring to numerous other standards for specific design or testing criteria.

5.2.3.1 Degraded Voltage Protection

Original nuclear plant voltage protection was generally based on a complete loss of voltage. However, additional design limitations have been placed on continuous operation of the Class IE buses at lower than allowed voltages. In the late 1970s, the NRC required an additional level of voltage protection to preclude continuous operation of Class IE equipment at sustained low voltages. The purpose of this protection is to prevent damage or misoperation of Class IE equipment due to continuous operation under degraded voltage conditions. This protection has been termed *degraded voltage protection.* A degraded voltage condition on the Class IE buses is indicative of a degraded voltage on the transmission system since the two voltages are directly related to each other by transformer turns ratios. The protective action in response to a degraded voltage condition is to separate the Class IE distribution system from the off-site power system.

Two time delays for degraded voltage protection are generally provided at each nuclear plant. The first time delay indicates a degraded voltage condition that will not actuate conventional undervoltage protection, but that could damage Class IE equipment during long term operation if not corrected. This first time delay typically actuates an alarm and immediately separates the Class IE distribution system from off-site power if an accident signal is present. The second time delay is set longer but is still of limited duration to ensure that the degraded voltage does not damage equipment. After the time delay is exceeded, the degraded voltage protection separates the Class 1E distribution system from off-site power.

NUREG-0800, Standard Review Plan, Branch Technical Position PSB-1 sets the NRC review criteria specifically applicable to the degraded voltage relays and the plant electric power system. Some of the key points from PSB-1 are as follows:

> "In addition to the undervoltage scheme provided to detect loss of offsite power at the Class 1E buses, a second level of undervoltage protection with time delay should also be provided to protect the Class IE equipment; this second level of undervoltage protection shall satisfy the following criteria:

> a) The selection of undervoltage and time delay setpoints shall be determined from an analysis of the voltage requirements of the Class 1E loads at all onsite distribution levels;
>
> b) Two separate time delays shall be selected for the second level of undervoltage protection based on the following conditions:
>
> 1) The first time delay should be of a duration that establishes the existence of a sustained degraded voltage condition (i.e., something longer than a motor starting transient). Following this delay, an alarm in the control room should alert the operator to the degraded condition. The subsequent occurrence of a safety injection actuation signal (SIAS) should immediately separate the Class IE distribution system from the offsite power system.
>
> 2) The second time delay should be of a limited duration such that the permanently connected Class 1E loads will not be damaged. Following this delay, if the operator has failed to restore adequate voltages, the Class 1E distribution system should be automatically separated from the offsite power system. Bases and justification must be provided in support of the actual delay chosen.
>
> The voltage levels at the safety-related buses should be optimized for the maximum and minimum load conditions that are expected throughout the anticipated range of voltage variations of the offsite power sources by appropriate adjustment of the voltage tap settings of the intervening transformers. The tap settings selected should be based on an analysis of the voltage of the Class 1E loads. The analyses performed to determine minimum operating voltages should typically consider maximum unit steady state and transient loads for events such as a unit trip, loss-of-coolant accident, startup or shutdown; with the offsite power supply (grid) at minimum anticipated voltage and only the offsite source being considered available. Maximum voltages should be analyzed with the offsite power supply (grid) at maximum expected voltage concurrent with minimum unit loads (e.g., cold shutdown, refueling). A separate set of the above analyses should be performed for each available connection to the offsite power supply."

The degraded voltage protection has the potential to disrupt plant operation during normal or abnormal, but tolerable, operating conditions. For this reason, the degraded voltage protection setpoints should be periodically reviewed. For example, the addition of loads to the plant over several years has the potential to increase the voltage drop throughout the plant. In this case, the margin between the transmission system voltage and the point at which the degraded voltage relays may actuate can be reduced. The plant voltage margins can be affected by changes to the power system external to the plant. For example, the addition of large loads to the transmission system may cause a lowering of the expected minimum voltage possible at the plant switchyard. This effectively reduces the margin to the degraded voltage protection setpoint also.

5.3 System Interfaces

Protective relays are only a part of the protection system. They receive input signals from the power system and, when the input signals exceed a predetermined threshold for the appropriate length of time, protective relays provide an output signal to perform the desired protective function. This section describes the input and output interfaces for protective relays.

5.3.1 Instrument Transformers

Instrument transformers are used as the sensing devices for protective relays. Relays do not sense electrical system parameters directly; instead, instrument transformers are used as intermediate sensing devices to reduce the sensed electrical quantities to lower levels for the following reasons:

- Instrument transformers reduce the system voltage and currents to lower levels to allow for a simpler and less expensive relay design.
- Lower voltages and currents at the relay provide a safer environment for personnel working around relays.

Instrument transformer design and performance is an important part of relay design. Protective relays can be no more accurate than the instrument transformers that provide the input information. Instrument transformers operate on the same principles as ordinary transformers; however, they are specifically designed to duplicate the input waveform as closely and predictably as possible.

5.3.1.1 Current Transformers

Current transformers (CTs) are connected in series with the circuit whose current is to be measured as shown in Figure 5-3.

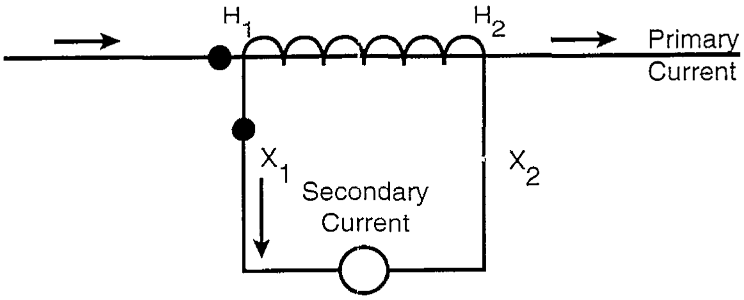


Figure 5-3
Current Transformer Circuit

CTs are intended to deliver a secondary current that is directly proportional to the primary current with as little distortion as possible. In most cases, the secondary output current is usually reduced to a level less than 5 amperes. Although there are CTs with 1 ampere or 10 ampere secondaries, the most common rating in the United States is 5 amperes.

CTs are rated for a certain turns ratio of operation. For example, a CT with a turns ratio of 500:vf5 reduces 500 amperes on the primary to 5 amperes on the secondary. A properly designed CT circuit yields a secondary current of 5 amperes or less at rated primary current. Although the CT secondary and the relay are not intended for continuous operation at higher than 5 amperes, they are designed to withstand greater values of current for short periods. For example, short circuit currents may be 20 times the normal current in a power system.

During normal operation, the CT secondary winding induces a magnetic flux that opposes and nearly cancels the primary induced flux. As a result, the flux density is very low and the resulting voltage at the secondary terminals is also very low. Relays, meters, or other connected devices are constructed with only a few turns of relatively large wire; this low impedance effectively functions as a short circuit across the CT secondary. The secondary voltage of a CT remains at a low value as long as the secondary circuit remains closed. An open circuit on the secondary side of a CT that still has current flow on the primary side can result in a dangerously high secondary voltage. Opening the secondary removes the opposing secondary flux, thus allowing the primary flux to generate a very high voltage at the secondary terminals. Equipment can be damaged and personnel can be injured by electrical arcing due to an open circuited CT. Whenever the primary side is carrying current, great care must be taken to ensure the secondary circuit remains closed at all times.

The CT's ability to produce a secondary current proportional to its primary current is limited by the highest secondary voltage that it can produce without saturation. Beyond a certain level of excitation (actual values are readily available from the manufacturer), the CT is said to enter saturation. Once the CT enters saturation, most of the primary current maintains the core flux, and the shape of both the exciting and secondary currents departs from the normal sine wave. The secondary voltage and current then collapse to zero where they remain until the next primary current zero is reached. The process is repeated each half-cycle and results in a distorted secondary waveform. Saturation of a CT can prevent a protective relay from operating properly. For this reason, a CT must be carefully sized so that it will perform properly for the maximum expected fault current. Low ratio CTs, i.e., 50:5, 75:5, etc., are particularly susceptible to saturation during fault conditions. The following problems may exist if a CT is allowed to saturate:

- False Tripping. Differential relays used for transformer protection may respond to a through fault condition.
- Delayed Tripping. A distorted secondary reproduction of the primary current can delay relay time response. This delay in tripping may result in deenergizing a larger portion of the system due to loss of relay coordination caused by the CT saturation.
- Failure to Trip. Failure to trip may occur if the CT secondary current is very low or extremely distorted. Backup relays must then respond to clear the fault.

5.3.1.2 Voltage Transformers

Voltage transformers (VTs), also called potential transformers, are connected in parallel with the circuit whose voltage is to be measured as shown in Figure 5-4.

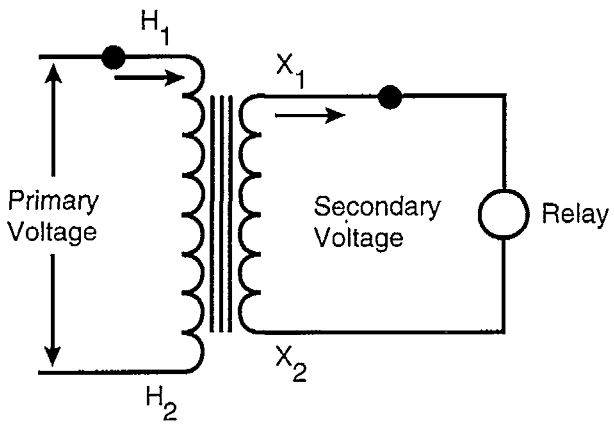


Figure 5-4
Voltage Transformer Circuit

VTs provide a secondary output voltage proportional to the primary voltage. For the typical primary voltages used in nuclear plants, the VT turns ratio will usually be designed to provide an output voltage of 120 V. The ideal VT delivers a secondary voltage directly proportional to the primary voltage, with as little phase angle difference as possible between the primary and secondary voltages.

VTs are generally far more accurate than CTs. Also, VTs do not experience saturation problems that may occur with CTs. CTs may have the primary current increase by 20 times or more during a fault, but VTs will never have the primary voltage increase as dramatically.

5.3.2 DC Tripping Circuits

Protective relay actuation closes a contact in the associated circuit breaker tripping circuit, resulting in the energization of the circuit breaker's trip coil. A battery-backed dc voltage source is normally used to perform the breaker tripping operation. A typical overcurrent protection scheme is shown in Figure 5-5. As shown, an overcurrent relay is installed on each phase with a single ground fault relay also used.

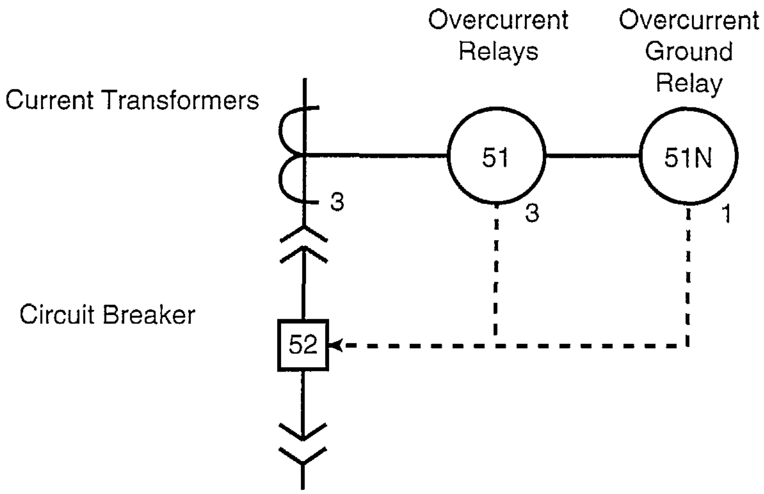


Figure 5-5
Overcurrent Relay One-Line Diagram

Figure 5-6 shows a typical configuration for the relay trip circuit. The overcurrent relay (51) closes a contact in the tripping circuit and also energizes the indicating contactor switch (ICS) coil. The ICS closes a parallel contact to seal in the trip signal to the breaker trip coil.

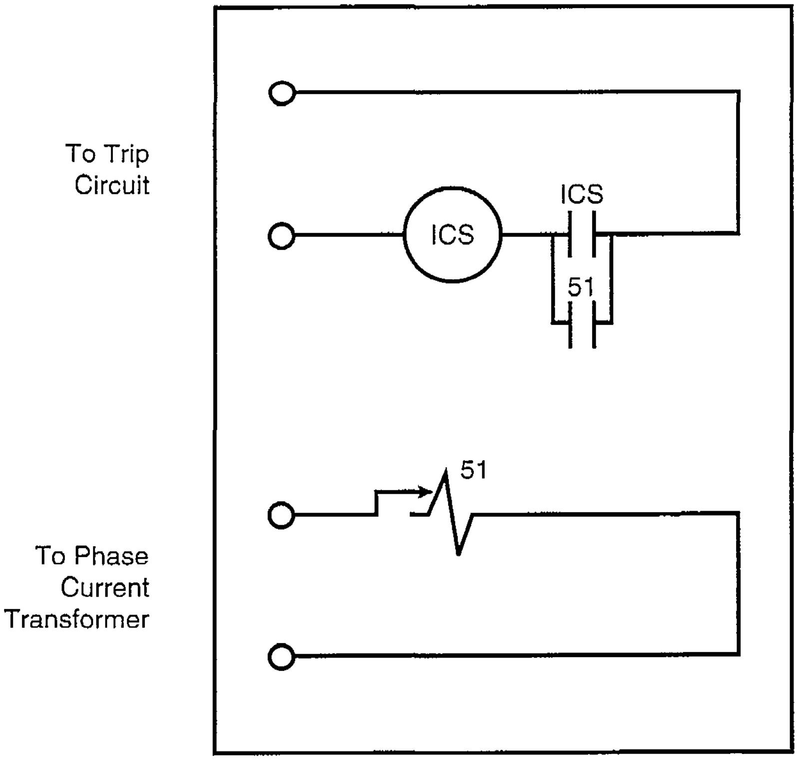


Figure 5-6
Relay Trip Circuit

A simplified trip circuit is shown in Figure 5-7. The protective relay contacts are connected in parallel so that any relay will trip the breaker under fault conditions. Figure 5-7 also shows how the control switch for manual breaker tripping is connected to the trip circuit.

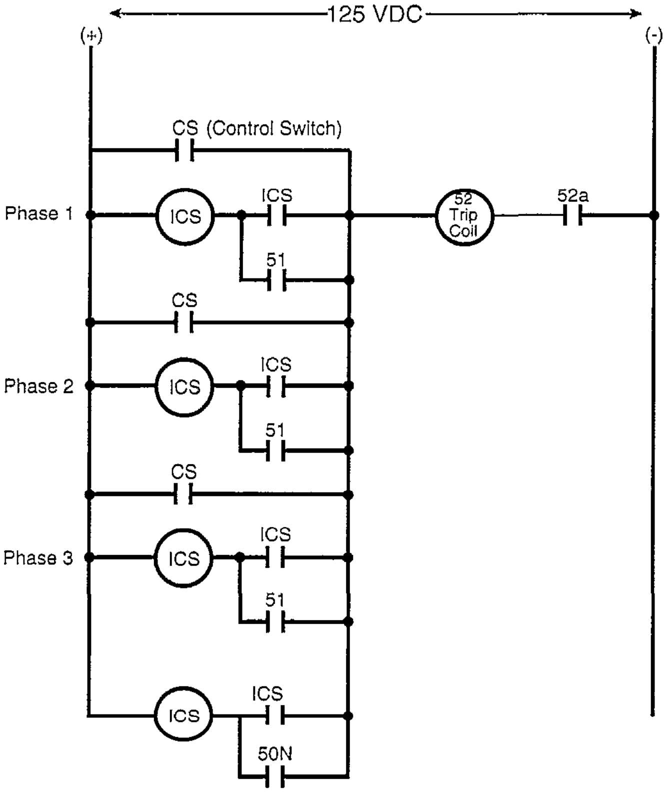


Figure 5-7
Protective Relay Trip Circuit

5.4 Selective Tripping

5.4.1 Inverse-Time Characteristics

Many protective relays have inverse-time response characteristics as shown in Figure 5-8. The term *inverse* means that the relay actuation time is inversely proportional to the applied signal. The higher the signal, the faster the relay operation time.

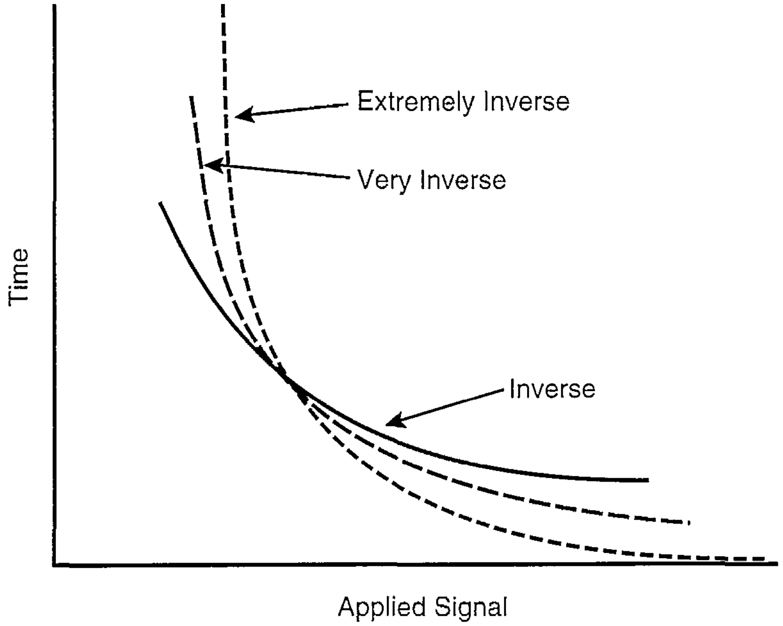


Figure 5-8
Inverse-Time Relay Characteristics

Time-overcurrent relays are used extensively for power plant protection. The time-current relationship is adjustable as shown on Figure 5-9. The time-dial setting controls the time delay between detection of a fault and closure of the main relay contacts. Note that the time dial establishes the angular distance the induction disk must travel before closing its contacts and does not affect the rate at which the disk rotates. Rotation rate of the disk is a function of the magnitude of the fault current. The tap setting establishes the minimum pickup point for the relay. Section 3.0 provides a more detailed discussion of relay operating principles.

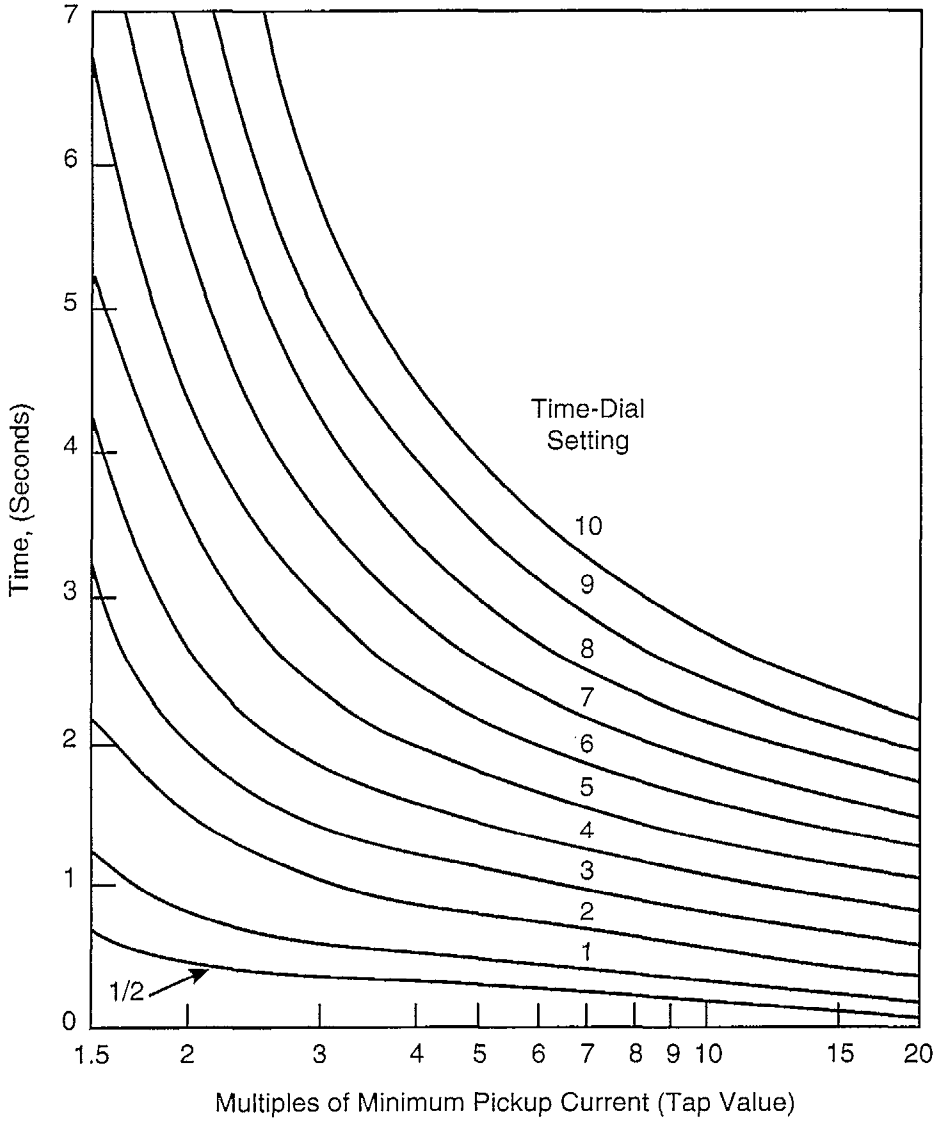


Figure 5-9
Typical Overcurrent Relay Time-Current Curves

5.4.2 Short Circuit Study

A short circuit study is the starting point for most relay applications. Three-phase faults and unbalanced faults should be included in the study. The fault currents should be understood for a fault anywhere in the power system. Knowledge of the maximum available fault current is necessary in order to verify that the CT selection is appropriate for the location and that equipment ratings are acceptable.

5.4.3 Protective Device Coordination

Protective device coordination requires a careful evaluation of the power system under various operating conditions. In general, the following steps are required to verify the protective coordination throughout an existing power system:

1. Obtain the following system information:
    - System one-line diagram
    - Acceptable system lineups and operating configurations
    - Protective device locations
    - Protective device time-current characteristics
    - Load currents, normal and maximum
    - Fault currents at each protective device location
2. Determine the minimum and maximum fault currents at each protective device location and at the end of all lines.
3. Determine the existing settings for all protective devices.
4. Draw a composite set of time characteristic curves showing the coordination of all protective devices.
5. Evaluate the results to verify that existing relay settings are acceptable.

6.0 Protective Relay Degradation and Failure Modes

In general, protective relays have a reputation for providing many years of reliable service. However, these relays do age in service and are susceptible to certain degradation mechanisms. Section 6 presents protective relay degradation, reliability, and failure information. The primary purpose of this information is to establish a baseline with which recommended maintenance practices can be linked to a degradation mechanism or a failure mode. Recommended maintenance practices are discussed in Section 7.

The types of protective relays used in nuclear plants are well documented. EPRI N-7147-S, *Seismic Ruggedness of Relays,* states that the most common protective relays used in nuclear plants are as follows:

General Electric CFVB - voltage balance relay
General Electric GGP - power directional relay
General Electric IAC - time overcurrent relay
General Electric IAV - time delay voltage relay
General Electric NGV - instantaneous voltage relay
General Electric PVD - bus differential voltage relay
ITE 27 - solid state undervoltage relay
Westinghouse CO - time overcurrent relay
Westinghouse CV - time delay voltage relay
Westinghouse SC - instantaneous overcurrent relay
Westinghouse SV - instantaneous voltage relay

The degradation, failure, and reliability information described in this section is applicable to the above types of relays and to electromechanical relays in general.

Aging, degradation and failure modes are discussed for completeness. Although present, aging mechanisms for protective relays are generally subtle and slow acting unless the application involves temperature extremes or continuous overheating due to high CT currents. For example, relay trouble reports at the Bonneville Power Administration (BPA) were reviewed as part of this project and very few relay problems were noted. BPA maintains thousands of relays throughout the Northwest United States and many relays have been in service for decades. Although problems were noted with relays that tend to overheat, such as distance relays, virtually no trouble reports were available for the standard types of relays most likely to be used in power plants. For example, overcurrent relays typically see very low levels of current during normal operation and are usually installed in environmentally controlled areas. For this reason, overcurrent relays stay relatively clean and are normally found to be in good working order during periodic testing. Overall, the large majority of protective relays continue to have a deserved reputation for long life and high reliability.

6.1 Aging and Degradation Mechanisms

Aging and degradation mechanisms for protective relays are reasonably well understood. If properly selected, installed, operated, and maintained, protective relays can provide many years of reliable service. Table 6-1 provides a summary of degradation mechanisms for protective relays.

Table 6-1
Degradation Mechanisms for Protective Relays
(Based on Information From NUREG/CR4715)

Stress	Effect on Relay	Effect on Operation
Electrical		
Inductive surge	Breakdown of coil insulation (corona attack and dielectric breakdown of insulation weak points)	Open-circuited coils
Overvoltage or overcurrent operation	Increases ohmic heating of relay	See Thermal Stresses
Mechanical		
High cycling rate	Wear of moving parts	Binding of relay
	Contact wear	Misoperation of relay
	Increased friction	Slow or sluggish response
	Mechanical fatigue	
	Electrical pitting and arcing of contacts	
Loose connections (relay socket/terminals)	Loosening of pin/socket interface	High resistance paths
	Air gaps between contacts and connections	Arcing across contacts
		Open circuits
Vibration	Material fatigue	Component failures
	Loosening of connections	Open circuits
	Intermittent contact opening (chatter)	Misoperation
	Inadvertent contact closure	Inadvertent operation
Dormancy (lack of operation)	Organic materials set	Failure to operate
	Organic materials adhere to adjacent material	Binding
Thermal		
Continuous energization Ohmic heating)	Accelerates aging of coil insulation and other non-metallic components	insulation and component failure
Temperature rises in cabinet housing	Accelerates aging of non-metallic materials including coil insulation, bobbin, relay base, end contact spacers	Same as above
Elevated ambient temperature	Accelerates aging of non-metaltic components	Same as above
Environmental		
Humidity	Corrosion of contacts	Open circuits/increased resistances
	Coil and contact leakage paths	
Dust, dirt, debris, and chemical contamination	Interferences	Binding
	Increases in friction forces	Slow or sluggish operation
	increased resistance	Open circuits/increased ohmic heating
		Excessive wear

The following sections discuss specific aging and degradation mechanisms in greater detail. The specific effects of these mechanisms on particular relay components are described in Section 6.2.

6.1.1 Electrical Stresses

During a protective relay's normal operational life, energization at its nominal design voltage or current should not place significant stress on the relay internal components. However, the cumulative effect of constant energization and other aging stresses (see Table 6-1) can result in relay failure. Operation of electrical relays at voltage or current levels above their rating (even for short periods) tends to accelerate deterioration of the relays because of elevated temperatures. For this reason, exposure to high current or voltage during routine testing should be minimized to the extent practical.

Interruption of the supply signal to direct current coils can result in an inductive surge (sometimes referred to as an "inductive kick"). This inductive surge can cuase dielectric breakdown of weak points in the coil insulation system. Breakdown of the coil insulating material will result in cascading insulation failure. The leakage current causes increased temperatures in the insulation, which reduces the insulation resistance and leads to greater leakage current in the coil. Eventually, the insulation breaks down completely and the coil short circuits.

Some types of protective relays contain electrolytic capacitors. The performance of these capacitors will degrade over time and affect relay performance.

6.1.2 Mechanical Stresses

The primary mechanical stresses for protective relays consist of operational stresses, loose connections, adjustment errors, and wear. Loose connections may result in mechanical fatigue on spring-loaded components. Loose connections in the electrical paths of relay coils and contacts may contribute to premature failure because of increased currents, arcing, or increased heating. Wear of moving parts and contacts can degrade mechanical tolerances, increase frictional forces, and affect operating performance or calibration. Electromechanical components that are not in proper adjustment can accelerate wear, cause misoperation, alter electrical calibration settings, increase frictional forces, cause poor contact mating, and otherwise degrade relay performance.

6.1.3 Thermal Stresses

Protective relays normally receive a continuous, but low, level of current. Certain relay types, e.g., distance relays, may experience significantly greater levels of operating current. Long-term energization of the relay coil results in I^2R coil heating and stresses all age-susceptible components. The effect on the coil and other nonmetallic materials is material degradation caused by thermally accelerated chemical reactions.

Relays located in plant areas with elevated ambient temperatures are also subject to material degradation by this thermal aging process. Also, the temperature inside switchgear and panels may be significantly greater than the room ambient temperature. While the room temperature may be in the range of 70°F to 80°F, the internal temperature inside panels may be 20°F to 40°F above the room ambient. Elevated temperatures of this magnitude will accelerate the deterioration of the relay components, resulting in premature failure.

6.1.4 Environmental Stresses

Environmental stresses that can contribute to degradation of relays are humidity, dirt, dust, oxidation, and chemical contaminants. Humidity can cause material degradation (rusting) and can contribute to short circuits or arcing if sufficient condensation occurs on live electrical paths. Dust and dirt can increase friction on moving parts and accelerate wear of precision relay components. Chemical contaminants may cause premature breakdown of relay materials as well as contribute to oxidation of contacts.

Most relays used in nuclear plants are contained in a dust-proof case, which helps reduce the rate of deterioration caused by these environmental stresses. Also, IEEE C37.105-1987, *IEEE Standard for Qualifying Class IE Protective Relays and Auxiliaries for Nuclear Power Generating Stations,* states that the following aging mechanisms are considered to be relatively insignificant based on operating experience:

- Humidity - provided the protective relay and auxiliary device enclosure internal air temperatures exceed surrounding air temperatures by 5°C minimum.
- Contamination - based on expected application in nuclear power plants where ambient air quality is controlled to habitable levels.
- Altitude - below 5,000 feet.
- Vibration - no evidence of sensitivity to normal in-plant vibration levels.

6.1.5 Design Basis Event Stresses

The most significant design basis event for electromechanical protective relays is the design basis seismic event. Few relays will be exposed to harsh environments arising from design basis reactor accidents because relays are normally located in mild environments in the plant and are not exposed to steam line breaks or high radiation.

A protective relay's capability to withstand a seismic event does not appear to change with age. The most significant expected operation is momentary contact chatter for a deenergized relay. Structural failure of relay components or electrical failure is not expected. Relays are not damaged by momentary chatter; however, severe contact chatter can result in a trip signal or inadvertent system initiation that may require operator action to correct.

EPRI N-7147-S, *Seismic Ruggedness of Relays,* and EPRI N-7148-S, *Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality,* provide detailed information regarding the ability of protective relays to withstand seismic events and high frequency vibration. Although some protective relays used in nuclear plants may be susceptible to seismic events or vibration, the resolution of NRC Unresolved Safety Issue (USI) A-46, "Seismic Qualification of Equipment in Operating Nuclear Plants", should confirm the operability of relays for use at each nuclear plant.

6.2 Failure Modes

This section presents failure modes for each protective relay component. Failure modes for relays are summarized as follows:

- Fails to close - the failure of a normally open relay to close upon demand
- Fails to open - the failure of a normally closed relay to open on demand
- Short circuit - the short circuit of either a normally open or normally closed relay, including the potential effects of improper relay operation
- Fails to operate (energize) - the failure of the relay to operate due to lack of an input signal

Familiarity with the aging and degradation mechanisms described in the previous section is crucial to an understanding of how relays fail. Table 6-2 summarizes the effects of degradation mechanisms for specific components.

Table 6-2
Effects of Degradation on Protective Relay Components

Component	Material	Degradation Mechanism
Case	Steel, aluminum, phenolic	Loose connections Chemical contamination
Coil wire Coil spools Coil coatings	Varnished magnet wire, nylon bobbins	Inductive surge Overvoltage/overcurrent High ambient temperature Chemical contamination Loose connections Continuous energization High humidity
Relay contacts	Silver	Oxidation High cycling Chemical contamination Dirt, dust, and debris Misadjustment Dormancy High humidity Overvoltage/overcurrent
Contact carriers	Nylon, metal alloy	Chemical contamination High cycling Misadjustment Dormancy
Lead wires	Copper	Vibration Loose connections
Bearings, springs	Steel, metal alloys	Wearout Dirt, dust, and debris Chemical contamination High humidity Dormancy Misadjustment High cycling
Electronic components - capacitors, resistors, diodes inductors	Various	Inductive surge Overvoltage/overcurrent Continuous energization High ambient temperature Wearout (electrolytic capacitors)
Induction disc and cylinder, permanent magnet	Aluminum, magnetized steel	Chemical contamination Dust, dirt, and debris*

* Metallic iron-based particles can lodge between the disc and magnet, and prevent relay operation. Debris of this type is normally introduced during manufacturing or maintenance.

6.3 Reliability and Failure Information

Additional reliability and failure information is presented in this section. This information is a consolidation of data obtained from a variety of nuclear industry sources, including the Nuclear Plant Aging Research (NPAR) program, Licensee Event Reports (LERs), and the Nuclear Plant Reliability Data System (NPRDS).

6.3.1 NRC-Sponsored Aging Research

The NPAR program was initiated by the NRC to investigate aging effects on installed equipment in nuclear power plants. The program included a significant research effort into the aging and reliability of the Class 1E power system, including protective relays. The overall NPAR program is described in NUREG-1144, Revision 1, *Nuclear Plant Aging Research (NPAR) Program Plan.* The general objectives of the NPAR program, as explained in NUREG-1144, include:

- Identify and characterize aging and service-wear effects associated with electrical and mechanical components, interfaces, and systems likely to impair plant safety.
- Identify and recommend methods of inspection, surveillance, and condition monitoring of electrical and mechanical components and systems that will be effective in detecting significant aging effects before loss of safety function so that timely maintenance and repair or replacement can be implemented.
- Identify and recommend acceptable maintenance practices that can be undertaken to mitigate the effects of aging and to diminish the rate and extent of degradation caused by aging and service wear.

The NRC has sponsored extensive research into relay aging and reliability as part of the NPAR reviews of the Class 1E power system. The results of this research effort are documented in a series of NUREG reports. In a summary report, the NRC makes two key observations: 1) reportable relay failures are small in comparison to the number of relays in each plant, and 2) relay reliability is generally good. Other relevant information resulting from the NPAR research is discussed in the following sections.

6.3.1.1 Nuclear Plant Reliability Data System Information

As part of the review of the electrical power system, the NPAR program compiled NPRDS data for all power system-related components. The purpose of the evaluation was to determine which components experience the largest failure rate. As shown in Table 6-3, relays have a relatively low failure rate compared to other components used in nuclear plants. Furthermore, the number of relay events listed in Table 6-3 includes control and auxiliary relays associated with the electrical power system. Therefore, the percentage of failures of protective relays alone is even less than the 3.9% shown in Table 6-3.

Table 6-3
NPRDS Failure Data for Nuclear Plant Components
(Obtained From NUREG/CR-5181)

Component	Number of Events	Percent
Engines	496	22.0
Inverter	263	11.6
Circuit breaker	243	10.8
Blower and compressors	215	9.5
Valve	178	7.8
Battery charger	164	7.3
Generator	99	4.4
Instrument switch	93	4.1
Relay	88	3.9
Battery	78	3.5
Pump	68	3.0
Mechanical function unit	55	2.4
Motor	31	1.4
Transformers	30	1.3
Alternator	28	1.2
Electrical conductor	24	1.1
Instrument transmitter	24	1.1
All other equipment	83	3.6

6.3.1.2 Licensee Event Report Data

The NPAR program reviewed Licensee Event Reports for the period from January 1976 to December 1983. Although this information is not current, it is still considered a reasonable indicator for the performance of these relays since the types of relays used in nuclear plants have not changed significantly since 1983.

NUREG/CR-5181, *Nuclear Plant Aging Research: The 1E Power System*, provides an extensive evaluation of LER data. This data is summarized in Tables 6-4 through 6-6. Table 6-4 summarizes the manner in which a relay failure or misoperation was discovered. Table 6-5 provides a tabulated summary of the voltage level for the failed relays. As shown in Table 6-5, 95% of relay failures occurred on the 480, 600 or 4,160 V buses. However, note that these failures were documented by the LER recording system. A non-Class 1E relay failure might not have resulted in the initiation of an LER. Therefore, Table 6-5 most likely reflects the percentage breakdown of failures within the Class 1E buses. Table 6-6 provides a more detailed assessment of the cause of failure for each relay.

Table 6-4
Summary of Relay Fault Modes
(Obtained From NUREG/CR-5181)

	Failures		Command Faults		Total	
Failure	Number	Percent	Number	Percent	Number	Percent
Improper Operation	342	83	57	73	399	81
Delayed Operation	40	10	10	13	50	10
Premature Operation	29	7	11	14	40	8
Chattering	1	<1	0	0	1	<1
Total	412		78		490	

Table 6-5
Summary of Relay Faults by Voltage
(Obtained From NUREG/CR-5181)

	Failures		Command Faults		Total	
Voltage	Number	Percent	Number	Percent	Number	Percent
4160	298	72	57	73	355	72
480	64	16	13	17	77	16
600	27	7	5	6	32	7
6900	5	1	1	1	6	1
460	4	1	0	0	4	1
2400	2	<1	1	1	3	1
13800	2	<1	0	0	2	1
Unknown	10	2	1	1	11	2
Total	412		78		490	

Table 6-6
Summary of Relay Faults by Fault Cause
(Obtained From NUREG/CR-5181)

Type of Failure	Failures		Command Faults		Total	
	Number	Percent	Number	Percent	Number	Percent
Drift	189	46	5	6	194	40
Electrical malfunction	45	11	2	3	47	10
Sticking	42	10	2	3	44	9
Mechanical malfunction	32	8	1	1	33	7
Environment	10	2	0	0	10	2
Overheating	9	2	0	0	9	2
Improper signal	5	1	7	9	12	2
Design	2	<1	8	10	10	2
Corrosion	1	<1	0	0	1	<1
Fabrication, construction, quality control	1	<1	12	15	13	3
Personnel test	1	<1	7	9	8	2
Personnel maintenance	0	0	18	23	18	4
Personnel operation	0	0	8	10	8	2
Defective operation	0	0	4	5	4	1
Unknown	75	18	4	5	79	16
Total	412		78		490	

6.3.2 Recent Relay Experience

Nuclear plant events involving protective relays were evaluated to determine the manner by which plant operations are affected by relay failures, misoperations, or other occurrences. The period from January 1987 to September 1992 was covered by this review. In each event, plant operation was affected in some way, such as turbine trip, reactor trip, forced shutdown, or other equipment shutdown. A summary of the reasons for relay-related problems or actuations is provided in Figure 6-1.

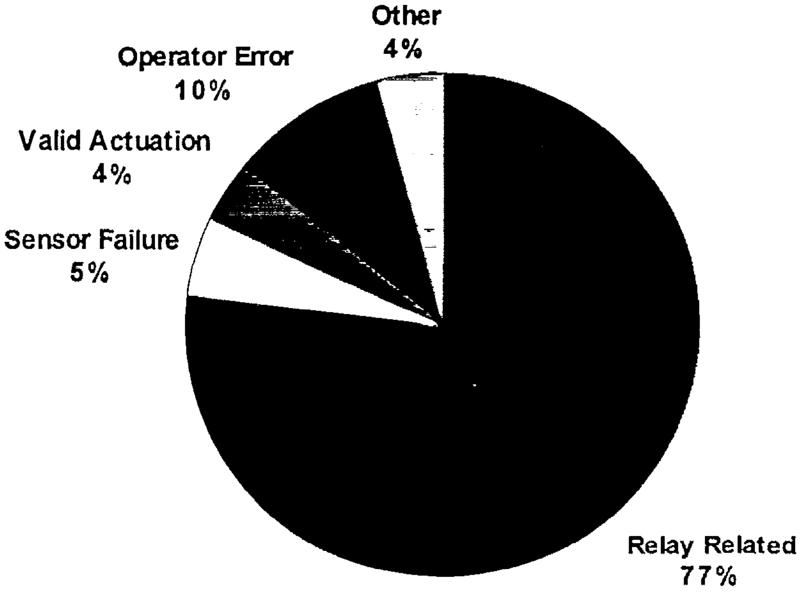


Figure 6-1
Causes for Recent Relay-Related Nuclear Plant Events

As shown in Figure 6-1, the majority of nuclear plant problems related to protective relays was due to relay failure. The definition of each category in Figure 6-1 is as follows:

- Relay Related. The relay did not perform its design function for any of the following reasons:
  - Failure during operation
  - Misoperation
  - Spurious operation
  - Relay failure due to loose wiring, wet environments, or other similar factors
  - Slow or improper response to system faults or transients
- Valid Actuation. The relay performed its design function in response to a system disturbance; however, a plant trip resulted from the relay actuation.
- Sensor Failure. The potential or current transformer input to the relay failed.

- Operator Error. Relay actuation occurred due to bumping of the panel, improper calibration, or other operator-related causes.
- Other. Relay problems that did not fit any of the above categories were combined into this category.

The frequency of plant transients resulting from protective relay actuation or failure has remained about constant during the period from 1987 to 1992 as shown in Figure 6-2.

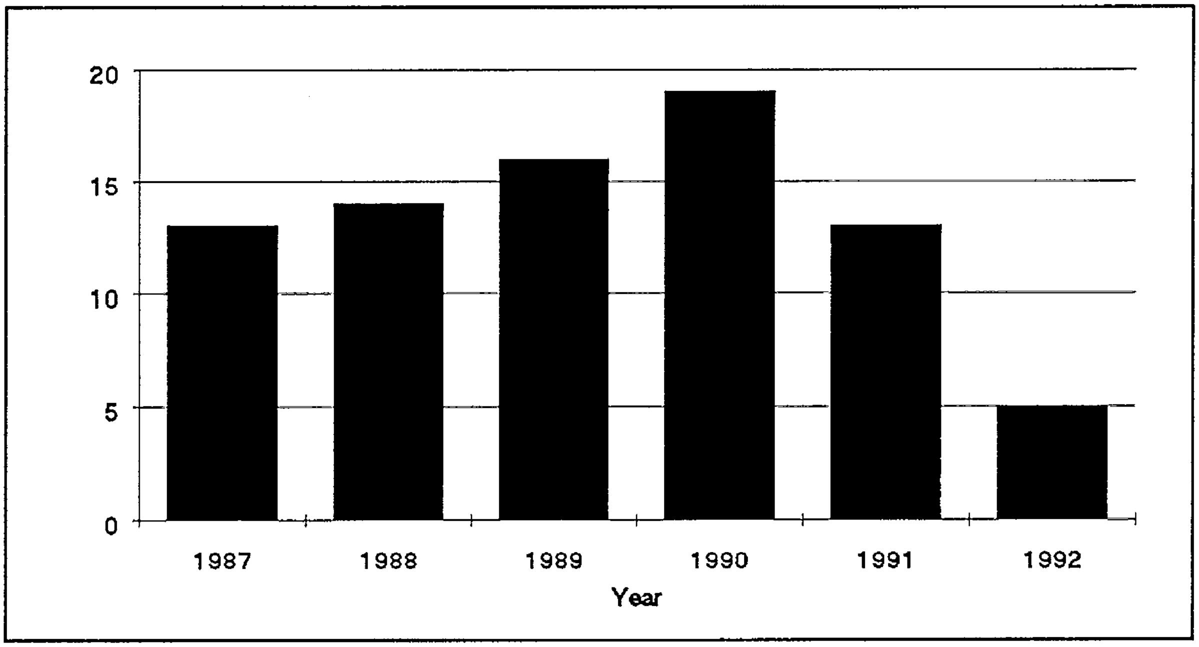


Figure 6-2
Frequency of Relay-Related Nuclear Plant Events
(Note that the available data only includes the first half of 1992)

The information used to create Figures 6-1 and 6-2 is provided in summary form in Table 6-7. The events summarized in Table 6-7 provide insight into the plant-wide consequences of a protective relay failure. Unfortunately, the raw data was not sufficiently detailed to allow a determination of the root cause for a majority of the events.

Table 6-7
Summary of Recent Relay-Related Industry Events

Date	Description of Event
Jan 1987	Relay failed, caused output breaker trip - caused turbine trip (no reactor trip)
Jan 1987	Potential transformer failed, caused electrical ground trip relay actuation - caused generator trip and caused reactor trip
Mar 1987	Field lost - caused by protective relay - caused generator trip - caused reactor trip
Mar 1987	Worker bumped generator relay cabinet - caused generator trip - caused reactor trip
Mar 1987	Main transformer sudden pressure relay trip - caused loss of load - caused reactor trip
Apr 1987	Anti-motoring relay actuated during shutdown - caused generator trip - caused reactor trip
Apr 1987	Generator exciter and field breaker failed open - caused by relay - caused generator trip - caused reactor trip
May 1987	Generator current differential relay incorrect actuation (after substation fault) caused generator trip - caused reactor trip
Jun 1987	Bus "1C" differential relay trip - caused by bump - caused loss of power on bus - caused reactor trip
Jun 1987	Auxiliary transformer "N1" pressure relay spurious actuation - caused loss of power - caused reactor trip
Jun 1987	Auxiliary transformer "N2" pressure relay spurious actuation - caused loss of power - caused reactor trip
Aug 1987	Wet switchyard relay caused output breaker to fail open - caused generator trip - caused reactor trip
Nov 1987	Electrical ground relay actuation - caused by contact failure during startup - caused generator trip - caused reactor trip
Jan 1988	"#2" protective relay failed and caused reactor coolant pump trip - caused reactor trip
Feb 1988	Generator field ground relay signal caused generator trip - caused reactor trip
Mar 1988	Operator bumped switchyard relay and caused load rejection - caused reactor trip
Apr 1988	4 KV Bus "2A" loss of power caused by relay - caused reactor coolant pump trip - caused reactor trip
May 1988	"B" circulating water pump tripped during undervoltage relay replacement - caused load reduction
May 1988	Circulating water pump "C" tripped - caused by phase imbalance relay failure - caused load reduction

Date	Description of Event
May 1988	Circulating water pump "B" tripped - caused by phase imbalance relay failure - caused load reduction
Jun 1988	500 KV line fault - followed by protective relay failure - caused loss of load - caused reactor trip
Jun 1988	Breaker relay operation on turbine power supply caused turbine trip - caused reactor trip
Jun 1988	Condensate pump trip due to current balance relay spurious actuation caused reactor trip
Jul 1988	Spurious anti-motoring relay actuation - caused generator trip - caused reactor trip
Sep 1988	Generator antimotor relay root isolation valve closed - caused generator trip - caused reactor trip
Oct 1988	Circulating water pump motor synch monitor relay failure - caused load reduction
Dec 1988	After turbine trip, startup transformer relay failed and caused non-vital bus loss of power
Feb 1989	Replaced generator relay "87G2" caused load reduction
Mar 1989	System auxiliary transformer failed - caused generator trip - caused by differential relay failure - caused reactor trip
Apr 1989	Potential transformer loose wire caused relay trip - caused loss of power and generator trip - caused reactor trip
Apr 1989	Generator protection relay actuated - caused by voltage transient - caused generator trip - caused reactor trip
Jun 1989	4.16 KV emergency bus relay failed - shutdown began but then stopped
Jul 1989	Generator output breaker trip - caused by relay failure - caused generator trip - caused reactor trip
Jul 1989	Operator error caused reactor coolant pump breaker undervoltage relay trip - caused reactor coolant pump trip and reactor trip
Aug 1989	Main transformer sudden pressure relay spurious trip - caused loss of load - caused reactor trip
Aug 1989	Voltage regulator current transformer failed due to voltage balance relay wiring error - caused generator trip - caused reactor trip
Sep 1989	Generator backup impedance relay trip -caused delay in startup
Sep 1989	"1HTA" relay breaker failed - caused by rain - caused load reduction
Sep 1989	"1HTA" relay breaker failed - caused by rain - caused load reduction
Oct 1989	Adjustment setpoint second level undervoltage relay - caused manual shutdown
Oct 1989	Gas detector relay failed on main transformer - caused load reduction
Dec 1989	After transmission line fault (which caused generator trip and reactor trip) relay failed and slow breaker transfer failed to clear - caused loss of power

Date	Description of Event
Dec 1989	After transformer failure, generator output breaker failed to open - caused by relay failure
Feb 1990	Differential current relay circuit estate" link - caused generator trip - caused reactor trip
Feb 1990	High differential current relay spurious actuation - caused RCP trip - caused reactor trip
Mar 1990	False high bus duct temperature - caused by relay failure - caused generator trip - caused reactor trip
Mar 1990	Transmission line fault with negative sequence time overcurrent relay failure - caused generator trip - caused reactor trip
Mar 1990	Operator error caused reactor coolant pump "B" motor generator set generator lockout relay trip - caused reactor trip
Mar 1990	Loss of field relay caused generator trip and caused reactor trip during shutdown
Mar 1990	After loss of power on 4,160 V bus, primary differential relay actuated and caused generator trip - caused reactor trip
Apr 1990	Underfrequency relay failed and caused reactor coolant pump breaker to open - caused reactor trip
Apr 1990	Electrical ground relay actuated during surveillance test - caused by operator error-caused generator trip
May 1990	Generator backup relay actuated - caused by loose connection - caused load reduction
May 1990	345 KV line fault and relay time delay caused loss of load - caused reactor trip
Jun 1990	Spurious relay actuation caused by moisture - caused generator trip and caused reactor trip
Jun 1990	Generator breaker relay failed - caused reactor trip and turbine trip
Jul 1990	"A" reserve station service transformer trip - caused by relay failure - caused load reduction
Jul 1990	Generator overvoltage/hertz relay out of calibration - caused generator trip and reactor trip
Sep 1990	Main transformer trip - caused by relay failure due to corrosion - caused loss of load and reactor trip
Sep 1990	Operator bumped turbine trip relay - caused reactor trip breaker to open
Nov 1990	Manual shutdown to install undervoltage relay noise filter
Nov 1990	6.9 KV board loss of power - caused by relay failure - caused reactor trip
Feb 1991	Relay actuation - caused by breaker vibration - caused reactor coolant pump loss of power - caused reactor trip
Feb 1991	Switchyard breaker trip - caused by relay failure - caused loss of power

Date	Description of Event
Mar 1991	Generator overcurrent relay calibration error - caused generator trip - caused reactor trip
Mar 1991	Generator protection relay failed and caused generator trip - caused reactor trip
Mar 1991	Generator protection relay failed and caused generator trip - caused reactor trip
Jun 1991	Switchyard breaker trip caused by relay failure - caused loss of load and reactor trip
Jun 1991	Lightning caused main transformer oil pressure relay trip and turbine trip
Jun 1991	Switchyard breaker trip - caused by relay failure caused loss-of-load - caused reactor trip
Aug 1991	Electrical ground fault sensed on generator relay - caused generator trip and reactor trip
Sep 1991	Protective relay current transformer failed - caused generator trip and reactor trip
Oct 1991	Generator reverse power relay failed during startup - replaced but delayed startup
Oct 1991	While shutting down, startup transformer loss of power - caused by breaker relay failure and salt water spray
Dec 1991	Generator electrical ground backup relay spurious actuation - caused generator trip - caused reactor trip
Mar 1992	"1W" main transformer pressure relay cable failure - caused turbine trip
Apr 1992	Main transformer trip - caused by relay failure - caused loss of load and reactor trip
May 1992	Protection relay spurious actuation - caused by loose connection - caused generator trip and reactor trip
Jul 1992	Protection relay spurious trip - caused by lightning - caused generator trip and reactor trip
Sep 1992	Maintenance error caused subsynch relay actuation - caused generator trip and reactor trip

7.0 Recommended Maintenance Practices

Protective relays have a reputation for providing reliable service for many years. Nonetheless, protective relays are delicate instruments that are susceptible to degradation mechanisms that affect performance. Failure of a protective relay to contain and isolate an electrical problem can have severe plant-wide repercussions. When an expected protective function does not occur, the end result of an electrical abnormality may be catastrophic equipment damage and prolonged down time instead of localized minor damage. Because of the severe consequences of a failure, protective relays should be maintained in a high state of readiness.

Section 7 provides an overview of recommended maintenance practices for protective relays. The information contained in this section is intended to provide a framework, or baseline, for establishing a successful protective relay maintenance program. However, it is stressed that each plant must view these recommendations in light of their specific circumstances and experience, and tailor their maintenance practices accordingly. Application and service conditions for protective relays vary too widely to simply prescribe a single, inflexible maintenance program for all facilities.

The information presented in this section is directly linked to Sections 8 and 9. This section presents recommendations on what inspections, checks, and tests to perform, and when to perform them. Sections 8 and 9 discuss the details of each inspection, check, or test. Section 8 addresses mechanical-related maintenance; Section 9 addresses electrical-related maintenance.

The recommended practices presented here pertain primarily to electromechanical protective relays. However, the recommendations are, in general, applicable to single-function solid-state relays used at nuclear plants (e.g., undervoltage and frequency relays). Maintenance activities for multi-function, microprocessor-controlled protective relays are not contained within the scope of this guide. These complicated programmable relays are usually applied to high-voltage transmission lines and are not typically used for generating plant protection.

7.1 Background Information

This section presents an overview of recommended maintenance practices for protective relays. The information presented is intended to provide an overall perspective of protective relay maintenance. The recommendations are based on a review of numerous inputs, including:

- Historic relay reliability and failure data
- Manufacturer's operating instructions
- Nuclear and industry standards and codes
- General user experience and field personnel input
- Test equipment manufacturer's recommendations
- Industry reviews, analyses, and papers
- Representative field test data (as-found/as-left data)
- Specific nuclear plant experience

A primary objective of this guide is to present the recommended maintenance practices in a logical, straightforward manner and to eliminate ambiguity over which inspections and tests to conduct in different circumstances. The general maintenance categories for protective relays appear to be well standardized and the array of possible inspections and tests is also fairly well understood. However, it is difficult to find clear guidance on which inspections and tests to conduct within each maintenance category (most existing literature tends to focus on the specifics of how to conduct a certain inspection or test; when and under what circumstances to conduct the test is typically delegated to the user). Hence, it is still emphasized that plant-specific experience must be factored into any maintenance program.

7.2 Classification of Maintenance

Maintenance and testing of protective relays is logically divided into four categories. Each category represents an event or circumstance that warrants some sort of maintenance action. The maintenance categories for protective relays are discussed in the following subsections.

7.2.1 Acceptance Testing

Acceptance testing is associated with the design and manufacturing of products. These tests are conducted by manufacturers or certifying authorities to validate new product designs and to ensure production units meet design and manufacturing requirements.

End users often choose to perform an acceptance test on newly received units (often referred to as a receipt inspection) to ensure that no shipping damage has occurred and to verify that performance characteristics and factory settings are as specified.

7.2.2 Installation Checks

Installation checks are conducted when a protective relay is initially placed in service. Installation checks include calibration, mechanical inspections, and electrical tests. These checks are conducted to ensure that a new unit is properly adjusted and calibrated, is installed correctly, and is otherwise fully capable of performing its intended function.

7.2.3 Preventive (or Periodic) Maintenance

Preventive maintenance is performed on a scheduled basis to:

- Detect and correct actual or impending problems
- Verify relay performance is within acceptable operating limits
- Reduce the likelihood of future failure or degraded performance by ensuring the relay is clean and in good working order.

Preventive maintenance may include tests, checks, inspections, measurements, replacements, adjustments, repairs, refurbishment, and similar activities.

7.2.4 Post-Repair or Replacement Checks

Post-repair or replacement checks are conducted subsequent to repairing/reworking a relay or replacing relay components. These checks are performed to verify that repairs were successful, replacement components were installed properly, and to otherwise ensure the relay is operating satisfactorily after corrective maintenance. Post-repair checks typically include pertinent installation checks. Additional adjustments, checks, or tests may also be necessary depending on the type of relay.

7.3 Overview of Protective Relay Checks, Inspections, and Tests

The four major categories of relay maintenance discussed in Section 7.2 establish a program-level structure for conducting protective relay maintenance. The next logical question is what specific checks, inspections, and tests should be performed within each category. The following subsections define specific maintenance items (i.e., types of checks, inspections, and tests) applicable to protective relay maintenance. Section 7.5 ties the specific maintenance items to the major maintenance categories.

7.3.1 Visual Inspection and Cleaning

A visual inspection is a thorough check of a relay to identify conspicuous signs of unusual degradation. A visual inspection is often the first method by which a pending problem is identified. Detailed mechanical checks are not performed as part of a visual inspection. Periodic cleaning helps preserve a relay by reducing the level of dirt, dust, debris, and contaminants that cause deterioration and wear.

7.3.2 Mechanical Checks and Adjustments

Mechanical checks are performed on electromechanical relays to ensure that mechanical components are operating within specified tolerances. If a mechanical parameter is out of tolerance, an adjustment is made to restore the parameter to an acceptable setting.

7.3.3 Electrical Tests

Electrical tests are performed to verify that performance characteristics are acceptable under a controlled set of input conditions. Electrical tests also provide diagnostic information regarding the condition of a relay and its components. Electrical testing of protective relays requires specialized test equipment.

7.3.4 Calibration

A calibration is the process of making adjustments to bring operating characteristics into a desired range or to within specification. The calibration process for protective relays generally involves adjustments that alter electrical or magnetic characteristics of the relay. The need for calibration is usually identified when performing the electrical tests.

7.3.5 Functional Check

For protective relays, a functional check is conducted to verify that the desired protective action occurs in response to a relay operation. In most cases a functional check is based on ensuring a circuit breaker opens when the relay's main contacts are closed.

7.4 Determining Maintenance Intervals

The ideal periodic maintenance interval for protective relays depends on many factors. These factors can vary considerably depending on the application and service conditions. Thus, it is overly simplistic to assume that one interval fits all situations. The optimum maintenance interval is achieved when the desired level of reliability is maintained with the least expenditure of resources.

The following factors should be considered when determining maintenance intervals:

- Analysis of past performance (demonstrated reliability, test data, trending information)
- Voltage level of circuit
- Likelihood of operation (based on past experience)
- Consequences of failure
- Application (safety-related, quality-related, or general purpose)
- Service environment and normal operating temperature
- Maintenance schedule of other associated equipment
- Outage periodicity, schedule, and duration
- Type of relay and its reliability
- Manufacturer's recommendations
- Manpower availability
- Age
- Self-checking capabilities

From objective evidence gained during industry studies and surveys, it is generally agreed that protective relays have, in the past, been over-tested. A general trend to reduce relay test frequencies at utilities is evident. Manufacturer's guidance has become less prescriptive and provides considerable latitude with regard to test intervals. Over-testing should be avoided for two reasons:

- Valuable resources are expended on maintenance that may not measurably improve plant safety, reliability, or efficiency. Other maintenance that is more beneficial to the plant may inappropriately receive a lower priority. Excessive maintenance contributes to high O&M costs and should be avoided.

- Protective relays are delicate instruments that require considerable expertise to test properly. Each time a relay is removed from service and tested, the potential exists for adjustment errors or equipment damage. Over-testing increases the risk of errors or damage without a justifiable improvement in reliability. Some utilities have actually experienced an improvement in relay performance after extending test intervals because of the reduction in personnel-related errors.

Past performance is generally the primary factor in establishing maintenance intervals for protective relays. Historic maintenance records provide a excellent source of information for assessing past performance. Maintenance records will typically indicate the as-found operational condition of a relay. This information provides tangible evidence regarding a relay's functional status and reliability. An analysis of as-found/as-left data provides a means of quantitatively assessing relay performance and drift characteristics. Section 10 discusses one possible method of reviewing as-found/as-left data.

7.5 Summary of Recommended Practices

Table 7-1 provides a summary of recommended maintenance practices for protective relays installed at nuclear power plants and links the specific maintenance items covered in Section 7.3 to the major maintenance categories defined in section 7.2.

The recommended interval for periodic maintenance is 2 to 6 years. This wide range provides the flexibility needed to optimize maintenance intervals and fully account for the many factors that influence relay maintenance practices. Circumstances may exist in which testing a protective relay, or group of relays, at an interval less than 2 years or greater than 6 years is appropriate; however, a range of 2 to 6 years covers most reasonable contingencies.

Electrical tests vary depending on the type of relay and its construction. Table 7-2 provides a breakdown of the recommended electrical tests for protective relays. Because each type of relay is unique in design and construction, electrical tests for similar types of relays will vary for different makes and models. Manufacturer's guidance must be used in conjunction with the recommendations presented in this guide to ensure adequate testing of a specific type of relay.

Table 7-1
Recommended Maintenance Practices

Category	When Performed	Maintenance Item	Reference Section
Acceptance testing (Note 1)	Receipt	Visual inspection	Section 8.3
Installation checks	Unit placed in service	Visual inspection & cleaning	Section 8.3
		Mechanical checks & adjustments	Section 8.4
		Calibration	Table 7-2
		Electrical tests	Table 7-2
		Functional check	Section 8.5
Preventive maintenance	2-6 year interval (Note 2)	Visual inspection & cleaning	Section 8.3
		Electrical tests	Table 7-2
		Functional check	Section 8.5
Post-repair or replacement checks	Following repair or component replacement	Mechanical checks & adjustments 3)(Note 3)	Section 8.4
		Calibration (Note 3)	Table 7-2
		Electrical tests	Table 7-2
		Functional check	Section 8.5

Notes for Table 7-1

1. If a relay is going to be installed immediately, a general inspection to verify no shipping damage is generally sufficient since a full series of inspections and tests will be performed at the time of installation. However, if the relay is intended as a spare or will not be installed in the near future, a more detailed receipt inspection is appropriate. In this case, checks should be performed to verify the relay was received in good working order.

2. Determination of an appropriate maintenance interval is covered in Sections 7.4 and 10.0. All factors considered, most facilities find that an interval between 24 years yields good reliability without placing an undue burden on maintenance resources. Maintenance intervals should be optimized to the degree justifiable, as determined by demonstrated reliability. Unusual applications or circumstances might require more frequent preventive maintenance intervals.

3. Perform applicable mechanical checks and calibration of the affected components. Components unaffected by the repair or replacement need not be disturbed. It is recommended that a full set of electrical tests be performed to verify that relay settings have not been inadvertently changed during the repair.

Table 7-2
Recommended Electrical Tests

Device Number	Description	Electrical Test	Reference Section	Notes
21	Distance relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Angle of maximum torque	Section 9.8	
		Reach	Section 9.9	
		Offset	Section 9.10	
		Spurious torque	Note 5	
25	Synchronizing & synchronism check relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Pickup or dropout	Sections 9.3 & 9.6	
		Angle of maximum torque	Section 9.8	
		ICS pickup & dropout	Section 9.5	
27	Undervoltage relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Dropout	Section 9.3	
		Induction unit timing	Section 9.4	
		ICS pickup & dropout	Section 9.5	

Table 7-2 (Continued)
Recommended Electrical Tests

Device Number	Description	Electrical Test	Reference Section	Notes
32	Directional power relay	Insulation resistance	Section 9.2	Notes I & 2
		Angle of maximum torque	Section 9.8	
		Directional unit pickup	Section 9.6	
		Induction unit pickup	Section 9.3	
		Induction unit timing	Section 9.4	
		ICS pickup & dropout	Section 9.5	
40	Loss of excitation relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Angle of maximum torque	Section 9.8	
		Reach	Section 9.9	
		Offset	Section 9. 10	
		Spurious torque	Note 5	
46	Phase-balance current relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Pickup	Section 9.3 & 9.6	
		Induction unit timing	Section 9.4	
		Slope or balance	Section 9.7	
		ICS pickup & dropout	Section 9.5	

Table 7-2 (Continued)
Recommended Electrical Tests

Device Number	Description	Electrical Test	Reference Notion	Notes
47	Phase-sequence voltage relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Voltage filter balance	Note 3	
		Instantaneous unit pickup (sensitivity)	Section 9.6	
		Induction unit dropout	Section 9.3	
		Induction unit timing	Section 9.4	
		Control of induction unit	Section 9.11	
		ICS pickup & dropout	Section 9.5	
49	Thermal relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Thermal unit timing	Section 9.4	
		ICS pickup & dropout	Section 9.5	
50/51	Overcurrent relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Induction unit pickup	Section 9.3	
		Induction unit timing	Section 9.4	
		Instantaneous pickup	Section 9.6	
		ICS pickup & dropout	Section 9.5	

Table 7-2 (Continued)
Recommended Electrical Tests

Device Number	Description	Electrical Test	Reference Section	Notes
59	Overvoltage relay	Insulation resistance Pickup Induction unit timing ICS pickup & dropout	Section 9.2 Section 9.3 & 9.6 Section 9.4 Section 9.5	Notes I & 2
60	Voltage balance relay	Insulation resistance Pickup Balance Auxiliary relay pickup	Section 9.2 Section 9.3 Note 4 Section 9.6	Notes 1 & 2
67	Directional overcurrent relay	Insulation resistance Induction unit pickup Induction unit. timing Directional unit pickup Angle of maximum torque ICS pickup & dropout Spurious torque	Section 9.2 Section 9.3 Section 9.4 Section 9.6 Section 9.8 Section 9.5 Note 5	Notes 1 & 2

Table 7-2 (Continued)
Recommended Electrical Tests

Device Number	Description	Electrical Test	Reference Section	Notes
81	Frequency relay	Insulation resistance	Section 9.2	Notes I & 2
		Pickup or dropout	Section 9.3	
		Induction unit timing	Section 9.4	
		ICS pickup & dropout	Section 9.5	
87	Differential relay	Insulation resistance	Section 9.2	Notes 1 & 2
		Pickup	Section 9.6	
		Slope	Section 9.7	
		Through fault	Section 9. 12	
		ICS pickup & dropout	Section 9.5	

Note:

1. Insulation resistance problems are rare in protective relays. Unless the relay is located in a particularly dirty or abusive environment, insulation resistance does not necessarily need to be tested at the same interval that other electrical tests are performed. A frequency of 7-10 years is recommended.
2. Never perform an insulation resistance test on a solid-state relay.
3. The filter balance test is unique to certain models of negative-sequence voltage relays. Refer to manufacturer's guidance for performing this test.
4. The voltage balance test is unique to voltage balance relays. Refer to manufacturer's guidance for performing this test.
5. The spurious torque test is unique to certain types of directional units. Refer to manufacturer's guidance for performing this test.

8.0 Mechanical Inspections and Checks

Section 8 provides information on recommended mechanical inspections and checks for protective relays. This information is intended to help plants establish and/or refine their protective relay maintenance practices consistent with their overall maintenance objectives.

The emphasis of this section is:

- How to perform each inspection and check
- What each inspection and check accomplishes

The purpose of each inspection and check is discussed and a recommended procedure for each is outlined. The procedures sections are intended to capture the essence of how to accomplish each recommended inspection and check. The information presented here should be supplemented with manufacturer- and plant-specific information to create actual field procedures. Section 7 provides a broader look at the recommended maintenance practices and discusses when each inspection and check should be performed.

The recommended inspections and checks are based on industry guidance, applicable standards, manufacturer recommendations, regulatory documents, and industry experience. Many different types of protective relays are in service. Consequently, the specific recommendations of this guide may not fully address unique requirements of a particular make and model of protective relay; conversely, some recommendations may not apply. For this reason, manufacturers' literature should always be reviewed to confirm intended maintenance practices.

8.1 Preparation

1. Ensure a complete set of protective relay tools and cleaning equipment are on hand.
2. Review schematics and/or circuit diagrams as appropriate to ensure the consequences of removing the relay from service are known.
3. Review pertinent relay data sheets and record relevant information on the relay test and inspection sheet. Information to be recorded may include, but is not limited to: make, model, tap settings, time dial settings, ratings, tag number, CT ratio, and pickup values.

8.2 Removing a Protective Relay From Service

1. Ensure plant conditions are consistent with the work to be performed and obtain permission to remove the relay from service. Always be aware of any off-normal plant condition or system lineup that may be impacted by removing the relay from service. Additional caution should be exercised during outages or periods of heavy maintenance.
2. Isolate the relay and tag it out of service in accordance with plant procedures.

3. Clean the outside of the relay cover before removing the cover from the case to minimize the possibility of dirt falling into the relay's electrical components when the cover is removed.

CAUTION: If the relay cover is configured with an external reset lever for the operation indicators, take care not to inadvertently catch the lever on the hinged armature of seal-in units or instantaneous units when taking the relay cover off. This error may accidently cause the contacts to close and operate the relay.

4. Remove the relay cover.

WARNING: Current transformers (CTs) and other relay electrical components represent a potential shock hazard. Follow all applicable safety precautions.

CAUTION: Take extreme care not to open circuit CTs when taking the relay out of service. Protective relays are designed to automatically short circuit CT leads when the relay is disconnected; however, these safeguards have failed. Immediately reconnect the relay if any arcing or sparking occurs while removing the relay from service.

5. Isolate the relay from external circuits. This action is completed by removing the connecting plug (GE relays) or by opening the disconnect switches (Westinghouse or ABB Relays). Follow the manufacturer's guidance for the sequence to follow when opening switches. An inadvertent operation may occur if the proper sequence is not followed.

CAUTION: For Westinghouse relays, always open the red handle switch before opening any other disconnect switches when removing the relay from service. Close the red handle switch last when returning the relay to service.

6. Release the latches that lock the chassis assembly to the case and gently remove the relay chassis assembly.

8.3 Visual Inspection and Cleaning

Protective relays should be inspected and cleaned periodically. A visual inspection is a thorough check of a relay to identify conspicuous problems or signs of unusual degradation. A visual inspection does not include a detailed check of all mechanical settings and tolerances. Detailed mechanical checks are covered in Section 8.4. Periodic cleaning helps preserve a relay by reducing the level of contaminates (e.g., dirt, dust, debris, corrosives, and other chemicals) that degrade the relay over time and affect its operation.

8.3.1 Purpose

A visual inspection and cleaning is intended to:

- Assess the general condition of the relay, identify signs of degradation such as overheating, and detect any damage that may affect proper relay operation
- Remove contaminates that cause wear and degrade components
- Identify any application issues or service conditions that are incompatible with reliable relay operation
- Verify that ratings and settings (e.g., time dial, tap, ICS pickup) are in accordance with design documents

The service environment for protective relays is relatively mild compared with other types of equipment. Protective relays are, by their very nature, inactive (dormant) devices and are not typically exposed to extreme operating or environmental conditions. However, electrical, mechanical, thermal, and environmental stresses are present and can, over time, degrade relay performance, as discussed in Section 6.

A good visual inspection can identify many degradation mechanisms at an early stage and flag potential problems or impending failures. Examples of degradation mechanisms detectable during a visual inspection are: corrosion, excessive dirt, loose connections, physical damage, and overheating.

8.3.2 Procedure

NOTE: A visual inspection and cleaning is most efficiently performed in conjunction with periodic electrical tests.

1. Remove the relay from service and remove the relay unit (chassis assembly) from the case as outlined in Section 8.2. Make note of any burnt or unusual odor detected when removing the relay cover.

2. Verify that relay nameplate information and relay settings are In accordance with design information. Items to check may include: make, model, tap settings, time dial settings, ratings, and tag number.

3. Inspect the cover and cover gasket (dust seal) for integrity.

4. Check the cover glass for tightness in the frame; verify it is not cracked or damaged.

5. Clean the cover glass inside and out with a soft, lint free cloth and water.

CAUTION: Do not use ammonia based cleaners or other unapproved chemicals that may damage plastic or metal relay components.

NOTE: If the visual inspection and cleaning is being done in conjunction with electrical testing, take as-found readings before proceeding to the next step.

6. Remove any dust, dirt, debris, or metal particles that have accumulated on the relay chassis assembly, electrical components, or case. Dust should be removed with a soft bristle brush and/or low pressure air (preferably a hand-operated syringe or canned air). Particular attention should be given to the air gap between the disk and magnet of induction disk units. Metal particles, which can cling to magnet pole faces, should be removed with a magnet cleaner or air gap brush.

7. Inspect the relay chassis assembly, electrical units, case, and connecting plug or disconnect switches (as applicable) for any signs of degradation, damage, or excessive wear. For induction disk units, ensure the delicate restraint spring is not deformed or tangled.

8. Inspect the relay for indications of moisture or rust. Pay close attention to critical moving parts, such as the bearings of induction units.

NOTE: Moisture or rust may indicate that the relay is not in a suitable environment.

9. Check taps and bolted connections for tightness. Do not loosen snug connections and do not overtighten connections.

10. If the relay has a current signal input, ensure that the CT shorting assembly is in good condition and making solid contact.

11. Check for smooth, free operation of instantaneous and seal-in units; gently operate the hinged armature by hand several times. This motion should cause the targets of any units so equipped to change status and indicate that the unit has operated. Reset targets by actuating the target reset lever.

12. Check for signs of thermal degradation or damage to the insulation of coils (exposure to voltage or current beyond a coil's rating causes overheating and premature failure). Thermal damage to coils is indicated by a burned smell, spongy insulation, or brittle insulation. Note any discoloration of components that may be indicative of overheating.

13. Thoroughly clean moving relay components that are in constant contact with each other during normal operation (e.g., the backstop of an induction unit). Even a very small build up of dirt and grime can cause the components to become sticky and affect relay pickup settings.

14. Check relay contact surfaces for cleanliness, pitting, burning, corrosion, and wear. If contacts need to be cleaned or smoothed, gently polish the contacts with a special burnishing tool. The burnishing tool is a very fine file that polishes rather than scratches the delicate silver contact surface.

CAUTION: Do not attempt to clean silver contacts with a knife, file, sandpaper, or any other abrasive material not specifically approved by the manufacturer. Unapproved abrasives may scratch the contacts or leave small particles of abrasive material in the contacts.

CAUTION: Do not clean contacts with solvents or touch with fingers. The residue left on the contacts may affect proper operation.

15. If the relay contains an induction disk unit, perform the following checks:

    a. Ensure the induction disk pivot bearings are in good working order by manually rotating the disk until the contacts close, then observe that the disk rotates smoothly, evenly, and without undue friction while resetting under the force of the restraint spring.

    b. Ensure the disk is not deformed or bent and that good clearance exists between the disk and magnet poles. Observe the disk over its entire travel while resetting and verify that the clearance between the disk and pole faces are approximately equal on each side.

c. Check closely to ensure that no metal particles are attached to the magnet pole faces that could cause the relay disk to hang up while rotating.

If the induction disk unit is out of adjustment or needs repair, consult the manufacturer or manufacturer's literature for guidance.

16. Document any unusual conditions identified or corrective action taken, such as excessive dirt, evidence of internal moisture, loose connection, or bent disk.

8.4 Mechanical Checks and Adjustments

8.4.1 Purpose

Mechanical checks are performed to verify that components within the relay are in proper mechanical adjustment. Out of adjustment components can result in improper operation and possibly damage.

8.4.2 Induction Disk Units

1. Some induction disk units have a leaf spring behind the stop arm that rests against the time dial stop. The leaf spring helps prevent sticking between the stop arm and time dial stop during prolonged periods of inactivity. Check to ensure the leaf spring gap is in accordance with the manufacturer's tolerance; adjust the leaf spring if necessary.

2. Check the contact wipe (overtravel) to ensure it is within the manufacturer's tolerance. Contact wipe is the amount the stationary contact deflects before reaching its backstop after the contacts close. Deflection of the stationary contact is adjusted via a setscrew; adjust the contact wipe if necessary.

3. Check the time dial zero position. When the contacts just close, the time dial zero position should be at a specific location relative to the time dial index mark. If the zero position is incorrect, adjust the time dial in accordance with the manufacturer's instructions.

NOTE: For General Electric relays, proper adjustment is usually indicated when the zero position aligns with the reference mark just as the contacts close. Proper adjustment of Westinghouse (ABB) relays depends on the specific model.

4. Check to see that the induction disk is properly centered between the magnet poles and that the shaft vertical end play is correct. As the disk rotates through its full travel, the disk should remain centered between the magnet poles. Adjust the disk height so that it is centered to within the manufacturer's tolerance if required. Ensure the end play (i.e., the amount the shaft is allowed to move up and down) is within the manufacturer's limits. Follow the manufacturer's instructions to adjust end play if it is not within tolerance.

8.4.3 Indicating Contactor Switches (Seal-In Units)

1. If the indicating contactor switch (ICS) has two contacts, ensure the moving contacts strike the stationary contacts simultaneously when the armature is gradually raised by hand. If not, adjust the contacts in accordance with the manufacturer's instructions.

2. Check the contact wipe to ensure it is within the manufacturer's tolerance; adjust the wipe if necessary.

3. Ensure the target, or operations indicator, is actuated at the correct point in the armature stroke.

8.4.4 Instantaneous Units

1. If the instantaneous unit has two contacts, ensure the moving contacts strike the stationary contacts simultaneously when the armature is gradually raised by hand (this applies only if the moving contacts are attached to a common armature). Adjust the contacts in accordance with the manufacturer's instructions if necessary.

2. Check the contact wipe to ensure it is within the manufacturer's tolerance; adjust the wipe if necessary.

3. Ensure the target, or operations indicator, is actuated at the correct point in the armature stroke.

8.4.5 Induction Cylinder Units

Mechanical adjustments of induction cylinder units are highly dependent upon make and model; consult the manufacturer's instructions for detailed guidance. Checks and adjustments of induction cylinder units generally involve the following components:

- Stationary and moving contact gap and wipe
- Vertical end play of the cylinder and shaft assembly
- Induction cylinder core
- Clutch (GE relays)
- Magnetic plugs (Westinghouse)
- Spring tension or sensitivity

8.4.6 Polar Units

1. Check the gap between moving contacts and stationary contacts to ensure it is within the manufacturer's tolerance; adjust the gap if necessary.

2. Verify that the armature floats near the center of the air gap when the permanent magnet is removed. Adjust the core screw to center the armature assembly if necessary.

8.5 Functional Check

8.5.1 Purpose

The purpose of a functional check is to verify that the protection system performs its design function when a protective action is manually initiated. A functional check confirms that the trip or actuation circuit is functioning properly. This test is usually performed subsequent to all other relay, switchgear, and circuit breaker maintenance to ensure the system is functioning properly prior to declaring the system fully operable.

During initial startup testing of overcurrent protection systems, detailed functional checks may be performed by primary injection testing. During this type of testing, a simulated fault current is injected on the line and the protection system response is monitored. Primary injection testing ensures that the entire system - from CT to breaker - is functioning properly. Primary injection testing is time consuming, requires special equipment, and is complex to perform. For these reasons, it is usually not performed on a regular basis and is reserved for post-construction startup.

The functional testing recommended here is considerably more simple than primary injection testing. The test is performed by closing the relay's main contacts (this is usually done manually) and verifying that the protective function is carried out.

8.5.2 Procedure

CAUTION: Ensure that undesired equipment operation will not occur as the result of functional testing. For example, functional testing may cause a circuit breaker to open, which in turn may initiate a subsequent action because of interlock circuits.

NOTE: Functional testing should be performed subsequent to all other relay, switchgear, and circuit breaker maintenance to ensure the entire system is functioning properly prior to restoring the system to full operation after maintenance.

1. Verify system and plant conditions are acceptable for the intended test.
2. Ensure the protective relay is installed, fully functional, and that tripping power is available.
3. Initiate protective relay operation by closing the main relay contacts. This is usually done manually.
4. Verify proper system response (e.g., circuit breaker opens or alarm actuates).

9.0 Electrical Tests and Calibration

Section 9 provides information on recommended electrical tests and calibrations for protective relays. This information is intended to help plants establish and/or refine their protective relay maintenance practices consistent with their overall maintenance objectives.

The emphasis of this section is:

- How to perform each electrical test and calibration
- What each test accomplishes

The purpose of each electrical test is discussed and recommended procedures for testing and calibration are outlined. The procedure sections are intended to capture the essence of how to accomplish each recommended electrical test. The information presented here should be supplemented with manufacturer- and plant-specific information to create actual field procedures. Section 7 provides a broader look at recommended maintenance practices and discusses when each electrical test should be performed.

The recommended electrical tests and calibrations are based on industry guidance, applicable standards, manufacturer recommendations, regulatory documents, and industry experience. Many different types of protective relays are in service. Consequently, the specific recommendations of this guide may not fully address unique requirements of a particular make and model of protective relay; conversely, some recommendations may not apply. For this reason, the manufacturer's literature should always be reviewed to confirm intended maintenance practices.

9.1 Test Preparation

9.1.1 Test Equipment

Several types of relay test equipment are available. Relay test equipment is becoming increasingly sophisticated as computer-based test sets work their way into the market. Proper operation of the test equipment is vital to obtaining good test results. It is advisable to ensure that all personnel conducting relay testing are familiar with the test equipment and its limitations.

Figure 9-1 shows an older style relay test set. Figures 9-2 and 9-3 show newer, more modern equipment.

Figure 9-1
Older Style Relay Test Set
(Courtesy of AVO Multi-Amp Corporation)

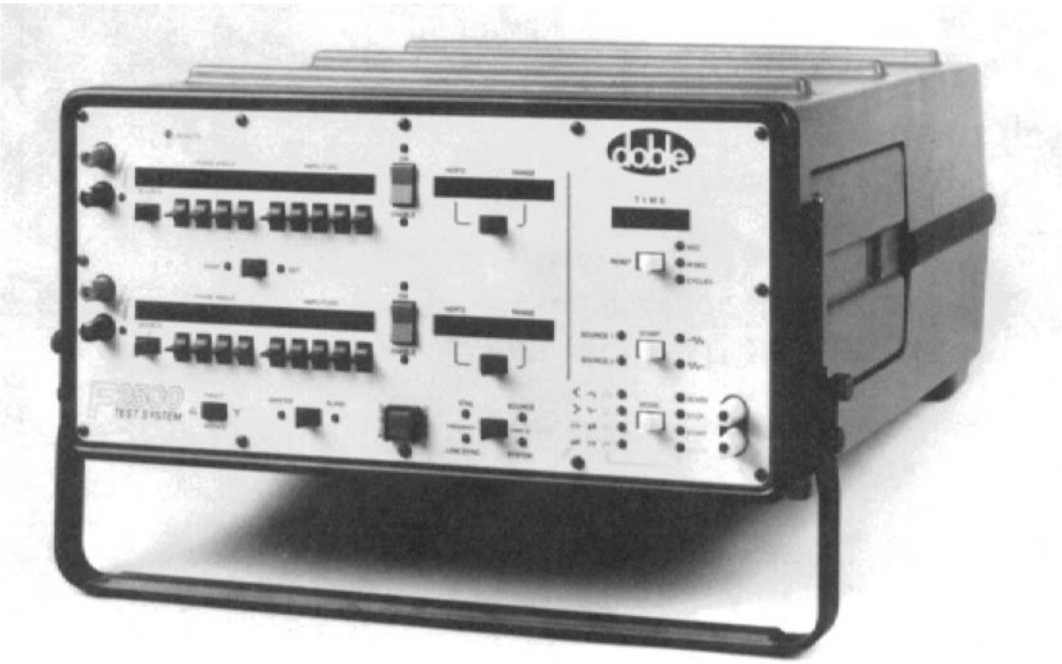


Figure 9-2
Portable Digital Relay Test Set
(Courtesy of Doble Engineering Company)

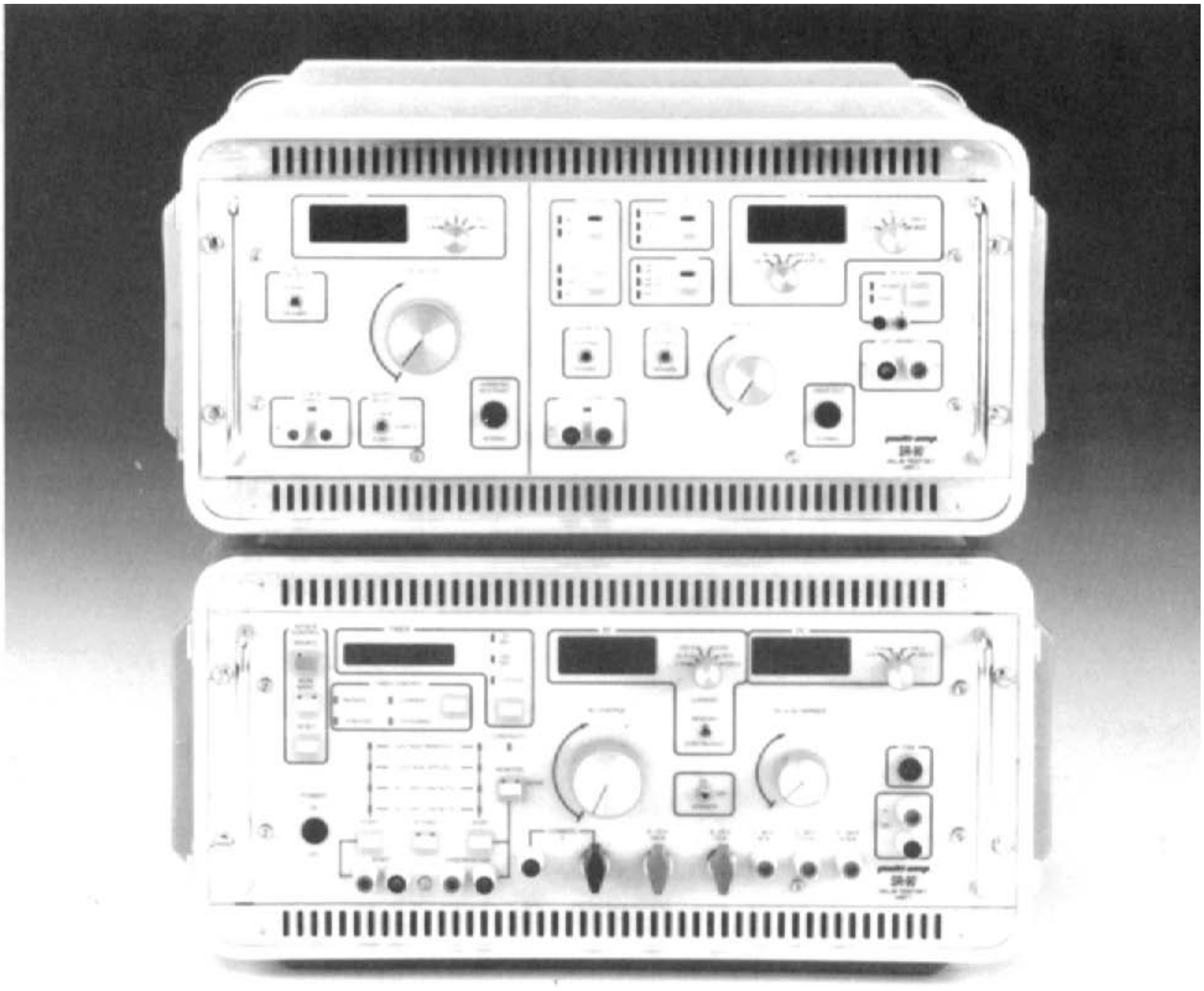


Figure 9-3
Digital Relay Test Set
(Courtesy of AVO Multi-Amp Corporation)

9.1.2 General Test Considerations

1. It is critical that the voltage and/or current waveform used for protective relay testing is a pure sinusoidal 60 Hertz signal (i.e., free from harmonics). Non-sinusoidal waveforms can significantly affect test results. Relays with filters or other tuned circuits are particularly susceptible to erroneous test results caused by non-sinusoidal test signals.

2. In most instances, relay manufacturers recommend testing protective relays in the case to duplicate any magnetic effects of the enclosure. There are, however, exceptions so the manufacturer's literature should be checked in either case.

3. Relay tests should be performed with the relay in the same orientation as installed in service, which is usually upright and level.

4. Protective relay dc circuits (tripping circuits) should be tested with a source containing less than 5% ripple. More restrictive requirements may apply when testing protective relays used in dc systems.

5. Before conducting electrical tests, energize the relay and allow sufficient time for it to reach operating temperature. Consult manufacturer's literature for proper warmup times.

6. Test blocks or test plugs specifically designed for the relay under test should be used to make test connections to the relay. Avoid making test connections directly to the relay connecting fingers or disconnect switches.

7. Ensure all test equipment is within calibration prior to beginning any tests.

8. Test acceptance values should be clear and unambiguous. Acceptance values are generally provided by the manufacturer or the engineering department.

9. Protective relays may be bench tested or tested in place. In either case, the relay must be removed from service to conduct electrical tests. Refer to Section 8.2 for guidance on removing a relay from service.

WARNING: Current transformers (CTs) and other relay electrical components represent a potential shock hazard. Follow all applicable safety precautions.

9.2 Insulation Resistance Test

9.2.1 Purpose

The purpose of an insulation resistance test is to identify any measurable deterioration in a relay's insulation. Service conditions such as high temperature, humidity, contamination, vibration, and physical abuse can degrade insulation integrity.

9.2.2 Procedure

CAUTION: Do not perform insulation resistance tests on solid-state relays. The test may damage sensitive semiconductor components.

1. Apply test voltage from each terminal of the relay to ground (case or chassis) and verify the readings are acceptable.

NOTE: The minimum recommended test voltage is 500 volts dc.

2. Apply test voltage across open trip circuit contacts and verify the reading is acceptable.
3. Investigate and correct the cause of any measurable degradation in the insulation.

9.3 Induction Disk Pickup (or Dropout) Test

9.3.1 Purpose

The purpose of a pickup test for an induction disk unit is to verify that the tap setting is correct and the unit's pick up point is within an acceptable tolerance. The pick up point is the minimum signal needed to cause the disk to rotate and eventually close the contacts. In theory, a steady signal equal to the pick up value requires an infinite amount of time to close the contacts. In practice, the pick up point is the signal that will just overcome the force of the restraint spring and close the contacts.

9.3.2 Pickup Test Procedure

CAUTION: Remove the relay from service and ensure CTs are shorted before removing the relay tap screw. Removing the tap screw while the relay is in service will open circuit the CT. Opening the secondary circuit of an energized CT is a potential fire hazard and may cause damage to the CT or relay.

1. Verify that the relay tap setting is correct.

2. Establish test circuits to monitor continuity of the main induction unit's contacts and to provide a test signal to the induction unit coil. Follow the relay and test equipment manufacturers' guidance for making test connections.

3. Energize the induction disk circuit with approximately 150% of the specified pickup setting (usually the tap value). The disk should rotate and close the contacts. Verify the continuity detector indicates that the contacts are closed.

NOTE: If desired, the induction unit can be energized with a signal equal to the specified pickup point + tolerance in lieu of a 150% signal. Under these conditions, the relay will slowly rotate and close the contacts. Performing the test in this manner takes longer but provides greater assurance that the relay is capable of rotating through its full travel with the minimum signal applied.

NOTE: The specified pickup point may not always be an exact tap value. An intermediate point between discrete tap settings may be called for. An intermediate setting is obtained by selecting the closest tap and adjusting the restraint spring as necessary.

4. After the contacts are firmly closed, decrease the applied signal until the continuity detector indicates rapid intermittent contact (fluttering light or buzzer).

5. Record the signal level as the pickup value. If the pickup value is not within the specified tolerance, adjust the setting in accordance with Section 9.13.

9.3.3 Alternate Pickup Test Procedure

For some makes and models, the following procedure may yield more accurate results. Refer to manufacturer's guidance to see if this alternate pickup test is preferable.

CAUTION: Remove the relay from service and ensure CTs are shorted before removing the relay tap screw. Removing the tap screw while the relay is in service will open circuit the CT. Opening the secondary circuit of an energized CT is a potential fire hazard and may cause damage to the CT or relay.

1. Verify that the relay tap setting is correct.
2. Establish test circuits to provide a test signal to the induction unit coil. Follow the relay and test equipment manufacturers' guidance for making test connections.
3. Alternate energizing the induction disk circuit with the expected pickup current ± tolerance. The disk should rotate in the close direction at pickup + tolerance and should rotate in the reset direction at pickup - tolerance.
4. Record the pickup value. If the pickup value is not within the specified tolerance, adjust the setting in accordance with Section 9.13.

9.3.4 Dropout Test Procedure

CAUTION: Remove the relay from service and ensure CTs are shorted before removing the relay tap screw. Removing the tap screw while the relay is in service will open circuit the CT. Opening the secondary circuit of an energized CT is a potential fire hazard and may cause damage to the CT or relay.

1. Verify that the relay tap setting is correct.
2. Establish test circuits to provide a test signal to the induction unit coil. Follow the relay and test equipment manufacturers' guidance for making test connections.
3. Energize the induction disk circuit with a nominal operating value (above the pickup setting). The disk should rotate to the backstop.
4. Gradually reduce the applied voltage or current until the disk moves off the backstop and begins to rotate.
5. Record the signal level as the dropout setting. If the dropout value is not within the specified tolerance, adjust the setting in accordance with Section 9.13.

9.4 Induction Unit Timing Test

Induction units provide inverse-time trip characteristics. These characteristics are portrayed by a set of curves called time-current, or characteristic curves. A typical set of time-current curves is shown in Figure 9-4. Each curve in the family of curves correlates to a time dial setting. Although the time dial is continuous, the curves are illustrated for discrete points only. For example, a time dial setting of 4.5 would follow a curve approximately halfway between the 4 and 5 curves.

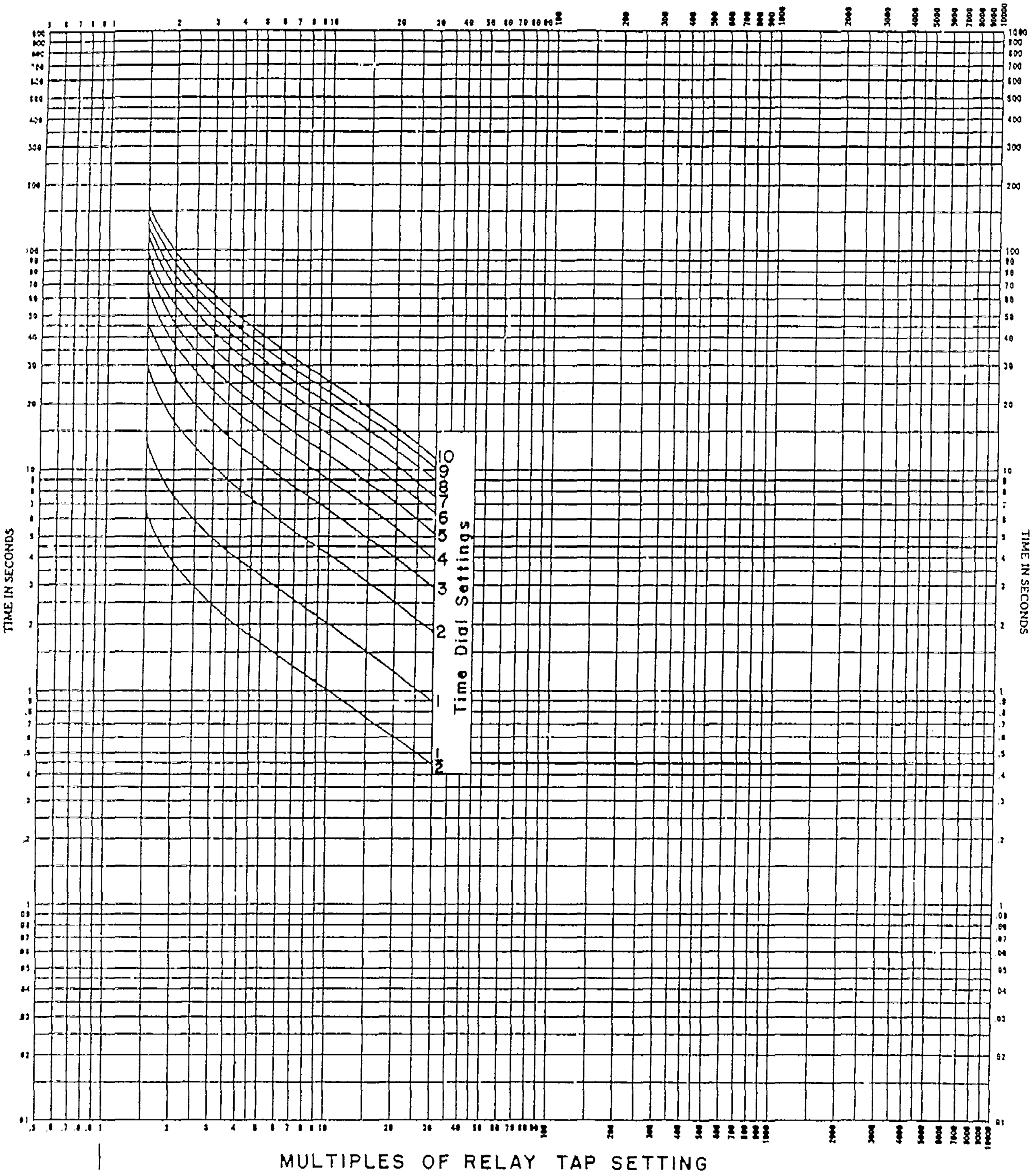


Figure 9-4
Inverse-Time Characteristic Curves

The shape of the curves are predetermined by hardware design characteristics of the induction unit and are not adjustable. However, the relative position of the curves (as a group) along the horizontal axis is adjustable and subject to variation. Changes that affect curve position affect all the curves as a group; the relative position of the curves to each other cannot be changed. For example, it is not possible to adjust the Time Dial 6 curve to the right without also shifting all other curves to the right by an equal amount. The curves can be shifted as a group along the horizontal axis by adjusting the restraint spring force (pickup setting) or by altering the degree of coupling between the disk and magnets.

The inherent characteristics of the induction disk unit are important to testing. Since the shape of the curves is a function of hardware design and not subject to significant alteration, confirmation of a single point along the curve is theoretically adequate to characterize the entire curve. That is, if the curve is verified to be within tolerance at one point, it is reasonable to assume it is within tolerance at all locations along the curve. Conversely, if the curve is not in calibration at the test point, it is not in calibration at any point along the curve.

Although a single point timing test is, in theory, adequate, most relay maintenance groups elect to test a minimum of two, and often three, points along the curve for greater assurance of accurate performance. A two or three point check is recommended since the additional time to test one or two more points is not significant in relation to the total time it takes to fully test the relay. Testing more than three points along the curve is not recommended since it unnecessarily subjects the relay to additional cycles.

9.4.1 Purpose

The purpose of the timing test is to verify that the time dial setting is correct and that the unit's timing characteristics are within tolerance. Errors in unit timing can result in miscoordination between protective devices, equipment malfunction, and possible equipment damage.

A timing test verifies that the induction unit operating time (as determined by the characteristic curves) for a given input signal level is within acceptable limits.

9.4.2 Procedure

1. Verify that the time dial is set correctly.

2. Establish test circuits to provide a test signal to the induction unit coil and to record the operating time. Follow the relay and test equipment manufacturers' guidance for making test connections.

3. Adjust the input signal to the desired test value.

NOTE: The optimum test points depend on the characteristics of the unit and the shape of the characteristic curves. The selected test points should provide good distinction on the curve, and should not be at locations of very steep or very flat slope.

4. Initiate the test by energizing the induction disk circuit. The disk should rotate and close the contacts.

5. Record the operating time of the relay and verify it is within acceptable limits. If the operating time is not within the specified tolerance, adjust the setting in accordance with Section 9.13.

6. Repeat Steps 3 - 5 for other test values.

9.5 Indicating Contactor Switch (Seal-In) Pickup and Dropout Test

Proper operation of the ICS (seal-in unit) assures adequate trip current is provided to the trip coil without risking damage to delicate induction disk components. Failure of the ICS to pick up or drop out at desired levels may cause unreliable tripping and relay damage.

9.5.1 Purpose

The purpose of a pickup and dropout test of an ICS unit is to verify that the unit operates within acceptable limits to assure positive tripping without damage to the relay. If the ICS fails to pick up, the entire tripping current is carried by the induction unit's spiral spring for a longer than expected period of time. This prolonged exposure to high current can overheat the spiral spring and permanently alter its characteristics, thereby affecting the pickup point of the relay. The amount of tripping current may also be affected because of increased resistance in the tripping circuit. If the ICS dropout point is too high, the ICS contacts may open prior to the main contacts. This abnormal sequence of contact operation may cause the main contacts to interrupt the tripping current. The main contacts are not designed to interrupt tripping current.

9.5.2 Procedure

1. Verify that the ICS tap setting is correct.

> *NOTE: Most ICS units have two possible tap settings. Typical tap values are 0.2 amperes and 2.0 amperes. Generally the larger tap setting is used for trip circuits in which the ICS unit is in the same circuit as the trip coil. The smaller tap setting is used when the ICS circuit actuates an auxiliary relay, which in turn carries out the protective function.*

2. Connect a dc supply to the relay's trip circuit. Follow the relay and test equipment manufacturers' guidance for making test connections.

3. Close the main induction disk unit's contacts manually or by applying a signal to the induction unit above the pickup point.

4. Gradually increase the dc supply current until the ICS picks up. Record the pickup current and verify it is within the manufacturer's specified range. Ensure that the operations indicator (target) actuates when the ICS picks up.

5. Raise the dc supply current to the rated tap value. Verify the seal-in function by opening the main relay contacts and ensuring the ICS remains energized.

6. Gradually decrease the dc supply current until the ICS drops out. Record the dropout current and verify it is within the manufacturer's specified range.

7. Most ICSs are not adjustable. Thus, if the unit does not pick up or drop out within the specified range, the mechanical checks and cleaning should be performed and the unit retested. If the problem cannot be corrected, the unit should be replaced.

9.6 Instantaneous Unit Pickup Test and Calibration

Instantaneous trip units are designed to detect an abnormal signal level and initiate protective action. Parameters typically monitored by instantaneous units include current, voltage, and frequency.

9.6.1 Purpose

The purpose of a pickup test for an instantaneous unit is to verify that the unit's pick up point is within an acceptable tolerance. The pick up point is the minimum signal needed to cause the unit to operate and close the contacts. In most cases, the pickup point is that level of signal that generates sufficient force to overcome some type of mechanical restraint - usually a spring.

9.6.2 Procedure

1. Establish test circuits to monitor continuity of the instantaneous unit's trip contacts and to provide an input test signal. Follow the relay and test equipment manufacturers' guidance for making test connections.

2. Establish the pickup point of the unit by applying the signal in short pulses. Adjust the signal level upwards between each pulse until the minimum signal necessary to cause operation is determined.

CAUTION: Do not apply high levels of current to the unit continuously. Subjecting the unit to high current for a prolonged period of time may cause overheating and insulation damage.

NOTE: Most overcurrent relays that are configured with the induction disk coil in series with the instantaneous unit coil have a separate test connection point to allow bypassing the induction unit coil when testing the instantaneous unit.

3. Record the signal level that just causes the unit to operate. If the pickup value is not within the specified tolerance, adjust the setting in accordance with the manufacturer's guidance and retest.

4. If the unit is equipped with an operations indicator, verify that the flag is actuated when the unit picks up.

9.7 Slope Test

Relays that contain both restraint and operate coils exhibit an operating feature called slope. The slope of a relay is the ratio of operating signal to restraint signal that, if exceeded, will cause the relay to operate. Thus, a relay with a 125% slope will operate when the operate signal exceeds the restraint signal by a factor of 1.25. Figure 9-5 shows a typical slope curve.

9.7.1 Purpose

The slope test verifies that a relay with slope characteristics is operating within the expected range. When the operate to restraint signal ratio exceeds the specified slope (including tolerance), the relay should operate. When the ratio is less than the specified slope (including tolerance), the relay should restrain.

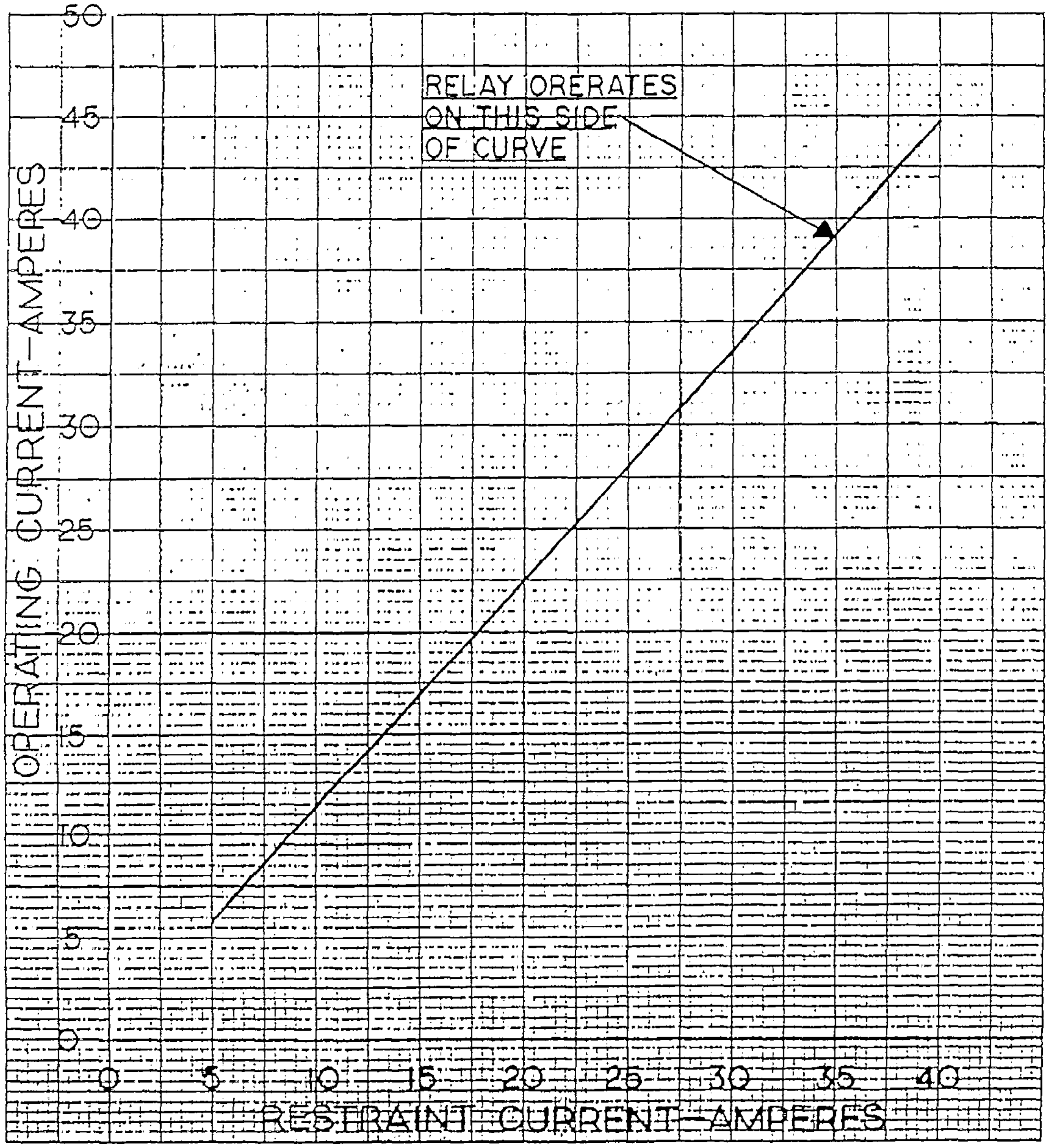


Figure 9-5
Typical Relay Slope Curve

9.7.2 Procedure

CAUTION: If the slope test is being performed on an induction-type unit, the test should be performed as a "Go - No Go" test to avoid energizing the coils for prolonged periods, potentially causing them to overheat.

1. If the relay has adjustable slope settings, verify the slope setting is correct.
2. Establish test circuits to apply test signals to the operate and restraint coils. Refer to the relay and test equipment manufacturers' guidance for making test connections.
3. From the relay manufacturer's literature determine the test signal levels.
4. Energize the restraint coil with the specified test signal.
5. Energize the operate coil with a test signal equal to the desired operating signal + tolerance. The relay should operate.
6. Energize the operate coil with a test signal equal to the desired operating signal - tolerance. The relay should restrain.

NOTE: Refer to the manufacturer's guidance to determine if more than one test point should be used to verify proper slope.

9.8 Angle of Maximum Torque Test

9.8.1 Purpose

The angle of maximum torque test is performed to verify that the specified angle of maximum torque is within limits. The test is accomplished by actually measuring the angles of zero torque and then calculating the angle of maximum torque by taking advantage of symmetry.

9.8.2 Procedure

1. Apply the voltage and current signal to the relay with a magnitude specified by the manufacturer.
2. Adjust the phase angle between the applied signals so that it equals the desired angle of maximum torque. Verify that the relay picks up.

3. With voltage and current held constant, widen the phase angle between the two applied signals toward one of the zero torque angle points.

4. Record the angle at which the relay drops out as θ_1.

5. Adjust the phase angle between the applied signals in the other direction.

6. Record the angle at which the relay drops out as θ_2.

7. Calculate the angle of maximum torque (θ_M) as follows:

   $\theta_M = [\theta_1 + \theta_2] / 2$, where θ_1 and θ_2 are expressed as +/- values from the horizontal axis

8. Adjust the relay in accordance with the manufacturer's guidance if the angle of maximum torque is not within the specified tolerance.

9.8.3 Alternate Test Procedure

For some relays, a more accurate determination of maximum torque angle can be obtained using an alternate test method. Consult the manufacturer's literature to see if this alternate test method is preferable.

1. Apply a voltage signal to the relay as specified by the manufacturer.

2. Set the phase angle at the maximum torque angle + θ, where θ is an angle specified by the manufacturer ($\theta = 30°$ is common).

3. Increase the applied current until the relay picks up. Record the pickup current.

4. Set the phase angle at the maximum torque angle - θ and repeat the test.

5. Verify that the recorded pickup values are within the manufacturer's tolerance.

6. Adjust the relay in accordance with the manufacturer's guidance if the pickup currents are not within the specified tolerance.

9.9 Reach Test

9.9.1 Purpose

The reach test is performed to verify that the reach of a relay is within limits. The reach test determines the maximum theoretical electrical distance that a relay can see down the transmission line.

9.9.2 Procedure

1. Perform the angle of maximum torque test in accordance with Section 9.8.
2. Apply a nominal voltage signal to the relay.
3. With the phase angle set at the angle of maximum torque, apply a current signal to the relay that results in an impedance beyond the relay's reach. The relay should not pick up.
4. Gradually increase the current level (decrease the impedance) until the relay picks up. This point represents the far side of the mho circle.

NOTE: The reach test may also be performed by initially applying a current that causes the relay to pickup, then gradually decreasing the current until the relay drops out. Performing the test this way may result in high current being applied to the relay for a longer duration than the other method.

5. Ensure the pickup point corresponds to the desired reach.
6. Adjust the relay in accordance with the manufacturer's guidance if the reach is not within the specified tolerance.

9.10 Offset Test

9.10.1 Purpose

The offset test is performed to verify the relay offset is within specified limits. The offset test determines the theoretical closest point along the transmission line that the relay will operate.

9.10.2 Procedure

For units with negative offset (characteristic circle excludes the origin):

1. Apply a nominal voltage signal to the relay.
2. With the phase angle set at the angle of maximum torque, apply a current signal to the relay that results in an impedance inside the relay's reach. The relay should pick up.
3. Gradually increase the current level (decrease the impedance) until the relay drops out. This point represents the near side of the mho circle.
4. Ensure the dropout point corresponds to the desired negative offset.

5. Adjust the relay in accordance with the manufacturer's guidance if the offset is not within the specified tolerance.

For units with positive offset (characteristic circle includes the origin), the offset test is performed following the same steps as outlined for the reach test, except the angle between the voltage and current signal is equal to the maximum torque angle + 180°.

9.11 Induction Unit Control Test

9.11.1 Purpose

The control test is performed to verify that induction disk units controlled by a directional unit are functioning properly. This test is a "Go - No Go" type of test.

9.11.2 Procedure

1. Apply a signal to the induction disk unit sufficient to pick up the unit.

2. Apply a signal to the directional or controlling unit sufficient to pick up the unit. Verify that the induction disk unit picks up or drops out (whichever is the case) when the directional unit changes state.

3. Investigate and correct the problem if the proper control is not exhibited.

9.12 Through Fault Test

9.12.1 Purpose

This test is performed on differential relays to verify they restrain on through fault current. This test is effectively a "Go - No Go" test.

9.12.2 Procedure

1. Apply test current to the relay as specified by the manufacturer and verify that the relay restrains and does not pick up.

2. Adjust the relay or correct the problem in accordance with the manufacturer's guidance if the relay operates during the through fault test.

9.13 Induction Unit Calibration

9.13.1 Purpose

The induction unit is calibrated to ensure pickup and timing characteristics are within the manufacturer's specified limits. Calibration should only be necessary upon initial installation or repair, or if the unit is found to be out of calibration during a timing test or pickup test.

9.13.2 Procedure

1. Check mechanical adjustments as outlined in Section 8.0.
2. Select the tap setting and time dial seeing specified by the manufacturer for calibration.

PICKUP

3. Establish test circuits to monitor continuity of the main induction unit's contacts and to provide a test signal to the induction unit coil. Follow the relay and test equipment manufacturers' guidance for making test connections.
4. Energize the induction disk circuit with a test signal equal to the tap setting. Rotate the spring adjusting ring (located just above or just below the spiral spring) until the proper pick up point is established.

NOTE: If the relay is to be installed with an intermediate pickup point between tap settings, the desired pickup point should be used for calibration in lieu of the standard recommended tap setting for calibration.

5. Verify pickup for the installed settings in accordance with Section 9.3.

TIMING

6. Establish test circuits to provide a test signal to the induction unit coil and to record the operating time. Follow the relay and test equipment manufacturers' guidance for making test connections.
7. Energize the induction disk circuit at the level specified by the manufacturer. Adjust the dampening magnet in accordance with the manufacturer's guidance to obtain the correct operating time. Several combinations of tap setting and signal magnitude may be specified.
8. Verify timing for the installed settings in accordance with Section 9.4.

10.0 Data Trending and Test Intervals

The industry has not standardized protective relay maintenance and test intervals. In many cases, the established interval is based more on tradition rather than an actual assessment of relay reliability. Generally, protective relays have proven to be quite reliable. As a result, a number of plants and utilities are considering extending the test interval as part of operations and maintenance cost reduction efforts. However, a technical assessment of past performance is usually needed in order to modify relay test intervals. Many relay maintenance personnel agree that most protective relays are reliable and are overtested, but a consensus of the optimum test interval has not yet been reached in the industry.

This section addresses methods for evaluating relay performance to help determine the optimum test interval for each application and installation. Trending performance data can provide an understanding of relay performance over time. In particular, overcurrent and undervoltage relays are well suited for the type of trending analyses discussed in this section. However, not all relay types are suitable for the trending methods discussed in this section. For example, each nuclear plant may have very few distance relays. Rather than trend the performance for these distance relays, an equal understanding of the relays' performance may be obtained simply by reviewing past maintenance records. Trending relay performance should not be more complicated than necessary.

10.1 Benefits of Trending Performance Data

Past relay maintenance and test data can be used to determine whether relay test intervals are appropriate. There are several possible outcomes that may result from an evaluation of past relay test records:

- The relay may exhibit a large drift and require checking more frequently.
- The relay may be very stable and require checking less frequently.
- The established relay test interval may be appropriate.

Trending protective relay performance data has the following potential benefits:

- Particularly stable relays may have their test interval extended if an analysis of past test performance indicates that they are not prone to drift.
- Relay tolerances that are too tight for the device can be identified. If tolerances are tighter than reasonable for the device, out of tolerance reviews might be required virtually each time that a test is performed. This adds to the resources needed to maintain the equipment. If tolerances can be relaxed without impacting system design requirements, trending of the test data may provide a basis for determining which relay tolerances can be expanded.

Relay maintenance records can also offer insight into long-term relay performance. For example, a distance relay that normally runs hot may require frequent cleaning and, without this periodic cleaning, the relay may not perform properly. Conversely, a simple overcurrent relay may see negligible resistive heating and seldom require cleaning or maintenance. Relay test records, in combination with the maintenance information, may easily show that the test interval can be extended.

10.2 Analysis Techniques for Trending Relay Performance

This section discusses methods that may be used to evaluate protective relay test data. The techniques presented here are based on statistically analyzing past test data to gain an understanding of how a relay or group of relays tends to drift between test intervals. Statistically determined drift values represent quantitative performance data that characterizes the actual performance of the relays. This information allows for more informed maintenance decisions.

The information presented in this section is somewhat technical in nature and assumes a working knowledge of basic statistical analysis methods. A detailed presentation of the analysis techniques discussed here is contained in EPRI Technical Report TR-103335, *Guidelines for Instrument Calibration Extension/Reduction Programs.* Regardless of the approach taken, trending programs should not become overly complex or cumbersome. The greatest understanding of a device can come from relatively simple evaluations; overly extravagant analyses tend to generate large amounts of paper and often obscure any real trends. Additionally, when applying statistical techniques, care must be exercised not to draw unsubstantiated conclusions from the data.

10.2.1 Test Data Analysis

Every protective relay periodic test has acceptance criteria for its settings. If a relay is found to be within the acceptance criteria, i.e., within tolerance, it may not be necessary or required to perform any adjustments. If the relay is found outside the acceptance criteria by some small amount, it may typically be reset without any further consideration. Finally, if it is outside the acceptance criteria by some larger amount, an evaluation of the impact may be necessary in addition to resetting it; this depends on the maintenance program.

Records are normally maintained for periodic tests. The as-found and as-left settings are typically recorded. If the relay is reset, the as-left settings will be different from the as-found settings. By evaluating as-found versus as-left data for a relay or a similar group of relays, the following information may be obtained:

- The typical drift between periodic tests
- Any tendency to drift in a particular direction
- Any tendency for the drift to increase in magnitude over time
- Confirmation that the selected setting tolerance is appropriate or achievable

10.2.2 Data Analysis Process

In general, the analysis of test data consists of the following steps:

- Obtain the data from a group of functionally equivalent instruments. For example, a review may focus on ITE 27N undervoltage relays.
- Format the data, if desired, for ease of analysis. Typically, this consists of loading the data into a spreadsheet for subsequent analysis.

- Determine the amount of relay drift. This initial analysis consists of calculating simple statistics such as mean and standard deviation for the selected devices.
- Establish predicted bounds for drift based on the initial analysis. Performance predictions usually state that a given proportion of the population is not expected to drift beyond a certain amount. This predicted performance includes an assessment of the level of confidence associated with the prediction, and is referred to as a tolerance interval.
- Evaluate data for the presence of any test data points that are not representative of the normal relay performance. These nonrepresentative data points are referred to as *outliers* and may possibly be excluded from the analysis.
- Determine if the available test data indicates any time-dependent trend. An evaluation of relay drift should include an assessment of the likelihood that the magnitude of drift may increase with time.

10.2.3 Loading Data Into a Spreadsheet

The term *test data* used in this section refers to the as-found and as-left relay settings available in plant equipment records. As part of the test of a relay, the technician records the as-found and as-left settings. If the relay was reset, the as-left setting will be different from the as-found setting. If the relay was not adjusted, the as-found and as-left settings will be the same. By evaluating the test data for all relays of a particular type, application and environment, the actual relay drift can be estimated. The use of a spreadsheet program is recommended for this analysis because it simplifies the calculations and ensures greater consistency in the results.

Using a simple spreadsheet program (e.g., Excel™, Lotus 1-2-3™, or Quattro-Pro™), the as-found and as-left data can be analyzed for drift. A spreadsheet analysis can establish confidence intervals or tolerance intervals for the relay drift. Any bias in the drift can also be determined.

The following sections provide an overview of one method that can be used to analyze plant-specific test data. In general, the analysis process is as follows:

- As-found and as-left test data is obtained from test records.
- The data is loaded into a spreadsheet program and formatted for initial analysis.
- The formatted spreadsheet is analyzed in greater detail for certain statistics.
- Predictions regarding instrument performance are made that bound the expected instrument drift.

In addition to the specific as-found and as-left data available in test records, the following information may be required to perform a trend analysis:

- The calibrated range of the relay
- The trip setpoint of the relay
- Any changes to the input parameters or trip setpoints
- The model number of the relay
- The time of data collection

Once the as-found and as-left data have been obtained for the relays of interest, this information can be loaded into a spreadsheet program for further analysis. The initial data entry into the spreadsheet program may consist of the following information:

- Date of test
- Relay identification (tag) number
- As-found and as-left values for the test check point(s)
- Comments regarding span, setpoint, or relay changes, if applicable

The format of the data entry should be such that any repetitive spreadsheet computations to follow will be optimized. Figure 10-1 shows an example of a typical spreadsheet with the initial data entry. In general, whatever data is recorded during the test should be entered into the spreadsheet.

Date Month/Day/Year			Interval (Days)	Tag Number	Data Status	Initial Data Low-Low Setting
5	2	93	365	127-11	As Found	73.45
					As Left	73.24
5	2	92	370		As Found	72.90
					As Left	73.17
4	27	91	386		As Found	73.14
					As Left	73.14
4	7	90	350		As Found	72.79
					As Left	73.09
4	22	89	350		As Found	73.51
					As Left	73.14
5	7	88	370		As Found	73.09
					As Left	73.13
5	2	87	411		As Found	73.13
					As Left	73.13
3	18	86	323		As Found	72.55
					As Left	73.12
4	29	85	184		As Found	73.13
					As Left	73.13
10	27	84	158		As Found	73.15
					As Left	73.15
5	22	84			As Found	New
					As Left	73.20

Figure 10-1
Example Spreadsheet Data Entry

The example shown in Figure 10-1 provides the following information that may be of value during an analysis:

- The day, month, and year of test are documented. The time interval since the previous test is calculated in days in the *Interval* column. Depending on the data, the time interval may be calculated in days or months.
- The as-found and as-left data are entered into the spreadsheet exactly as recorded on the test data sheet. In the case shown on Figure 10-1, the values are in volts and are associated with an undervoltage relay setting.
- In this case, data was entered into the spreadsheet from the time the relay was installed up to the latest available information. Notice in this example that the undervoltage relay, 127-11, was installed in May 1983. Since the instrument is tested at approximately annual intervals, all data was considered. However, for an instrument that is checked monthly, only the last one to two years of data may be needed. The goal is to have enough data to be confident that the relay's performance is characterized.
- Figure 10-1 only shows a portion of the total spreadsheet. All functionally-equivalent instruments can be combined into a single spreadsheet for analysis.

10.2.4 Data Setup

Once the initial data entry is complete, the data is prepared for subsequent analysis. The data can be normalized to a percent of setpoint value[1] or can be left unformatted in the original test units, e.g., voltage, trip time, etc., depending on the nature of the data. For example, the data provided in Figure 10-1 is converted into a percent of setpoint output as follows:

- Subtract the as-left value of the previous test from the present as-found value.
- Divide the result by the instrument setpoint in the same units as the test units, 73.2 volts in the case of data shown in Figure 10-1.
- Record this value on the spreadsheet as a percent of setpoint.

This value represents the actual instrument drift, expressed in percent of setpoint, since the last test. The values calculated during this step are cumulatively referred to as the raw data. An example of a spreadsheet with the raw data formatted is shown in Figure 10-2.

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[1] Accuracies for electromechanical protective relay settings are most often expressed as a percent of setpoint. However, this may not always be the case, especially for solid-state devices. The basis for accuracy expressions should be confirmed.

						Initial Data	Raw Data
Date Month/Day/Year			Interval (Days)	Tag Number	Data Status	Low-Low Setting	As-Found Minus As-Left
5	2	93	365	127-11	As Found	73.45	0.38 %
					As Left	73.24	
5	2	92	370		As Found	72.90	-0.33 %
					As Left	73.17	
4	27	91	386		As Found	73.14	0.07 %
					As Left	73.14	
4	7	90	350		As Found	72.79	-0.48 %
					As Left	73.09	
4	22	89	350		As Found	73.51	0.53 %
					As Left	73.14	
5	7	88	370		As Found	73.09	-0.05 %
					As Left	73.13	
5	2	87	411		As Found	73.13	0.02%
					As Left	73.13	
3	18	86	323		As Found	72.55	-0.79%
					As Left	73.12	
4	29	85	184		As Found	73.13	-0.03 %
					As Left	73.13	
10	27	84	158		As Found	73.15	-0.07 %
					As Left	73.15	
5	22	83			As Found	New	
					As Left	73.20	

Figure 10-2
Calculation of As-Found Versus As-Left Drift Data

For the case provided in Figure 10-2, the input data was recorded in volts and the raw data for subsequent analysis consists of the as-found value from the current test minus the as-left value of the previous test divided by 73.2 V to obtain a percent of setpoint result. This raw data represents the instrument drift since the last test for each value shown.

10.2.5 Evaluation of Relay Drift

Simple statistics for the drift data can be computed to characterize the stability of the relay or relays. An example of raw data statistics for a typical spreadsheet is shown in Figure 10-3.

Raw Data Statistics	
	Low-Low Setting
Mean	-0.07%
Standard Deviation	0.25%
Number of Points	76

Figure 10-3
Raw Data Statistics

Note that the statistics calculated in Figure 10-3 are based on all of the data points contained in the spreadsheet, not just the single relay shown in Figure 10-1. Statistics can be calculated for individual relays if there is enough data for each relay; this may be appropriate in some instances. However, one goal of this analysis should be to characterize the plant-specific performance of a functionally-equivalent group of relays, e.g., ITE 27N undervoltage relays or IAC 53 overcurrent relays.

If the absolute value of the mean, or average, of the data is near zero, then a bias is generally assumed not to exist. For example, if a relay tends to always drift high, the calculated mean for the data should be some positive value. Random fluctuations with no bias tendency should be somewhat self-cancelling in the calculation of the mean, with the result that the mean should be near zero. Typically, a mean of less than 0. 1% is adequate to state that the relay drift does not appear to have a bias. If the absolute value of the mean is greater than 0.1%, a bias with the appropriate sign should be assumed to exist.

Predicted limits regarding the magnitude of drift can be calculated by use of a tolerance interval. A tolerance interval is a statement of probability that a certain proportion of the total population is contained within a defined set of bounds. The tolerance interval description also includes an assessment of the level of confidence in the statement of probability. For example, a 95/95 tolerance interval indicates a 95% level of confidence that 95% of the population is contained within the stated interval. A 95/99 tolerance interval means that 95% confidence exists that 99% of the population is contained within the stated interval. Table 10-1 provides 95/95 and 95/99 tolerance factors; these values are available in most statistical textbooks.

A tolerance interval is calculated by multiplying the data standard deviation by the appropriate tolerance factor from Table 10-1 based on the number of data points. For example, the 95%/95% tolerance interval for the relay statistics provided in Figure 10-3 is the standard deviation (0.25%) multiplied by the tolerance interval factor for 76 data points (2.29), or ±0.57%.

Table 10-1
Tolerance Interval Factors

Sample Size	95/95 Percent Tolerance Factor	95/99 Percent Tolerance Factor
10	3.38	4.43
20	2.75	3.62
30	2.55	3.35
40	2.45	3.21
50	2.38	3.13
75	2.29	3.00
100	2.23	2.93
150	2.18	2.86
200	2.14	2.82
300	2.11	2.77
400	2.08	2.74
500	2.07	2.72
600	2.06	2.71
800	2.05	2.69
1000	2.04	2.68
∞	1.96	2.58

The as-found versus as-left data can also be graphed for each instrument to determine any performance trends. Figures 10-4 and 10-5 show graphed data for individual relays. Figure 10-4 shows the variation over time for three undervoltage relays since their installation. Figure 10-5 shows the variation over time for three different undervoltage relays that were tested on a monthly interval.

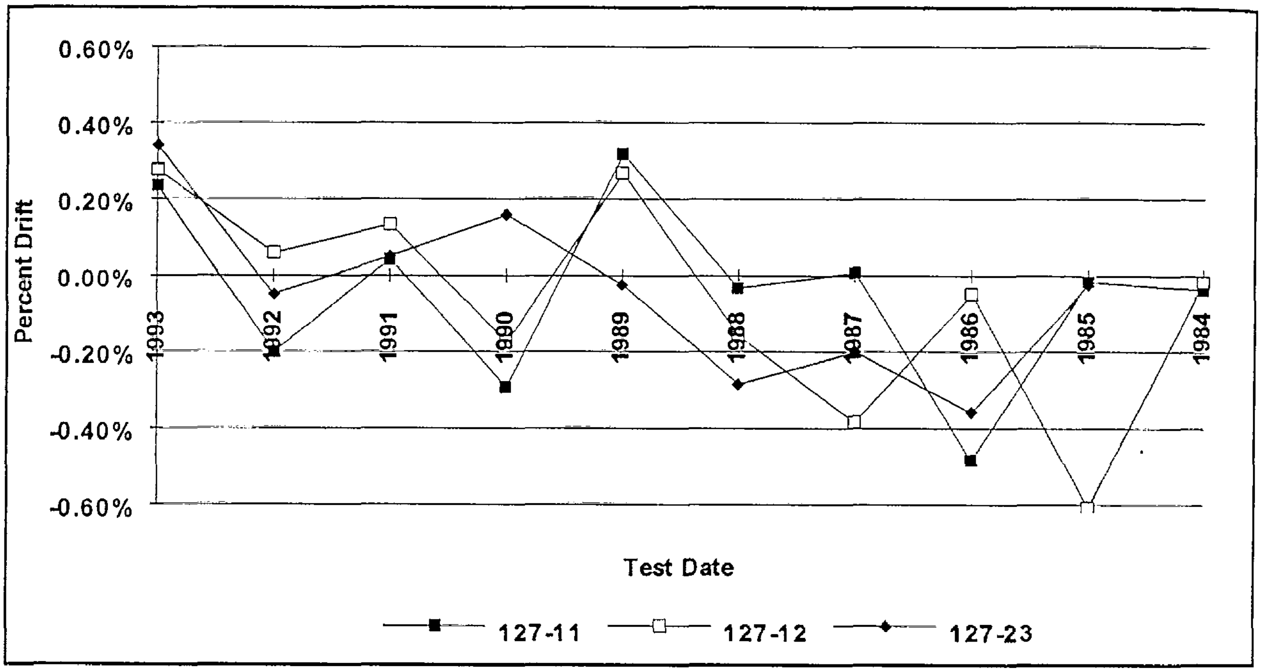

Figure 10-4
Relay Drift Over Several Years of Test Data

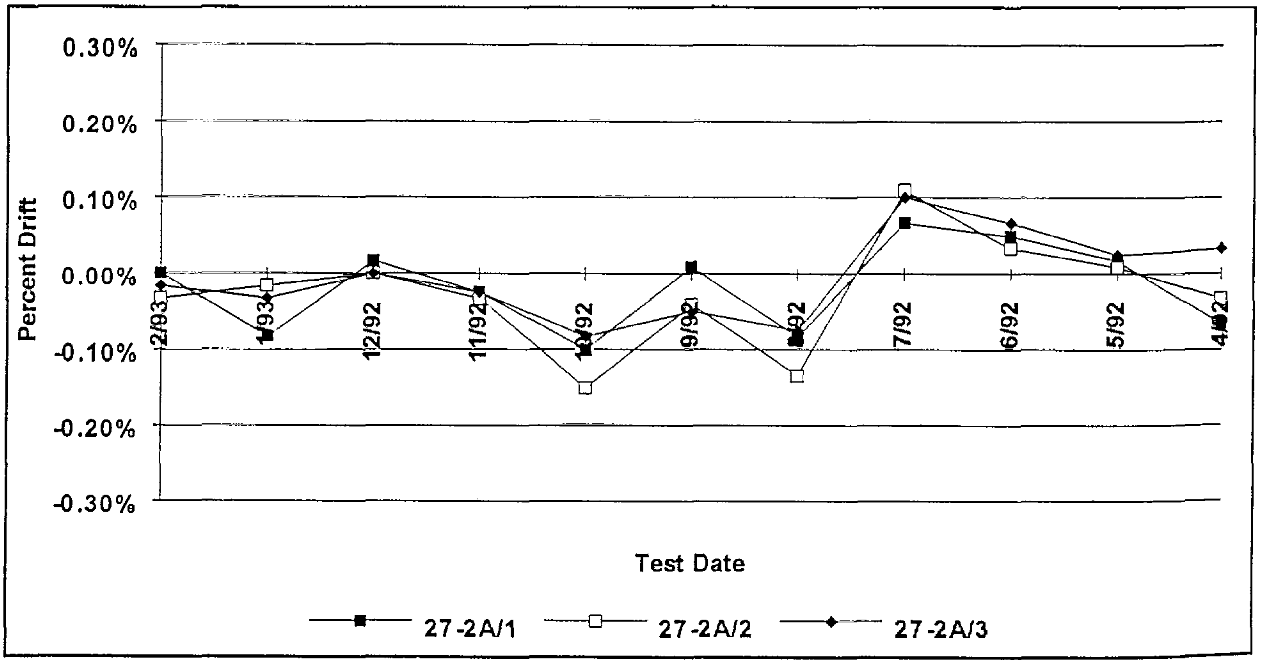

Figure 10-5
Relay Drift During a Single Year of Performance Monitoring

An evaluation of relay data from several nuclear plants indicated that relay drift based on as-found versus as-left data consistently tends to follow the shape of a normal distribution. Histograms for typical relay data are provided in Figures 10-4 and 10-7. As might be expected, relays generally drift by some small amount around the setpoint with a lower likelihood for larger amounts of drift. As a result, the shape of the data usually appears similar in shape to a normal distribution.

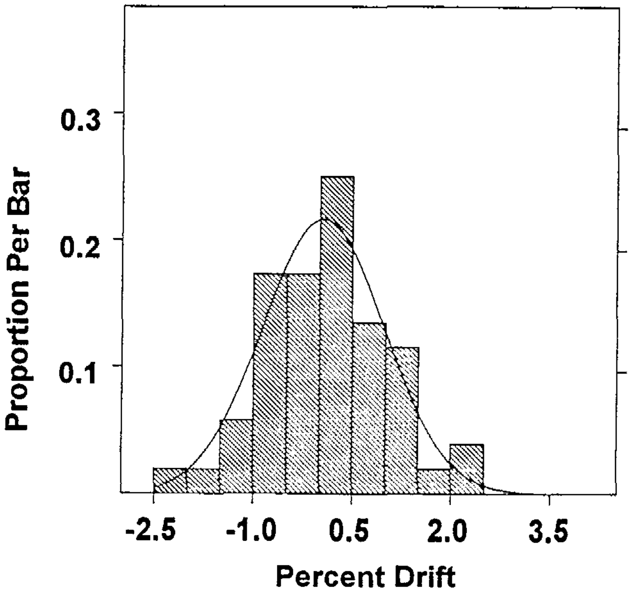

Figure 10-6
Histogram of Relay Test Data - Plant #1

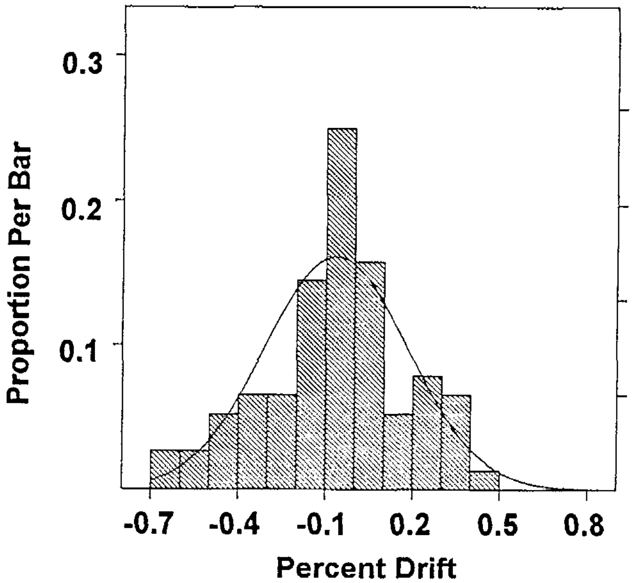

Figure 10-7
Histogram of Relay Test Data - Plant #2

Relay drift data for typical relays is generally centered around zero with no clear tendency to drift in either the positive or negative direction. A typical scatter plot of relay test data is shown in Figure 10-8. In this case, most relays were tested about every 12 months with a few relays tested at a 6 month interval.

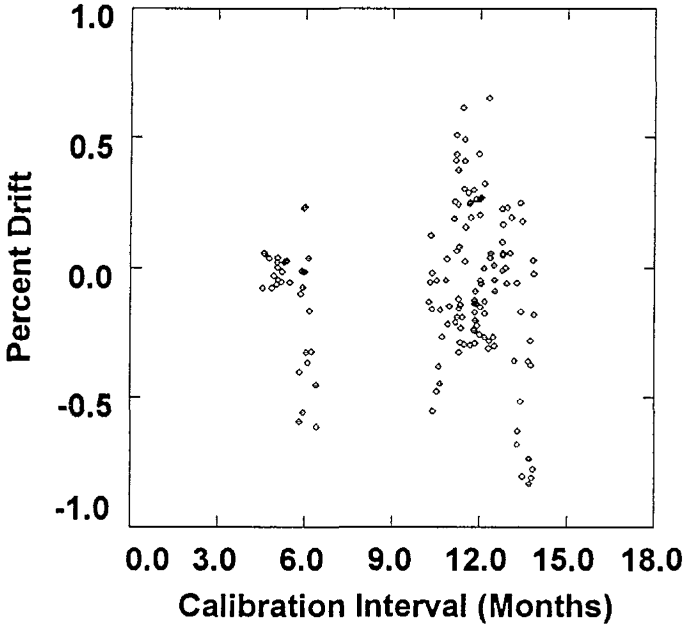

Figure 10-8
Scatter Plot of Relay Test Data

Sometimes, a scatter plot of the data can help answer whether relays may drift more because of a longer interval between tests. This approach may not always be successful if the only information available is for a single test interval. In this case, the data is clumped around the 6 to 12 month points with no means of comparing to other intervals.

Another approach that can be considered is an evaluation of the absolute value of drift as shown in Figure 10-9. This method analyzes for the *magnitude* of drift to increase with time.

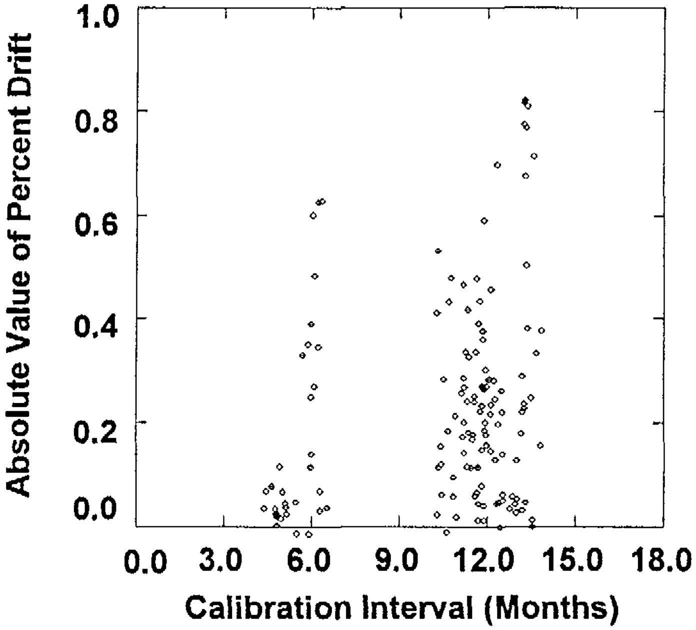

Figure 10-9
Absolute Value Scatter Plot of Relay Test Data

Figures 10-8 and 10-9 are somewhat typical of test data. A tendency for increased drift with time is not evident from the available data. Although the 12-month data visually appears to have greater variation than the 6-month data, an analysis readily shows that the 6-month data has a larger standard deviation of drift than the 12-month data. This applies to either the raw data or the absolute value of the data. A time-dependent trend possibly could have been claimed if the longer calibration interval demonstrated a larger variation than the shorter duration calibration interval. This is not the case for the data in Figures 10-8 and 10-9.

10.3 Reliability Centered Maintenance

Reliability centered maintenance (RCM) is a systematic methodology for evaluating preventive maintenance programs. RCM was developed by the commercial air transport industry in the late 1960s as a means to more efficiently allocate maintenance activities as the size and complexity of the aircraft increased. RCM can be an effective tool for evaluating preventive maintenance programs because it concentrates on system functions, critical components, and dominant failure modes rather than addressing every component in the plant.

Several EPRI documents are available regarding the application of RCM techniques to nuclear plant systems:

EPRI NP-7133, *Guide for Generic Application of Reliability Centered Maintenance (RCM) Applications*, February 1991.

EPRI NP-6152, Volume 1, *Demonstration of Reliability-Centered Maintenance, Project Description*, January 1989.

EPRI NP-6152, Volume 2, *Demonstration of Reliability-Centered Maintenance, First Annual Progress Report From San Onofre Nuclear Generating Station,* September 1989.

EPRI NP-6152, Volume 3, *Demonstration of Reliability-Centered Maintenance, First Annual Progress Report From Ginna Nuclear Station,* September 1989.

EPRI NP-5430, *Application of RCM to San Onofre Units 2 and 3 Auxiliary Feedwater System,* September 1987.

EPRI NP-4795, *Use of RCM for McGuire Nuclear Station Feedwater System,* September 1986.

EPRI NP-4271, *Application of RCM to Component Cooling abater System at Turkey Point Units 3 and 4,* October 1985.

Protective relays are not discussed in any particular detail as specific critical components in the above reports. In part, their absence in the above reports may be because they serve only a component protection function rather than an active role in system operation. Under the most idealistic conditions, a protective relay would never actuate. Furthermore, as discussed in section 6, protective relays have a deserved reputation for reliability. Thus, they do not appear to be a major contender for RCM attention.

The role of protective relays in an RCM program is discussed here because many plants are undertaking RCM programs. The focus of an RCM analysis is at the system level; remember that one RCM goal is to avoid preventive maintenance arbitrarily defined at the component level. However, protective relays should be trended and evaluated at the component level rather than ranked and sorted at the system level. Therefore, any ongoing or completed RCM projects should be reviewed for protective relays only to confirm that these relays are not treated differently by RCM evaluations for different systems. For example, protective relay test frequencies probably should not be different for similar applications of Class 1E relays throughout the plant. Also, protective relays should not be combined with control relays by any RCM study. Control relays often have an important and active role in system operation whereas protective relays are passive during normal system operation.

10.4 Determining Relay Test Intervals

There are no set practices regarding the frequency at which relays should be tested. Although manufacturers may recommend a test periodicity, the recommendations contained in manufacturer's operating instructions have changed over time. For example, as one manufacturer's relay literature has been revised through the years, it has progressively recommended longer maintenance intervals - from every 6 months, to annually, to every 2 years. Although the trend is clearly towards longer test intervals, most manufacturers now emphasize that optimum test intervals are best determined by the user.

As part of the generation of this maintenance guide, typical practices outside the nuclear industry were surveyed. As might be expected, there is no generally-accepted optimal frequency for testing protective relays. However, the trend has been towards longer maintenance intervals. The trend for users to test relays less frequently is not based solely on a desire to reduce expenses associated with each test. The actual frequency for testing protective relays at each facility depends on a balance of the following factors:

- Analysis of past performance (demonstrated reliability, test data, trending information)
- Voltage level of circuit
- Likelihood of operation (based on past experience)
- Consequences of failure
- Application (safety-related, quality-related, or general purpose)
- Service environment and normal operating temperature
- Maintenance schedule of other associated equipment
- Outage periodicity, schedule, and duration
- Type of relay and its reliability
- Manufacturer's recommendations
- Manpower availability
- Age
- Self-checking capabilities

Section 10.2 describes one possible method that can be used to evaluate relay test data. This information can be used to help determine the optimum relay maintenance and test interval. In particular, the analysis of protective relay as-found versus as-left test data can assist in obtaining the following performance information:

- Functional status at the time of test
- Typical drift between tests
- Any tendency to drift in a particular direction
- Any tendency for the drift to increase in magnitude over time
- Confirmation that the selected setting tolerance is appropriate or achievable

Although this information is important in understanding relay performance, it does not alone provide all information needed to establish the optimal relay maintenance and test interval. Frequently, relay maintenance is performed at the same periodicity as relay testing. Thus, the relay may be tested, thoroughly cleaned and adjusted as needed, and tested again. Even though the relay test data shows very stable performance, the maintenance records should also be reviewed to confirm that the relays of interest show little or no degradation between maintenance checks.

As an example of the importance that maintenance may have in proper relay performance, consider distance relays. These relays usually run hot and tend to emit gaseous contaminants from the interior insulation. Over time, distance relays may become dirty to the point that cleaning is an essential part of the periodic maintenance. Despite the results of as-found versus as-left test data analysis, it may not be prudent to extend the test interval because periodic maintenance is still needed.

Very few distance relays are installed at generating facilities. Overcurrent relays are the most common type of protective relay installed at power generating facilities. Unlike distance relays, overcurrent relays normally see very low levels of current and do not usually run hot. As a result, they tend to stay clean and require very little maintenance. Thus, extending test intervals based on as-found versus as-left test data analysis may be justifiable since periodic maintenance may not significantly affect relay performance.

In summary, as-found versus as-left test data analysis is important to understanding relay performance over time. And, a review of maintenance records is also important in order to understand the potential impact that an extended test interval may have on relay performance. If relay performance has been very stable and the relay has required little or no maintenance, an extension in the test interval may be justifiable.

Finally, it must be stressed that establishing the optimal protective relay test interval may be an iterative process. After modifying the relay maintenance and test interval, relay performance should still be monitored to confirm that the revised test frequency is optimal for the application and installation.

11.0 Relay Maintenance Program Guidelines and Considerations

Section 11 covers general information pertaining to protective relay maintenance. The guidance presented in this section is intended to suggest issues that may warrant consideration as plants develop and refine their maintenance practices for protective relays.

11.1 Maintenance Philosophy for Protective Relays

The goal of this guide is to provide practical and cost-effective guidance for implementing a successful protective relay maintenance program. A strong emphasis is placed on understanding protective relay construction, application, operation, degradation mechanisms, and failure modes. The philosophy of this guide is that a solid grasp of these fundamentals will enable maintenance personnel to develop and implement a more successful maintenance program.

An effective maintenance program for protective relays accomplishes two primary goals:

- It provides a high degree of confidence that the electrical power protection system will respond to abnormal conditions as designed. Periodic assurance that protective relays are in an operable status is particularly important since relay malfunctions are generally not obvious during routine operation.
- It preserves the relays and helps counteract normal and abnormal in-service deterioration that can affect relay performance over time. Even under normal conditions, electrical, mechanical, thermal, and environmental stresses are continually at work, slowly but predictably degrading the relays. Routine preventive maintenance helps curb the deterioration process and prolong useful service life, thereby reducing the probability of failure or degraded performance.

11.2 Program Objectives

The objectives of a protective relay maintenance program are similar to the objectives of other maintenance programs. The maintenance program should:

- Maintain each protective relay in a high state of readiness as determined by an acceptable level of reliability.
- Demonstrate compliance with applicable regulatory and industry requirements.
- Demonstrate that each protective relay can fulfill its design basis function.
- Provide performance trending information for the purpose of assessing program effectiveness.
- Establish streamlined practices and procedures that minimize the complexity and administrative burden of implementing the program, without compromising other objectives.
- Implement efficient and cost-effective maintenance practices that yield measurable results and avoid costly practices that provide little or no payback.

11.3 General Recommendations

A few general recommendations and guidelines are offered for consideration:

- Protective relay maintenance programs should recognize the excellent track record of electromechanical protective relays. It is the general consensus of the industry that protective relays have historically been overtested.
- Abstract and theoretical approaches to practical maintenance issues are generally less effective than simple, straightforward practices. Complex programs are considerably more difficult to keep focused in the nuclear environment.
- Each maintenance activity's contribution to overall system reliability and safety should be fully understood. Maintenance resources should be expended on activities that have a defined benefit.
- Not all relays have equal importance and thus should not receive equal attention. An arbitrary decision to standardize all maintenance to the same level and periodicity as that for Class 1E equipment can become a great burden on maintenance department resources. Each maintenance department has limited resources; these resources should be applied in a manner that provides maximum payback in overall plant reliability.
- Relays should not necessarily be treated the same. For instance, distance and loss of excitation relays most likely require more frequent maintenance than simple overcurrent relays.

11.4 Design Basis Maintenance

The design basis and purpose of protective relays must be fully understood before applicable maintenance and test requirements can be established. By understanding the design basis, the maintenance department can tailor the periodic inspection, test, and maintenance requirements to achieve the desired level of reliability. Design basis information includes, but is not limited to:

- The specific purpose of the relay (i.e., under what fault or abnormal condition is the relay expected to operate)
- Relay operating parameters and settings (e.g., pickup points, CT ratios, tap settings, time dial settings)
- The selectivity, coordination, and accuracy requirements for the relay
- The quality classification of the relay and associated material requirements
- Regulatory commitments or internal practices that impact planning, scheduling, performance, or documentation of relay maintenance

11.5 Practical Considerations

The maintenance program should take into account all relevant practical limitations. Typical considerations for a maintenance department include the following:

- Protective relay maintenance procedures should be streamlined and efficient. The procedures will be most effective if they are developed from a perspective that a skilled technician is required to perform the work. Overly detailed instructions are not a good substitute for practice and field experience. For example, the ability to properly burnish a set of relay contacts is a skill that comes with experience and practice, words alone are not sufficient to ensure a good job. **No procedure, regardless of how well it is written, can substitute for a properly trained and experienced relay technician**. Procedures can be streamlined by considering the following:
    - What administrative controls must be satisfied and what level of documentation is needed?
    - What training is needed to support the program? This item is particularly true for protective relay maintenance. Development of complex procedures is often considered the solution to maintenance-related problems. Unfortunately, attempting to compensate for a lack of training by adding more and more detail to procedures does not necessarily solve the real problem, and can result in less effective procedures in the long run.
    - What are the acceptance criteria for tests? Procedures that clearly state acceptance criteria increase efficiency, minimize ambiguity, and reduce errors. Tolerances, when applicable, should be stated in a format convenient to the test technician and should not require conversion factors to determine whether readings are acceptable. For example, a setting of 5.6 seconds with an acceptable tolerance of ±5% should be stated as an acceptance range of 5.32 - 5.88 seconds.
    - How can several different types of relays best be accommodated procedurally? Can one procedure cover an entire class of relays or are individual procedures necessary?
- Different policies exist for determining when a relay setting should be adjusted. Clearly, if the setting is out of tolerance, the relay should be calibrated. The question that arises is whether the setting should be adjusted if it is within tolerance but not at the midpoint value. Procedures should provide guidance in this area based on individual plant policy.
- Can periodic maintenance and testing of protective relays be combined with other required maintenance activities? It is usually beneficial to coordinate protective relay maintenance with switchgear, circuit breaker, and instrument transformer maintenance.
- What plant conditions are needed to perform the required maintenance? This issue is not always straightforward. For example, it may be possible to perform maintenance on some generator relays when the unit is at power; however, the potential risk of a generator trip may outweigh any benefits of doing so.
- What technical specification surveillance requirements apply? The test frequency for some Class IE protective relays may be predetermined by technical specifications.

- What are acceptable calibration tolerances? Is the same tolerance appropriate for all relays? Specified tolerances should be tied to a design basis. Obviously it is not appropriate to use a calibration tolerance greater than the accuracy required by the system design or electrical coordination study. However, a calibration tolerance that is much more restrictive than required by design places an unnecessary burden on maintenance personnel and may result in meaningless out of tolerance reports. Although manufacturer's recommended tolerances are generally the basis for both design and maintenance, this is not always the case. In some circumstances, field experience dictates that a wider or narrower tolerance is appropriate.

11.6 Personnel Training

Maintenance and testing of protective relays requires considerable expertise and experience. For this reason, most relay work is performed by dedicated relay specialists (someone whose work duties are substantially limited to relays). Very few utilities use non-dedicated personnel for protective relay maintenance.

Proper training of personnel is an integral part of a successful maintenance program. Properly trained workers directly support plant safety and reliability. Improperly trained personnel make mistakes or overlook problems. In particular, protective relays require well-trained and skilled personnel to assure effective maintenance.

Personnel involved with protective relay maintenance should receive thorough training. Training should include formal classroom work; however, it is recommended that protective relay training programs stress practical, hands-on work. Sources of formal training include:

- In-house training
- Industry workshops
- Test equipment manufacturer's classes
- Relay manufacturer's training
- Other specialized courses

Relay maintenance is very much an acquired skill. For this reason, on the job training should be made an integral part of the training program. On the job training is most effective when a concerted effort is made to pair junior personnel with a knowledgeable group lead or foreman.

An area of training that should not be overlooked is test equipment. Protective relay test sets are very specialized equipment that require considerable knowledge to operate correctly. Maintenance personnel must fully understand the test equipment, how to use it, and its limitations.

11.7 Performance Trending

Inspection and test data should be compared to previous data. Although the results from each inspection and test are worthwhile for evaluating the current state of a relay, the data becomes even more valuable when compared to previous results to reveal performance trends.

Trending of performance data can also be useful for optimizing maintenance intervals. For example, it may be desirable to extend the maintenance frequency for a particular class of relays. Trending data provides objective evidence upon which to base a technical evaluation of relay performance in support of a longer interval. See Section 10 for more information regarding trending data and test intervals.

The maintenance program should emphasize consistency and completeness in the recording of inspection and test data to support a trending program.

Appendix A
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   Malvern, PA 19355-1337

2. ABB Power T&D Company, Inc.
   Relay Division
   4300 Coral Ridge Drive
   Coral Springs, FL 33065

   NOTE: ABB Power T&D Company manufactures the Westinghouse line of protective relays.

Appendix B
Glossary

The definitions provided in this appendix were obtained from the references listed in the report.

A

AC - Alternating Current.

Acceptance Criteria - Specified limits placed on the characteristics or performance of an item, process, or service as defined in codes, standards, or other requirement documents.

Alarm Relay - A monitoring relay whose function is to operate an audible or visual signal to announce the occurrence of an Operation or a condition needing personal attention, and which is usually provided with a signaling cancellation device.

Armature (of a Relay) - The moving element of an electromechanical relay that contributes to the designed response of the relay and which usually has associated with it a part of the relay contact assembly.

Auxiliary Relay - A relay whose function is to assist another relay or control device in performing a general function by supplying supplementary actions.

Auxiliary Relay Driver - A circuit which supplies an input to an auxiliary relay.

Available Short-Circuit Current - The maximum current that the power system can deliver through a given circuit point to any negligible impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point.

Available Short-Circuit Test Current - The maximum short-circuit current for any given setting of a test circuit that the test power source can deliver at the point of test, with the test circuit short-circuited by a link of negligible impedance at the line terminals of the device to be tested.

B

Backup Protection - A form of protection that operates independently of specified components in the primary protective system. It may duplicate the primary protection or may be intended to operate only if the primary protection fails or is temporarily out of service.

Balance Relay - A relay which operates by comparing the magnitude of two similar input quantities.

Bias - A shift in the signal zero point by some amount.

Blocking - A relay function which prevents action that would otherwise be initiated by the relay system.

Blocking Relay - A relay whose function is to render another relay or device ineffective under specified conditions.

Burden (of a Relay) - Load impedance imposed by a relay on an input circuit expressed in ohms and phase angle at specified conditions.

C

Calibration - The adjustment of a device to have the designed operating characteristics, and the subsequent marking of the positions of the adjusting means, or the making of adjustments necessary to bring operating characteristics into substantial agreement with standardized scales or marking.

Calibration Error - In the operation of a device the departure, under specified conditions, of actual performance from performance indicated by scales, dials, or other markings on the device.

Calibration Scale - A set of graduations marked to indicate values of quantities, such as current, voltage, or time, which an automatic device can be set to operate.

Case (Frame) Ground Protection - Overcurrent relay protection used to detect current flow in the ground or earth connection of the equipment or machine.

Class IE - The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment. The terms "Class IE" and "safety-related are used interchangeably in this report.

Clearing Time - The interval between the time actuating quantity in the main circuit reaches the value causing actuation of the release and the instant of final arc extinction on all poles of the primary arcing contacts.

Closing Relay - A form of auxiliary relay used with an electrically operated device to control the closing and opening of the closing circuit of the device so that the main closing current does not pass through the control switch or other initiating device.

Confidence Interval - An interval that contains the population mean to a given probability.

Control Relay - An auxiliary relay whose function is to initiate or permit the next desired operation in a control sequence.

Critical Impulse (of a Relay) - The maximum impulse in terms of duration and input magnitude which can be applied suddenly to a relay without causing pickup.

Current-Balance Relay - A balance relay that operates by comparing the magnitudes of two current inputs.

Current Phase-Balance Protection - A method of protection in which an abnormal condition within the protected equipment is detected by the current unbalance between the phases of a normally balanced polyphase system.

Current Rating (of a Relay) - The limiting current at specified frequency that may be sustained by the relay for an unlimited period without causing any of the prescribed limitations to be exceeded.

Current Relay - A relay which responds to current.

Current Transformer - An instrument transformer that is intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled.

D

DC - Direct current.

Definite-Minimum-Time Relay - An inverse-time relay in which the operating time becomes substantially constant at high values of input.

Definite-Time Relay - A relay in which the operating time is substantially constant regardless of the magnitude of the input quantity.

Degree of Asymmetry (of a Current at any Time) - The ratio of the direct-current component to the peak value of the symmetrical component determined from the envelope of the current wave at that time.

Delayed Release Trip) - A release with intentional delay introduced between the instant when the activating quantity reaches the release setting and the instant when the release operates.

Dependability (of a Relay or Relay System) - The facet of reliability that relates to the degree of certainty that a relay or relay system will operate correctly.

Design Tests - Those tests made to determine the adequacy of a particular type, style, or model of equipment with its component parts to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions, if specified.

Dielectric Withstand-Voltage Tests - Tests made to determine the ability of insulating materials and spacings to withstand specified overvoltages for a specified time without flashover or puncture.

Differential Protection - A method of apparatus protection in which an internal fault is identified by comparing electrical conditions at all terminals of the apparatus.

Differential Relay - A relay that by its design or application is intended to respond to the difference between incoming and outgoing electrical quantities associated with the protected apparatus.

Directional-Comparison Protection - A form of pilot protection in which the relative operating conditions of the directional units at the line terminals are compared to determine whether a fault is in the protected line section.

Directional Control (as Applied to a Protective Relay or Relay Scheme) - A qualifying term that indicates a means of controlling the operating force in a nondirectional relay so that it will not operate until the two or more phasor quantities used to actuate the controlling means (directional relay) are in a predetermined band of phase relations with a reference input.

Directional-Ground Relay - A directional relay used primarily to detect single-phase-to-ground faults, but also sensitive to double-phase-to-ground faults. This type of relay is usually operated from the zero-sequence components of voltage and current, but is sometimes operated from negative-sequence quantities.

Directional-Overcurrent Protection - A method of protection in which an abnormal condition within the protected equipment is detected by the current being in excess of a predetermined amount and in a predetermined band of phase relations with a reference input.

Directional-Overcurrent Relay - A relay consisting of an overcurrent unit and a directional unit combined to operate jointly.

Directional-Power Relay - A relay that operates in conformance with the direction of power.

Directional Relay - A relay that responds to the relative phase position of a current with respect to another current or voltage reference.

Distance Protection - A method of line protection in which an abnormal condition within a predetermined electrical distance of a line terminal on the protected circuit is detected by measurement of system conditions at that terminal.

Distance Relay - A generic term covering those forms of protective relays in which the response to the input quantities is primarily a function of the electrical circuit distance between the relay location and the point of fault.

Drift - An undesired by relatively slow change in output over a period of time, which change is unrelated to the input, environment, or load.

Dropout (of a Relay) - A term for contact operation (opening or closing) as a relay just departs from pickup. Also identifies the maximum value of an input quantity which will allow the relay to depart from pickup.

Dropout Ratio (of a Relay) - The ratio of dropout to pickup of an input quantity.

Dropout Time (of a Relay) - The time interval to dropout following a specified change of input conditions.

Dual Release (Trip) - A release that combines the function of a delayed and an instantaneous release.

E

Electrical Test - To ascertain the performance characteristics while functioning under controlled conditions.

Electrically Reset R elay - A relay that is so constructed that it remains in the picked-up condition even after the input quantity is removed; an independent electrical input is required to reset the relay.

Electromagnetic Relay - An electromechanical relay that operates principally by action of an electromagnetic element which is energized by the input quantity.

Electromechanical Relay - A relay that operates by physical movement of parts resulting from electromagnetic, electrostatic, or electrothermic forces created by the input quantities.

Equipment Qualification - The generation and maintenance of evidence to assure that the equipment will operate upon demand to meet the system performance requirements.

F

Failure - Termination of the ability of an item to perform its required function.

Failure Mechanism - The physical, chemical, or other process that results in failure.

Failure Mode - The effect by which a failure is observed.

Failure Rate - The expected number of failures of a given type, per item, in a given time interval or a given number of operating cycles.

Failure to Trip - In the performance of a relay or relay system, the lack of tripping which should have occurred considering the objectives of the relay system design.

False Tripping - In the performance of a relay or relay system, the tripping which should not have occurred considering the objectives of the relay system design.

Fault Bus (Fault Ground Bus) - A bus connected to normally grounded parts of electric equipment, so insulated that all of the ground current passes to ground through fault detecting means.

Fault Bus Protection (Relaying) - A method of ground fault protection which makes use of a fault bus.

Fault-Detector Relay - A monitoring relay whose function is to limit the operation of associated protective relays to specific system conditions.

Fault Incidence Angle - The phase angle as measured between the instant of fault inception and a selected reference, such as the zero point on a current or voltage wave.

Frequency Relay - A relay that responds to the frequency of an alternating electrical input quantity.

G

Ground Overcurrent - The net (phasor sum) current flowing in the phase and neutral conductors or the total current flowing in the normal neutral to ground connection which exceeds a predetermined value.

Ground Protection - A method of protection in which faults to ground within the protected equipment are detected.

Ground Relay - A relay that by its design or application is intended to respond primarily to system ground faults.

Groundable Parts - Those parts that may be connected to ground without affecting operation of the device.

Grounded Parts - Parts that are intentionally connected to ground.

H

Hand-Reset Relay (Mechanically Reset Relay) - A relay that is so constructed that it remains in the picked-up condition even after the input quantity is removed; specific manual action is required to reset the relay.

Harmonic-Restraint Relay - A restraint relay that is so constructed that its operation is restrained by harmonic components of one or more separate input quantities.

High-Speed Relay - A relay that operates in less than a specified time. Three cycles on a 60 Hz basis is generally considered high speed.

I

IEEE - Institute of Electrical and Electronics Engineers, Inc.

Impedance Relay - A distance relay in which the threshold value of operation depends only on the magnitude of the ratio of voltage to current applied to the relay, and is substantially independent of the phase angle of the impedance.

Impulse Time) Margin - In the operation of a relay, the difference between characteristic operating times and the critical impulse times.

Incorrect Relay Operation - Any output response or lack of output response by the relay that, for the applied input quantities, is not correct.

Incorrect Relaying-System Performance - Any operation or lack of operation of the relays or associated equipment that, under existing conditions, does not conform to correct relaying-systems performance.

Independent Power Operation - An operation by means of energy other than manual where the completion of the operation is independent of the continuity of the power supply.

Induction Cup (of a Relay) - A form of relay armature in the shape of a cylinder with a closed end that develops operating torque by its location within the fields of electromagnets that are excited by the input quantities.

Induction Cylinder (of a Relay) - A form of relay armature in the shape of an open-ended cylinder that develops operating torque by its location within the fields of electromagnets that are excited by the input quantities.

Induction Disc (of a Relay) - A form of relay armature in the shape of a disc that usually serves the combined function of providing an operating torque by its location within the fields of an electromagnet excited by the input quantities and a restraining force by motion within the field of a permanent magnet.

Induction Loop (of a Relay) - A form of relay armature consisting of a single turn or loop that develops operating torque by its location within the fields of electromagnets that are excited by the input quantities.

Initiating Relay - A programming relay whose function is to constrain the action of dependent relays until after it has operated.

Input (to a Relay) - A physical quantity or quantities to which the relay is designed to respond.

Inspection - Examination or measurement to verify whether an item or activity conforms to specified requirements.

Installed Life - The interval from installation to removal, during which the equipment or component thereof may be subject to design service conditions and system demands.

Instantaneous - A qualifying term indicating that no delay is purposely introduced in the action of the device.

Interposing Relay (of a Supervisory System) - An auxiliary relay at the master or remote station, the contacts of which serve: 1) to energize a circuit (for closing, opening, or other purpose) of an element of remote station equipment when the selection of a desired point has been completed and hen suitable operating signals are received through the supervisory equipment from the master station; or 2) to connect in the circuit the telemeter transmitting and receiving equipments, respectively, at the remote and master stations. The interposing relays are considered part of a supervisory system.

Inverse-Time Relay - A relay in which the input quantity and operating time are inversely related throughout at least a substantial portion of the performance range. Types of inverse-time relays are frequently identified by such modifying adjectives as definite minimum time" "moderately", "very", and "extremely" to identify relative degree of inverseness of the operating characteristics of a given manufacturer's line of such relays.

L

Latching Relay - A relay that is so constructed that it maintains a given position by means of a mechanical latch until released mechanically or electrically.

Level Detector - A device that produces a change in output at a prescribed input level.

Line Terminal - A connection to a line with equipment that can feed energy into a fault on the line in sufficient magnitude to require consideration in the relay pan and which has means for automatic disconnection.

Linear-Impedance Relay - A distance relay for which the operating characteristic on an R-X diagram is a straight line.

Load Shedding - The process of deliberately removing preselected loads from a power system in response to an abnormal condition in order to maintain the integrity of the system.

Local Backup - A form of backup protection in which the backup protective relays are at the same station as the primary protective relays.

Lockout Relay - An electrically reset or hand-reset auxiliary relay whose function is to hold associated devices inoperative until it is reset.

Loss-of-Excitation Relay - A relay that compares the alternating voltages and currents at the terminal of a synchronous machine and operates to produce an output if the relationship between these quantities indicates that the machine has substantially lost its field excitation.

Low-Voltage System - An electrical system having a maximum root-mean-square (rms) voltage of less than 1000 V.

M

Maintainability - The ease with which equipment can be maintained, including the ease with which maintenance can be performed in accordance with prescribed requirements.

Maintenance - The combination of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function.

Maintenance Interval - The period, defined in terms of real time, operating time, number of operating cycles, or a combination of these, during which satisfactory performance is required without maintenance or adjustments.

Mandatory Maintenance - Periodic maintenance required by insurance, operating license, vendor warranty, government regulations, or other safety regulations.

Maximum Design Voltage - The highest root mean square or direct voltage at which a relay is designed to be energized continuously.

Mean - The average value of a random sample or population.

Mean Time Between Failure - A measure of reliability giving either the time before first failure or, for repairable equipment, the average time between repairs.

Medium Voltage System - An electrical system having a maximum rms ac voltage of 1000 V to 13.8 KV.

Mho Relay - A distance relay for which the inherent operating characteristic on an R-X diagram is a circle which passes through the Origin.

Mild Environment - An environment that would at no time be significantly more severe than the environment that would occur during normal plant operations, including anticipated Operational occurrences.

Modified Impedance Relay - An impedance form of distance relay for which the operating characteristic of the distance unit on an R-X diagram is a circle having its center displaced from the origin.

Monitoring Relay - A relay which has as its function to verify that system or control-circuit condition conform to prescribed limits.

Multirestraint Relay - A restraint relay that is so constructed that its operation may be restrained by more than one input quantity.

N

Negative-Phase-Sequence Relay - A relay that responds to the negative-phase-sequence component of a polyphase input quantity.

NEMA - National Electrical Manufacturers Association.

Neutral Relay - A relay that responds to quantities in the neutral of a power circuit.

NFPA - National Fire Protection Association.

Nominal System Voltage- A nominal value assigned to designate a system of a given voltage class.

Normal-Frequency Recovery Voltage - The normal-frequency rms voltage that occurs across the terminals of an ac circuit-interrupting device after the interruption of the current and after the high-frequency transients have subsisted.

Normality Test - A statistical test to determine if a sample is normally distributed.

NRC - Nuclear Regulatory Commission.

O

Offset - (impedance relay) The distance from the origin of the R - X axis to the closest point on the circumference of the characteristic circle.

Open-Phase Protection - A form of protection that operates to disconnect the protected equipment on the loss of current in one phase conductor of a polyphase circuit, or to prevent the application of power to the protected equipment on the absence of one or more phase voltages of a polyphase system.

Open-Phase Relay - A polyphase relay designed to operate when one or more input phases of a polyphase circuit are open.

Operable - For a given point in time, a device or equipment that has been demonstrated by testing at that time to have met a set of functional performance requirements under specified test conditions.

Operating Characteristic - The response of the relay to the input quantities which result in relay operation.

Operating Time - (relay) The time interval from occurrence of a specified input conditions to a specified operation.

Operating Voltage - The voltage of the system on which a device is operated.

Overcurrent Protection - A form of protection that operates when current exceeds a predetermined value.

Overcurrent Relay - A relay that operates when its input current exceeds a predetermined value.

Overcurrent Release (Trip) - A release that operates when the current in the main circuit is equal to or exceeds the release setting.

Overreach - The extension of the zone of protection beyond that indicated by the relay setting.

Overreaching Protection - A form of protection in which the relays at one terminal operate for faults beyond the next terminal. They may be constrained from tripping until an incoming signal from a remote terminal has indicated whether the fault is beyond the protected line section.

Outlier - A data point significantly different in value from the rest of the sample.

Overspeed Protection - A form of protection that operates when the speed of rotation exceeds a predetermined value.

Overtravel - The amount of continued movement of the responsive element after the input is changed to a value below pickup.

Overvoltage Relay - A relay that operates when its input voltage exceeds a predetermined value.

Overvoltage Release (Trip) - A release that operates when the voltage of the main circuit is equal to or exceeds the release setting.

P

Percentage Differential Relay - A differential relay in which the designed response to the phasor difference between incoming and outgoing electrical quantities is modified by a restraining action of one or more of the input quantities.

Periodic Test - A test performed at scheduled intervals to detect failures and verify operability.

Permissive - A general term indicating that functional cooperation of two or more relays is required before control action can become effective.

Phase-Balance Relay - A relay that responds to differences between quantities of the same nature associated with different phases of a normally balanced polyphase circuit.

Phase-Comparison Protection - A form of pilot protection that compares the relative phase-angle position of specified currents at the terminals of a circuit.

Phase Relay - A relay that by its design or application is intended to respond primarily to phase conditions of the power system.

Phase-Sequence Relay - A relay that responds to the order in which the phase voltages or currents successively reach their maximum positive values.

Phase-Sequence Reversal Protection - A form of protection that prevents energization of the protected equipment on the reversal of the phase sequence in a polyphase circuit.

Phase-Undervoltage Protection - A form of protection that disconnects or inhibits connection of the protected equipment on deficient voltage in one or more phases of a polyphase circuit.

Phase-Undervoltage Relay - A relay that operates when one or more phase voltages in a normally balanced circuit is less than a predetermined value.

Pickup - The action of a relay as it makes designated response to progressive increase of input. As a qualifying term, the state of a relay when all response to progressive increase of input has been completed. Also, used to identify the minimum value of an input quantity reached by progressive increases which will cause the relay to reach the pickup state from reset.

Pilot Protection - A form of line protection that uses a communication channel as a means to compare electrical conditions at the terminals of a line.

Pilot Wire Protection - Pilot protection in which a metallic circuit is used for the communicating means between relays at the circuit terminals.

PM - Periodic maintenance.

Polarization - A term identifying the input that provides a reference for establishing the direction of system phenomena such as direction of power or reactive flow, or direction to a fault or other disturbance on a power system.

Polyphase Relay - A descriptive term indicating that the relay is responsive to polyphase alternating electrical input quantities.

Positive-Phase-Sequence Relay - A relay that responds to the positive-phase-sequence component of a polyphase input quantity.

Potential Transformer - see Voltage Transformer.

Power Relay - A relay that responds to a suitable product of voltage and current in an electric circuit.

Preventive Maintenance - Regularly scheduled inspections, tests, servicing, repairs, and replacements intended to reduce the frequency and impact of equipment failures.

Primary Protection - First-choice relay protection in contrast with backup relay protection.

Product Relay - A relay that operates in response to a suitable product of two alternating electrical input quantities.

Protective Relay - A relay whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action.

Q

Qualified Life - The period of time for which satisfactory performance can be demonstrated for a specific set of service conditions.

R

Radial System - A system in which independent feeders branch out radially from a common source of supply.

Random - Describing a variable whose value at a particular future instant cannot be predicted exactly, but can only be estimated by a probability distribution function.

Raw Data - As-found minus as-left test data used to characterize the performance of a device or functionally equivalent group of devices.

Rated - A qualifying term that, applied to an operating characteristic, indicates the designated limit or limits of the characteristic for application under specified conditions.

Rate-of-Change Protection - A form of protection in which an abnormal condition causes disconnection or inhibits connection of the protected equipment in accordance with the rate of change of current, voltage, power, frequency, pressure, etc.

Rate-of-Change Relay - A relay that responds to the rate of change of current, voltage, power, frequency, pressure, etc.

Reach - The extent of the protection afforded by a relay in terms of the impedance or circuit length as measured from the relay location.

Reactance Relay - A linear-impedance form of distance relay for which the operating characteristic of the distance unit on an R-X diagram is a straight line of constant reactance.

Reactive Power Relay - A power relay that responds to reactive power.

Reclosing Relay - A programming relay whose function is to initiate the automatic reposing of a circuit breaker.

Regulating Relay - A relay whose function is to detect a departure from specified system operating conditions and to restore normal conditions by acting through supplementary equipment.

Relay - An electrical device designed to respond to input conditions in a prescribed manner and after specified conditions are met to cause contact operation or similar abrupt change in associated electrical control circuits.

Relay Backup - That part of the backup protection that operates in the event of failure of the primary relays.

Release-Delay grip-Delay) Setting - A calibrated setting of the time interval between the time when the actuating value reaches the release setting and the time when the release operates.

Release (Trip) Setting - A calibrated point at which the release is set to operate.

Reliability - A measure of the degree of certainty that the relay, or relay system, will perform correctly.

Remote Backup - A form of backup protection in which the protection is at a station or stations other than that which has the primary protection.

Reset - The action of a relay as it makes designated response to decreases in input. Reset as a qualifying term denotes the state of the relay when all response to decrease of input has been completed. Reset is also used to identify the maximum value of an input quantity reached by progressive decreases that will permit the relay to reach the state of complete reset from pickup.

Reset Time - The time interval from occurrence of specified conditions to reset.

Residual Relay - A relay that is so applied that its input, derived from external connections of instrument transformers, is proportional to the zero-phase-sequence component of a polyphase quantity.

Resistance Relay - A linear-impedance form of distance relay for which the operating characteristic on an R-X diagram is a straight line of constant resistance.

Restraint Relay - A relay so constructed that its operation in response to one input is restrained or controlled by a second input.

Reverse-Current Relay - A relay that operates on a current flow in a direct-current circuit in a direction opposite to a predetermined reference direction.

Reverse-Current Release - A release that operates upon reversal of the direct current in the main circuit from a predetermined direction.

R-X Diagram - A graphic presentation of the characteristics of a relay unit in terms of the ratio of voltage to current and the phase angle between them.

S

Saturation - A high flux density in the current transformer iron core created by abnormally high primary currents, high secondary burden, or a combination of these factors.

Seal-In Relay - An auxiliary relay that remains picked up through one of its own contacts which bypasses the initiating circuit until deenergized by some other device.

Security - That facet of reliability that relates to the degree of certainty that a relay or relay system will not operate incorrectly.

Selective Opening (Tripping) - The application of switching devices in series such that (of the devices carrying fault current) only the device nearest the fault will open and the devices closer to the source will remain closed and carry the remaining load.

Selective Release (Trip) - A delayed release with selective settings that will automatically reset if the actuating quantity falls and remains below the release setting for a specified time.

Selectivity - A general term describing the interrelated performance of relays and breakers, and other protective devices; complete selectivity being obtained when a minimum amount of equipment is removed from service for isolation of a fault or other abnormality.

Self-Test Relay (Automatically Reset Relay) - A relay that is so constructed that it returns to its reset position following an operation after the input quantity is removed.

Sequence Network - An electrical circuit that produces an output proportional to one or more of the sequence components of a polyphase system of voltages or currents, e.g., positive-sequence network, negative sequence network, or zero-sequence network.

Service Conditions - The conditions under which the equipment is to be applied.

Setting - The desired characteristic, obtained as a result of having set a device, stated in terms of calibration markings or of actual performance bench marks such as pick-up current and operating time at a given value of input.

Setting Error - The departure of the actual performance from the desired performance resulting from errors in adjustment or from limitations in testing or measuring techniques.

Setting Limitation - The departure of the actual performance from the desired performance resulting from limitations of adjusting devices.

Short Circuit - An abnormal condition (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential.

Short-Time Current - The current carried by a device, an assembly, or a bus for a specified short time interval.

Short-Time Delay Phase or Ground Trip Element - A direct-acting trip device element that functions with a purposely delayed action (milliseconds).

Short-Time Rating - The highest value of current or voltage or their product that the relay can stand, without Injury, for specified short-time intervals (for alternating-current circuits, root-mean-square total value including the direct-current component shall be used). The rating shall recognize the limitations imposed by both the thermal and electromagnetic effects.

Shunt Release - A release energized by a source of voltage.

Solid-State Relay - A static relay constructed exclusively of solid-state components.

Split-Winding Protection - A form of differential protection in which the current in all or part of the winding is compared to the normally proportional current in another part of the winding.

Startup - The action of a relay as it just departs from complete reset. Startup as a qualifying term is also used to identify the minimum value of the input quantity which will permit this condition.

Static Relay - A relay in which the designed response is developed by electronic, solid-state, magnetic, or other components without mechanical motion.

Sudden-Pressure Relay - A relay that operates by the rate of rise in pressure of a liquid or gas.

Susceptance Relay - A mho-type distance relay for which the center of the operating characteristic on the R-X diagram is on the X axis.

Symmetrical Component - That portion of the total current that constitutes the symmetry.

Synchronism-Check Relay - A verification relay whose function is to operate when two input voltage phasors are within predetermined limits.

Synchronizing Relay - A programming relay whose function is to initiate the closing of a circuit breaker between two ac sources when the voltages of these two sources have a predetermined relationship of magnitude, phase angle, and frequency.

T

Target (Operation Indicator) - A supplementary device operated either mechanically or electrically, to indicate visibly that the relay has operated or completed its function.

Temperature Relay - A relay whose operation is caused by specified external temperature.

Time-Dependent Drift - The tendency for the magnitude of drift to vary with time.

Time Dial - An adjustable, graduated element of a relay by which, under fixed input conditions, the prescribed relay operating time can be varied.

Time-Independent Drift - The tendency for the magnitude of drift to show no specific trend with time.

Time-Overcurrent Relay - An overcurrent relay in which the input current and operating time are inversely related throughout a substantial portion of the performance range.

Time-Undervoltage Protection - A form of undervoltage protection that disconnects the protected equipment upon a deficiency of voltage after a predetermined time interval.

Timing Relay - An auxiliary relay whose function is to introduce one or more time delays in the completion of an associated function.

Tolerance - The allowable variation from a specified or true value.

Tolerance Interval - An interval that contains a defined proportion of the population to a given probability.

Torque Control - A method of constraining the pickup of a relay by preventing the torque-producing element from developing operating torque until after another associated relay unit operates.

Transfer Trip - A form of remote trip in which a communication channel is used to transmit a trip signal from the relay location to a remote location.

Transient Response - The manner in which a relay or relay system responds to a sudden change in the input.

Travel - The amount of movement in either direction (towards pickup or reset) of a responsive element.

Trip (or Tripping) - Pertaining to a release that initiates either an opening or a closing operation or other specified action.

Trip-Free Relay - An auxiliary relay whose function is to open the closing circuit of an electrically operated switching device so that the opening operation can prevail over the closing operation.

U

Undercurrent Relay - A relay that operates when the current is less than a predetermined value.

Underreaching Protection - A form of protection in which the relays at a given terminal do not operate for faults at remote locations on the protected equipment, the given terminal being cleared either by other relays with different performance characteristics or by a transferred trip signal from a remote terminal similarly equipped with underreaching relays.

Undervoltage Protection - A form of protection that operates when voltage is less than a predetermined value.

Undervoltage Relays - A relay that operates when its voltage is less than a predetermined value.

Undervoltage Release Trip) - A release that operates when the voltage of the main circuit is equal to or less than the release setting.

V

Voltage Balance Relay - A balance relay which operates by comparing the magnitudes of two voltage inputs.

Voltage-Phase-Balance Protection - A form of protection that disconnects or prevents the connection of the protected equipment when the voltage unbalance of the phases of a normally balanced polyphase system exceeds a predetermined amount.

Voltage Rating - The voltage at a specified frequency that may be sustained by the relay for an unlimited period without causing any of the prescribed limitations to be exceeded.

Voltage Relay - A relay that responds to voltage.

Voltage Restraint - A method of restraining the operation of a relay by means of a voltage input which opposes the typical response of the relay to other inputs.

Voltage Transformer - An instrument transformer intended to have its primary winding connected in shunt with a power supply circuit, the voltage of which is to be measured or controlled.

Volts Per Hertz Relay - A relay whose pickup is a function of the ratio of voltage to frequency.

W

Withstand Voltage - The voltage that electrical equipment is capable of withstanding without failure or disruptive discharge when tested under specified conditions.

Z

Zero-Phase-Sequence Relay - A relay that responds to the zero-phase-sequence component of a polyphase input quantity.

Zone of Protection - That segment of the power system in which the occurrence of assigned abnormal conditions should cause the protective relay system to operate.

Appendix C
Overview of Industry Standards

Industry standards are used to define accepted practices for system or product design, application, installation, service, operation, or maintenance. The following sections discuss some of these standards and their applicability to protective relay design, application, and maintenance.

C.1 Institute of Electrical and Electronics Engineers (IEEE)

1. ANSI/IEEE 242-1986, *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.*

   This standard discusses electrical protection for industrial and commercial facilities. Chapter 4 of the standard provides good general information relating to the selection and application of protective relays. Protection of motors, generators, busses, and transformers is also covered. Chapter 15 addresses maintenance, testing, and calibration of electrical protection equipment, including protective relays.

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

   This standard prescribes criteria for the protection of Class IE electrical equipment and systems at nuclear power plants. The standard addresses general and specific design requirements, documentation and records, and testing and surveillances.

3. ANSI/IEEE C37.2-1991, *IEEE Standard Electrical Power System Device Function Numbers.*

   This standard establishes unique numbers to identify the function of electrical devices commonly used in electrical power systems. Device function numbers for all protective relays are defined. The numbers established by this standard are used extensively in electrical drawings, specifications, reports, and other related engineering documents.

4. ANSI/IEEE C37.90-1989, *IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.*

   This standard is a primary reference for protective relays. It standardizes service conditions, ratings, performance requirements, and testing requirements for power system relays. Relay classifications and terminology are also addressed. The standard is a good reference for fundamental design and test requirements used by manufacturers to design and build protective relays.

5. ANSI/IEEE C37.90.1-1989, *IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.*

   This standard establishes standardized surge withstand capability (SWC) tests for protective relays. The tests are primarily used by manufacturers to verify design adequacy of their products and are not generally performed by users.

6. ANSI/IEEE C37.90.2-1989, *IEEE Trial-Use Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.*

   This standard establishes a test method for evaluating the susceptibility of solid-state protective and control relays to electromagnetic interference. Similar to SWC tests, the test specified in this standard is primarily used by manufacturers to verify design adequacy of their products and is not generally performed by users.

7. ANSI/IEEE C37.91-1985, *IEEE Guide for Protective Relay Applications to Power Transformers.*

   This standard addresses protection of power transformers. Protection philosophy, practical considerations, and economic factors are covered in the standard. The application of various types of protective relays is covered in considerable depth.

8. ANSI/IEEE C37.95-1989, *IEEE Guide for Protective Relaying of Utility-Consumer Interconnections.*

   This standard contains information on protective relay practices applicable to utility-consumer interconnections .

9. ANSI/IEEE C37.96-1988, *IEEE Guide for AC Motor Protection.*

   This standard addresses protection of ac motors. Generally accepted practices for motor protection are reviewed. Protection philosophy, protective relay applications, and relaying schemes are covered in depth.

10. ANSI/IEEE C37.97-1979, *IEEE Guide for Protective Relay Applications to Power System Buses.*

    This standard addresses protection of power system buses. Various protection methods for typical substation and switchyard bus arrangements are covered. The standard is not directly applicable to the protection of in-plant distribution switchgear.

11. ANSI/IEEE C37.98-1987, *IEEE Standard Seismic Testing of Relays.*

    This standard specifies procedures for seismic testing of relays used in power systems. The standard is primarily used to evaluate the seismic performance of protective and auxiliary relays that are intended for use in Class IE electrical systems at nuclear power plants. This standard supports IEEE C37.105-1987, *IEEE Standard for Qualifying Class IE Protective Relays and Auxiliaries for Nuclear Power Generating Stations.*

12. ANSI/IEEE C37.99-1990, *IEEE Guide for the Protection of Shunt Capacitor Banks.*

    This standard discusses the application of protective relays to shunt capacitors used in substations.

13. ANSI/IEEE C37.100-1981, *Definitions for Power Switchgear.*

    This standard is the primary reference source for terms and definitions applicable to power switchgear, including protective relays. The standard is a good reference document for unfamiliar terms.

14. ANSI/IEEE C37.101-1985, *IEEE Guide for Generator Ground Protection.*

    This standard provides guidance for the protection of synchronous generators against ground faults. Protective relay applications and relaying schemes are covered in depth.

15. ANSI/IEEE C37.102-1987, *IEEE Guide for AC Generator Protection.*

    This standard provides guidance for the protection of ac synchronous generators. Generally accepted protection practices are reviewed and the application of protective relays is summarized. Abnormal conditions and faults requiring protective action are discussed at length.

16. ANSI/IEEE C37.103-1990, *IEEE Guide for Differential and Polarizing Relay Circuit Testing.*

    This standard provides recommended tests to ensure ground relay polarizing and differential relays are connected properly. The standard is limited to ensuring proper circuit connections and does not address routine testing or calibration. These tests are applicable to system startup.

17. ANSI/IEEE C37.105-1987, *IEEE Standard for Qualifying Class IE Protective Relays and Auxiliaries for Nuclear Power Generating Stations.*

    This standard describes the requirements and methods to be used for qualification of Class IE protective relays. The standard is intended to demonstrate the design adequacy of protective relays under normal and abnormal conditions, during design basis events, and after a design basis event.

18. ANSI/IEEE C37.106-1987, *IEEE Guide for Abnormal Frequency Protection for Power Generating Plants.*

    This standard provides guidance for the application of protective relays to power plant equipment to guard against damage from abnormal frequencies.

C.2 National Fire Protection Association (NFPA)

1. ANSI/NFPA 70-1993, *National Electrical Code.*

   This code is a nationally accepted guide for the safe design and installation of electrical conductors, equipment, and systems. The code contains provisions considered necessary to ensure the practical safeguarding of people and property from the hazards associated with electricity. The code serves as a primary reference source for electrical installations in the United States.

2. ANSI/NFPA 70B-1990, *Recommended Practice for Electrical Equipment Maintenance.*

   The purpose of this code is to reduce the hazards to life and property that can result from failure or malfunction of industrial electrical systems and equipment. The code provides good general guidance for preventive maintenance programs associated with industrial electrical equipment. General maintenance recommendations for protective relays are included in Appendix I of the code.

3. ANSI/NFPA 70E-1988, Standard for *Electrical Safety Requirements for Employee Workplaces*

   This standard addresses electrical safety requirements that are necessary for the practical safeguarding of employees in the work place.

C.3 InterNational Electrical Testing Association (NETA)

1. NETA ATS-1991, *Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems.*

   This document provides recommendations for acceptance testing of electrical power systems and equipment. It provides practical recommendations intended to identify shipping damage, wiring errors, manufacturing defects, and other similar problems that can occur during startup of new equipment or systems. Some brief guidance is provided for protective relays.

2. NETA MTS-1989, *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems.*

   This document is intended to list the majority of field tests available for assessing the condition of electrical distribution equipment. Suitability of continued service and expected reliability are emphasized. Maintenance recommendations for protective relays are provided.

Appendix D

Electrical Power System Device Function Numbers

Every protective device has an associated device function number. These numbers are designated by ANSI/IEEE C37.2-1991, *IEEE Standard Electrical Power System Device Function Numbers.* The numbering scheme defined by this national standard is used in electrical schematics, engineering specifications, textbooks, and other documents referring to electrical devices.

Standard device designations are given below:

Device Number	Definition and Function
1	**Master Element** is the initiating device, such as a control switch, voltage relay, float switch, etc., which serves either directly, or through such permissive devices as protective and time-delay relays to place an equipment in or out of operation.
2	**Time-Delay Starting, or Closing, Relay** is a device which functions to give a desired amount of time delay before or after any point or operation in a switching sequence or protective relay system, except as specifically provided by device functions 62 or 79 described later.
3	**Checking or Interlocking Relay** is a device which operates in response to the position of a number of other devices, or to a number of predetermined conditions in an equipment to allow an operating sequence to proceed, to stop, or to provide a check of the position of these devices or of these conditions for any purpose.
4	**Master Contactor** is a device, generally controlled by device No. 1 or equivalent, and the necessary permissive and protective devices, which serves to make and break the necessary control circuits to place an equipment into operation under the desired conditions and to take it out of operation under other or abnormal conditions.
5	**Stopping Device** functions to place and hold an equipment out of operation.
6	**Starting Circuit Breaker** is a device whose principal function is to connect a machine to its source of starting voltage.
7	**Anode Circuit Breaker** is one used in the anode circuits of a power rectifier for the primary purpose of interrupting the rectifier circuit if an arc back should occur.
8	**Control Power Disconnecting Device** is a disconnecting device - such as a knife switch, circuit breaker, or pull-out fuse block - used for the purpose of connecting and disconnecting, respectively, the source of control power to and from the control bus or equipment. Control power is considered to include auxiliary power which supplies such apparatus as small motors and heaters.
9	**Reversing Device** is used for the purpose of reversing a machine field or for performing any other reversing functions.
10	**Unit Sequence Switch** is used to change the sequence in which units may be placed in and out of service in multiple-unit equipments.
11	Reserved for future application.

Device Number	Definition and Function
12	**Over-Speed Device** is usually a direct-connected speed switch which functions on machine overspend.
13	**Synchronous-Speed Device,** such as a centrifugal speed switch, a slip-frequency relay, a voltage relay, an undercurrent relay, or any type of device, operates at approximately synchronous speed of a machine.
14	**Under-Speed Device** functions when the speed of a machine falls below a predetermined value.
15	**Speed or Frequency Matching Device** functions to match and hold the speed or the frequency of a machine or of a system equal to, or approximately equal to, that of another machine, source, or system.
16	Reserved for future application.
17	**Shunting, or Discharge, Switch** serves to open or to close a shunting circuit around any piece of apparatus (except a resistor), such as a machine field, a machine armature, a capacitor, or a reactor.
18	**Accelerating or Decelerating Device** is used to close or cause the closing of circuits which are used to increase or to decrease the speed of a machine.
19	**Starting-to-Running Transition Contactor** is a device which operates to initiate or cause the automatic transfer of a machine from the starting to the running power connection.
20	**Electrically Operated Valve** is a solenoid- or motor-operated valve which is used in a vacuum, air, gas, oil, water, or similar, lines. The function of the valve may be indicated by the insertion of descriptive words such as Brake" or "Pressure Reducing" in the function name, such as "Electrically Operated Brake Valve."
21	**Distance Relay** is a device which functions when the circuit admittance, impedance, or reactance increases or decreases beyond predetermined limits.
22	**Equalize Circuit Breaker** is a breaker which serves to control or to make and break the equalizer or the current-balancing connections for a machine field, or for regulating equipment, in a multiple-unit installation.
23	**Temperature Control Device** functions to raise or to lower the temperature of a machine or other apparatus, or of any medium, when its temperature falls below, or rises above, a predetermined value. An example is a thermostat which switches on a space heater in a switchgear assembly when the temperature falls to a desired value as distinguished from a device which is used to provide automatic temperature regulation between close limits and would be designated as 90T.
24	Reserved for future application.
25	**Synchronizing, or Synchronism-Check, Device** operates when two a-c circuits are within the desired limits of frequency, phase angle, or voltage, to permit or to cause the paralleling of these two circuits.

Device Number	Definition and Function
26	**Apparatus Thermal Device** functions when the temperature of the shunt field or the armortisseur winding of a machine, or that of a load limiting or load shifting resistor or of a liquid or other medium exceeds a predetermined value; or if the temperature of the protected apparatus, such as a power rectifier, or of any medium decreases below a predetermined value.
27	**Undervoltage Relay** is a device which functions on a given value of undervoltage.
28	Reserved for future application.
29	**Isolating Contactor** is used expressly for disconnecting one circuit from another for the purposes of emergency operation, maintenance, or test.
30	**Annunciator Relay** is a nonautomatically reset device which gives a number of separate visual indications upon the functioning of protective devices, and which may also be arranged to perform a lockout function.
31	**Separate Excitation Device** connects a circuit such as the shunt field of a synchronous converter to a source of separate excitation during the starting sequence; or one which energizes the excitation and ignition circuits of a power rectifier.
32	**Directional Power Relay** is one which functions on a desired value of power flow in a given direction, or upon reverse power resulting from arc back in the anode or cathode circuits of a power rectifier.
33	**Position Switch** makes or breaks contact when the main device or piece of apparatus, which has no device function number, reaches a given position.
34	**Motor-Operated Sequence Switch** is a multi-contact switch which fixes the operating sequence of the major devices during starting and stopping, or during other sequential switching operations.
35	**Brush-Operating, or Slip-Ring Short-Circuiting, Device** is used for raising, lowering, or shifting the brushes of a machine, or for short-circuiting its slip rings, or for engaging or disengaging the contacts of a mechanical rectifier.
36	**Polarity Device** operates or permits the operation of another device on a predetermined polarity only.
37	**Undercurrent or Underpower Relay** is a device which functions when the current or power flow decreases below a predetermined value.
38	**Bearing Protection Device** is one which functions on excessive bearing temperature, or on other abnormal mechanical conditions, such as undue wear, which may eventually result in excessive bearing temperature.
39	Reserved for future application.
40	**Field Relay** is a device that functions on a given or abnormally low value or failure of machine field current, or on an excessive value of the reactive component of armature current in an a-c machine indicating abnormally low field excitation.
41	**Field Circuit Breaker** is a device which functions to apply, or to remove, the field excitation of a machine.

Device Number	Definition and Function
42	**Running Circuit Breaker** is a device whose principal function is to connect a machine to its source of running voltage after having been brought up to the desired speed on the starting connection.
43	**Manual Transfer or Selector Device** transfers the control circuits so as to modify the plan of operation of the switching equipment or of some of the devices.
44	**Unit Sequence Starting Relay** is a device which functions to start the next available unit in a multiple-unit equipment on the failure or on the non-availability of the normally preceding unit.
45	Reserved for future application.
46	**Reverse-Phase, or Phase-Balance, Current Relay** is a device which functions when the polyphase currents are of reverse-phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.
47	**Phase-Sequence Voltage Relay** is a device which functions upon a predetermined value of polyphase voltage in the desired phase sequence.
48	**Incomplete Sequence Relay** is a device which returns the equipment to the normal, or off, position and locks it out if the normal starting, operating, or stopping sequence is not properly completed within a predetermined time.
49	**Machine, or Transformer, Thermal Relay** is a device which functions when the temperature of an a-c machine armature, or of the armature or other load carrying winding or element of a d-c machine, or converter or power rectifier or power transformer (including a power rectifier transformer) exceeds a predetermined value.
50	**Instantaneous Overcurrent, or Rate-of-Rise Relay** is a device which functions instantaneously on an excessive value of current, or on an excessive rate of current rise, thus indicating a fault in the apparatus or circuit being protected.
51	**A-C Time Overcurrent Relay** is a device with either a definite or inverse time characteristic which functions when the current in an a-c circuit exceeds a predetermined value.
52	**A-C Circuit Breaker** is a device which is used to close and interrupt an a-c power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
53	**Exciter or D-C Generator Relay** is a device which forces the d-c machine field excitation to build up during starting or which functions when the machine voltage has built up to given value.
54	**High-Speed D-C Circuit Breaker** is a circuit breaker which starts to reduce the current in the main circuit in 0.01 second or less, after the occurrence of the d-c overcurrent or the excessive rate of current rise.
55	**Power Factor Relay** is a device which operates when the power factor in an a-c circuit becomes above or below a predetermined value.

Device Number	Definition and Function
56	**Field Application Relay** is a device which automatically controls the application of the field excitation to an a-c motor at some predetermined point in the slip cycle.
57	**Short-Circuiting or Grounding Device** is a power or stored energy operated device which functions to short-circuit or to ground a circuit in response to automatic or manual means.
58	**Power Rectifier Misfire Relay** is a device which functions if one or more of the power rectifier anodes fails to fire.
59	**Overvoltage Relay** is a device which functions on a given value of overvoltage.
60	**Voltage Balance Relay** is a device which operates on a given difference in voltage between two circuits.
61	**Current Balance Relay** is a device which operates on a given difference in current input or output of two circuits.
62	**Time-Delay Stopping, or Opening, Relay** is a time-delay device which serves in conjunction with the device which initiates the shutdown, stopping, or opening operation in an automatic sequence.
63	**Liquid or Gas Pressure, Level, or Flow Relay** is a device which operates on given values of liquid or gas pressure, flow, or level, or on a given rate of change of these values.
64	**Ground Protective Relay** is a device which functions on failure of the insulation of a machine, transformer or of other apparatus to ground, or on flashover of a d-c machine to ground. This function is assigned only to a relay which detects the flow of current from the frame of a machine or enclosing case or structure of a piece of apparatus to ground, or detects a ground on a normally ungrounded winding or circuit. It is not applied to a device connected in the secondary circuit or secondary neutral of a current transformer, or current transformers, connected in the power circuit of a normally grounded system.
65	**Governor** is the equipment which controls the gate or valve opening of a prime mover.
66	**Notching, or Jogging, Device** functions to allow only a specified number of operations of a given device, or equipment, or a specified number of successive operations within a given time of each other. It also functions to energize a circuit periodically, or which is used to permit intermittent acceleration or jogging of a machine at low speeds for mechanical positioning.
67	**A-C Directional Overcurrent Relay** is a device which functions on a desired value of a-c overcurrent flowing in a predetermined direction.
68	**Blocking Relay** is a device which initiates a pilot signal for blocking of tripping on external faults in a transmission line or in other apparatus under predetermined conditions, or co-operates with other devices to block tripping or to block reposing on an out-of-step condition or on power swings.

Device Number	Definition and Function
69	**Permissive Control Device** is generally a two-position manually operated switch which in one position permits the closing of a circuit breaker, or the placing of an equipment into operation, and in the other position prevents the circuit breaker or the equipment from being operated.
70	**Electrically Operated Rheostat** is a rheostat which is used to vary the resistance of a circuit in response to some means of electrical control.
71	Reserved for future applications.
72	**D-C Circuit Breaker** is used to close and interrupt a d-c power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
73	**Load-Resistor Contactor** is used to shunt or insert a step of load limiting, shifting, or indicating resistance in a power circuit, or to switch a space heater in circuit, or to switch a light, or regenerative, load resistor of a power rectifier or other machine in and out of circuit.
74	**Alarm Relay** is a device other than an annunciator, as covered under device No. 30, which is used to operate, or to operate in connection with, a visual or audible alarm.
75	**Position Changing** mechanism is the mechanism which is used for moving a removable circuit breaker unit to and from the connected, disconnected, and test positions.
76	**D-C Overcurrent Relay** is a device which functions when the current in a d-c circuit exceeds a given value.
77	**Pulse Transmitter** is used to generate and transmit pulses over a telemetering or pilot-wire circuit to the remote indicating or receiving device.
78	**Phase Angle Measuring, or Out-of-Step Protective Relay** is a device which functions at a predetermined phase angle between two voltages or between two currents or between voltage and current.
79	**A-C Reclosing Relay** is a device which controls the automatic reposing and locking out of an a-c circuit interrupter.
80	Reserved for future application.
81	**Frequency Relay** is a device which functions on a predetermined value of frequency-either under or over or on normal system frequency-or rate of change of frequency.
82	**D-C Reclosing Relay** is a device which controls the automatic closing and reposing of a d-c circuit interrupter, generally in response to load circuit conditions.
83	**Automatic Selective Control, or Transfer, Relay** is a device which operates to select automatically between certain sources or conditions in an equipment, or performs a transfer operation automatically.
84	**Operating Mechanism** is the complete electrical mechanism or servo-mechanism, including the operating motor, solenoids, position switches, etc., for a tap changer, induction regulator or any piece of apparatus which has no device function number.

Device Number	Definition and Function
85	**Carrier, or Pilot-Wire, Receiver Relay** is a device which is operated or restrained by a signal used in connection with carrier-current or d-c pilot-wire fault directional relaying.
86	**Lockout Relay** is a hand or electrically reset auxiliary relay that is operated upon the occurrence of abnormal conditions to maintain associated equipment or devices inoperative until it is reset.
87	**Differential Protective Relay** is a protective device which functions on a percentage or phase angle or other quantitative difference of two currents or of some other electrical quantities.
88	**Auxiliary Motor, or Motor Generator,** is one used for operating auxiliary equipment such as pumps, blowers, exciters, rotating amplifiers, etc.
89	**Line Switch** is used as a disconnecting or isolating switch in an a-c or d-c power circuit, when this device is electrically operated or has electrical accessories, such as an auxiliary switch, magnetic lock, etc.
90	**Regulating Device** functions to regulate a quantity, or quantities, such as voltage, current, power, speed, frequency, temperature, and load, at a certain value or between certain limits for machines, tie lines or other apparatus.
91	**Voltage Directional Relay** is a device which operates when the voltage across an open circuit breaker or contactor exceeds a given value in a given direction.
92	Voltage and Power Directional Relay is a device which permits or causes the connection of two circuits when the voltage difference between them exceeds a given value in a predetermined direction and causes these two circuits to be disconnected from each other when the power flowing between them exceeds a given value in the opposite direction.
93	**Field Changing Contactor** functions to increase or decrease in one step the value of field excitation on a machine.
94	**Tripping, or Trip-Free, Relay** is a device which functions to trip a circuit breaker, contactor, or equipment, or to permit immediate tripping by other devices; or to prevent immediate reclosure of a circuit interrupter, in case it should open automatically even though its closing circuit is maintained closed.
95 96 97 98 99	Numbers 95 through 99 are used only for specific applications on individual installations where none of the assigned numbered functions from 1 to 94 is suitable.

A similar series of numbers, prefixed by the letters RE (for "remote") are normally used for interposing relays performing functions that are controlled directly from the supervisory system. For example, a remote stopping device controlled by the remote supervisory system would be designated RE5.

Index