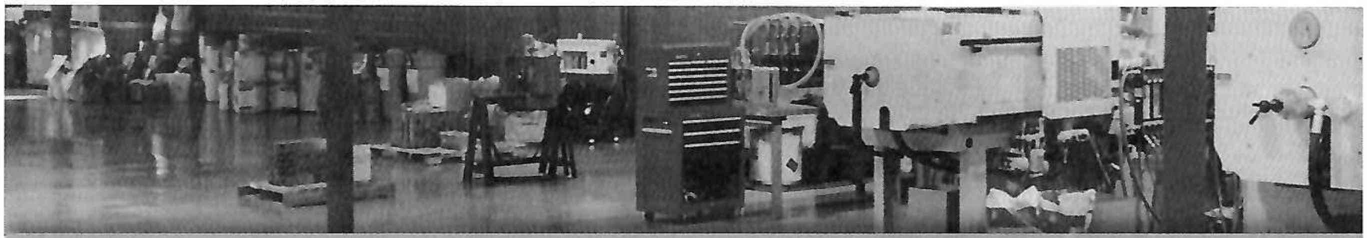
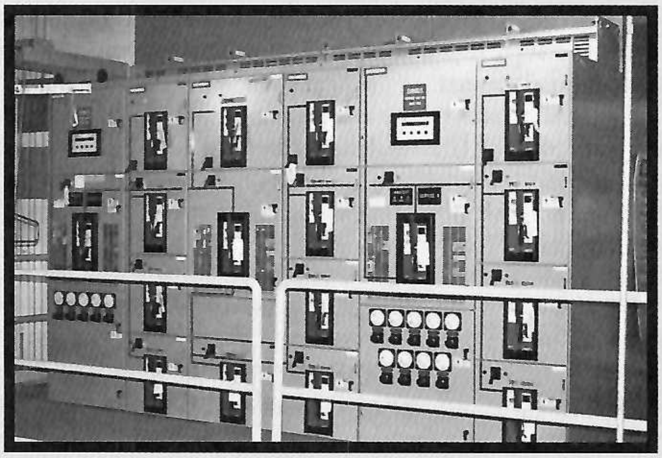


Industrial Maintenance E & I Technician Level Three

40305-09

Distribution Equipment

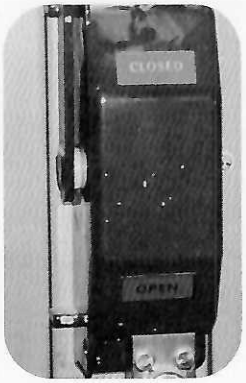


40305-09

Distribution Equipment

Topics to be presented in this module include:

Overview



Electrical power is generated at power plants. The voltage is stepped up at the source to compensate for voltage drops that may occur when sending the power across long runs of transmission lines. Once the voltage arrives at local substations, it must be stepped down to usable levels and distributed to consumers. Stepping down and distributing the power is accomplished by distribution equipment.

Switchboards make up a large portion of distribution equipment. They are used to control the routing of power to large areas of usage or directly to high-end consumers such as industrial or manufacturing facilities. Technicians who maintain switchboard equipment must be trained in the proper inspection, testing, and maintenance of this type of equipment. The *NEC®* regulates the construction, installation, and accessories used with switchboard equipment.

Distribution systems are typically illustrated using one-line electrical drawings. These types of drawings provide a traceable path from the incoming power in a substation, through step-up or step-down transformers, fuses, circuit breakers, switches, and eventually out to the consumer or individual loads.

Note: *NFPA 70®*, *National Electrical Code®*, and *NEC®* are registered trademarks of the National Fire Protection Association, Inc., Quincy, MA 02269. All *National Electrical Code®* and *NEC®* references in this module refer to the 2008 edition of the *National Electrical Code®*.

Objectives

When you have completed this module, you will be able to do the following:

1. Explain the necessity of overcurrent protection devices in electrical circuits.
2. Define the terms associated with fuses and circuit breakers.
3. Describe the purpose of switchgear.
4. Describe the four general classifications of circuit breakers and list the major circuit breaker ratings.
5. Describe switchgear construction, metering layouts, wiring requirements, and maintenance.
6. List *National Electrical Code*® (*NEC*®) requirements pertaining to switchgear.
7. Describe the visual and mechanical inspections and electrical tests associated with low-voltage and medium-voltage cables, metal-enclosed busways, and metering and instrumentation.
8. Describe a ground fault relay system and explain how to test it.

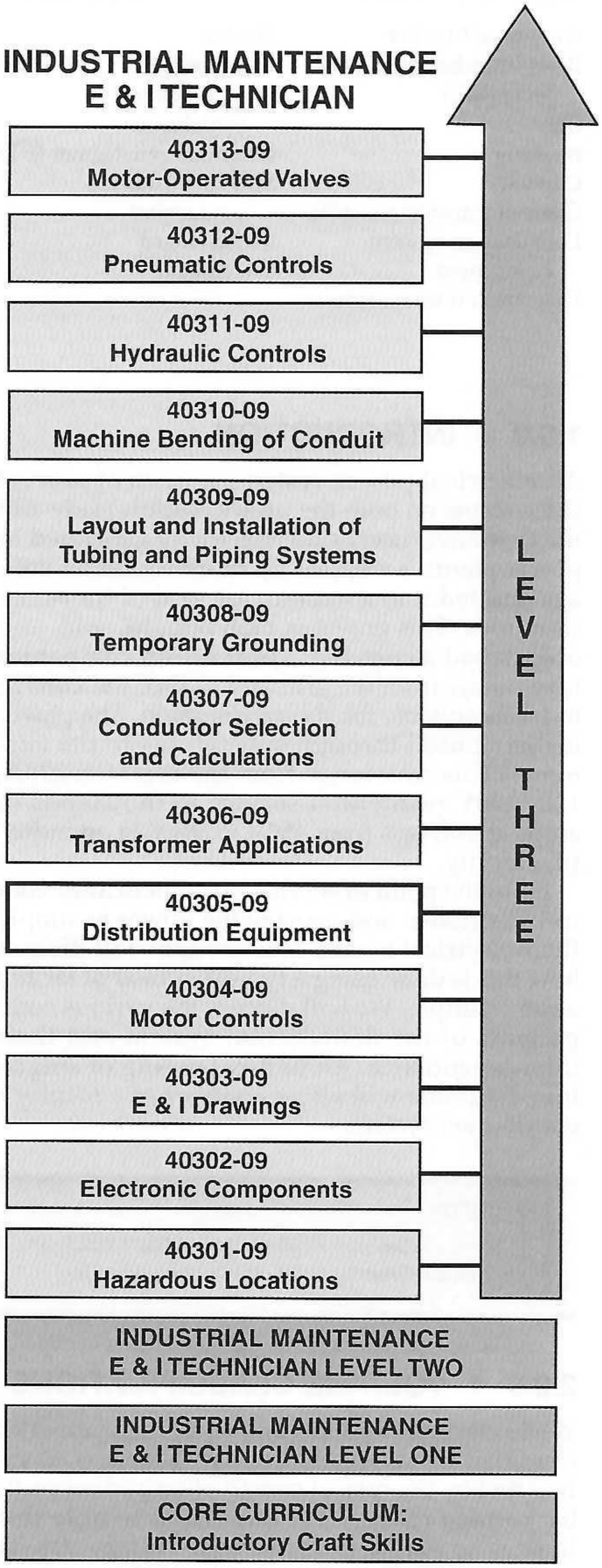
Required Trainee Materials

1. Pencil and paper
2. Appropriate personal protective equipment
3. Copy of the latest edition of the *National Electrical Code*®

Prerequisites

Before you begin this module, it is recommended that you successfully complete *Core Curriculum; Industrial Maintenance E & I Technician Level One; Industrial Maintenance E & I Technician Level Two;* and *Industrial Maintenance E & I Technician Level Three,* Modules 40301-09 through 40304-09.

This course map shows all of the modules in *Industrial Maintenance E & I Technician Level Three.* The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map. The local Training Program Sponsor may adjust the training order.



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Trade Terms

- Air circuit breaker
- Basic impulse insulation level (BIL)
- Bus
- Bushing
- Capacity
- Current transformer (CT)
- Distribution system equipment
- Distribution transformer
- Feeder
- Frame size
- Metal-enclosed switchgear
- Potential transformer (PT)
- Service-entrance equipment
- Switchboard
- Switchgear

1.0.0 ◆ INTRODUCTION

An electrical power system consists of several subsystems on both the utility (supply) side and the customer (user) side. Electricity generated in power plants is stepped up to transmission voltage and fed into a nationwide grid of transmission lines. This power is then bought, sold, and dispatched as needed. Local utility companies take power from the grid and reduce the voltage to levels suitable for subtransmission. The power is distributed through substations to the customer. This may range from the common 200A, 120/240V residential service to thousands of amps at voltages from 480V to 69kV in an industrial facility.

From the point of service, customers must control, distribute, and manage the power to supply their electrical needs. This module will discuss how this is done using a typical industrial facility as an example. We will discuss the various components of the distribution system and their interdependence. An understanding of single-line diagrams will allow analysis of a facility's distribution system.

NOTE

The voltage conventions used in this module are industry standards for distributions systems.

2.0.0 ◆ VOLTAGE CLASSIFICATIONS

While electrical systems and equipment are often classified by voltage rating, **switchgear** is classified first by the type of construction and secondly by voltage rating. It is important to note that there is no official industry-wide voltage classification system. For example, the *NEC®* considers anything above 600V as high voltage, while the transmission sector considers anything below 72,500V (72.5kV) as low voltage. In industrial applications, the term *low-voltage* refers to systems rated up to 1,000V, while medium voltage refers to systems rated above 1,000V and up to 38,000V (38kV). This is the range in which metal-clad switchgear and circuit breakers are manufactured in standard configurations. This is also the voltage range in which pre-molded and shrink-on termination kits are readily available for shielded cable terminations. Above this voltage level, cable is run on overhead power lines rather than in raceway or cable tray.

Low-voltage power circuit breaker switchgear, for example, may be rated up to 1,000VAC or 3,200VDC. Metal-clad or **metal-enclosed switchgear** is applied at voltages over 1,000VAC up to a maximum of 38,000VAC.

3.0.0 ◆ SWITCHBOARDS

According to the *National Electrical Code®*, a **switchboard** is defined as a large single panel, frame, or assembly of panels on which switches, overcurrent and other protective devices, **buses**, and instruments may be mounted, either on the face or back or both. Switchboards may be accessible from both the rear and from the front and are not intended to be installed in cabinets.

3.1.0 Applications

Switchboards are used in modern distribution systems to subdivide large blocks of electrical power. One typical location for switchboards is where the main power enters the building. In this location, the switchboard is referred to as **service-entrance equipment**. The other location common for switchboards is downstream from the service-entrance equipment. In the downstream location, the switchboard is commonly referred to as **distribution system equipment**.

3.2.0 General Description

A switchboard consists of stationary cubicles that include one or more freestanding units of uniform height that are mechanically and electrically joined to make a single, coordinated installation. These cubicles contain circuit-interrupting devices. They take up less space in a plant, have more eye appeal, and eliminate the need for a separate room to protect personnel from contact with lethal voltages.

The main portion of the switchboard is formed from heavy-gauge steel welded with members across the top and bottom to provide a rigid enclosure. Most switchboard enclosures are divided into three sections: the incoming section, the bus section, and the cable section. These three sections are physically separated from one another by metal partitions. This confines any damage that may occur to any one section and keeps it from affecting the other sections.

Typical switchboard components include the following:

- Circuit breakers
- Fuses
- Motor starters
- Ground fault systems
- Instrument transformers
- Switchboard metering
- Control power transformers
- Busbars

Electrical ratings include three-phase, three-wire and three-phase, four-wire systems with voltage ratings up to 600V and current ratings up to 4,000A.

A switchboard enclosure is described as a dead front panel, which means that no live parts are exposed on the opening side of the equipment; however, it contains energized breakers. Busbars can be a standard size or customized. Standard sizes are usually made of silver-plated or tin-plated copper or tin-plated aluminum. Conventional bus sizing is 0.25" × 2" through 0.375" × 7". Copper provides an ampacity of 1,000A/in^2 of cross-sectional area. When using aluminum, the ampacity is 750A/in^2.

When two busbars are bolted together using Grade S hardware with the proper torque, the ampacity of the connection is 200A/in^2 of the lapped portion for aluminum or copper bussing. Bussing joints must be bolted together to the specified torque and include Belleville washers or Keps nuts. Aluminum busbars must be tin-plated, and copper busbars over 600A must be plated with tin or silver.

3.3.0 Switchboard Frame Heating

Table 1 shows guidelines that should be observed in order to keep heat losses in the iron switchboard frame members to a safe minimum. The dimensions are recommended values and should be adhered to whenever possible.

NOTE

Some switchboard frames are engineered differently and will have values other than those shown in *Table 1*.

3.4.0 Low-Voltage Spacing Requirements

To minimize tracking or arcing from energized parts to ground, switchboard construction includes spacing requirements. These spacing requirements are measured between live parts of opposite polarity and between live parts and grounded metal parts. *Figure 1* illustrates typical switchboard spacing requirements.

An isolated dead metal part, such as a screwhead or washer, interposed between uninsulated live parts of opposite polarity or between an uninsulated live part and grounded dead metal is considered to reduce the spacing by an amount equal to the dimension of the interposed part along the path of measurement.

Table 1 Switchboard Frame Heating Guidelines

Amperes	Minimum Distance from Phase Bus to Closest Steel Member	Minimum Distance from Neutral Bus to Closest Steel Member
3,000	4"	2"
4,000	6"	3"
5,000 and over	12"	see below
5,000 to 6,000	An aluminum or nonmagnetic material should be used in place of steel frame sections. Wherever possible, you must maintain 12" to steel members and 6" to aluminum or nonmagnetic members. Neutral spacing can be 6" and 3", respectively. If the main bus is tapered, it is permissible (at 4,000A and below) to use steel frames	
6,000 and over	You must use an aluminum or nonmagnetic material for frame sections and maintain 12" to steel members and 6" to aluminum or nonmagnetic members. Neutral spacing can be 6" and 3", respectively. The use of any steel frame members is discouraged. If the main bus is tapered, it is permissible (at 4,000A and below) to use steel frames for those sections containing the tapered bus.	

Note: For amperages above 8,000A, the neutral spacing must be 12" wherever possible.

VOLTAGE INVOLVED		MINIMUM SPACING BETWEEN LIVE PARTS OF OPPOSITE POLARITY		MINIMUM SPACING THROUGH AIR AND OVER SURFACE BETWEEN LIVE PARTS AND GROUNDED METAL PARTS
GREATER THAN	MAX.	THROUGH AIR	OVER SURFACE	BOTH THROUGH AIR AND OVER SURFACE
0	125	½"	¾"	½"
125	250	¾"	1¼"	½"
250	600	1"	2"	*1"

* A through air spacing of not less than ½" is acceptable (1) at a molded-case circuit breaker or a switch other than a snap switch, (2) between uninsulated live parts of a meter mounting or grounded dead metal, and (3) between grounded dead metal and the neutral of a 480Y/277V, three-phase, four-wire switchgear section.

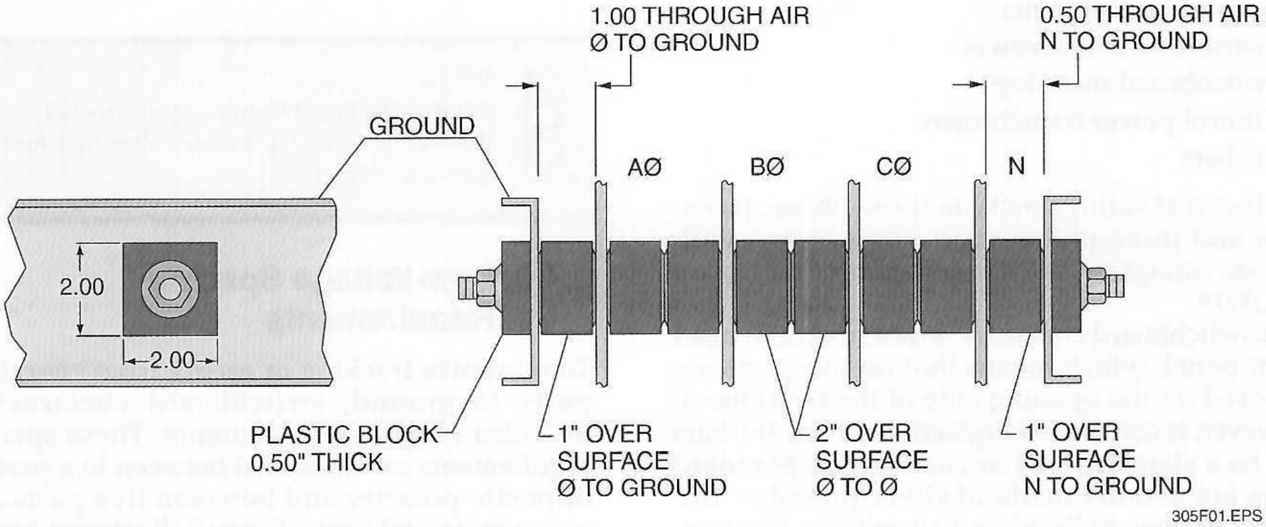
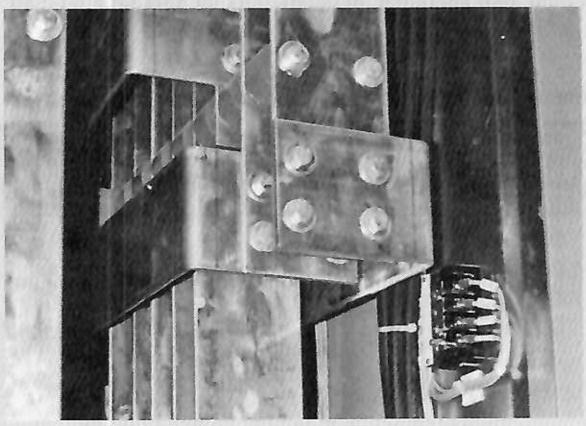


Figure 1 ◆ Typical busbar spacing requirements.

INSIDE TRACK

Bus Bracing

One characteristic of fault currents is an induced torque in conductors carrying the fault. Because of this torque, the busbars must be mounted in the enclosure in such a manner as to allow them to withstand the fault current that may be imposed. This is accomplished by the use of bracing as shown here. Larger available fault current values require more substantial bracing, and braces that are placed closer together. For example, bussed gutters may be manufactured with an AIC rating of 20,000 AIC, 30,000 AIC, or 200,000 AIC. Manufacturers typically have standard ratings to accommodate project requirements. The listing for bussed gutters must include the fault current rating.



When measuring over-surface spacing, any slot, groove, and the like that is 0.013" (0.33 mm) wide or less and in the contour of the insulating material is to be disregarded.

When measuring spacing, an air space of 0.013" or less between a live part and an insulating surface is to be disregarded, and the live part is to be considered in contact with the insulating material. A pressure wire connector shall be prevented from any turning motion that would result in less than the minimum acceptable spacings. The means used to ensure turn prevention must be reliable, such as a shoulder or boss. A lock washer alone is not acceptable.

A means of turn prevention need not be provided if spacings are not less than the following minimum accepted values:

- When the connector and any connector of opposite polarity have each been turned 30 degrees toward the other
- When the connector has been turned 30 degrees toward other live parts of opposite polarity and toward grounded dead metal parts

3.5.0 Cable Bracing

All construction using conductors and having a short circuit current rating greater than 50,000 rms symmetrical amperes requires a cable brace positioned as close to the supply lugs as possible. The cable brace is intended to be mounted in the same area that is allotted for wire bending. It is not necessary to provide additional mounting height to accommodate the cable brace.

The cable brace requirement does not apply to load-side cables, main breakers, or switches. It only applies when cables are connected directly to an unprotected line-side bus. The bus restrictions for a line-side bus are as follows:

- There can be no splice in edgewise bus mounting of 2,100A or less rated at 50,000 rms symmetrical amperes.
- There can be no splice in flatwise bus mounting of 600A or less rated over 50,000 rms symmetrical amperes.

NOTE

This splicing limitation does not apply to connections made from the through bus to a switch or circuit breaker.

The cable restrictions for a line-side bus include:

- Busing of 600A or less that is rated over 50,000 rms symmetrical amperes cannot use cables; it must be bus connected.
- If cabling is required, 800A minimum busing must be used.

Cable bracing requirements may be excluded if the busing can fully withstand the total available short circuit current.

4.0.0 ◆ SWITCHGEAR

NOTE

Some people in the industry use the terms *switchboard* and *switchgear* interchangeably. Technically, however, they are not exactly the same. Switchgear is manufactured and tested to more exacting standards and is configured differently than switchboards. For example, in switchgear there are physical barriers between breakers, and between the breakers and the bus. Switchgear is more durable and fault resistant, and is commonly selected for larger applications where low voltage power circuit breakers and selective coordination are applied. Examples are computer data centers, manufacturing plants, and process facilities, which are typically required to operate full-time.

Switchgear is a general term used to describe switching and interrupting devices and assemblies of those devices containing control, metering, protective, and regulatory equipment, along with the associated interconnections and supporting structures. Switchgear performs two basic functions:

- Provides a means of switching or disconnecting power system apparatus
- Provides power system protection by automatically isolating faulty components

Switchgear can be classified as:

- Metal-enclosed switchgear (low voltage)
- Metal-clad switchgear (low and medium voltage)
- Metal-enclosed interrupters
- Unit substations

Low-voltage and medium-voltage switchgear assemblies are enclosed on all sides and topped with sheet metal, except for ventilating openings and inspection windows. They contain primary power circuit switching or interrupting devices, buses, connections, and control and auxiliary devices. *Figure 2* shows typical low-voltage, metal-clad switchgear.

The station-type cubicle switchgear consists of indoor and outdoor types with power circuit breakers rated from 14.4kV to 34.5kV, 1,200A to 5,000A, and 1,500kVA to 2,500kVA interrupting **capacity**. Equipment can be special ordered and built at higher kVA ratings.

4.1.0 Switchgear Construction

Switchgear consists of a stationary structure that includes one or more freestanding units of uniform height that are mechanically and electrically joined to make a single coordinated installation. These units, commonly referred to as cubicles, contain circuit-interrupting devices such as circuit breakers.

Switchgear enclosures are formed from heavy-gauge sheet steel that has been welded or bolted together. Structural members across the top, sides, and bottom provide a rigid enclosure. Metal-clad switchgear enclosures are divided into three sections: the front section, the bus section, and the cable or termination section.

These three sections are physically separated from one another by metal partitions. This confines any damage that may occur to any one section and keeps it from affecting the other sections. It also separates power between the sections for ease and safety of maintenance.

The rigid enclosure provides the primary structural strength of the switchgear assembly and the means by which the switchgear is fastened to its foundation. The strength of the enclosure and its mounting system will vary depending on its intended use. For example, switchgear used in a nuclear application must meet certain seismic qualifications.

The enclosure also provides the required supports and mounts for items to be located in the switchgear and provides for the necessary interconnections between the switchgear and other plant systems. The number of sections and physical makeup of switchgear varies depending on the voltage and current ratings, project specifications, and manufacturer.

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Figure 2 ◆ Typical low-voltage, metal-clad switchgear.

Figures 3 and *4* show external and internal views, respectively, of medium-voltage, metal-clad switchgear. This equipment is available in voltages from 4.76kV to 27kV and current ranges from 1,200A through 3,000A.

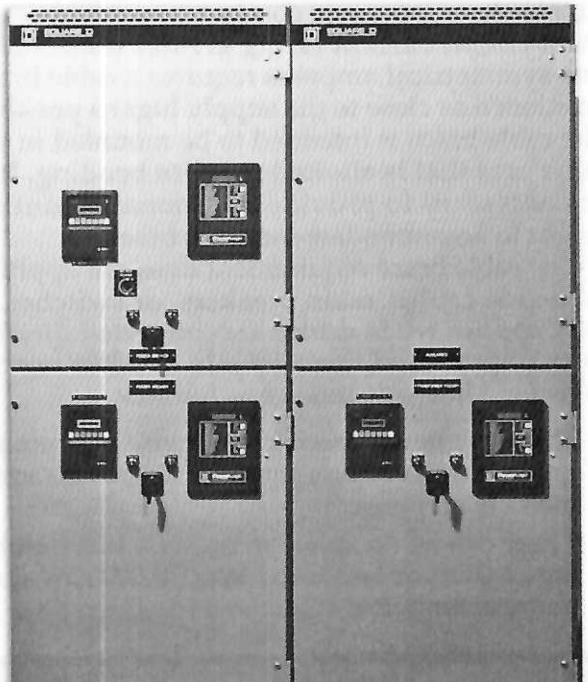

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Figure 3 ◆ Medium-voltage, metal-clad switchgear (exterior view).

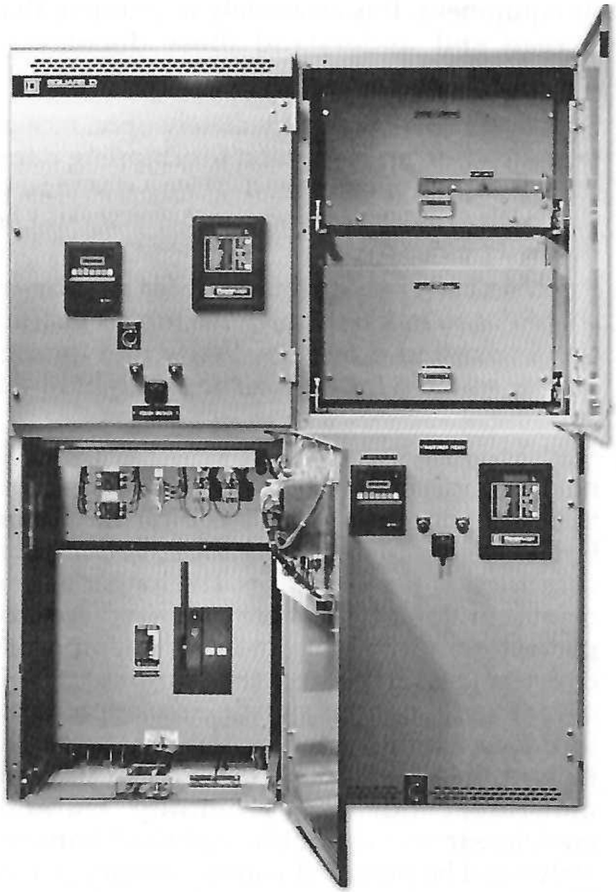

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Figure 4 ◆ Medium-voltage, metal-clad switchgear (interior view).

4.2.0 Control and Metering Safety Standards

Switchboard control and meter wiring standards must meet the requirements of *Machine Tool Wires and Cables Safety Standard UL 1063, Switchboard Safety Standard UL 891,* and *Service Equipment Safety Standard UL 869,* including the following highlights:

- Stranded copper conductor with thermoplastic insulation, UL and CSA approved
- Insulation thickness of 0.030" (1⁄32") for No. 16–No. 10 AWG size conductor
- 600V, 90°C minimum rating for dry locations; 60°C minimum rating when exposed to oil and moisture
- Conductors no smaller than No. 14 AWG for control wiring

4.3.0 Wiring System

The *NEC®* requires wiring to be supported mechanically to keep the wiring in place. Wire harnessing is generally used within the switchboard with the following restrictions:

- Each bundle or cable of wires must be run in a vertical or horizontal direction, securing the harness by means of plastic cable ties or cable clips.
- Plastic wire cable clamps shall be placed at strategic locations along the harnessing to hold the harness firmly in place to prevent interference with the control components' required electrical, mechanical, and arcing clearances.
- Apply wire ties to the harnessed wiring every 3" to 4" with self-adhesive cable ties spaced at every 12".
- Observe the following precautions when wiring the switchboard electrical components:
  - Keep control wires at least ½" from moving parts.
  - Avoid running wires across sharp metal edges. To protect the wiring from mechanical damage, use approved cable protectors, such as a nylon clip cable guard, a wire guard for edge protection, or special edge protection molding.
  - Wires must not touch exposed bare electrical parts of opposite polarity.
  - Wires must not interfere with the adjustment or replacement of components.
  - Wires should be as straight and as short as possible.
  - Wires shall not be spliced.
  - To eliminate possible strain on the control wire, a certain amount of slack should be given to the individual or harnessed conductor terminated at a component connection.
  - The equipment ground busbar shall not be used as a portion of the control or metering circuits.
  - Pliers may not be used to bend control wiring. Use your hands or an approved wire bending device.

4.3.1 Door-Mounted Wiring Restrictions

No incoming wiring connections may be made directly to the door-mounted devices. Wires from the door-mounted equipment to the panel terminal block should be a minimum of 19-strand wire.

Wires from the door must be neatly cabled so that the door can be opened easily without placing excessive strain on the wire terminal connections. In some cases, the cable must be separated into two bundles to accomplish this. Insulated sleeving, tubing, or vinyl tape must be used to bundle and protect the flexible wires.

4.3.2 Terminal Connections

All control or metering wiring entering or leaving the switchboard should terminate at terminal blocks, leaving one side of the terminal block free for the user's connections. No factory connections are allowed on a user's terminal connection point. For factory wiring, allow a maximum of two control wires on the same side of a terminal block. No more than three connections are allowed on terminals of control transformers, meters, meter selector switches, and metering equipment.

Since bolted pressure switches or any 100 percent current-rated, molded-case circuit breaker's line and load power terminals are allowed a higher maximum operating temperature than the recommended insulated conductor's operating temperature, the control wires cannot be placed directly on the 100 percent-rated disconnect device's line and load connections.

In all cases, control wires cannot touch any exposed part of opposite electrical polarity.

4.4.0 Metering Current and Potential Transformers

Ground connections on a **potential transformer (PT)** or **current transformer (CT)** secondary terminal must be connected to the ground bus. CT secondary terminals must be shorted if no metering equipment is connected to the current transformer.

PTs are required to have primary and secondary fusing. If protective circuits, such as ground fault or phase failure protective systems, are placed in the secondary circuit of the potential transformer, no secondary fusing is required.

Metering circuit connections made directly to the incoming bus must be provided with current-limiting fuses that are equal in rating to the available interrupting capacity.

> **NOTE**
>
> CTs and PTs will be discussed later.

4.5.0 Switchgear Handling, Storage, and Installation

The following is a basic guideline for the handling of switchgear. It is important to note that these recommendations only supplement the manufacturer's instructions. Manufacturers include instruction books and drawings with their equipment. It is absolutely imperative that you read and understand those documents before handling any equipment.

- *Switchgear handling* – Immediately upon receipt of switchgear, an inspection for shipping damage should be performed. If any damage is noted, the transportation company should be notified immediately.
- *Switchgear rigging* – Instructions for switchgear should be found in the manufacturer's instruction books and drawings. Verify that the rigging is suitable for the size and weight of the equipment.
- *Switchgear storage* – Indoor switchgear that is not being installed right away should be stored in a clean, dry location. The equipment should be level and protected from the environment if construction is proceeding. The longer equipment is in storage, the more care is required for protection of the equipment. If a temporary cover is used to protect the equipment, this cover should not prevent air circulation. If the building is not heated or temperature controlled, heaters should be used to prevent moisture/condensation buildup. Outdoor switchgear that cannot be installed immediately must be provided with temporary power. This power will allow operation of the space heaters provided with the equipment.
- *Bus connections* – The main bus that is usually removed during shipping should be reconnected. Ensure that the contact surfaces are clean and pressure is applied in the correct manner. The conductivity of the joints is dependent on the applied pressure at the contact points. The manufacturer's torque instructions should be referenced.
- *Cable connections* – When making cable connections, verify the phasing of each cable. This procedure is done in accordance with the connection diagrams and the cable tags. When forming and mounting cables, ensure that the cables are tightened per the manufacturer's instructions.
- *Grounding* – Any sections of ground bus that were previously disconnected for shipping should be reconnected when the units are installed. In addition, the system must be bonded at this time. The ground bus should be connected to the system ground with as direct a connection as possible. If the system ground is to be run in metal conduit, bonding to the conduit is required. The ground connection is necessary for all switchgear and should be sized per the *NEC®*.

5.0.0 ◆ TESTING AND MAINTENANCE

This section covers general testing and maintenance procedures.

WARNING!

When working on switchgear or any piece of electrical equipment, you must always be aware of and follow all applicable safety procedures. You must also understand the construction and operation of the equipment. You must be specifically trained and qualified to work on or near energized electrical circuits and equipment. National consensus standards such as *NFPA 70E* and *70B* provide specific guidance for achieving an electrically safe work condition. *NFPA 70E, Standard for Electrical Safety in the Workplace, Article 120*, provides a step-by-step procedure for achieving an electrically safe work condition. Chapter 7 in *NFPA 70B, Recommended Practice for Electrical Equipment Maintenance*, provides personnel safety for qualified electrical workers, while other chapters provide specific direction for maintenance and troubleshooting of various types of equipment.

NOTE

Test values will differ depending on whether you are performing an acceptance test or a maintenance test.

5.1.0 General Maintenance Guidelines

To perform a visual inspection:

Step 1 Check the exterior for the proper fit of doors and covers, paint, etc.

Step 2 Check the interior, particularly the current-carrying parts, including:

- Inspect the busbars for dirt, corrosion, and/or overheating.
- If necessary, perform an infrared or thermographic test. Note any discoloration that would represent a poor bus joint.
- Check the busbar supports for cracks.
- Check for correct electrical spacing.
- Verify the integrity of all bolted connections.

To clean the switchboard:

Step 1 Vacuum the interior (do not use compressed air).

Step 2 Wipe down the interior using a clean, lint-free cloth. Use nonconductive, nonresidue solution, such as contact cleaner or denatured alcohol.

To check equipment operation:

Step 1 Manually open and close circuit breakers and switches.

Step 2 Electrically operate all components, such as ground fault detectors, sure trip metering, current transformers, test blocks, ground lights, blown main fuse detectors, and phase failure detectors.

To perform a megger test:

Step 1 Isolate the bus by opening all circuit breakers and switches.

Step 2 Disconnect any devices, such as relays and transformers, that may be connected to the busbars.

Step 3 Make sure all personnel are clear of the switchboard.

Step 4 Use a 1,000V megger to check the phase-to-phase and phase-to-ground resistance. Megger readings should reflect the values listed in the equipment manufacturer's instructions. Typical values are shown in *Table 2*.

Table 2 Typical Insulation Resistance Tests on Electrical Apparatus and Systems at 68°F

Minimum Voltage Rating of Equipment	Minimum Test Voltage (VDC)	Recommended Minimum Insulation Resistance (in Megohms)
2–250V	500	50
251–600V	1,000	100
601–5,000V	2,500	1,000
5,001–15,000V	2,500	5,000
15,001–39,000V	5,000	20,000

INSIDE TRACK

Protective Grounding

Even after a circuit has been isolated, de-energized, locked out, and verified without voltage, it still may not be safe to work on. This is because there is still a possibility that a circuit or conductor may be inadvertently re-energized through any one of the following means:

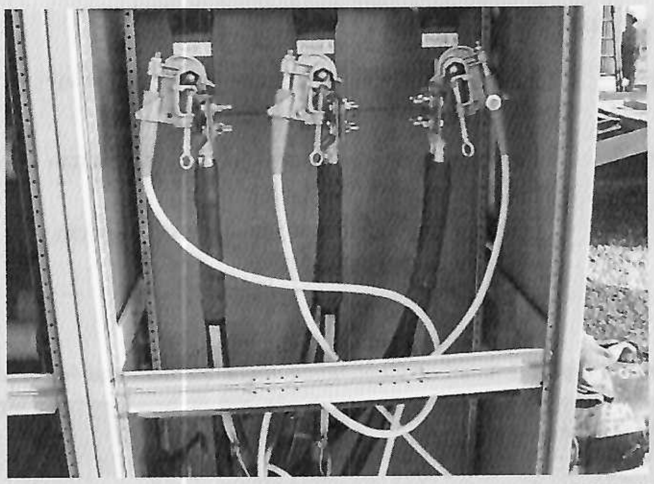
- Induced voltages from other energized conductors
- Static buildup from wind on outdoor conductors
- High voltage from lightning strikes
- Any condition that might bring an energized conductor into contact with the de-energized circuit
- Switching errors causing re-energizing of the circuit
- Capacitive charges in equipment or conductors

When any of these conditions are possible, *NFPA 70B, Recommended Practice for Electrical Equipment Maintenance,* requires that temporary grounds be applied before the circuit or equipment is considered safe. In fact, standard practice in overhead line construction and within open substations is that any conductor without a temporary ground connection is considered energized. While the terms *temporary ground*, *safety ground*, and *protective ground* are often used interchangeably, temporary grounds cover both personal protective grounds and static grounds. Personal protective grounds consist of cable connected to de-energized lines and equipment by jumpering and bonding with appropriate clamps, to limit the voltage difference between accessible points at a work site to safe values if the lines or equipment are accidentally re-energized. Protective grounds are sized to carry the maximum available fault current at the work site for the expected fault duration. Static grounds include any grounding cable or bonding jumper (including clamps) that has an ampacity less than the maximum available fault current at the work site, or is smaller than No. 2 AWG copper equivalent. Static grounds are used for potential equalizing between conductive parts in grounding configurations that cannot subject them to significant current. Therefore, smaller wire that provides adequate mechanical strength is sufficient (e.g., No. 12 AWG).

Low-voltage equipment with only a single source of supply usually does not require temporary grounding for safety. Low-voltage equipment with dual supply and medium-voltage equipment should be grounded at the bus.

ASTM International Standard F855-04, Temporary Protective Grounds to be used on De-energized Electric Power Lines and Equipment, is the national consensus standard covering the equipment making up the temporary grounding system. This standard addresses the parts of a temporary grounding system, which include the clamps, ferrules, cables, or a complete protective ground assembly of clamps, ferrules, and cables. These components work together and must be capable of conducting the maximum available fault current that could occur at a work location if lines or equipment become re-energized from any source, and for the expected duration of the fault. Because the circuit is NOT safe until grounding is applied, placing and removing temporary grounds is considered work on live parts, and appropriate PPE and safe work practices must be followed.

This picture shows a temporary protective ground cluster on incoming medium-voltage feeders at equipment. Not shown is the connection to the permanent system and feeder grounding conductors. This arrangement will provide safety for the connected equipment bus. Notice the phase arrangement is from left to right at the front of the equipment (the back of the equipment is shown here).



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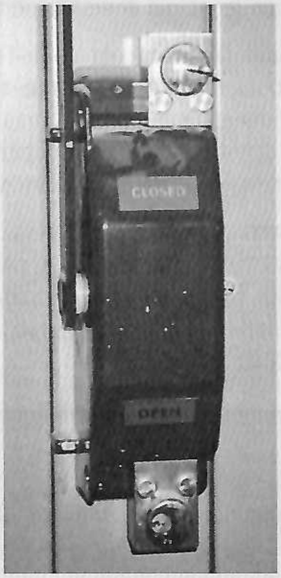
INSIDE TRACK

Keyed Interlocks

Keyed interlocks, such as the one shown here, ensure that qualified personnel perform operations in the required sequence by preventing or allowing the operation of one part only when another part is locked in a predetermined position. These devices can be used for a variety of safety applications, such as preventing personnel from accessing a high-voltage compartment before opening the disconnect switch.



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5.2.0 Test Guidelines

This section provides typical guidelines for performing various tests on distribution equipment.

5.2.1 Thermographic Survey

A thermographic survey involves checking switches, busways, open buses, switchgear, cable and bus connections, circuit breakers, rotating equipment, and load tap changers. *Figure 5* shows an infrared image used for thermographic surveys.

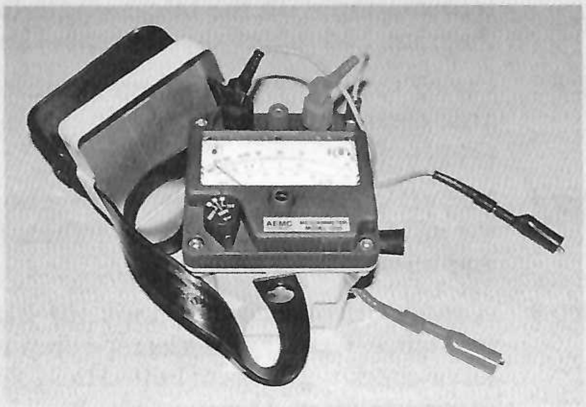
WARNING!

This test is performed while the equipment is energized and the covers are removed. This test may only be performed by qualified personnel under the appropriate safe work plan or permit.

INSIDE TRACK

Meggers

To test for potential insulation breakdown, phase-to-phase shorts, or phase-to-ground shorts in switchgear, you need to apply a much higher potential than that supplied by the battery of an ohmmeter. A megohmmeter, or megger, is commonly used for these tests. The megger is a portable instrument consisting of a hand-driven DC generator, which supplies the level of voltage for making the measurement, and the instrument portion, which indicates the value of the resistance being measured.



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Infrared surveys should be performed during periods of maximum possible loading and not at less than 40 percent of the rated load of the electrical equipment being inspected. Negative test results include:

- Temperature gradients of 1°C to 3°C indicate a possible deficiency and require investigation.
- Temperature gradients of 4°C to 15°C indicate a deficiency. Repair as time permits.
- Temperature gradients of 16°C and above indicate a major deficiency. Secure power and repair as soon as possible.

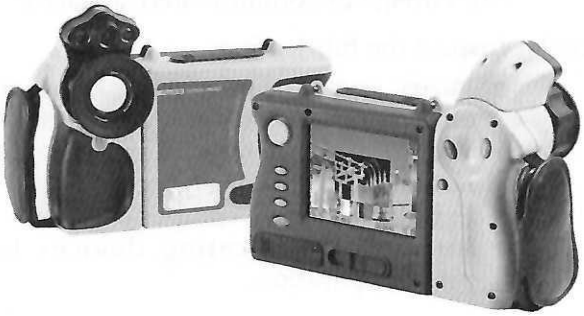

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Figure 5 ◆ Infrared imager used in thermographic surveys.

5.2.2 Metal-Enclosed Switchgear and Switchboards

WARNING!
You must be certified and authorized to perform these tests; care should be taken to ensure that there is no voltage present.

To perform a visual and mechanical inspection:

Step 1 Inspect the physical, electrical, and mechanical condition of the equipment.

Step 2 Compare the equipment nameplate information with the latest single-line diagram, and report any discrepancies.

Step 3 Check for proper anchorage, required area clearances, physical damage, and proper alignment.

Step 4 Inspect all doors, panels, and sections for missing paint, dents, scratches, fit, and missing hardware.

Step 5 Inspect all bus connections for high resistance. Use a low-resistance ohmmeter or check tightness of bolted bus joints using a calibrated torque wrench.

Step 6 Test all electrical and mechanical interlock systems for proper operation and sequencing:
- A closure attempt must be made on all locked-open devices. An opening attempt must be made on all locked-closed devices.
- A key exchange must be made with all devices operated in normally off positions.

Step 7 Clean the entire switchgear using the manufacturer's approved methods and materials.

Step 8 Inspect insulators for evidence of physical damage or contaminated surfaces.

Step 9 Inspect the lubrication:
- Verify appropriate contact lubricant on moving current-carrying parts.
- Verify appropriate lubrication of moving and sliding surfaces.
- Exercise all active components.
- Inspect all indicating devices for proper operation.

WARNING!
Electrical testing may produce hazardous voltages and therefore may only be performed by qualified personnel under the appropriate safe work plan or permit. Prepare the area to avoid any accidental contact with the system under test, and wear appropriate personal protective equipment.

To perform electrical testing:

Step 1 Perform ratio and polarity tests on all current and voltage transformers.

Step 2 Perform ground resistance tests.

Step 3 Perform insulation resistance tests on each bus section (phase-to-phase and phase-to-ground) for one minute. Refer to the specific manufacturer's guidelines, an example of which is shown in *Table 2.*

Step 4 Perform an overpotential test on each bus section (phase-to-ground) for one minute. Refer to specific manufacturer's guidelines, an example of which is shown in *Table 3.*

NOTE
The values shown in *Tables 2* and *3* are typical acceptance values. Maintenance values will vary by manufacturer.

Step 5 Perform an insulation resistance test on the control wiring. Do not perform this test on wiring connected to solid-state components.

Step 6 Perform a phasing check on double-ended switchgear to ensure proper bus phasing from each source.

Table 3 Overpotential DC Test Voltages for Electrical Apparatus Other Than Inductive Equipment

	DC Test Voltage Max.	
Nominal Voltage Class	**New**	**Used**
250V	2,500VDC	1,500VDC
600V	3,500VDC	2,000VDC
5,000V	18,000VDC	11,000VDC
15,000V	50,000VDC	30,000VDC

Any values of insulation resistance less than those listed in the manufacturer's literature should be investigated. Overpotential tests should not proceed until insulation resistance levels are raised above minimum values.

Overpotential test voltages must be applied in accordance with the manufacturer's literature. Test results are evaluated on a go/no-go basis by slowly raising the test voltage to the required value. The final test voltage is applied for one minute.

5.2.3 Low-Voltage Cables (600V Maximum)

To perform a visual and mechanical inspection:

Step 1 Inspect cables for physical damage and proper connection in accordance with the single-line diagram.

Step 2 Verify the integrity of all bolted connections.

Step 3 Check color-coded cable against the applicable engineer's specifications and *NEC*® standards.

To perform electrical testing:

Step 1 Perform an insulation resistance test on each conductor with respect to ground and adjacent conductors. The applied potential should be 1,000VDC for one minute.

Step 2 Perform a continuity test to ensure proper cable connection. The minimum insulation resistance values must not be less than two megohms.

5.2.4 Medium-Voltage Cables (15kV Maximum)

To perform a visual and mechanical inspection:

Step 1 Inspect exposed sections for physical damage.

Step 2 Inspect for shield grounding, cable support, and termination.

Step 3 Inspect for proper fireproofing in common cable areas.

Step 4 If cables are terminated through window-type CTs, make an inspection to verify that neutrals and grounds are properly terminated for normal operation of the protective devices.

INSIDE TRACK

Manufacturer's Data

Never assume anything when it comes to equipment operation, testing, or maintenance. Always refer to the manufacturer's installation, operating, and maintenance instructions for the equipment in use. These materials provide important data that explain the warranty requirements, appropriate test procedures, and specific maintenance and test points.

Step 5 Visually inspect the jacket and insulation condition.

Step 6 Inspect for proper phase identification and arrangement.

5.2.5 Metal-Enclosed Busways

To perform a visual and mechanical inspection:

Step 1 Inspect the bus for physical damage.

Step 2 Inspect for proper bracing, suspension, alignment, and enclosure.

Step 3 Check the tightness of bolted joints using a calibrated torque wrench.

Step 4 Check for proper physical orientation per the manufacturer's labels to ensure proper cooling. Perform continuity tests on each conductor to verify that proper phase relationships exist.

Step 5 Check outdoor busways for removal of weep-hole plugs if applicable and also for the proper installation of a joint shield.

To perform electrical testing:

Step 1 Perform an insulation resistance test. Measure the insulation resistance on each bus run (phase-to-phase and phase-to-ground) for one minute.

Step 2 Perform AC or DC overpotential tests on each bus run, both phase-to-phase and phase-to-ground.

Step 3 Perform a contact resistance test on each connection point of the uninsulated bus. On an insulated bus, measure the resistance of the bus section and compare values with adjacent phases.

NOTE
Insulation resistance test voltages and resistance values must be in accordance with the manufacturer's specifications.

Step 4 Apply overpotential test voltages in accordance with the manufacturer's specifications.

5.2.6 Metering and Instrumentation

To perform a visual and mechanical inspection:

Step 1 Examine all devices for broken parts, indication of shipping damage, and wire connection tightness.

Step 2 Verify that meter connections are in accordance with appropriate diagrams.

To perform electrical testing:

Step 1 Check the calibration of meters at all cardinal points.

Step 2 Calibrate watt-hour meters to one-half of one percent (0.5 percent).

Step 3 Verify all instrument multipliers.

6.0.0 ◆ *NEC®* REQUIREMENTS FOR SWITCHBOARDS

This section is designed to provide a brief description of the *NEC®* articles that are applicable to switchboard construction, installation, and accessories.

6.1.0 Requirements for Electrical Installations

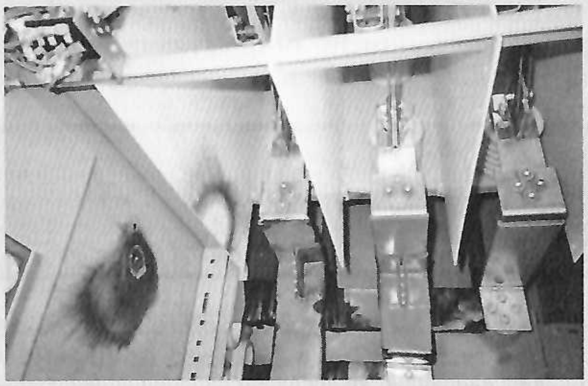
NEC® requirements for electrical installations include the following:

- *Interrupting rating* – The interrupting rating is the maximum current a device is intended to interrupt under standard test conditions. ***NEC Section 110.9*** defines the equipment interrupting rating as sufficient to interrupt the current that is available at the line-side terminals of the equipment.
- *Deteriorating agents* – ***NEC Section 110.11*** provides for the protection of equipment and conductors from environments that could cause deterioration, such as gases, vapors, liquids, or moisture, unless specifically designed for such environments.
- *Mechanical execution of work* – ***NEC Section 110.12*** states that electrical equipment is to be installed in a neat and professional manner. Any openings provided by the equipment manufacturer or unused at the time of installation must be sealed equivalent to the structure wall. This section also forbids the use of electrical equipment with damaged parts that may affect the safe operation or mechanical strength of the equipment.
- *Mounting and cooling* – ***NEC Section 110.13*** states that electrical equipment shall be securely fastened to its mounting surface by mechanical fasteners, excluding wooden plugs driven into concrete, masonry, plaster, or similar materials. Equipment shall be located so as not to restrict airflow required for convection or forced-air cooling.
- *Electrical connections* – Due to the resistive oxidation created when dissimilar metals are connected, splicing devices and pressure connectors must be identified for the conductor material with which they are to be used *(**NEC Section 110.14**)*. Dissimilar metal conductors may not be mixed in terminations or splices. Antioxidation compounds must be suitable for use and must not adversely affect conductors, installation, or equipment. Terminals for use with more than one conductor or aluminum must be identified as such.
- *Markings* – The manufacturer's trademark or logo and system ratings, including voltage, current, and wattage, must be permanently attached to the equipment *(**NEC Section 110.21**)*. Whether a service is single-phase or three-phase, overhead or underground, ***NEC Article 230, Part VI*** requires that a means be provided to disconnect all conductors in a building from the service-entrance conductors. The service disconnecting means must be in a readily accessible location, marked as a service disconnect, and listed as suitable for use as a service disconnecting means. The service disconnect can be a fusible switch or a circuit breaker and is typically located at the point where the service-entrance conductors come into the building or structure. In some cases, the utility company requires cold sequence metering, in which the service disconnect is installed ahead of the electric meter. Cold sequence metering provides the utility company the opportunity to work on the metering equipment with the power disconnected.

How *Not* to Build a Better Mousetrap

The expensive switchgear shown here had an unused opening that was left uncovered after the installation. A rodent entered the compartment, shorting out one of the busbars and causing extensive damage.

The Bottom Line: ***NEC Section 110.12(A)*** requires that any unused openings must be sealed equivalent to the structure wall.



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- *Disconnect identification* – Each disconnecting means, such as circuit breakers, fused switches, **feeders**, and unfused disconnects, must be clearly marked as to its purpose at its point of origin unless located in such a manner that its purpose is evident *(**NEC Section 110.22**)*.
- *Working space* – Suitable access and working space must be maintained around electrical equipment to permit safe operation and maintenance *(**NEC Section 110.26**)*. Minimum clearances in front of all electrical enclosures must conform to those specified in ***NEC Section 110.26***; in all cases, space must be adequate to allow doors or hinged parts to open to a 90-degree angle. In differing conditions, the distances in ***NEC Table 110.26(A)(1)*** must be adhered to. Storage of any kind is not permitted within the clearance area. In accordance with ***NEC Section 110.26(C)(1)***, at least one entrance of ample size must be provided to enter and exit the work area. Two entrances are required for services over 1,200A and over 6' wide. The work space must be adequately illuminated.
- *Flash protection* – ***NEC Section 110.16*** states that electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers in other-than-dwelling occupancies that are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

6.2.0 Requirements for Conductors

NEC Section 200.6 covers requirements associated with identifying grounded conductors. It includes the following:

- *Neutrals* – Grounded conductors (neutrals) size No. 6 AWG and smaller are color coded with a solid white or gray marking for the entire length of the conductor. Conductors size No. 6 and larger may be color coded with a solid white marking tape at termination points at the time of installation. Where different electrical systems are run together, each system's grounded conductor must be distinctively identified *[**NEC Section 200.6(D)**]*.
- *Protection* – Branch circuit conductors must be protected by overcurrent devices, as specified in ***NEC Section 240.4***.
- *Loading* – ***NEC Section 210.19(A)*** states that protective device calculations for continuous-duty circuits are calculated at 125 percent of the continuous load. This equates to an 80 percent loading factor on the branch circuit.
- *Tap rules* – Tap conductors are conductors that are tapped onto the line-side bus of the switchboard to feed control circuits, control power transformers, and metering devices. Overcurrent devices (typically fuses) are connected where the conductor to be protected receives its supply. Per ***NEC Section 240.21***, tap conductors do not require protection if the following conditions are met:
  - The length of the conductor is not over 10'.
  - The ampacity of the conductor is not less than the combined loads supplied by the conductor.
  - The conductors do not extend beyond the switchboard.
  - The conductors are enclosed in a raceway except at the point of connection to the bus.

  - For field installations where the tap conductors leave the enclosure or vault in which the tap is made, the rating of the overcurrent device on the line side of the tap conductors does not exceed 10 times the tap conductor's ampacity.
- *Markings* – All conductors and cables must be permanently marked to indicate the manufacturer, voltage, AWG size, and insulation type *(**NEC Section 310.11**)*.
  - Grounded conductors (neutrals) size No. 6 and smaller shall have a continuous marking of white or gray for the entire length of the conductor. Larger conductors may be marked at each termination with white marking tape.
  - Grounding conductors (equipment grounding wires) shall be permitted to be bare wire. In cases of insulated grounding conductors, the conductor will have a continuous marking of green for the entire length of the conductor. Larger conductors may be marked at each end and every point where the conductor is accessible.
  - Ungrounded conductors (phase wires) must be distinguishable from grounded or grounding conductors with colors other than white, gray, or green. Typical ungrounded conductor identification colors are black, red, blue, brown, orange, and yellow. Conductors size No. 6 or smaller must have a continuous marking. Larger cables may be marked at each termination.
  - In switchboards fed by a four-wire delta system in which one phase is grounded at its midpoint, the phase with the higher voltage must be marked with an orange color according to ***NEC Section 110.15***.
- *Ampacities* – The ampacities of cable are determined by the tables referenced in ***NEC Section 310.15(B)*** or with engineering support per ***NEC Section 310.15(C)***.

6.3.0 Grounding

NEC® grounding requirements include the following:

- *Grounding* – ***NEC Section 250.20(B)*** states that AC systems between 50V and 1,000V must be grounded when any of the following conditions are met:
  - Where the system can be grounded in such a way that the maximum phase-to-ground voltage does not exceed 150V
  - When the system is three-phase, four-wire, wye-connected and the neutral is used as a circuit conductor
  - When the system is three-phase, four-wire, delta-connected and the midpoint of a phase is used as a conductor (developed neutral)
- *Grounding electrode conductor* – ***NEC Sections 250.24 and 250.66*** cover the requirements of grounding electrode conductors, including proper sizing of the equipment grounding conductors to the service equipment enclosures. ***NEC Section 250.24*** states that for grounded systems (delta or wye), an unspliced main bonding jumper in the service equipment must be used to connect the grounding conductor and the service disconnect enclosure to the grounded conductor of the system within the enclosure.

CAUTION

Some systems are ungrounded and will not blow fuses.

- *Electrodes* – ***NEC Sections 250.52, 250.53, and 250.56*** require that when rod or pipe electrodes are used, they must extend a minimum of 8' into the soil. The electrode must be no less than ¾" in diameter for pipe and ⅝" in diameter for rods. It must be galvanized metal or copper-coated to resist corrosion. Underground structures, such as water piping systems, may also be used as an electrode. Underground gas piping systems must not be used. Aluminum electrodes are not permitted. Rod, pipe, or plate electrodes must maintain a resistance of no more than 25Ω to ground. If the resistance is above 25Ω, an additional electrode is required to maintain the minimum resistance.
- *Grounding of ground wire conduits* – ***NEC Section 250.64(E)*** states that a grounding conductor or its enclosure must be securely mounted to the surface along which it runs. In cases where the conductor is enclosed, the enclosure must be electrically continuous and firmly grounded.
- *Ground connection surfaces* – Nonconducting coatings, such as paint, enamel, and insulating materials, must be thoroughly removed at any point where a grounding connection is made *(**NEC Section 250.12**)*.

6.4.0 Switchboards and Panelboards

NEC® requirements for switchboards and panelboards include the following:

- *Dedicated space* – ***NEC Section 110.26(F)*** states that panelboards and switchboards may only be installed in spaces specifically designed for such purposes. No other piping, ducts, or devices may be installed or pass through such areas, except equipment that is necessary to the operation of the electrical equipment.
- *Inductive heating* – ***NEC Section 408.3(B)*** states that busbars and conductors must be arranged so as to avoid overheating due to inductive forces.
- *Phasing* – ***NEC Section 408.3(E)*** states that phasing in switchboards must be arranged A, B, C from front to back, top to bottom, and left to right, respectively, when facing the front of the switchboard. In systems containing a high leg, the B phase must be the phase conductor having a higher voltage to ground.
- *Wire bending space* – ***NEC Section 408.3(G)*** states that the wire bending space must be in accordance with ***NEC Table 312.6***.
- *Minimum spacing* – ***NEC Section 408.56*** states that the spacing between bare metal parts and conductors must be as specified in ***NEC Table 408.56***. Conductors entering the bottom of switchboards must have the clearances specified in ***NEC Table 408.5***.
- *Conductor insulation* – Insulated conductors within switchboards must be listed as flame-retardant and rated at not less than the voltage applied to them or any adjacent conductors they may come in contact with *(**NEC Section 408.19**)*.

7.0.0 ◆ GROUND FAULTS

Ground faults exist when an unintended current path is established between an ungrounded conductor and ground on a solidly grounded service. These faults can occur due to deteriorated insulation, moisture, dirt, rodents, foreign objects, such as tools, and careless installation.

Ground faults are usually high arcing and low level in nature, which conventional breakers will not detect. Ground fault protection is used to protect equipment and cables against these low-level faults.

Ground fault protection is required per the *NEC®* on solidly grounded wye services of more than 150V to ground but not exceeding a phase-to-phase voltage of 600V with each service disconnecting means of 1,000A or more.

7.1.0 Ground Fault Systems

The three basic methods of sensing ground faults include the following:

- Ground-return method
- Residual method
- Zero sequence method

The ground-return method incorporates a sensing coil around the grounding electrode conductor. The residual method uses three individual sensing coils to monitor the current on each phase conductor. The zero sequence method requires a single, specially designed sensor to monitor all the phases and the neutral conductor of a system at the same time, as shown in *Figure 6*.

7.2.0 Sensing Operation

When circuit conditions are normal, the currents from all the phase and neutral (if used) conductors add up to zero, and the sensor current transformer produces no signal. When any ground fault occurs, the currents add up to equal the ground fault current, and the sensor produces a signal proportional to the ground fault. This signal provides power to the ground fault relay, which trips the circuit breaker.

A ground fault lasting for less than the time-delay period will not pick up the ground trip coil, thus eliminating nuisance tripping of self-clearing faults.

The ground fault relay is a high-reliability device due to its solid-state construction. The use of redundant, self-protecting, and high-reliability components further improves the performance. Self-protection against failure is provided through

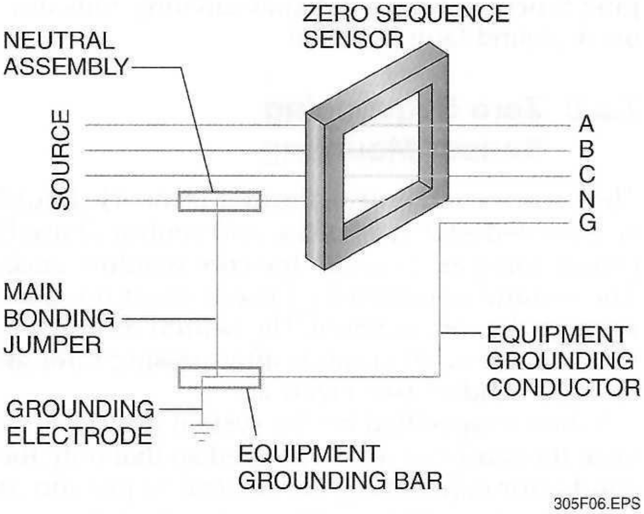

Figure 6 ◆ Zero sequencing diagram.

INSIDE TRACK

Transformer Grounding

This is the secondary termination compartment of a 2.5MVA padmount transformer that shows the connection and arrangement of parallel feeders serving downstream 480V switchgear. This is a solidly grounded wye transformer.

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an internal fuse that will blow and result in a tripping function if the solid-state circuitry fails during a ground fault situation.

7.3.0 Zero Sequencing Sensor Mounting

The sensor current transformer (sensor) should be mounted so that all phase and neutral (if used) conductors pass through the core window once. The ground conductor (if used) must not pass through the core window. The neutral conductors must be free of all grounds after passing through the core window (see *Figure 6*).

When so specified by the system design engineer, the sensor may be mounted so that only the conductor connecting the neutral to ground at the service equipment passes through the core window. In such cases, the sensor must provide power to the particular ground fault relay that is associated with the main circuit breaker.

Maintain at least two inches of clearance from the iron core of the sensor to the nearest busbar or cable to avoid false tripping. Cable conductors should be bundled securely and braced to hold them at the center of the core window. The sensor should be mounted within an enclosure and protected from mechanical damage.

7.4.0 Relay Mounting

The ground fault relay should be mounted in a vertical position within an enclosure, with the terminal block at the lower end. The location of the relay should be such that the trip setting knob is accessible without exposing the operator to contact with live parts or arcing from disconnect operations.

7.5.0 Connections

Connections for standard applications should be made in accordance with the wiring diagrams in the manufacturer's literature. An example of one circuit is shown in *Figure 7*. Wires from the sensor to the ground fault relay should be no longer than 25' and no smaller than No. 14 AWG wire. Wires from the ground fault relay to the trip coil should be no longer than 50' and no smaller than No. 14 AWG wire. All wires should be protected from arcing fault and physical damage by barriers, conduit, armor, or location in an equipment enclosure. Do not disconnect or short circuit wires to the circuit breaker trip coil at any time when the power is turned on.

7.6.0 Relay Settings

The ground fault relay has an adjustable trip setting. The amount of time delay is factory set and is available in nominal time delays of 0.1, 0.2, 0.3, and 0.5 second. When ground fault protection is used in downstream steps, the feeder should have the next lower time-delay curve from the main, the branch the next lower curve from the feeder, and so on.

High trip settings on main and feeder circuits are desirable to avoid nuisance tripping. High settings usually do not reduce the effectiveness of the protection if the ground path impedance is reasonably low. Ground faults usually quickly reach a value of 40 percent or more of the available short circuit current in the ground path circuit.

7.6.1 Coordination with Downstream Circuit Breakers

It is recommended that the magnetic trips of any downstream circuit breakers that are not equipped with ground fault protection be set as low as possible. Likewise, the ground fault relay trip settings for main or feeder circuits should be higher than the magnetic trip settings for unprotected downstream breakers where possible. This will minimize nuisance tripping of the main or feeder breaker for ground faults occurring on downstream circuits.

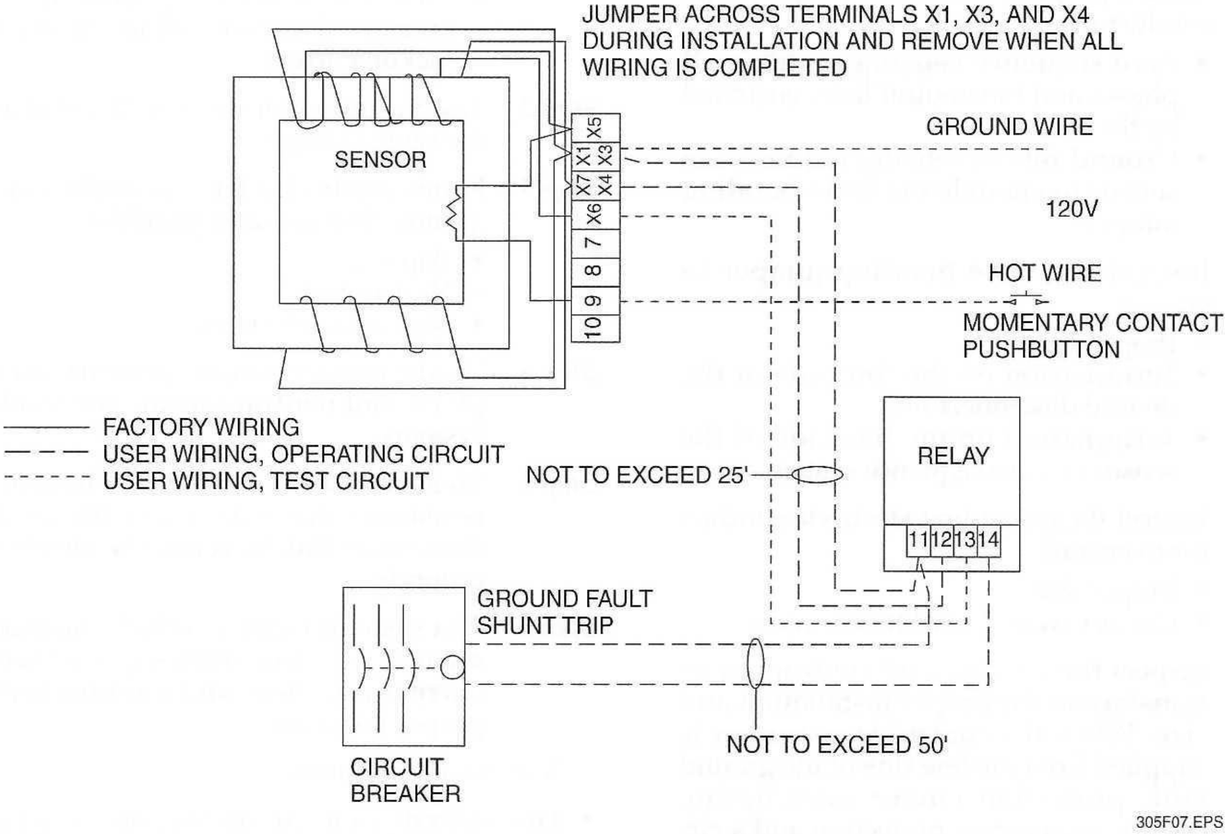

Figure 7 ◆ Typical wiring diagram.

7.6.2 *Instantaneous Trip Feature*

Standard ground-powered ground fault relays have a built-in instantaneous trip feature. This instantaneous trip has a fixed time delay of approximately 1½ cycles, and the fixed trip setting is higher than that found on most feeder or branch breakers to avoid nuisance tripping. Its purpose is to interrupt very high-current ground faults on main disconnects as quickly as possible and to protect the ground fault relay components.

7.7.0 Ground Fault System Test

This section provides an overview of a generic visual inspection and electrical test for ground faults. Always follow the procedures specified by the equipment manufacturer for the system being tested.

7.7.1 *Procedures*

Start by performing a visual inspection:

Step 1 Inspect the components for physical damage.

Step 2 Determine if a ground sensor was located properly around the appropriate conductor(s):

- Zero sequence sensing requires all phases and the neutral to be encircled by the sensor(s).
- Ground return sensing requires the sensor to encircle the main bonding jumper.

Step 3 Inspect the main bonding jumper to ensure:

- Proper size
- Termination on the line side of the neutral disconnect link
- Termination on the line side of the sensor on zero sequence systems

Step 4 Inspect the grounding electrode conductor to ensure:

- Proper size
- Correct switchboard termination

Step 5 Inspect the ground fault control power transformer for proper installation and size. When the control transformer is supplied from the line side of the ground fault protection circuit interrupting device, overcurrent protection and a circuit disconnecting means must be provided.

INSIDE TRACK

Ground Fault Trip Settings

Even minor ground faults will usually arc, causing immediate damage. Major damage can occur in a matter of a second. Ideally, the ground fault relay should respond in less than 30 cycles (½ second in a 60Hz system).

Step 6 Visually inspect the switchboard neutral bus downstream of the neutral disconnect line to verify the absence of ground connections.

Perform electrical tests as required by *NEC Section 230.95(C)*:

Step 1 Check for proper ground fault system performance, including correct response of the circuit interrupting device confirmed by primary/secondary ground sensor current injection:

- Measure the relay pickup current.
- Ensure that the relay time delay is measured at two values above the pickup current.

Step 2 Test system operation at 57 percent of the rated voltage.

Step 3 Functionally check the operation of the ground fault monitor panel for:

- Trip test
- No-trip test
- Nonautomatic reset

Step 4 Verify proper sensor polarity on the phase and neutral sensors for residual systems.

Step 5 Measure the system neutral insulation resistance downstream of the neutral disconnect link to verify the absence of grounds.

Step 6 Test systems (zone interlock/time coordinates) by simultaneous ground sensor current injection, and monitor for the proper response.

Test result evaluation:

- The system neutral insulation resistance should be above 100Ω and preferably one megohm or greater.

- The maximum pickup setting of the ground fault protection must be 1,200A and the maximum time delay must be one second for ground fault currents equal to or greater than 3,000A, according to ***NEC Section 230.95(A)***.
- The relay pickup current should be within 10 percent of the manufacturer's calibration marks or fixed setting.
- The relay timing should be in accordance with the manufacturer's published time-current characteristics.

8.0.0 ◆ HVL SWITCHES

Figure 8 shows the general appearance of an HVL (high-voltage limiting) switch. The HVL switch is a switching device for primary circuits up to the full interrupting current of the switch. The switches are single-throw devices designed for use on 2.4kV to 34.5kV systems.

HVL switches may provide both switching and overcurrent protection. HVL switches are commonly used as service disconnects in unit substations and for sectionalizing medium-voltage feeder systems. The HVL switch is designed to conform to ANSI standards for metal-enclosed switchgear.

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Figure 8 ◆ High-voltage limiting switch.

8.1.0 Ratings

Switch ratings are as follows:

- *Switch kV* – The design voltage for the switch. Of course, nominal system voltage is the normal application method; thus, a 5kV switch may be used for nominal system voltages of 2.4kV or 4.16kV, etc.
- ***Basic impulse insulation level* (*BIL*)** *(kV)* – The maximum voltage pulse that the equipment will withstand.
- *Frequency (Hertz)* – All HVL switches may be used in either 50Hz or 60Hz power systems.
- *Withstand (kV)* – The maximum 60Hz voltage that can be applied to the switch for one minute without causing insulation failure.
- *Capacitor switching (kVAR)* – The maximum capacitance expressed in kVAR that can be switched with the HVL.
- *Fault close* – The maximum, *fully offset* fault current that the switch can be closed into without sustaining damage. The term *fully offset* means that the fault current will have a delaying DC component in addition to the AC component.
- *Short-time current* – The amount of current that the switch will carry for 10 seconds without sustaining any damage.
- *Continuous current (amps)* – The amount of current that the switch will carry continuously.
- *Interrupting current (amps)* – The maximum amount of current that the switch will safely interrupt.

8.2.0 Variations

There are six main types of switches:

- *Upright* – The upright switch design is the most common type. The upright construction of the service entry, jaws, and arc chutes are located near the top of the cubicle. The hinge point is below the jaws and arc chutes.
- *Inverted* – The inverted switch design has the terminals, jaws, and arc chutes located near the bottom of the cubicle. The hinge point is above the jaws and arc chutes. This type of switch is used primarily as a main switch to a lineup of other switches. Its handle operation is identical to that of an upright switch; to close the switch, the handle is moved up, and to open it, the handle is moved down.

- *Fused/unfused* – HVL switches are available in both fused and unfused models. If equipped with fuses, the entire HVL switch has the fault interrupting capacity of the fuse and therefore provides fault protection. Either current-limiting or boric acid fuses may be used in the HVL switch.
- *Duplex* – A duplex switch is actually two switches, each in its own bay. The bays are mechanically connected and the switches are electrically connected on the load side. This switch may be used to supply power to a single load from two different sources.
- *Selector* – A selector allows an HVL switch to have double-throw characteristics. The selector switch is a single switch with a load connected to the moving or switch mechanism. Throwing the switch to one side connects the load to one source, while throwing it the other way connects it to a second source. The selector switch will be interlocked with another switch to prevent the selector switch from interrupting current flow. The selector serves a purpose similar to that of the duplex switch. However, the selector switch is not an interrupter; it is a disconnect.
- *Motor-operated* – This type of switch is most commonly used as the major component in an automatic transfer scheme. It can also be used when open and close functions are to be initiated from remote locations.

8.3.0 Opening Operation

In the closed position, the main switch blade is engaged on the stationary interrupting contacts. The circuit current flows through the main blades.

As the switch operating handle is moved toward the open position, the stored energy springs are charged. After the springs become fully charged, they toggle over the dead center position, discharging force to the switch operating mechanism.

The action of the switch operating mechanism forces the movable main blade off the stationary main contacts while the interrupting contacts are held closed, momentarily carrying all the current without arcing. Once the main contacts have separated well beyond the striking distance, the interrupting blade contact that was held captive has charged the interrupter blade hub spring, and the interrupter blade is suddenly forced free and flips open.

The resulting arc drawn between the stationary and movable interrupting contacts is elongated and cooled as the plastic arc chute absorbs heat and generates an arc-extinguishing gas to break up and blow out the arc. The combination of arc stretching, arc cooling, and extinguishing gas causes a quick interruption with only minor erosion of the contacts and arc chutes. The movable main and interrupting contacts continue to the fully open position and are maintained there by spring pressure.

8.4.0 Closing

When the switch operating handle is moved toward the closed position, the stored energy springs are being charged and the main blades begin to move. As the main and interrupter blades approach the arc chute, the stored energy springs become fully charged and toggle over the dead center position.

When the main and movable blades approach the main stationary contacts, a high-voltage arc leaps across the diminishing air gap in an attempt to complete the circuit. The arc occurs between the tip of the stationary main contacts and a remote corner of the movable main blades. This arc is short and brief because the fast-closing blades minimize the arcing time.

The spring pressure and momentum of the fast-moving main blades completely close the contacts. The force is great enough to cause the contacts to close even against repelling short circuit magnetic forces if a fault exists. At the same time, the interrupter blade tip is driven through the twin stationary interrupting contacts, definitely latching and preparing them for an interrupting operation when the switch is opened.

8.5.0 Maintenance

WARNING!

Maintenance and testing may only be performed by qualified personnel under the appropriate safe work plan or permit.

Maintenance tasks for an HVL switch include the following:

Step 1 Operate the HVL switch several times. Observe the mechanism and check for binding.

Step 2 Inspect the interrupting and main blades every 100 operations for excessive wear or damage; replace as necessary. Also, inspect the arc chutes for damage.

Step 3 Clean the switch and its compartment thoroughly. Use a clean cloth and avoid solvents.

Step 4 Lubricate the switch. The pivot points on the switch should be greased. The switch contacts should also be lubricated with a light film of grease after being cleaned.

Step 5 Confirm the final maintenance checks, including phase-to-ground and phase-to-phase megger testing. If the results are satisfactory, then a DC high-potential test is performed.

8.6.0 Sluggish Operation

A switch that is operating sluggishly hesitates on the opening cycle. This contrasts with the normal snapping action. Observing the interrupter blade during the opening operation is the proper way to determine sluggish operation. Sluggishness must be repaired to prevent the switch from locking up completely. Perform the following procedure:

Step 1 Tease the switch closed and then open it again while watching the interrupter blades closely. Sluggishness on close is shown by the main blade's being engaged behind the contacts of the arc chute. On opening, the interrupter blades may hesitate momentarily.

Step 2 Disconnect the links from the operating shaft. Never operate the switch with the links off as this may break the handle crank casting. This is because the main spring energy is absorbed by the handle crank rather than the main blades.

Step 3 Rotate the handle approximately 45 degrees, and hold it in this position while trying to operate the switch by hand. Excessive binding will prevent rotation of the shaft.

Step 4 Check the contact adjustment at the jaw and hinge.

Step 5 Check for binding between the interrupter blade and the arc chute.

Step 6 Remove the front panel over the operating mechanism and disconnect the spring yoke from the cam. Check for binding between the spring pivot and the sides of the operator. Check the spring for breaks.

9.0.0 ◆ BOLTED PRESSURE SWITCHES

Bolted pressure switches *(Figure 9)* are used frequently on service-entrance feeders in switchgear such as that shown in *Figure 10*. They are often used in lieu of circuit breakers because they are inexpensive. Bolted pressure switches can be manually operated or motor operated. However, unlike a circuit breaker, they can only be automatically tripped by three events: a ground fault, a phase failure, or a blown main fuse detector.

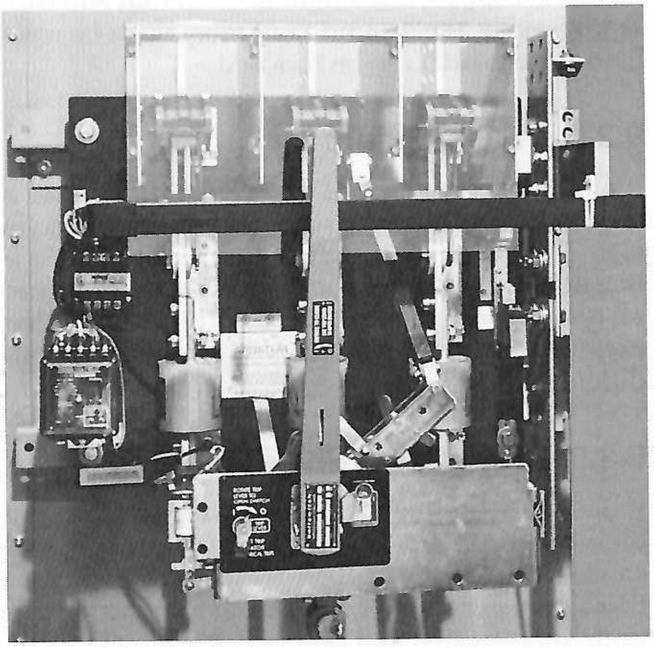

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Figure 9 ◆ Bolted pressure switch.

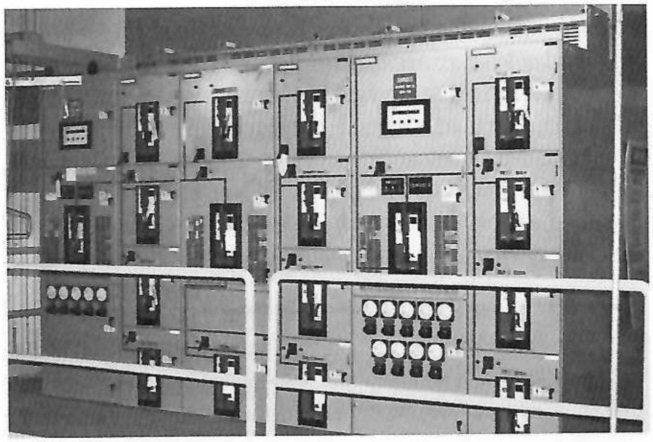

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Figure 10 ◆ Switchgear.

9.1.0 Ground Fault

Under normal conditions, the currents in all conductors surrounded by the ground fault CT equal zero. When a ground fault occurs, this sensed current increases, eventually reaching the ground fault relay pickup point and causing the bolted pressure switch to trip.

The ground fault system may also be tested. By pressing the test button, a green test light will illuminate, indicating correct circuit operation. To actually test the switch, press the TEST and RESET buttons simultaneously. This sends an actual trip signal through the current sensor, thus tripping the switch. Whenever a bolted pressure switch is tripped, a red light or a red flag will trip. Additionally, the ground fault relay must be reset before the switch can be reclosed.

9.2.0 Phase Failure

If a phase failure relay is installed, it will cause a trip of the bolted pressure switch if a phase is lost. This could occur when a tree limb knocks a line down. Under this condition, the phase failure relay will sense the lost phase and trip the bolted pressure switch, preventing a single-phasing condition.

9.3.0 Blown Main Fuse Detector

If one of the in-line main fuses were to blow, the blown main fuse detector would detect it and cause a trip of the bolted pressure switch. The trip signal generated comes from a capacitor trip unit. This ensures that power is always available to trip the switch.

9.4.0 Maintenance

Bolted pressure switches have a high failure rate due to lack of maintenance. All manufacturers of bolted pressure switches recommend annual maintenance. Lack of annual maintenance will eventually result in a switch that is stuck shut. Since these switches are often used as service-entrance equipment, a stuck switch can pose immediate personnel safety hazards, as well as equipment failures.

WARNING!

When performing any maintenance, always follow your company's safety procedures.

Due to the high interrupting capacity of the switch when operated under load, the grease that is used on the movable blades deteriorates over time and eventually turns into an adhesive. Even when the switch is not operated on a recurring basis, the grease still deteriorates due to the high temperatures associated with the current drawn by the phase. The deterioration of this grease has been shown to cause the switch to stick shut. The grease must be cleaned off yearly with denatured alcohol and replaced.

CAUTION

Regular electrical grease cannot be used; only the grease specifically recommended by the switch manufacturer may be used.

Infrared scanning of in-service bolted pressure switches has revealed a marked heating concern in switches. A digital low-resistance ohmmeter (DLRO) is used to ensure that all three phases carry similar current loads. DLRO readings should never be greater than 75 microhms, and there should not be more than a 5 percent difference between the phases.

Typical annual maintenance includes the following steps:

Step 1 De-energize the switch, lock and tag it, and perform a preliminary operational check.

Step 2 Record pre-maintenance DLRO readings.

Step 3 With the switch open, disassemble the crossbar to free all three phases.

Step 4 Clean off all old grease with denatured alcohol or a similar solvent.

Step 5 Inspect the arc tips and arc chutes for damage.

Step 6 Adjust all pivotal connections on each blade to within the manufacturer's recommended tolerances.

Step 7 Apply an appropriate grease to the movable blades and the area where the blades come in contact with the stationary assembly.

Step 8 Check the pullout torque on each individual blade prior to crossbar reassembly following the manufacturer's instructions. It should be in accordance with the manufacturer's prescribed limits. Too much torque will result in a switch that will be unable to open under load.

Step 9 Record the DLRO readings.

INSIDE TRACK

High-Resistance Grounding

High-resistance grounding (HRG) is increasingly applied in both medium- and low-voltage distribution systems to limit ground fault energy. Medium-voltage systems have long used low-impedance grounding systems to limit ground fault current. Limiting ground fault current to values of 25A or less increased system reliability by allowing ground faults to be detected and selectively cleared. These systems used either a large resistor or inductance (transformer primary with a shorted secondary or a relay coil in the secondary) connected between the neutral bushing of the service transformer and the system bonding jumper. Detection of a ground fault at certain levels caused a protective relay to open the circuit and clear the fault. The resistors used were mounted in wire cages next to the supply transformers. The resistors were rated at maximum ground fault power for the duration of the fault before it cleared. If the resistors burned up due to failure to clear the fault, the system became an ungrounded wye and extremely dangerous.

In practice, low-resistance grounding for 480V or 600V systems was seldom applied due to the requirements for large resistors and space for enclosures and heat dissipation. The use of high-resistance grounding for low-voltage, high-current systems is becoming common. The high fault currents available on large 480V or 600V systems present a significant arc flash hazard, while at the same time the arcing fault may be seen as only an overload by the protective device. High-resistance ground systems allow detection of ground faults and facilitate location of the faulted circuit.

The most common types of faults in power systems are:

- Three phase (balanced)
- Phase to phase
- Phase to phase to ground
- Phase to ground

In industrial facilities, it is estimated that 98 percent or more of all faults begin as a ground fault. If the arcing ground fault current is high enough, the fault develops into a phase-to-phase or three-phase fault. High-resistance grounding in 600V systems limits ground fault current to less than 10A; 5A is a common limit. This level of fault current is too low to present an arc flash hazard or to sustain an arc by itself. This makes development of phase-to-phase faults unlikely. The low fault current also allows continuity of service for a period of time with little risk of equipment damage. Good practice requires that a fault be located and cleared as quickly as possible. The current allowed in the ground fault must be greater than the capacitive coupled charging current in the system in order to avoid false alarms. In low-voltage systems, a sensed ground fault is usually indicated and alarmed but does not send a trip signal to controlling equipment. This is done to allow location of the fault using various features available in HRG panels and cabinets.

In the event of a ground fault in an HRG 480V system, the two non-faulted phases will be at 480V (line potential) to ground and to the faulted phase. If a second phase should fault to ground before an existing fault is cleared, the second fault will NOT be limited and fault currents greater than encountered on a solidly grounded system should be expected. In performing arc hazard analysis, we are aware that there is a much lower risk of our actions causing an uncontrolled fault but we cannot reduce the evaluated incident energy levels or PPE. This is because the risk is not eliminated and a line-to-line or three-phase fault is still possible. Surveys indicate that human error is responsible for most faults that start as line to line or three phase. It should be noted that resistance or reactance grounded systems may NOT supply line-to-neutral loads, but may supply line-to-line loads.

Step 10 Reassemble the crossbar assembly.

Step 11 Close and open the switch manually several times. Ensure that no phases hang up on the arc chute assembly.

Step 12 Megger the switch.

Step 13 Energize and test all accessories, such as the ground fault detector, phase failure detector, and blown main fuse detector.

WARNING!

If the switch is physically stuck shut, de-energize the switch from the incoming power supply and take extra precautions when trying to unstick the switch. It may be necessary to pry the blades open, but beware of the excessive outward force that will result from a charged opening spring. To alleviate this, discharge the opening spring before commencing any work on the switch.

10.0.0 ◆ TRANSFORMERS

Transformers are used to step voltage up and down in the power transmission and distribution system.

The reason for such high transmission voltages is twofold. First, as a transformer increases transmission voltage, the required current decreases in the same proportion; therefore, larger amounts of power can be transmitted and line losses reduced. Second, to send large amounts of power over long distances at a high current and a low voltage requires a very large diameter wire. The reduction in current reduces the conductor size, which results in a cost reduction.

A transformer is an electrical device that uses the process of electromagnetic induction to change the levels of voltage and current in an AC circuit without changing the frequency, and with very little loss of power.

10.1.0 Transformer Theory

As current flows through a conductor, a magnetic field is produced around the conductor. This magnetic field begins to form at the instant current begins to flow, and expands outward from the conductor as the current increases in magnitude. When the current reaches its peak value, the magnetic field is also at its peak value. When the current decreases, the magnetic field also decreases.

Alternating current (AC) changes direction twice per cycle. These changes in direction or alternation create an expanding and collapsing magnetic field around the conductor.

If the conductor is wound into a coil, the magnetic field expanding from each turn of the coil cuts across other turns of the coil. When the source current starts to reverse direction, the magnetic field collapses, and again the field cuts across the other turns of the coil.

The result in both cases is the same as if a conductor is passed through a magnetic field. An electromotive force (EMF) is induced in the conductor. This EMF is called a self-induced EMF because it is induced in the conductor carrying the current.

The direction of this induced EMF is always opposite the direction of the EMF that caused the current to flow initially. This principle is known as Lenz's law: An induced EMF always has such a direction as to oppose the action that produced it. For this reason, the EMF induced is also known as a counter-electromotive force (CEMF).

The counter-electromotive force reaches a value nearly equal to the applied voltage; thus, the primary current is limited when the secondary is open circuited.

10.1.1 No-Load Operation

The operation of a transformer is based on the principle that electrical energy can be transferred efficiently by mutual induction from one winding to another. When the primary winding is energized from an AC source, an alternating magnetic flux is established in the transformer core. This flux links the turns of the primary with the secondary, thereby inducing a voltage in them. Since the same flux cuts both windings, the same voltage is induced in each turn of both windings. Whenever the secondary of a transformer is left disconnected (or open), there is no current drawn by the secondary winding. The primary winding draws the amount of current required to supply the magnetomotive force, which produces the transformer core flux. This current is called the exciting or magnetizing current.

The exciting current is limited by the CEMF in the primary and a small amount of resistance, which cannot be avoided in any current-carrying conductor.

10.1.2 Load Operation

When a load is connected to the secondary winding of a transformer, the secondary current flowing through the secondary turns produces a counter-magnetomotive force. According to

Lenz's law, this magnetomotive force is in a direction that opposes the flux that produced it. This opposition tends to reduce the transformer flux and is accompanied by a reduction in the CEMF in the primary. Since the primary current is limited by the internal impedance of the primary winding and the CEMF in the winding, whenever the CEMF is reduced, the primary current continues to increase until the original transformer flux reaches a state of equilibrium.

10.2.0 Transformer Types

Transformers can be divided into two main categories: power transformers and **distribution transformers**. Power transformers handle large amounts of power and step down from transmission voltages to distribution voltages. Distribution transformers are designed to handle larger currents at lower voltage levels. Distribution transformers have smaller kVA ratings and are physically much smaller than power transformers. Power transformers often have an auxiliary means of cooling, such as fans and radiators. Distribution transformers are usually self-cooled, using no fans or other cooling methods. While distribution transformers may be pole-mounted or pad-mounted, power transformers are always freestanding.

Although there is some overlap between power and distribution transformers, a transformer that is rated at more than 500kVA and/or 34.5kV is generally a power transformer. A transformer rated below these values can be considered a distribution transformer. Remember, there is an overlap in kVA capacity and voltage, depending on the system and power requirements.

10.3.0 Dry Transformers (Air-Cooled)

Many transformers do not use an insulating liquid to immerse the core and windings. Dry or air-cooled transformers are used for many jobs where small, low-kVA transformers are required. Large distribution transformers are usually oil-filled for better cooling and insulating. However, for installations in buildings and other locations where the oil in oil-filled transformers would be a serious fire hazard, dry transformers are used. These transformers are generally of the core form. The core and coils are similar to those of other transformers. A three-phase, dry-type transformer is shown in *Figure 11*.

The case is made of sheet metal and provided with ventilating louvers for the circulation of cooling air. To increase the output, fans can be installed to draw cooling air through the coils at a faster rate than is possible with natural circulation.


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Figure 11 ◆ Dry-type transformer.

Either Class B or Class H insulation is used for the windings. Class B insulation may be operated safely at a hot-spot temperature of 130°C. Class H insulation may be operated safely at a hot-spot temperature of 180°C. The use of these materials makes it possible to manufacture smaller transformers. Both Class B and Class H insulation consist of mica, asbestos, fiberglass, and similar inorganic material. Temperature-resistant organic varnishes are used as the binder for Class B insulation. Silicone or fluorine compounds or similar materials are used as the binder for Class H insulation. Such transformers use high-temperature insulation only in locations where the high temperature requires such insulation.

10.4.0 Sealed Dry Transformers

Hermetically sealed dry transformers are made in large sizes for voltages above 15kV. They are used for installations in buildings and other locations where oil-filled transformers would be a serious fire hazard, but they may also be used for lower voltages and kVA ratings and for water-submersible transformers in locations subject to floods. Nitrogen is typically used for the insulation and cooling of sealed dry transformers.

10.5.0 Transformer Nameplate Data

Transformer nameplate data includes the following:

- *Electrical ratings* – The information relating to the transformer electrical parameters can be found on the nameplate.
- *Voltage ratings* – The voltage rating identifies the nominal root mean square (rms) voltage value at which the transformer is designed to operate. A transformer can operate within a ±5 percent range of its rated primary voltage. If the primary voltage is increased to more than +5 percent, the windings of the transformer can overheat. Operation of the transformer at more than −5 percent decreases its power output proportionally to the percent voltage reduction. Transformer windings are rated as follows:
  - Phase-to-phase and phase-to-neutral for wye windings, such as 480Y/277VAC
  - Phase-to-phase for delta windings, such as 480VAC
  - Dual-voltage windings, such as 480VAC 3 240VAC

  When transformers are equipped with a tap changer, the voltage ratings in the nameplate indicate the nominal voltages.
- *BIL* – This identifies the maximum impulse voltage the winding insulation can withstand without failure.
- *Phase* – The phase information indicates the number of phase windings contained in a transformer tank.
- *Frequency* – The frequency rating of a transformer is the normal operating system frequency. When a transformer is operated at a lower frequency, the reactance of the primary winding decreases. This causes a higher exciting current and an increase in flux density. In addition, there is an increase in core loss, which results in overall heating.
- *Class* – Transformers are classified by the type of cooling they employ.
- *Temperature rise* – The temperature rise rating is the maximum elevation above ambient temperature that can be tolerated without causing insulation damage.
- *Capacity* – The capacity of a transformer to transfer energy is related to its ability to dissipate the heat produced in the windings. The capacity rating is the product of the rated voltage and the current that can be carried at that voltage without exceeding the temperature rise limitation.
- *Impedance* – Impedance identifies the opposition of a transformer to the passage of short circuit current.
- *Phasor diagrams* – Phasor diagrams show phase and polarity relationships of the high and low windings. They can be used with the schematic connection diagram to provide test connection points and to provide proper external system connections.

10.6.0 Transformer Case Inspections

When inspecting the inside of a dry-type, air-cooled transformer case, look for the following:

- Temporary shipping supports or guards
- Bent, broken, or loose parts
- Debris on the floor or in the coils
- Corrosion of any part
- Worn or frayed insulation
- Shifted core members
- Damaged tap changer mounts or mechanisms
- Misaligned core spacers and loose coil elements
- Broken or loose blocking

Upon completion of the inspection, replace the covers and bolt securely. All information should be recorded on appropriate inspection sheets.

10.7.0 Transformer Tests

The following tests are the recommended minimum tests that should be included as part of a maintenance program. These tests are conducted to determine and evaluate the present condition of the transformer. From the results of these tests, a determination is made as to whether the transformer is suitable for service. All tests should be performed using the standards and procedures provided by the transformer manufacturer.

- *Continuity and winding resistance test* – There should be a continuity check of all windings. If possible, measure the winding resistance and compare it to the factory test values. An increase of more than 10 percent could indicate loose internal connections.

- *Insulation resistance test* – To ensure that no grounding of the windings exists, a 1,000V insulation resistance test should be made.
- *Ratio test* – A turns ratio test should be made to ensure proper transformer ratios and to ensure that all connections were made. If equipped with a tap changer, all positions should be checked.
- *Core ground* – This test is performed in the same way as the insulation resistance test, except the measurement is made from the core to the frame and ground bus. Remove the core ground strap before the test.
- *Heat scanning* – After the transformer is energized, a heat scan test should be done to detect loose connections. This test is performed using an infrared scanning device that shows or indicates hot spots.

11.0.0 ◆ INSTRUMENT TRANSFORMERS

For all practical purposes, the voltages and currents used in the primary circuits of substations are much too large to be used in relaying or metering circuits. Transformers are employed in order to reduce voltage and currents to usable levels. Instrument transformers are used to:

- Protect personnel and equipment from the high voltages and/or currents used in electric power transmission and distribution
- Provide reasonable use of insulation levels and current-carrying capacity in relay and metering systems and other control devices
- Provide a means to combine voltage and/or current phasors to simplify relaying or metering

Instrument transformers are manufactured with a multitude of different ratios to provide a standard output for the many different system primary voltage levels and load currents. There are two types of instrument transformers: potential transformers and current transformers (*Figure 12*). In general, a potential transformer is used to supply a voltage signal to devices such as voltmeters, frequency meters, power factor meters, watt-hour meters, and protective relays. The voltage is proportional to the primary voltage, but it is small enough to be safe for the test instrument. The secondary of a potential transformer may be designed for several different voltages, but most are designed for 120V. The potential transformer is primarily a distribution transformer especially designed for voltage regulation so that the secondary voltage (under all conditions) will be as close as possible to a specified percentage of the primary voltage.

A current transformer is used to supply current to an instrument connected to its secondary with the current being proportional to the primary current but small enough to be safe for the instrument. The secondary of a current transformer is usually designed for a rated current of 5A.

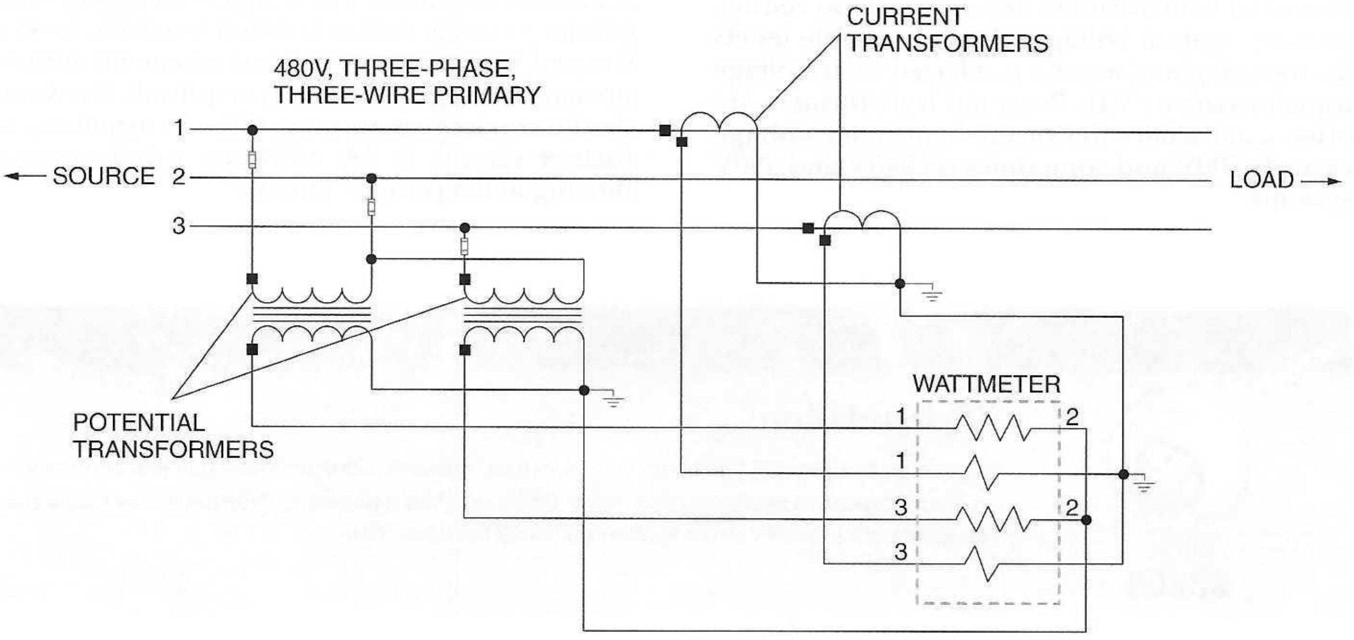

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Figure 12 ◆ Current and potential transformers connected for power metering of a three-phase circuit.

A current transformer operates in the same way as any other transformer in that the same relationship exists between the primary current and the secondary current. A current transformer uses the circuit conductors as its primary winding. The secondary of the current transformer is connected to current devices such as ammeters, wattmeters, watt-hour meters, power factor meters, some forms of relays, and the trip coils of some types of circuit breakers.

When no instruments or other devices are connected to the secondary of the current transformer, a short circuit device or shunt is placed across the secondary to prevent the secondary circuit from being opened while the primary winding is carrying current.

WARNING!

If the secondary circuit is open, there will be no secondary ampere turns to balance the primary ampere turns, so the total primary current becomes exciting current and magnetizes the core to a high flux density. This produces a high voltage across both the primary and secondary windings and endangers the life of anyone coming in contact with the meters or leads. This is why current transformers should never be fused. A current transformer is the only transformer that may be short-circuited on the secondary while energized.

11.1.0 Potential Transformers

Potential transformers are designed to reduce primary system voltages down to usable levels for metering and are often referred to as voltage transformers or VTs. Potential transformers are often used where the system's primary voltage exceeds 600V and sometimes on 240V and 480V systems.

The standard secondary circuit voltage level for a potential transformer circuit is 120V for circuits below 25kV and 115V for circuits above 25kV at the potential transformer's rated primary voltage. These voltages correspond to typical transformation ratios of standard transmission voltages. The current flowing in the secondary of the potential transformer circuit is very low under normal operating conditions, typically less than one ampere.

Potential transformers are constructed to be lightly loaded, with the design emphasis on winding ratio accuracy rather than current rating. Potential transformer construction can be air-insulated dry, case epoxy-insulated, oil-filled, or SF_6-insulated, depending upon the primary circuit voltage level.

The standard output voltage of potential transformers is either 120V or 69.3V, depending on whether its primary winding uses phase-to-phase or phase-to-neutral connections. Understanding the operation of a potential or voltage transformer is simplified by the inspection of its equivalent circuit.

Potential transformers must have their secondary circuits grounded for safety reasons in the event that a short circuit develops between the primary and secondary windings and to negate the effects of parasitic capacitance between the primary and the secondary. *Figure 13* shows the connection of an ideal potential transformer circuit.

11.2.0 Current Transformers

A current transformer is designed to reduce high primary system currents down to usable levels. Current transformers are used whenever system primary voltage isolation is required. The standard secondary circuit current for a current transformer circuit is 5A with full-rated current flowing in the primary circuit.

GOING
GREEN

SF_6 Insulation

Sulfur hexafluoride (SF_6) is a colorless, odorless, nontoxic, nonflammable gas that is used as an insulating gas in electrical equipment. SF_6 is used as a gaseous dielectric for transformers, capacitors, and circuit breakers, often replacing harmful PCBs.

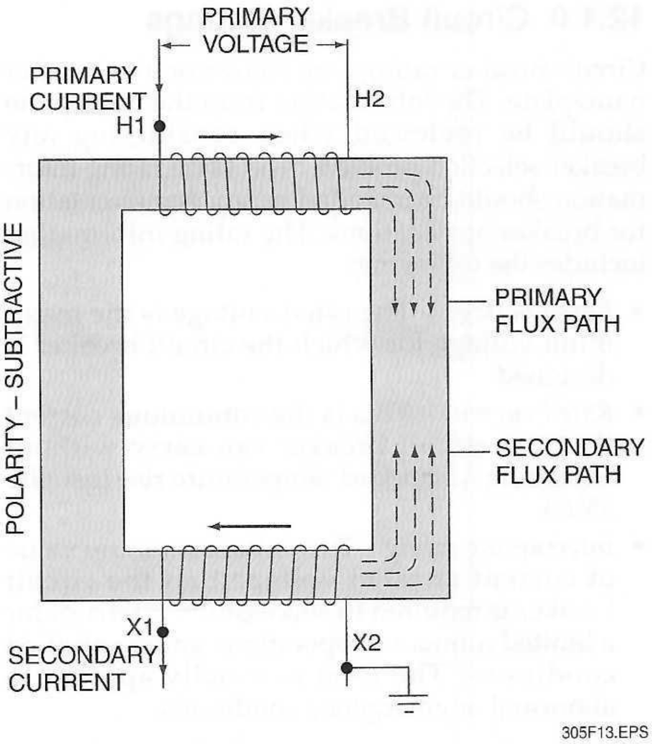

Figure 13 ◆ Potential transformer construction.

WARNING!

The voltage level across a current transformer's secondary terminals can rise to a very dangerous level if the secondary circuit opens while the primary circuit is energized.

The primary considerations in current transformer design are the current-carrying capability and saturation characteristics. Insulation systems are of the same generic types as potential transformers.

Current transformers are manufactured in four basic types: oil-filled (for example, donut type), bar, window, and **bushing**. The bushing-type transformer is normally applied on circuit breakers or power transformers. The other types are used for the remaining indoor and outdoor installations. *Figure 14* illustrates some common types of current transformer construction.

The major criteria for the selection of the current transformer for relaying are its primary current rating, maximum burden, and saturation characteristics. Saturation is particularly important in relaying due to the fact that many relays are called upon to operate only under fault conditions.

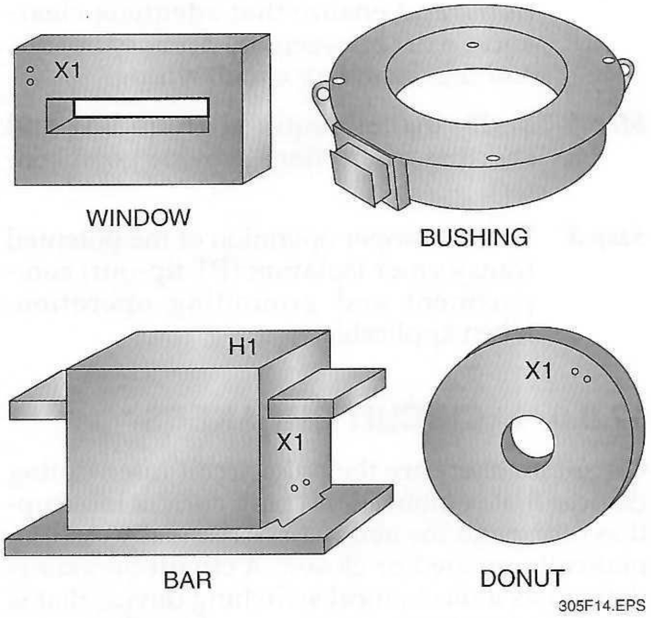

Figure 14 ◆ Types of current transformer construction.

Current transformer circuits operate at a very low voltage. Connected loads (burdens) range from 0.2Ω to 2Ω. These small impedances, together with a maximum continuous current of up to 5A, keep these circuits at low potentials. The voltage can become high momentarily during faults when large secondary currents flow. This voltage is a function of the current, burden, and transformer VA capability.

Like potential transformers, current transformers must also have their secondary windings grounded in the event of an insulation breakdown between the primary and secondary, and to negate the effects of parasitic capacitance.

11.3.0 Instrument Transformer Maintenance

Instrument transformers require regular inspection and maintenance. A typical inspection process includes the following steps:

Step 1 Inspect for physical damage and check the nameplate information for compliance with instructions and specification requirements.

Step 2 Verify the proper connection of transformers against the system requirements.

Step 3 Verify the tightness of all bolted connections, and ensure that adequate clearances exist between the primary circuits and the secondary circuit wiring.

Step 4 Verify that all required grounding and shorting connections provide good contact.

Step 5 Test for proper operation of the potential transformer isolation (PT tip-out) compartment and grounding operation, when applicable.

12.0.0 ◆ CIRCUIT BREAKERS

Circuit breakers are the only circuit interrupting devices that combine a full fault current interruption rating and the ability to be manually or automatically opened or closed. A circuit breaker is defined as a mechanical switching device that is capable of making, carrying, and breaking currents under normal circuit conditions and also making, carrying (for a specified time), and breaking currents under specified abnormal circuit conditions, such as a short circuit (according to IEEE). The four general classifications of circuit breakers, based on insulation medium, are as follows:

- **Air circuit breakers (ACBs)**
- Oil circuit breakers (OCBs)
- Vacuum circuit breakers (VCBs)
- Gas circuit breakers (GCBs)

Circuit breakers may conveniently be divided into low-voltage, medium-voltage, and high-voltage classes. Although there is considerable overlap among these classes, each one has certain characteristic features.

12.1.0 Circuit Breaker Ratings

Circuit breaker ratings are shown on the breaker nameplate. The information from the nameplate should be reviewed when considering any breaker selection problem. The same rating information should be included in any documentation for breaker applications. The rating information includes the following:

- *Rated voltage* – The rated voltage is the maximum voltage for which the circuit breaker is designed.
- *Rated current* – This is the continuous current that the circuit breaker can carry without exceeding a standard temperature rise (usually 55°C).
- *Interrupting rating* – This is the maximum value of current at rated voltage that the circuit breaker is required to successfully interrupt for a limited number of operations under specified conditions. The term is usually applied to abnormal or emergency conditions.

Circuit breakers are classified according to given current ranges. Each group is classified by the largest ampere rating of its range. These groups are as follows:

- 15A–100A
- 125A–225A
- 250A–400A
- 500A–1,000A
- 1,200A–2,000A

The circuit breaker groups are therefore classified as 100A, 225A, 400A, 1,000A, and 2,000A frames. These numbers are commonly referred to as frame classifications or **frame sizes,** and are terms applied to groups of molded-case circuit breakers that are physically interchangeable with each other.

INSIDE TRACK

Tripped Circuit Breaker Indications

When tripped, the handle of a circuit breaker can position itself in one of several ways, depending on the design of the breaker. Some common handle positions (indications) of a tripped circuit breaker are as follows:

- *Center trip* – The handle of the breaker moves to a center position on the breaker.
- *Center position flag* – The handle of the breaker moves to the center position on the breaker and displays a red flag.
- *Full OFF position* – The handle of the breaker moves to the full OFF position on the breaker.
- *OFF position outward* – A center button protrudes to display OFF.

12.2.0 Types of Circuit Breakers

Most circuit breakers protect against overloads and ground fault short circuits (overcurrents), but some circuit breakers are designed with additional capabilities or other functions. The following are some examples of these breakers:

- *Shunt trip circuit breaker* – In addition to the normal operating devices that protect against overcurrents, this breaker has a built-in electric coil that causes it to open the breaker contacts when the coil is energized by an outside source. Typical sources may include fire suppression circuits, pushbuttons, or alarm circuits.
- *Arc fault circuit breaker* – In addition to the normal operating devices that protect against overcurrents, this breaker includes electronic circuits to monitor current flow within the breaker. If it detects a pattern of small continuous surges or spikes in that current flow, the breaker will operate and open the circuit. This pattern of surges or spikes is typical of currents in a short, high-resistance arcing circuit, such as a frayed electrical cord or a loose connection. ***NEC Section 210.12(B)*** requires these types of breakers to be used to protect all 120V, 5A, and 20A branch circuits in residential family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, or similar rooms or areas.
- *GFCI breaker* – In addition to the normal operating devices that protect against overcurrents, this breaker includes circuitry to monitor currents on both conductors in the circuit. If there is an imbalance of those currents of 6mA or more, the breaker will operate and open the circuit. This imbalance would indicate that a current path other than that intended has formed, possibly through equipment or persons and flowing to ground. GFCI breakers have different ranges to enable protection of people, equipment, or both.
- *Switched neutral breaker* – In addition to the normal operating devices that protect against overcurrents, this breaker disconnects the neutral or grounded conductor simultaneously with all ungrounded conductors. The use of breakers that switch grounded conductors is limited to installations such as fuel-dispensing equipment.
- *Non-automatic breaker* – This breaker has no devices to protect the circuit against overcurrent. It is used as a means of manually disconnecting circuits by operating the handle. Its use would be similar to a non-fused disconnect switch. It is also known as a molded-case switch.

13.0.0 ◆ PANELBOARDS

This section covers panelboard construction and protective devices.

13.1.0 Lighting and Power Panelboards

Circuit control and overcurrent protection must be provided for all circuits and the power-consuming devices connected to these circuits. Lighting and power panels located throughout large buildings being supplied with electrical energy provide this control and protection. *Figure 15* shows a schedule of fifteen panelboards provided in a typical industrial building to feed electrical energy to the various circuits.

13.2.0 Panelboard Construction

In general, panelboards are constructed so that the main feed busbars run the height of the panelboard. The buses to the branch circuit protective devices are connected to the alternate main buses. In an arrangement of this type, the connections directly across from each other are on the same phase, and the adjacent connections on each side are on different phases. As a result, multiple protective devices can be installed to serve the 208V equipment. An example of a panelboard is shown in *Figure 16*.

13.2.1 Identification of Conductors

The ungrounded conductors may be any color except green (or green with a yellow stripe), which is reserved for grounding purposes only, or white or gray, which are reserved for the grounded circuit conductor. See ***NEC Section 200.6***.

NEC Section 210.5(C) requires that where different voltages exist in a building, the ungrounded conductors for each system must be identified at each accessible location. Identification may be by color-coding, marking, tape, tagging, or other approved means. The means of identification must be permanently posted at each branch circuit panelboard, or readily available.

PANEL NO.	LOCATION	MAINS	VOLTAGE RATING	NO. OF CIRCUITS	BREAKER RATINGS	POLES	PURPOSE
P-1	BASEMENT N. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	19 2 5	20A 20A 20A	1 2 1	LIGHTING AND RECEPTACLES SPARES
P-2	BASEMENT N. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	24 2 0	20A 20A	1 2	LIGHTING AND RECEPTACLES SPARES
P-3	2ND FLOOR N. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	24 2 0	20A 20A	1 2	LIGHTING AND RECEPTACLES SPARES
P-4	BASEMENT S. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	24 2 0	20A 20A	1 2 1	LIGHTING AND RECEPTACLES SPARES
P-5	1ST FLOOR S. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	23 2 1	20A 20A 20A	1 2 1	LIGHTING AND RECEPTACLES SPARES
P-6	2ND FLOOR S. CORRIDOR	BREAKER 100A	208/120V 3Ø, 4W	22 2 2	20A 20A 20A	1 2 1	LIGHTING AND RECEPTACLES SPARES
P-7	MFG. AREA S. WALL E.	BREAKER 100A	208/120V 3Ø, 4W	5 7 2	20A 20A 20A	1 1 1	LIGHTING AND RECEPTACLES SPARES
P-8	MFG. AREA S. WALL W.	BREAKER 100A	208/120V 3Ø, 4W	5 7 2	20A 20A 20A	1 1 1	LIGHTING AND RECEPTACLES SPARES
P-9	MFG. AREA S. WALL E.	BREAKER 100A	208/120V 3Ø, 4W	5 7 2	50A 20A 20A	1 1 1	LIGHTING AND RECEPTACLES SPARES
P-10	MFG. AREA S. WALL W.	BREAKER 100A	208/120V 3Ø, 4W	5 7 2	50A 20A 20A	1 1 1	LIGHTING AND RECEPTACLES SPARES
P-11	MFG. AREA EAST WALL	LUGS ONLY 225A	208/120V 3Ø, 4W	6	20A	3	BLOWERS AND VENTILATORS
P-12	BOILER ROOM	BREAKER 100A	208/120V 3Ø, 4W	10 4	20A 20A	1 1	LIGHTING AND RECEPTACLES SPARES
P-13	BOILER ROOM	LUGS ONLY 225A	208/120V 3Ø, 4W	6	20A	3	OIL BURNERS AND PUMPS
P-14	MFG. AREA EAST WALL	LUGS ONLY 400A	208/120V 3Ø, 4W	3 2 1	175A 70A 40A	3 3 3	CHILLERS FAN COIL UNITS FAN COIL UNITS
P-15	MFG. AREA WEST WALL	LUGS ONLY 600A	208/120V 3Ø, 4W	5	100A	3	TROLLEY BUSWAY AND ELEVATOR

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Figure 15 ◆ Schedule of electric panelboards for an industrial building.

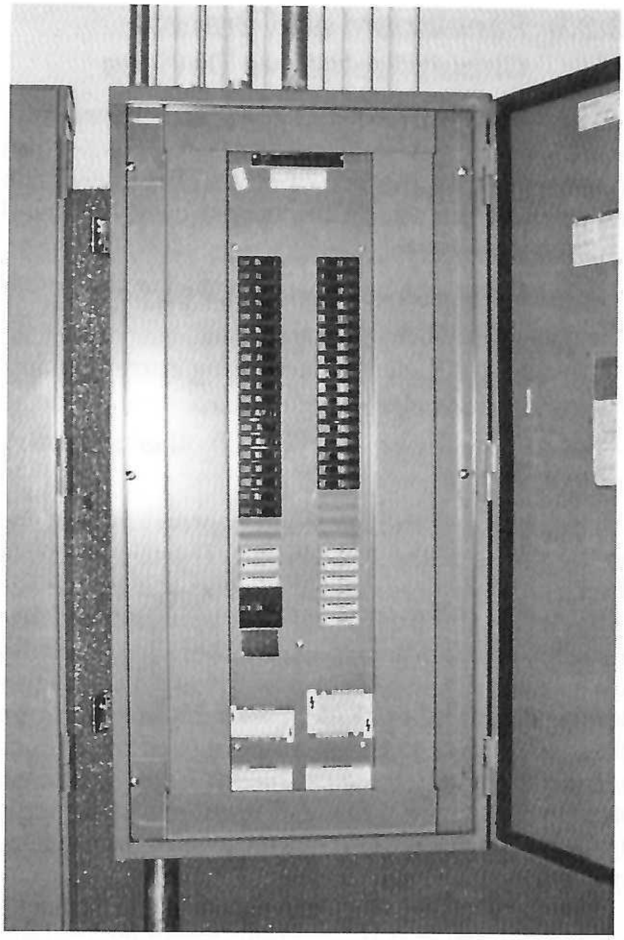

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Figure 16 ◆ Typical panelboard.

For example, this situation may occur when the building is served with 277/480V and step-down transformers are used to provide 120/208V for lighting and receptacle outlets. Examples of panelboard wiring connections are shown in *Figures 17, 18, 19,* and *20.*

13.2.2 Number of Circuits

The number of overcurrent devices in a panelboard is determined by the needs of the area being served. Using the bakery panelboard in *Figure 19* as an example, there are 13 single-pole circuits and five three-pole circuits. This is a total of 28 poles. When using a three-phase supply, the incremental number is six (a pole for each of the three phases on both sides of the panelboard). The minimum number of poles that could be specified for the bakery is 30. This would limit the power available for growth and would not permit the addition of a three-pole lead. The reasonable choice is to go to 36 poles, which provides flexibility for growth loads.

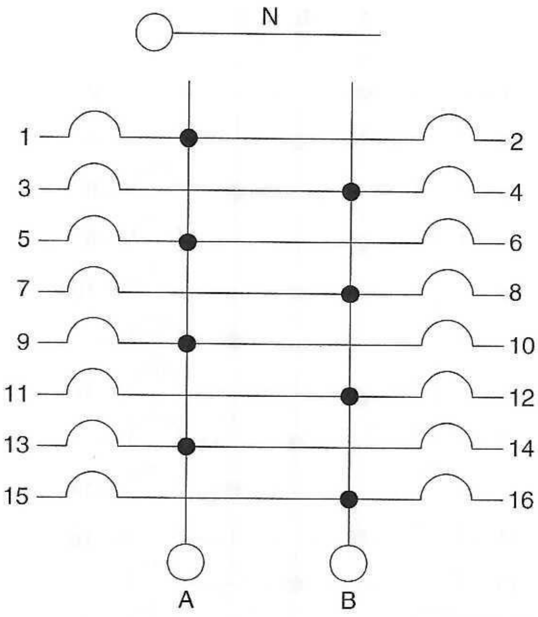

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Figure 17 ◆ Lighting and appliance branch circuit panelboard—single-phase, three-wire connections.

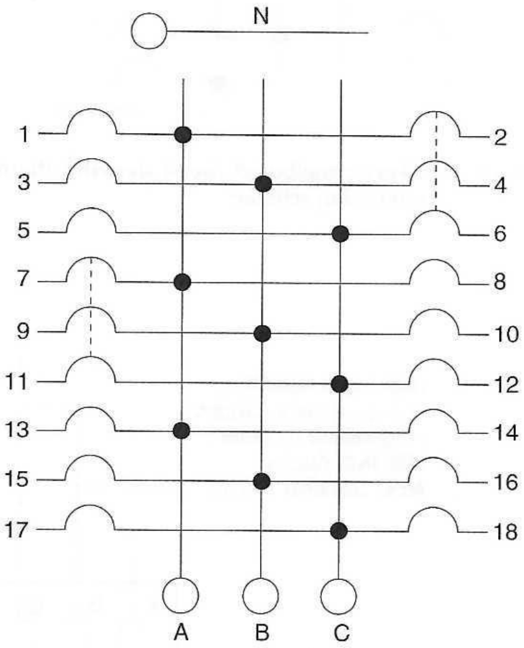

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Figure 18 ◆ Lighting and appliance branch circuit panelboard—three-phase, four-wire connections.

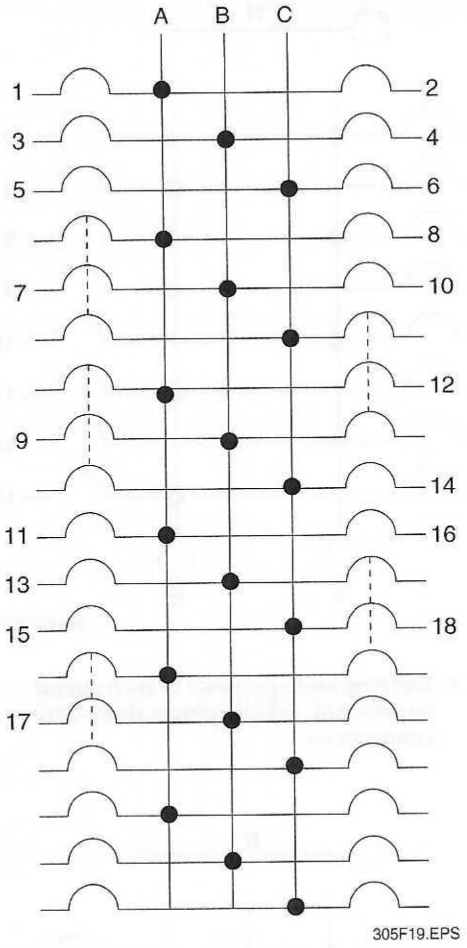
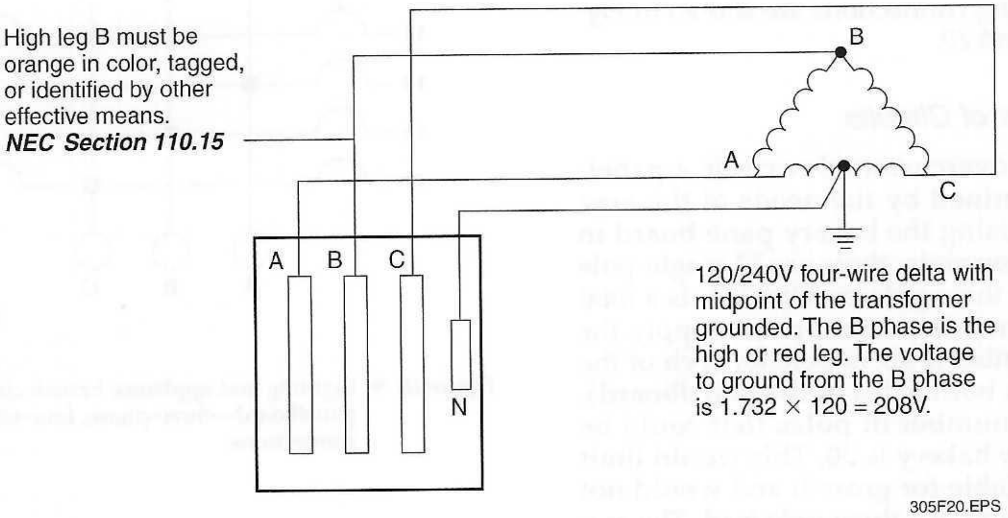


Figure 19 ◆ Bakery panelboard circuit showing alternate numbering scheme.



High leg B must be orange in color, tagged, or identified by other effective means.
NEC Section 110.15

120/240V four-wire delta with midpoint of the transformer grounded. The B phase is the high or red leg. The voltage to ground from the B phase is 1.732 × 120 = 208V.

Figure 20 ◆ Panelboards and switchboards supplied by four-wire, delta-connected system.

13.3.0 Panelboard and Branch Circuit Protective Devices

The main protective device for a panelboard may be either a fuse or a circuit breaker. This section concentrates on the use of circuit breakers. The selection of the circuit breaker should be based on the necessity to:

- Provide the proper overload protection
- Ensure a suitable voltage rating
- Provide a sufficient interrupting current rating
- Provide short circuit protection
- Coordinate the breaker(s) with other protective devices

The choice of the overload protection is based on the rating of the panelboard. The trip rating of the circuit breaker cannot exceed the amperage capacity of the busbars in the panelboard. The number of branch circuit breakers is generally not a factor in the selection of the main protective device except in a practical sense. It is a common practice to have the total amperage of the branch breakers greatly exceed the rating of the main breaker; however, it makes little sense for a single branch circuit breaker to be the same size as, or larger than, the main breaker.

The voltage rating of the breaker must be higher than that of the system. Breakers are usually rated at 250V to 600V.

The importance of the proper interrupting rating cannot be overstressed. You should recall that if there is ever any question as to the exact value of the short circuit current available at a point, the circuit breaker with the higher interrupting rating is to be installed.

Many circuit breakers used as the main protective device are provided with an electronic trip unit (*Figure 21*). Adjustments of this trip determine the degree of protection provided by the circuit breaker if a short circuit occurs. The manufacturer of this device provides exact information about the adjustments to be made. In general, a low setting may be 10 or 12 times the overload trip rating.

Two rules should be followed whenever the trip is set:

- The trip must be set to the minimum practical setting.
- The setting must be lower than the value of the short circuit current available at that point.

If subfeed lugs are used, ensure that the lugs are suitable for making multiple breaker connections, as required by ***NEC Section 110.14(A)***. In general, this means that a separate lug is to be provided for each conductor being connected.

If taps are made to the subfeeder, they can be reduced in size according to ***NEC Section 240.21***. This specification is very useful in cases such as that of panel P-12 in *Figure 15*. For this panel, a 100A main breaker is fed by a 350MCM conductor. Within the distances given in ***NEC Section 240.21(B)(1)***, a conductor with a 100A rating may be tapped to the subfeeder and connected to the 100A main breaker in the panel.

Per ***NEC Section 110.14(C)***, the temperature rating of conductors must be selected and coordinated so as not to exceed the lowest temperature rating of any connected termination, conductor, or device.

The schedule of panelboards for the industrial building (*Figure 15*) shows that lighting panels P-1 through P-6 have 20A circuit breakers, including double-pole breakers to supply special receptacle outlets. A double-pole breaker requires the same installation space as two single-pole breakers. Breakers are shown in *Figure 22*.

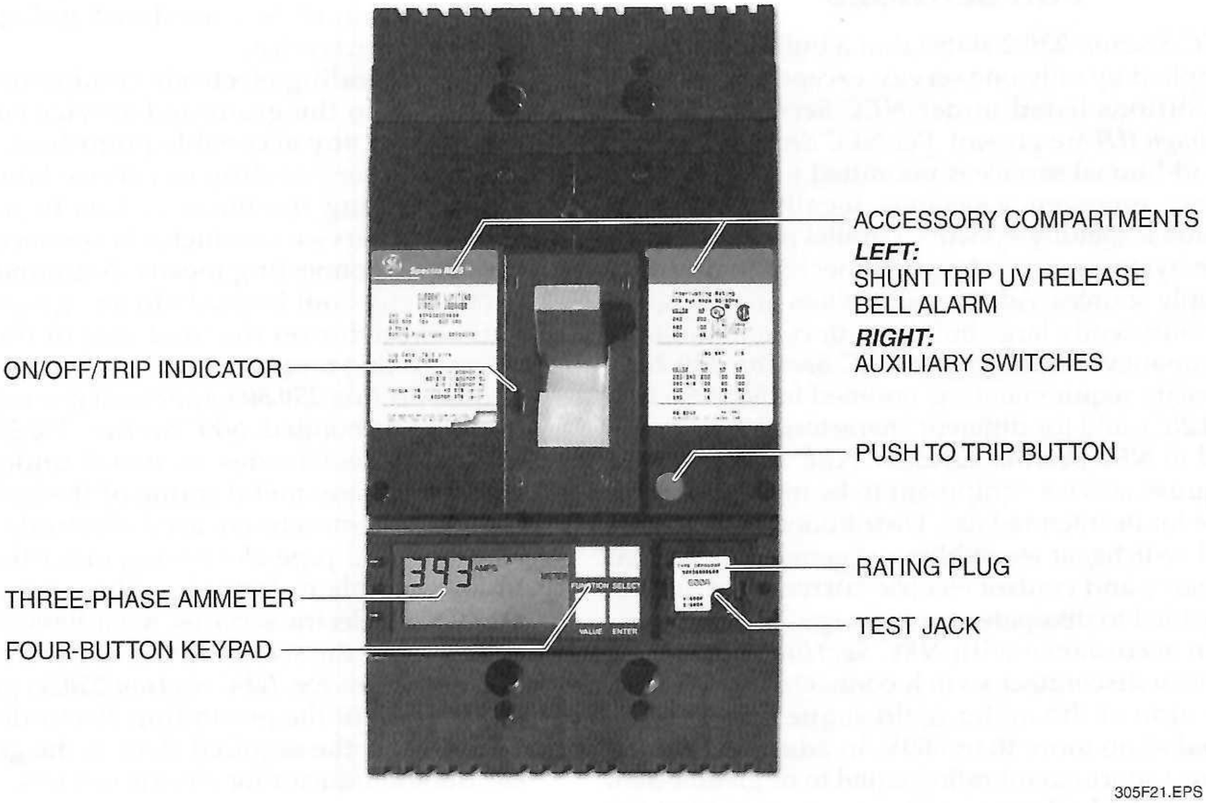


Figure 21 ◆ Circuit breaker with adjustable magnetic trip.

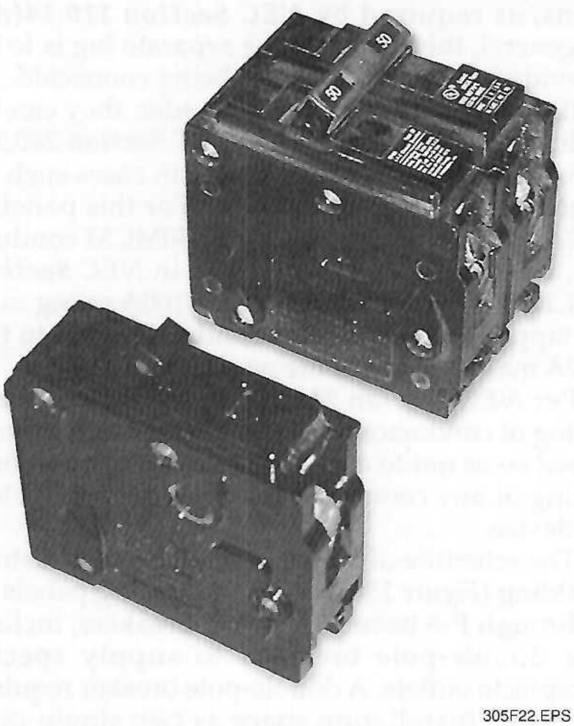


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Figure 22 ◆ Branch circuit protective devices.

14.0.0 ◆ *NEC*® REQUIREMENTS FOR SERVICES

NEC Section 230.2 states that a building shall be supplied by only one service except when special conditions listed under ***NEC Section 230.2(A) through (D)*** are present. Per ***NEC Section 230.2(A)***, an additional service is permitted to supply a fire pump, emergency systems, legally required or optional standby systems, parallel power production systems, or systems connected to multiple supply sources. Additional services are permitted for sufficiently large buildings or certain multiple occupancy buildings per ***NEC Section 230.2(B)***, capacity requirements as outlined in ***NEC Section 230.2(C)***, and for different characteristics as identified in ***NEC Section 230.2(D)***. ***NEC Section 230.66*** requires service equipment to be marked as suitable for its intended use. Distribution panelboards and switchgear assemblies are generally intended to carry and control electric current, but are not intended to dissipate or use energy.

In accordance with ***NEC Section 230.82(3)***, a service disconnect switch connected to the supply side of the meter (cold sequence) must be rated at no more than 600V. In addition, it must have a short-circuit rating equal to or greater than the available short-circuit current, provided the housings and service enclosures are grounded and bonded in accordance with ***NEC Article 250, Parts V and VII***. The switch must be capable of interrupting the load served.

14.1.0 Services Passing Through Buildings

Per ***NEC Section 230.3***, service conductors supplying one building cannot pass through the interior of another building or structure. ***NEC Section 230.6*** states that conductors are considered to be outside of a building if any of the following conditions are met:

- Where installed beneath the building under at least 2" of concrete
- Where buried under at least 18" of earth in conduit
- Located inside the building if encased in at least 2" of concrete or brick
- Installed in a vault that meets the requirements of ***NEC Article 450, Part III***

14.2.0 Grounding and Bonding

NEC Article 250 covers the requirements for grounding and bonding electric services. In general, the *NEC*® requires that a premises AC service be grounded with a grounding electrode conductor connected to a grounding electrode. It follows that all of the requirements for grounding and bonding identified in ***NEC Figure 250.1 and Table 250.3*** must be considered and applied to every electric service.

The grounding electrode conductor must be grounded to the grounded service conductor (neutral) at any accessible point from the load end of the service drop or service lateral up to and including the terminal bus to which the grounded service conductor is connected at the service disconnecting means. A grounding connection must not be made to any grounded circuit conductor on the load side of the service disconnecting means.

NEC Section 250.50 requires all grounding electrodes to be bonded. ***NEC Section 250.52*** lists the grounding electrodes as metal underground water pipe, the metal frame of the building or structure, concrete-encased electrode, ground ring, rod and pipe electrodes, other listed electrodes, and plate electrodes. These requirements apply to all electric services, regardless of the voltage rating of the service or the size (ampacity rating) of the service. ***NEC Section 250.53*** guides the installation of the grounding electrode system. *Table 4* gives the required sizes of the grounding electrode conductor for electric services.

14.3.0 High-Leg Marking

The conductor or busbar with a higher voltage to ground in a delta-connected four-wire system,

Table 4 Grounding Electrode Conductors for AC Systems

Size of Largest Service-Entrance Conductor or Equivalent for Parallel Conductors		Size of Grounding Electrode Conductor	
Copper	**Aluminum or Copper-Clad Aluminum**	**Copper**	**Aluminum or Copper-Clad Aluminum**
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250 kcmil	4	2
Over 3/0 through 350 kcmil	Over 250 kcmil through 500 kcmil	2	1/0
Over 350 kcmil through 600 kcmil	Over 500 kcmil through 900 kcmil	1/0	3/0
Over 600 kcmil through 1,100 kcmil	Over 900 kcmil through 1,750 kcmil	2/0	4/0
Over 1,100 kcmil	Over 1,750 kcmil	3/0	250 kcmil

also known as the high leg, is required to be durably and permanently marked with an outer finish that is orange in color per ***NEC Section 110.15***. If the grounded conductor is also present, this marking must appear at each point where a connection is made. In panelboards, the phase having the higher voltage to ground is the B phase.

14.4.0 Clearances

NEC Section 230.24 lists the minimum service drop clearances for various applications. Service drop conductors require a vertical clearance of no less than 8' above roof surfaces per ***NEC Section 230.24(A)*** and no less than 10' at the electrical service entrance to buildings, at the lowest point of the drip loop, and over sidewalks accessible to pedestrians only per ***NEC Section 230.24(B)(1)***. Note that this is the minimum for the lowest point of the drip loop and the weatherhead or tie point for the service drop should be a minimum of 13'-6" above grade. This accounts for the height of the weatherhead itself, the insulator that attaches to the mast below the weatherhead, the drip loop, and the conductor sag (lowest point) in a service drop, which varies by conductor size and length of drop. The insulator, whether attached to the mast or to the building, is the point of attachment for the service drop. If the service mast is to support the service drop, it must be well secured per ***NEC Section 230.28***. Meter bases should be installed with anchors to hold the weight of the meter as well as the raceway system resting on the meter base.

Service conductor clearances on buildings, porches, and platforms are covered in ***NEC Section 230.9***. They must be located at least 3' from windows, doors, porches, balconies, ladders, stairs, fire escapes, and similar locations. These clearances do not apply to windows that are not designed to be opened, or to locations where the conductor is run above the top level of the window [***NEC Section 230.9(A) Exception***].

Review Questions

1. In industrial applications, medium voltage may refer to systems rated in excess of _____.
   a. 50V to 480V
   b. 600V to 120,000V
   c. 1,000V to 38,000V
   d. 2,000V to 69,000

2. The minimum distance from a phase bus to the nearest steel member in a 4,000-amp system is _____ inches.
   a. 4
   b. 6
   c. 8
   d. 12

3. The term *interrupting rating* refers to the _____.
   a. trip setting of a circuit breaker
   b. voltage rating of a fuse
   c. highest voltage level a device can withstand
   d. maximum current a device will safely interrupt at rated voltage

4. Which of the following is a color that can be used to designate an ungrounded conductor?
   a. Green
   b. White
   c. Gray
   d. Red

5. When an unintended path is established between an ungrounded conductor and ground, it is called a(n) _____.
   a. phase fault
   b. open circuit
   c. ground fault
   d. overload

6. A device that is specifically designed to protect equipment from ground faults through the use of sensors is a _____.
   a. molded-case circuit breaker
   b. dual-element fuse
   c. ground fault relay
   d. ground fault circuit interrupter

7. The maximum voltage that a piece of equipment can withstand is known as its _____.
   a. interrupting capacity
   b. basic impulse insulation level (BIL)
   c. current limit
   d. frequency

8. A transformer rated at more than 500kVA is considered a(n) _____ transformer.
   a. power
   b. control
   c. distribution
   d. isolation

9. The term *capacity* on a transformer nameplate refers to _____.
   a. its voltage rating
   b. its ability to transfer energy
   c. the voltage produced by the secondary
   d. the number of secondary windings

10. The term *class* on a transformer nameplate refers to _____.
    a. its use, such as control or power
    b. the type of cooling it uses
    c. whether it is –step-up or –step-down
    d. its range of operating frequencies

11. Potential transformers and current transformers are both types of instrument transformers.
    a. True
    b. False

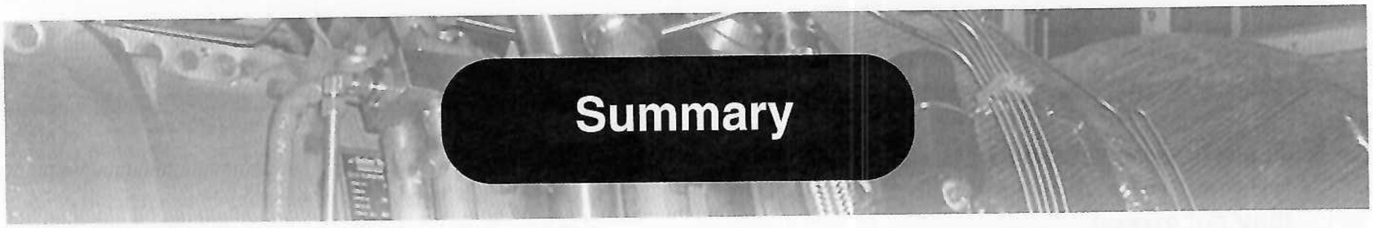
12. Of the following types of current transformers, which is normally used with circuit breakers or power transformers?
    a. Bar
    b. Bushing
    c. Oil-filled
    d. Window

13. Which of the following is a general classification of circuit breakers?
    a. Fuse circuit breaker
    b. Air circuit breaker
    c. Liquid circuit breaker
    d. Bonded circuit breaker

Review Questions

14. The trip rating of a circuit breaker used as the main protective device in a panelboard may not exceed _____.
    a. the total amperage of the branch breakers
    b. the amperage capacity of the busbars in the panelboard
    c. the amperage of the individual branch fuses
    d. 250V

15. According to the IEEE Identification System found in the *Appendix* of this module, if device No. 51 is indicated on an electrical print, it would be a(n) _____.
    a. circuit breaker
    b. reverse power relay
    c. field circuit breaker
    d. AC time overcurrent relay



Summary

This module explained the purpose of switchgear. Switchgear construction, metering layouts, wiring requirements, and maintenance were discussed. It also explained *NEC®* requirements for these systems and provided a basic understanding of how to apply them. Circuit breakers, their four general classifications, and the major circuit breaker ratings were also addressed. Additionally, ground fault relay systems and the testing of such systems were explained. This module also covered visual and mechanical inspections and electrical tests associated with low-voltage and medium-voltage cables, metal-enclosed busways, and metering and instrumentation.

Notes

Trade Terms Introduced in This Module

Air circuit breaker: A circuit breaker in which the interruption occurs in air.

Basic impulse insulation level (BIL): The maximum impulse voltage the winding insulation can withstand without failure.

Bus: A conductor or group of conductors that serves as a common connection for two or more circuits in a switchgear assembly.

Bushing: An insulating structure including a through conductor, or providing a passageway for such a conductor, for the purpose of insulating the conductor from the barrier and conducting from one side of the barrier to the other.

Capacity: The rated load-carrying ability, expressed in kilovolt-amperes or kilowatts, of generating equipment or other electric apparatus.

Current transformer (CT): A single-phase instrument transformer connected in series in a line that carries the full-load current. The turns ratio is designed to produce a reduced current in the secondary suitable for the current coil of standard measuring instruments and in proportion to the load current.

Distribution system equipment: Switchboard equipment that is downstream from the service-entrance equipment.

Distribution transformer: A transformer that is used for transferring electric energy from a primary distribution circuit to a secondary distribution circuit. Distribution transformers are usually rated between 5kVA and 500kVA.

Feeder: A set of conductors originating at a main distribution center that supply one or more secondary distribution centers, one or more branch circuit distribution centers, or any combination of these two types of loads.

Frame size: A method used to classify circuit breakers according to given current ratings.

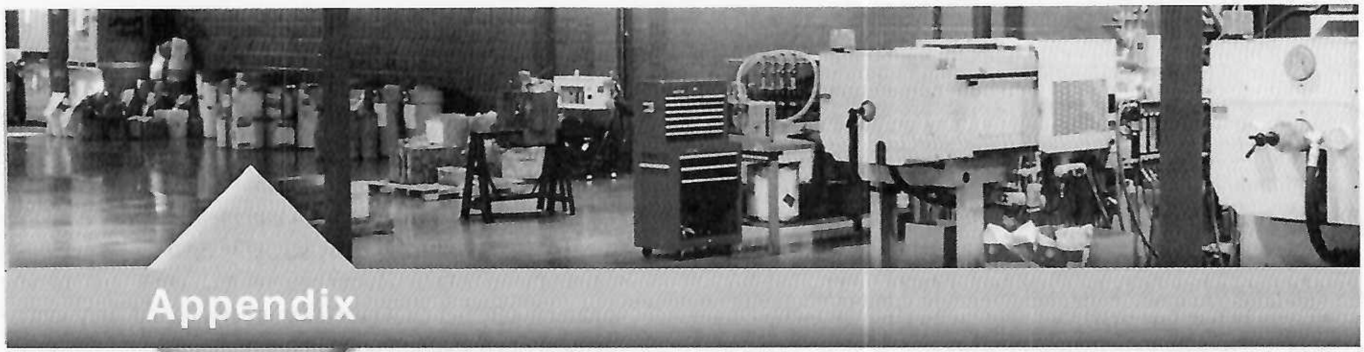
Metal-enclosed switchgear: Switchgear that is primarily used in indoor applications up to 600V.

Potential transformer (PT): A special transformer designed for use in measuring high voltage; normally, the secondary voltage is 120V.

Service-entrance equipment: Equipment located at the service entrance of a building that provides overcurrent protection to the feeder and service conductors and also provides a means of disconnecting the feeders from the energized service equipment.

Switchboard: A large single panel, frame, or assembly of panels on which switches, fuses, buses, and instruments are mounted.

Switchgear: A general term covering switching or interrupting devices and any combination thereof with associated control, instrumentation, metering, protective, and regulating devices.



Appendix

IEEE Identification System

The devices in switching equipment are referred to by numbers with appropriate suffix letters when necessary, according to the functions they perform.

These numbers are based on a system adopted as standard for automatic switchgear by IEEE and incorporated in *American Standard C37.2-1970*. This system is used in connection diagrams, instruction books, and specifications.

Device Number	Definition and Function
1	**Master Element** – The initiating device, such as a control switch, voltage relay, float switch, that serves either directly, or through such permissive devices as protective and time-delay relays, to place equipment in or out of operation.
2	**Time-Delay Starting or Closing Relay** – A device that functions to give a desired amount of time delay before or after any point of operation in a switching sequence or protective relay system, except as specifically provided by device functions 48, 62, and 79 described later.
3	**Checking or Interlocking Relay** – A device that operates in response to the position of a number of other devices (or to a number of predetermined conditions) in 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** – A device, generally controlled by device No. 1 or equivalent, and the required permissive and protective devices, that serves to make and break the necessary control circuits to place equipment into operation under the desired conditions and to take it out of operation under other or abnormal conditions.
5	**Stopping Device** – A control device used primarily to shut down equipment and hold it out of operation. [This device may be manually or electrically actuated, but excludes the function of electrical lockout (see device function 86) on abnormal conditions.]
6	**Starting Circuit Breaker** – A device whose principal function is to connect a machine to its source of starting voltage.
7	**Anode Circuit Breaker** – A device 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** – A disconnective device, such as a knife switch, circuit breaker, or pullout fuse block, that is used for the purpose of connecting and disconnecting the source of control power to and from the control bus or equipment. ***Note:*** Control power is considered to include auxiliary power which supplies such apparatus as small motors and heaters.
9	**Reversing Device** – A device used for the purpose of reversing a machine field or for performing any other reversing functions.
10	**Unit Sequence Switch** – A device used to change the sequence in which units may be placed in and out of service in multiple-unit equipment.
11	Reserved for future application.
12	**Over-Speed Device** – Usually a direct-connected speed switch that functions on machine over-speed.
13	**Synchronous-Speed Device** – A device such as a centrifugal-speed switch, slip-frequency relay, voltage relay, or undercurrent relay, that operates at approximately the synchronous speed of a machine.
14	**Under-Speed Device** – A device that functions when the speed of a machine falls below a predetermined value.
15	**Speed- or Frequency-Matching Device** – A device that functions to match and hold the speed or frequency of a machine or of a system equal to, or approximately equal to, that of another machine, source, or system.

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Device Number	Definition and Function
16	Reserved for future application.
17	**Shunting or Discharge Switch** – A device that serves to open or close a shunting circuit around any piece of apparatus (except a resistor), such as machine field, machine armature, capacitor, or reactor. ***Note:*** This excludes devices that perform such shunting operations as may be necessary in the process of starting a machine by devices 6 or 42, or their equivalent, and also excludes the device 73 function, which serves for the switching of resistors.
18	**Accelerating or Decelerating Device** – A device used to close or to cause the closing of circuits that are used to increase or decrease the speed of a machine.
19	**Starting-to-Running Transition Contactor** – A device that operates to initiate or cause the automatic transfer of a machine from the starting to the running power connection.
20	**Electrically Operated Valve** – An electrically operated, controlled, or monitored valve in a fluid line. ***Note:*** The function of the valve may be indicated by the use of suffixes.
21	**Distance Relay** – A device that functions when the circuit admittance, impedance, or reactance increases or decreases beyond predetermined limits.
22	**Equalizer Circuit Breaker** – A breaker that serves to control or to make and break the equalizer or the current-balancing connections for a field, or for regulating equipment, in a multiple-unit installation.
23	**Temperature Control Device** – A device that functions to raise or lower the temperature of a machine or other apparatus, or of any medium, when its temperature falls below or rises above a predetermined value. ***Note:*** An example is a thermostat that switches on a space heater in a switchgear assembly when the temperature falls to a desired value as distinguished from a device that 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** – A device that operates when two AC circuits are within the desired limits of frequency, phase angle, or voltage to permit or to cause the paralleling of these two circuits.
26	**Apparatus Thermal Device** – A device that 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; it also functions if the temperature of the protected apparatus, such as a power rectifier, or of any medium decreases below a predetermined value.
27	**Undervoltage Relay** – A device that functions on a given value of undervoltage.
28	**Flame Detector** – A device that monitors the presence of the pilot or main flame in such apparatus as a gas turbine or steam boiler.
29	**Isolating Contactor** – A device used expressly for disconnecting one circuit from another for the purposes of emergency operation, maintenance, or testing.
30	**Annunciator Relay** – A nonautomatic reset device that gives a number of separate visual indications upon the functioning of protective devices and that may also be arranged to perform a lockout function.
31	**Separate Excitation Device** – A device that connects a circuit, such as the shunt field of a synchronous converter, to a source of separate excitation during the starting sequence or one that energizes the excitation and ignition circuits of a power rectifier.

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Device Number	Definition and Function
32	**Directional Power Relay** – A device that 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** – A device that makes or breaks its contacts when the main device or piece of apparatus that has no device function number reaches a given position.
34	**Master Sequence Device** – A device, such as a motor-operated multi-contact switch or the equivalent, or a programming device, such as a computer, that establishes or determines the operating sequence of the major devices in equipment during starting and stopping or during other sequential switching operations.
35	**Brush-Operating or Slip-Ring Short-Circuiting Device** – A device used for raising, lowering, or shifting the brushes of a machine; for short-circuiting its slip rings, or for engaging or disengaging the contacts of a mechanical rectifier.
36	**Polarity or Polarizing Voltage Device** – A device that operates or permits the operation of another device on a predetermined polarity only, or one that verifies the presence of a polarizing voltage in equipment.
37	**Undercurrent or Underpower Relay** – A device that functions when the current or power flow decreases below a predetermined value.
38	**Bearing Protective Device** – A device that functions on excessive bearing temperature or on other abnormal mechanical conditions, such as undue wear, that may eventually result in excessive bearing temperature.
39	**Mechanical Condition Monitor** – A device that functions upon the occurrence of an abnormal mechanical condition (except that associated with bearings as covered under device function 38), such as excessive vibration, eccentricity, expansion, shock, tilting, or seal failure.
40	**Field Relay** – 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 AC machine indicating abnormally low field excitation.
41	**Field Circuit Breaker** – A device that functions to apply or remove the field excitation of a machine.
42	**Running Circuit Breaker** – A device whose principal function is to connect a machine to its source of running or operating voltage. This function may also be used for a device, such as a contactor, that is used in series with a circuit breaker or other fault protecting means, primarily for frequent opening and closing of the circuit.
43	**Manual Transfer or Selector Device** – A device that 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** – A device that functions to start the next available unit in multiple-unit equipment on the failure or non-availability of the normally preceding unit.
45	**Atmospheric Condition Monitor** – A device that functions upon the occurrence of an abnormal atmospheric condition, such as damaging fumes, explosive mixtures, smoke, or fire.
46	**Reverse-Phase or Phase-Balance Current Relay** – A device that 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** – A relay that functions upon a predetermined value of polyphase voltage in the desired phase sequence.
48	**Incomplete Sequence Relay** – A relay that generally 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. If the device is used for alarm purposes only, it should preferably be designated as 48A (alarm).

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Device Number	Definition and Function
49	**Machine or Transformer Thermal Relay** – A relay that functions when the temperature of a machine armature, or other load-carrying winding or element of a machine or the temperature of a power rectifier or power transformer (including a power rectifier transformer) exceeds a predetermined value.
50	**Instantaneous Overcurrent or Rate-of-Rise Relay** – A relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise, indicating a fault in the apparatus or circuit being protected.
51	**AC Time Overcurrent Relay** – A relay with either a definite or inverse time characteristic that functions when the current in an AC circuit exceeds a predetermined value.
52	**AC Circuit Breaker** – A device that is used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
53	**Exciter or DC Generator Relay** – A relay that forces the DC machine field excitation to build up during starting or which functions when the machine voltage has built up to a given value.
54	Reserved for future application.
55	**Power Factor Relay** – A relay that operates when the power factor in an AC circuit rises above or below a predetermined value.
56	**Field Application Relay** – A relay that automatically controls the application of the field excitation to an AC motor at some predetermined point in the slip cycle.
57	**Short-Circuiting or Grounding Device** – A primary circuit switching device that functions to short-circuit or ground a circuit in response to automatic or manual means.
58	**Rectification Failure Relay** – A device that functions if one or more anodes of a power rectifier fail to fire, to detect an arc-back, or on failure of a diode to conduct or block properly.
59	**Overvoltage Relay** – A relay that functions on a given value of overvoltage.
60	**Voltage or Current Balance Relay** – A relay that operates on a given difference in voltage or current input or output of two circuits.
61	Reserved for future application.
62	**Time-Delay Stopping or Opening Relay** – A time-delay relay that serves in conjunction with the device that initiates the shutdown, stopping, or opening operation in an automatic sequence.
63	**Pressure Switch** – A switch that operates on given values or on a given rate of change of pressure.
64	**Ground Protective Relay** – A relay that functions on failure of the insulation of a machine, transformer, or other apparatus to ground or on flashover of a DC machine to ground. ***Note:*** This function is assigned only to a relay that detects the flow of current from the frame of a machine or enclosing case or structure of a piece of apparatus to ground or one that 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 connected in the power circuit of a normally grounded system.
65	**Governor** – The assembly of fluid, electrical, or mechanical control equipment used for regulating the flow of water, steam, or other medium to the prime mover for such purposes as starting, holding speed or load, or stopping.

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Device Number	Definition and Function
66	**Notching or Jogging Device** – A device that 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 for fractions of specified time intervals or that is used to permit intermittent acceleration or jogging of a machine at low speeds for mechanical positioning.
67	**AC Directional Overcurrent Relay** – A relay that functions on a desired value of AC overcurrent flowing in a predetermined direction.
68	**Blocking Relay** – A relay that initiates a pilot signal for blocking of tripping on external faults in a transmission line or in other apparatus under predetermined conditions, or a relay cooperates with other devices to block tripping or to block reclosing on an out-of-step condition or on power swings.
69	**Permissive Control Device** – Generally a two-position, manually operated switch that in one position permits the closing of a circuit breaker or the placing of equipment into operation and in the other position prevents the circuit breaker or the equipment from being operated.
70	**Rheostat** – A variable resistance device used in an electric circuit that is electrically operated or has other electrical accessories, such as auxiliary, position, or limit switches.
71	**Level Switch** – A switch that operates on given values or on a given rate of change of level.
72	**DC Circuit Breaker** – A circuit breaker used to close and interrupt a DC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
73	**Load-Resistor Contactor** – A contactor used to shunt or insert a step of load limiting, shifting, or indicating resistance in a power circuit, to switch a space heater in a circuit, or to switch a light or regenerative load resistor of a power rectifier or other machine in and out of a circuit.
74	**Alarm Relay** – A device other than an annunciator, as covered under device No. 30, that is used to operate or to operate in connection with a visual or audible alarm.
75	**Position Changing Mechanism** – A mechanism that is used for moving a main device from one position to another in equipment (for example, shifting a removable circuit breaker unit to and from the connected, disconnected, and test positions).
76	**DC Overcurrent Relay** – A relay that functions when the current in a DC circuit exceeds a given value.
77	**Pulse Transmitter** – A device used to generate and transmit pulses over a telemetering or pilot-wire circuit to remove the indicating or receiving device.
78	**Phase Angle Measuring or Out-of-Step Protective Relay** – A relay that functions at a predetermined phase angle between two voltages, between two currents, or between voltage and current.
79	**AC Reclosing Relay** – A relay that controls the automatic reclosing and locking out of an AC circuit interrupter.
80	**Flow Switch** – A switch that operates on given values, or a given rate of change of flow.
81	**Frequency Relay** – A relay that functions on a predetermined value of frequency, either under, over, or on normal system frequency or rate of change of frequency.
82	**DC Reclosing Relay** – A relay that controls the automatic closing and reclosing of a DC circuit interrupter, generally in response to load circuit conditions.
83	**Automatic Selective Control or Transfer Relay** – A relay that operates to select automatically between certain sources or conditions in equipment or that performs a transfer operation automatically.

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Device Number	Definition and Function
84	**Operating Mechanism** – The complete electrical mechanism or servo-mechanism, including the operating motor, solenoids, position switches, and for a tap changer, induction regulator, or any similar piece of apparatus that has no device function number.
85	**Carrier or Pilot-Wire Receiver Relay** – A relay that is operated or restrained by a signal used in connection with carrier-current or DC pilot-wire fault directional relaying.
86	**Locking-Out Relay** – An electrically operated relay that functions to shut down and hold equipment out of service on the occurrence of abnormal conditions. It may be reset either manually or electrically.
87	**Differential Protective Relay** – A protective relay that functions on a percentage of phase angle or other quantitative difference of two currents or of some other electrical quantities.
88	**Auxiliary Motor or Motor Generator** – A device used for operating auxiliary equipment, such as pumps, blowers, exciters, and rotating magnetic amplifiers.
89	**Line Switch** – A switch used as a disconnecting load-interrupter or isolating switch in an AC or DC power circuit when this device is electrically operated or has electrical accessories, such as an auxiliary switch or magnetic lock.
90	**Regulating Device** – A device that functions to regulate a quantity, or quantities, such as voltage, current, power, speed, frequency, temperature, and load, at a certain value or between certain (generally close) limits for machines, tie lines, or other apparatus.
91	**Voltage Directional Relay** – A relay that 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** – A relay that 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** – A device that functions to increase or decrease in one step the value of field excitation on a machine.
94	**Tripping or Trip-Free Relay** – A device that functions to trip a circuit breaker, contactor, or equipment, 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	Used only for specific applications on individual installations where none of the assigned numbered functions from 1 to 94 is suitable.

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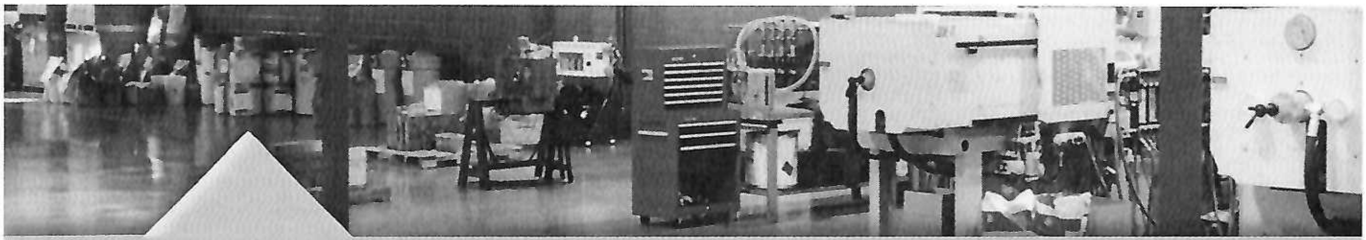

Resources & Acknowledgments

Additional Resources

This module is intended to be a thorough resource for task training. The following reference work is suggested for further study. This is optional material for continued education rather than for task training.

National Electrical Code® Handbook, Latest Edition. Quincy, MA: National Fire Protection Association.

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