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An Introduction to Switchgear for Auxiliary Power Systems

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An Introduction to Switchgear for Auxiliary Power Systems

J. Paul Guyer, P.E., R.A.

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1. SWITCHGEAR DEFINITION. Switchgear is a general term covering switching and interrupting devices that control, meter and protect the flow of electric power. The component parts include circuit breakers, instrument transformers, transfer switches, voltage regulators, instruments, and protective relays and devices. Switchgear includes associated interconnections and supporting or enclosing structures. The various configurations range in size from a single panel to an assembly of panels and enclosures (see fig 5-l). Figure 5-2 contains a diagram of typical switchgear control circuitry. Switchgear subdivides large blocks of electric power and performs the following missions:

- Distributes incoming power between technical and non-technical loads.
- Isolates the various loads.
- Controls auxiliary power sources.
- Provides the means to determine the quality and status of electric power.
- Protects the generation and distribution systems.

2. TYPES OF SWITCHGEAR. Voltage classification: Low voltage and medium voltage switchgear equipment are used in auxiliary power generation systems. Switchgear at many installations is usually in a grounded, metal enclosure (see fig 5-l). Per the Institute of Electrical and Electronics Engineers (IEEE), equipment rated up to 1000 volts AC is classed as low voltage. Equipment equal to or greater than 1000 volts but less than 100,000 volts AC is classed as medium voltage.

2.1 LOW VOLTAGE. Major elements of low voltage switchgear are circuit breakers, potential transformers, current transformers, and control circuits, refer to paragraph 5-3. Related elements of the switchgear include the service entrance conductor, main box, switches, indicator lights, and instruments. The service entrance conductor and bus (sized as required) are typical heavy duty conductors used to carry heavy current loads.

2.2 MEDIUM VOLTAGE. Medium voltage switchgear consists of major and related elements as in low voltage switchgear. Construction of circuit breakers employed in the two types of switchgear and the methods to accomplish breaker tripping are the primary differences. The service entrance conductors and main bus are typical heavy-duty conductors rated for use between 601 volts AC and 38,000 volts AC, as required.

3. LOW VOLTAGE ELEMENTS.

3.1 CIRCUIT BREAKERS. Either molded-case or air circuit breakers are used with low voltage switchgear. Usually the air circuit breakers have draw-out construction. This feature permits removal of an individual breaker from the switchgear enclosure for inspection or maintenance without de-energizing the main bus.

3.1.1 AIR CIRCUIT BREAKERS. Air circuit breakers are usually used for heavy-duty, low voltage applications. Heavy-duty circuit breakers are capable of handling higher power loads than molded-case units and have higher current-interrupting capacity. Air circuit breakers feature actuation of contacts by stored energy which is either electrically or manually applied. Accordingly, the mechanism is powered to be put in a position where stored energy can be released to close or open the contacts very quickly. Closing or tripping action is applied manually (by hand or foot power) or electrically (where a solenoid provides mechanical force). The mechanical force may be applied magnetically. Air circuit breakers contain power sensor overcurrent trip devices that detect an overcurrent to the load and initiate tripping or opening of the circuit breaker.

3.1.1.1 MANUAL CIRCUIT BREAKERS employ spring operated, stored-energy mechanisms for operation. Release of the energy results in quick operation of the mechanism to open or close the contacts. Operating speed is not dependent on the speed or force used by the operator to store the energy.

3.1.1.2 FAST AND POSITIVE action prevents unnecessary arcing between the movable and stationary contacts. This results in longer contact and breaker life.

3.1.1.3 MANUAL STORED-ENERGY circuit breakers have springs which are charged by operation of the insulated handle. The charging action energizes the spring prior to closing or opening of the circuit breaker. The spring, when fully charged, contains enough stored energy to provide at least one closing and one opening of the circuit breaker. The charged spring provides quick and positive operation of the circuit breaker. Part of the stored energy, which is released during closing, may be used to charge the opening springs.

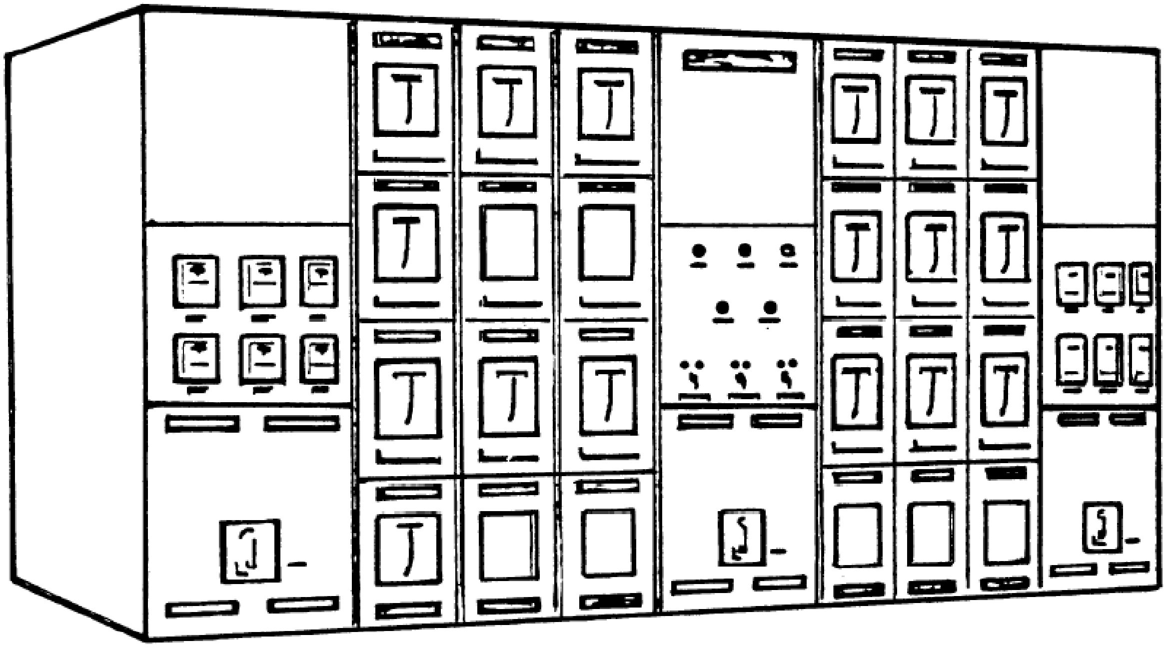


Figure 5-l

Typical arrangement of metal enclosed switchgear

3.1.1.4 SOME MANUAL BREAKERS require several up-down strokes to fully charge. The springs are released on the final downward stroke. In either of the manual units, there is no motion of the contacts until the springs are released.

3.1.1.5 ELECTRICAL QUICK-MAKE/QUICK-BREAK breakers are operated by a motor or solenoid. In small units, a solenoid is used to conserve space. In large sizes, an AC/DC motor is used to keep control-power requirements low (4 amps at 230 volts).

3.1.1.6 WHEN THE SOLENOID is energized, the solenoid charges the closing springs and drives the mechanism past the central/neutral point in one continuous motion.

Motor-operated mechanisms automatically charge the closing springs to a predetermined level. When a signal to close is delivered, the springs are released and the breaker contacts are closed. The motor or solenoid does not aid in the closing stroke; the springs supply all the closing power. There is sufficient stored-energy to close the contacts under short-circuit conditions. Energy for opening the contacts is stored during the closing action.

3.1.1.7 A SECOND SET OF SPRINGS opens the contacts when the breaker receives a trip impulse or signal. The breaker can be operated manually for maintenance by a detachable handle.

3.1.1.8 CIRCUIT BREAKERS usually have two or three sets of contacts: main; arcing; and intermediate. Arcing and intermediate contacts are adjusted to open after the main contacts open to reduce burning or pitting of the main contacts.

3.1.1.9 A TYPICAL POWER sensor for an air circuit breaker precisely controls the breaker opening time in response to a specified level of fault current. Most units function as overcurrent trip devices and consist of a solenoid tripper and solid-state components.

The solid-state components are part of the power sensor and provide precise and sensitive trip signals.

3.1.2 MOLDED-CASE CIRCUIT BREAKERS. Low current and low energy power circuits are usually controlled by molded-case circuit breakers. The trip elements act directly to release the breaker latch when the current exceeds the calibrated current magnitude. Typical time-current characteristic curves for molded-case circuit breakers are shown in figure 5-3.

3.1.2.1 THERMAL-MAGNETICCIRCUIT BREAKERS have a thermal bi-metallic element for an inverse time-current relationship to protect against sustained overloads. This type also has an instantaneous magnetic trip element for short-circuit protection.

3.1.2.2 MAGNETIC TRIP-ONLY CIRCUIT BREAKERS have no thermal elements. This type has a magnetic tripping arrangement to trip instantaneously, with no purposely introduced time delay, at currents equal to, or above, the trip setting. These are used only for short-circuit protection of motor branch circuits where motor overload or running protection is provided by other elements.

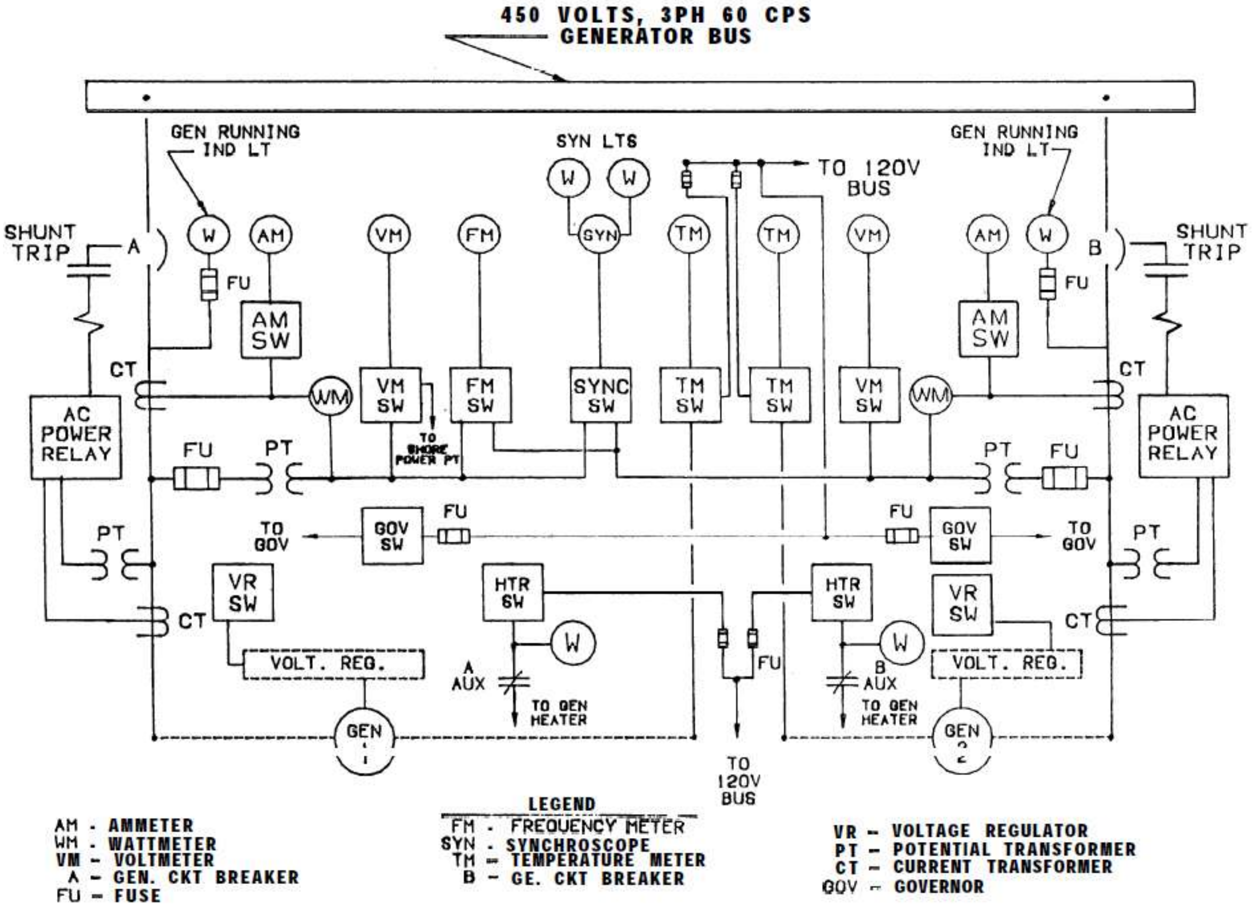


Figure 5-2

Typical switchgear control circuitry, one-line diagram

3.1.2.3 NON-AUTOMATIC CIRCUIT INTERRUPTERS have no automatic overload or short circuit trip elements. These are used for manual switching and isolation. Other devices must be provided for short circuit and overload protection.

3.2 POTENTIAL TRANSFORMERS. A potential transformer (PT) is an accurately wound, low voltage loss instrument transformer having a fixed primary to secondary "step down" voltage ratio. The PT is mounted in the high voltage enclosure and only the

low voltage leads from the secondary winding are brought out to the metering and control panel. The PT isolates the high voltage primary from the metering and control panel and from personnel. The step down ratio produces about 120 VAC across the secondary when rated voltage is applied to the primary. This permits the use of standard low voltage meters (120 VAC full scale) for all high voltage circuit metering and control.

3.2.1 RATINGS. A PT is rated for the primary voltage along with the turns (step down) ratio to secure 120 VAC across the secondary.

3.2.2 APPLICATION. The primary of potential transformers is connected either line-to-line or line-to neutral, and the current that flows through this winding produces a flux in the core. Since the core links the primary and secondary windings, a voltage is induced in the secondary circuit (see fig 5-4). The ratio of primary to secondary voltage is in proportion to the number of turns in the primary and secondary windings. This proportion produces 120 volts at the secondary terminals when rated voltage is applied to the primary.

3.2.3 DOT CONVENTION. A dot convention is used in figure 5-5. The dot convention makes use of a large dot placed at one end of each of the two coils which are mutually coupled. A current entering the dotted terminal of one coil produces an open-circuit voltage between the terminals of the second coil. The voltage measured with a positive voltage reference at the dotted terminal of the second coil.

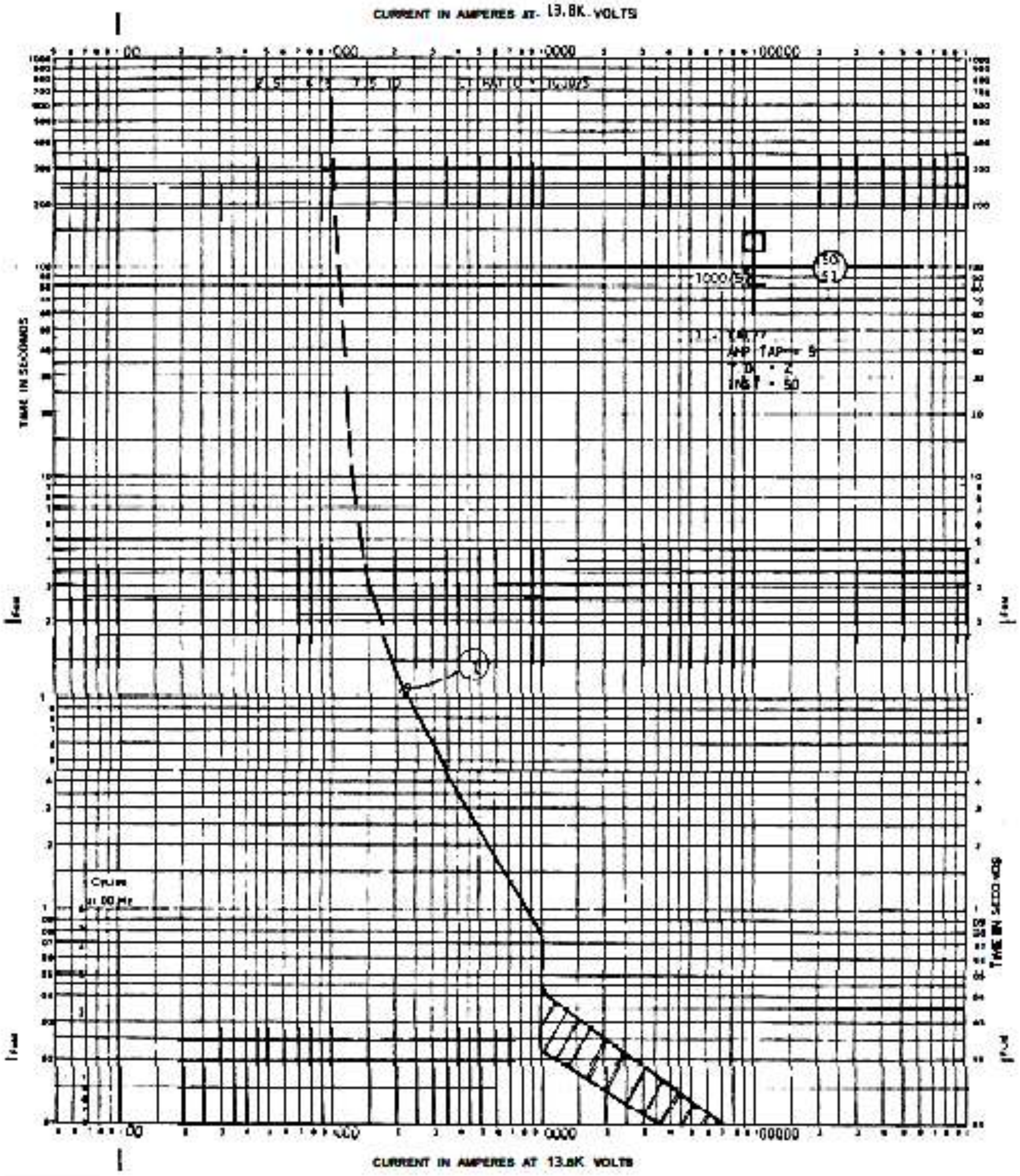


Figure 5-3

Typical time-current characteristic curve

3.3 CURRENT TRANSFORMERS. A current transformer (CT) is an instrument transformer having low losses whose purpose is to provide a fixed primary to secondary step down current ratio. The primary to secondary current ratio is in inverse proportion to the primary to secondary turns ratio. The secondary winding thus has multiple turns. The CT is usually either a toroid (doughnut) winding with a primary conductor wire passing through the “hole”, or a section of bus bar (primary) around which is wound the secondary. The bus bar CT is inserted into the bus being measured. The CT ratio is selected to result in a five ampere secondary current when primary rated current is flowing (see fig 5-4).

3.3.1 RATINGS. Toroidal CTs are rated for the size of the primary conductor diameter to be surrounded and the primary to secondary current (5A) ratio. Bus bar type CTs are rated for the size of bus bar, primary voltage and the primary to secondary current ratio.

3.3.2 APPLICATION. The primary of a CT is either the line conductor or a section of the line bus. The secondary current, up to 5A, is directly proportional to the line current. The ratio of the primary to secondary current is inversely proportional to the ratio of the primary turns to secondary turns.

3.3.3 SAFETY. A CT, in stepping down the current, also steps up voltage. The voltage across the secondary is at a dangerously high level when the primary is energized. The secondary of a CT must either be shorted or connected into the closed metering circuit. Never open a CT secondary while the primary circuit is energized.

3.4 POLARITIES. When connection secondaries of PTs and CTs to metering circuits the correct polarities of all leads and connections must be in accordance with the metering circuit design and the devices connected. Wrong polarity connections will give false readings and result in inaccurate data, damage and injury. All conductors and terminations should carry identification that matches schematics, diagrams and plans used for construction and maintenance.

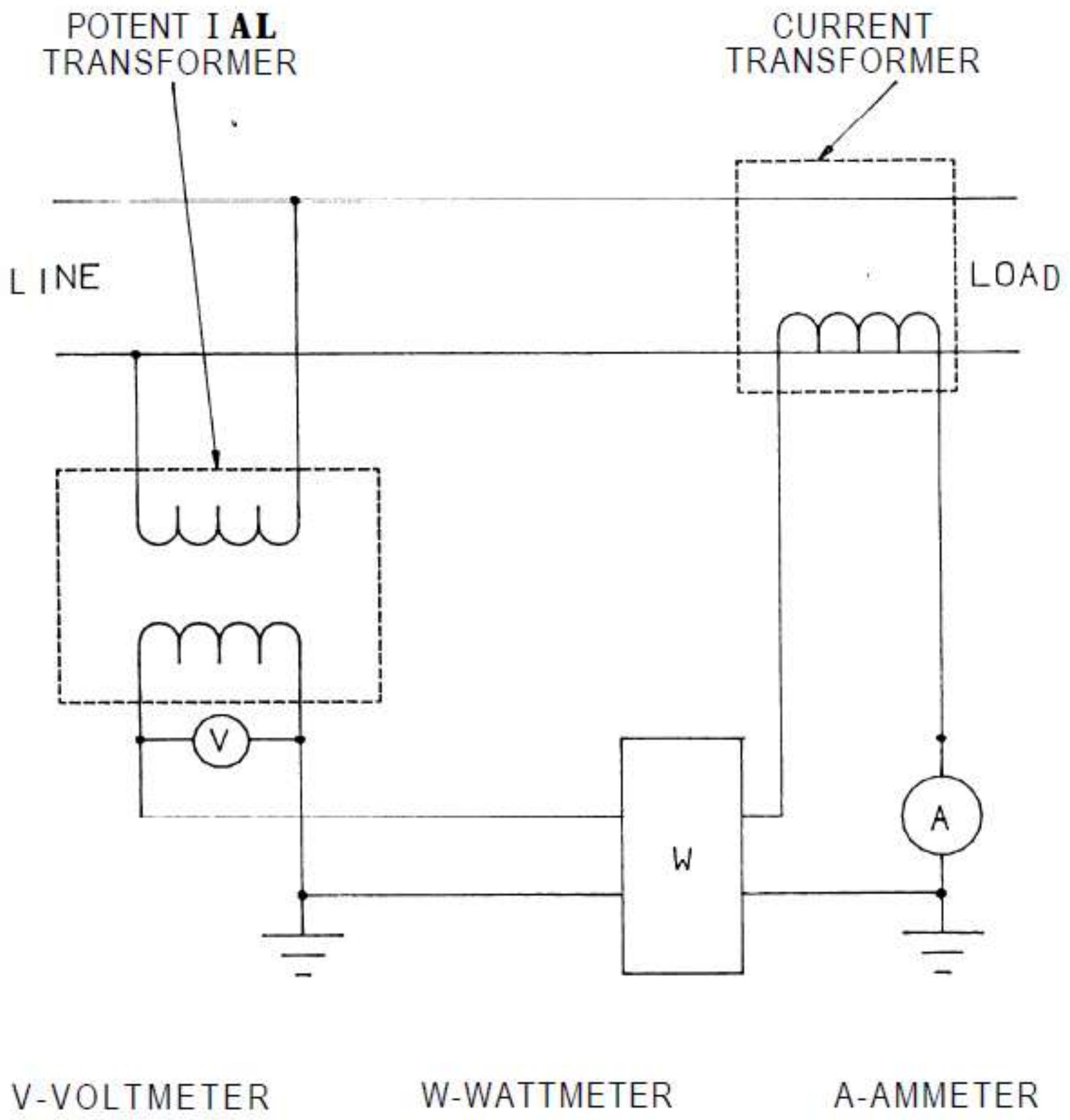


Figure 5-4

Instruments transformers, typical applications

3.5 CONTROL CIRCUITS. Switchgear control circuits provide control power for the starting circuit of the prime movers and the closing and tripping of the switchgear circuit breakers. Additionally, the control circuits provide control power to operate the various relays and indicating lights associated with the control circuitry. The control circuits are classified as either AC or DC.

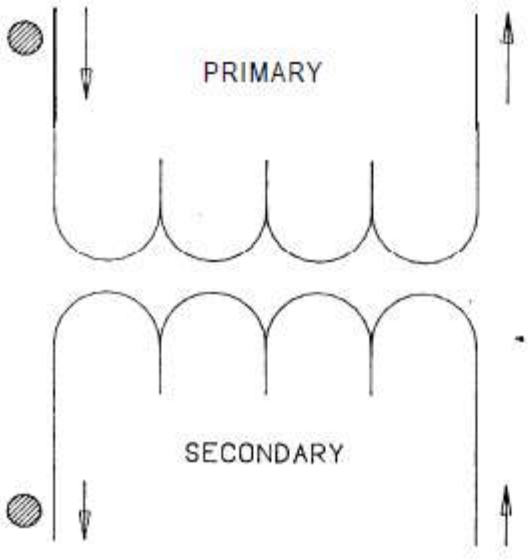


Figure 5-5

Current flow in instrument transformers. ‘Polarity” marks show instantaneous flows

3.5.1 AC CONTROL CIRCUITS. AC control circuits usually derive their power from the source side of the circuit breaker being controlled. This procedure applies to main incoming line circuit breakers, generator circuit breakers, and feeder circuit breakers (see fig 5-6). Depending on the system voltage, the control power can be taken directly from the main bus since it can be connected through a control power transformer.

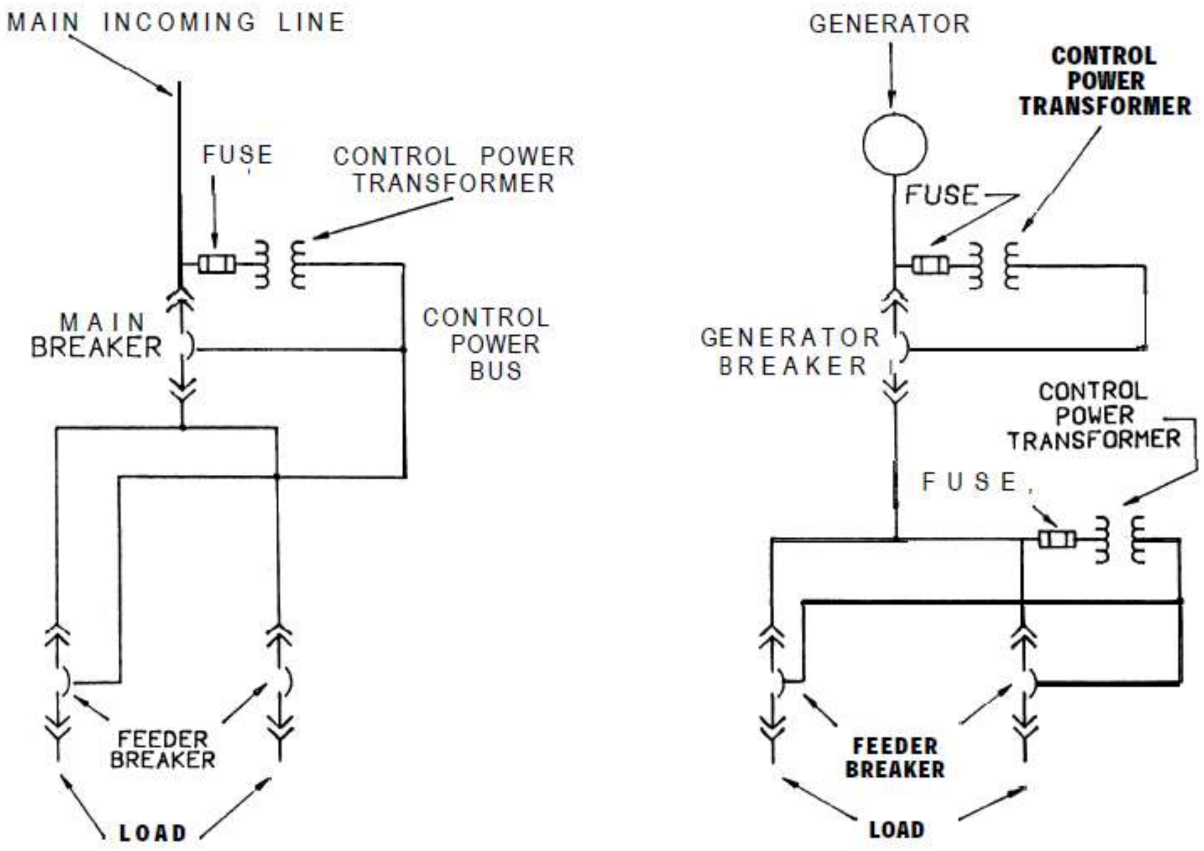


Figure 5-6

AC control circuits

3.5.2 TIE BREAKER CONTROL CIRCUITS. In systems using a tie breaker, the control power for the tie breaker and the feeder breakers is supplied through a throw-over scheme so control power is available if either side of the tie breaker is energized (see fig 5-7). In applications that require synchronizing circuitry, the running and incoming control buses are usually supplied via the potential transformers. The transformer primaries are connected to both the line side and the load side of the circuit breakers that are used for synchronizing. The transformer secondaries are connected to the proper control bus through contacts on the synchronizing switch, or through contacts on certain auxiliary relays. The synchronizing switch would be used for manual operation and the auxiliary relay would be used when automatic synchronizing is provided.

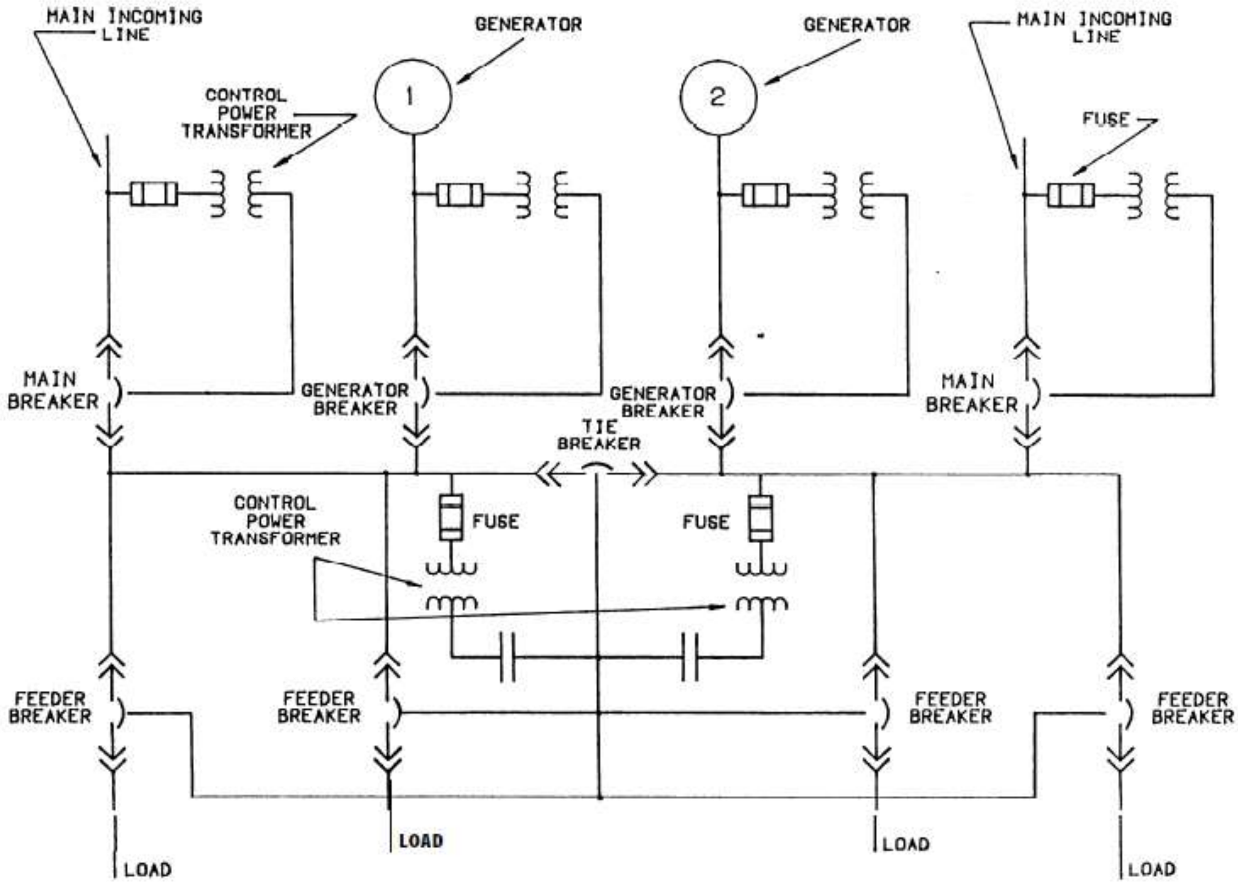


Figure 5-7

AC control circuits with tie circuit breaker

3.5.3 DC CONTROL CIRCUITS. DC control circuits derive their power from a battery source consisting of a bank of batteries and a battery charger that maintains the batteries at the proper charge. The battery bank can be rated at various levels ranging between 24 volts and 125 volts DC. Those circuits that require a source of control power completely independent of the power system are connected to the DC control bus. Examples of these are the prime mover starting circuits, and in some cases, the trip circuits for the circuit breakers when devices, other than the direct-acting overcurrent trip devices, are used. Also, the closing circuits for the circuit breakers are sometimes connected to the DC control bus.

3.6 OWNER PRACTICES. Owner practices for low voltage switchgear consist of a complete maintenance program that is built around equipment and system records and visual inspections. The program is described in the manufacturer’s literature furnished with the components. If a problem develops, the user should perform general troubleshooting procedures. The program includes appropriate analysis of the records.

3.6.1 RECORD KEEPING. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets must be specifically developed to suit individual application (i.e., auxiliary use).

3.6.2 TROUBLESHOOTING. Perform troubleshooting procedures when abnormal operation of the system or equipment is observed. Maintenance personnel must then refer to records for interpretation and comparison of performance data (i.e., log sheets). Comparisons of operation should be made under equal or closely similar conditions of load and ambient temperature. The shooting is outlined in a troubleshooting table and the following paragraphs.

3.6.2.1 USE RECOGNIZED INDUSTRIAL PRACTICES as the general guide for servicing and refer to manufacturer’s literature.

3.6.2.2 THE USER SHOULD refer to manufacturer’s literature for specific information on individual circuit breakers.

3.6.2.3 GENERAL SERVICE INFORMATION for circuit breakers includes the following safety requirements. Do not work on an energized breaker. Do not work on any part of a breaker with test couplers engaged. Test couplers connect the breaker to the control circuit during testing. Spring-charged breaker mechanisms shall be serviced only by personnel experienced in releasing the spring load in a controlled manner. Make operational tests and checks on a breaker after maintenance, before it is returned to service. Do not work on a spring charged circuit breaker when it is in the charged position.

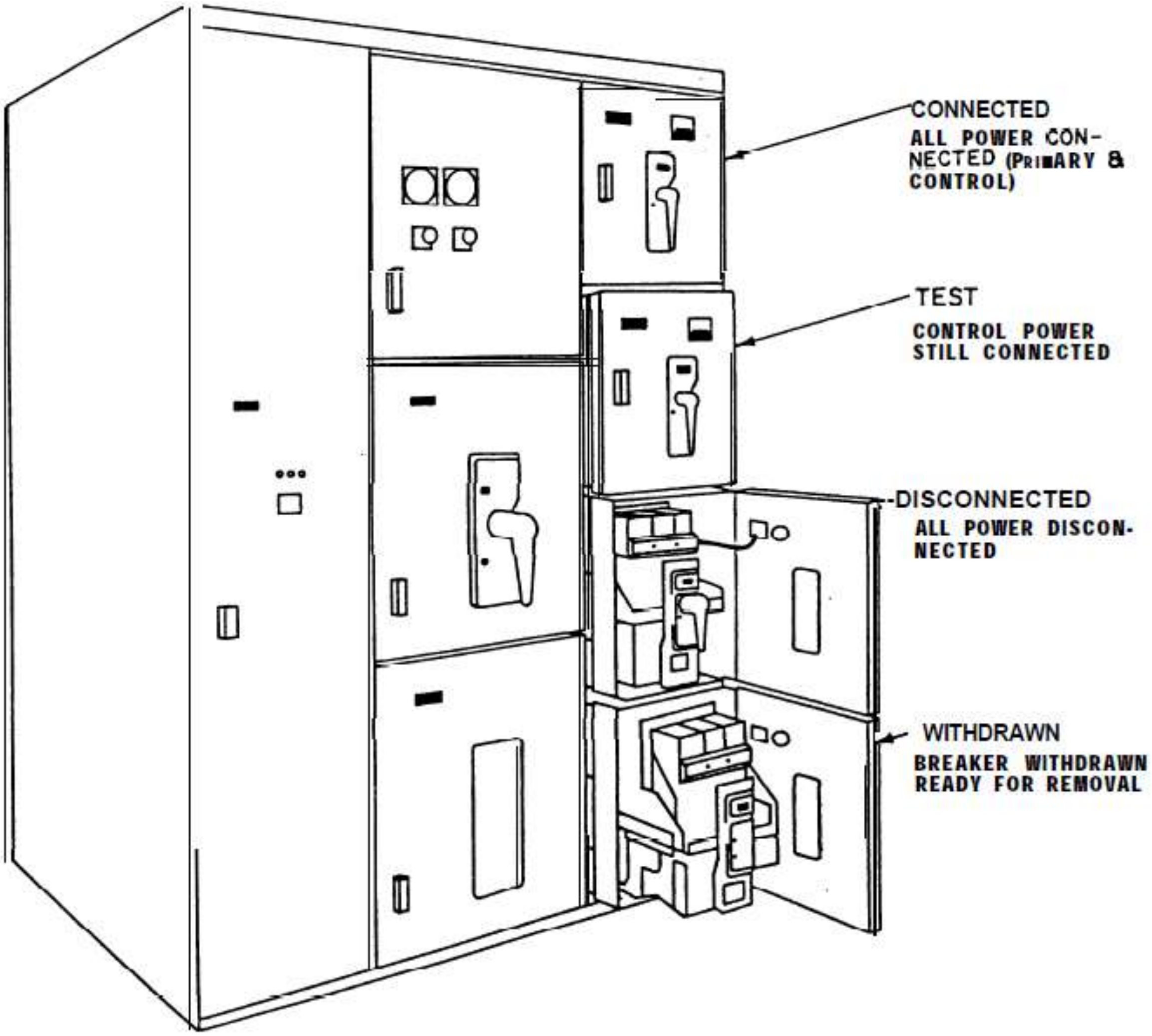


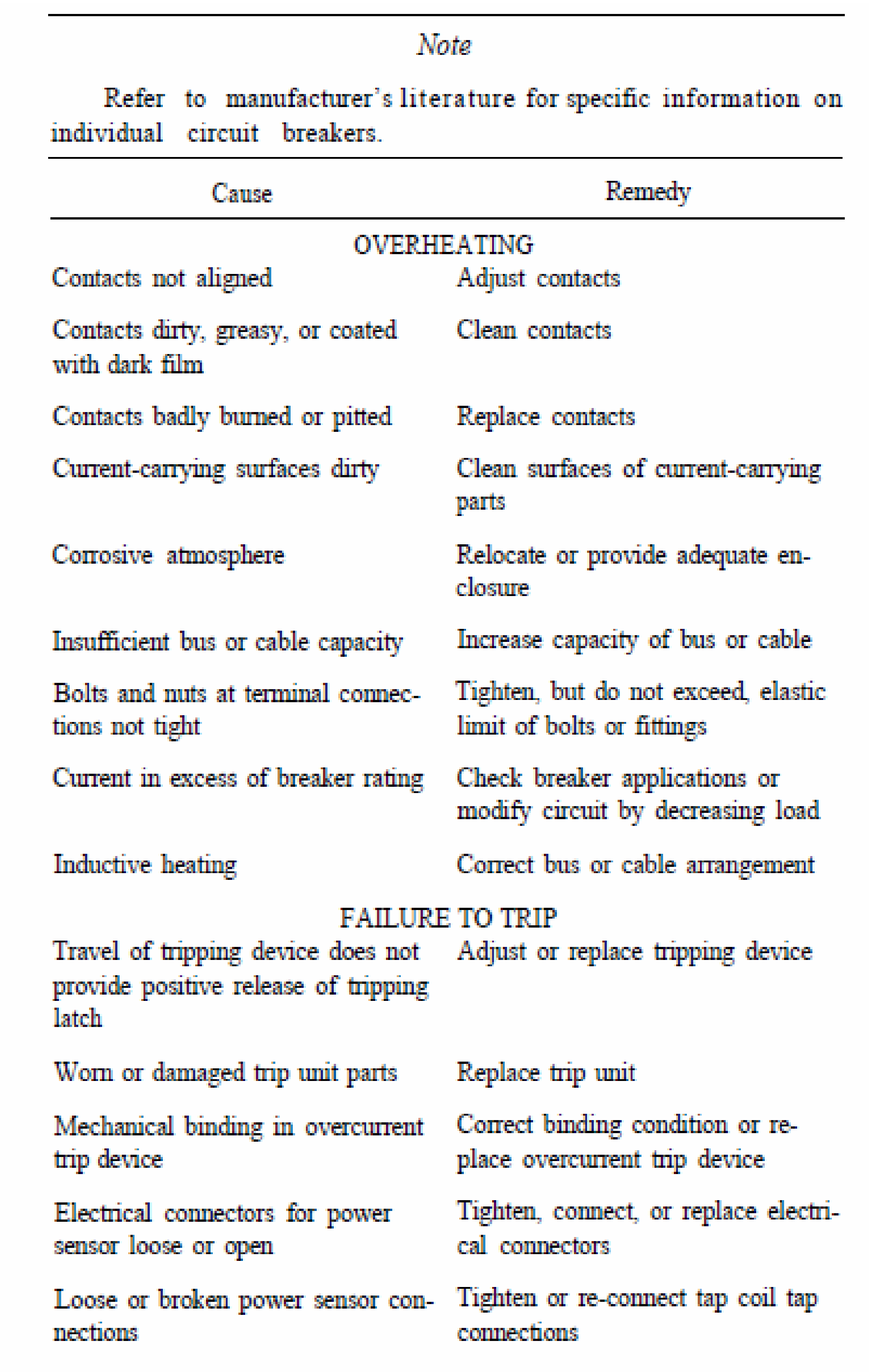
Figure 5-8

Maintenance for typical low voltage switchgear with air circuit breakers

3.6.2.4 SWITCHGEAR NEEDS EXERCISE. If the circuit breaker remains idle, either open or closed, for six months or more, it should be opened and closed several times during the period, preferably under load. If the breaker is operated by a relay or a switch, it should be so operated at this time.

3.6.2.5 SERVICE FOR MOLDED-case circuit breakers consists of the following procedures. Inspect connections for signs of arcing or overheating. Replace faulty connectors and tighten all connections. Clean the connecting surfaces. Perform overload tripping tests. Verify automatic opening of breaker. Verify that the magnetic tripping feature is operating. Perform circuit breaker overload tripping tests. Proper action of the breaker tripping components is verified by selecting a percentage of breaker current rating (such as 300%) for testing. This overload is applied separately to each pole of the breaker to determine how it will affect automatic opening of the breaker. Refer to manufacturer's test information. Turn the breaker on and off several times to verify satisfactory mechanical operation.

3.6.2.6 SERVICE FOR AIR CIRCUIT BREAKERS consists of the following procedure (see fig 5-8). Install the safety pin to restrain the closing spring force. With the pin in place, the contacts will close slowly when the breaker is manually operated. Inspect connections for signs of arcing or overheating. Replace faulty connectors and tighten all connections. Clean the connecting surfaces. An infrared (IR) survey is a recommended inspection procedure. The IR survey should be performed when the circuit breaker is under load and closed to detect overheating of connections. Perform general troubleshooting of the breaker (refer to the following table) if a problem develops. If the trouble cannot be corrected, refer to the manufacturer's literature for specific information on individual breakers. Instrument transformers require no care other than keeping them dry and clean. Refer to manufacturer's literature if specific information is required.



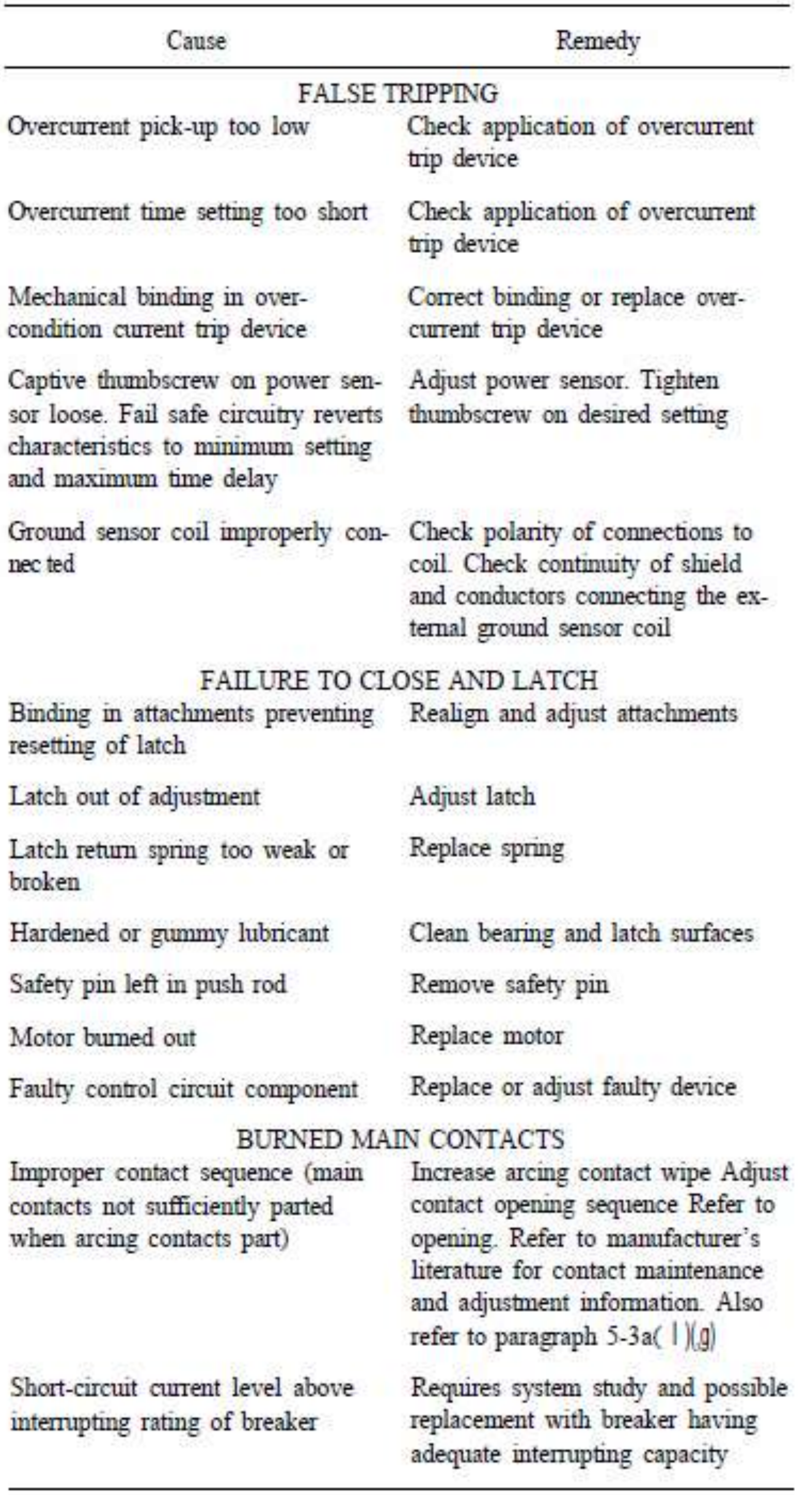
Note

Refer to manufacturer's literature for specific information on individual circuit breakers.

Cause	Remedy
OVERHEATING	
Contacts not aligned	Adjust contacts
Contacts dirty, greasy, or coated with dark film	Clean contacts
Contacts badly burned or pitted	Replace contacts
Current-carrying surfaces dirty	Clean surfaces of current-carrying parts
Corrosive atmosphere	Relocate or provide adequate enclosure
Insufficient bus or cable capacity	Increase capacity of bus or cable
Bolts and nuts at terminal connections not tight	Tighten, but do not exceed, elastic limit of bolts or fittings
Current in excess of breaker rating	Check breaker applications or modify circuit by decreasing load
Inductive heating	Correct bus or cable arrangement
FAILURE TO TRIP	
Travel of tripping device does not provide positive release of tripping latch	Adjust or replace tripping device
Worn or damaged trip unit parts	Replace trip unit
Mechanical binding in overcurrent trip device	Correct binding condition or replace overcurrent trip device
Electrical connectors for power sensor loose or open	Tighten, connect, or replace electrical connectors
Loose or broken power sensor connections	Tighten or re-connect tap coil tap connections

Table 5-I

Low voltage circuit breaker troubleshooting



Cause	Remedy
FALSE TRIPPING	
Overcurrent pick-up too low	Check application of overcurrent trip device
Overcurrent time setting too short	Check application of overcurrent trip device
Mechanical binding in overcondition current trip device	Correct binding or replace overcurrent trip device
Captive thumbscrew on power sensor loose. Fail safe circuitry reverts characteristics to minimum setting and maximum time delay	Adjust power sensor. Tighten thumbscrew on desired setting
Ground sensor coil improperly connected	Check polarity of connections to coil. Check continuity of shield and conductors connecting the external ground sensor coil
FAILURE TO CLOSE AND LATCH	
Binding in attachments preventing resetting of latch	Realign and adjust attachments
Latch out of adjustment	Adjust latch
Latch return spring too weak or broken	Replace spring
Hardened or gummy lubricant	Clean bearing and latch surfaces
Safety pin left in push rod	Remove safety pin
Motor burned out	Replace motor
Faulty control circuit component	Replace or adjust faulty device
BURNED MAIN CONTACTS	
Improper contact sequence (main contacts not sufficiently parted when arcing contacts part)	Increase arcing contact wipe Adjust contact opening sequence Refer to opening. Refer to manufacturer's literature for contact maintenance and adjustment information. Also refer to paragraph 5-3a(1)(g)
Short-circuit current level above interrupting rating of breaker	Requires system study and possible replacement with breaker having adequate interrupting capacity

Table 5-l (continued)

Low voltage circuit breaker troubleshooting

4. MEDIUM VOLTAGE ELEMENTS.

4.1 CIRCUIT BREAKERS. Medium voltage switchgear uses oil, air-blast, or vacuum circuit breakers. Usually the circuit breakers have draw-out construction to permit removal of an individual breaker from the enclosure for inspection or maintenance without deenergizing the main bus. All of these circuit breakers can quickly interrupt and extinguish the electric arc that occurs between breaker contacts when the contacts are separated.

4.1.1 OIL CIRCUIT BREAKERS. When the contacts are separated in oil, the interrupted voltage and current can be greater as compared to contact separation in air at room temperature.

4.1.1.1 ARC INTERRUPTION is better in oil than air because the dielectric strength of oil is much greater than air. Also, the arc generates hydrogen gas from the oil (see fig 5-9). The gas is superior to air as a cooling medium.

4.1.1.2 USUALLY THE CONTACTS and the arc are enclosed in a fiber arcing chamber, with exhaust ports on one side, to increase the capacity.

4.1.2 AIR CIRCUIT BREAKERS. Arc extinction by high pressure air blast is another method of quickly interrupting and extinguishing electric arc. Cross-blast type breakers are usually used in medium voltage switchgear.

4.1.2.1 A CROSS-BLAST BREAKER uses an arc chute with one splitter (insulating fin) that functions as an arc barrier (see fig 5-10).

4.1.2.2 THE ARC IS DRAWN between the upper and lower electrodes. During interruption, a blast of high-pressure air is directed across the arc pushing the arc against the splitter. The arc is broken at current zero and carried downstream.

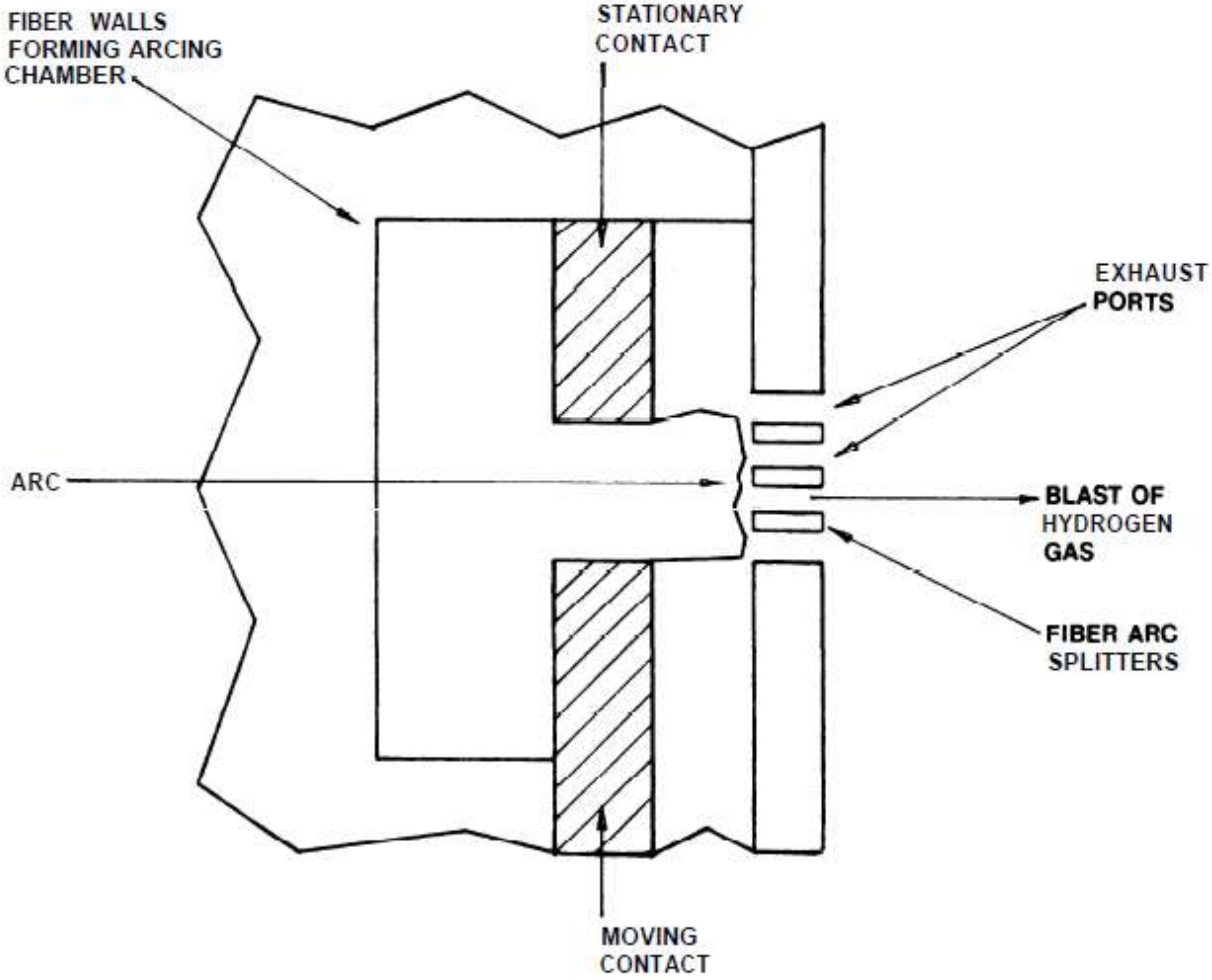


Figure 5-9

Arc interruption in oil, diagram

4.1.2.3 VACUUM CIRCUIT BREAKERS. Vacuum arc interruption is the newest and quickest method of extinguishing an electric arc. This type of breaker (see figure 5-11) is oil-less, fireproof and nearly maintenance free. Service life is very long. Arc interruption is very rapid, usually in the first current zero. High dielectric strength of a small vacuum gap contributes to the rapid interruption of the arc. Short contact travel permits the mechanism to part the contacts much faster than for oil breakers.

4.1.2.4 WARNING. Mechanical indication of “open” may not be true. Always make sure no voltage exists on load/line side before performing any work.

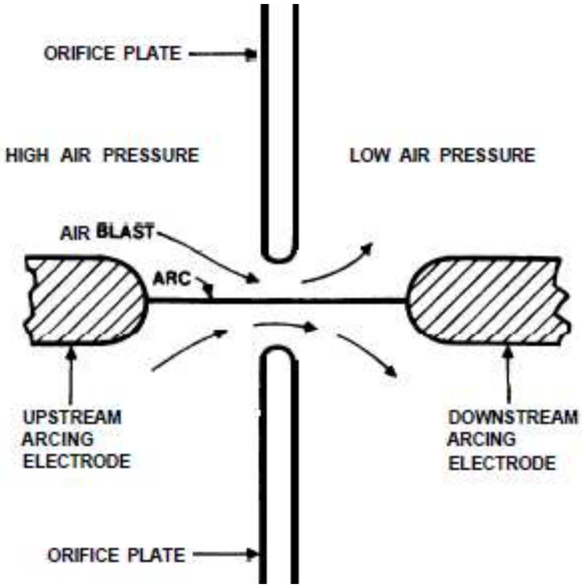


Figure 5-10

Air blast arc interrupter, diagram

4.2 POTENTIAL TRANSFORMERS. A potential transformer (PT) is an accurately wound, low voltage-loss instrument transformer having a fixed primary to secondary "step down" voltage ratio. The PT is mounted in the high voltage enclosure and only the low voltage leads from the secondary winding are brought out to the metering and control panel. The PT isolates the high voltage primary from the metering and control panel and from personnel. The step down ratio produces about 120 VAC across the secondary when rated voltage is applied to the primary. This permits the use of standard low voltage meters (120 VAC full scale) for all high voltage circuit metering and control.

4.2.1 RATINGS. Potential transformers are usually rated at 120 volts in the secondary circuit.

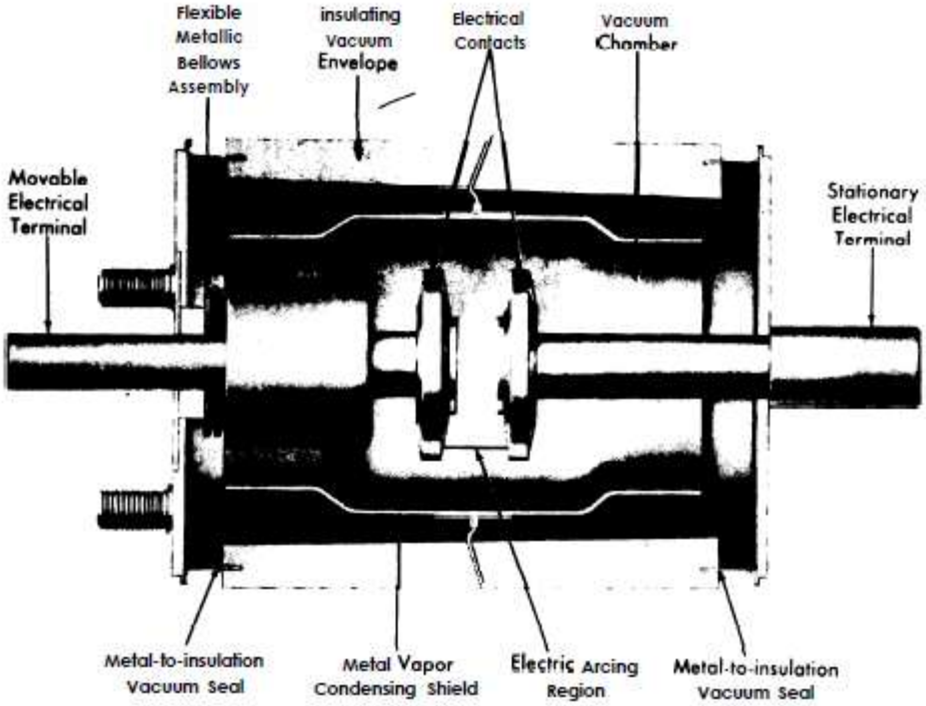


Figure 5-11

Cross sectional view of vacuum arc interrupter

4.3 CURRENT TRANSFORMERS. A Current Transformer (CT) is an instrument transformer having low losses whose purpose is to provide a fixed primary to secondary step down current ratio. The primary to secondary current ratio is in inverse proportion to the primary to secondary turns ratio. The secondary winding thus has multiple turns. The CT is usually either a toroid (doughnut) winding with primary conductor wire passing through the “hole” or a unit section of bus bar (primary), around which is wound the secondary, inserted into the bus run. The CT ratio is selected to result in a five ampere secondary current when primary rated current is flowing. Current transformers are usually rated at 5 amperes in the secondary circuit.

4.4 CONTROL CIRCUITS. Switchgear control circuits for medium voltage are functionally similar to those used for low voltage systems. The control circuits are similarly classified as either AC or DC.

4.5 OWNER PRACTICES. Owner practices for medium voltage switchgear consist of a complete maintenance program that is built around equipment, system records, and visual inspections. The program is described in the manufacturer's literature furnished with the components. If a problem develops, the user should perform general troubleshooting procedures. The program includes appropriate analysis of the records.

4.5.1 RECORD KEEPING. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets must be specifically developed to suit individual applications (i.e., auxiliary use).

4.5.2 TROUBLESHOOTING. Perform troubleshooting procedures when abnormal operation of the system or equipment is observed. Maintenance personnel must then refer to records for interpretation and comparison of performance data (i.e., log sheets). Comparisons of operation should be made under equal or closely similar conditions of load and ambient temperature. The general scheme for troubleshooting is outlined in the following paragraphs.

4.5.2.1 USE RECOGNIZED INDUSTRIAL PRACTICES as the general guide for servicing and refer to manufacturer's literature.

4.5.2.2 THE USER SHOULD refer to manufacturer's literature for specific information on individual circuit breakers.

4.5.2.3 GENERAL SERVICE INFORMATION for circuit breakers includes the following safety requirements:

- Do not work on an energized breaker.
- Do not work on any part of a breaker with the test couplers engaged. Test couplers connect the breaker to the control circuit during testing.

- Maintenance closing devices for switchgear are not suitable for closing in on a live system.
- Speed in closing is as important as speed in opening. A wrench or other maintenance
- tool is not fast enough.
- Before working on the switchgear enclosure, remove all draw-out devices such as circuit breakers and instrument transformers.
- Do not lay tools down on the equipment while working on it. It is too easy to forget a tool when closing an enclosure.

4.5.2.4 SWITCHGEAR NEEDS EXERCISE. If the circuit breaker remains idle, either open or closed, for six months or more, it should be opened and closed several times during the period, preferably under load. If the breaker is operated by a relay or a switch, it too should be operated at this time.

4.5.2.5 SERVICE CIRCUIT BREAKERS USING INSULATING LIQUID REQUIRE SPECIAL HANDLING. Elevate the breaker on an inspection rack and untank it to expose the contacts. The insulating liquid usually used in circuit breakers is mineral oil. Equipment using liquids containing polychlorinated biphenyls (PCBs) may still be in use. Since PCBs are carcinogenic and not biodegradable, some restrictions to their use apply. Silicone insulating liquid can be used as substitute for PCBs when authorized by the engineer. Special handling is required if PCBs are used in any equipment. Refer to 40 CFR 761 for PCB details. PCBs are powerful solvents. Handling and disposal information and special gloves are required. Check condition, alignment, and adjustment of contacts. Verify that contacts surfaces bear with firm, even pressure. Use a fine file to dress rough contacts; replace pitted or burned contacts. Wipe clean all parts normally immersed in liquid, remove traces of carbon that remain after the liquid has drained. Inspect insulating parts for cracks, or other damage requiring replacement. Test the dielectric strength of the liquid, using a 0.1 inch gap with 1.1 inch diameter disk terminals. If strength is less than 22 kV, remove and filter or replace with new liquid having a dielectric strength of at least 26 kV. Filter the liquid whenever inspection shows excessive carbon, even if its dielectric strength is satisfactory, because the carbon will deposit on insulating surfaces decreasing the insulation strength. Liquid samples should be taken in a large-mouthed glass bottle that has been cleaned and dried with benzene. Use a cork stopper with this bottle. Draw test samples from the bottom of the tank after the liquid has settled. The samples should be from the tank proper and not from the valve or drain pipe. Periodically remove the liquid from the tank and wipe the inside of the tank, the tank linings, and barriers to remove carbon. Inspect breaker and operating mechanisms for loose hardware and missing or broken cotter pins, retaining rings, etc. Check adjustments and readjust when necessary (refer to the manufacturer’s instruction book). Clean operating mechanism and lubricate as for air-magnetic type breakers (refer to the manufacturer’s instruction book). Before replacing the tank, operate breaker slowly with maintenance closing device to verify there is no friction or binding to prevent or slow down its operation; then, check the electrical operation. Avoid operating the breaker any more than is necessary when testing it without liquid in the tank. It is designed to operate in liquid and mechanical damage can result from excessive operation without it. When replacing the tank, fill to the correct level with liquid, be sure the gaskets are undamaged and the tank nuts and flange nuts on gauges and valves are tightened properly to prevent leakage.

4.5.2.6 SERVICE AIR-BLAST TYPE CIRCUIT BREAKERS. Circuit breakers should be serviced (tested, exercised, and calibrated) at intervals not to exceed two years (refer to AR 420-43). Withdraw the breaker from its housing for maintenance. Circuit breakers are designed to perform up to 5000 and 3000 operations for 1200 ampere or 200 ampere breakers, respectively, without major overhaul. More frequent servicing may be necessary if operating conditions are severe. Inspection and servicing should be performed after every fault clearing operation. Refer to instructions provided by the manufacturer. Wipe insulating parts, including bushings and the inside of box barriers; clean off smoke and dust. Repair moderate damage to bushing insulation by sanding smooth and refinishing with a clear insulating varnish. Inspect alignment and condition of movable and stationary contacts. Check their adjustment as described in the manufacturer’s instruction book. To check alignment, close the breaker with pieces of tissue and carbon paper between the contacts and examine the impression. Do not file butt-type contacts. Contacts which have been roughened in service may carry current as well as smooth contacts. Remove large projections or “bubbles” caused by unusual arcing, by filing. When filing to touch up, keep the contacts in their original design; that is, if the contact is a line type, keep the area of contact linear, and if ball or point-type, keep the ball or points shaped out. Check arc chutes for damage. Replace damaged parts. When arc chutes are removed, blow out dust and loose particles. Clean silver-plated breaker primary disconnecting devices with alcohol or silver polish (refer to the manufacturer’s instruction book). Lubricate devices by applying a thin film of approved grease. Inspect breaker operating mechanism for loose hardware and missing or broken cotter pins, retaining rings, etc. Examine cam, latch and roller surfaces for damage or excessive wear. Clean and relubricate operating mechanism (refer to the manufacturer’s instruction book). Lubricate pins and bearings not disassembled. Lubricate the ground or polished surfaces of cams, rollers, latches and props, and of pins and bearings that are removed for cleaning. Check breaker operating mechanism adjustments and readjust as described in the manufacturer’s instruction book. If adjustments cannot be made within specified tolerances, excessive wear and need for a complete overhaul is indicated. Check control device for freedom of operation. Replace contacts when badly worn or burned. Inspect breaker control wiring for tightness of connections. After the breaker has been serviced, operate it slowly with closing device to check absence of binding or friction and check that contacts move to the fully-opened and fully-closed positions. Check electrical operation using either the test cabinet or test couplers.

4.5.2.7 SERVICE VACUUM CIRCUIT BREAKERS. This breaker has primary contacts enclosed in vacuum containers (flasks), and direct inspection or replacement is not possible. The operating mechanism is similar to that used in other medium voltage circuit breakers, and the general outlines are the same for maintenance work. The enclosures are similar. Figure 5-11 shows a breaker with the primary electrical contacts exposed. The stationary contact is solidly mounted; the moving contact is mounted in the enclosure with a bellows seal. Contact erosion is measured by the change in external shaft positions after a period of use. Consult the manufacturer's instruction book. High voltage applied during testing may produce X-ray emission. Personnel performing a hi-pot test must stay behind a protective shield during testing. Condition of the vacuum is checked by a hi-pot test applied every maintenance period. Consult manufacturer's instruction book for test procedures. The contacts in a vacuum circuit breaker cannot be cleaned, repaired or adjusted. The vacuum bottle is usually replaced if the test indicates a fault.

5. TRANSFER SWITCHES. During actual or threatened power failure, transfer switches are actuated to transfer critical electrical load circuits from the normal source of power to the auxiliary (emergency) power source. When normal power is restored, the transfer switches either automatically retransfer their load circuits to the normal supply or must be transferred manually. Voltage and frequency-sensing relays are provided to monitor each phase of the normal supply. The relays initiate load transfer when there is a change in voltage or frequency in any phase outside of predetermined limits. Additionally, the relays initiate retransfer of the load to the normal source as soon as voltage is restored in all the phases beyond the predetermined pick-up value of the relay. A transfer switch obtains its operating current from the source to which the load is being transferred.

5.1 TYPES OF TRANSFER SWITCHES. There are two types of transfer switches: electrically operated or manually operated. Electrically operated transfer switches also come with an optional bypass function.

5.1.1 ELECTRICALLY OPERATED. An electrically operated switch obtains its operating current from the source to which the load is being transferred. A separate voltage supply is used in some systems. Electrically operated switches consist of three functional elements: main contacts to connect and disconnect the load to and from the sources of power; sensing circuits to constantly monitor the condition of the power source and provide the information necessary for switch and related circuit operation; and transfer mechanism to make the transfer from source to source.

5.1.1.1 CIRCUIT BREAKER TYPE. Circuit breaker transfer switches are mechanically held devices using two circuit breakers. Usually the breaker handles are operated by a transfer mechanism which provides double-throw switching action connecting one circuit terminal to either of two others. The transfer mechanism is operated electrically by a unidirectional gear motor (motor and integral speed-reducing gearbox) or by dual motor operators with all parts in positive contact at all times. These switches can also be operated manually and have provisions for disengaging the generator when necessary.

5.1.1.2 NEUTRAL POSITION. Some transfer switches have a neutral position. However, the switch is mechanically and electrically interlocked so that a neutral position is not possible during electrical operation. Also, load circuits cannot be connected by the switch to normal and emergency sources simultaneously whether the switch is operated electrically or manually.

5.1.1.3 CONTACTOR TYPE. Contactor type transfer switches have mechanically or electrically held contactors with a command load bus. The switches are mechanically and electrically interlocked so that a neutral position is not possible under normal electrical operation. Additionally, the load circuits cannot be connected to normal and emergency sources simultaneously.

5.1.2 BYPASS FUNCTION. An electrically operated transfer switch can be provided with a bypass function. The bypass function manually transfers the power around the automatic transfer switch. The electrically operated switch can then be tested, removed, and repaired. The bypass function may or may not cause a momentary interruption to the load depending upon the manufacturer. The bypass is purely a manual function, therefore, if the source to which the bypass is connected fails the bypass must be manually transferred to the alternate source. Bypass transfer switches are only used in the most critical applications where the load is operational continuously.

5.1.3 MANUALLY OPERATED. Manual transfer switches are mechanically held devices using two circuit breakers operated by a handle. All parts are in positive contact at all times. The switch is mechanically interlocked; it is impossible for the load circuits to be connected to normal and emergency sources simultaneously. Manually operated transfer switches are available with single or dual operating handles. A common operating mechanism across the two breakers mechanically connects and operates the breakers.

5.2 OPERATION. Transfer switches have two operating modes: automatic and non-automatic.

5.2.1 AUTOMATIC. Automatic transfer switches have voltage sensing relays for each phase. The sensing relays are connected to the normal power bus, behind the protecting devices.

5.2.1.1 THE TRANSFER SWITCH is connected to the normal power source under normal conditions. When the sensing relays detect a sustained drop in the voltage of the normal power source, the relays will automatically start the auxiliary generator. The transfer switch operates upon a sustained drop in voltage in any phase of the normal source (approximately a 30 percent drop and delay of about two seconds) to start the auxiliary generator.

5.2.1.2 WHEN VOLTAGE AND FREQUENCY of the auxiliary generator are at rated values, and the normal power source is still below normal, the automatic control will transfer the load to the emergency source.

5.2.1.3 UPON RETURN OF NORMAL POWER to within 10 percent of rated voltage on all phases and after a preset time delay, the switch automatically transfers the load to the normal source. Usually the auxiliary generator will run unloaded for about five minutes after the transfer, before it shuts down. The controls automatically reset for the next emergency start.

5.2.1.4 USUALLY THE CONTROLS of a power transfer system have a test switch. This permits simulation of failure of the normal power source and test of transfer switch operation.

5.2.1.5 POWER TRANSFER INDICATORS are provided in most automatic transfer systems to indicate the currently used power source. Usually an amber light marked “Emergency Power” shows that the system is on emergency power when illuminated. A white light marked “Normal Power” shows that the system is receiving power from its normal source when illuminated.

5.2.2 NONAUTOMATIC. In nonautomatic operation, an operator is needed to manually transfer to or from the emergency power source. The operator can usually make the transfer without opening an enclosure. The transfer is usually based on instrument indications and is made by placing the transfer switch in the required emergency or normal position.

5.2.2.1 POWER TRANSFER INDICATORS are provided for the operator. An amber light (Emergency Power) shows that the system is on emergency power when illuminated. A white light (Normal Power) shows that the system is receiving power from its normal source when illuminated.

5.2.2.2 THE OPERATOR IS USUALLY provided with an override switch which bypasses the automatic transfer controls. This feature permits indefinite connection of the emergency power source regardless of the condition of the normal power source.

5.3 OWNER PRACTICES. Owner practices for transfer switches consist of a complete maintenance program that is built around records and visual inspections. The program includes appropriate analysis of these records.

5.3.1 RECORD KEEPING. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets must be specifically developed to suit auxiliary use.

5.3.2 TROUBLESHOOTING. Use recognized industrial practices as the general guide for transfer switch and systern troubleshooting. Troubleshooting of system circuits that are not performing according to specifications and to the required performance level should be accomplished as follows: refer to engineering data and drawings pertaining to the particular plant.

5.3.2.1 THE USER SHOULD refer to manufacturer's literature for specific information on individual transfer switches.

5.3.2.2 PERFORM GENERAL TROUBLESHOOTING of the transfer switch if a problem develops. Refer to the manufacturer's literature for specific information. Usually, all control elements are renewable from the front of the switch without removing the switch from its enclosures and without removing the main power cables.

6. REGULATORS. A voltage regulator maintains the terminal voltage of an alternator or generator at a predetermined value. Voltage is controlled by regulating the strength of the electromagnetic field produced in the alternator exciter. A voltage regulator automatically overcomes voltage drop within the alternator by changing field excitation automatically as it varies with the load.

6.1 TYPES OF REGULATORS. The types of voltage regulators are electromechanical, static voltage, and static exciter.

6.1.1 ELECTRO -MECHANICAL VOLTAGE REGULATORS. These regulators usually have a servo-control system with three principal elements.

6.1.1.1 FIRST IS A VOLTAGE sensing device with a voltage regulating relay. The device monitors the output voltage and sends a signal to the control circuits.

6.1.1.2 SECOND IS AN AMPLIFYING section with or without time delay, which amplifies the voltage signal.

6.1.1.3 THIRD IS A MOTOR DRIVE which responds to the signal by moving a tap changer or induction regulator in a direction to correct the voltage.

6.1.2 STATIC VOLTAGE REGULATORS. A static regulator usually has a static voltage sensor instead of a voltage-regulating relay.

6.1.2.1 OPERATION. The voltage sensor output is applied to a solid-state or magnetic amplifier and a discriminator circuit. Signals are thereby provided for changing alternator output to raise or lower the voltage as required. The voltage zone between initiation of raising or lowering control action is called the voltage band. The band must be more than the minimum correction obtainable through the regulator or regulator hunting will occur.

6.1.2.2 ACCESSORIES. Accessories include either thermal delay relays or a resistance capacitance network to provide time delay for load trend correction. Time delay retards the signal until accumulated time outside the voltage limit, less accumulated time inside the voltage limit, exceeds the time delay setting.

6.1.3 STATIC EXCITER REGULATORS. A static exciter regulator supplies the alternator field with DC voltage obtained from a three-phase, full wave bridge rectifier.

6.1.3.1 OPERATION. A small part of the alternator's output goes to the regulator which meters the rectified DC voltage back to exciter's field windings. The rectified DC voltage produces a 60 cycle ripple. If the ripple gets into the field windings, an electrical discharge from windings to shaft can occur. A filter can be used to reduce ripple. The discharge is caused because copper in the field windings and the metal shaft act like the plates in a capacitor. This action may result in shaft and bearing pitting and eventual bearing failure. A static exciter is a manufactured subassembly, assembled and wired at the manufacturer's plant, usually using one or more silicon rectifiers to convert AC voltage to DC. The subassembly usually includes a regulator and a filter. Refer to the manufacturer's literature for test and adjustment details.

6.1.3.2 ACCESSORIES. Accessories include either thermal delay relays or a resistance capacitance network to provide time delay for load trend correction. A suppressor circuit or ripple filter is usually provided to bypass ripple to ground before it gets to the generator field.

6.2 OWNER PRACTICES. Owner practices for voltage regulators consist of a complete maintenance program that is built around records and visual inspections. The program includes appropriate analysis of these records.

6.2.1 RECORD KEEPING.EQUIPMENT and system log sheets are important and necessary functions of record keeping. The log sheets must be specifically developed to suit auxiliary use.

6.2.2 TROUBLESHOOTING. Use recognized industrial practices as the general guide for servicing. Refer to manufacturer's literature for specific information on individual voltage regulators. Troubleshooting procedures include the following:

6.2.2.1 CHECK VOLTAGE for compliance with manufacturer's specifications.

6.2.2.2 CHECK FOR 1OOSE or insecure electrical connections

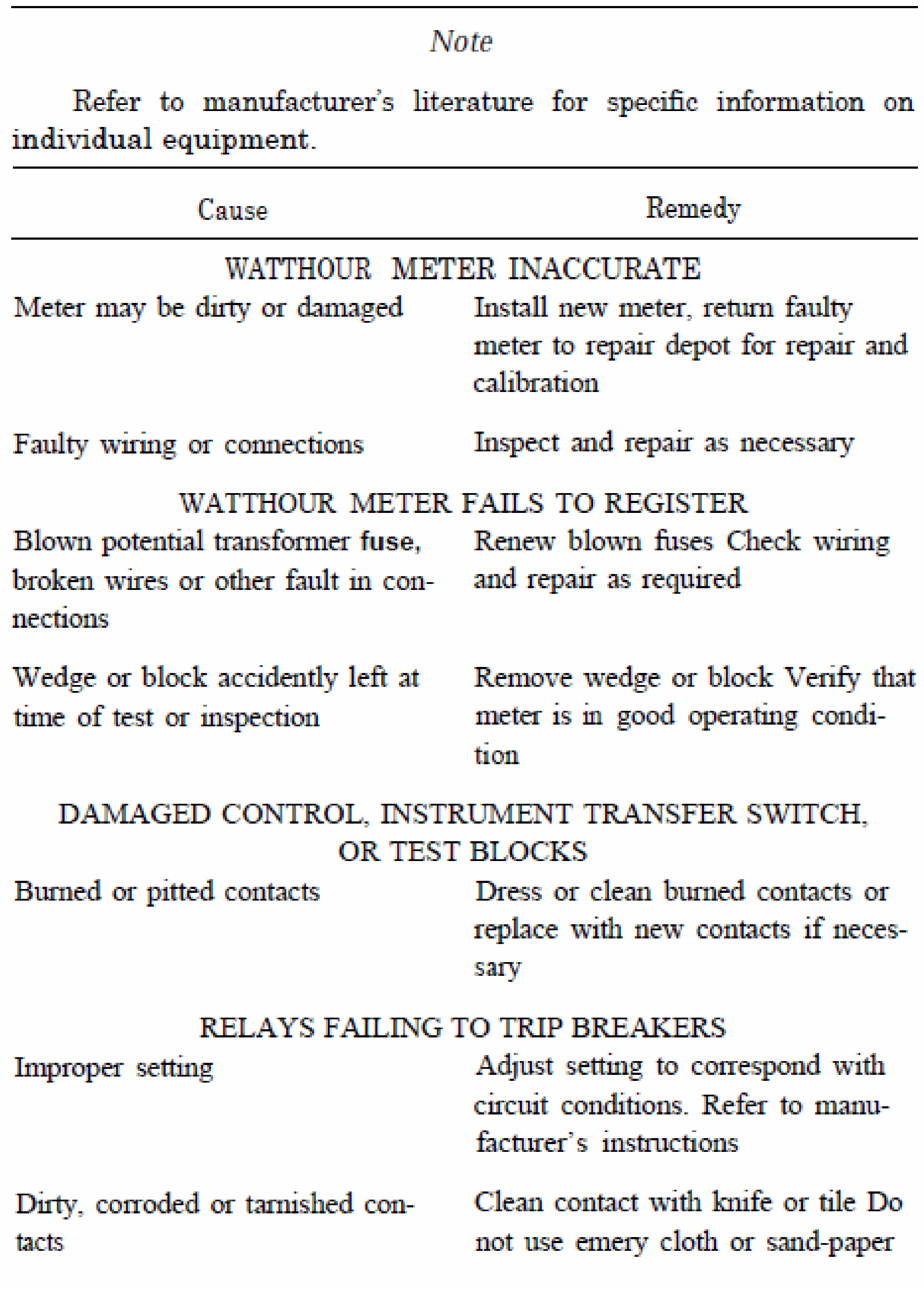
6.2.2.3 CHECK FOR CORRECT setting, refer to manufacturer's literature.

6.2.2.4 CHECK FOR UNREGULATED voltage. Refer to manufacturer's literature.

6.2.2.5 CHECK THE ENCLOSURE. Should be weathertight.

6.2.2.6 CHECK MOTOR FOR PROPER operation and loose connections. Clean and lubricate as required. Refer to manufacturer's literature for details.

6.2.2.7 VOLTAGE REGULATORS and associated equipment are normally mounted within switchgear equipment and are interconnected with different components. The proper operation and troubleshooting of voltage regulator equipment can depend on these different components. Perform the procedures in the following table:



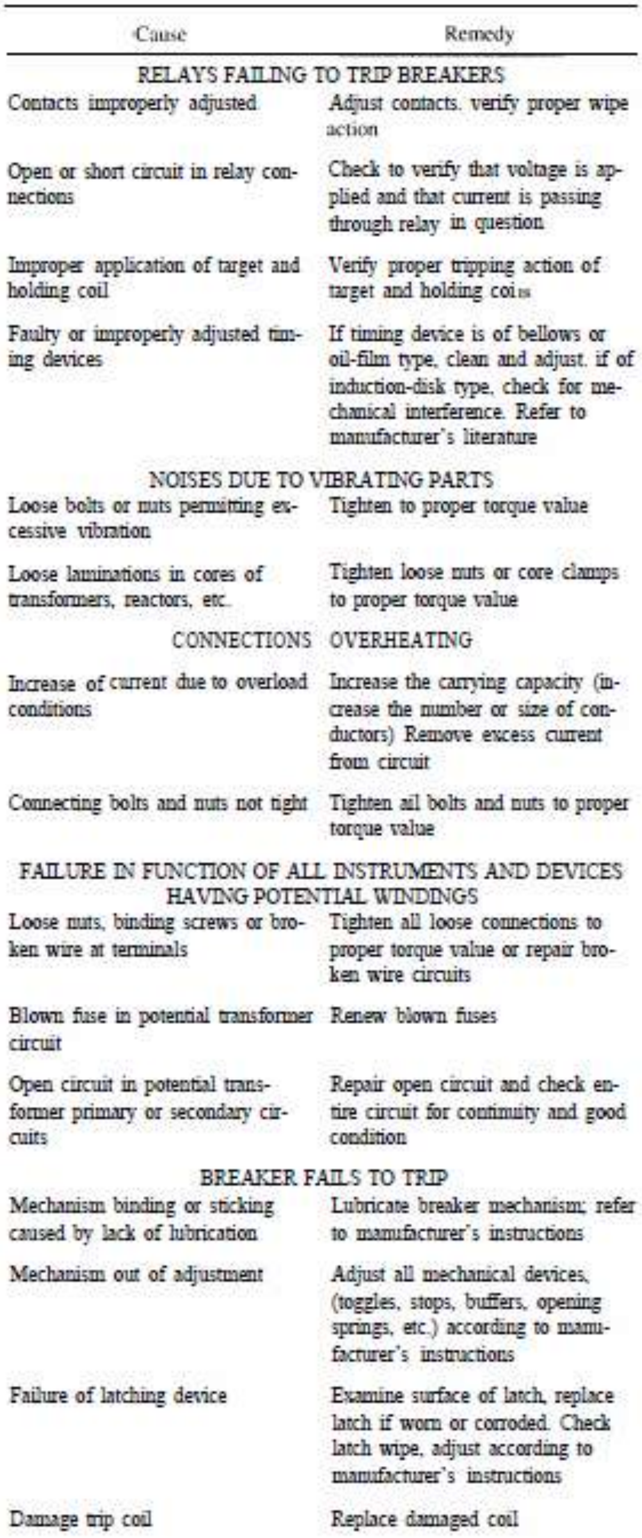
Note

Refer to manufacturer's literature for specific information on individual equipment.

Cause	Remedy
WATTHOUR METER INACCURATE	
Meter may be dirty or damaged	Install new meter, return faulty meter to repair depot for repair and calibration
Faulty wiring or connections	Inspect and repair as necessary
WATTHOUR METER FAILS TO REGISTER	
Blown potential transformer fuse, broken wires or other fault in connections	Renew blown fuses Check wiring and repair as required
Wedge or block accidently left at time of test or inspection	Remove wedge or block Verify that meter is in good operating condition
DAMAGED CONTROL, INSTRUMENT TRANSFER SWITCH, OR TEST BLOCKS	
Burned or pitted contacts	Dress or clean burned contacts or replace with new contacts if necessary
RELAYS FAILING TO TRIP BREAKERS	
Improper setting	Adjust setting to correspond with circuit conditions. Refer to manufacturer's instructions
Dirty, corroded or tarnished contacts	Clean contact with knife or tile Do not use emery cloth or sand-paper

Table 5-2

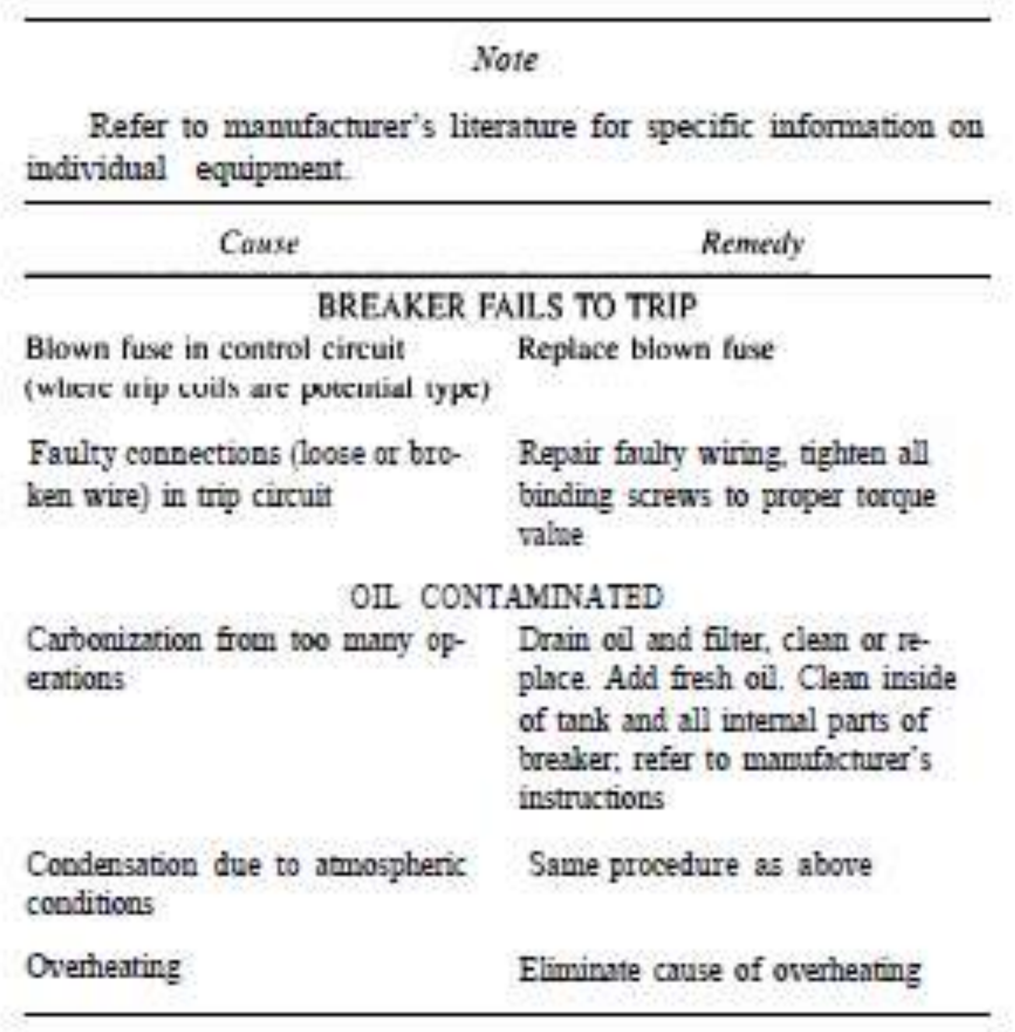
Switchgear equipment troubleshooting



Cause	Remedy
RELAYS FAILING TO TRIP BREAKERS	
Contacts improperly adjusted	Adjust contacts, verify proper wipe action
Open or short circuit in relay connections	Check to verify that voltage is applied and that current is passing through relay in question
Improper application of target and holding coil	Verify proper tripping action of target and holding coils
Faulty or improperly adjusted timing devices	If timing device is of bellows or oil-film type, clean and adjust, if of induction-disk type, check for mechanical interference. Refer to manufacturer's literature
NOISES DUE TO VIBRATING PARTS	
Loose bolts or nuts permitting excessive vibration	Tighten to proper torque value
Loose laminations in cores of transformers, reactors, etc.	Tighten loose nuts or core clamps to proper torque value
CONNECTIONS OVERHEATING	
Increase of current due to overload conditions	Increase the carrying capacity (increase the number or size of conductors) Remove excess current from circuit
Connecting bolts and nuts not tight	Tighten all bolts and nuts to proper torque value
FAILURE IN FUNCTION OF ALL INSTRUMENTS AND DEVICES HAVING POTENTIAL WINDINGS	
Loose nuts, binding screws or broken wire at terminals	Tighten all loose connections to proper torque value or repair broken wire circuits
Blown fuse in potential transformer circuit	Renew blown fuses
Open circuit in potential transformer primary or secondary circuits	Repair open circuit and check entire circuit for continuity and good condition
BREAKER FAILS TO TRIP	
Mechanism binding or sticking caused by lack of lubrication	Lubricate breaker mechanism; refer to manufacturer's instructions
Mechanism out of adjustment	Adjust all mechanical devices, (toggles, stops, buffers, opening springs, etc.) according to manufacturer's instructions
Failure of latching device	Examine surface of latch, replace latch if worn or corroded. Check latch wipe, adjust according to manufacturer's instructions
Damage trip coil	Replace damaged coil

Table 5-2 (continued)

Switchgear equipment troubleshooting



Note

Refer to manufacturer's literature for specific information on individual equipment.

Cause	*Remedy*
BREAKER FAILS TO TRIP	
Blown fuse in control circuit (where trip coils are potential type)	Replace blown fuse
Faulty connections (loose or broken wire) in trip circuit	Repair faulty wiring, tighten all binding screws to proper torque value
OIL CONTAMINATED	
Carbonization from too many operations	Drain oil and filter, clean or replace. Add fresh oil. Clean inside of tank and all internal parts of breaker; refer to manufacturer's instructions
Condensation due to atmospheric conditions	Same procedure as above
Overheating	Eliminate cause of overheating

Table 5-2 (continued)

Switchgear equipment troubleshooting

7. INSTRUMENTATION. Switchgear instrumentation, based on the complexity of the complete system, may include all or any combination of indicating, recording, and metering instruments. Potential and current transformers are used to isolate instrument circuits from the power circuit. Usually, the secondary winding of potential transformers is rated at 120 volts. Current transformer output is 5 amperes.

7.1 TYPES OF INSTRUMENTATION. Instrumentation includes indicating and recording types.

7.2 APPLICATION. Information related to instrument transformer application is covered in the technical and commercial literature.

7.2.1 VOLTAGE. Voltage values are indicated by a voltmeter.

7.2.2 CURRENT. Current values are indicated by an ammeter.

7.2.3 POWER. Power values are described as watts, vars and power factor.

- **WATTS.** Watts or kilowatts (units of electric power) are indicated by a wattmeter.
- **VARS.** Vars or kilovars (units of reactive power) are obtained by multiplying effective value of current, effective value of voltage and the sine of the angular phase difference between current and voltage.
- **POWER FACTOR.** Power factor, the ratio of active power to apparent power, is displayed on a power factor meter. The meter scale is usually graduated in percentage power factor.

7.2.4 FREQUENCY. Frequency of alternating current is indicated on a frequency meter. The meter scale is usually graduated in 50/60 Hertz.

7.2.5 SPEED. Rotational speed of the prime mover is indicated by a tachometer in revolutions per minute (rpm). Generating systems covered herein usually use an impulse tachometer, including the inductor and eddy current types. These tachometers use a magnetic pick-up to sense speed.

7.2.6 TEMPERATURE. Several temperature values (including coolant, lubricating oil and exhaust) are usually required to assure safe prime mover operation. Each value is monitored by a sensing device with a remote indicator or thermometer. The sensing device can be thermocouple or a combination of sensing bulb and capillary tube.

- Thermocouple. A thermocouple consists of a pair of electrical conductors, each of different metal, which are joined at the end adjacent to the temperature to be measured. A thermal emf is produced at the junction of the conductors. The other end of each conductor is connected to a voltmeter which measures and indicates the thermal emf.

- Sensing bulb and capillary tube. The sensing bulb and capillary tube contain a specific amount of liquid or gas whose pressure varies with temperature. The variation appears on the thermometer and represents the temperature of coolant,oil or exhaust.

7.2.7 PRESSURE. Pressure in the prime mover is indicated by sensing devices and remote gauges. Usually a bourdon tube is used. The variation appears on the gauge and represents lubricating oil or other pressure. Other pressure values may be shown on the system instrument panel depending on the type of prime mover and the overall system requirements. These pressure values include starting air, turbo boost, scavenging air, exhaust manifold and fuel gas. Gauges or meters are used for indication as required.

7.2.8 FUEL LEVEL. Various methods are used for fuel level measurement. Fuel in underground storage tanks can be measured by immersing a calibrated dip stick in the tank. For day tanks, a glass sight-gauge or a float actuated gauge can be used to measure the quantity of liquid fuel, Remote indicators using pneumatic, electric or hydraulic devices are also used.

7.2.9 RUNNING TIME. The amount of time an auxiliary generating system operates is a required part of system record keeping. Time is usually recorded on a digital measuring device or counter located on the system instrument panel. Usually the counter is used with electric or electronic circuitry. An electric system usually has an AC synchronous motor that is geared to the counter. Accuracy of motor and counter depends on the frequency of the generator output voltage. An electronic system also records operating time on a digital measuring device. This system measures time by counting the number of cycles produced by the frequency of the generator output voltage. Counter indications are proportional to frequency vs time.

8. RELAYS. Relays are used with the automatic controls for auxiliary power generating systems. A relay responds to electrical or other operating parameters and causes an abrupt change in the control circuits when the measured values change. A relay consists of a sensing element and a control element with contacts.

8.1 TYPES OF RELAYS. Relays used in switchgear include general purpose and protective types.

8.1.1 GENERAL PURPOSE. General purpose relays function as part of regulation and verification devices throughout the system including the prime mover.

8.1.1.1 INDUSTRIAL. Portions of electrical systems are energized or de-energized under normal or abnormal conditions by relays. Since the relays are usually used with subsystems or equipment circuit breakers, the overall operating plan must be electrically coordinated. Coordination is usually accomplished by designing the system circuitry to selectively initiate the opening or closing of the relays. Relays constantly monitor the power system.

8.1.1.2 OVERLOAD. 0verload relays are used to provide overload protection for the auxiliary motors. When an overload condition occurs in any of the three phases in which heaters are inserted, it will cause the relay to trip.

8.1.1.3 TIME DELAY. Relays employed for time delay purpose are usually solid-state type. Some pneumatic relays may still be in use. Pneumatic relays utilize a bellows type arrangement to provide the time delay. They can be adjusted for time periods of less than a second to several minutes.

8.1.1.4 SOLID-STATE. Solid-state relays derive their time delay from a combination of several electronic components. They are also adjustable between fractions of a second to several minutes.

8.1.1.5 VOLTAGE SENSITIVE. Voltage sensitive relays are used to sense an increase or decrease in a specific voltage. They provide an output signal when the voltages pass the preset level.

8.1.2 PROTECTIVE RELAYS. Protective relays detect, isolate, and/or indicate abnormal electrical conditions. The operation of circuit breakers or other protective devices is initiated by relays as required. Some of the electrical hazards protected against are short circuit, overcurrent, over or under voltage, and phase or frequency irregularities. Relays installed to protect generator stator windings from internal shorts and overheating are sensitive to faults in the generator and do not respond to faults outside the generator. These relays act rapidly to prevent damage to the generator and isolate the generator from the system. Relay action includes de-energizing the generator field winding. Protective relays are provided in systems when reverse power flow occurs. Those relays operate on a succession of power reversals and current impulses to detect loss of synchronism. Protective relays include the following types:

8.1.2.1 OVERCURRENT. Overcurrent relays function when current flow exceeds the normal or desired value. Induction disk relays with time delay and cup type relays (without time delay) are known as electromechanical type relays. Solid state relays are normally used on more recently installed equipment.

8.1.2.2 OVERVOLTAGE. Overvoltage relays function when voltage exceeds the normal or desired value. Induction disk relays with time delay and cup type relays without time delay are used.

8.1.2.3 UNDERVOLTAGE. Undervoltage relays function when voltage is less than normal or desired value. Induction disk relays with time delay may be used in a balanced position between minimum and maximum voltages.

8.1.2.4 REVERSE POWER. Reverse power relays function whenever power flows in the reverse direction from normal or desired. These relays detect loss of synchronism.

8.1.2.5 UNDERFREQUENCY. Underfrequency relays function whenever the desired frequency becomes less than normal value. This condition is usually the result of reduced prime mover speed and may be caused by the prime mover governor or excess electrical load.

8.1.2.6 DIFFERENTIAL. Differential relays function due to the difference between two quantities of the same kind such as, two currents or two voltages. Differential relays, usually used to detect stator winding electrical failure, respond to current percentage differences. Current or voltage transformers used in differential network should be in matched sets. Percentage differential relays are also used to prevent relay operation for faults due to current transformer ratio error outside the protected zone. In this application, the overcurrent relay operates instantly when there is a bus short circuit but will not operate if a current transformer secondary opens. The contacts of the two relays are connected in series.

8.1.2.7 CURRENT BALANCE. A current balance relay circuit monitors two or more current circuits and provides an output if the difference between any two exceeds the setting of the relay. The relay senses the difference between the current of one generator and the current of another generator or the average of all other generators. Relay output may be used to trip bus tie contactors and split a parallel system to remove an unbalance.

8.1.2.8 GROUND FAULT PROTECTION. Ground fault protection is usually provided by a ground sensor relay which measures the sum of currents in the lines to the load in a three-phase system. Another relay is sometimes added to the transformer neutral-to-ground connection for backup.

8.2 TESTING OF RELAYS. Periodic testing of relays is considered preventive maintenance. The preventive maintenance program is built around records and visual inspections and includes analysis of the records.

8.2.1 THE FREQUENCY OF TESTING is dependent on the variables involved i.e., type of relay, environmental conditions, history, and experience. The ambient operating temperature must be recorded. Most relays have draw-out construction so that a relay can be separated from its enclosure. Disconnection for test or repair is usually not required.

8.2.2 CHECKS AND TESTS to be performed are determined by the type of relay. Proceed as follows:

- Inspect the relay cover before testing. Remove dust and other foreign matter to prevent it from entering the relay. Record the inspection results.
- Check relay for “flag” indication. Also, check cover glass for fogging. If fogging is excessive, investigate the cause.
- Check all connections for proper tightness. If necessary, tighten to proper torque value.
- Check armature and connect gaps. Compare with previous measurements. Adjust gaps if necessary and refer to manufacturer’s instructions.
- Check contacts for burned or eroded condition. Burnish if necessary and refer to manufacturer’s instructions.
- Verify proper contact operation. Open or close contacts to observe proper trip or reclose action and refer to manufacturer’s instructions.
- Apply current or voltage to verify that pickup is within manufacturer’s tolerances.

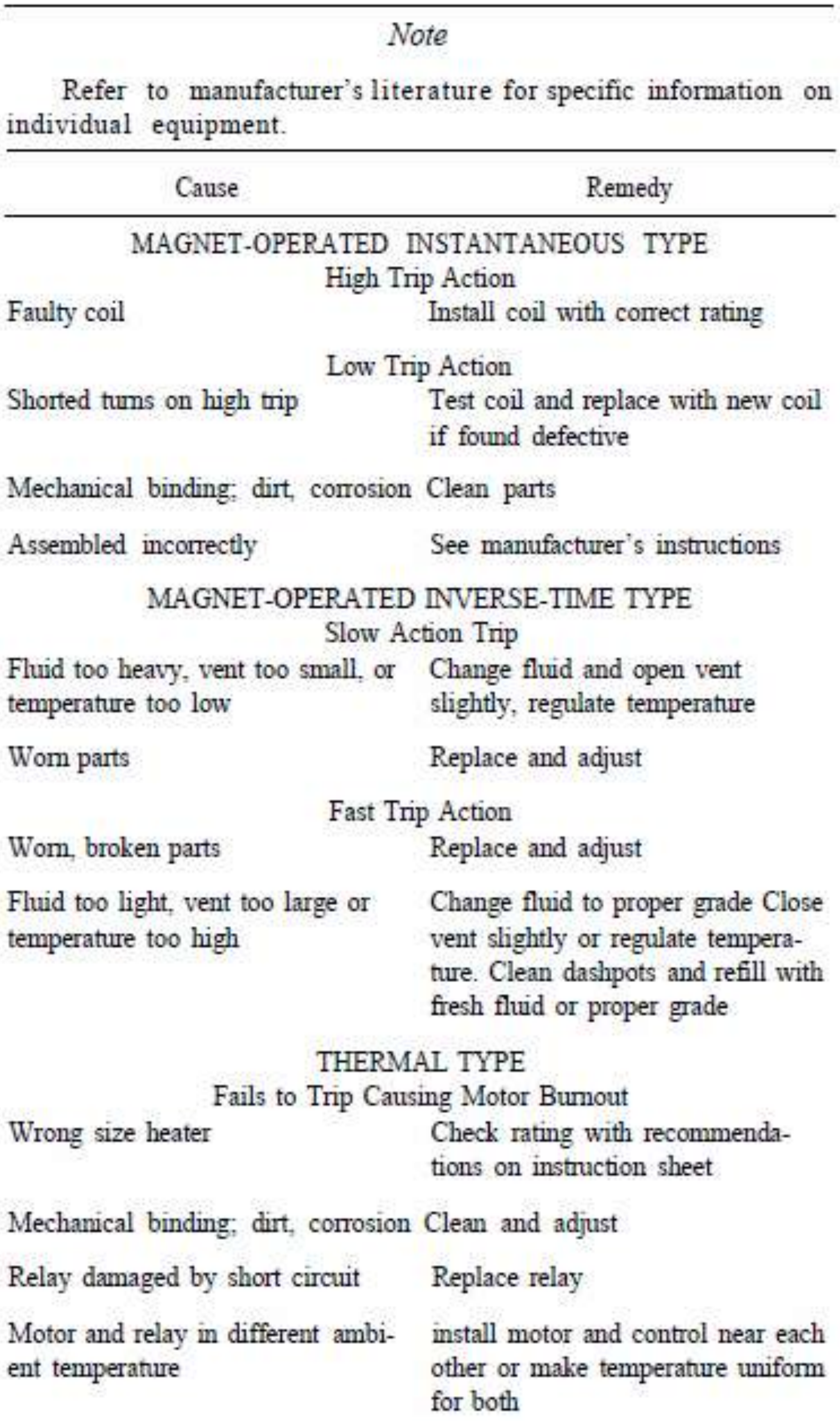
- Reduce the current until the relay drops out or fully resets. Verify that there is no binding during operation and refer to manufacturer's instructions.

- Verify that related devices such as capacitors are functioning properly and refer to manufacturer's instructions.

- Note that differential relays are usually very sensitive devices that use polarized sensing circuitry. Repeat the pickup test. Use the second test for comparison with previous and future test data. Refer to manufacturer's instructions.

8.3 RECORD KEEPING. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets must be specifically developed to suit auxiliary use.

8.4 TROUBLESHOOTING. Perform troubleshooting procedures when abnormal operation of the system or equipment is observed. Maintenance personnel must then refer to records for interpretation and comparison of performance data, i.e., log sheets. Comparisons of operation should be made under equal or closely similar conditions of load and ambient temperature. The general scheme for troubleshooting is outlined in the following table.



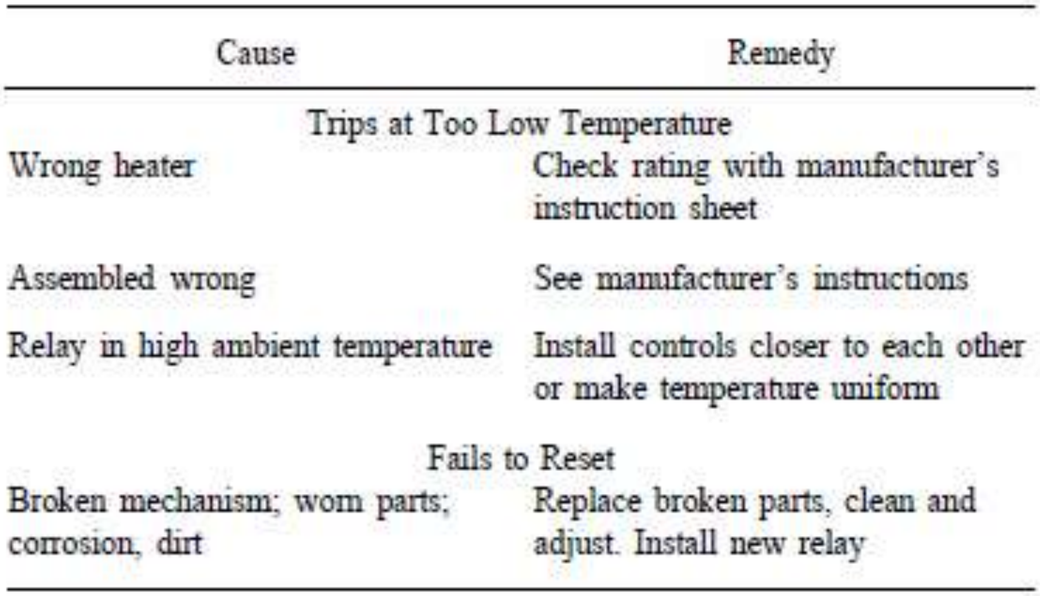
Note

Refer to manufacturer's literature for specific information on individual equipment.

Cause	Remedy
MAGNET-OPERATED INSTANTANEOUS TYPE	
High Trip Action	
Faulty coil	Install coil with correct rating
Low Trip Action	
Shorted turns on high trip	Test coil and replace with new coil if found defective
Mechanical binding; dirt, corrosion	Clean parts
Assembled incorrectly	See manufacturer's instructions
MAGNET-OPERATED INVERSE-TIME TYPE	
Slow Action Trip	
Fluid too heavy, vent too small, or temperature too low	Change fluid and open vent slightly, regulate temperature
Worn parts	Replace and adjust
Fast Trip Action	
Worn, broken parts	Replace and adjust
Fluid too light, vent too large or temperature too high	Change fluid to proper grade Close vent slightly or regulate temperature. Clean dashpots and refill with fresh fluid or proper grade
THERMAL TYPE	
Fails to Trip Causing Motor Burnout	
Wrong size heater	Check rating with recommendations on instruction sheet
Mechanical binding; dirt, corrosion	Clean and adjust
Relay damaged by short circuit	Replace relay
Motor and relay in different ambient temperature	install motor and control near each other or make temperature uniform for both

Table 5-3

Relay troubleshooting



Cause	Remedy
Trips at Too Low Temperature	
Wrong heater	Check rating with manufacturer's instruction sheet
Assembled wrong	See manufacturer's instructions
Relay in high ambient temperature	Install controls closer to each other or make temperature uniform
Fails to Reset	
Broken mechanism; worn parts; corrosion, dirt	Replace broken parts, clean and adjust. Install new relay

Table 5-3 (continued)

Relay troubleshooting

9. MISCELLANEOUS DEVICES. Miscellaneous devices include control switches, push buttons, indicating lights, batteries, surge capacitors, lightning arresters, maintenance tools, test equipment, and fuses.

9.1 CONTROL SWITCHES AND PUSH BUTTONS. Switchgear and related control panels contain complete controls for all functions of the auxiliary generator equipment. Control for voltage regulation, phase adjustment, current compensation, engine operating parameters as well as engine start, stop, and running speed, battery charging and brightness or dimming of indicator lights are usually provided.

9.2 INDICATING LIGHTS. White indicating lamps with colored caps are used to show breaker positions. Green lights indicate open breakers, red lights indicated closed breakers. White lights, when used, are energized from potential transformers to indicate live circuits. Some stations include amber or orange lights to indicate that the circuit has been tripped automatically. Low voltage lamps, connected in series with appropriate resistors, are usually used to reduce lamp size and glare. Red and green lights are usually wired so that they are energized through the trip coil of the breaker. An opening in the trip coil circuit is indicated by a dark unlit lamp. Similar indicating lamps and colored caps are used to indicate normal and abnormal conditions for other control functions of the system.

9.3 BATTERIES. Storage batteries and battery systems are frequently a part of an auxiliary power system. Batteries are used for prime mover cranking, or an uninterruptible power system. The batteries maintain a charge through the application of a “floating” battery charger. As the battery discharges its energy the charger increases its charge rate by increasing the flow of current into the battery. The converse is true as the battery reaches a full charge, a very small current flows into the battery. In addition, batteries provide power for switchgear control and power to trip some circuit breakers. Most applications for auxiliary power use some form of “wet” lead acid battery, however, some systems use “dry” nickel cadmium (nicad) batteries. Both types of batteries produce direct current repeatedly by chemical reactions.

Batteries must be recharged after each use to restore their power. Wet cell batteries require scheduled maintenance. This includes a visual inspection of all cells, a weekly hydrometer reading of the sample cell, and monthly readings of floating voltage, water level, hydrometer, and temperature of each cell. Cell connectors must be kept.clean and tight to prevent heating due to high resistance or voltage drop. Tops of cells must be kept free of dirt or conductive materials. Charging area must be exhausted to positively prevent hydrogen build up and explosion.

9.4 SURGE CAPACITORS. Surge absorbing capacitors are sometime used, with or without lightning arresters, to modify the shape of the surge voltage wave. These capacitors operate at voltages of 240, 480, 600 and higher for single or three-phase operation. Capacitor banks, formed by individual units connected in parallel, are sometimes used. Fuses and circuit breakers with time-current characteristics are used to prevent rupture of the capacitor case under severe conditions. Safety precautions must be observed when working on capacitors.

9.4.1 SURGE CAPACITORS using polychlorinated biphenyls (PCBs) may still be in use. Refer to 40 CFR 761. Since PCBs are carcinogenic and are not biodegradable, some restrictions to their use apply.

9.4.2 SPECIAL HANDLING IS required if PCBs are used in any equipment. PCBs are powerful solvents.

9.5 LIGHTNING ARRESTERS. A lightning arrester (a protective device) limits voltage caused by a lightning strike and bypasses the related current surge to a ground system which absorbs most of the strike energy. An overvoltage condition can also be caused by a fault in the electrical system.

9.5.1 THERE ARE TWO GENERAL TYPES of arrester designs, valve type and expulsion type. The valve type has one or more sets of spark gaps (series connected) which establish spark-over voltage, interrupt the flow of current, and prevent high current flow. The expulsion type has an arc extinguishing chamber in series with the gaps to interrupt the power frequency current which flows after the gaps have been sparked over. Design refinements include using oxide film coated components and sealing the inner components in a chamber filled with an inert gas. Aluminum cells are used in some units.

9.5.2 INSTALLED LIGHTNING ARRESTERS can retain a lethal electric charge. Accordingly, lightning arresters must be considered as loaded to full circuit potential unless disconnected from the circuit and grounded.

9.6 SPECIAL MAINTENANCE TOOLS. Always use the proper tool for the job being done. Avoid the use of improvised tools or tools in poor condition. Store tools not in use properly.

- Hand tools include the following: screwdrivers, pliers, wrenches, wire insulation strippers, and wire cutters.

- Powered hand tools include the following: hydraulic, pneumatic and electrical. Unless an electrical tool is battery powered or double insulated, make sure the tool has a line cord with a grounded conductor and polarized grounding plug. Make sure the receptacle to be used is properly grounded.

- Machine tools include grinding wheels and cutting tools.

9.7 TEST EQUIPMENT. Before using any test equipment make sure that it has valid calibration certification. Test equipment required for switchgear maintenance usually includes many or all of the following items.

9.7.1 MULTIMETER. The multimeter is sometimes called a volt-ohm-milliammeter or VOM. It is a single test instrument with a number of different ranges for measuring voltage, current, and resistance.

9.7.2 VOLTMETER. An instrument used for measuring voltage. Its scale indicates microvolts, millivolts, volts or kilovolts.

9.7.3 VOLTAMMETER.. An instrument used as either a voltmeter or an ammeter.

9.7.4 OHMMETER. An instrument used for measuring resistance. It consists of a DC milliammeter, a DC source, and a resistor network.

9.7.5 AMMETER. An instrument that measures the amount of current in amperes. Its meter shows current value in microamperes, milliamperes, or kiloamperes.

9.7.6 FREQUENCY METER. An instrument for measuring the frequency of an alternating current. Its scale shows Hertz (cycles per second), kilohertz (kilocycles), or megahertz (megacycles).

9.7.7 WATTMETER. An instrument for measuring electric power. Its scale is usually graduated in watts or kilowatts.

9.7.8 MEGOHMMETER. A device that is a high range ohmmeter, sometimes referred to as a megger. It consists of a hand driven, motor driven, or battery driven generator as the DC source, and a meter. It is used to measure insulation resistance and other high resistance. It can be used to check for continuity, grounds, and short circuits.

9.7.9 ELECTRICAL ANALYZER: An instrument for measuring the various parameters of AC circuits. It consists of a voltmeter, ammeter, wattmeter, and power factor meter. The analyzer also includes two current transformers and switches necessary for use. It can be used for testing insulation.

9.7.10 CERTIFICATION. Test equipment should have valid calibration certification.

9.7.11 FUSES. Fuses detect circuit overload conditions and open when there is too much current flowing. Fuses are the safety valves of the installation’s electrical system and provide the most economical type of circuit protection.

9.7.11.1 APPLICATION. There are many types of fuses with various characteristics. Always verify that a fuse, whether a new or replacement unit, is of the proper type and rating before installing. Never arbitrarily replace one type of fuse with another fuse of the same physical size just because it fits the fuse holder. The fuse used should have the correct current and voltage ratings, proper time delay and current limiting characteristics and an adequate interrupting rating to protect the circuit and its components. Fuse holders should never be altered or forced to accept fuses which do not fit.

9.7.11.2 CONSTRUCTION. A fuse consists of two main parts: the fusible link and the enclosing housing or body. The link is a metallic alloy that melts when excessive current flows through it, thereby breaking the circuit. When the current heats the alloy to its melting point, the link breaks and an arc forms. Melting continues rapidly until the resultant gap is too wide for the arc to span. A fuse usually can carry a 100 percent load indefinitely and will blow in a specified time at 150 percent overload. The following fuse types are usually used.

- **CURRENT LIMITING FUSES.** Current limiting fuses are used where necessary to limit the amount of fault energy flowing through a fuse to the circuit. A fuse must clear a fault in less than l/2 cycle of the fault current sine wave to be considered a current limiting fuse. If the fault current is allowed to flow for % cycle or more, the maximum (peak) fault current is passed through the fuse. A current limiting fuse must act quickly to limit the energy let through the fuse to the protected circuit. The total clearing time of a fuse is made up of two components; the melting time, and the arcing time. The fault current reaches maximum at the conclusion of the melting time, much less than l/4 cycle. An arc is established inside the fuse at the conclusion of the melting time. The arc presents a high resistance to the flow of fault current and the current decays to zero, clearing the fault. Whenever possible de-energize the fuse-holder circuit before removing or installing a fuse.

- **METAL-ENCLOSED FUSE.** Fuse enclosed in an oil filled metal housing and used (up to 7,500 volts) for protecting transformer banks and other distribution elements. Refer to the manufacturer's literature for details.

- **GLASS-ENCLOSED FUSE.** Fuse enclosed in a glass tube filled with arc quenching liquid. Carbon tetrachloride is the liquid frequently used. Refer to the manufacturer's literature for details.

- **EXPLOSION FUSE.** Fuse enclosed in a fiber tube filled with dry (powdered) boric acid. When the fuse element blows, the boric acid produces a gas which aids in promptly deionizing the arc. Used on circuits up to 138 kV. Refer to the manufacturer's literature for details.

9.7.11.3 CHECKS AND EXAMINATIONS. Examine fuse terminals and holders for discoloration caused by heat from poor contact and/or corrosion. Checks to be performed are determined by the type of fuse and fuse holder, proceed as follows:

- Inspect fuse and fuse holder contact surfaces for pitting, burning, alignment, and spring pressure. Badly pitted or burned components must be replaced.

- Examine the fuse unit, and renewable element if the fuse type is used, for corrosion. Check for signs of discharge tracking on the fuse. Replace components that show deterioration.

- Verify that all attaching parts are installed and tightened to proper torque value.

- Check fuse tubes made of fiber or other organic material. Refinish the fuse tube as required. Refer to manufacturer's literature.

- Check vented expulsion fuses. Some fuses may have condensers or mufflers to restrict expulsion of gases during operation. A dropout feature that automatically disengages the fuse when it operates may be used. These fuses usually have seals to keep moisture out of the interrupting chamber. Refer to manufacturer's literature for instructions.

- Replace fuse holders and clips which are worn or make poor contact. Remove oxidation and corrosion from fuses, holders and clips. Determine the causes of overheating and correct as required.

9.8 SYNCHROSCOPE. A synchroscope, usually installed on a switchgear control panel, is used to determine the phase difference or degree of synchronism of two alternating current quantities or two generators. The synchronism always indicates the condition of the incoming machine with respect to the bus. If the frequency of the incoming machine is higher than the bus frequency, the synchroscope point revolves in the "fast" direction. If the frequency of the incoming machine is lower than the bus frequency, the synchroscope pointer revolves in the "slow" direction. If the pointer stops at a position other than 0 degrees, it indicates that the incoming machine is at the same frequency as the bus but out of phase. Correct the phase error by adjusting the prime mover governor of the incoming machine for higher speed. The synchroscope pointer should revolve slowly in the "fast" direction. The machines are paralleled when the pointer reaches the 0 degree position while traveling in the "fast" direction. When paralleled, the pointer will stay at 0 degrees. Refer to manufacturer's literature for specific operation and inspection information on individual equipment.

1. STEAM BOILER SYSTEMS

1.1 STEAM BOILER SYSTEM DEFINED. A steam boiler is an enclosed vessel that holds water and is heated by an external source that converts the water to steam. All steam boilers contain tubes that separate the water from the heat source. Steam boilers are described in this publication.