ABSTRACT
        This third-year course for electrical power station
wirer apprentices is a foundation for the study of all aspects of
installation and maintenance of power station equipment. It also
provides a good technical background as well as the general knowledge
essential to power station operator trainees. The course is intended
to be equivalent to a classroom course requiring a minimum of 5 hours
of class attendance each week for 36 weeks. The seven units consist
of one to six lessons each. Unit topics include care and maintenance
of electric motors and generators, insulating materials for
electrical machinery, electrical drawings, switches and circuit
breakers, protective devices and relays, insulating oil, system
voltage regulation and power capacitors, and control electronics.
Each lesson provides a brief rationale for the content to be learned,
lists directions, cites the required reference, lists check-up
questions, and provides information sheets. (YLB)

ELECTRICAL POWER STATION THEORY

A

Course of Technical Information
for

Electrical Power Station Wireman Apprentices

ACKNOWLEDGEMENT

STATEMENT OF ASSURANCE

PREFACE

This third-year course for electrical power station wireman apprentices is a foundation for the study of all aspects of installation and maintenance of power station equipment. It does not cover in detail all the devices utilized in design, construction, or operation. It is felt that manufacturers' literature on specific equipment will serve as an adequate source for such details.

To assure maximum continuity of electrical service with minimum damage to life and property, the equipment in our modern electrical power systems has become more and more sophisticated. Substations frequently become complex nerve centers and may be found in large and small systems, in power company and industrial installations. Wide usage of electrical energy and high demand for reliable operation have created a need for trained personnel who are qualified to be directly responsible for the installation, operation, and maintenance of equipment.

Power station operator trainees will also find that this basic course provides a good technical background as well as the general knowledge so essential to understand the work performed on the job.

The course is intended to be equivalent to a classroom course requiring a minimum of five hours of class attendance each week for 36 weeks of the year.

CONTENTS

(more)

ELECTRICAL POWER STATION THEORY

UNIT I

A.   CARE AND MAINTENANCE

OF ELECTRICAL MOTORS AND GENERATORS

B.   INSULATING MATERIALS

FOR ELECTRICAL MACHINERY

CARE AND MAINTENANCE OF ELECTRICAL MOTORS AND GENERATORS

Motors and generators ordinarily found in power stations and substations do not demand extraordinary care to keep them operating efficiently. Like all machines, they should receive planned attention. A regular system of examining, adjusting, and servicing will certainly pay dividends.

It is highly desirable that you know how to tell when a motor or generator has failed or needs some minor repair or adjustment. All types of motors and corresponding generators have many elements in common for which maintenance work is fairly uniform item for item.

Too often motor maintenance is considered a handyman's job that almost anyone can do without experience or craining. This concept has led to many failures, expensive production delays, high repair costs, unnecessary motor replacements, broken shafts, poor working tools, and cmployee injuries. No one would expect an automobile to run year-after-year without proper inspection or to run with just any kind of oil in the crankcase; yet this is the kind of treatment that many electric motors receive.

Here are some important rules for preventive maintenance of rotating equipment:

- Keep it clean.
- Keep it properly lubricated.
- Don't wait for a motor to smoke or squeak before oiling or other maintenance.
- Don't continuously overload.
- Correct poor conditions before motor fails.
- Remember an ounce of prevention is better than a pound of cure.

REMEMBER, it is cheaper to take care of motors than to replace them.

A simple lubrication job will sometimes clear up symptoms of distress which are taken for much more serious troble. When an apparently good motor starts to act up, look first at the lubrication.

ENEMIES OF AN ELECTRIC MOTOR

Dust
Excessive oil
Moisture
Condition of insulation
Friction
Misalignment
Vibration
Overload
Lack of lubrication

Dust

Dust is probably motor enemy number one. It is eternally getting into the motors and settles on housings, windings, frame, slip rings, commutators, and bearings. On windings, dust acts as an added layer of heat insulation. Dust stops the ventilation ports. It acts as an abrasive and insulator on slip rings, commutators, and bearings. On windings, dust acts as an added layer of heat insulation and impairs ventilation. It acts as an abrasive and insulator on slip rings and commutator; inside a bearing it will ruin it.

The time to eliminate dust inside a motor is before it has had a chance to unite with moisture or oil. Thus, it is necessary to wipe off motors and to blow the dust out of the winding at regular intervals. Compressed air up to about forty pounds of pressure may be used. This air should be dry and must not contain grit or metal.

Excessive Oil

Oil inside bearings is the life blood of motors. Oil outside of bearings is poison to electric motors.

Dust plus oil forms gum. Gum or oil on a commutator makes for poor operation. The faces of the brushes become glazed, and harmful sparking follows. Gum or oil on the windings is even more harmful. Once the winding is thoroughly soaked with dirty oil, the motor is in danger of a turn out or breakdown. Oil plus dust on windings limits the ventilation and holds stray metallic particles, thus further lowering the insulation values.

When oil and dust have been allowed to build up on a motor insulation, it can be removed by use of scrapers, rags, or a solvent such as electrolene. Solvents should be used with caution and care taken not to soak the insulation or it may be softened. When through cleaning, dry the windings and apply a coat of insulating varnish if necessary. The room should be ventilated when washing a motor.

It is imperative that oil be kept away from windings. Wipe off stray oil; don't lubricate sleeve bearings while the motor is running or overfill them with oil.

Moisture

An ideal operating location for a motor is a dry place. Since this is often impractical the best practice is to dry a motor as quickly as possible after it gets wet. This is important for two reasons. First, it takes time for moisture to soak in and soften the insulation. Thus, if the moisture can be removed in a hurry, little damage will be done. Second, water that is left on the insulation surface will absorb harmful compounds from the air, such as alkalies and salts, and may thus become a destructive agent.

Every effort should be made to keep water from dripping, splashing, or flooding a motor. A motor may be dried out by -

a. Placing it in an oven.
b. Circulating current through the windings with motor blocked.
c. Using a fan to force hot air through the windings.
c. Cover motor with a tarpaulin leaving a hole at the top and then heat the inside with resistors or light bulbs.
e. Any combination of the above.

Occasional megger readings should be taken during drying. Maximum temperature should normally be below the boiling point of water.

A common method for drying out generators is to short circuit the output. The generator is then run with a sufficient amount of field current to cause rated current to circulate in the windings.

Condition of Insulation

The rate of deterioration of insulation in motors and generators depends directly upon the temperature at which the machines are operated. Old insulation becomes dry and brittle and will very easily flake off, while new insulation will be more flexible and elastic. As insulation dries out, it will have a tendency to shrink. The coils will become loose in the slots and and will move, thus causing mechanical wear which will result in early failure of the insulation.

There are several methods of testing insulating materials, but the most widely used is an instrument called the megger. The megger consists of a high resistance voltmeter. Its source of d-c supply is in the form of a magneto. These machines are built in various sizes and ranges. The voltage ranges from 150 volts to 2,500 volts, d-c.

The most useful quality of the megger is that it will indicate insulation change between periodic readings. The readings will indicate the condition of the insulation and make it possible to avoid unexpected breakdowns. Consistent decreasing values of periodic readings generally indicate a pending breakdown in the insulation.

In preparing to use a megger, the needle should be adjusted to infinity with the leads disconnected. The megger may be of the hand-cranked or motor-driven type. For larger pieces of equipment, the motor-driven megger should be used because the test voltage can be applied steadily and continuously over a 15- to 30-minute period, and sometimes longer.

No exact formulas or rules are used in insulation resistance measurements because temperature, surface leakage, and other conditions affect insulation resistance. Some guidelines have been established. One company uses the following standard formula as applied in the megger test.

$$\frac{\text{Rated voltage}}{\text{Capacity in KVA (or KW)} \div 1,000} = \text{megohms}$$

For a machine rated 1,000 KVA, 2,300 volts, the minimum insulation resistance should be:

$$\frac{2,300}{1,000 + 1,000} = 1.15 \text{ megohms}$$

Friction

In theory, little or not wear will take place in a bearing if the surfaces are smooth and well lubricated. A film of oil keeps them apart and prevents wear. However, in actual practice bearings may not have enough oil in them, may have the wrong oil, grit and dirt may get into the oil and scrape the bearings, or the load may be so heavy that the film of oil breaks down. Preventing any of these conditions is a job for the maintenance man.

One of the very best ways to fight friction is to pay close attention to the manufacturer's lubrication instructions covering type and grade of lubricant and frequency of use. Don't try to guess the grade and type of oil. Use only the best quality of oil as it is one of the lowest items of cost.

In sleeve bearings, it is vital to see that the oil ring is free and is turning with the shaft. At regular intervals, the reservoir should be flushed and the dust seals checked.

In ball and roller bearings the main purpose of the grease is to guard the steel rolling elements against corrosion and not friction. Too much grease increases friction and heat and also shortens life.

Extra tension on belt or chain drives should be avoided.

Misalignment

Misalignments often cause burned-out bearings, overload failures, broken shafts and damage the driven machine. Settlement of foundations, too heavy floor loading, excessive wear, warped bases, and excessive belt, or chain-driven tension are common causes of misalignment.

Warnings of misalignment may be excessive bearing temperature, increased vibration, and rapid knocking. It may be lessened by loosening the mounting bolts and experimenting with positions while the motor is running. Decrease in the degree of noise or vibration or its disappearance will indicate improved alignment.

A level may be used to indicate if a motor is not level. Use shims to level.

The tension in a belt drive should be correct - too much will cause increased wear and too little will result in belt slippage.

Vibration

Vibration may be caused by misalignment with the driven machine (load), rotor out of balance, loose mounting bolts or worn bearings. Excessive vibration should be eliminated as soon as possible as it can shake electrical connections loose, crystallize metal parts, or increase frictional wear.

Stopping vibration is a process of elimination. A good method is as follows:

a. Tighten all motor support bolts. Check motor for loose parts and check for loose shims.
b. Compare size of supporting structure with a motor support that does not vibrate.
c. Check bearings for looseness.
d. Disconnect motor from load and see if motor runs without undue vibration. (Be sure to have proper alignment.)
e. Check rotor bore balance - dynamic or static.
f. Check for correct alignment.

Overload

A motor worked far beyond its rated capacity will sooner or later break down. Overloading will fry the insulation and melt solder out of joints. To prevent this, motors are given overload protection such as thermal elements, fuses, or circuit breakers.

An underloaded a-c motor has an excess of wattless current which produces useless heat. This is known as low power-factor. This low power-factor results in high line losses, higher voltage drop, and lower motor efficiency. This problem is largely eliminated by the correct application of motors.

Incorrect voltage or frequency will cause a motor to overheat; too low a voltage will cause the motor to draw too many amperes. Check the motor nameplate values, and check the voltage at the motor terminals with motor underload.

Lubrication

An analysis of induction motor failures shows the bearings to be the principal offenders. Failure of a bearing allows the rotor to rub against the stator, and failure of the motor follows. Probably the most commonly used bearing is the sleeve type. The newer sealed-sleeve-type bearings requires very little attention since the oil is not contaminated and there is little oil leakage. The real advantage of ball and roller bearings is that the starting friction is practically the same as the running friction.

Many greases deteriorate in time and in service by either oxidation, separation, or both. In the case of separation, the oil comes out of the mixture and escapes, leaving a hard, flaky residue without any lubricating value. This residue may act as an abrasive. In the case of oxidation, the

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grease progressively becomes tacky and may be discolored. Lastly, it becomes sticky and gummy thus preventing the free movement of the balls and inner race. As a result, dry metal-to-metal friction may follow and ruin the bearings.

The pressure-relief method of greasing ball and roller bearings is generally all right as most of the old grease is forced out by the pressure of the gun and the new oil. However, bearings should be completely cleaned at regular intervals depending on the type of service. They should be washed with a grease solvent and then flushed with a solvent such as a light mineral oil.

Oil should be drained from the housing of sleeve-type bearings at least every year. Remove the drain plug from t! bottom of the frame, where available, and flush. If the motor is not equipped with a drain plug, the end shield should be removed, then turned upside down and cleaned. After cleaning refill with the proper oil.

If motors are equipped with waste-packed bearings re-oil every month if continuous operation; if periodic operation, re-oil about every six months.

Motors should <u>not</u> be oiled while they are running. The excess oil may get into the windings causing a fire hazard and deteriorating the insulation. Also it is <u>not</u> safe to lubricate many motors while they are running.

Be sure to use a good grade and correct type of oil. Most oil-filler gages should be filled to within 1/8" of the top. Do not fill until they overflow.

REPLACING BALL BEARINGS

A good fit is very important when working on ball and roller bearings. This includes the engagement of the inner race with the shaft, the fit of the outer race in its housing, and the clearances between the bearing and its races. The total radial clearances between balls and races may be as little as the thickness of a human hair. This degree of precision is a must if the bearing is to operate satisfactorily. The inner race should not be forced on the shaft as it may change the clearances; also, it should not be so loose as to permit its turning as this will, in time, ruin the bearing. Likewise, a too tight fit of the outer race is harmful. Also, it should not be permitted to turn in its housing. (Probably more bearings are ruined by turning of one of the races than by any other cause.) One of the bearings of a motor must be free to move axially because of the heating of the rotor shaft. This change of length may be as much as .003".

A <u>Ball-bearing race</u> must be assembled on the shaft so that the race is exactly square with the shaft. Even the slightest burr will cause trouble. When installing, pressure should be applied evenly all around and only light tapping should be done. Heavy pounding will ruin the bearing. Be sure the grease retainers are in place. Rotate the outer race by hand to see if it operates without friction and to check for noise. The inner race may be preheated with an electric heater before placing on a shaft.

Sleeve bearings should be pressed into position without pounding or distortion. Check the end play of the rotor. Be sure the bearing is located so that it will get oil from the reservoir. See that the oil and oil ways are clean and free from burrs. See that the oil rings and retainers are in place and operate freely.

CAUTION: Never handle ball bearings with sweaty or dirty hands. Perspiration marks on a highly polished surface will damage (corrode) the surface.

CLEANING OF ELECTRIC MOTORS

Many motor failures are directly due to use of wrong solvents for cleaning.

A good solvent cleaner should not dry too rapidly. Excessive speed of drying tends to cause sweating of the windings because of the rapid cooling and the resulting moisture condensation.

A solvent that dries too slowly will hasten the break-down of both rubber and enamel insulation because of the oily residues which are left. Thus, the problem of selecting a cleaning solvent is a compromise between these two. Toxic effects of a too-rapid drying solvent, such as carbon tetrachloride, and fire hazards of slow-drying solvents, such as gasoline, must be considered.

Fumes from carbon tetrachloride may be lethal. One may inhale them in an enclosed space, feel O.K. today, and be dead in a week or so from their effects. Toxicity is the effect on the health of the user when a solvent vapor is inhaled or the solvent is absorbed through the skin. Do not use carbon tetrachloride for cleaning. Use chlorothene or electrolene. The following table shows the relative characteristics of some of the more common solvents.

Name of Solvent	Fire Hazard Class	Health Hazard Class	Rate of Evaporation	Special Notes
Gasoline. . . .	High	Medium	Fast	Prohibited as solvent
Acetone	High	High	Fast	Very explosive
Alcohol	High	Low	Fast	
Solvsol (1,500A). . .	High	High	Fast	Very explosive
Methyl, Ethyl, Ketone. . . .	High	High	Fast	Very explosive
3,661 Lacquer Thinner . . .	High	High	Fast	Very explosive
Cleaning Solvent . . .	Medium	Low	Medium	
Painters Thinner . . .	Medium	Low	Medium	

(more)

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(Continued)

Name of Solvent	Fire Hazard Class	Health Hazard Class	Rate of Evaporation	Special Notes
Chlorothene . .	None	Medium	Fast	
Electrolene . .	Low	Medium	Medium	
Kerosene. . . .	Low	Low	Slow	
Turpentine. . .	Low	Medium	Medium	Avoid skin contact
Carbon Tetra-chloride. . .	None	High	Fast	Harmful (restricted use)
Chloroform. . .	None	High	Fast	Vapor extremely harmful (restricted use)

INSULATING MATERIALS FOR ELECTRICAL MACHINERY

CLASSIFICATION AND CHARACTERISTICS

Many solid insulating materials are porous and will readily absorb moisture upon contact. A very small amount of moisture may ruin the insulation by changing to a conductor. Generator, motor, and condenser windings must be baked in ovens for long periods of time to drive all moisture from the insulation and allow the varnish or other impregnating material to replace it in the pores.

Most insulating materials would maintain their properties indefinitely if it were not for mechanical damage, contamination by water, or other conducting materials. Insulation deterioration also results from oxidation or the presence of acids and other corroding chemicals. Measurement of insulation resistance affords an indication of the fitness of the machine to undergo dielectric tests. Insulation resistances will vary inversely with the temperature. That is the insulation resistance will decrease with increase in temperature. Various methods are used to measure insulation resistance, but the megger method is most generally used. Dielectric strength is expressed in terms of voltage at which the insulation punctures or fails under electrostatic stress and is not dependent on the cross-sectional area of a homogeneous insulation material under test, but increases with thickness.

Excessive heat increases the rate of oxidation of any material and causes many insulating materials to become brittle and more subject to mechanical damage. Wide variations of temperature, resulting in mechanical expansion and contraction, will eventually cause insulation to crack.

Heat and moisture are the worst enemies of insulating materials. Since heat is developed when an electric current passes through a conductor, the amount of current which can be safely carried in the conductor is limited by the effects of the heat on the insulation. The practical limitation of the carrying capacity of a piece of electrical equipment is therefore determined by the maximum amount of heat which can be tolerated without resulting in a deterioration of the insulation.

TYPES OF MATERIALS

Some of the insulating materials commonly used in maintenance and repair of electrical machines are as follows.

Asbestos for electrical insulating purposes is generally used in the form of asbestos paper or paper tape, asbestos millboard, or asbestos lumber. In such forms, it may contain from 10 percent to 20 percent wood pulp and glue to give it strength. Asbestos may be spun and made

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into asbestos cloth or cloth tape, which generally contains approximately 14 percent cotton. Asbestos is very poor electrical insulation, but an excellent vehicle for insulating compounds. When dry and properly treated it is valuable for high voltage apparatus.

Mica is mined in large crystals and is probably the most valuable insulating material in general use. ica has high dielectric strength, high insulation resistance, acid resistance, good mechanical strength, flexibility, and deterioration from the heat factor is very slight. In the construction of commutators, the manufacturer most commonly uses mica for commutator segments.

Cotton, like all other organic materials, is not suitable for high temperature applications, but the uses of cotton for electrical insulation are many and diversified. Cotton fabrics are generally processed with various varnishes, compounds, or gums. Treated fabrics are the fundamental Class A insulating materials. There are many varieties of these treated fabrics. The two most commonly used are varnish-treated cloths in tan or black. When tested in sheet form between 2" electrodes, the instantaneous breakdown voltage of the tan varnished cloths will generally be not less than 1,000 volts per mil, and the black cloths 1,200 volts per mil. The other dielectric properties of these materials are very good.

Paper of many varieties is used in insulating electrical apparatus. These range from the very thinnest Japanese tissues through the cotton rag, Manila (hemp), kraft (wood pulp), and jute (used principally in making fiber), to the thickest fish paper and fullerboard types. Because of an extreme tendency to absorb moisture, untreated papers have little insulating value.

Shellac is one of the oldest insulating materials, and it is still one of the natural gums most commonly used in the electrical industry. Shellac is an excellent binder for mica and other solid insulation, as it has particularly good adhesive properties. Orange shellac, generally used for insulating purposes, has a dielectric strength of 450 to 580 volts per mil. It has extremely high insulation resistance and low dielectric loss, or power factor. Although shellac dries with a hard, tough film, it is very brittle. The melting point increases after each melting until after prolonged heating it becomes more or less infusable. The moisture resistance of shellac is low and consequently it is affected by climatic conditions.

Insulating varnishes are of great importance in the electrical industry and particularly in the maintenance of electrical motors and generators. An insulating varnish is a chemical compound of varnish gums and drying oils, having high dielectric strength and other properties that afford protection to the windings of the electrical apparatus.

There are several distinct types of insulating varnishes in general use. Clear varnishes, in general, are not as moisture-resisting as the insulating black or Glyptal No. 1,201 red which also is widely used as

a surface coating on windings of motors and generators. A good air-drying varnish would have a minimum dielectric strength of from 800 to 1,500 volts per mil. Baking varnishes are usually applied by the dipping process. When mixed with air, vapors from solvents in varnishes are inflammable and explosive. They sometimes affect the nose and throat of persons in constant exposure to the fumes so adequate ventilation should be provided.

The usual baking temperature is from 110° to 135° C. The baking time will vary from six hours to forty-eight hours, or even longer, depending on the size of the apparatus.

Micarta is made of layers of cloth, paper, or wood saturated with either synthetic or organic resin, and then compressed under heat. This makes the resin permanently hard and the micarta will never thereafter be softened by heat, pressure, or solvents. Micarta is almost the equivalent of a metal that is non-magnetic and also an insulator. It absorbs very little moisture and is not affected by moderate strength acid solutions.

Flexible glass textiles are woven from thread made entirely of glass fibers, and are not destroyed by exposure to high temperatures as are cotton, silk, paper, or other organic materials. Untreated glass fibers are not suitable as electrical insulation when exposed to moisture. They should always be treated with a suitable insulating varnish or compound. Many hot-line tools in use today are composed of some form of fiberglas.

ELECTRICAL POWER STATION THEORY

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UNIT II

ELECTRICAL DRAWINGS

This unit contains the following lessons:

CIRCUIT DIAGRAMS USED IN CONTROLLER WORK

Motor control circuits contain protective devices, starters, brakes, and limit switches. An understanding of schematic and wiring diagrams of such control circuits is imperative for anyone working with motors. In studying this lesson, you will be preparing yourself for the more complicated schematic diagrams representing complete electrical systems.

Directions: (3-2-1)

Study the material presented in Information Sheet No. 3.

Read any reference material that may be assigned by your instructor.

Write out and hand in to your instructor the answers to the check-up questions.

Required reference:

Information Sheet No. 3

Check-up: (3-2-1)

1. Draw a schematic diagram of a basic motor control circuit which contains an overload protective contactor and three control stations which start and stop the motor when the push buttons are pressed momentarily.

2. A contact making clock and an across-the-line starter is to be used to start and stop an induction motor. The clock will be set to turn the motor on at 7:00 a.m. and off at 6:00 p.m. Would you sav the control would be classed as low-voltage release or low-voltage protection?

3. Draw the schematic diagram symbol for the following devices:

    a. Control relay coil
    b. Normally open contact of a control relay
    c. Normally closed contact of a control relay
    d. Stop button
    e. Start button

4. What is meant by electric-seal-in?

5. What is electrical interlocking? Mechanical interlocking?

6. Draw a schematic diagram for the compensated starter control using autotransformers explained in this lesson.

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7. Complete the wiring diagram on the worksheet, "Sequence Control Interlocked Through Push Buttons for Conveyor Drive." Wire as per schematic. Use a straightedge and make your drawing neat.

8. Complete the wiring diagram on the worksheet, "Forward-Reverse-Stop, Low-voltage Protection Interlocked Through Push Buttons." Wire as per schematic. Use a straightedge and make your drawing neat.

9. What would happen if the forward and reverse buttons in the diagram in question 8 were pushed simultaneously?

10. A 10-horsepower, 220-volt, three-phase, 60-cycle, squirrel-cage induction motor is rated at 28 amperes per terminal. What size heater overload units should be used in the magnetic starter?

SEQUENCE CONTROL INTERLOCKED THROUGH PUSH BUTTON FOR CONVETOR DRIVE

STATION 1
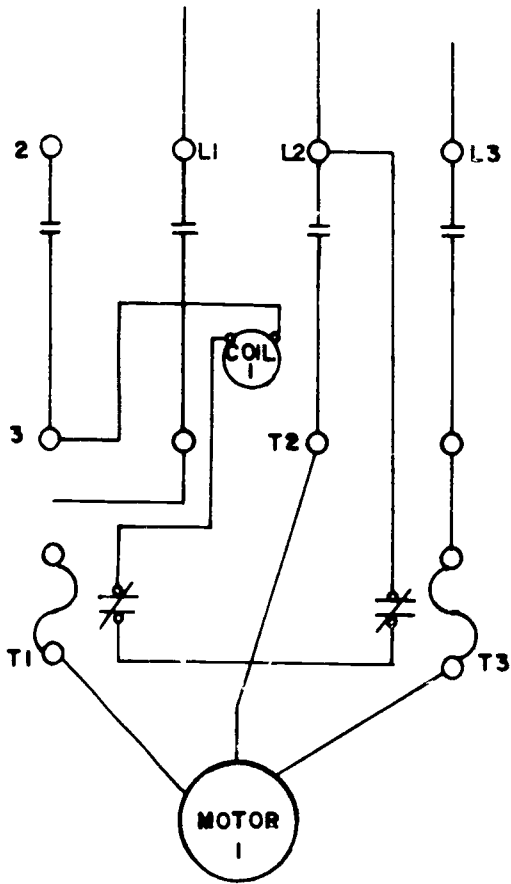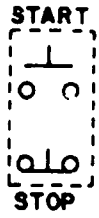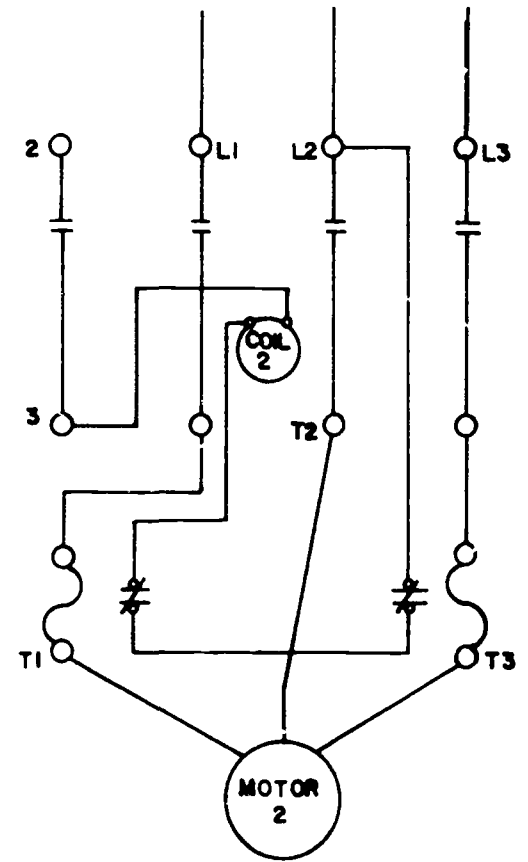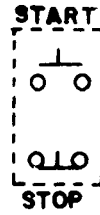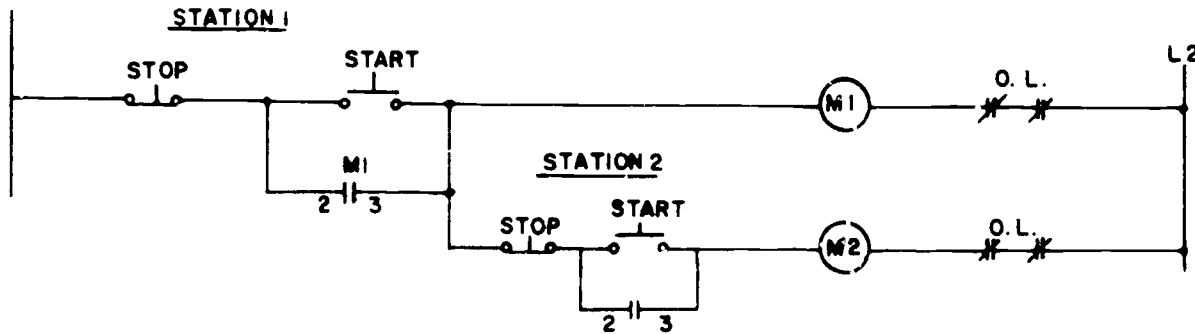
STATION 2
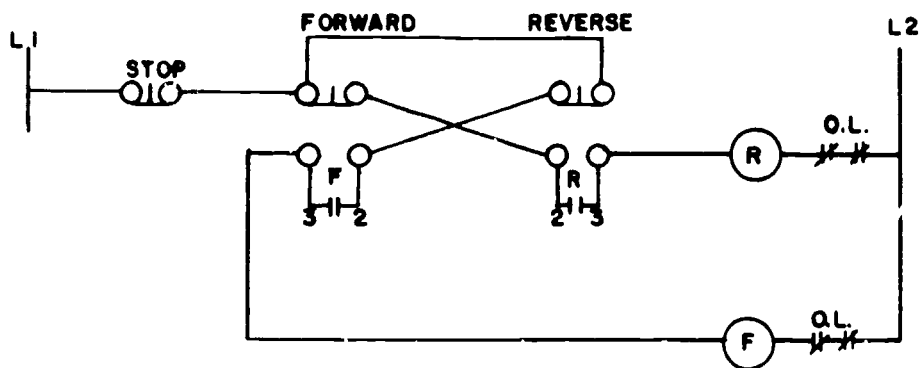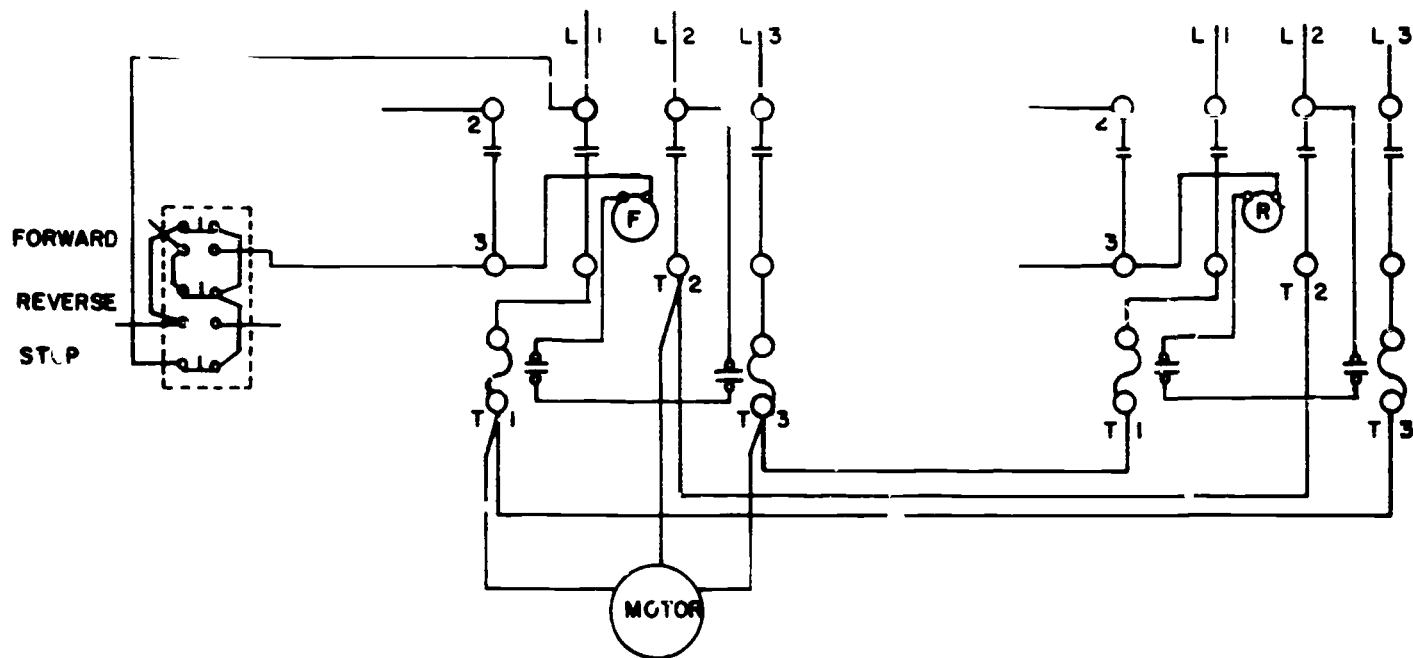
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FORWARD – REVERSE – STOP, LOW VOLTAGE PROTECTION
INTERLOCKED THROUGH PUSHBUTTONS

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CONTROL CIRCUIT DIAGRAMS

Several types of circuit diagrams are used in controller work. The two most commonly used are the WIRING DIAGRAM and the ELEMENTARY (SCHEMATIC) DIAGRAM.

Wiring diagrams include all devices in the system and show their physical relation to each other. All poles, terminals, coils, etc. are shown in their proper places on each device. These diagrams are helpful in wiring-up systems because connections can be made exactly as they are shown on the diagrams. In trying to follow the electrical sequence of a circuit, however, the wiring diagram does not show the connections in a manner that can be easily followed.

The elementary or schematic diagram is a representation of the system showing everything in the simplest way. No attempt is made to show the various devices in their actual relative positions. All control devices are shown between vertical lines which represent the source of control power. Circuits are shown connected as directly as possible from one of these lines to the other.

A wiring diagram gives the necessary information for actually wiring-up a group of control devices or for physically tracing wires when tracing wires when trouble-shooting is necessary. A schematic diagram is also a great aid in trouble-shooting as it shows in a simple way the effect that opening or closing various contacts has on other devices in the circuit.

Two terms that are sometimes confusing whenever motor control is discussed are low-voltage release and low-voltage protection. The main distinction between the two is that with low-voltage release (also called no-voltage release) the coil circuit is maintained through the control switch. If for any reason the power source voltage is inadequate, the coil will drop out, but when the voltage again reaches sufficient value the control will function automatically to connect the aparatus to the line again. Low-voltage protection is maintained through a stop contact on the push button station and an auxiliary contact on the starter. These allow the control to be removed from the line if the power source fails. In order to start the apparatus again, it is necessary to actuate the start button.

These two types of control circuits, commonly known as two- and three-wire controls, require different types of push buttons. The low-voltage release-control circuit requires a push button that remains closed until released by hand. The low-voltage protection is secured by a momentary-contact-type push button.

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WIRING DIAGRAM OF LOW-VOLTAGE RELEASE
TWO WIRE CONTROL STARTER

Two wires lead from the control device to the starter. "No-voltage release" and "two-wire control" should bring to mind an automatic control device such as a limit switch, float switch, or a push button that remains closed until released whose function is opening and closing the control circuit by means of a single contact.

CONTROL DEVICE SUCH AS THERMOSTAT, FLOAT SWITCH, PRESSURE SWITCH ETC.

LINE

TWO WIRES

THERMAL OVERLOAD

MOTOR

CONTROL DEVICE
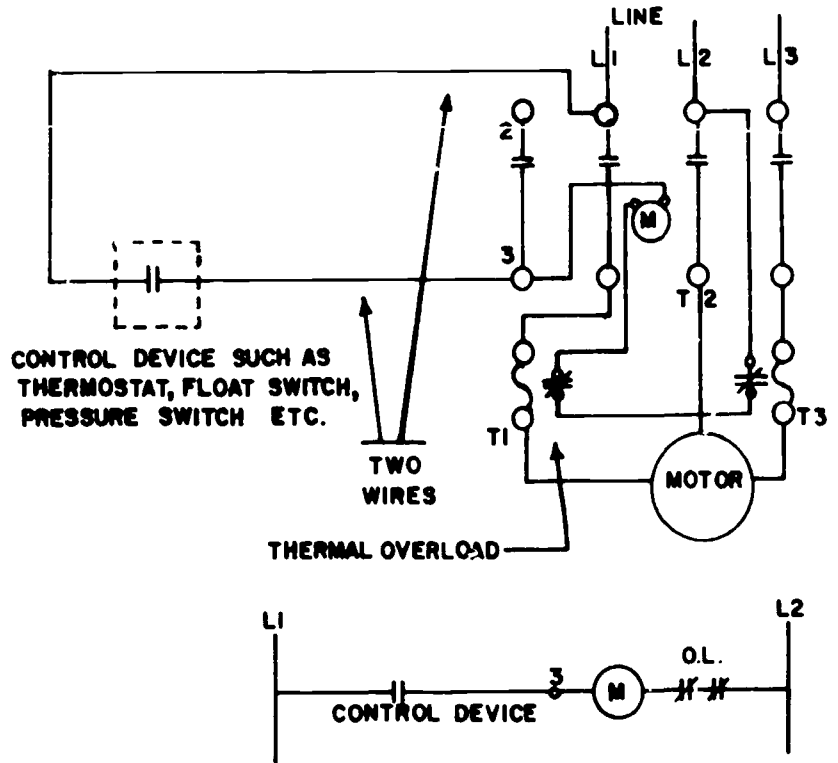
SCHEMATIC DIAGRAM

STANDARD STOP-START PUSHBUTTON CONTROL WITH LOW-VOLTAGE PROTECTION THREE WIRE CONTROL

The designations "two-wire" and "three-wire" are used only because they describe the simplest applications of the two types. Actually, in other systems, there might be more wires leading from control station to starter but the principle of "two-wire" or "three-wire" control would still be present.

START

STOP

THREE WIRES

MOTOR

WIRING DIAGRAM

STOP START

SCHEMATIC DIAG

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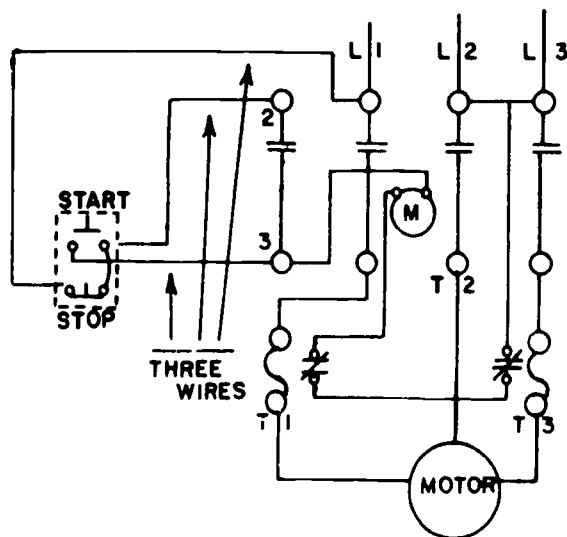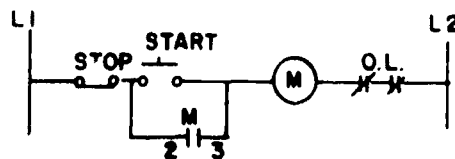
TWO START STOP PUSHBUTTON STATIONS
WITH LOW-VOLTAGE PROTECTION

Three wires lead from
the control station to
the starter. "No volt-
age protection" and
"three-wire" control
should bring to mind a
"Start-Stop" push button
station which is the most
common means of providing
this type of control.
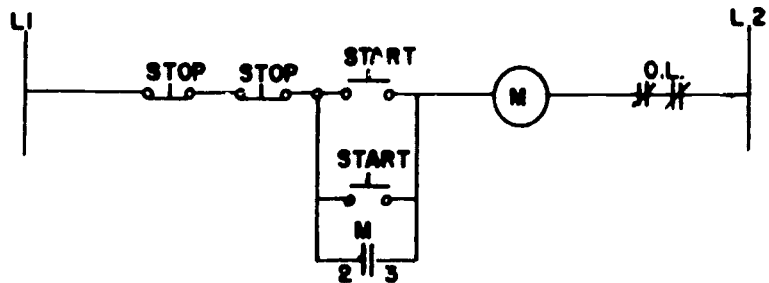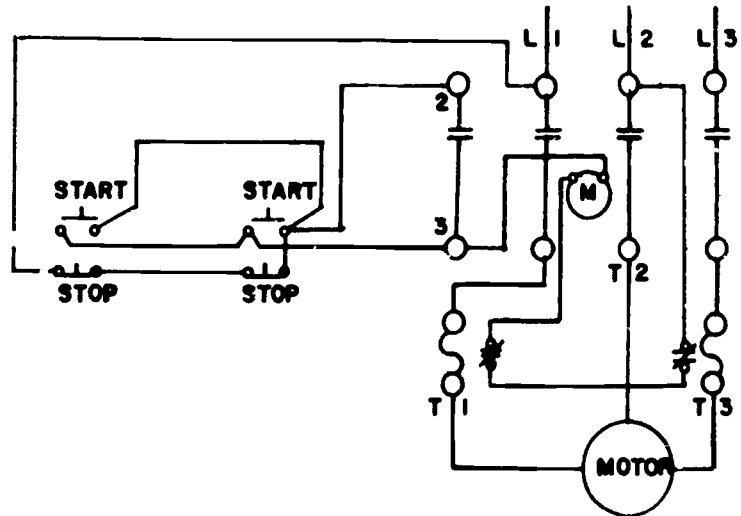
You will note in the low-voltage protection wiring diagram that the
three-wire source lines are indicated by L_1, L_2, and L_3 and the motor termi-
als of the starter by T_1, T_2, and T_3. Two phases have overload protection
devices "O.L." connected in series with the normally open contacts that feed
T_1 and T_3.

The control station consists of a normally open start button and a
normally closed stop button. The same connections are represented in the
schematic diagram, but show only the control. It is customary to draw
schematics in the de-energized position and the normally open contacts are
open. There is no complete path for the current unless the start button is
pushed. Always read the schematic from left to right or from L_1 to L_2.

When the start push button is momentarily pressed down, the path is
complete from L_1 through the closed stop button, through the start button,
through the coil M, and the normally closed overload contacts to the line
L_2. The current will flow through this circuit and energize the coil M. The
coil M closes the auxiliary, or sealing, contactor, contacts 2 and 3. Now
the start button may be released, but the auxiliary contacts of the contactor

marked 2 and 3 seal in the circuit and keep it closed as long as the coil M is energized.

At the same time you can see from the wiring diagram that the circuit to the motor is completed.

When the stop push button is pressed momentarily, the circuit is open, the coil M will be de-energized, and the seal in contact and the line contacts open. There is no path for current to the motor, so the motor will stop. Every device which has the function of stopping the motor must be in series with the stop button and be normally closed. You will note that if too much current flows through the overload devices this will cause the normally closed O.L. contacts to open and de-energize the coil M also.

The overload relay whose action depends on the movement of a bimetallic strip under heat has an inverse time limit which means the greater the overload, the shorter the time of tripping. Heaters for thermal relays are made with different current ratings. So, within its limits, any starter can be used with different size motors and still afford proper protection by selection of the size of heater that corresponds to the full-load current of the motor being used.

If the motor should be started from two control stations, the additional station with its two push buttons must be connected so that the additional start button is in parallel with the original start button. The additional stop button must be in series with the original stop button as shown on the immediately preceding diagram.

Induction-type and synchronous a-c motors have a high starting current; therefore large motors are mostly started with a reduced voltage, although there are many quite large a-c motors which are started across the line, that is by applying the full-rated voltage.

On power systems, the high starting current from a large motor may cause serious voltage disturbances. The starting current may be reduced by using a resistance starter or a reactor starter. In a third method, shown in the following diagram, the starter uses autotransformers to provide reduced-voltage starting.

When the start button is pressed, a circuit is established from line 1 through the normally closed stop button, through the start button, through contacts TM to coil S, through the normally closed overload contacts and then to line 2. When coil S is energized, all contacts marked S close. The three autotransformers are connected in wye across the three-phase line supply reduced voltage to the motor. The motor starts to accelerate to rated speed. A circuit is also established through the motor of the accelerating relay by means of contacts TM. The accelerating relay motor starts operating and after a definite period mechanically actuates all contacts marked TM. This action de-energizes the starting contactor coil and causes the S contacts to open. However, the same action also energizes the running contactor coil R which closes the running contacts, applying full-line voltage to the motor terminals. The accelerating relay motor now stops because its circuit was opened when the contact TM opened.

21
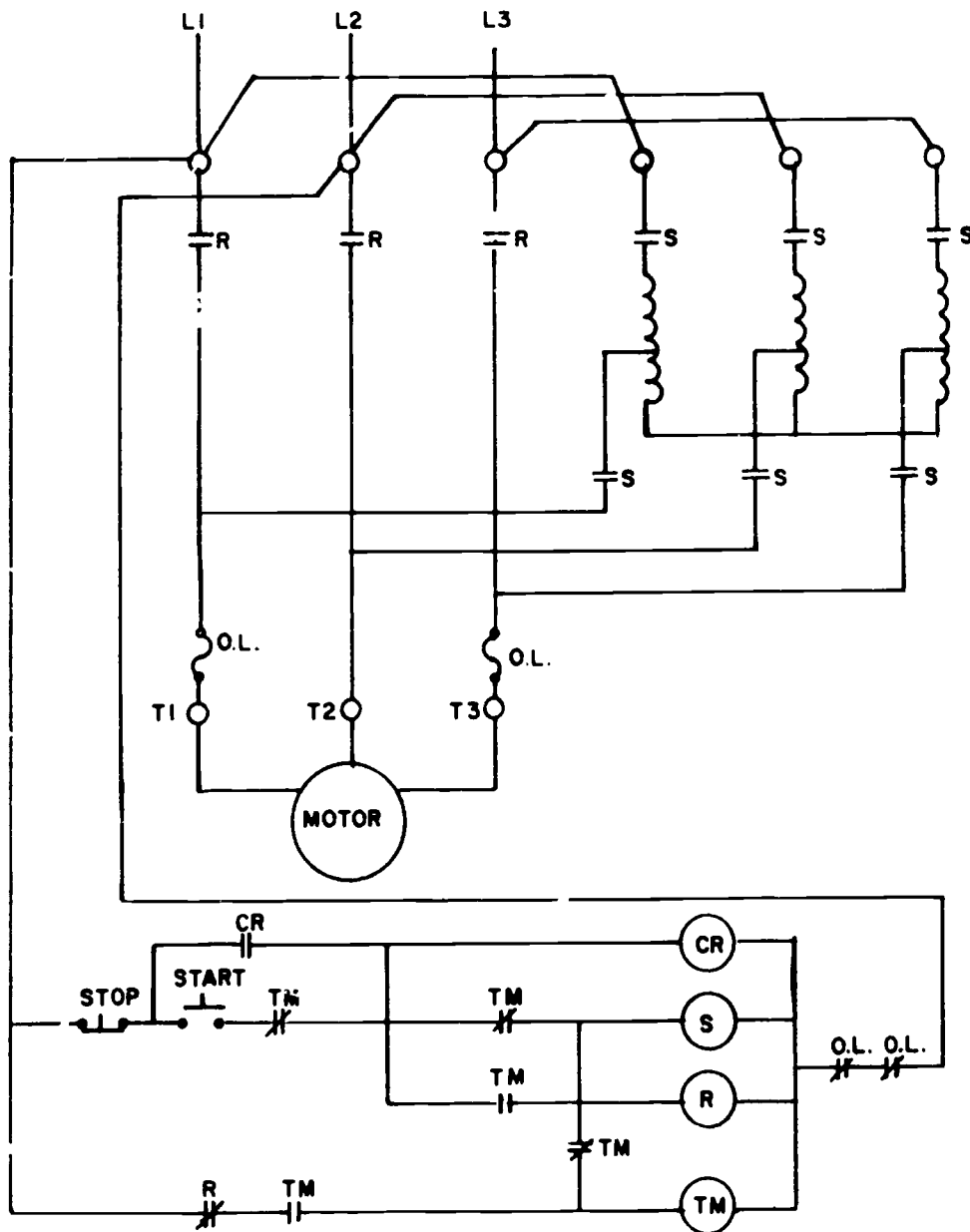
The control relay CR is energized when the start button is closed and provides the seal-in to keep the motor running after the start button is released.

If the stop button is pressed, the holding coil curcuit for both coils CR and R opens. This causes the R contacts to the motor to open, and it stops. When coil R becomes de-energized, the normally closed contacts R close the accelerating relay motor circuit, and the motor runs to set all contacts TM for the next starting cycle.

ONE-LINE DIAGRAMS

The objective of this lesson is to provide you with sufficient infor-
mation and training to enable you to read and understand one-line diagrams.
The one-line diagram is a tremendous aid to electricians, load dispatchers,
station operators, electrical engineers and all personnel who work with or
around power stations or industrial installations of electrical equipment.
These systems contain many components, such as transformers, voltage regula-
tors, and switch-gear, housed in transmission and distribution substations.
The electrical connections of all these components are complicated and
numerous. The one-line diagrams give a simplified overall view which helps
in tracing the function of these systems.

Directions:

    Study the material presented in Information Sheet No. 4.

    Read any reference material that may be assigned by your instructor.

    Study any one-line diagrams of the substations near your headquarter
    as may be available to you.
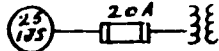
    Write out and hand in to your instructor the answers to the check-up
    questions.

Required reference:

    Information Sheet No. 4

Check-up: (3-2-2)

    1.   Draw a one-line schematic of a 4,150-volt-3ϕ-draw-out circuit
         breaker, feed from a delta-wye transformer bank rated, 63 Kv-
         2,400/4,150 kv, 7,500 kva. Show high-side fuses and motor-
         operated disconnect switch. Show lightning arrestors on the
         high side only. Indicate 600/5 current transformers and 3 time
         over-current relays on the load side (4,150 volt) of the trans-
         former to trip the circuit breaker.

    2.   A selector switch that is wired into the control circuits of a
         circuit switcher has three positions: "Automatic," "Off,"
         "Manual." What would be the most appropriate switch-gear device
         function number?

    3.   Draw the symbol for a step type, 3ϕ distribution voltage regulator.
         Draw the symbol for an induction type regulator and label EACH as
         such.

    4.   Draw a line disconnect switch mechanically interlocked with a
         ground switch.

30

5. What is the device function number for a reclosing relay?

6. Draw the relay function symbol and give the device function number for the following relays:
    a. Current differential
    b. Directional overcurrent
    c. Overvoltage
    d. Over temperature
    e. Phase balance current

7. For directional relays, what do the arrow points indicate?

8. If the symbol ⊘─▭─ appeared on a one-line schematic, what would it represent?

9. What device function number is used to describe:
    a. A field breaker?
    b. A motor operated field rhoestat?

10. Describe the method of numbering disconnect switches, power circuit breakers, transformers, transmission lines, substation bus and feeder lines in the power company where you work.

ONE-LINE DIAGRAMS

Electrical drawings are a specialized form of mechanical drawings. They deal mainly with electrical apparatus and its installation in power plants, substations, or industrial plants. Drawings that represent the physical arrangement and views of specific electrical apparatus or their parts, with their shapes and dimensions, and that represent the wiring necessary for their connections to the source of power are sometimes made for construction purposes. More often drawings that show connections of electrical devices, indicated by symbols, are used and referred to as schematic and wiring diagrams. Schematic electrical diagrams indicate only the basic connections without regard to their physical relationship or position. Wiring diagrams give additional information about the equipment used and in a general way try to show the physical location of the equipment.

Some workers refer to any electrical print or electrical diagram as a wiring diagram. Standard terms have not been generally established and applied. In studying electrical drawings, you will soon acquire the ability to recognize whether a print gives the wiring details or only a scheme of connections, regardless of the title used.

The one-line diagram in its simple form (see example included with this information sheet) indicates by means of single lines and simplified symbols the component devices or parts of a substation or plant and the path or paths for energy transfer. The one-line diagram is one of the most used electrical drawings. When a new job is contemplated, the first drawing to be made is a one-line, and its use continues during all the life of the station. If you understand the information on a single or one-line diagram and know how to use it, you have the necessary basic information to understand the operating instructions. You will be able to locate trouble and know the switching necessary to remove defective equipment and restore service.

One-line diagrams are drawings that are intended to show, in diagrammatic form, electrical connections. They are never drawn to scale as they only show the electrical association of the different electrical equipments. In diagrams, work symbols are used extensively to represent the various pieces of electrical apparatus, and these symbols are connected by lines indicating the wires or bus that complete the electrical circuits.

Electrical symbols most frequently used on single or one-line diagrams are included in this information sheet. This is only a partial list, and you may find that your company uses these as shown or somewhat modified. Also, there is no standard size for electrical symbols. Usually manufacturers or drafting rooms establish their own sizes. The type and rating of the device represented by a symbol are often added adjacent to the symbol. For example, next to a transformer symbol could be added these data: 15,000-kva, 3-phase, 62,700-13,470 Y / 7,200 volts.

In switching equipment, devices are often referred to by numbers. Most power companies use a system of numbering circuit breakers, disconnecting

switches, transformers, regulators, etc. There is no standard used through-
out the industry, however. There is a standard device number used according
to the functions that a piece of equipment performs. These numbers are based
on a system which has been adopted as standard by the American Standards
Association. This system is often used in part to better identify some piece
of equipment.

READING A ONE-LINE DIAGRAM

A one-line diagram is intended to show only all major equipment of the
primary circuits. It shows the entire substation at a glance; that is, it
shows the electrical relationship of the equipment. Each line in the diagram
represents three wires or phases. Each device symbol indicates one three-
phase device or three single-phase devices which are connected to each wire.
Accordingly, one switch symbol indicates one three-phase switch or three
single-phase switches. If only one single-phase device is used in a three-
phase system, the notation next to the symbol indicates this fact.

VISUALIZATION OF A ONE-LINE DIAGRAM

Oftentimes, one of the most difficult jobs is that of visualizing (tying-
in) what each symbol on a one-line diagram means and where the object itself
is located. One of the best methods is to take the single-line diagram, study
it, then go to an oil circuit breaker and identify the particular oil circuit
breaker with its symbol on the drawing. Next identify the disconnects on both
sides of the breaker (physically and on the drawing). Then identify the leads
between the breaker and the disconnects both physically and on the drawing.
Go over this process mentally until you can look at a breaker symbol on the
drawing and see the breaker in your mind. Take another breaker or a trans-
former and repeat the process. Continue this process until one small station
is mastered.
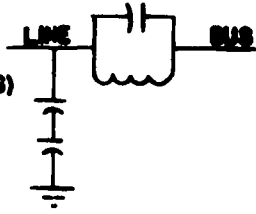
Do not try to learn all of a single-line diagram at one time. Take it
piece by piece and fit the small parts into the complete diagram. This
method may take considerable time and study the first few times it is tried.
After you once get the general idea of visualizing a one-line diagram, it
soons becomes a routine process.

ONE-LINE SCHEMATIC DIAGRAM

The single or one-line diagram, as previously mentioned, is limited to
representing the main or primary circuits. A more elaborate one-line diagram
that includes such things as current transformer circuits, potential trans-
former secondary circuits, metering, and protective-relay circuits is often
referred to as a one-line-schematic. (See example included with this infor-
mation sheet.) Heavy lines are commonly used to indicate primary circuits,
thin lines indicate secondary circuits such as low-voltage potentials,
secondary of a current transformer, excitation circuits, etc. This form of·
diagram is a type of shorthand which makes use of abbreviated symbols and
conventions to convey many ideas. The wires between symbols are drawn either
horizontally or vertically. They are rarely slanted. This does not mean
that the actual wire which physically connects components must always be

horizontal or vertical. The use of symbols presumes that the person looking
at the diagram is reasonably familiar with the operation of the device and
will be able to assign the correct meaning to the symbols. A dot at the
junction of two crossing wires means a connection between the two wires. The
absence of a dot at the crossing means that the wires do not connect.

COMMON SYMBOLS FOR ONE-LINE AND CONTROL SCHEMATICS

OIL CIRCUIT BREAKER

AIR CIRCUIT BREAKER   (WITH THERMAL TRIP)

DISCONNECT OR KNIFE SWITCH   (MOTOR OPERATED DISC)

FUSE, HIGH VOLTAGE   (FUSE CUT OUT)

FUSE, LOW VOLTAGE

DISCONNECTING PLUG

TRANSFORMER (ONE LINE)   (COMPLETE WIRING)

REGULATOR (STEP TYPE)   (INDUCTION TYPE)

CURRENT TRANSFORMER   (BUSHING TYPE)

POTENTIAL TRANSFORMER   (CAPACITOR POTENTIAL DEVICE)

GROUND

LIGHTING ARRESTER

RESISTOR   (WITH SLIDE WIRE)

RHEOSTAT

REACTOR

CAPACITOR   (CARRIER WAVE TRAP WITH CAPACITOR COUPLING)

MOTOR

GENERATOR

FIELD

MECHANICAL CONNECTION — — —

MECHANICAL INTERLOCK — + — —

BATTERY   (THE LONG LINE IS ALWAYS POSITIVE)

RELAY COIL   ✶ WITH DEVICE FUNCTION NUMBER IN CIRCLE

METER OR INSTRUMENT   ✶ WITH LETTER INDICATING TYPE OF METER (AMMETER, VOLTMETER ETC.)

METER SHUNT

LIGHT   ✶ WITH LETTER IN CIRCLE INDICATING COLOR (R-RED, G-GREEN, Y-YELLOW, ETC.)

CONTACT (NORMALLY OPEN)   (NORMALLY CLOSED)

TERMINAL   O

SYMBOLS DERIVED FROM AMERICAN STANDARDS ASSOCIATION

DEVICE FUNCTION NUMBERS

The American Standards Association (ASA) has adopted a standard system of numbers for devices performing a given function. This system is used by all member companies in connection with wiring diagrams, instruction books, and specifications.

Each device has a function number which is placed adjacent to the device symbol on all wiring diagrams and arrangement drawings. In addition, the device function number is attached to or located adjacent to each device so that it may be readily identified.

SWITCHGEAR DEVICE FUNCTION NUMBERS

Device Number	Function of Device
1.	Master element
2.	Time-delay starting or closing relay
3.	Checking, or interlocking relay
4.	Master contactor or relay
5.	Stopping device
6.	Starting circuit breaker, contactor, or switch
7.	Anode circuit breaker
8.	Control power switch
9.	Reversing device
10.	Unit sequence switch
11.	Control power transformer
12.	Over-speed device. Functions on machine overspeed
13.	Synchronous-speed device
14.	Underspeed device
15.	Speed, or frequency, matching device
16.	Battery-charging control device
17.	Series-field-shunting circuit breaker or contactor
18.	Accelerating or decelerating circuit breaker, or relay
19.	Starting-to-running transition contactor or relay
20.	Electrically operated valve
21.	Impedance or distance relay
22.	Equalizer circuit breaker or contactor
23.	Temperature regulating or controlling device
24.	Bus-tie circuit breaker, contactor, or switch
25.	Synchronizing or synchronism-check device
26.	Apparatus thermal device
27.	A-C undervoltage relay
28.	Resistor thermal device
29.	Isolating circuit breaker, contactor, or switch
30.	Annunciator relay
31.	Separate excitation divice
32.	D-C reverse power relay or device
33.	Position switch
34.	Motor operated sequence switch
35.	Brush-operating or slip-ring short-circuiting device
36.	Polarity device

Device Number	Function of Device
37.	Undercurrent or underpower relay
38.	Bearing thermal device
39.	Field-reducing contactor
40.	Field relay
41.	Field-circuit breaker, contactor, or switch
42.	Running circuit breaker, contactor, or switch
43.	Transfer or selector switch, manually operated
44.	Unit sequence starting contactor or relay
45.	Reserved for future application
46.	Reverse-phase, or phase-balance, current relay
47.	Phase-sequence voltage relay
48.	Incomplete sequence relay
49.	Machine, or transformer, thermal relay
50.	Instantaneous overcurrent, functions on excessive value of current
51.	A-C time overcurrent relay
52.	A-C circuit breaker or contactor
53.	Exciter, or d-c generator, relay
54.	High-speed, d-c circuit breaker
55.	Power factor relay
56.	Field application relay or device
57.	Short-circuiting, or grounding, device
58.	Power rectifier misfire relay
59.	Overvoltage relay, functions on a given value of overvoltage
60.	Voltage-balance relay
61.	Current-balance relay
62.	Time-delay stopping or opening relay
63.	Fluid-pressure, level, or flow relay
64.	Ground protective relay
65.	Governor, controls the gate or valve opening of a prime mover
66.	Notching, or jogging device
67.	A-C directional overcurrent relay
68.	D-C thermal relay or device
69.	Permissive control device
70.	Electrically operated rheostat
71.	D-C line emergency circuit breaker or contactor
72.	D-C line circuit breaker or contactor
73.	Load-resistor circuit breaker or contactor
74.	Alarm relay
75.	Position changing mechanism
76.	D-C over-current relay
77.	Impulse transmitter
78.	Phase-angle measuring, or out-of-step protective relay
79.	A-C reclosing relay
80.	D-C under-voltage relay or device
81.	Frequency relay
82.	D-C reclosing relay
83.	Automatic selective control or transfer, relay
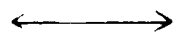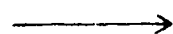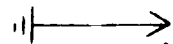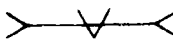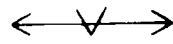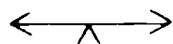
Device Number	Function of Device
84.	Operating mechanism
85.	Carrier or pilot wire receiver relay
86.	Locking-out relay or device
87.	Differential current relay
88.	Auxiliary motor or motor generator
89.	Line switch
90.	Regulating device
91.	D-C voltage-directional relay
92.	D-C voltage and current directional relay
93.	Field changing contactor or relay
94.	Tripping or trip-free relay or contactor
95.	
96.	
97.	Reserved for future application
98.	
99.	

The basic symbol for a secondary device is a small circle which may represent a relay, meter, motor or instrument. These are identified by letters and numbers within the basic symbol. The numbers are ASA standards for station-device functions. A small square is used to represent some form of switch-transfer switch or selector switch, or even a complete modual of equipment. Meters, instruments, and other devices not included under relays are identified by abbreviations within or adjacent to the basic symbol. For example: A 3∅ = ammeter, 3-phase; WH = watthour meter, etc.
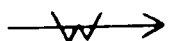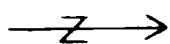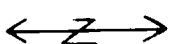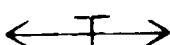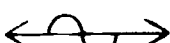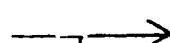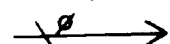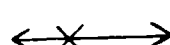
FUNCTIONS AND OPERATIONS SYMBOLS

In addition to, or as an alternative to ASA standard automatic station device function numbers, a standard graphic function symbol may be placed adjacent to a relay symbol. The direction of the arrow on such symbols of directional functions may be used to indicate the direction of power flow in the primary circuit required to operate the relay.

<div align="center">RELAY-FUNCTION SYMBOLS</div>

Symbol	Function
←——————→	Overcurrent
———————→	Directional overcurrent
‖————→	Directional residual overcurrent
>——V——<	Under-voltage
←——V——→	Over-voltage
←——Λ——→	Balanced current
←——Λ——→	Voltage-balance
←——X——→	Differential current

31

Symbol	Description
⟶〰⟶	Power directional
⟶Z⟶	Directional distance
⟵Z⟶	Distance
⟵丅⟶	Over temperature or thermal overload
⟵〰⟶	Over frequency
⟶⚏⟶	Directional ground
⟶✕⟶ (oK)	Carrier directional comparison (phase and ground)
⟶∅⟶ (cK)	Carrier phase comparison
⟵✕⟶ (Pω)	Pilot wire (differential current)

OPERATOR LINES
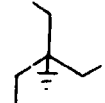
Another device used on one-line diagrams sometimes are dotted lines, known as "operator lines." These are used to associate relays with the auxiliary relays or primary-circuit devices which they actuate. Arrows at the termini of operator lines point to the devices operated by the devices at the other termini. In the following diagram, for example, the IJD relay 87 actuates auxiliary HEA relay 86, which in turn trips the power circuit breakers A and B, whereas the GCX directional-distance relay trips circuit breaker A directly, when fault current flows in the direction indicated by the arrow of the function symbol.
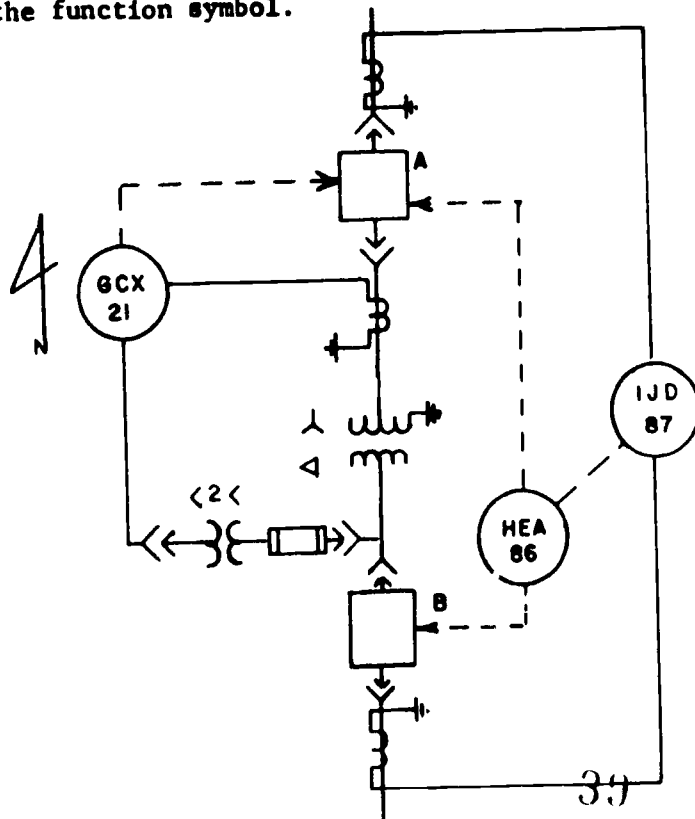
TRANSFORMER VECTOR SYMBOLS

Transformer vector symbols many times are shown adjacent to the transformer symbol. The most commonly used are shown below.

$\triangle$ 3 φ-3 wire delta

$\not\triangle$ 3 φ-3 wire delta grounded

$\triangle$ 3 φ-4 wire delta grounded

$\curlywedge$ 3 φ-wye ungrounded

3 φ-zig zag grounded

φ to neutral on 3φ system

$\angle$ 3 φ-open delta

3 φ-wye grounded

EXAMPLE OF ONE LINE DIAGRAM

HARMONY 13 KV PRI

R- 103

2 R-104

R-105

NORMALLY OPEN
TIE SWITCH

R-107 R-108 R-109

2

BUS R-52

HARMONY - MILWAUKIE
13 KV PRI

STA SER
1-10 KVA 1∅

WR-1
1-15000 KVA, 3∅

HARMONY-SELLWOOD
115 KV LINE

SMD-2B
150E, SLOW

AUTO/MAN

43

W-101

W-117

W-121

BUS W-51

W-113 W-111

CLACKAMAS-HARMONY
115 KV LINE
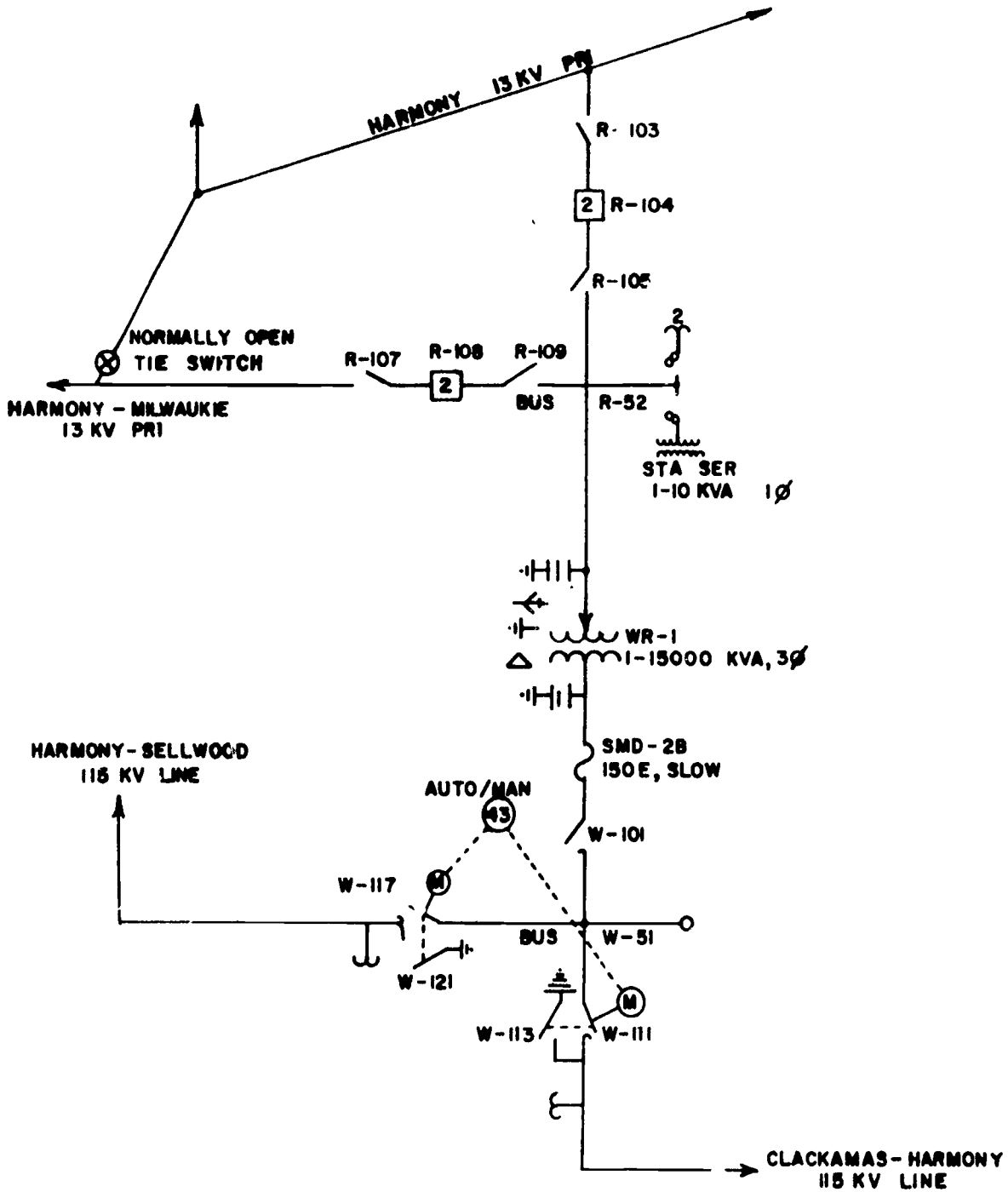
NAME OF ELECTRIC CO.		
NAME OF SUBSTATION ONE-LINE DIAGRAM		
DATE		
DESIGN ENG.		
DRAWN BY		
DATE OF LAST REVISION		

EXAMPLE OF A ONE-LINE SCHEMATIC DIAGRAM
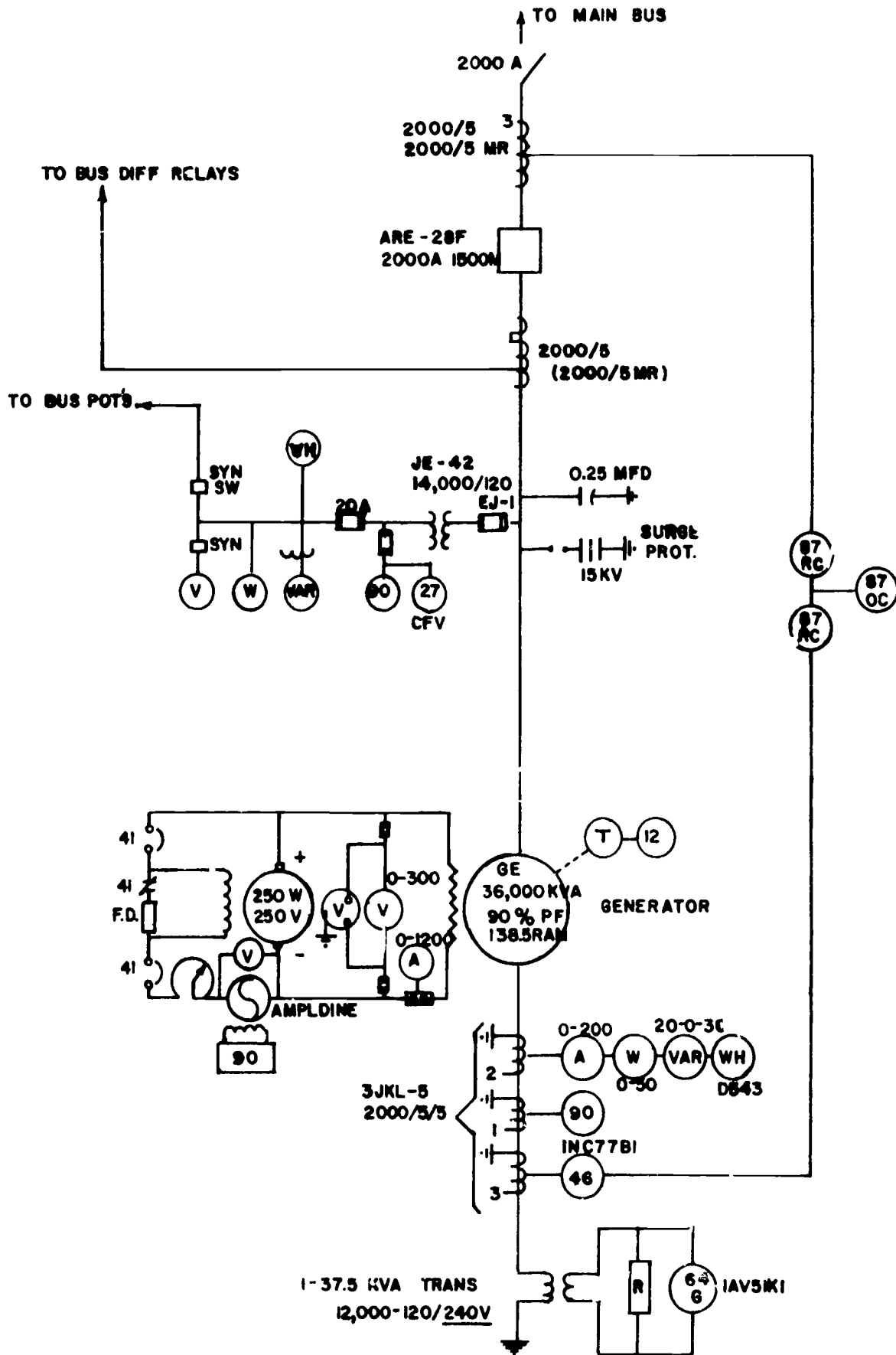
ELEMENTARY DIAGRAMS AND CONTROL SCHEMATICS

This lesson is designed to give you both know-how and some practice in reading and understanding control schematics. A set of schematics used in an actual substation is discussed.

You should concentrate when reading this type of drawing and develop a sequence of operation from the information presented on control schematics that you will work with most often on your job.

Direction:

Study Information Sheet No. 5, and any additional references that may be assigned by your instructor, thoroughly before you answer the check-up questions at the end of the lesson.

Read each check-up question carefully and be sure you understand it. (The questions are designed to aid you in obtaining a better understanding of the topic.)

Write the best answer that you can to all the check-up questions. When you complete your work, examine it closely, correct any errors that you find, and hand it in to your instructor.

Required reference:

Information Sheet No. 5

Check-up: (3-2-3)

1. What is meant by the term "anti-pump"? What is an "X-Y" scheme?

2. Write the electrical symbol for
   a. Relay contacts-open when de-energized
   b. Relay contacts-closed when de-energized
   c. A control fuse
   d. An electrical connection
   e. An a-c circuit breaker "b" switch
   f. An a-c circuit breaker trip coil

3. Write the device function number of the following devices:
   a. An alarm relay
   b. A time-overcurrent relay
      A transformer differential relay
   d. An a-c circuit breaker reclosing relay
   e. An undervoltage relay
   f. An impedance relay

NOTE: Refer to the G.E. prints in this lesson for the answers to the following questions.

4. Draw a one-line schematic of the G.E. metal-clad substation.

5. Are the transformer breakers and the bus tie breaker tripped by a-c power or d-c power? What size fuse is used in the tripping bus?

6. Trace the manual tripping circuit of the 52-1 circuit breaker. (List each contact.)

7. How would you describe the manner in which the 94-1 relay and the 94T-1 relays are connected? Why do you suppose they use two relays?

8. What contacts block manual tripping of the circuit breakers with the SB-1 control switch when the transfer switch is in the automatic position?

9. With the 43 switch in the manual position:
   a. Can the overload relays trip the transformer breakers?
   b. Can the thermal (over-temperature) relays trip the transformer breakers?
   c. Can the under-voltage relays trip the transformer breakers?

10. Which transformer normally supplies the station service (lighting and heat) for the substation? Explain the sequence of operation for the automatic transfer of the station service. (What happens if the normal source is de-energized?)

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ELEMENTARY DIAGRAMS AND CONTROL SCHEMATICS

The simple one-line diagrams studied in the last lesson point out only the essential parts of a substation or power system. In each system, there are many devices necessary for protection, regulation, control, and measuring. The substations and generating stations are an important part of every electric power system. The purpose of most substations is to receive high voltage power and transform it to a lower voltage power suitable for distribution to various customers.

To portray all details of construction and operation it is necessary to produce blueprints or drawings. Of the many types of electrical diagrams, the ones covered in this material can be classified as follows: one-line diagrams one-line schematics, three-line schematics, and wiring diagrams and control schematics. There are many others, such as the line-arrangement plan, the grounding and conduit plan, and electrical arrangement drawings which consist of plan views, elevation views, and lighting plans. You should become familiar with all of these on the job.

THREE-LINE SCHEMATIC DIAGRAMS

The three-line schematic, sometimes called the elementary diagram, is a three-line, or complete diagram in arrangement similar to the one-line schematic that shows all necessary lines, such as all three phases of the circuit, and all devices used. Where possible, even the actual physical relationship and phase arrangement of the busses is shown. Symbols are again used to represent the various pieces of equipment.

Each circuit is drawn in the so-called "straight line" form. Practical experience has shown that the more complicated circuits of control apparatus can be much more clearly and accurately indicated by elementary diagrams. In order to keep the diagram in the "straight line" form the coils and contacts of different pieces of apparatus are sometimes entirely disassociated; that is, the physical relationship of the elements may be disregarded. The approximate physical relation of device terminals, and connections to their elements, are shown as internal device diagrams separate from the main three-line schematic. The three-line schematic normally shows every device element and all circuits of the equipment together with its associated apparatus, such as generators, motors, transformers, etc.

Wherever applicable, devices are designated by standard ASA function numbers and elements are identified by these numbers. Refer to G.E. print KK-6576843, Sheet No. B1 and B2 for examples of the three-line schematic or elementary diagram as some companies refer to it. You will note that con ductors carried from one section of the diagram to another are terminated in small, similarly numbered circles in each section thus avoiding congestion of intermediate sections with unnecessary lines. The conductors are identified at the points of entry to the circles in order to definitely establish their destinations. When conductors are carried from one diagram sheet to another, the same system is used and cross references are made between diagram sheets.

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Current circuits which originate at the current transformers are called current circuits. Polarity marks at the transformers indicate the instantaneous direction of the flow of current in the secondary.

Polarity is very important in some types of relaying and metering. If current is considered to be flowing into the polarity mark in the primary, then at the same instant, it is flowing out of the polarity mark in the secondary.

Let us trace the a-c current circuit on sheet No. B-1 of the G.E. print. We will trace one phase only, phase 1. If we assume that current flows out of the X-1 terminal of the power bank and flows toward the No. 1 feeder, then when primary current enters the non-polarity terminal of the 800/5 current transformer, secondary current will flow out of the non-polarity secondary terminal. The diagram shows that there is a circuit (a wire) to carry the current to the ammeter terminal 11. The element of the ammeter for phase 1 is terminals 11 and 12. The current circuit continues on through the recording watthour-demand-meter entering on terminal 18 and leaving by terminal 17, and in a similar manner continues on through more wire to a test device with terminals 8 and 4. At this point, the currents from phase 2 and phase 3 common-up or "wye-up" and continue on through the test device terminals 1 and 5. A common return conductor returns the current to the polarity side of the current transformer which is "wye-connected" and grounded along with phase 2 and the phase 3 transformer which completes the circuit. The test device or test block facilitates the inserting of a portable ammeter or other current testing device to check for the correct amount of current in any phase or neutral. An ammeter inserted in series with terminals 1 and 5 of the TD would show the amount of unbalance or ground current.

In a similar manner, all the current circuits can be traced through. The potential circuits, commonly called potential circuits, may also be traced. You will note that PT circuits have their devices connected in parallel, whereas the CT circuits have their devices connected in series. You will remember that CT circuits must never be opened circuited and PT circuits should never be short circuited.

CONTROL SCHEMATIC DIAGRAMS

Learning to read a schematic drawing may be likened to learning to drive an automobile. A considerable amount of knowledge is required before one can even start to drive. Likewise, it is necessary to know basic symbols, what the drawing says, and have a fair practical knowledge of the equipment under study to read a schematic drawing. A schematic is somewhat like a cross-word puzzle or playing cards. Once you get the general idea and know the fundamentals, you can take a new schematic, study it, and then follow it through.

Some engineering companies and drafting offices include the control schematic with the three-line or elementary diagram. More often, however, on more complex installations, control schematics are shown on a separate drawing.

When reading schematics, the following rules should be kept in mind:

1. Control schematics are drawn with all equipment shown in the de-
    energized position unless otherwise stated. Normally open switches
    will be shown open and normally closed switches will be drawn
    closed.

2. Control schematics are drawn in the straight line form and the coils
    and contacts of relays, contactors or different pieces of equipment
    are sometimes entirely disassociated. The contacts of a relay, for
    example, may appear on an entirely different drawing than the coil.
    Also some relays or devices have several coils or several contacts
    that may be shown completely separated from each other even though
    physically, if you examine the relay or device, they are all con-
    tained within one case. If several switches or contacts of the same
    device are used, they should be designated numerically – 1, 2, 3,
    etc., or identified by terminal number. All relays have their
    terminals numbered, usually stamped into the relay case.

3. Wherever applicable, devices are designated by standard ASA function
    numbers, and suffix letters are used for various purposes. To pre-
    vent any possible conflict, one letter or combination of letters
    should have only one meaning on an individual equipment. All other
    words beginning with the same letter should be written out in full
    each time, or some distinctive abbreviation should be used.)

SUFFIX LETTERS

For purposes of clarification, these suffixes have been classified in
certain natural groupings as follows:

1. To denote separate auxiliary devices, such as:
        X
        Y Auxiliary relay or contactor
        Z
        etc.

2. To indicate the medium or condition or electrical quantity to which
    the device responds, such as:
        A – Air
        C – Current
        etc.

3. To denote the location of the main device in the circuit or the
    type circuit in which the device is used or with which it is asso-
    ciated, or to otherwise identify its application in the circuit or
    equipment, such as:
        A – Alarm
        B – Battery, Blower, or Bus
        etc.

4. To denote parts of the main device (except auxiliary switches as previously described), such as:
   A - Accelerating Device
   BB - Bucking Bar
   etc.

5. To indicate special features or characteristics or the conditions when the contacts operate or are made operative or placed in circuit, such as:
   A - Accelerating or Automatic
   C - Close or cold
   etc.

AUXILIARY SWITCHES

Auxiliary switches, for contactors, circuit breakers, safety enclosed trucks, etc., are designated as follows:

a: Closed when the device is closed in the energized or operated position.

b: Closed when the device is in the open, or nonoperated position or the de-energized position, i.e., b switches will open when the device is closed.

aa: Closed when the operating mechanism of the main device is closed or in the energized or operated position (usually adjustable).

bb: Closed when the operating mechanism of main device is in the open position or de-energized or nonoperated position. (Usually adjustable to open or close as some desirable point of the operating motion.)

e:
f:
h: Special auxiliary switches other than a, b, aa, or bb.
k:

Lc: Latch-checking switch, closed when the circuit breaker-mechanism linkage is relatched. Usually preceded by the ASA device No. (52 Lc sw.)

Distinguishing features of device elements are frequently placed with the function number—70 LS (limit switch); or 52 TC, (trip coil); or 52 CC (closing coil); or 62 TDC (time delay close).

TROUBLE SHOOTING

In order to intelligently install, test, or shoot trouble on breakers, switchboards, and relays, it is absolutely necessary to be able to read and understand this type of drawing. As a result of the fast electrical development in this country, this type of diagram is quite common. In fact, there

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are many complicated circuits that can only be understood by using a schematic diagram.

Most schematic diagrams used for power circuit breakers and control circuits in substations are fundamentally alike. In other words, they follow a general pattern. However, each manufacturer has his own individual designs and methods. Once you understand the general pattern they are easy to follow. Each substation has a few variations which are peculiar to it.

When a breaker which may be tripped by a variety of individual relays will not reclose, it is sometimes difficult to find the trouble. When the trouble is in the relay circuits, it may be located by eliminating the various trip circuits one at a time so that each relay circuit may be isolated. A schematic diagram of various trip circuits is a big help in this kind of trouble, and many trouble shooters will resort to drawing their own if necessary.

When you have a difficult case of trouble to shoot, reduce the circuits to their fundamentals by keeping the schematic diagrams in mind. Keep a logical sequence in your process of elimination.

CIRCUIT BREAKER CLOSING SCHEME USING "X" AND "Y" RELAYS

The conventional "X - Y" closing scheme is employed with solenoid operating circuit breakers. This circuit performs the following functions:

1. When energized by a control switch, automatic recloser or other contact making device, it energizes the closing coil of the circuit breaker.

2. A seal-in circuit is established by the relays in this circuit so that even a momentary contact of the control switch or other closing device will result in a complete closing operation.
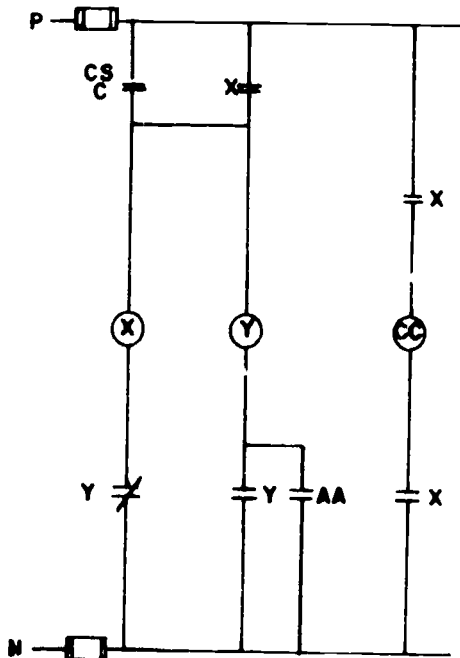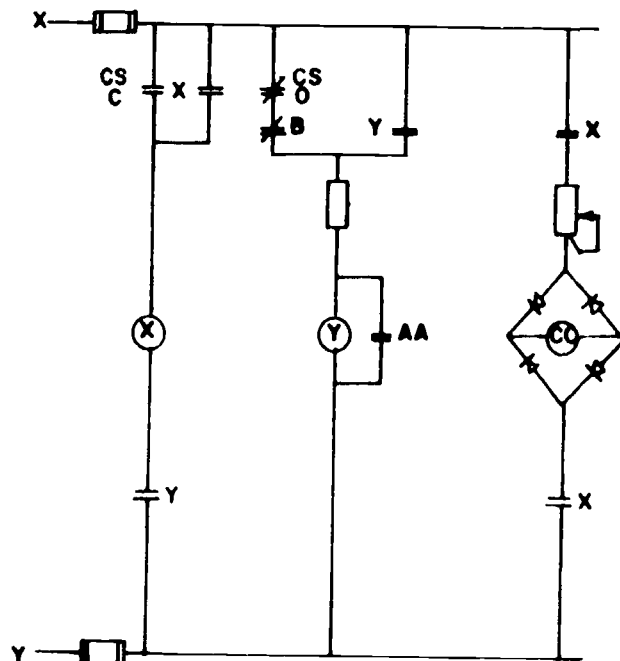
D-C CIRCUIT BREAKER CONTROL   A-C CIRCUIT BREAKER CONTROL

3. At the end of the closing stroke, the closing solenoid, which is an intermittent duty device, is de-energized.

4. For each operation of the control switch or other device, the circuit breaker will attempt to close only once, even though it trips automatically on overload, due to under-voltage or because of latch failure during the closing operation. This is the so-called anti-pumping feature of the circuit.

In general the operation of a d-c controlled breaker is as follows (refer to the preceding left-hand diagram):

1. When the control switch or closing device closes its contacts, the "X" or closing relay is energized. A contact of the "X" relay closes around the control switch to seal the relay in. One, or sometimes two, contacts of the "X" relay close in the circuit to the breaker closing coil, usually designated as "CC," thereby energizing it and closing the circuit breaker.

2. At a point very near the closed position of the breaker, a cutoff contact on the breaker mechanism, designated "aa," closes. This contact energizes one side of the "Y" or cutoff relay. The other side of the "Y" relay is maintained energized by the control switch contact or closing device and the sealing contact of the "X" relay. After the "Y" relay picks up, one of its contacts seals around the "aa" cutoff contact. Another contact of the "Y" relay open circuits the "X" relay coil causing it to drop out.

A modification of this scheme is used for A-C control. (Refer to the preceding right-hand diagram.)

1. When the control switch or other closing device is in the "off" position and the breaker is open, the "Y" relay is picked up and seals itself in.

2. When the control switch or other closing device is operated to close the breaker, the "X" relay is picked up and seals itself in. The "X" relay closes the circuit to the Rectox thereby energizing the closing coil and closing the circuit breaker.

3. At a point very near the closed position of the breaker, the cutoff-contact will close, short circuiting the coil of the "Y" relay. As the "Y" relay drops out, the "X" relay is de-energized. The "Y" relay will remain dropped out, holding the "X" relay inoperative as long as the control switch or other closing device is in the operated position.

BASIC CONTROL CIRCUIT FOR CIRCUIT BREAKERS

The following diagram is typical of the scheme used on many of the power-circuit-breakers that are used in substation work. In this scheme, the red indicating lamp burns in series with the breaker trip coil. The current needed to light the red indicating lamp is only a fraction of an ampere and

is not sufficient to operate the trip coil. The red lamp not only indicates that the circuit breaker is closed, but also serves to show that the trip-coil-circuit is complete and ready to trip the circuit breaker if necessary. (It is very important that any circuit breaker be capable of always tripping in the event that the line or equipment becomes faulted, short-circuited, etc.) The red lamp would fail to light if, for example, the trip coil was burned open.

From the schematic you can see that the circuit breaker can be opened either manually with the 52 CS or by the contacts of the protective relay, which if closed would put full voltage across the trip coil. As soon as the circuit breaker opens, the 52 a switch opens to de-energize the trip coil and the green indicating lamp will burn through the 52 b switch.

This diagram also shows the "X-Y" or anti-pump feature. Modern circuit breakers should be both anti-pump and trip-free. The trip-free mechanism is arranged to mechanically disconnect the breaker linkage system from the closing force each time the trip coil is energized. This insures that the breaker contacts will open at the proper speed by the force of the opening springs. Proper contact opening speed is essential for proper circuit interruption.

BASIC CONTROL CIRCUIT FOR CIRCUIT BREAKERS

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LEGEND

52 a - Auxiliary switch on circuit breaker, closed when breaker is
          closed
52 b - Auxiliary switch on circuit breaker, closed when breaker is
          open
52 aa - High speed auxiliary switch on circuit breaker, closed when
          circuit breaker is in closed position
52 cs - Circuit breaker control switch
52 ps - Low pressure switch (on pneumatic breakers), open on low pressure
52 cc - Circuit breaker closing coil
52 tc - Circuit breaker trip coil
52 X - Closing relay
52 Y - Auxiliary closing relay (anti-pump)
PR   - Protective relay (over current or other)
RL   - Red indicating lamp
GL   - Green indicating lamp

SEQUENCE OF OPERATION OF THE BASIC CONTROL FOR CIRCUIT BREAKERS

Starting with the breaker in the open position, the control fuses
installed, and the green light burning normally, the operation sequence of
the various parts in the closing of a breaker is as follows:

1. The control handle is turned clock-wise. This operation places
    positive potential on the #1 wire which picks up the 52X coil,
    provided the 52 pressure switch is closed (pressure up to normal).

    When the contacts of the 52X relay close, the closing coil is
    energized, the solenoid valve is opened, allowing air pressure to
    exert a force against the closing piston and operating mechanism,
    thus closing the main contacts of the breaker.

2. As the breaker starts to close, the auxiliary switch on the breaker
    (52 b switch) opens, thus removing potential from the green light.
    As the breaker approaches the closed position, the 52 a switch
    makes contact, connecting negative through the trip circuit to the
    red light, causing the red light to burn at normal brilliancy.

3. As the breaker approaches the closed position the 52 aa switch
    closes, connecting negative to the 52-y coil. The circuit is com-
    pleted to the positive bus through contacts of the 52X relay, and/
    or, the 52CS (close) contacts if held closed. When the 52-y coil
    is energized, it's normally open contacts are closed and the
    normally closed contacts are opened, thus sealing in its own coil
    and at the same time breaking the circuit to the 52-X coil, de-
    energizing the 52-X coil will open the 52-X contacts. This, of
    course, will de-energize the closing coil. Therefore, there is no
    danger of the operator burning up the closing coil by holding the
    52CS closed too long. This feature will prevent "pumping" of the
    circuit breaker as previously mentioned. Notice that the 52-X
    coil cannot be energized again until the 52 control switch (close)
    is returned to its neutral position.

Circuit breakers are usually closed as they ar; generally applied. Circuit breakers are essentially circuit-opening devices. When used in circuits for conventional power plant equipment, they remain closed for long periods of time, but must be able to trip automatically at any time that a fault occurs.

To supervise these breakers, standard green and red indicating lights are commonly used. The green light shows the breaker to be fully opened, and since it is normally connected across the closing circuit, it also indicates the availability of closing power before the breaker is closed. The red light shows that the breaker is fully closed and that the trip coil is in working order, ready to perform the major role for which the breaker was designed – to break the circuit quickly and effectively under fault conditions.

When testing for potential on the red light, (with breaker closed), use a voltmeter or neon light. An ordinary light bulb, used as a test light may trip the breaker.

Note that, if the red light is out when the breaker is closed, the trip circuit may be open and a dangerous condition may exist. Check for a blown control fuse.

SCHEMATICS FOR A SUBSTATION

Included with this information sheet is a set of G.E. schematics for a duplex unit substation, metal-clad switchgear. This substation is served from two separate sources and feeds two 4,160-volt, 3-phase, 4-wire feeders or primaries. The equipment is so designed that, if one of the high-side sources is de-energized (tripped out, single phased), the transformer breaker will automatically open, the bus-tie breaker will close, and the load will be carried on the remaining energized transformer. If and when both sources return to normal, the bus-tie breaker will open and the transformer breaker will close, restoring each feeder to its own respective transformer.

NO. 1 FEEDER OR TRANSFORMER BREAKER-SEQUENCE OF OPERATION (REFER TO SHEET NO. B3 OF G.E. PRINTS)

Manual Closing: With the 52-1 control switch and the 43 switch in the manual position, turn the SB-1 control switch to the closed position energizes the (52X-1) relay, i.e., current flows from the X side of the 230 volts control circuit through $\frac{3}{4}$ of the (49XX-1) relay, $\frac{4}{4C}$ of the (86X) relay, through $\frac{1-2C}{1}$ (43 Man.), $\frac{4}{4C}$ (52-1 CS), 6 of (52-1 b) switch, 12 (52Y-1), through the (52X-1) coil to the Y side of the 230 volts control circuit. (52X-1) relay will pick up and seal itself in through (52X-1) contacts; (52X-1) will energize the 52-1 closing coil, which in turn closes the 52-1 breaker. At the proper moment in the close operation, the (52-1 aa) switch will close to energize the (52Y-1) relay that de-energizes the (52X-1).

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Automatic Closing: With the 43 switch on automatic, (refer to sheet B4) breaker open, thermal auxiliary (49XX-1) and auxiliary (86X) contacts closed, phase sequence auxiliary (47x-1) will then operate the "X-Y" scheme provided (1) other transformer breaker is open, (2) bus tie breaker is open, or (3) phase sequence auxiliary (47x-2) of other transformer is picked up. Note: (1) Lock-out relay (86-1) contacts opened by first overload trip, closes when 86-1 is electrically reset at the end of recloser cycle to by-pass (79X-1) contact. (2) (86X) HEA relay, trips on lock-out of either transformer breaker when the bus tie breaker is closed. This trips the bus-tie breaker and locks out both transformer and bus-tie breaker closing circuits. It must be hand reset. When reset, the transformer breaker will close immediately.

Reclosing Circuit: With the 43 switch on automatic, (refer to sheet B4) breaker open, lock-out relay (86-1) contact will be closed by the first trip-out, and the AC-1 recloser (79-1 aux) is energized by current flowing from X of the 230 volts a-c control through $\frac{3-4C}{4}$ 34 AUTO; $\frac{11}{12}$ (86-1/ER); 8 (52-1 b) switch; (52-1 LC) switch; 79-1 cut out switch; $\frac{K}{L}$ (79-1) relay; $\frac{A}{B}$ (79-1) relay; through the 79-1 aux coil and resistor; through 79-1 cut-out switch; $\frac{7}{8}$ of the (47X-1) relay and to the Y side of the 230 volts a-c control. You will note that the 79-1 motor is energized at the same time through contacts $\frac{G}{H}$ & $\frac{D}{E}$ (79-1). The (79-1/aux) picks up and seals itself in. As soon as the 79-1 motor begins to run it causes cam operated contacts $\frac{A}{B}$ to open and $\frac{B}{C}$ to close. The (79X-1) relay will then be energized and close contacts $\frac{1}{7}$ (79X-1) to operate the "X-Y" scheme (see sheet No. B3). Recloser auxiliary (79Y-1) is picked up during the reclosing cycle and performs the following functions: (1) prevents automatic closing of the bus-tie breaker, (2) blocks instantaneous trip after the first trip-out, and (3) prevents electrical resetting of the lock-out relay (86-1) during the recloser cycle.

Trip Circuit: Manual trip is possible with the SB-1 control switch with the transfer switch in manual position.

Overload Trip: Contacts of tripping relay (94-1) are energized by the time and instantaneous overload relays (51-1 and 50-1) to trip the breaker.

Phase and Voltage Trip: With the transfer switch on "automatic," lock-out relay (86-1) contacts normally closed, and with No. 2 transformer phase (47-2) and voltage (27A-2 and 27B-2) relays normally picked up, breaker will trip if No. 1 transformer phase and voltage relays drop out.

Transformer Thermal Protection: Thermal relay (49-1) contacts W3 and W4 light amber indicating lamp. Contacts W5 and W6 close to energize PJV time-delay relay (49X-1) which closes circuit to energize auxiliary (49XX-1). (49XX-1) trips breaker and connects reclosing auxiliary relay (79Y-1) directly

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to control bus which picks up to prevent automatic closing of the bus-tie breaker. When the transformer cools sufficiertly, thermal relay (49-1) contacts will open, (49X-1) and (49XX-1) reset, and the breaker will close immediately.

Lock-out Circuit (86-1): (86-1) operates on overload condition. It may be reset manually or will reset electrically upon completion of the recloser cycle, providing thermal protector is not actuated and tripping relay (94-1) is de-energized. The main function of 86-1 is to permit the recloser cycle to start when the breaker trips due to overload.

BUS-TIE BREAKER

Manual Closing: With the transfer switch to "manual" the bus-tie control switch will operate the "X-Y" scheme to close the breaker unless (86-X) contact is open due to lock-out at the end of the recloser cycle of either transformer breaker. (86-X) must then be hand reset (HEA relay).

Automatic Operation: With the 86-X contact closed and with the transfer switch to "automatic," the opening of either transformer breaker will operate the "X-Y" scheme to close the bus tie breaker providing (1) neither transformer thermal relay is actuated and (2) neither transformer breaker is in its reclosing cycle. (86-1 or 86-2) has reset due to 79Y-1 or 79Y-2 becoming de-energized at the end of the recloser cycle.

Bus-Tie Breaker Tripping can be manual with the control switch when the transfer switch is on "manual."

The bus-tie breaker will trip automatically with the 43 transfer switch "automatic" if the second transformer breaker closes. The tie breaker will also trip if either transformer breaker locks-out.

THROWOVER CIRCUIT

With phase sequence and under-voltage relay (47-1) of the No. 1 transformer normally energized, throwover relay (83) is picked up, which energizes the whole control bus from the control power transformer of the No. 1 transformer with the exception of the actual closing circuit of No. 2 transformer breaker which is on its own control power transformer.

If such a condition exists that (47-1) of the No. 1 transformer drops-out, all the control bus, with the exception of the No. 1 transformer breaker closing circuit, becomes energized from the No. 2 transformer control power transformer.

Other contacts of relay 83 provide a similar selection of power sources to the lighting, receptacle, and heater circuits.

* * * * * * *

One set of devices not shown in the internal device diagrams for this G.F. metal clad substation is the (52-1 sta aux sw, 52-2 sta aux sw. and the 24 sta aux sw). This device is a set of auxiliary switches that attach to

the breaker mechanism and function the same as (52 a) and (52 b) switches
when the breaker is raised into its normal operating position.

If, after studying this set of schematics, you are able to interpret the
meaning and understand the sequence of operation, you are well on your way
to being able to understand any control schematic you may encounter in your
line of work.

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GENERAL GE ELECTRIC

Rev	Title
KK-6576843	CLOSING CONTROL OF 52-1 & 52-2
Cont. On Sh 84 Sh No B3	

FU 35

8-1

49XX-1
86X HR
43 MAN
43 AUTO
52-1 CS
4C
47X-1
52X-1
86-1
79X-1
52-2 STA AUX SW
24 STA AUX SW
47X-2
1R 5L
52-1 CC 2L 1L
6 52-1
52-1 aa
6L 7L
52Y-1
12 52Y-1
52Y-1
52X-1

52X-1
47-2
47X-2
RES 200
RECT
47X-2
47-2 TDC

TO SH B1
X
Y
CP₁
50

8-2

FU 35

49XX-2 TDC
86X HR
43 MAN
43 AUTO
52-2 CS
47X-2
52X-2
86-2
79X-2
52-1 STA AUX SW
24 STA AUX SW
47X-1
1R 5L
52-2 CC 2L 1L
6 52-2 b
52-2 aa
6L 7L
52Y-2
12 52Y-2
52Y-2
52X-2

52X-2
47-1
RES 200
RECT
47XX-1
47X-1
47-1

TO SH B2
X
Y
CP2

FU 35 Y

8-1 FU 35 Y

8-2

GENERAL ELECTRIC

Rev No	TITLE
KK-6576843	POWER CIRCUIT
Cont On Sh B3 Sh No.B2	

TO 57100 V SOURCE NO 2

TO SH B1   LR

N8
N7

N4
N5
N6
N9

LRC 2 THIS DWG

LOAD RATIO CONTROL
STEP VOLTAGE REGULATOR

H2
H1   H3

X2
X1   X0
X3

X0 X1 X2 X3
X2C
X3C

H1 H2 H3

REC AM
11 12
9 10
7 8

REC WHDM
16 17
7 8
3 4

TD
8 4
5 3
6 3
2
5 1

CT 800/5
PM

PT 2400/120

4 3 2 1
TD

19   REC WHDM   5
20   6
M   REC WHDM

10   REC WHDM
8
9

7   47-2   15   27-2
RES 6600   16   RES 1700

5   47-2   6   27-2
6   RES 9000   5   RES 1700

2   REC WHDM   1

P1
P2
P3

VM SW   PN
1
3C
2 3   1   VM
4
4C

86-2

N4
N9
N5
N6

FU 20
N6

DD   FU EJ-1   PM   DD
DD   DD DD DD

X1
X2
X3
H2
H1

11-10 KVA
2400/115-230

Y
X

6   83E   E28   Y
8   83E

8   83TR   E1B   83E
4   83N
5

83N   E21   83TR   83N   Y
Z
83N   E1A   83E   X
4   47XX1   91   83TR
8

CP SH B1

KEY INTERLOCK

CP2 TO SH B3

L1   L2

2-2
DC

TO SH P1 B1

50-51-2
5 6

CT 800/5
50-51N-2
5 6
5 6

1 2 3

FEEDER NO. 2 4160 V

FU 80
TO SH B5   DC
RES 500
FU 80

+   X
BATTERY CHARGER
FOR INTERNAL CONNEC- IONS
SEE K 8477495
-    Z

48V BATT

X
RE PE

LT SW FE
FU 10
LT PE

LT SW BE
FU 10
LT BE   RE BE

CP3 TO SH B4
Y
X

HTR SW   HTR SW
X FU 20   Y FU 20
HTR 250W   HTR 250W

SH NO B2

BEST COPY AVAILABLE

60

59

GENERAL ⊛ ELECTRIC

Rev No

KK-6576843

Cont On Sh 82   Sh No 81

TITLE

POWER CIRCUIT

STEP VOLTAGE REGULATOR

LOAD RATIO CONTROL

TO 57100 v SOURCE NO 1

3000/3650 KVA TRANS 57100/2400/4160V
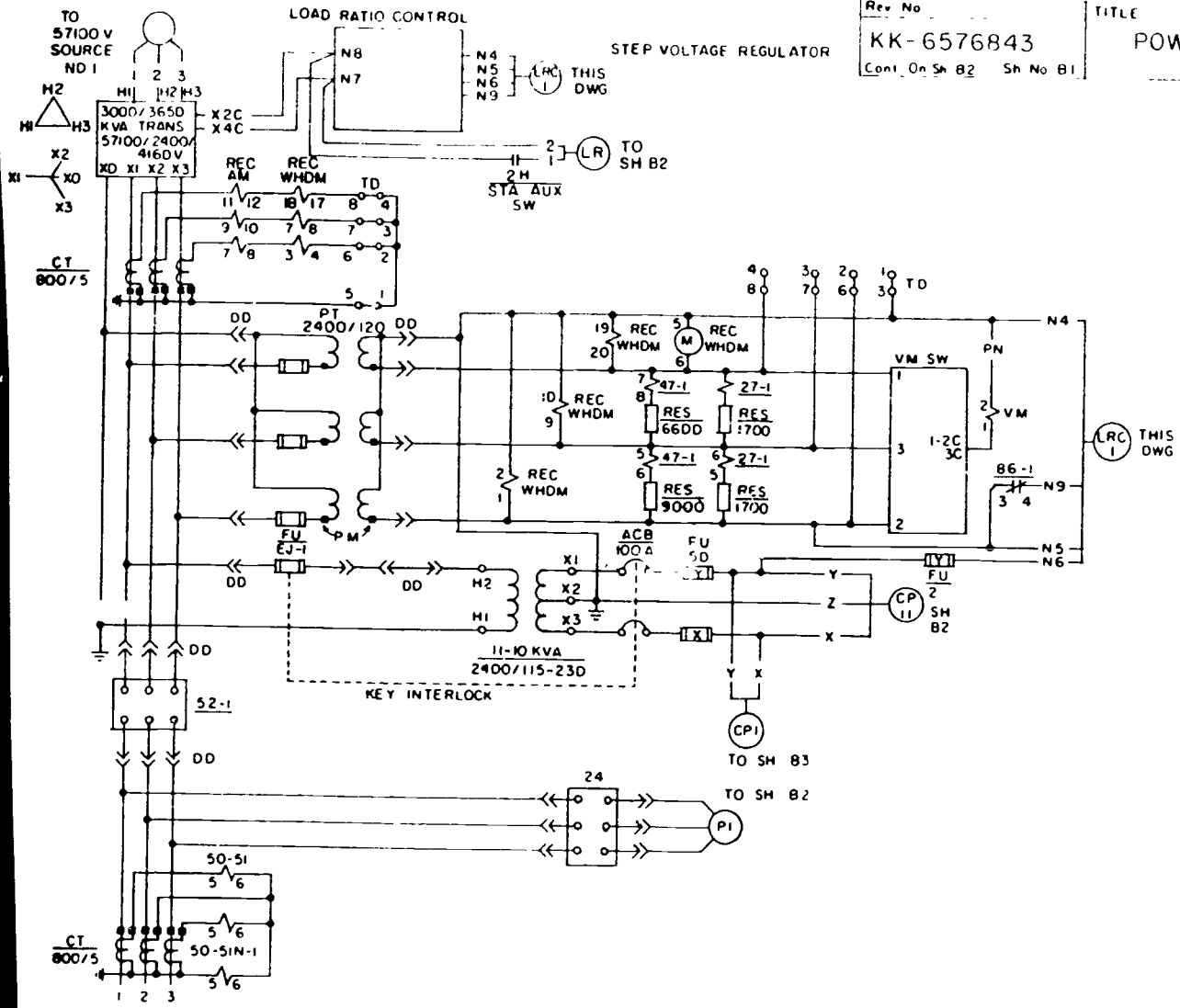
FEEDER NO 1   4160 VOLTS

SWITCHGEAR

SH NO 81

KEY INTERLOCK

61

TIE BKR CLOSING AND INC.
LINE RECLOSING CIRCUITS
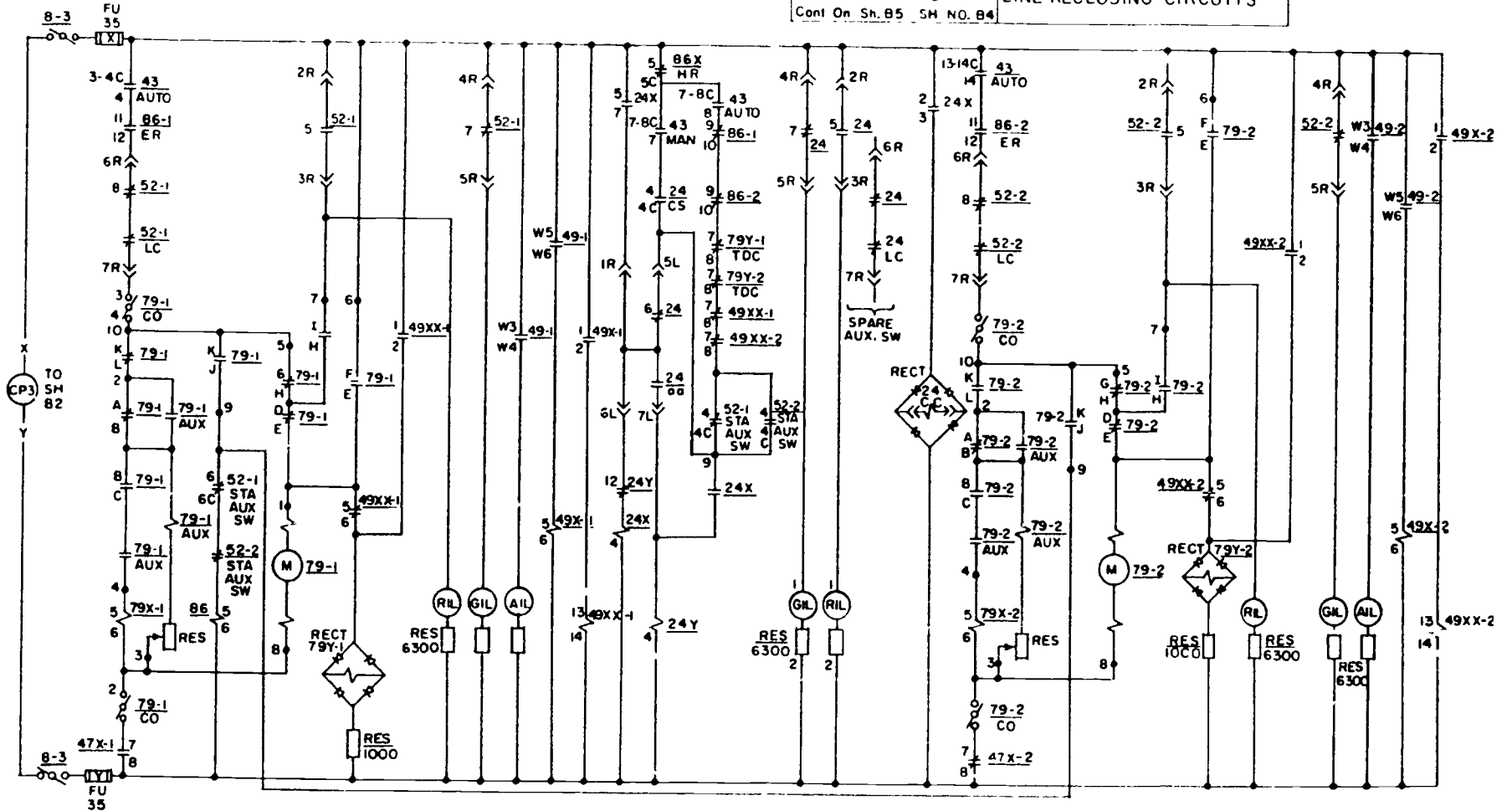
KK-6576543
Cont On Sh. 85   SH NO. 84

54
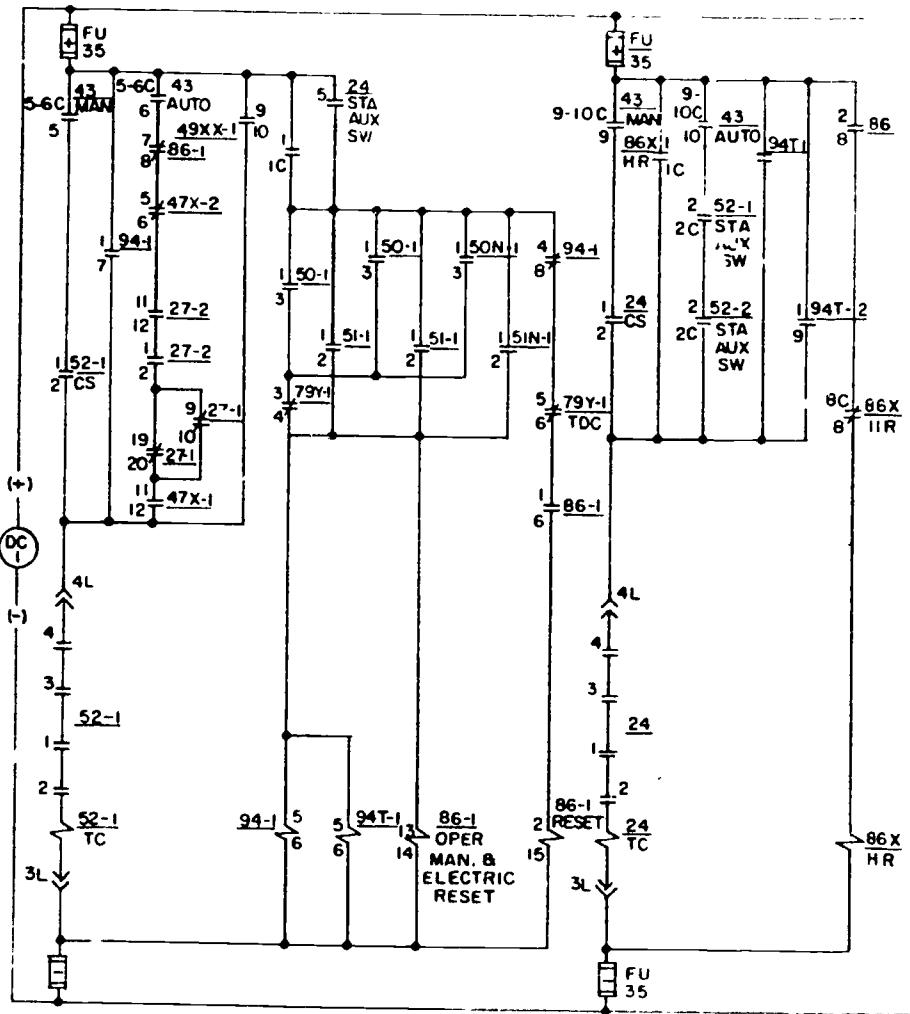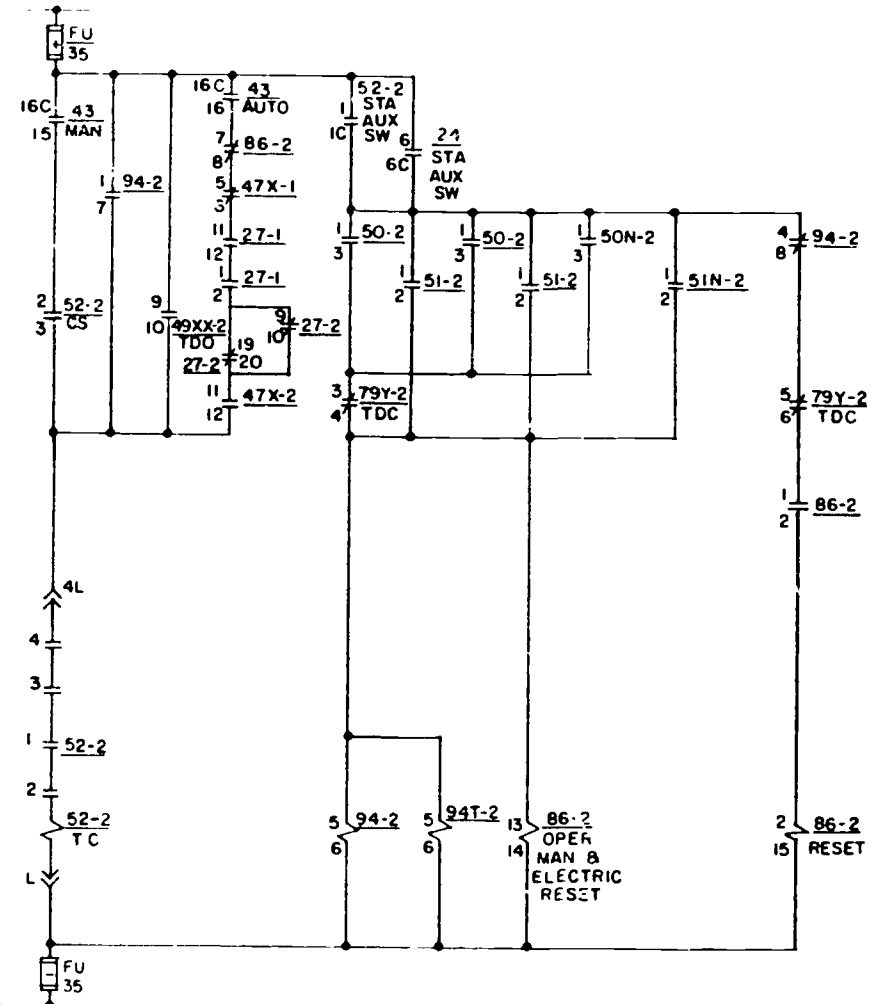
INTERNAL DEVICE DIAGRAMS (BACK VIEW UNLESS OTHER-
WISE NOTED)

24CS
52-ICS

CONTACTS		POSITIONS		
HANDLE END	NO	CLOSE	NORM AFTER CLOSE	NORM AFTER TRIP	TRIP
1 2	1				X
	2				X
3 3C 4C 4	3		X	X	
	4	X			
5 5C 6C 6	5	X	X	
	6	X			

SPRING RETURN TO NORMAL
X DENOTES CONTACT CLOSED

S81B9
27-1,2
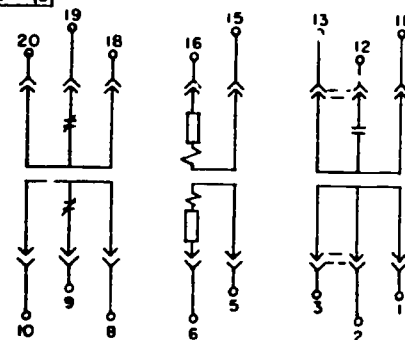
PJV11AJ
43

CONTACTS		POSITIONS	
HANDLE END	NO	MAN.	AUTO.
1 1-1C 2	1	X	
	2		X
3 3-4C 4	3	X	
	4		X
5 5-6C 6	5	X	
	6		X
7 7-8C 8	7	X	
	8		X
9 9-10C 10	9	X	
	10		X
11 11-12C 12	11	X	
	12		X
13 14	13	X	
	14		X
15 16	15	X	
	16		X

X DENOTES CONTACT CLOSED

SWITCHGEAR DIVISIONS
PHILADELPHIA

24X-Y | 52X-Y-1
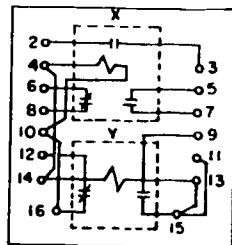
FRONT CONNECTED
FRONT VIEW

HKA-27EM
47-1,2

ICR15A
47X-1,2 | 79Y-1,2

HFA25B
86X

HANDLE END

HAND RESET
SHOWN IN RESET POSITION

HEA11A

49X 1,2

PJV14C
52

SECONDARY CONNECTING DEVICES

* SHORT FINGERS

LEFT ← | → RIGHT

SCHEMATIC CONNECTIONS OF BREAKER
MECHANISM

79-1,2

AC-1   IMMEDIATE INITIAL RECLOSE

49XX-1,2

HFA11A
50-51 | 50N-51N

SEAL-IN
ELEMENT
INST
ELEMENT
INDUCTION
ELEMENT

IAC53B
79X-1 | 94-1 | 94T-2 | 86
94T-1 | 94-2

FRONT CONNECTED-FRT VIEW

HGA
86-1,2 RESET COIL   OPER. COIL

HFA14B
VMSW

24 | 52-1,2
STA. | STA. AUX.

CONTACTS			
HANDLE END			
1 1C 2C 2	1		X
	2		X
3 3C 4C 4	3	X	
	4	X	
5 5C 6C 6	5		X
	6		X
7 7C 8C 8	7	X	
	8	X	

CONTACTS		POSITIONS		
HANDLE END	NO	3	2	1	OFF
1 1-2C 2	1				
	2	X			
3 3C	3		X		

S81C   X DENOTES CONTACT CLOSED

WIRING (CONNECTION) DIAGRAMS

The purpose of the next three lessons is to provide sufficient infor-
mation and training to enable you to read and understand wiring diagrams.
You should also be able to combine the information given on schematic dia-
grams with that on wiring diagrams as an aid to installation and maintenance
of electrical equipment.

You will be introduced to several types of wiring diagrams. Each type
has its advantages. Different engineering firms may utilize different types.
If you as a wireman acquire an understanding of basic electrical drawings,
you will have the tool to eventually understand any electrical drawing.

Directions: (3-2-4) (3-2-5) (3-2-6)

Study thoroughly the information sheet for each lesson and any addi-
tional references that may be assigned by your instructor before you
answer the check-up questions.

Read each check-up question carefully and be sure you understand it.

Write the best answer that you can to the questions. When you have
completed the check-up for a lesson, hand it in to your instructor.
Do not hold it until the next check-up is ready. If you have any
difficulty, your instructor can help you.

Required reference:

Information Sheet No. 6

Check-up: (3-2-4)

Instructions: Refer to the schematic diagrams for breakers 1 and 2 and
the wiring diagram for the Westinghouse substation. Fill in the missing
words or device numbers in the following sequence of operation.

1. Assume, with everything set up normal and the plant feeding from
   Line No. 1, the preferred source goes dead. Relays (27-1 and 27-2)
   will close contacts labeled (8 and 9) to pick up and latch in
   relay (1)_____ through the (43-1, L1) contacts labeled
   (2)_____. (27-1X) relay contacts labeled (3)_____
   and _____ will trip the No. 1 breaker by energizing the
   (52-1) trip coil. (27-1X) relay contacts labeled (4)_____
   and _____ close to turn on a white light; also contacts
   labeled (5)_____ and _____ of the (27-1X) relay
   close to energize the (6)_____ relay when the (7)
   _____ b switch contacts labeled (8)_____ and
   _____ close. The (52-2X) relay contacts close to ener-
   gize the No. 2 breaker (9)_____ coil. When the No. 2
   breaker closes the (52-2 aa) switch will (10)_____ to
   drop out the (11)_____ relay, which in turn de-energizes
   the (12)_____ relay so that the No. 2 breaker (13)
   _____ will be de-energized.

2. With potential restored to the plant from the alternate source the
    (14)_____ and _____ relays open their contacts
    to de-energize the (27-1X) coil, which will remain latched up, how-
    ever, until manually reset, permitting the (15)_____ to
    burn.

3. From a study of the schematic diagrams for breakers 1 and 2, would
    you say it is possible to unite Line No. 1 to Line No. 2 by elec-
    trically closing breakers 1 & 2? _____

4   If the 43 switch is in the automatic position, would you be able
    to open or close either breaker by means of the CS-1 or CS-2 con-
    trol switches? _____

INFORMATION SHEET NO. 6   (3-2-4)

WIRING (CONNECTION) DIAGRAMS

The wiring or equipment diagram, also called connection diagram, shows detailed connections of the main equipment. It is intended primarily for use in construction or manufacturing. It also has value when shooting trouble or in the maintenance of electrical equipment as it normally shows all necessary lines and correct physical relationship of all major equipment, where possible. It makes it easier to locate equipment and its relationship to other equipment. The wiring diagram is not adaptable as a means of tracing circuits through various device elements. Circuit tracing is nearly always accomplished more easily by use of schematic diagrams.

Most equipment shown on a wiring diagram is somewhat symbolic in form, and physical relationships are not necessarily drawn to scale. All wiring diagrams are not drawn with the same system. Various manufacturers have developed their own systems of portraying connections and circuits that exist on their equipment. Individual power companies that buy and install equipment may adopt their own individual systems as they develop connection diagrams of switchboards, control panels, and interconnection diagrams. There are, however, a number of conventions and a similarity that make it possible, with a minimum of familiarity, to read a connection diagram regardless of the system used.

Wiring diagrams for switchgear are usually made up in sections or parts. (See Switchgear Diagram GEI-25274A included with this material.) Because of the detail shown, it may be necessary to provide several separate drawings for one piece of equipment. Wiring diagrams of switchboard panels are always shown as back views because the wires are on the back of the panels. The space between equipment is often governed by the number of wires that must be shown. Sometimes a front view of a dead-front control or relay panel may be shown. It is drawn to scale and will show all existing equipment which can be seen from the front.

Included with this lesson are a schematic diagram and a switchboard wiring diagram of the control and relay panel for a Westinghouse designed substation. The panel is divided into two sections, an upper panel and a lower panel. The rear view of this panel indicates all wiring connections and represents a type of diagram commonly used by many companies. Some wiring diagrams portray all wires by individual lines, but in the Westinghouse drawing each line from a device terminal is given an identification code number. The wire is then combined with other wires so that a group of wires is represented by a single line. At the other end, the terminals are given a similar code number to indicate to what each wire connects.

The internal wiring of any equipment, such as a relay or meter, will often be shown on a separate diagram or off to the side of the connection diagram. All terminals are normally shown, and anything added to a relay or switch, when not shown on the internal wiring diagram, is usually shown

outside the rectangle representing that equipment on the switchboard or equipment diagram.

To illustrate the method of reading this type of wiring diagram, let us refer to the diagram of the Westinghouse substation which follows. Let us trace the 240-volt a-c from No. 1 control transformer through a port on of the circuit; for example, X1-1 is connected to the terminal block. At the point where it joins a group of wires, it curves in the direction to be followed to find the other end. The group of wires terminate in circle A which is continued on the upper-panel wiring diagram and eventually will be found connected to a 30-ampere fuse. Leaving the other side of the fuse, we find a wire X21 which joins a group of wires. Tracing up along the groups, you will eventually find a point X21 on the 43 selector switch which is the other end of the wire. You will notice that there are several wires on the 43 selector switch called X21. You should now refer to the sehematic diagram of Breaker No. 1 and you will observe that X21 actually should be on three separate contacts of the 43 switch. In the same manner, you may trace any wire on the switchboard.

Although the previously discussed diagram is quite common and used by many companies, another widely used type does not show any lines to represent the wires and is commonly called the "lineless diagram," or may be referred to as a "point-to-point diagram." The key to the entire scheme is the code, which consists of code letters, code numbers, or both.

Each device on a unit of switchgear assembly, such as a metal-clad switchgear unit, control panel, or relay panel, is assigned an arbitrary letter, pair of letters, numbers, or both. Such letters are also assigned to each terminal board, fuse block, resistor, or other accessory device to which wires are attached. All terminals on the devices must also be numbered. Every physical wire has to be coded by number or by a letter and number. Some companies call these numbers "wire numbers." Others call them "code numbers." The wires are not shown as lines between the device terminals, but are listed on a chart next to the diagram.

A page from the General Electric Company instruction pamphlet, GEI-25374A, has been reproduced for reference in this lesson. In the G.E. diagrams, connections are indicated by designations which are derived from the identification letters on the devices and their studs or terminal numbers. A lead connection point #1 on terminal board "A" to stud #5, device "F," is designated on the terminal board as connecting to F5 and on device "F" in the stud number assignment as connection to A1. Short jumpers, connections between terminals on the same device, are usually shown in full and do not bear any lead identification.

The method outlined for tracing out a circuit on the simple diagram of GEI-25374A, Fig. 3, also holds for more complicated diagrams.

Included in Lesson 3-2-5 is a portion of one of the connection diagrams (swinging panel) from the G.E. metal-clad substation studied in lesson 3-2-3. You will see on this diagram that each device is given an identifying code letter as shown in the list that follows. Space has not been provided to show the full length of the panel.

ELEMENTARY DIAGRAM FIG 2
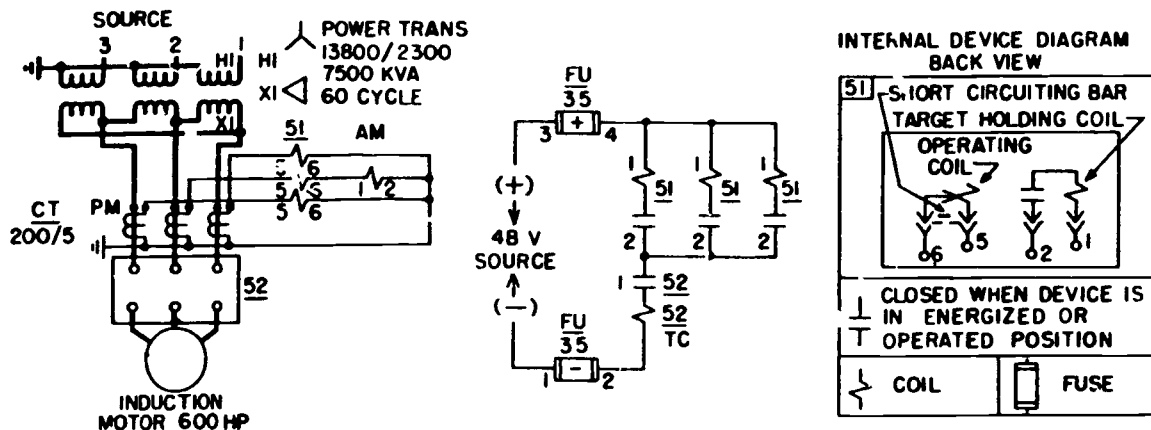
CONNECTION DIAGRAM FIG. 3

PANEL-BACK VIEW
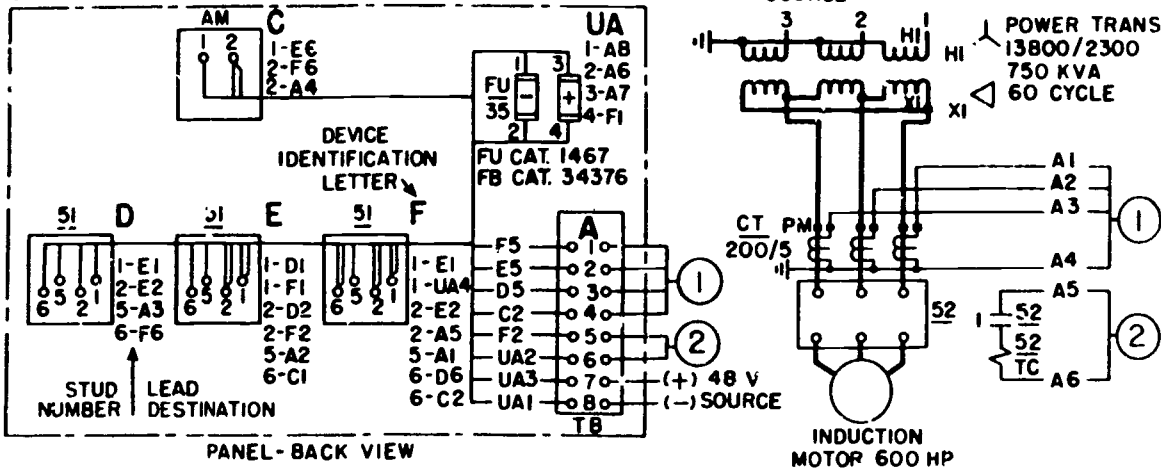
CROSS REFERENCE FOR LEAD GROUP CONNECTIONS
FIG. 4

LETTERS ADJACENT TO NUMBERED CIRCLES
PROVIDE A CONVENIENT METHOD OF SELECTING
CORRESPONDING REFERENCE DRAWINGS
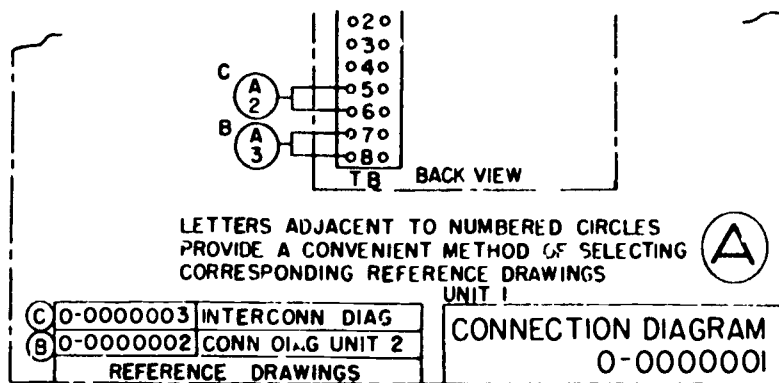
INTERCONNECTION DIAGRAM
FIG. 5

FOR INTERNAL CONNECTIONS SEE
RESPECTIVE UNIT DRAWINGS
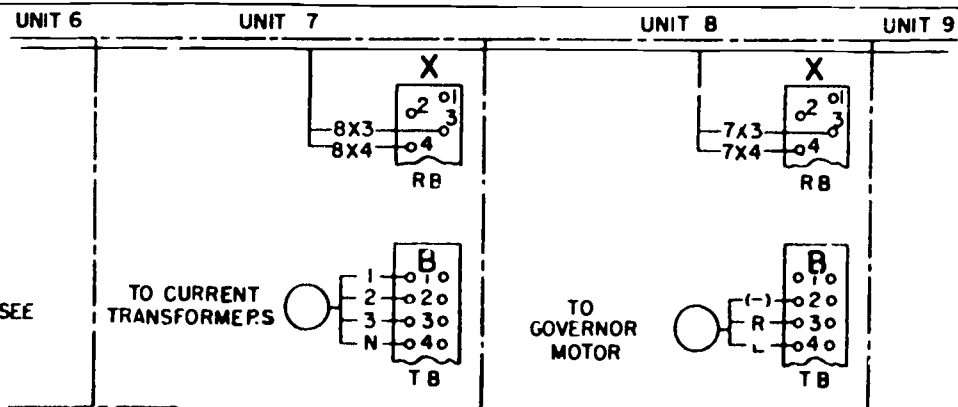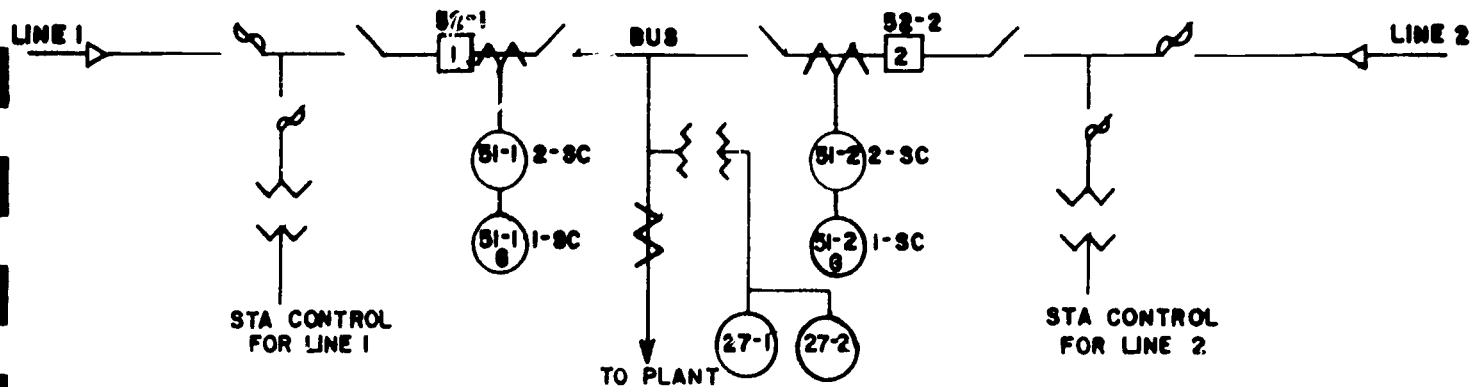
See the following schematic diagrams 1 and 2 and wiring diagram for control details. Note that breakers No. 1 and 2 are used as throw-over switches only. They are load breaks, not fault interruptors. Assume that Line No. 1 is the preferred source feeding power to the plant and Line No. 2 is the alternate source.

Overcurrent relays 51-1 and 51-2 are instantaneous overcurrent devices (type sc relays) which open the breaker closing circuit to prevent automatic throw over when bus faults occur.

Under oltage relays 27-1 and 27-2 are connected in parallel. The contacts are paralleled so that either or both relays can initiate a transfer from the preferred source to the alternate source on loss of potential.

Control power to close each breaker is obtained from transformers on their associated line. Thus, no throw over results if the alternate source is de-energized when service is interrupted.

Control switches 43-1 (right-hand front view) is a selector switch used to limit automatic operation and must be turned to Line No. 1 if the plant is to feed from Line No. 1 as the preferred source. When turned to Line No. 1 position, it places auxiliary relay 27-1X in service and cuts out 27-2X . Auxiliary relay 27-1X controls automatic transfer from Line 1 to Line 2 permitting tripping of Line 1 and closing of Line 2. If 43-1 is in Line 2 position when Line 1 is the source in use, loss of voltage will not transfer to the other line because 27-2X will be picked up to try to trip the open breaker on Line 2 and to close the breaker that is already closed on Line 1.

Control switch 43, on the left-hand, front-view side of the panel must be in the automatic position if loss of preferred source is to automatically cause a throw over to the alternate source.

61

Control switches CS-1 and CS-2 are for manual control. They are spring returned to the off position.

Auxiliary relays 27-1X and 27-2X latch in the operated position and must be manually reset when operated. White lights indicate this condition. These relays must be reset before automatic operation can be repeated.
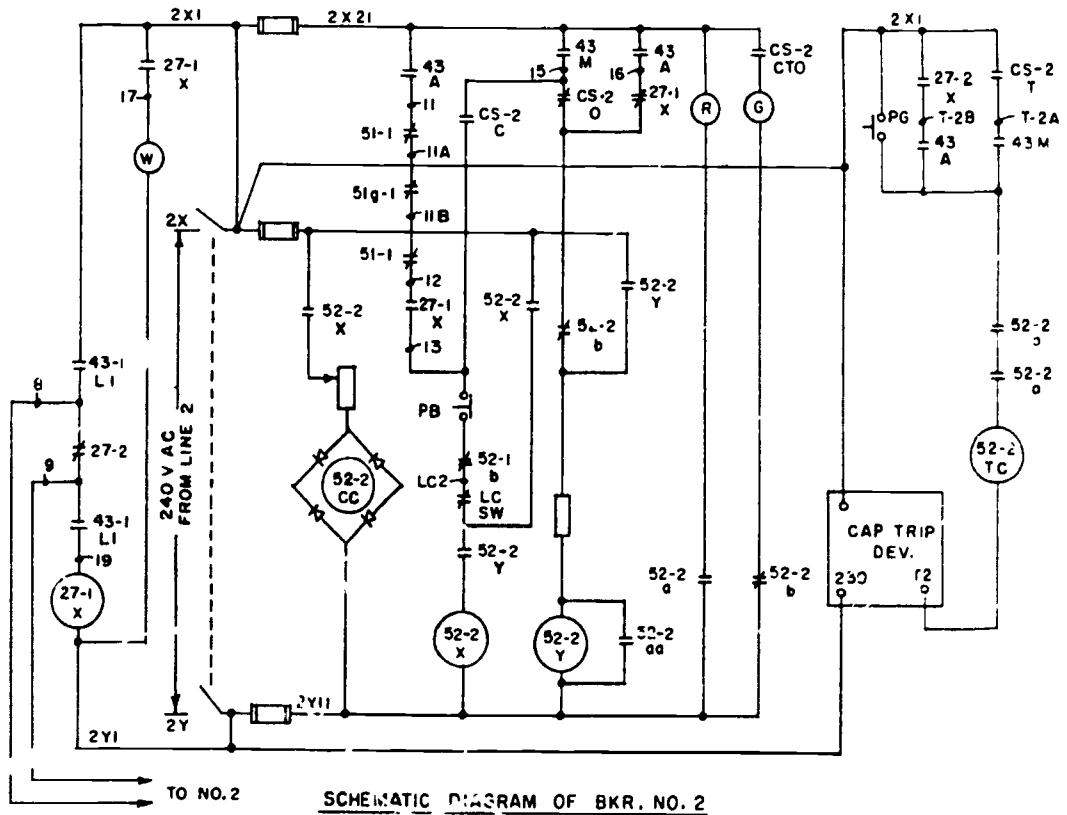
SCHEMATIC DIAGRAM OF BKR. NO. 2

WESTINGHOUSE ELECTRIC CO.
SPECIAL RELAY PANEL
GG8D544 SCHEMATIC DIAGRAM

SCHEMATIC DIAGRAM OF BKR. NO.1

75

LOWER PANEL (R.V.)

UPPER PANEL (R.V.)

WESTINGHOUSE ELECTRIC CO.
SPECIAL RELAY PANEL
GG8D544 CONN DIAGRAM
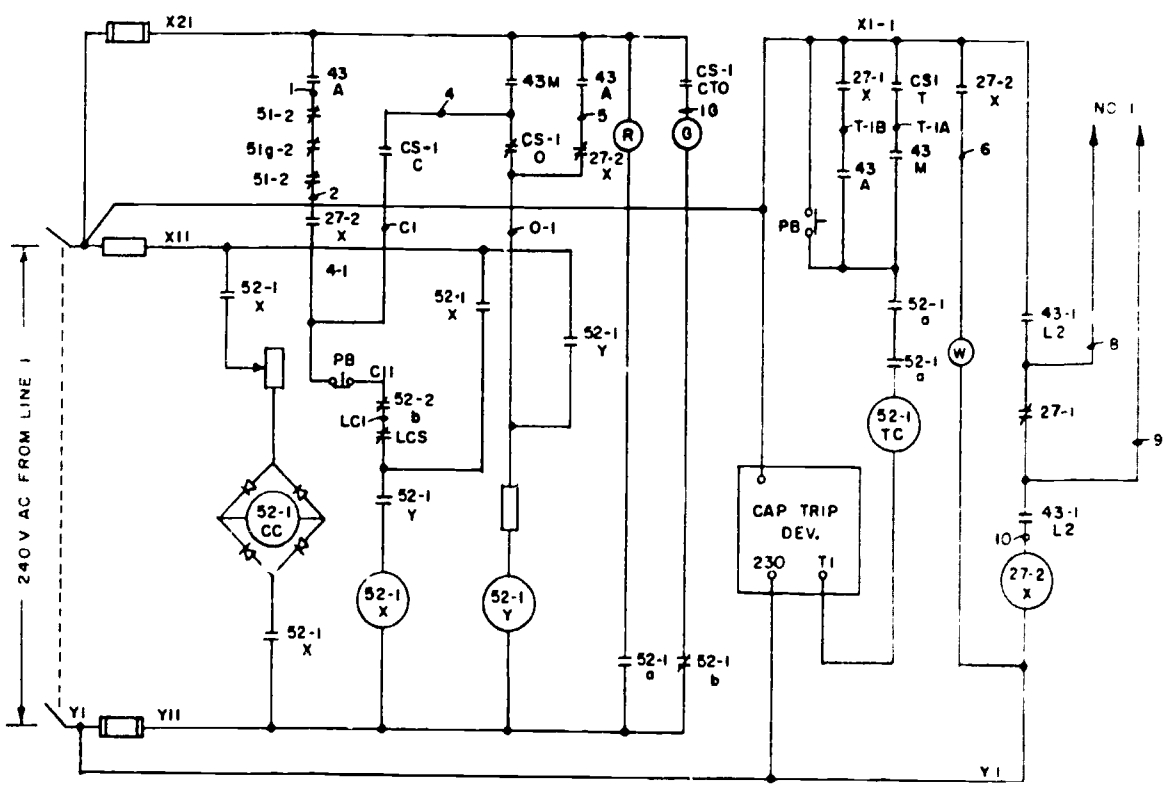
ELECTRICAL PRINT READING

It should be quite obvious that the wiring diagram is a cumbersome device for tracing out a complete circuit. If you must trace the wiring on a wiring diagram, particularly on a lineless diagram, it is logical to start with the schematic diagram. If you try to trouble shoot entirely from the lineless diagram, you are sure to waste a lot of time. The wiring diagram is a tremendous aid in locating devices, terminal blocks, etc. It is essential that you be able to locate any part of the circuit such as a switch, a relay terminal, a fuse, or any terminal point both on the wiring print and on the schematic diagram to intelligently shoot trouble in a substation.

For example, when a piece of equipment fails to operate, the first logical question is does it have power? Is a fuse blown or, if not that, is the circuit open somewhere? If you are adept at reading a schematic, you can see where you should have potential and where you should not. Then with the aid of a voltage tester and the wiring diagram you can go right to the devices and test for voltage. By using a logical system of elimination, you should quickly find if the circuit is open and where.

Each type of wiring diagram has its advantages. There are times when one type is to be preferred, but a person skilled in print reading should understand all of them equally well.

Required reference:

Information Sheet No. 6 (3-2-4)

Check-up: (3-2-5)

Refer to the connection diagram of the swinging panel included with this lesson. A point-to-point check on this diagram will show that the following statements are either true or false.

The connection diagram shows that there is -

1. A wire from terminal 5 of the tripping relay to terminal 2 of the ground relay. True____ False____

2. A wire from terminal 3 of the ground relay to the a-c circuit-breaker control switch contact 5c. True____ False____

3. A wire from the a-c circuit-breaker control switch contact 1 to the terminal strip B1. True____ False____

4. A wire from 3 on the B terminal strip to the C ϕ overload relay terminal 1. True____ False____

5. A wire from terminal 11 on the ammeter to terminal 5 on the A ϕ over-current relay. True____ False____

6. A wire from terminal strip C 1 to the tripping relay, terminal 1.
    True___ False___

7. A wire from the tripping relay, terminal 1, to the ground relay
    terminal 6. True___ False___

8. A wire from the a-c circuit-breaker control switch terminal 4C to
    the terminal strip A7. True___ False___

9. A wire from the a-c circuit-breaker control switch contact 2 to
    the tripping relay terminal 2. True___ False___.

10. A wire from the reclosing relay terminal 7 to the red indicating
     light. True___ False___

11. A wire from the ammeter terminal 12 to the bottom test device
     terminal 8. True___ False___

12. A wire from terminal strip A4 to terminal 5 on the bottom test
     device. True___ False___

13. A wire on the reclosing relay-cut-out-switch terminal 3 to the A
     terminal strip 8. True___ False___

14. A wire from the green indicating light to the a-c circuit-breaker
     control switch contact 5. True___ False___

15. A wire from terminal 6 on c φ overcurrent relay to terminal 6 on
     A φ overcurrent relay, to terminal 6 on the ground relay.
     True___ False___

16. A wire from terminal 3 on the reclosing relay to terminal 2 on the
     reclosing relay cut-out-switch. True___ False___

17. Current circuits for the ammeters are "Y" connected on the lower
     test device. True___ False___

18. Terminal strip C8 is a "CO" or common point for A, B, and C φ
     current wires. True___ False___

19. If the wire that is common to both the red and green indicating
     lights is 48-volts, d-c negative, then terminal 7 of the tripping
     relay is also negative. True___ False___

20. If terminal strip B5 is 48-volts, d-c positive, then terminal 4 of
     the 94 relay is also positive. True___ False___

AM

7 8 9 10 11 12

H

7 - C7
8 - 86
9 - C6
10 - 87
11 - C8
12 - 86

A

X1	1	Q8
X2	2	Q7
X3	3	Q6
X4	4	Q5
R4	5	T6
D6	6	N4
L5	7	N4C
R7	8	P3
AK6	9	T9
	10	PI
	11	TI
	12	N-R2

50-51 ØC

J

1 - B3
1 - KI
2 - B7
2 - K2
3 - B8
3 - K3
5 - C11
6 - K6

50-51 ØA

K

1 - J1
1 - MI
2 - J2
2 - M2
3 - J3
3 - M3
5 - C9
6 - M6
6 - J6

B

	1	N1
L4	2	N2
AK1C	3	JI
R3	4	T7
R5	5	N-61
UA4	6	AC1
	7	J2
	8	J3
	9	AC8
X7	10	AE2
X6	11	AE1
AN2	12	AD1

50-51 N

4
1 - KI
1 - AC4
2 - K2
2 - AC5
3 - K3
5 - C12
6 - K6
6 - C10

84

2 1
4 3
6 5
8 7

AC

1 - 86
4 - MI
5 - M2
6 - C2
7 - N2
8 - 89

C

	1	AD7
	2	AC6
	3	
	4	
	5	HI
	6	H9
	7	H7
	8	S5
	9	K5
	10	M6
	11	J5
	12	M5

RIL 2 1

8N 2 1

N
R1 - T7
R2 - A12
61 - B5

52CS

2C 2
3 3C 4C 4
5 5C 6C 6

4C-A7
1 - B1
2 - B2
2 - AC7
4 A6

79CO

1 3
2 4

P

1 - A10
2 - T3
3 - A8
4 - T5

CC

	1	AB1
	2	AB7
	3	AB6
	4	AB5
	5	AB4
	6	AB3

T.D.

1 2 3 4
5 6 7 8

Q
5 - A4
6 - A3
7 - A2
8 - A1

79

T.D.

1 2 3 4
5 6 7 8

S
5 - C5
6 - H8
7 - H10
8 - 12

T
1 - A11
3 - P2
4 - AD5
5 - P4
6 - A5
7 - B4
7 - N-R1
8 - AD6
9 - A9

67 80

DEVICES ON SWINGING PANEL

Code Letters	Devices
A	Terminal block (12 point)
B	Terminal block (12 point)
C	Terminal block (12 point)
D	Terminal block (12 point)
CC.	Terminal block (6 point)
AC.	HGA relay, front connected
H	Demand ammeter
J	Overload relay (type IAC53B) for ϕ C
K	Overload relay (type IAC53B) for ϕ A
N	Control switch with red and green lights
P	Recloser cutoff switch
Q	Test device (potential)
M	Overload relay (type IAC53B) for neutral and ground
S	Test device (current)
T	Reclosing relay (type AC-1)

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SCHEMATICS FOR MOTOR-OPERATED DISCONNECTS SECTIONALIZING STATION

Required reference:

Information Sheet No. 7

Check-up: (3-2-6)

1. The disconnects come equipped with a hand crank to facilitate
   closing the disconnect if no power is available to run the motor.
   When the hand crank is inserted into its useable position, it will
   open an N.C. contact (89-E). What does this do to the electrical
   circuit?

2. What would happen if someone would pull one of the potential fuses
   when the 42 switch is on automatic and the lines in service with
   the disconnects normal?

3. How many spare "a" and "b" switches are there?

4. How many wires are necessary in the conduit that runs between the
   control cabinet and the motor-operated disconnect No. 1? No. 2?

5. How many amperes would the heaters in the mechanism cabinet draw?

6. Study the wiring diagram and control schematic until you think you
   understand it, then write a sequence of operation on this control
   and its automatic operation.

MOTOR-OPERATED DISCONNECTS SECTIONALIZING STATION

Motor-operated disconnects may be used to sectionalize a section of a
high-tension line. In the event there is a fault on the high-line, power
circuit breakers at each end of the line will be opened by protective relay
action to de-energize the faulted line. A motor-operated disconnect switch
control schematic and wiring diagram is included with this lesson. Refer to
the one-line schematic, also. In this particular scheme a 115 kv to 12.47
kv transformer is tapped off the high-line between two motor-operated dis-
connect switches and feeds a distribution substation.

The motor-operated switches, when automatic, are designed to run
normally closed with a source of power from either end of the high-tension
line. If the entire line is de-energized, both motor-operated disconnects
will open after a ' second delay and remain open until the high-line is
re-energized fr _ one side or the other and remains hot for 5 seconds. The
motor-operated switch on the side that is hot will then close (t.d.c.) to
re-energize the transformer and distribution substation. The faulted section
of the line can be left out of service until repairs can be made.

The motor-operated switches are said to sectionalize and help isolate
the faulted section of the line. The switches are not intended to break
load, so in the automatic scheme they are made to open for deadline condi-
tions only.
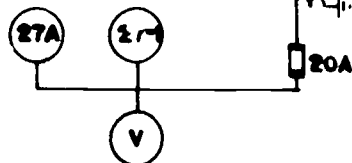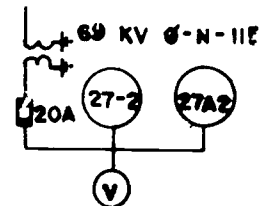
ONE LINE DIAGRAM
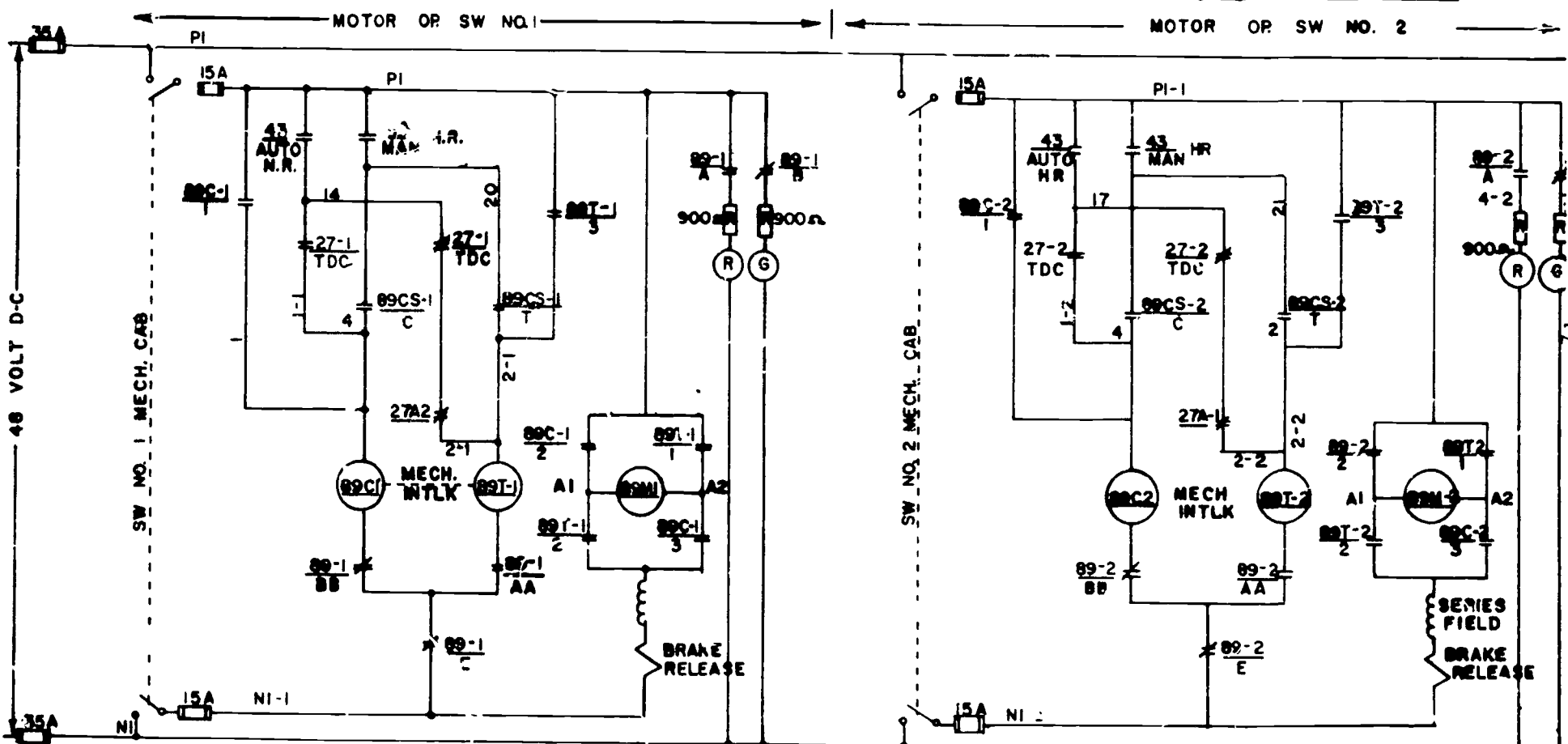
MOTOR OP. DISC. SW. CONTROL SCHEMATIC

WIRING DIAG. OF 115 KV MTR. OP. DISC. SW. MECHANISM
SWCO. TYPE CM-1 W/48 V D.C. MTR.

WIRING DIAG. OF 115 KV MTR. OP. DISC. SW. MECHANISM
SWCO. TYPE CM-1 W/48 V D.C. MTR.

FOR INTERNAL WIRING SEE DETAIL OF SW. NO.1 ABOVE

TO MTR. OP. DISC. SW. NO.2
LINE P.T.
TO MTR. OP. DISC. SW. NO.1
LINE P.T.

CONTROL PANEL WIRING

TO STA.
SERVICE
PANEL

TO STATION
BATTERY

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ELECTRICAL POWER STATION THEORY

UNIT III

SWITCHES AND CIRCUIT BREAKERS

This unit contains the following lessons:

Lesson 3-3-1: Fundamentals of Circuit Interruption
Lesson 3-3-2: Circuit Breaker Mechanisms
Lesson 3-3-3: Maintenance of Circuit Breakers

FUNDAMENTALS OF CIRCUIT INTERRUPTION

In the power industry and our entire system of transmission and dis-
tribution, the control of electric energy is predicated upon the possibility
of controlling the flow of current. Switches which may be safely and con-
veniently opened or closed play an important part in this control. Your
required reference book covers the field of low-voltage switches which are
important, but are secondary in importance to the substation wireman whose
work is quite often with the operation of high-voltage switchgear. This
course cannot begin to cover all types of switches used today in modern
substations and switching stations. For more detailed information as to
specific switches, the workman must refer to the manufacturers' instruction
books and literature, usually supplied with the equipment. This informa-
tion sheet presents some of the fundamentals that should help you under-
stand the operation of these devices when you work with them on the job.

Any circuit-interrupting device is intended to form an integral part
of an electric circuit. Disconnect switches as their name implies are
normally just that, a switch which, when operated, can connect or discon-
nect a portion of the power system or isolate a piece of equipment such as
a line, a transformer, or a section of bus. These disconnect switches
used for making, breaking, and changing connections in a circuit in which
the flow of current does not exceed certain load proportions do not have
any real interrupting capability such as would be needed to interrupt or
break abnormal or fault currents. Circuit interrupting devices intended
for that duty are commonly called circuit breakers or more exactly "POWER
CIRCUIT BREAKERS," and they may also perform the functions of a switch.
The terms switch and circuit breaker refer to circuit interrupting devices.
A circuit interrupting device for interrupting overloads having a circuit-
opening fusible member directly heated and destroyed by the passage of the
over-current through it is called a fuse.

Interruption of an a-c circuit is a complicated operation because of
the characteristics of an arc. As soon as the contacts of a circuit breaker
are separated, an arc is drawn, and whether the arc is drawn in air or oil,
it has this interesting property: the higher the current the lower the
voltage across the arc. For currents of more than a few hundred amperes,
the arc voltage is so low as to have negligible effect on the current
magnitude. The current is limited almost entirely by the impedance of the
external circuit. Therefore, efforts to cool and interrupt the arc result
only in increasing the voltage across the arc. Thus, in interrupting
currents of any magnitude, it is virtually impossible to produce interrup-
tion except at the very instant of normal current zero.

An arc current consists of an electron current (known as conduction
current) in an extremely hot core, surrounded by an envelope of hot though
relatively lower-temperature gases. There is a basic distinction between
the interruption of an a-c circuit and the interruption of a d-c circuit.
In direct currents there are no current zeros and current pauses; hence,

to interrupt a d-c circuit, the current must be forced to zero by progres-
sively increasing the arc resistance until the voltage drop across the con-
tacts equals the circuit voltage. This may be achieved by arc elongation
or arc constriction.

The tremendous amount of heat generated by an arc will result in some
of the contact metal being vaporized. Hot metal vapors are good conductors
of electricity. Electron emission may also take place from the surfaces and
ionization of the air or gas will occur. By ionization, the atoms and
molecules of an electrically neutral gas are broken up into free negatively
charged electrons and positively charged ions. An arc can be initiated or
maintained between two contacts when the degree of ionization of the gap is
sufficiently high.

Circuit breakers may be divided into two broad classes: oil-less and
oil circuit breakers. The oil-less class comprises air-break, air-blast
(compressed air), gas-filled, and vacuum-break switches. In air-break cir-
cuit breakers, the arc is initiated and extinguished in substantially static
air in which the arc moves. In air-blast circuit breakers, a blast of air
having a velocity approaching that of sound is used to convert the arc path
into an insulator. In oil circuit breakers, oil plays the major role in
the interrupting process.

Different kinds of circuit breakers have common structural features -
contacts, insulators, operating mechanisms. Air-break circuit breakers,
among which the magnetic type is the most important, dominate the low-
voltage field, while oil circuit breakers dominate where large blocks of
power are to be switched in the high-voltage class. These power circuit
breakers are required to interrupt normal-load currents of perhaps a few
hundred amperes. They are expected to interrupt line-charging currents
which may range from less than one hundred to several hundred amperes short-
circuit currents which may range up to 20,000 to 100,000 amperes.

The most vital parts of a switch are the contacts. Copper, which has
a low specific resistance, is well suited for carrying currents permanently
without excessive heating. Yet copper has a low melting point (1,083
degrees centigrade); consequently, copper contacts have a tendency to freeze
or weld when subjected to considerable amounts of arcing. Copper contacts
also have a tendency to form tough films of copper oxide on their surfaces.
This has a high resistance and can cause heating when large amounts of
current must be conducted. Tungsten has a high specific resistance, but
also has a high melting point (3,380 degrees centigrade). Tungsten contacts,
therefore having little tendency to vaporize or burn away as does copper.
As a result, interrupting devices are frequently provided with a pair of
copper contacts, or copper contacts coated with silver, for carrying current
permanently. In addition, they have a pair of contacts of tungsten or
similar material that are required to carry the total current only during
the closing or interrupting process. The contacts for carrying current
permanently are referred to as main contacts and those between which the arc
is drawn as arcing contacts.

When an arc is initiated by opening a pair of contacts, it will be elongated as the contacts are progressively opened to a greater distance until a current zero is reached w' n the dielectric strength of the arc gap exceeds permanently the recovery voltage which the circuit impresses upon it. Due to the high temperature in an arc, it is also subjected to a strong convection force which causes the arc to rise vertically and to form an upward loop, whereby its length may become considerably greater than the shortest distance between separated contacts. Arc elongation is a relatively ineffective interrupting means inasmuch as the rate of cooling and de-ionization increases slowly with increasing arc length.

Many disconnecting switches come equipped with arc horns. The principle of operation is to elongate the arc. When the horn-shaped contacts shown in the following illustration are opened, and an arc is initiated close to the lowermost point, the arc will rise by reason of its buoyancy. Successive positions of the arc are indicated. As the arc rises within the gap formed between the horns, it is subjected to elongation. Its rapid movement through the surrounding cool medium accelerates de-ionization by cooling and dif-fusion of electrons and ions out of the arc zone. Arc horns are just one of many extremely important elements in the design of circuit breakers and switches. Most interrupting devices depend on the motion of the arc to help in the   erruption process.

Another basic principle is to constrict the arc by some means. It has been found that a much higher voltage is required to maintain an arc in a small hole or narrow slot than is needed to maintain an uncon-fined arc. By using inverted, V-shaped, arc-constricting notches in spaced insulating plates, the arc is moved against these insulated plates and is cooled when it engages them. The arc elongation occurs in the interplate gaps, increasing the arc resistance.

ARC HORNS ARE USED IN THE BASIC
DESIGN OF MANY SWITCHES AND
CIRCUIT BREAKERS

A magnetic blowout principle is used in some breaker designs. An arc, as in the case of any other electricity conductor, will be acted upon by mag-netic field and will move unless restrained. This movement or displace-ment of the arc causes the arc to bulge and thereby become elongated, usually in an upward direction along an arc chute passageway where it will be interrupted.

The principle of interruption in all modern circuit breakers is to cool the hot, current-carrying ionized gases between the contacts by replacing them with insulating gases or insulating liquids. One simple method of doing

PLATES OF HEAT SHOCK
RESISTANT MATERIAL

INVERTED V - SHAPED SLOTS

ARC CORE

ENVELOPE OF ARC

BARRIERS FOR CONSTRICTION OF THE ARC ARE
FREQUENTLY USED IN CIRCUIT
BREAKERS

this is to draw two arcs in series. Arc initiation is like a violent explo-
sion, and there is a release of large quantities of heat and generation of
pressure at an extremely rapid rate. Many varieties of interrupting cham-
bers have been designed to utilize this pressure so that one arc vaporizes
oil to produce pressure, which in turn forces oil or neutral gas across the
second arc. This introduces fresh dielectric between the contacts of the
second arc which results in interruption of the circuit.

EXHAUST PORTS

SELF - PRESSURE – GENERATING
INTERRUPTER WITH SINGLE
ARC

MOVABLE CONTACT
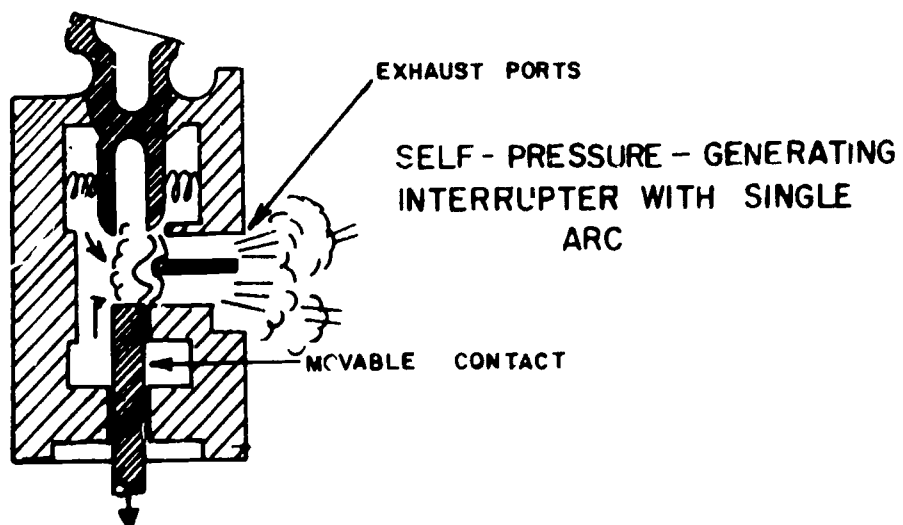
In some types of interrupting chambers, two separate arcs are unneces-
sary and the action seems to consist of one portion of a single arc intro-
ducing oil into a portion of the same arc. Still another type consists of
a spring energized piston which is released at the same time the contacts
start to open and drives a quantity of oil between the opening and the form-
ing arc.

Another method for increasing interrupting capacity and decreasing
interrupting time is the use of resistors which shunt the arc gap to limit
the rate of rise of the recovery voltage. The term "recovery voltage"
designates the voltage impressed by the circuit upon the interrupting device
after interruption of the current at or about the time of a natural current
zero. The recovery voltage tends to break down the arc gap and re-establish
the arc.

When an arc is shunted by a resistor, a part of the arc current is
diverted to and flows through the resistor resulting in a decrease of the

RESISTORS
DISTRIBUTE
RECOVERY
VOLTAGE ACROSS
TWO INTERRUPTING
BREAKS

INTERRUPTERS

STATIONARY CONTACT

RESISTOR &
CONTACT

STATIONARY CONTACT

MOVABLE CONTACT

CROSSHEAD

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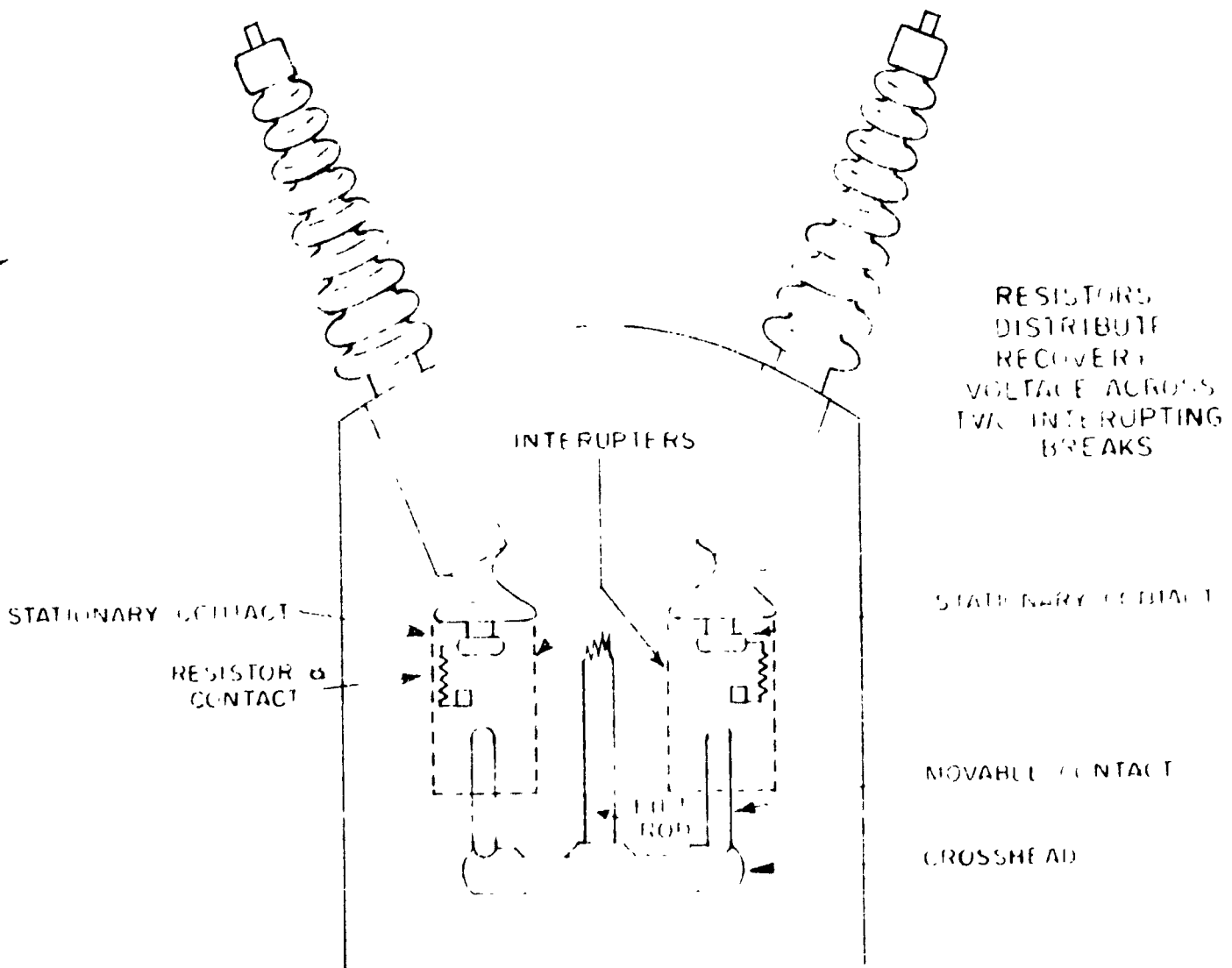
arc current. Resistor shunting of an arc is a most effective method of arc suppression. During switching of capacitance currents, restrikes are sometimes experienced. A restrike is a resumption of main current flow one-quarter cycle or later after interruption and can result in transient over-voltages of varying magnitudes. If breaker resistors of suitable value are switched into the circuit at the time of interruption, the possibility of restrikes are lessened. If restriking does occur, the magnitude of resultant overvoltages is reduced.

In modern air-blast breakers, compressed air stored in a tank and released through a nozzle to form a high velocity jet is used as the arc extinguishing means. The basic parts of an air-blast breaker are the com-pressed-air storage tank, normally at ground potential; the blast valve which controls the escape of the blast from the tank; the arcing chamber where arc extinction takes place; and the insulating blast tube for conduct-ing the blast from the tank to the arcing chamber.

For use on systems above 230 kv, particularly 500 and 700 kv, the oil-less air-blast breaker has some economic advantages over the bulk-oil dead-tank breaker. Almost all breakers for EHV systems are of the oil-less type. Their greatest advantage is in the cost and size of the means used to provide insulation between the working parts of the EHV breaker and ground. While these breakers are at present finding their greatest application at EHV levels, the breakers may also be designed and applied at high-voltage levels of 115 to 230 kv. The interrupting time of air-blast breakers is in the order of two cycles rather than the present American standard rating of three cycles.

Shorter interrupting time means reduced arcing damage to lines, trans-formers, and cables under fault and higher line loading capability through improved stability because of shorter fault duration time.

In certain locations, such as a chemical plant, the arc of an air breaker could touch off an explosion and at locations in or near populated areas, the cannon-like report of the air-blast breaker would not be toler-ated. Obviously the fully enclosed oil breaker could be used here since the arc is under oil and inside a steel tank, but there is a desire in the power industry to eliminate oil, primarily because of the complaints about oil maintenance. In spite of the complaints, the bulk oil breaker continues to be the "work-horse of the industry" and probably will remain so for several years. It has a good record of performance, is available in all needed ratings, fits well into most station layouts, and its built-in interrupting ability is relatively free of delicate or sensitive valves.

Outdoor-power circuit breakers have been in a continual state of improve-ment. The unusual arc-interrupting properties of sulfur hexafloride gas led to the development of the gas-filled circuit breaker. In the United States, the Westinghouse research scientists and the switchgear engineers have developed a line of circuit breakers sealed in an atmosphere of SF_6 gas (sulfur hexafloride gas). SF_6 gas stands out in comparison with both oil and air in all areas of insulation recovery after arcing, dielectric strength, noninflammability, safety, operating pressures and chemical stability.

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In the design of the gas breaker, the engineers have combined a gas
interrupter with proven features of air and oil breakers - dead-tank con-
struction, provision for bushing-type current transformers, and mechanical
interconnection of all contacts with the circuit breaker operating mechanism.
Some of the features inherent with sulfur hexafloride are quiet operation,
freedom from fire hazard, light foundation requirements, and a minimum of
auxiliary equipment. Westinghouse engineers predict that SF_6 breakers will
eventually be designed and built for most ratings new called for in A.S.A.
standards.

One more type of breaker that is finding a place in the industry today
is the vacuum circuit breaker. The advantage of arc interruption in vacuum -
the opening contact gap recovers its dielectric strength almost instantane-
ously after a current zero with very little energy dissipation - makes this
interrupter ideal for a-c circuit breaker application. Recent developments
in materials and manufacturing techniques have made possible a vacuum inter-
rupter that is technically and economically competitive with conventional
methods of arc interruption. Speed of interruption, reduced maintenance,
and increased life are the greatest advantages claimed by the manufacturers.
The vacuum interrupter can consistently clear a current after one-half cycle
of arcing. The contacts cannot oxidize and there is little chance of fire or
explosion. The construction of a vacuum interrupter is basically a pair of
contacts enclosed in a vacuum-tight bottle. When the contacts separate, the
arc vaporizes the contact faces forming a charged vapor, but because of the
extremely rapid dispersion of vapor in a vacuum, there is little or no
charged medium in which to re-establish the arc after current zero.

The moving contact is sealed to the bottle through a flexible metal
bellows, which allows contact movement without disrupting the vacuum seal.
The mating stationary contact is attached to the metal end-plate at the
other end of the bottle. Both metal end-plates are hermetically sealed to
a ceramic insulating envelope with a ceramic seal. To date, the largest
application has been to provide vault protection for 15-kv substations, but
the physical simplicity and reliability of vacuum interrupters may someday
open up their use for higher voltage applications.

CIRCUIT BREAKER MECHANISMS

This lesson gives you knowledge of a number of power circuit breakers and their mechanisms. These circuit breakers became necessary when the installed generation capacity of stations increased.

Required reference:

Information Sheet No. 9

Check-up: (3-3-2)

1. Name four methods that are used to operate circuit breakers.

2. What source of power ir commonly used to operate circuit breakers?

3. What is meant by a solenoid operated breaker?

4. What names are usually applied to a device which closes a circuit breaker by means of compressed air?

5. What is meant by a trip-free breaker?

6. Is a-c or d-c voltage normally used on: (a) the compressor motor, (b) the heater circuit, (c) the trip circuit?

7. What are the advantages of a phenumatic closing mechanism over an electrical solenoid mechanism?

8. What is the purpose of the anti-pump relay?

9. The power for closing a breaker comes from a solenoid coil, the stored energy in a spring, or from compressed air. Where does the power for tripping a breaker come from?

10. How many times may a breaker be operated from one tank of air while the compressor is not running?

INFORMATION SHEET NO. 9   (3-3-2)

CIRCUIT BREAKER MECHANISMS

When disconnecting devices and circuit breakers were first developed
and were still comparatively small, they were provided with only manual
means for closing. As power systems grew, circuit breakers and disconnecting
devices of higher interrupting and continuous current ratings were required.
The effort needed to close these breakers began to exceed the physical capa-
bilities of the average station operator. This resulted in a hazard to the
operator's safety and possible damage to equipment if he attempted to close
the switch against a heavy fault or load or if he closed it too slowly or
with hesitancy. Therefore it became necessary to confine manual closing to
switches of low interrupting ratings only.

As larger and larger stations were built and as interconnections
increased, the magnitude of short-circuit currents on the system increased,
too. Therefore, it has become necessary to provide some source of power for
breaker closing and opening. There are many instances, also, where it is
desirable to close a modern power circuit breaker during normal operation
by remote control. Centralized and supervisory control and automatic and
unattended operation of many substations and generating stations are common.
Most circuit breakers and many disconnect switches are today provided with
electrically powered closing mechanisms operated from the station battery
or from the secondary of a control power transformer.

In most generating stations and substations, a 125-volt direct-current
source is used for all control work. This source of power is usually a
storage battery with provisions for a battery charger set floating across
the battery. The reason for using batteries is obvious if one considers
the dependability of the control power. A dependable source of tripping
power must be provided if a circuit breaker is to operate for any short
circuit on the protected portion of the high-voltage system. If the second-
ary of a control power transformer were used for tripping, the short circuit
that required tripping of the circuit breaker would always reduce the voltage.
It would sometimes be extremely low and there might not be enough energy
available from the control power transformer to assure tripping the circuit
breaker.

The operator or operating mechanism consists of a source of motive power
for closing the breaker, a mechanism to connect this source of power to the
breaker contact mechanism, and a tripping means to release the breaker con-
tacts for tripping. Operators normally fall into one of the following clas-
sifications: manually operated, motor operated, spring operated, sole. id
operated, pneumatically operated, hydraulically operated, or pneudraui .
The power for opening most circuit breakers comes from a compressed spring
usually mounted on the last pole of the breaker. This spring is compressed
when the breaker is closed. The energy stored in this spring, plus the pull
of gravity of the movable parts, force the breaker open when the trip latch
is operated.

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Many early model circuit breakers were operated with a motor, but clos-
ing by means of the motor alone was entirely too slow. Schemes were devised
so the motor could wind up a powerful spring and the energy stored in the
spring could be used to quickly close the breaker. This solenoid closing
coil principle has been widely used for operating mechanisms for many years
and today has many applications. As power systems became larger, the
practical limit of solenoid closings was reached, and it was necessary to
use other means to obtain power.

A pneumatic operating mechanism was developed and used for a good many
years. For its closing operation, compressed air is admitted to the mecha-
nism cylinder by an electrically-operated control valve causing the piston
to move up and close the breaker. At the end of the stroke a switch is
actuated which shuts off the incoming air. A pneumatic operating mechanism
is almost a necessity where modern high-speed reclosing is required or when
it is desirable to keep the closing current low. Operating pressure is
automatically maintained in the storage reservoir by a motor-driven com-
pressor unit contained in the mechanism housing. At normal operating pres-
sure, the reservoir contains enough air for at least five immediate closing
operations without recharging.

The complete operating mechanism is contained within a weatherproof
housing. Gasketed doors are usually provided for access to the mechanism
and for ease in maintenance and testing. The mechanism should include a
motor driven compressor, storage reservoir, motor, alarm and lockout pres-
sure switches, pressure gage, counter, thermostatically controlled space
heater, auxiliary switches, a trip-free mechanism, anti-pump control relay,
and terminal blocks for current transformer leads and external connections.
Provision for maintenance closing by a hydraulic jack or some other similar
method is normally included.

To supervise these breakers, standard green and red indicating lights
are commonly used. The green light shows the breaker to be fully opened,
and since it is normally connected across the trip circuit, it also
indicates the availability of tripping power before the breaker is closed.
The red light shows that the breaker is fully closed and that the trip coil
is in working order, ready to perform the major role for which the breaker
was designed - to break the circuit quickly and effectively under fault
conditions.

If a circuit breaker is to be closed manually against a possible fault,
it should be mechanically trip-free from the closing linkage. The circuit
breaker contacts can then be tripped free anywhere in the closing stroke
without waiting for the closing current to be cut off before acceleration
toward the open position can start. If the circuit breaker trips automatic-
ally when it is closed on a fault, it will open and will not reclose even
though the operator holds the control switch in the closed position. The
X-Y relay scheme prevents pumping and makes the circuit breaker electrically
trip-free. (An explanation was given for the conventional X-Y closing
scheme in the lessons on control schematics.) Some breakers are equipped
with a trip-free relay which provides a similar action through the use of

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a specially designed contactor for controlling the heavy current to the breaker-closing solenoid. The moving contact assembly of this contactor is tripped free from the operating armature by a release coil energized by an auxiliary switch when the circuit breaker reaches its closed position. Thus, even though the closing contact of the control switch remains closed, the circuit to the closing solenoid of the circuit breaker remains open after the circuit breaker has once closed in and tripped out. This situation continues until the control switch is restored to neutral.

There are several ratings of power circuit breakers that are defined by the AIEE and NEMA standards that are of interest to the apprentice wireman. Rated voltage - The standard rms voltage rating of a particular breaker is based on its use at an altitude of 3,300 feet or less. For operation at higher altitudes, the voltage rating is reduced one percent for each 330 feet of altitude above 33,000 ft. No breaker should be operated above its rating under any conditions. Continuous Current Rating is based on an ambient temperature of 40 degrees centigrade. Rated Interrupting Current is an important factor in the design of a breaker. It is the maximum rms total current that the breaker should be required to interrupt in a circuit operating at the rated voltage of the breaker. This rating is also usually given as a kva interrupting capacity for three-phase breakers. Interrupting Time of a circuit breaker is the maximum interval from the time the trip coil is energized at normal control voltage until the arc is extinguished. This time is published for standard breakers for the interruption of currents from 25 percent to 100 percent of the rated value.

OPENING OR TAIL SPRING

5   6

POLE 3

OIL GAGE

MECHANISM COVER PLATE
REMOVE TO PROVIDE VENT
OPENINGS

3   4

POLE 2

PROVISION FOR
SPEED RECORDER

OUTSIDE TRIP

MECHANISM
CABINET

2

DOOR SWING
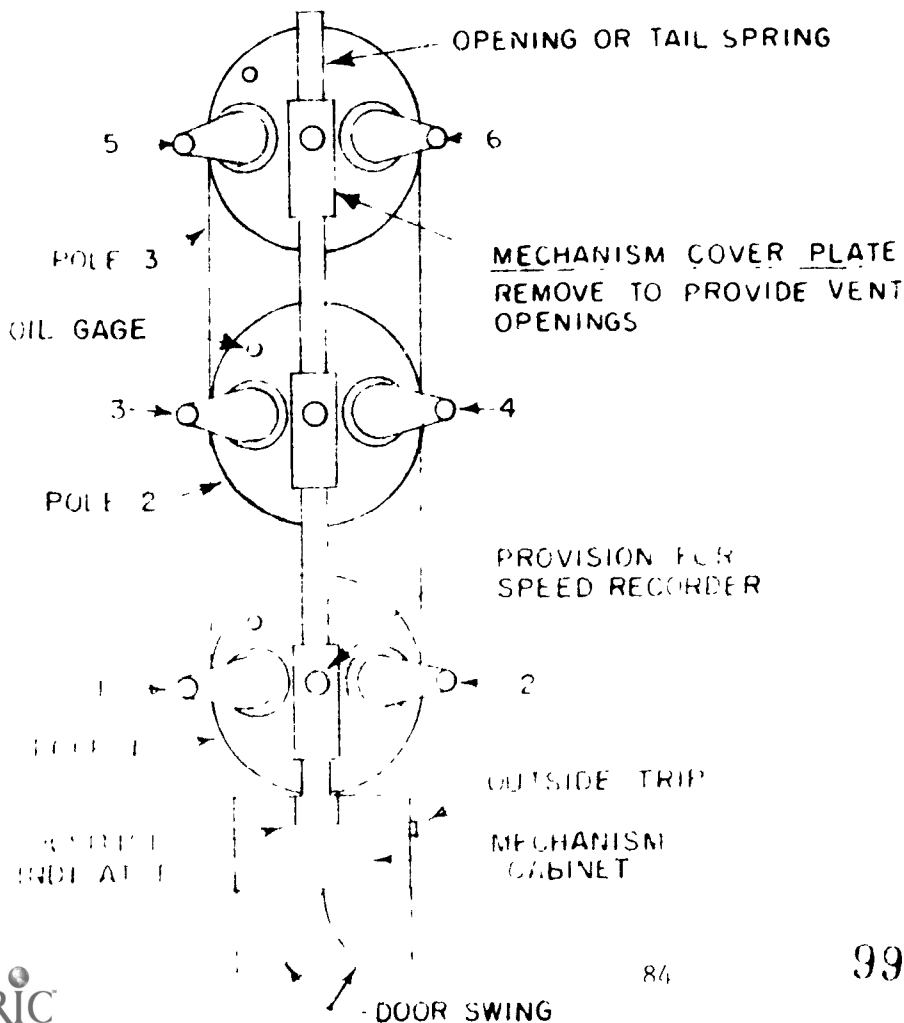
In the classic design tank-type oil breaker, it is conventional to number the terminals so that as you face the breaker from the mechanism end, the terminals, bushings, CT's, etc. are numbered left to right and front to back. Bushings 1 and 2 therefore are on the No. 1 pole in the first tank. Bushings 3 and 4 are on the second pole in the second tank, etc.

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In a trip-free breaker, a mechanism if arranged to mechanically dis-
connect the breaker linkage system from the closing force each time the trip
coil is energized. This insures that the breaker contacts will open at the
proper speed, by the force of the opening spring, without being delayed by
the effect of the closing piston rod. (Proper contact opening speed is
essential for proper circuit interruption.)

Closing of the breaker is accomplished by the piston rod which pushes
up on the toggle shaft, which in turn rotates the crank, and pulls down on
the vertical connecting rod. In this way, the closing force is transmitted
to the breaker contacts through the breaker linkage system. The breaker is
held in the closed position by the prop latches which seat themselves under
the main toggle shaft when the breaker reaches the fully-closed position.
During the closing operation, the opening spring is compressed to provide
the required force for opening when the breaker is tripped.

Tripping of the circuit breaker is accomplished by energizing the trip
coil which in turn releases the trip latch. Release of the trip latch per-
mits the toggle shaft to slide off the prop latches and rotate to one side
of the piston rod. The breaker is then free to open at full speed since
the trip-free mechanism has mechanically disconnected the closing force
from the breaker linkage, even if the piston rod is still held in the
raised position by air pressure, jamming, or the maintenance closing jack.

When the breaker approaches the fully-open position, and when the piston
rod is retracted by the spring under the air cylinder, the trip latch is
reset and the breaker is ready for a reclosing operation.

The high speed of the trip-free mechanism permits fast 20-cycle
reclosing operation of the breaker and still maintains the advantages of
a mechanically trip-free system.

The piston rod is connected to the toggle shaft by means of a link
which reduces mechanical shock during reclosing operations and leaves the
toggle shaft free to rotate so it does not prevent a trip-free operation.
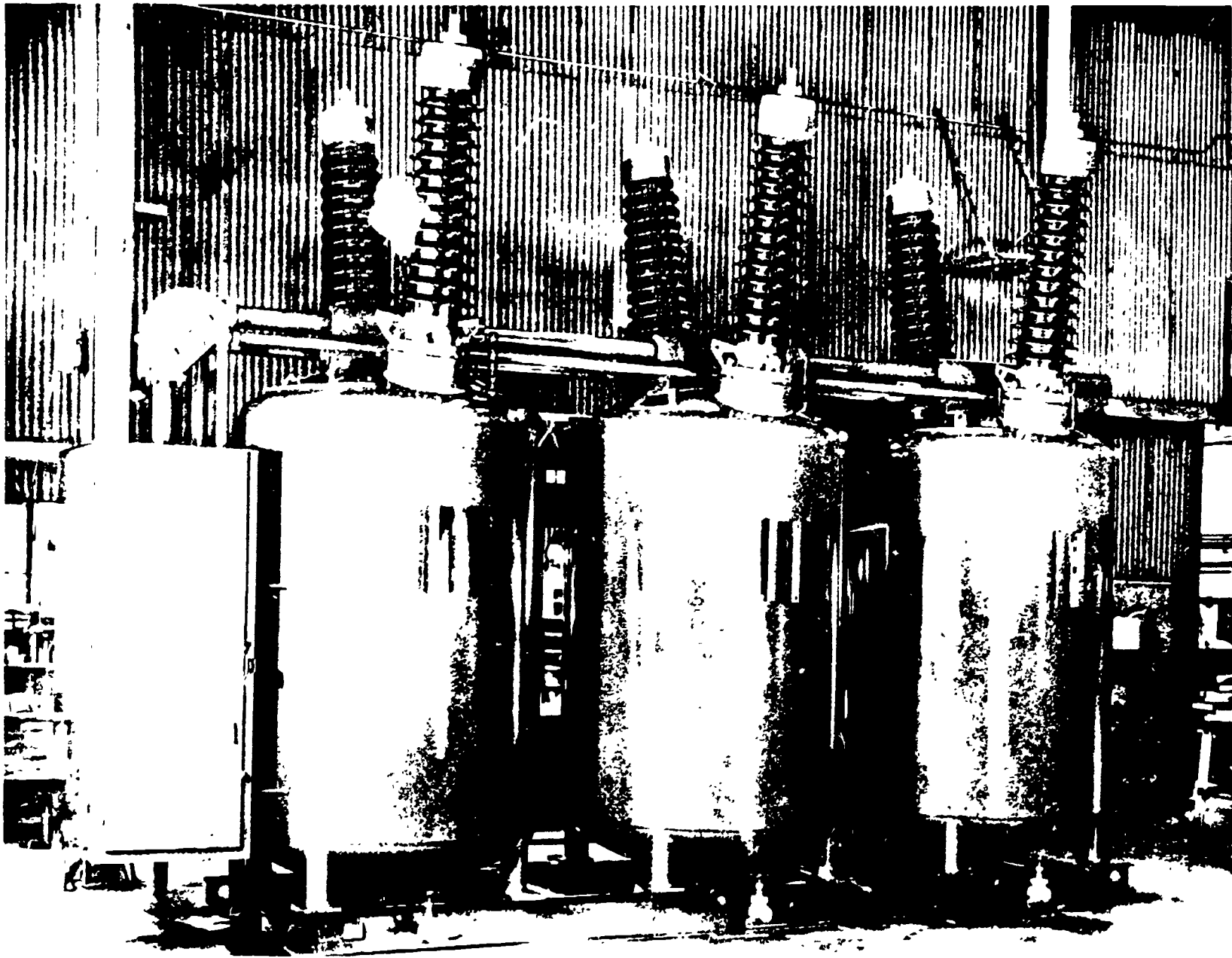
I-T-E CIRCUIT BREAKER COMPANY
POWER CIRCUIT BREAKER DIVISION
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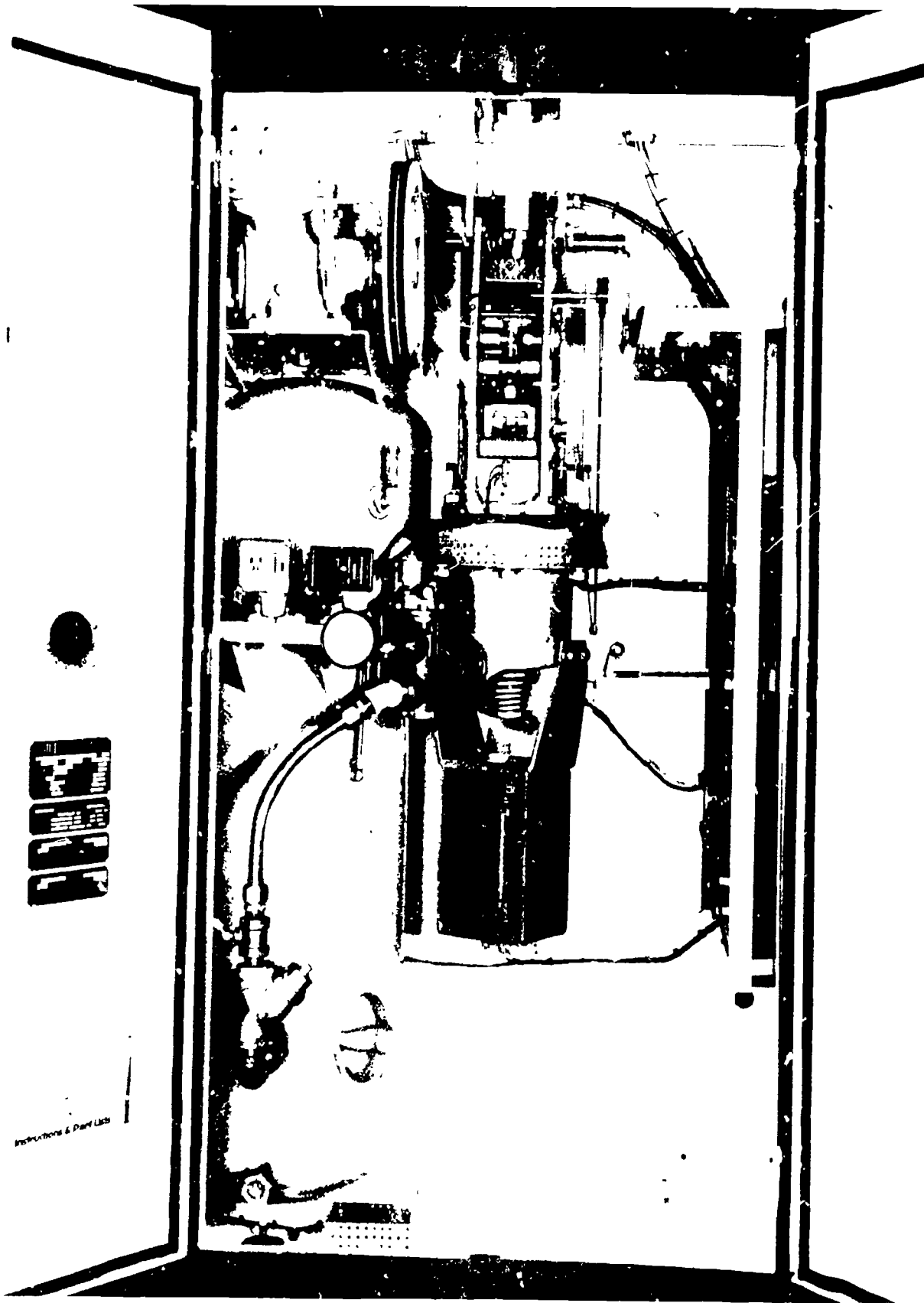
"The I-T-E pneumatic operating
mechanism turns out fast operating
speeds with low
energy requirements".

I-T-E CiRCUIT BREAKER COMPANY
CIRCUIT BREAKER DIVISION

A 4835

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meet the
p r r e.
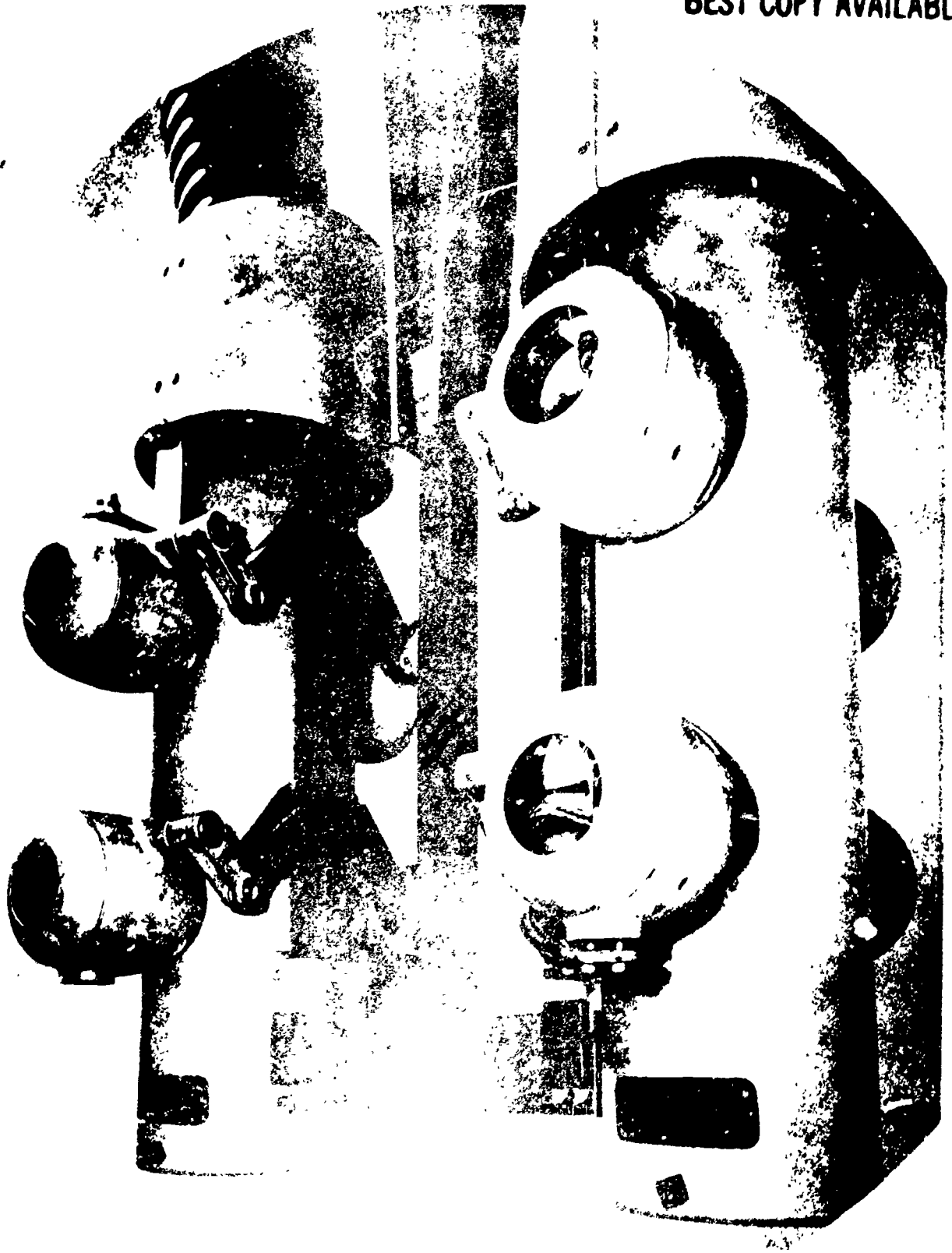
breaks
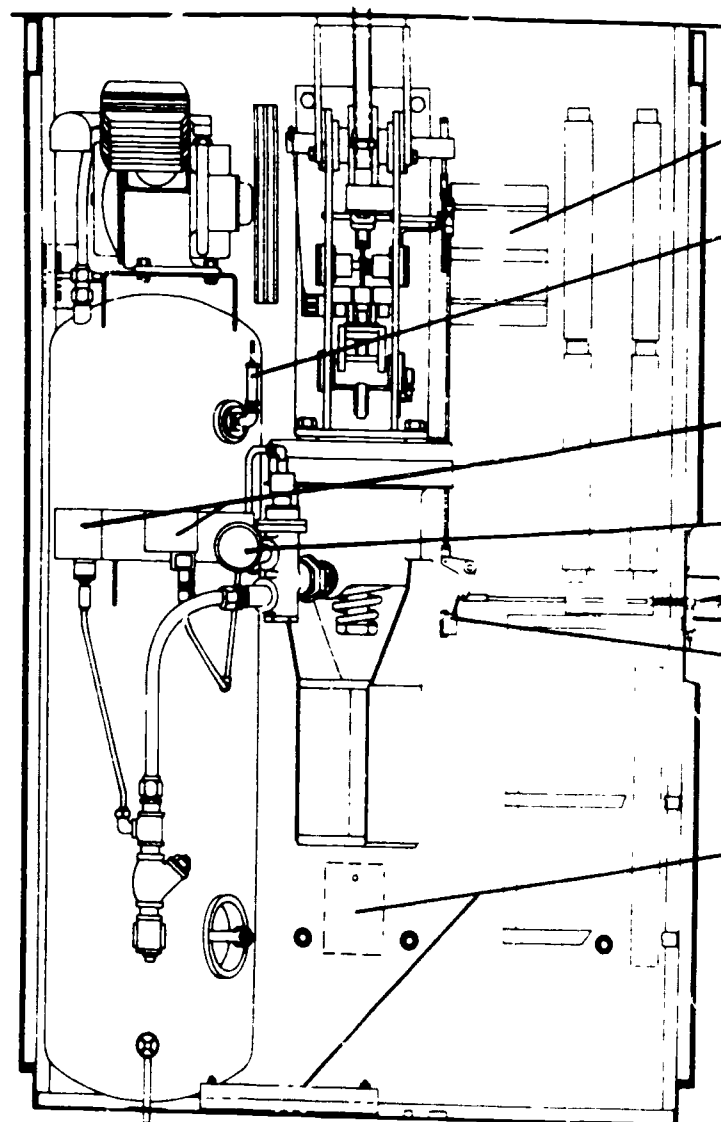
COMPRESSOR UNIT

AUXILIARY SWITCH

LATCH MECHANISM

SAFETY VALVE

OPERATION COUNTER

LIMIT SWITCH

LATCH CHECKING SWITCH

PRESSURE SWITCHES—
MOTOR CONTROL, AL-
ARM AND INTERLOCK

PRESSURE GAUGE

MANUAL TRIP DEVICE

MECHANICAL LOCKOUT

ELECTRICAL LOCKOUT

MAINTENANCE CLOSING
DEVICE

SPACE HEATERS

MOISTURE DRAIN VALVE
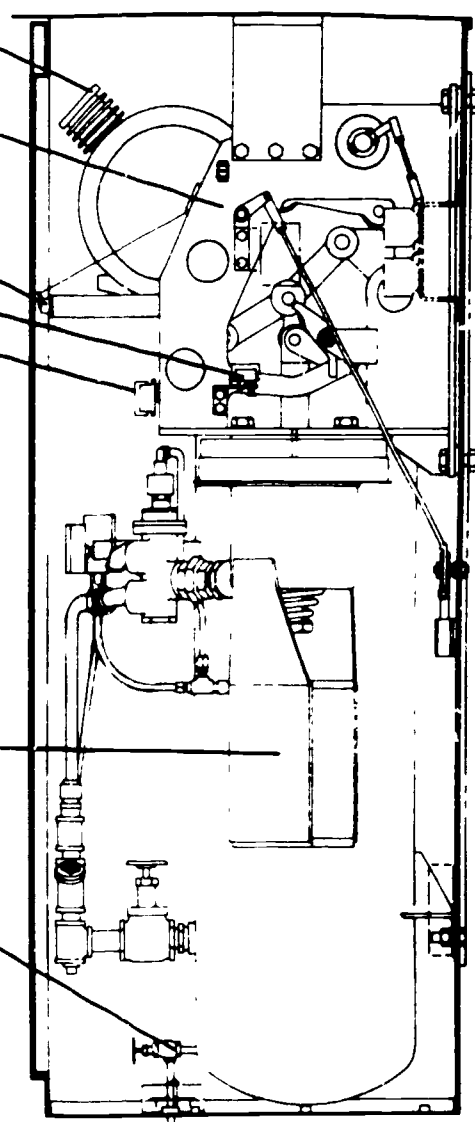
PNEUMATIC OPERATING
MECHANISM
TYPE P-43A

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BUSHING

TRANSFORMER

PULL RODS

LIFT MECHANISM

OPENING DASHPOT

GUIDE

RESISTORS

INTERRUPTER

CROSS BAR

TANK THICKNESS

84 ID
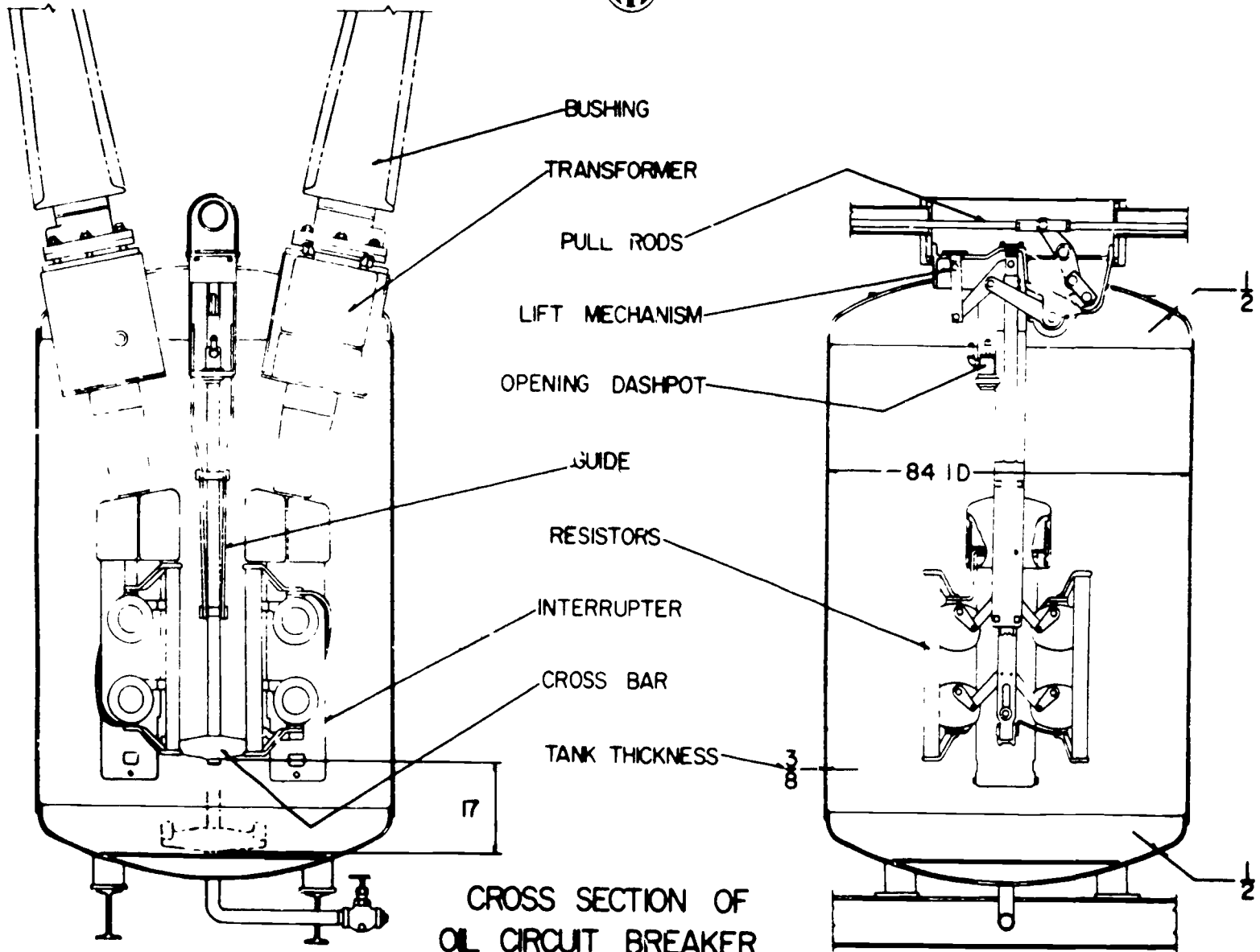
CROSS SECTION OF
OIL CIRCUIT BREAKER
230K 10000-16

6-60

107

108
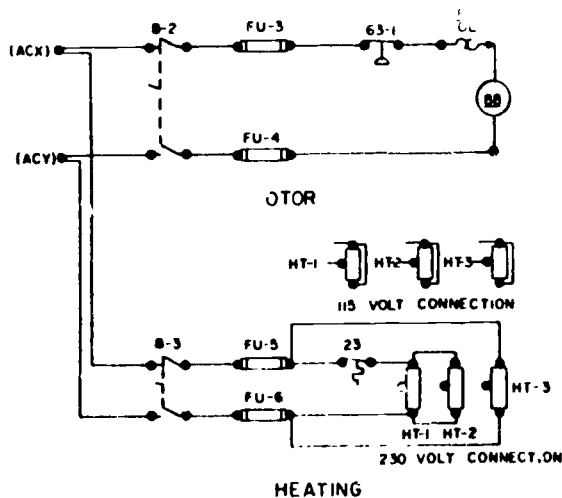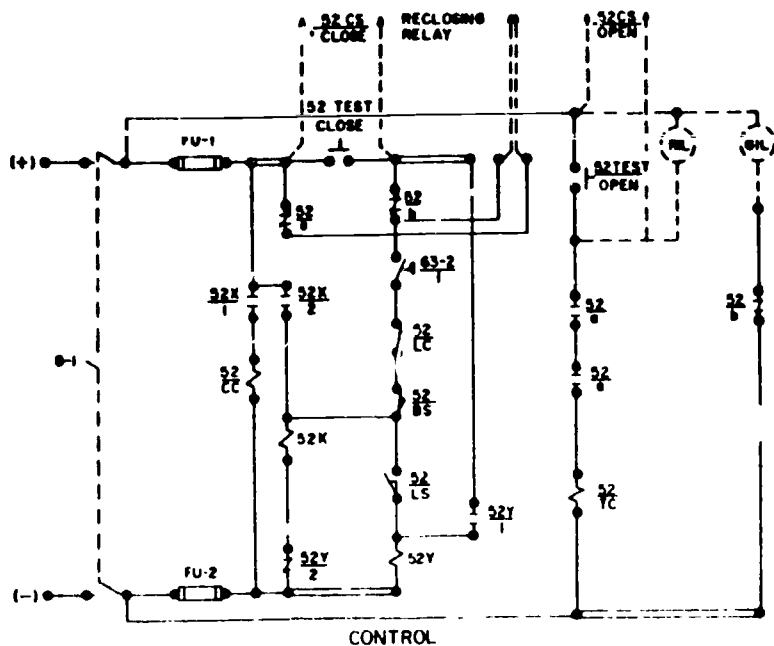
ITEM	DESCRIPTION
8-1	Knife Switch; Control Supply
8-2	Knife Switch; Motor Supply
8-3	Knife Switch; Heater Supply
23	Thermostat
52	Oil Circuit Breaker
63-1	Pressure Relay; Compressor
63-2	Pressure Relay; "1" Lockout, "2" Alarm
88	Compressor Motor
AS	Auxiliary Switch
BS	Blocking Switch; Opens When OCB is Manually Tripped
a	Auxiliary Switch Contact; Opens When OCB is Open
b	Auxiliary Switch Contact; Closed When OCB is Open
e	Auxiliary Switch Contact; Adjustable
f	Auxiliary Switch Contact; Closes Momentarily When OCB Opens
CC	Closing Coil (Air Valve)
CS	Control Switch
FU-1 to 6	Fuse
GIL	Green Indicating Lamp
HT-1 to 3	Heater
LC	Latch Checking Switch
LS	Limit Switch
OL	Overload Relay
RIL	Red Indicating Lamp
TB	Terminal Board
TC	Trip Coil
X	Closing Relay
Y	Antipump Relay

CONTROL

MOTOR

HEATING

115 VOLT CONNECTION

230 VOLT CONNECTION

LOW PRESSURE ALARM
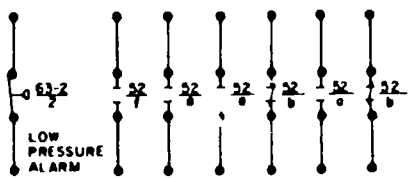
SPARE AUXILIARY SWITCH CONTACTS

TYPICAL CONNECTION DIAGRAM
PNEUMATIC OPERATING MECHANISM
DC CLOSE & TRIP, AC MOTOR

POLE 3

X1 X2 X3 X4 X5
5X1 5X2 5X3 5X4 5X5
X5 X4 X3 X2 X1
6X5 6X4 6X3 6X2 6X1

POLE 2

X1 X2 X3 X4 X5
3X1 3X2 3X3 3X4 3X5
X5 X4 X3 X2 X1
4X5 4X4 4X3 4X2 4X1

POLE 1

X1 X2 X3 X4 X5
1X1 1X2 1X3 1X4 1X5
X5 X4 X3 X2 X1
2X5 2X4 2X3 2X2 2X1

ALL TERMINAL POINTS MARKED G6 (WHICH IS CONNECTED TO THE SHORTING BAR) SHOULD BE GROUNDED TO THE BREAKER FRAME TO FACILITATE GROUNDING ONE SIDE OF THE TAPS BEING USED

OIL CIRCUIT BREAKER

MECHANISM HOUSING LOCATED AT POLE 1 END OR ON 2-4-6 SIDE OF BREAKER

TERMINAL BLOCKS

Terminal blocks 1-6 with points X1, X2, X3, X4, X5, G6

1-3-5 BUSHINGS

1200/5

MARKED RATIO	TURN RATIO	SECONDARY TAPS
100/5	20/1	X2-X3
200/5	40/1	X1-X2
300/5	60/1	X1-X3
400/5	80/1	X4-X5
500/5	100/1	X3-X4
600/5	120/1	X2-X4
800/5	160/1	X1-X4
900/5	180/1	X3-X5
1000/5	200/1	X2-X5
1200/5	240/1	X1-X5

2-4-6 BUSHINGS

1200/5

MARKED RATIO	TURN RATIO	SECONDARY TAPS
100/5	20/1	X2-X3
200/5	40/1	X1-X2
300/5	60/1	X1-X3
400/5	80/1	X4-X5
500/5	100/1	X3-X4
600/5	120/1	X2-X4
800/5	160/1	X1-X4
900/5	180/1	X3-X5
1000/5	200/1	X2-X5
1200/5	240/1	X1-X5

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ERIC

MAINTENANCE OF CIRCUIT BREAKERS

It is impossible in this course to set down any specific program for the care and maintenance of circuit breakers, switchgear, and disconnect switches because conditions vary due to surrounding circumstances and the policy of the respective power company. As an aid to the apprentice, however, some key points of an equipment maintenance program are set forth in this lesson.

Required reference:

Information Sheet No. 10

Check-up: (3-3-3)

1. How often should oil circuit breakers be overhauled?

2. What precautions should be taken before making any mechanical adjustments or doing any other work on a breaker or its mechanism?

3. What normal amount of attention do circuit breakers require in service?

4. What action does breaking a heavy short circuit have on the oil used in oil circuit breakers?

5. How are water and carbon removed from switch oils?

6. Should switch oil be filtered while switches are in service?

7. What information can be obtained from a travel analyzer?

8. If breaker is overheating because of high current, what is the most probable cause? Explain.

9. Name three things to look for if a circuit breaker fails to close.

10. On a 125-volt coil, what is the minimum pickup value that the trip coil must operate? On pneumatic operators?

11. What is the purpose of the low pressure lockout switch?

12. What is the purpose of the 52Lc latch-check switch?

13. What is the purpose of the pressure alarm switch?

14. After an adjustment has been made on the mechanism, should the first operation of the breaker be manual or electrical?

15. What is the purpose of the pressure-governor switch?

INFORMATION SHEET NO. 10   (3-3-3)

MAINTENANCE OF CIRCUIT BREAKERS

Today electric power is a mighty force in industry, in national defense, and in everyday good living. Millions of dollars worth of valuable equipment are required in the generation and transmission of electric power. When a fault occurs in a power system, the power circuit breaker is allowed only one opportunity to clear the fault. If the power circuit breaker does not open when called upon, extensive damage to equipment may result or the lives of people may be jeopardized. To help prevent serious outages and damages to equipment, most power companies resort to a practical maintenance program aimed at preventing trouble.

Substation wireman are usually assigned the task of inspecting and maintaining the circuit breakers and disconnect switches that make up a large portion of any substation equipment. Trouble is often forestalled by tightening a wire or switch, replacing spring cotter pins, readjusting contacts, cleaning the oil, and keeping latches free of corrosion when regular periodic inspections are made.

Before approaching any switch or circuit breaker for a general inspection, sufficient precautions should be taken to guarantee the safety of the workmen. In the case of the circuit breaker, it must be de-energized since it will be necessary to work on top of the unit. Most maintenance experts feel that positive methods of determining the circuit breakers condition can be accomplished simply and accurately without lowering or draining the oil-filled tanks. In addition to opening the breaker and disconnecting switches, some approved grounding clamp, with cable, should be used to securely ground each terminal of the breaker. The control circuit and closing source of power should be cleared to prevent damage or injury from mechanical operation. Extreme caution must be used when working on a breaker or mechanism while it is in the closed position unless the trip latches have been securely wired or blocked to prevent accidental tripping.

Circuit breakers may work out of adjustment during operation. The mechanism should be given a very thorough inspection. Check all pins and bearings to make sure they are not worn to the point of needing replacement. Lubrication with a good grade of oil is recommended. Check for missing or broken cotter pins, or ones worn enough to warrant replacing. The ground surface of all latches should be observed closely for rust, corrosion, or dirty grease. On air-operated mechanisms, the compressors should be checked periodically for leaks. Air leaks in the system may be found readily by going over all joints, fittings, gasket seals, valves, and valve stems with a solution of liquid soap and a brush. Occasionally, the reservoir drain valve should be opened slightly just enough to drain off the water without losing the pressure in the supply reservoir. Check the heaters in the mechanism cabinet. These are intended to reduce the amount of condensation.

The condition of the current carrying components can be determined by using a low-resistance, test-set reading in micro-ohms, or by the volt-drop-method. At least 100 amperes of d-c are recommended when making this milli-volt-drop test. Contact resistance varies with manufacturers' designs. A general guide follows. If the contact resistance of a breaker measures slightly higher than the values shown, it is not necessarily a sign of trouble. One contact resistance is made and recorded, and any change in excess of 150 percent of subsequent tests should be investigated for contact deterioration or loose connections. High contact resistance will lead to overheating on high current carrying circuit breakers. I^2R = HEATING; therefore, poor contacts can cause enormous heating.

TYPICAL MAXIMUM CONTACT RESISTANCE OF OIL CIRCUIT BREAKERS

KV	AMPERES	MICRO-OHMS
7.2 - 15	600	300
	1,200	150
	2,000	75
23 - 34	ALL	500
46 -	ALL	700
69	600	500
	1,200	100
115 - 345	ALL	1,000

Accurate checks on the operating mechanism can be made by taking speed-graph tests, or timing records can be taken with a cycle counter, a Cincinnati circuit breaker analyzer, or an oscillograph. Often one or more of these tests are made at the time of the installation and are kept on file as a guide in checking the breaker when regular inspections are made.

The time-travel analyzer, or Cincinnati circuit breaker analyzer, is a device which may be attached to a lift-rod of most circuit breakers. (Provisions are usually provided by the manufacturer for such a device.) Owing to the high speeds encountered in most modern breakers, a straight-line type of travel analyzer is recommended.

TRIP COIL ENERGIZED

FULLY CLOSED POSITION

OVERTRAVEL = $\frac{3"}{8}$

CONTACT INDICATION

TRAVEL - 1 SPACE = $\frac{1"}{2}$

INTERRUPTION AREA

CLOSING CURVES

300 PSI 125V DC NORMAL PRES
210 PSI 125V DC MINIMUM PRES.

TIME IN CYCLES 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
60 hz BASIS

STROKE - 18"

1ST OPERATION
5TH OPERATION

TRIPPING CURVE
125V DC

230 PSI = LOW PRES. ALARM
200 PSI = LOW PRES. LOCK OUT

SAMPLE

CLOSING COIL ENERGIZED

FULL OPEN POSITION

OIL CIRCUIT BREAKER ANALYSER CHART

Station BOON DOCKS SUb

OCB Make G.E.   Type FK-439-161

Mech. Type MA 16 ,   OCB No. 943

Tested by SMITH & DOE   Date 7-20-70

115   BEST COPY AVAILABLE

96
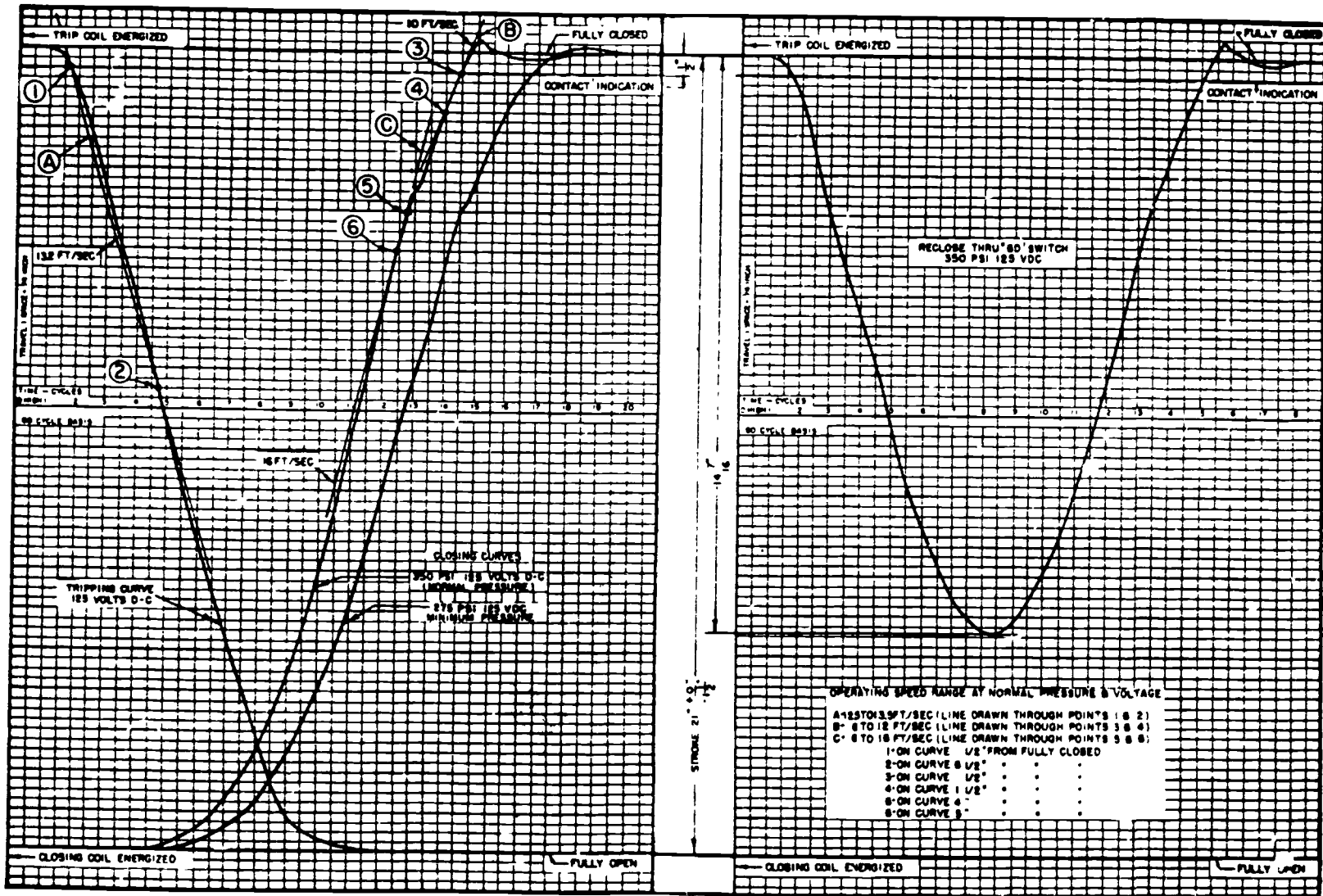
Representative Travel Curves

Steel-Clad Impulse Oil Circuit Breaker Type PGK   GEI-57138

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When a travel analyzer, or Cincinnati circuit breaker analyzer is used to obtain an accurate travel record of the breaker performance, the opening speed of the contacts and lift-rods may be obtained by drawing a straight line through two points on the travel curve. A representative travel curve of a General Electric Type FGK, 230 kv, oil circuit breaker is included in this lesson.

First, mark the point where the contacts open on the graph and then mark the end of the arcing zone, usually about four inches. (The manufacturer's instruction book should provide this information.) Second, draw a straight line using these two marks. The slope of this line is an indication of the opening speed. This speed may be determined by counting out five cycles from where the contacts open, and counting the inches vertically, the distance from this line to the line representing the average speed through the arcing zone. The number of inches measured is equal to the feet per second velocity of contacts through the arcing zone.

The average closing speed can be determined in a similar manner. The closing speed is controlled by the pneumatic operating mechanism. The opening speed is controlled by the setting of the opening springs. Before making any adjustments, pay particular attention to the section on INSTALLATION AND ADJUSTMENTS in the manufacturer's instruction book for the mechanism. The travel-recorder graph is an excellent tool in the hands of an experienced maintenance man. It gives him a check on the opening dash-pot action. Also, where a direct-reading type of recorder is used the over-travel can be measured directly from the travel curve. By comparison with previous graphs taken on the same breaker, he can quickly spot any changes in the action of the breaker.

Internal inspection of circuit breakers is made less often but is none the less important. The frequency of periodic inspection should be determined by each operating company on the basis of the number of operations (including switching), the magnitude of currents interrupted, and any unusual operations that occasionally occur.

The tanks should be opened only when the weather is suitable, or when sufficient precautions have been taken to guard against the entrance of moisture or dirt. Drain the oil, remove the manhole covers, and thoroughly clean the dirt and carbon from the arc shields or lower ends of the bushings. The static shields should be removed and the surface of the moving and stationary contacts examined. These contacts usually need no attention other than a good cleaning. However, if there are any burrs, roughness, or particles of burnt copper projecting from the general contour of the contact, they may be dressed up with a file. Interrupting troubles are rare; however, oil throw, excessive carbonization, or excessive contact burning may be the result of improper adjustments.

Carbonization of the oil will also be caused from many operations. Breaker tanks and all inside parts should be thoroughly cleaned with clean, dry, lint-free cloths and flushed out with a little clean oil before refilling with new or purified oil. When tank liners are used, they should be

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examined for burned spots or parts that may have come loose. It is recommended that oil be removed and the tank cleaned at regular intervals because filtering the oil only does not remove the carbon that adheres to the inside of the tank.

The quality of the oil should be checked. Oil in service should be tested at frequent intervals. When sampling oil, the sample container should be a large-mouthed, glass bottle. The bottle should be cleaned and dried with benzine and should be free from moisture before it is used. The sample of oil should be at least one pint. If the dielectric strength of the oil tests less than 17,000 volts, it should be filtered.

Most circuit breakers have some type of opening dashpot to absorb the shock of opening, and the oil levels of these should be checked. All bolts, nuts, washers, cotter pins, and terminal connections should be in place and properly tightened.

Before bolting up the manhole covers or raising the tanks, check to see that all tools, rags, or foreign pieces of equipment have been removed from the tank. When bolting up manhole covers, it is best to place a film of grease on the gaskets so that they will not be destroyed when the covers are again opened. In filling the tanks, care must be taken that moisture will not be absorbed by the oil during the filling process. Metal or oil-proof rubber hose must be used because oil dissolves the sulphur in ordinary hose. This may cause trouble as sulphur attacks copper.

Check the bushings for cracks or foreign deposits. Inspect the oil gages, the breathers, and vents. The operator cabinet should be cleaned of dirt, dust, and oil drippings. The maintenance man should check that all control connections and wiring are in good order and see that the C.T. connections are all tight. Check the overtravel stops, the power connections, and the operation counter.

After everything has been checked over and put in good condition, slowly operate the mechanism manually with the hand closing device to see that all parts move freely and with no undue friction. CAUTION: Always open the main, double-pole, control switch on the breaker panel before manually operating the breaker. DO NOT USE THE MAINTENANCE CLOSING DEVICE FOR CLOSING THE BREAKER ON LOAD. An air-operated or electrically-operated breaker should never be closed against a hot line with the hand closing device. See that the trip free latch is free to reset as the mechanism retrieves from the trip position.

When you are satisfied that the mechanism is in good working order, a few operations should be tried by power from the operator's control switch. Be sure that the hand closing device is in the clear and take care to keep everybody clear of the mechanism and breaker while it is being operated. Moving parts move fast and serious injury may result.

Although it is not a general practice, some maintenance or test departments test operate circuit breakers at a reduced voltage to enable minimum

values of close-coil voltage and trip-coil current to be obtained. Most breaker mechanisms will still trip even though the supply voltage is reduced as much as 50%. This gives a good indication of satisfactory breaker and mechanism adjustment.

The following information is given as a guide for locating breaker trouble sources.

Breaker fails to close
or to latch closed

Check for blown fuses.
Check to see if closing coil is energized with
  rated voltage.
If voltage is too low, closing solenoid will
  not close breaker sufficiently to operate
  limit switch and cut off closing current.
Check to see if "X" relay coil is open cir-
  cuited or burned cut.
Check continuity of closing control circuit
  and see if the control relay contacts are
  closing satisfactorily.
Closing coils are designed for intermittent
  duty only and will burn out if subjected to
  closing current for too long a period.
Check cut-off switch "aa," if operating too
  late causing the breaker to "bounc," open.
Check main and trip-free latches or props to
  see that they are functioning properly.
Check for mechanism binding or sticking because
  of improper adjustment or lack of lubrica-
  tion.
FOR PNEUMATIC OPERATORS:
Check lock-out pressure switch contacts. The
  cut-off switch as it is sometimes called is
  used to prevent the mechanism from attempt-
  ing to close when there is insufficient air
  to complete the operation. (Also used on
  spring actuated mechanisms to insure that
  spring has enough stored energy to complete
  a successful close.)
Check to see if solenoid operated air valve is
  functioning properly.

Breaker fails to trip

Check for blown fuses.
Check to see if voltage at trip-coil terminals
  with current flowing is within tripping
  range established by manufacturer.
Check to see if trip coil is open circuited or
  burned out.
Check adjustment of trip-coil armature.
Check all auxiliary switches in trip circuit
  to make sure of continuity of circuit.

Breaker fails to trip (Continued)	Check to see if trip mechanism is binding and preventing tripping. Check impulse or tail-spring for proper compression. Raise the trip rod manually and observe whether trip latch moves sufficiently to release prop.
Breaker pumps on closing operation	Check anti-pump relay operation. Check to see if coil of the "Y" relay is open circuited, or the relay contacts are closing properly. The "Y" relay coil is designed for intermittent duty, but on some applications it is required to be energized continuously. In such cases it may be necessary to insert a resistor in series with the coil to prevent it from burning out.
Breaker fails to reclose on reclosing duty-cycle	Check the reclosing relay to see if it is functioning properly. Check setting of latch check switch per manufacturer's recommendation. (The purpose of the latch check switch is to prevent the mechanism from attempting to close until the latch returns to its normal position.) Check setting of "b" switch in reclosing circuit. Check recloser cut-out switch to see if it is in the closed position. If breaker recloses but fails to stay closed, check freedom of all moving parts in trip-free linkage. Check that the trip coil is not remaining energized.
Breaker opening speed is slow	Check breaker and operating mechanism to see if they need cleaning and relubrication. Check impulse or tail spring to see if it needs adjustment. Check whether the main contacts need dressing or replacement.
All air is lost in storage tank on closing operation (pneumatic)	Check limit switch operation and adjustment of "b" auxiliary switch to insure cutoff of closing circuit at end of closing operation.
Relays fails to trip breakers	Check for dirty, corroded, or tarnished contacts. Check for open circuits or short circuits in the relay connections Check for improper setting.

ELECTRICAL POWER STATION THEORY

UNIT IV

PROTECTIVE DEVICES AND RELAYS

This unit contains the following lessons;

Lesson 3-4-1: Protective Relays

Lesson 3-4-1
PROTECTIVE RELAYS

This lesson presents briefly a few of the applications of protective relays. A complete understanding of relays and their associated circuits would require considerable more study and concentration than can be given here. The lesson aims to acquaint you with the general purpose of protective relays, their principles of operation, and where they are used.

Required reference:
Information Sheet No. 11

Check-up (3-4-1)

1. What is meant by inverse-time trip on overcurrent relays?

2. What is the purpose of the taps on the current coil of an induction disc type relay? What is the purpose of the time dial?

3. What is an under-voltage relay and for what purpose is it used?

4. What is a differential relay and for what protection are they used?

5. Does the direction of flow of current affect the speed of the turning of the disc in an overcurrent relay?

6. What method is used to trip more than one breaker when the differential relays operate in a large substation?

7. Why do we have different time settings on protective relays.

8. What is the purpose of the "IT" or "quick trip" relay?

9. What is the disadvantage of using only fuses to protect power lines?

10. What source of power is commonly used to operate circuit breakers? Why?

11. Why are directional relays sometimes used?

12. In general, what two methods are used to polarize ground relays?

13. What is an impedance relay?

14. What safety precautions must be taken when working on the current circuit of a relay which is connected to the CT's of and OCB carrying load?

INFORMATION SHEET NO. 11 (3-4-2)

PROTECTIVE RELAYS

A relay is a device which is operated by electrical current - an over-load current or voltage, or by a physical condition - too much gas pressure in a transformer, or the overspeed of a generator to cause the operation of other devices in electrical circuits. Relays stand guard twenty-four hours a day every day of the year. They protect tremendous investments in property and equipment and help provide good service to customers. They are insurance against service interruptions and costly shutdowns. Relays should be handled carefully at all times. Many are more delicate than a watch.

Protective relays and apparatus aim to provide (1) continuous electric service to all customers limited by economic considerations; (2) protection for power system equipment; (3) protection that will de-energize lines on the ground, consistent with service requirements and yet within economic limits; and (4) a means to modify the protective scheme when personnel are engaged in dangerous work such as tree trimming, hot-line work, etc.

Continuity of service is provided by selective protection that isolates only the faulted apparatus or line section; by automatically removing perma-nently faulted equipment or lines from service to maintain service through alternate circuits; and by interrupting temporary faults with high speed breaker and recloser operation before fuses are damaged.

Protection for the power system is also effected by removing temporary faults at high speed and interrupting power before any permanent damage can be done by arcing of the fault. Damage to equipment is proportional to the duration of the fault. If faults are quickly removed, burning will be limited. The cost of transformer repairs may not be greatly affected by the speed of fault interruption; however, the possibility of damage to adjacent apparatus and extensive outages that may be caused by oil fires is greatly lessened by the use of relatively fast and sensitive protection.

Ground fault protection should be the most sensitive possible to avoid the hazard of hot wires on the ground. Since the resistance of a ground fault is extremely variable, it is not practical to provide protection that will detect all grounded wires.

The ground detecting equipment is not normally energized by load current, but an unbalance in line to neutral loading will be seen by ground relays. Consequently, ground current detecting devices usually have to be set so that they will not be operated on line to neutral loading that can be encountered under normal operating conditions. Line-to-line unbalances will not affect ground detecting devices.

Selective operation of protective devices can be described as circuit interruption by protective devices nearest the fault. No unfaulted section of line should be de-energized. Installations which include many protective

devices in series my require the acceptance of some compromises to avoid slow operation at the source.

OVERLOAD RELAYS

Protective relays that the wireman comes in contact with are the instantaneous and the time-delay types.

The instantaneous type is the simplest type of relay. Essentially it consists of a solenoid and plunger, or clapper. This relay is used where time-delay operation is not required.

Most of the time-delay overcurrent relays used on power systems are of the rotating disc type. These relays are somewhat similar to the watthour meter. They are essentially a small induction rotor in which the rotor starts to turn at some predetermined current.

Overload relays are used to protect equipment from excessive currents. They usually consist of the rotating disc type and the instantaneous type, both in one relay case. In the rotating disc type, t: e disc starts to turn when a predetermined alternating current is passed through the coils. It is usually provided with current taps to vary the amount of current required to turn the disc. Thus, a relay with a current setting on the six-ampere tap, and 6 amperes flowing, will turn at about the same speed as when it is set on the four-ampere tap, and 4 amperes flowing through the relay coil. Trip circuit contacts are provided to trip a circuit breaker when an overload current flows. Most of these relays have five studs. One is used for positive or negative, one for the time trip, and one for the instantaneous trip. Two of the studs are used to connect to the secondary of the current transformer. (Caution: The secondary of this current transformer must not be open-circuited.) Thus, when changing a relay on an energized circuit, it is necessary to short circuit the current transformer before removing the relay.

In general, the more overload current in the coil, the faster the disc will rotate. There is a time lever to change the time the disc rotates before the trip contacts close. This gives a variation of time that an overload or short circuit is on the system before the breaker trips.

The operating torque on the disc is produced by an electromagnet. The larger the current, the larger will be the torque. The control of the speed of the disc rotation may be varied by (1) the damping magnet which acts as a load on the disc and (2) by the saturation of the iron core. Thus, if a relay disc rotates slowly on a little more than rated current, it will then rotate faster as the current is increased. However, it will not rotate twice as fast at 500% current as with 250% current. Also a place will be reached where the disc will only rotate so fast regardless of the current. This is known as magnetic saturation of the iron.

By varying the above factors, we get (1) a standard-time curve and (2) an inverse-time curve, or (3) a very inverse-time curve.

OPERATION INDICATOR

The operation indicator is a small solenoid coil connected in the trip circuit. When the coil is energized, an armature releases or lifts the white or orange target to indicate completion of the trip circuit. The indicator is reset from outside the case by a push rod in the cover or cover stud.

INSTANTANEOUS UNIT

The instantaneous unit consists of a small overcurrent relay similar in appearance to the standard target and seal-in unit. Its coil is connected in series with the main coil and its contact is brought out separately. (One side of the contact has a common connection with the main overcurrent contact, but the other is brought out to a separate stud.) This relay is adjusted to operate by positioning the plunger in the solenoid. The relay will trip almost instantaneously on heavy currents above its setting, such as found in a short circuit, and thus trouble on a line is isolated long before the time-delay relay could time out and close its tripping contacts.

FAULT-SELECTIVE FEEDER RELAYS

There is a growing trend in the application of overcurrent and automatic-reclosing relays to provide a scheme whereby the breaker will first trip instantaneously, but after the first reclosure it will trip on time delay. This provides for the clearing of temporary faults without blowing the line fuses on the first trip out.

This scheme provides low-operating expense and improved service on the residential and suburban feeders of many utility systems. Fault-selective feeder relaying allows the feeder breaker to handle nonpersistent faults on the entire feeder, even beyond branch fuses, without blowing the fuses. In the event of a persistent fault beyond a fuse, the fuse will blow to isolate the faulty section. Operating engineers report reductions of 65 to 85 percent in fuse blowing on nonpersistent faults, as well as the benefits previously listed, through the use or this scheme of relaying.

The circuit-breaker overcurrent relays are provided with inverse-time overcurrent tripping and also instantaneous tripping. When a fault occurs, the instantaneous relay trips the circuit breaker faster than any of the branch-circuit fuses can blow. When the breaker opens, the instantaneous trip circuit is automatically opened by an auxiliary relay and remains open until the reclosing relay has completely timed out and reset. If the fault is nonpersistent, service is restored all around when the breaker recloses, after which the reclosing relay times out to the reset position, and the instantaneous trip function is automatically restored.

If the fault is persistent, the circuit breaker closes in on a fault. When it does, it must trip on the time-delay characteristic because the

instantaneous trip is effective
only on the first opening. The
time-delay trip is slower than
the branch-circuit fuses. This
gives a branch fuse a chance to
blow and isolate the branch if
the fault is beyond it.

TYPICAL DISTRIBUTION SYSTEM
WITH BRANCH FUSEING
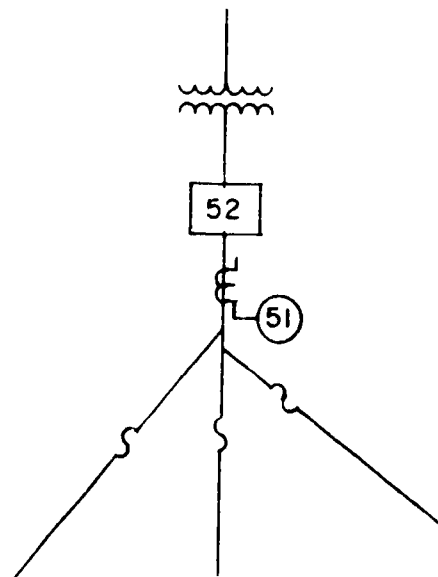
AUTOMATIC RECLOSING RELAYS

Experience indicates that many line faults are nonpersisting. Little
or no physical damage results if these faults are promptly cleared by the
operation of protective relays and circuit breakers. The sooner a line can
be returned to service by the reclosing of its breaker, the less will the
operation of the system be affected by the temporary lack of the line.

These facts encourage returning a line to service immediately following
a trip out and investigating the extent of the damage later. In the very
few cases where damage is sufficient to re-establish a short circuit, as
many as two more successive attempts may be made to return the line to
service before it is finally removed and repaired. Two basic types of
reclosing relay are in general use: the multi-reclosure and the single-shot.

The General Electric Company ACR relay and the Westinghouse RC reclos-
ing relay are examples of the multi-reclosure type. They can be adjusted to
give any combination of reclosures up to immediate initial plus three delayed.
The relays will automatically reset if the breaker stays in and lockout if
the breaker trips immediately after the third reclosure. The relay is anti-
pump and adaptable for either a-c or d-c electrically operated breakers.

In the majority of cases, the use of automatic reclosing relays to
restore service immediately is an obvious advantage at an unattended switch-
ing station. Even at attended stations, service is restored much more
quickly than by manual reclosing. The attendant is relieved of this respon-
sibility so he can otherwise be employed more effectively. The combination
of fast protective relaying and high-speed automatic reclosing on a single

line may approach very closely the protection and service continuity offered by duplicate lines.

The relay is normally de-energized and is usually started when the breaker is automatically tripped by closing of "b" auxiliary switches on the breaker mechanism.

The Westinghouse SGR-1 and General Electric HGA13 are examples of the single-shot type of recloser which provides one immediate reclosure only. Its operating coil is energized by the discharge of a charged capacitor. If the breaker remains closed for a period of 20 seconds, the capacitor is recharged and the relay is ready for another operation.

OVERVOLTAGE AND UNDERVOLTAGE TIME DELAY RELAYS

Perhaps the nearest to the overcurrent relay is the voltage relay. In construction, the two are practically identical except the voltage relay electromagnet is wound with a large number of turns of fine wire for operation on voltage instead of current. The relay may be an under or overvoltage device and either circuit-opening or circuit closing depending upon the arrangement of the contacts. The circuit-closing overvoltage relay contacts are held open by the control spring until the system voltage rises and the increased electromagnetic torque overcomes the torque of the control spring.

The circuit-closing undervoltage relay operates in a similar manner except the control spring torque closes the contacts when the system voltage drops below a predetermined point.

Time delay is obtained by adjusting the travel of the contacts and the braking effect of the permanent magnet exactly as with the overcurrent relay. The pick-up or minimum operating voltage is adjustable by changing the resistance of a small internally-mounted slide-wire resistor or by changing the position of the electromagnet pole pieces, depending upon the design of the relay.

The voltage relay is usually used to protect apparatus against voltage changes of predetermined value by closing the trip circuit of a breaker to disconnect the equipment from the line. It is particularly useful in protecting a-c generators against overvoltage caused by sudden loss of load. Often, to insure continuity of service to an important customer, voltage relays are used to control the operation of change-over equipment, such as motor operated disconnects which automatically switch the load to an emergency feeder during abnormal voltage conditions.

All a-c motors, synchronous condensers, and synchronous converters should be provided with a-c undervoltage relaying to disconnect the armature circuit from the a-c system upon loss of voltage or upon the occurrence of low a-c voltage. This undervoltage relaying should function with time-delay drop out to prevent shut down on temporary dips in voltage.
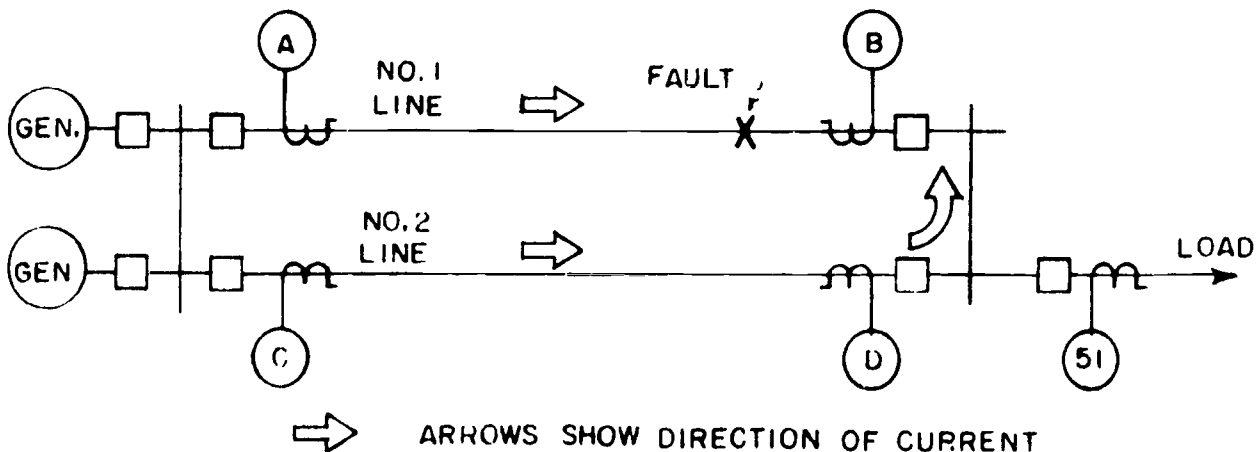
USE OF DIRECTIONAL RELAYS

Directional relays are not used to aid tripping but to prevent it when short-circuit current flows contrary to the tripping direction. The directional element is similar to a watthour meter. This element has both a current and potential element in it. The contacts are normally held open by a spiral spring when de-energized. This element is designed to be as sensitive as possible to assure positive operation over the widest range of current and voltage relations encountered during faults.

Although the operation of both of these elements is essential, the actual tripping of the circuit is done by the contact on the overcurrent element. With the directional control scheme, the overcurrent element cannot begin to operate until the current is flowing in the desired direction and is above the pickup value for which the current element is set.

The directional overcurrent relay finds one of its most important applications in the protection of so-called "ring or loop" transmission systems. The loop system is simply a continuous transmission line running through a series of substations and terminating at its original source.

In the following example, assume a fault on the #1 line. Fault current would flow in both lines to the fault location. All overcurrent elements in the loop would tend to close, but since power flow is not in the tripping direction for relay D, it cannot close its contacts. Power flow is in the tripping direction for relay B so its contacts will close. Relays A and C can both operate so it is necessary to use the definite, minimum-time characteristics of the overcurrent elements to secure selective operation.

ARROWS SHOW DIRECTION OF CURRENT

Simple line diagram of a simple loop transmission layout showing the application of directional overcurrent relays for isolating faults with a minimum of interference to other sections of the system.

DIRECTIONAL GROUND RELAYS

Ground relays are used in addition to phase relays for the protection
of lines in grounded neutral systems. Ground relays can generally be made
faster and more sensitive for ground faults. The directional relay can be
used for ground-fault protection where current may flow in either direction
to a fault through the relay location.

The method of obtaining directional action in ground relays, or polari-
zation, is often misunderstood. By the term "polarizing source for a direc-
tional relay," we mean a dependable source of current or voltage which can
be used as a reference for comparing the phase angle of the current in a
line where directional selectivity is required. Such a reference may be
obtained from any part of the system whose current or voltage does not reverse
its relative direction when the line current reverses. The current in the
neutral of a grounded wye-delta power transformer offers a good example.

A grounded-neutral power autotransformer with a delta winding can supply
polarizing current for ground directional relays from a current transformer
inside the delta. Only one CT is required unless load is taken off the
tertiary. In the latter case, CT's in each phase of the tertiary must be
paralleled.

When there are no grounded-neutral wye-delta power transformers in a
station from whose neutral suitable polarizing current can be obtained,
relays may be polarized by voltage. Voltage for this purpose can be obtained
by leaving open one corner of the delta of a grounded-neutral wye-delta
potential-transformer bank and using the voltage across the open corner of
this delta.

A directional unit uses the residual current from the protected line
in conjunction with a polarizing quantity to determine the direction of power
flow. In some cases dual-polarized relays are used. These can be simultan-
eously or alternately polarized by zero sequence current and voltage.
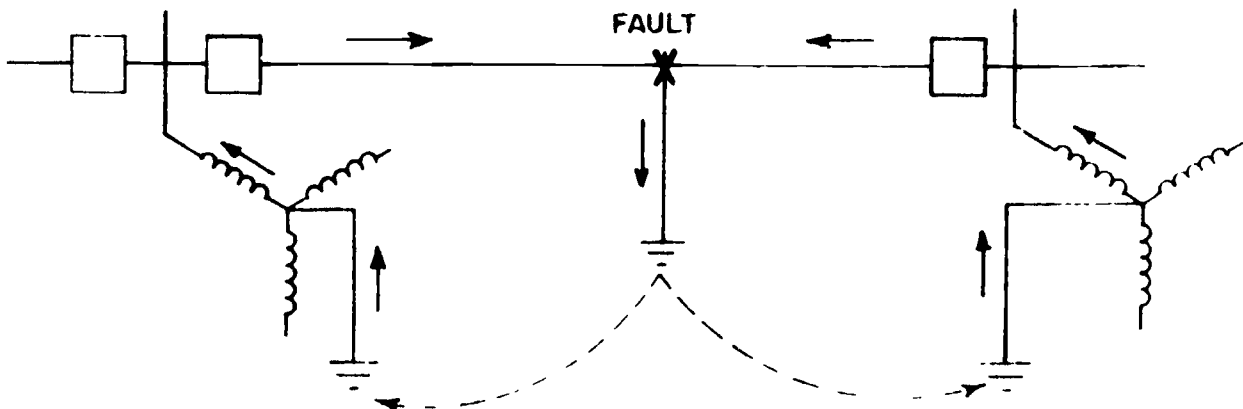
Schematic Diagram Showing Direction of Current
Flow for Fault as Shown
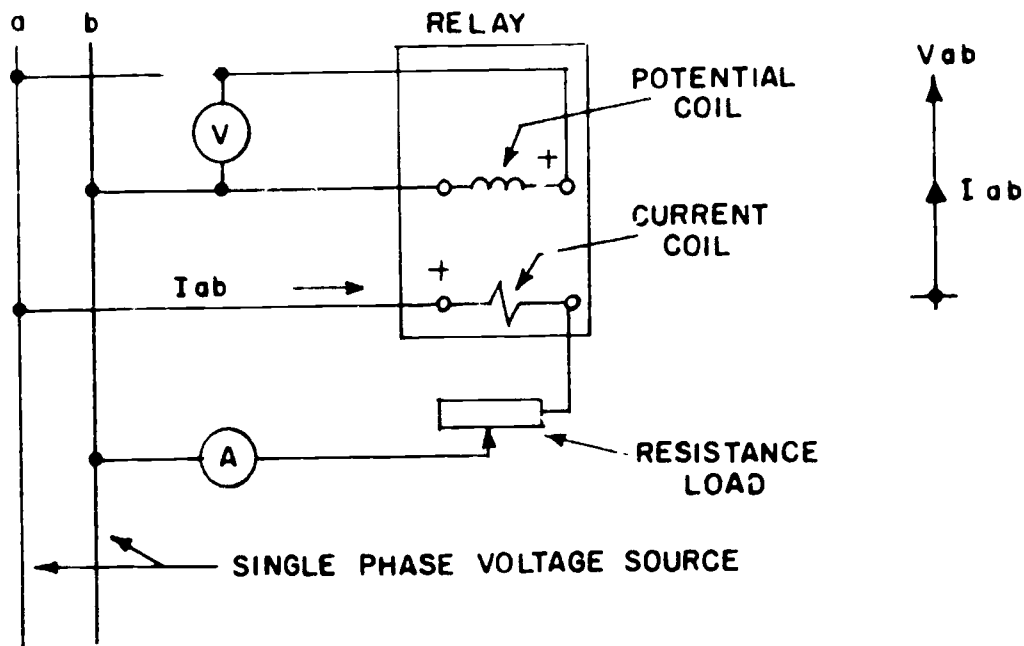
Circuit Diagram for Proving Polarity of a Relay
the Contacts Should Close

A typical polarity note on a relay wiring diagram reads as follows:
"With relative instantaneous polarity as shown, the directional contacts
close." This means that when the voltage drop from the polarity marked to
the nonpolarity terminal of the potential coil is in phase with the current
flowing in at the polarity marked current coil terminal, the directional
element will close its contacts. In the preceding diagram the voltage and
current vectors are shown in phase.

For watt type directional elements, the contacts will still close if
the current is shifted in phase up to 90 degrees leading or 90 degrees lag-
ging from the in-phase position shown. For current leading, the voltage at
any angle from 90 degrees leading through 180 degrees to 270 degrees leading
(90 degrees lagging), the contacts will have contact opening torque. The
boundary line between the zones for contact closing torque and contact open-
ing torque is known as the zero torque line.

In general, one volt or more is sufficient to polarize a directional
ground relay. The voltage or current obtained from these sources equals
three times the zero sequence component of current or voltage in the power
circuit.

STATION BUS

POWER TRANSFORMER

TO TRIP
CIRCUIT

POLARIZING
WINDING

DIRECTIONAL
GND RELAY

PHASE
RELAYS

DIRECTIONAL
CURRENT
WINDING

OVERCURRENT
ELEMENT
WINDING

TRAPPING DIRECTION

LINE
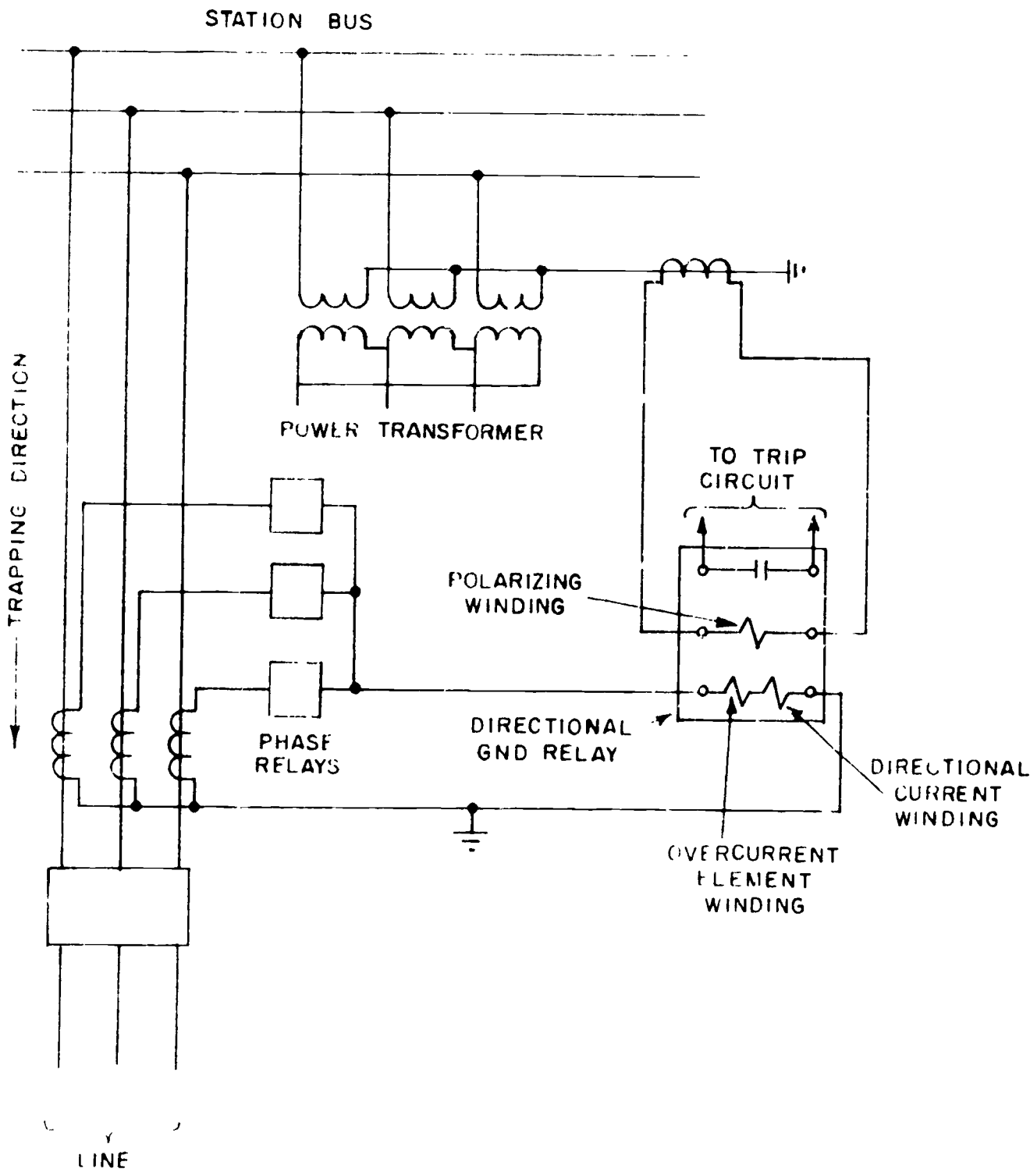
Ground Fault Protection With Current Polarization

112
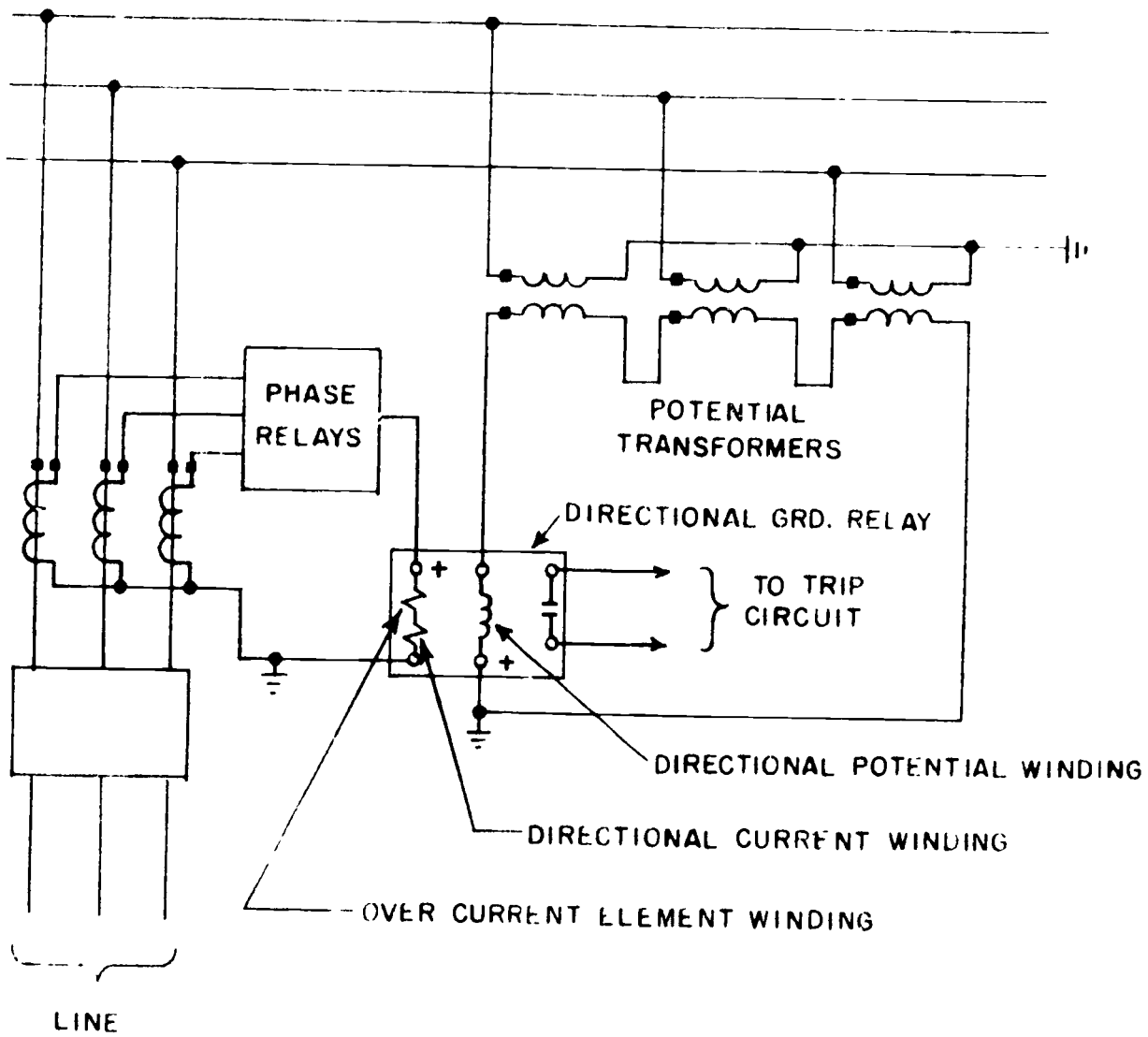
Ground Fault Protection With Potential
Polarization from a Broken-Delta to Obtain
Residual Voltage

DISTANCE RELAYS

Distance relaying is by far the most satisfactory method of protecting transmission circuits when phase faults occur. Impedance relays generally are not recommended for ground protection because of wide variations in the ground circuit impedance.

Each relay consists essentially of three zone-type fault detectors, a directional element, and a timer. The first zone element is set to operate instantaneously (1 to 3 cycles) when phase-to-phase or three-phase faults occur. This element is set to protect 80% to 90% of the line. Obviously we would like to set this zone to protect 100% of the line length. However, the accuracy of the relay operation, the accuracy of the relay adjustment, and accuracy of data-on-line characteristics, plus errors in potential and current transformer ratios, all combine to limit the permissible reach of this instantaneous element. It must be set so that it will not operate for faults beyond the remote-line terminal; hence, the restricted reach.

The second zone element is normally set to operate for all faults on the protected line, plus one-half way through the shortest line beyond the remote line terminal. In this manner it provides protection for the end zone not protected by the instantaneous first zone element, and also provides back-up protection for the remote bus and a portion of the lines beyond it. The timer for this second zone element is usually set for about 0.35 seconds. It must be slower than the slowest relay on the remote bus or line connected to it.

The third zone element is preferably set to protect all the line to which it is connected, plus all of the longest line beyond the remote bus. Its associated timer is frequently set for .7 to 1.5 seconds. The maximum available time delay is 3.0 seconds. It must be set so that relays on the remote bus operate first. If a breaker or relay on the remote bus fails, action of this element provides back-up protection by tripping the line that feeds into the faulty circuit.

Faults on transmission lines show these symptoms: excess current and low voltage. Short-circuits near the generator end of a line cause a heavy flow of current and a big dip in voltage, while those some distance away have less effect on either current or voltage.

This is illustrated graphically in the following diagram which shows a theoretical transmission line (with substations A, B, and C) and the voltage gradient along the line resulting from a fault at some point X. The actual slope of the voltage gradient curve derends upon individual transmission line characteristics.

THEORETICAL TRANSMISSION LINE
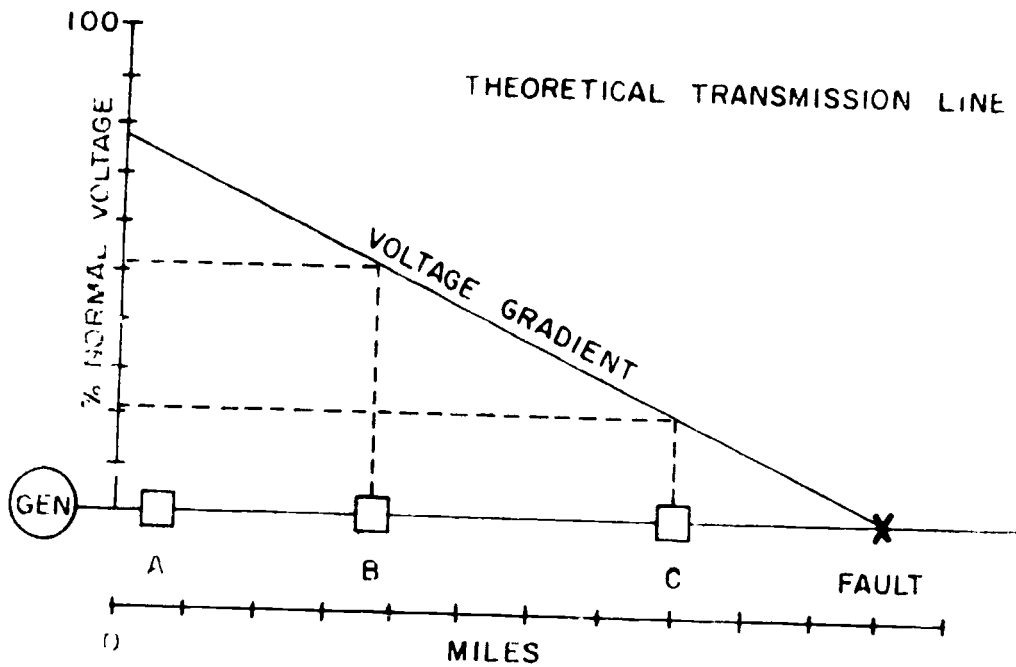
Theoretical Transmission Line

A simple explanation of the effect noted is that the impedance (resistance and reactance) of the line up to the point of fault tends to limit the short-circuit current and reduces the voltage dip proportionately. From this, the general statement may be made that the greater the distance to the fault the less the reduction in voltage at the generator end. It is upon this basic principle that the impedance relay is designed.

The Westinghouse impedance element is most easily described. It is a balanced beam device, current operated, and voltage restrained. An adjustable air gap in a tapped current coil is used to set the relay for desired balance of current against voltage pull. The operating characteristic, plotted on an R-X diagram, is essentially a circle. That is the relay's balance point $(E/I = Z)$ is a constant regardless of phase angle. The contacts of the first impedance element are in series with directional element contacts so the trip circuit is completed only when the fault current flows in the proper direction.

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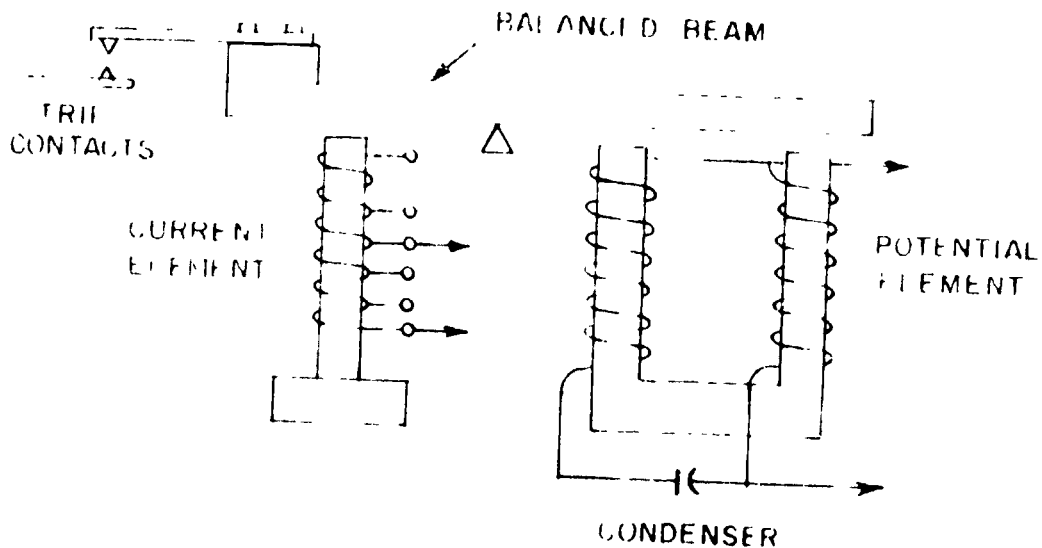
The second impedance element is similar to the first, but its contacts
are in series both with the directional contacts and the first set of
synchronous-timer contacts so that even with the fault current flowing in the
proper direction this element cannot complete the trip circuit until after a
short time delay. The third impedance element is similar to the other two.

The length and the loading of a line determine the specific type of dis-
tance relay to be applied. Short, moderately loaded lines are often protected
by General Electric Companies. GCX distance relays operating on the reactance
principle. Such relays are least affected by the resistance of arcs and, hence,
can be adjusted to give high speed protection. The reactance element is more
difficult to use successfully than an impedance element because it operates on
normal load current. Therefore it must be supervised by another element to
keep it out of trouble. Under normal load conditions, the reactance element
stands with its contacts closed, the supervisory mho element contacts are open.

The modified impedance element (HZM) or mho element (GCY) has essentially
an offset impedance element. The operating characteristic plotted on an R and
X diagram is circular and may be shifted so that the circle passes through the
origin (as is done in the GCY) or to various positions along a centerline (as
is done in the HZM). When the operating circle passes through the origin of
the R and X diagram, it also acts as a directional element, and no directional
element is needed for the GCY G.E. Company type relay. The GCY is adaptable
to use for long lines.

The mho relay is generally to be preferred because of its simplicity.
It has only one relay contact between the d-c control source and the breaker
trip coil. However, the Westinghouse KD Phase distance relays, which operate
on somewhat the same principle, are finding favor in the industry.
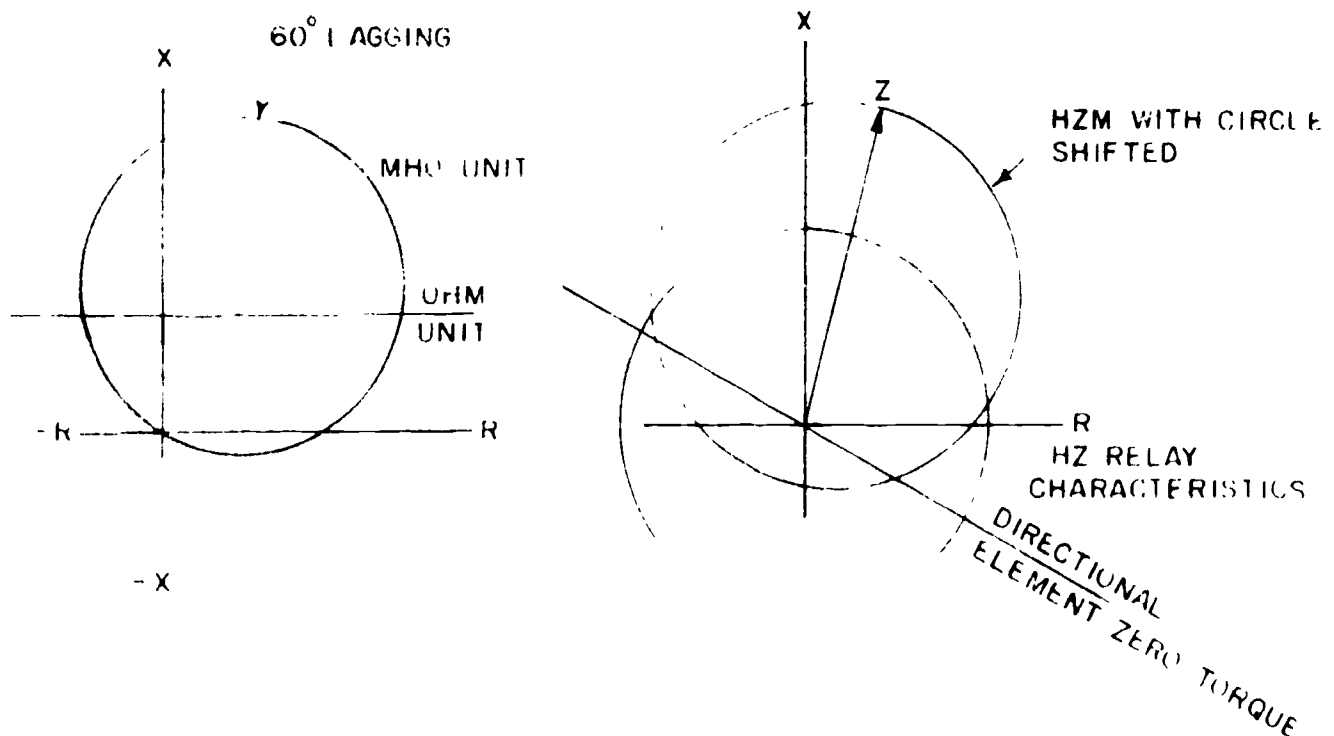
DIFFERENTIAL RELAY PROTECTION

Kirchoff's law states that the algebraic sum of the currents at any
point in an electrical circuit is zero. Or, the current flowing into a
system is equal to the current flowing out. If we can balance these two
currents against each other, as in the case of a generator or bus, we have
an almost ideal setup for relay protection. If the indulation fails in the
generator, then the current flowing into the generator is equal to the cur-
rent flowing out on the line plus that current flowing in the short circuit
or ground in the generator itself. This short-circuit or ground current
flows through the relays which are known as differential relays. The short-
circuit current flows through one set of CT's but not the other and creates
an unbalance. Since this method only operates when there is a fault, the
relays may be set to operate very fast. Also, it is not necessary to have
large currents to operate the relays as is the case with overcurrent pro-
tection.

In the cases of generators and buses, the incoming current is generally
equal numerically to the outgoing current. However, in the case of a trans-
former the two currents are seldom equal because of the voltage differences
between HV and LV sides. The problem of balancing the currents is then more
difficult and will be described later.

Differential relay protection is the most effective type of protection
for clearing faults on transformers, buses, and generators. It consists of
two differentially-connected current transformers – one connected to each
side of the protected apparatus. The relay coils are connected to measure
the unbalanced current.

In this type of relay protection, the outgoing current is balanced
against the incoming current with the difference of current, if any, going
through the protective relays.

PROTECTED BUS

OPERATING
WINDING

TO TRIP
CIRCUIT

DIFFERENTIAL RELAY
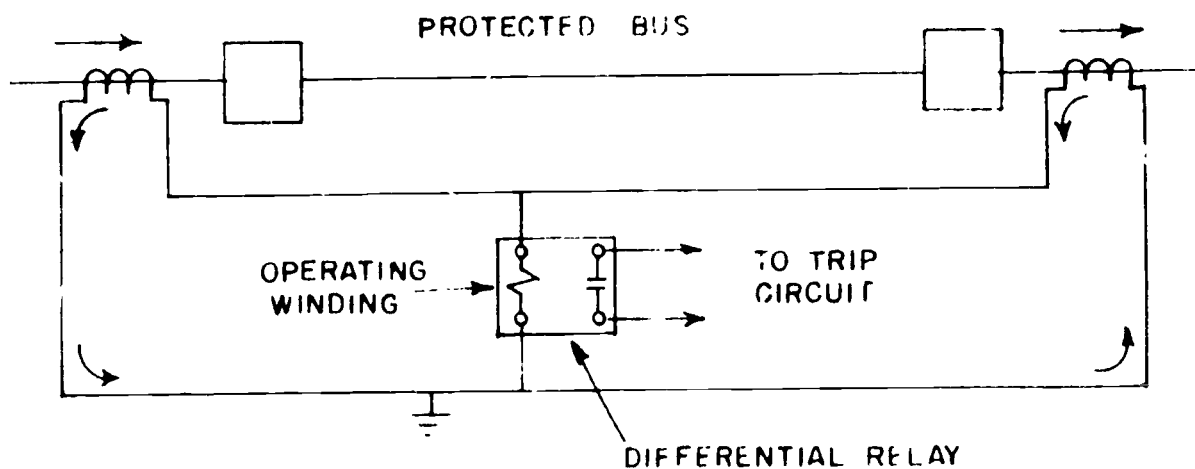
The simplest form of this protection uses induction disc overcurrent relays connected in differential. In cases where the two currents are not equal under normal operation, a set of balancing transformers may be used to make these two currents equal. This method is commonly used on substation buses. This simple design has been used successfully for many years and is applicable even where there are several sources of power.

The type CA (Westinghouse) differential relay is made up of three coils - one coil for incoming current, one coil for outgoing current, and one coil for the resultant of these two currents. Taps are provided on the first two coils to balance the current in the third (common) coil. This relay eliminates the use of balancing transformers. It is commonly used on transformer banks.

The type CA-6 differential is particularly well suited to bus protection where there are a number of sources for power. It includes one operating coil and six restraining coils arranged to obtain a variable differential operating characteristic. Each operating coil is energized through an individually-matched, saturating transformer which reduces the effects of d-c transient errors in the current transformer output.

Sensitive instantaneous relay operation is obtained by the use of the CA-6 for transformer protection also.

The General Electric Company type P.V.D. relay is a one-cycle device that can be used if all current transformers are of bushing type, and have the same ratio. The relay is connected to parallel-connected current transformers as in the simplest bus differential scheme. However, the P.V.D. relay has a high impedance coil, instead of the usual low impedance current coil. Operation of the relay depends upon the fact that external faults will circulate current between the many current transformers. The voltage will consequently be low at the relay being limited to the IR drop through the leads and in current transformer secondaries. There is only one objection to the use of this type of relay - it places as much as 1,500 volts on the back of the switchboard at the moment of fault. Since it is well-known that voltages of this magnitude can be obtained when a CT secondary is opened, this appears to be within the limits of safe operation.

CURRENT-DIFFERENTIAL SCHEME FOR PROTECTION OF TRANSFORMERS

The current differential scheme as applied to transformers is in principle the same as that applied to generators and buses. The transformer, however, has practical problems that make the solution more difficult.

When a transformer is energized or subjected to sudden voltage fluctuations, the magnetizing current, for a number of cycles, may attain values comparable to, or in excess of full load current. This looks like an internal fault to the differential relays protecting the bank. To prevent the operation of the relays from this cause, it is customary to introduce a slight time delay in their operation. Steady normal values of magnetizing current are so small as to introduce less unbalance than that due to other

causes. A maximum in rush will not cur on every energization because the
probability is low for energizing at zero voltage. Energizing at maximum
voltage will not produce an in-rush with no residual. In a three-phase bank,
the in-rush will vary appreciably in the three phases. The magnitude of the
current depends on the point of the voltage wave and the polarity and amount
of retained flux in the transformer iron at the instant the transformer is
energized. A typical oscillogram of this in-rush current follows.

INRUSH
CURRENT

A Typical Magnetizing Inrush
Current Wave

APPLIED
VOLTAGE
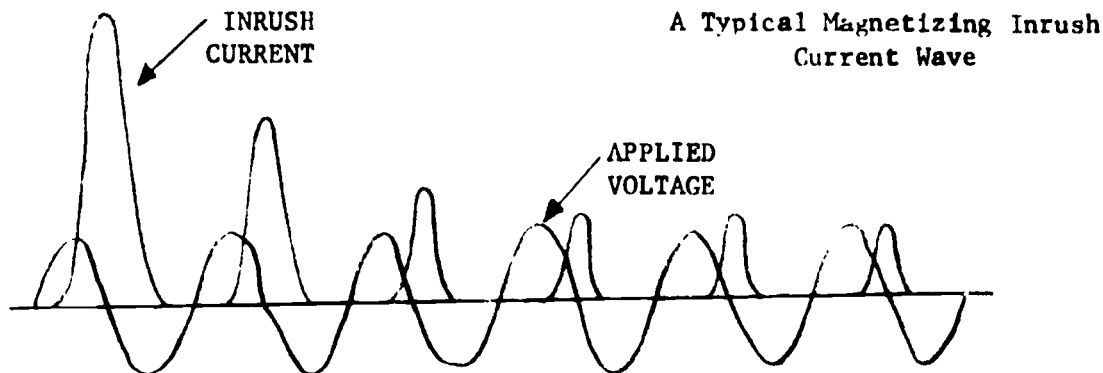
A transformer may be subjected to short circuits, open circuits, and
oveiload. Two principal causes of insulation failure in a transformer are
overvoltage and overheating. Transient overvoltage resulting from lightning,
switching transients, or ground faults on ungrounded systems will subject
transformer windings to severe voltage stresses unless suitable voltage-
limiting means are used to block this ove.voltage from entering the windings.

Repeated overheating because of overloading or failure of the cooling
system will deteriorate the insulation. Insulation thus weakened may fail
when it is stressed by only a moderate overvoltage.

Most short circuits resulting from insulation failure occur between
turns of a winding or between windings. The likelihood of fire in trans-
formers with inflammable insulating fluid make high speed relaying essential
in many applications.

DIFFERENCE BETWEEN PRIMARY AND SECONDARY CURRENTS OF A TRANSFORMER

The difference between primary and secondary currents of a transformer
makes it necessary to choose current transformers of the proper ratio so
that the secondary currents of the two sets of current transformers shall
be as nearly as possible exactly equal. It is also necessary to connect
these current transformers, as related to the connections of the main trans-
formers, that the currents to be balanced in the current transformers
secondary circuit shall be in phase. (Connect the current transformer
secondaries in wye on the delta side of the main bank and in delta on the
wye connected side of the main bank.)

PERCENTAGE DIFFERENTIAL RELAY FOR PROTECTING TWO-WINDING TRANSFORMERS

In the differential protection of generators and buses, the current
transformers are usually similar in construction and performance so that
the possible errors, due to their unequal outputs are small. In protecting

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power transformers, however, it is difficult to make the two current transformers alike because the two sides of the power transformer operate at different voltages, and consequently at different current values. This usually results in current transformers which have different characteristics, at high overloads. Also, it is customary to use current transformers of standard rating. Quite often the difference between secondary currents from them will be so large that the differential relays will not balance them. Some means must be used to obtain equal secondary currents, actually, or in effect.

This can be done by the use of auxiliary current transformers. In order to eliminate their use to a large extent, the transformer type CA relay is provided with taps on one restraining winding and on the operating windings, so that the balance between normally unequal currents can be made inside the relay by adjusting the number of turns in the coils. The relay is provided with eight sets of taps so that it can be used with current transformers which have equal outputs and also with those having a ratio of as much as 2 to 1 in their secondary currents.

APPLICATION OF TYPE CA RELAY

The type CA percentage differential relay for transformer protection is designed for the differential protection of power transformers. The relay consists of a percentage differential element, an operation indicator, and a contactor switch.

PERCENTAGE DIFFERENTIAL ELEMENT

This element has an electromagnet with several windings. Two restraining windings are placed on the lower left-hand pole (front view). The operating coil winding is wound on the lower right-hand pole. A transformer winding is supplied on both the left- and right-hand poles, and these are connected in parallel to supply current to the upper-pole windings. The upper-pole current generates a flux, which is in quadrature with the lower-pole resultant flux, and the two fluxes react to produce a torque on the disc. If the operating winding is energized, the torque produced is in the contact closing direction; if current flows through the two restraining windings in the same direction, a contact opening torque is produced.

With the relay connected as in the schematic diagram, a through fault caused current to flow through the two restrainings in the same direction. If the current transformers operate properly, the restraining currents are equal, or effectively equal, if appropriate auto balance taps are used to compensate for a mismatch in current transformer ratios, no effective current flows in the operating coil winding, and only contact opening torque is produced. If the currents in the two restraining windings are effectively unequal, the effective difference must flow in the operating coil. The operating coil current required to overcome the restraining torque and close the relay contacts is a function of the restraining current.

In the case of heavy internal fault, when an external souce feeds current into the fault, the restraining currents are in opposite directions,

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and restraining torque tends to cancel out. When the currents fed from the two sides are equal or effectively equal because of the taps used, the restraint is totally cancelled. When effectively unequal currents flow in from the two sides, the restraint is equivalent to the difference in the two effective currents divided by two. Since the more sensitive operating coil is energized by the sum of the two currents, the restraint in this case is inconsequential, and a large amount of contact closing torque is produced.

The Westinghouse type HU and the General Electric Company BDD relays for transformer differential use the harmonic content of the in-rush current to restrain, and thus desensitize the relay. In the HU, the harmonic unit contains a 120 cycle (2nd harmonic) blocking filter in the operating coil circuit and a 120-cycle pass, 60-cycle block filter in the restraining coil circuit. When an in-rush occurs with its second harmonic predominant characteristic, ample restraint with minimum operating energy exists in the unit.

For internal faults, ample operating energy exists from the 60-cycle fundamental and all harmonics except the second which is in low predominance during a fault. In addition, minimum restraint energy is produced by the fundamental. Thus, in the absence of second harmonic, this unit will operate at the same pickup as the differential unit.

CONNECTING DIFFERENTIAL RELAYS

On a star-delta bank, the current transformers on the star side are connected in delta and the current transformers on the delta side are connected in star. This is done for correct phasing and to eliminate zero sequence from operating the differential relays when the star is grounded. If the star is ungrounded, then opposite connections could be used, but are not conventional. The connections of differential relays are important. They must be correct.

REMOTE TRIPPING OF TRANSFORMER BANK

There is a growing trend to make a transformer bank a part of the line section with no high-side breakers. Some means is required to trip the circuit breaker at the far end of the line when a power-transformer fault occurs. The protective relays at the remote end cannot recognize the presence of many such faults. This will be discussed under carrier relays.

CARRIER-CURRENT RELAYS

The high-speed impedance (distance) relaying scheme approaches the ideal but falls short of this goal in that it does not provide instantaneous clearances of faults over the entire associated line section. Earlier it was explained why it was usually necessary to limit the instantaneous-operation coverage of the impedance relays to about 90% of the line section, but the following illustration will describe this action more fully.

The section of line (Fig. 1) represents part of a loop transmission system. Circuit breakers at substations A and B are tripped by high-speed impedance relays set to operate for faults with power flow shown by the arrows. The relays at A are set to operate instantly for faults between A and Y. Those at B operate instantly for faults between B and X. Any fault between X and Y will therefore cause instantaneous and simultaneous tripping of circuit-breakers at both A and B. A fault between B and Y will be cleared immediately by operation of the first impedance elements at B. Since it is beyond the range of the first impedance elements of A relays, a short time delay will be introduced by the action of the second elements. Similarly a fault between A and X will not be cleared immediately by the B relays.
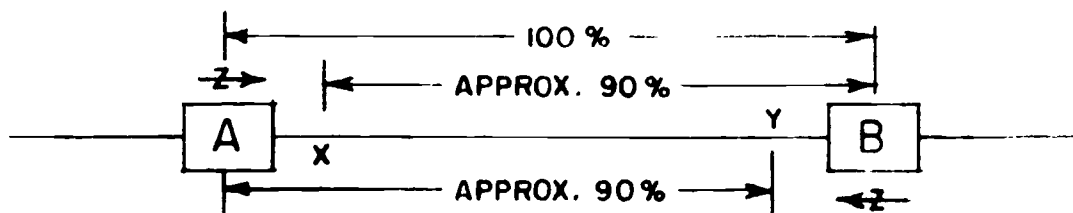

FIG. 1 - Schematic Line Section, Representing Part of a Loop Transmission System

However, from the standpoint of system stability, continuity of service, quick reclosing, and minimum damage to equipment, it is extremely desirable that the breakers at each end of the line section be tripped simultaneously.

By the use of carrier current, it is possible to compare instantly conditions at the two ends of a line section and to operate both circuit breakers simultaneously for faults anywhere within the section.

Fundamentally, carrier current is nothing more than a high-frequency current superimposed on a power-transmission line for the transmission of signals from one end of a line section to the other. It may be thought of as a radio signal which is confined to the path of the transmission line instead of being broadcast through space.

CARRIER EQUIPMENT

The carrier-current transmitter-receiver is in many respects similar to radio communication equipment. However, since its only function is to send and receive a tuned radio signal it is made as simple as possible to insure the greatest reliability with the least maintenance. A transmitter may employ a simple one-tube oscillator circuit to generate the high-frequency signal and a two or more tube power amplifier having an output between 10 and 40 watts depending upon the design. The oscillator can be turned to any frequency between 50 and 150 kilocycles. This frequency band is used because

lower frequencies may interfere with communication on adjacent telephone lines. Higher frequencies increase radiation with a consequent loss of signal strength. For comparison, the ordinary broadcast range is 540 to 1,500 kilocycles. The receiver is also a simple unit which can readily be tuned to the frequency of its associated transmitters.

The line-tuning unit (mounted in weather-proof cabinet and connected between the carrier set and the coupling-capacitor) consists of a tapped inductance coil and condenser and serves to tune the transmission line to the desired carrier frequency. A small milliammeter connected in the output lead facilitates tuning to obtain the maximum signal strength.

Since it is obviously impractical to connect the carrier sets directly to the high-voltage transmission line conductors, the connection is made through coupling capacitors.

Coupling capacitors are essentially high-voltage condenser units mounted in a weather-proof porcelain housing and connected to ground through a drainage coil and radio-frequency choke coil. The physical size of the coupling capacitor is governed by the transmission line voltage. In general, the units have somewhat the same size and appearance as lightning arrestors and the same voltage rating. The carrier set is connected across the terminals of the radio-frequency choke coil and is this at a low voltage to ground.
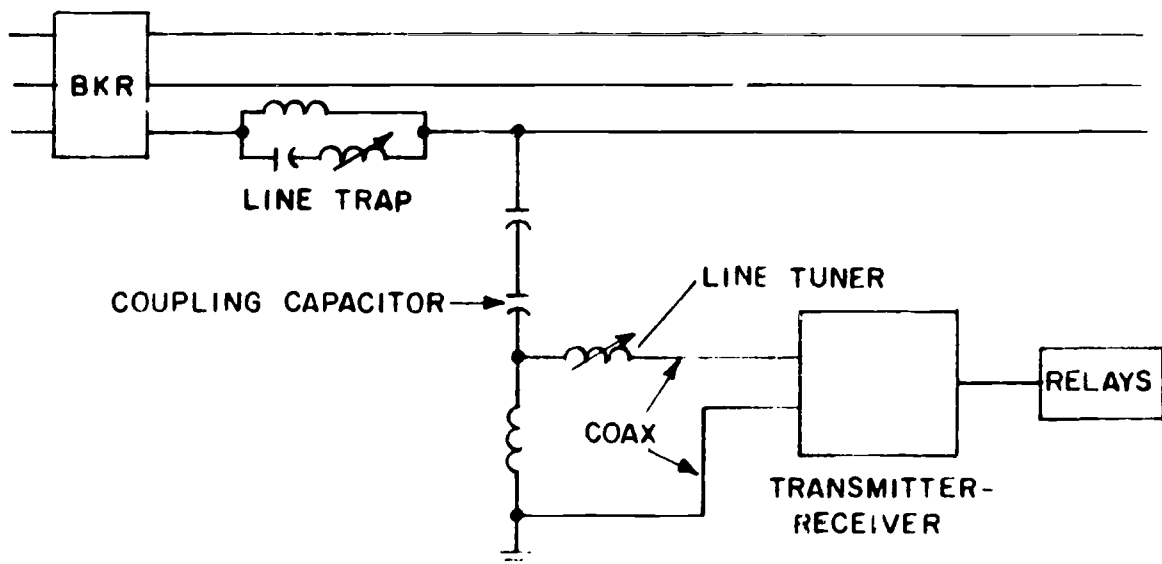
The line trap (radio-frequency choke) forms a low-impedance path for the 60-cycle current but offers a high impedance to the flow of carrier current. Thus, in effect, the carrier-current is impressed directly on the transmission-line conductor. By the addition of a few condensers and reactors, it is also possible to use the coupling capacitor as a potential source for voltage relays.

To secure the proper selectivity between relays on a transmission system, each line-section is assigned to a different carrier frequency to

eliminate interference between sections. All receivers and transmitters on any one line section are tuned to the same frequency so that either receiver may receive a signal from its own transmitter or from the one at the other end of the line. The line trap effectively confines the carrier-current to its own line section.

The fault-detecting relays which control the carrier sets are usually of the high-speed impedance type (fundamentally the same as those used in step-type distance relaying). In addition, the carrier-current auxiliary relay and a directional overcurrent ground relay.

RELAYING SYSTEMS

At the present time, relaying is generally utilizing one of the three following systems:

Directional Comparison - At each station, directional distance, phase, and directional overcurrent ground units are set to operate for faults anywhere in the protected line section. That is, they are set to reach beyond the remote ends of the line. In order to prevent operation on external faults, fault relay tripping is supervised by a receiver relay contact, which is held open by a blocking signal. In the absence of a blocking signal, the fault relays are permitted to trip

Phase Comparison - In a fashion similar to the HCB (pilot wire relays), the 3-phase line currents are converted to a single phase voltage proportional to the input currents. This voltage is used to key the channel equipment on alternate half cycles of the power system frequency. The phase angle of the received signal and the local filter output voltage are compared to determine if the protected line is faulted. If no signal is received, local tripping is permitted.

Remote Tripping - The channel is utilized to transmit a tripping signal. There are two mains types. One application of transferred tripping is where a transmission line terminates in a power transformer with no circuit breaker at the junction. Some means is required to trip the circuit breaker at the far end of the line when a power transformer fault occurs. The protective relays at the remote breaker cannot recognize the presence of many such faults. The power transformer differential relaying equipment, through the agency of transferred tripping, can trip the remote breaker.

The second type of application is for line protection where fault detecting relay equipment located at one terminal not only trips the local breaker, but also the remote circuit breaker via the transferred trip channel. Field tests of transmitting a tripping signal past a line fault have been reported in AIEE Technical Papers, with the conclusion that it is possible to get reliable results and that the reliability is improved by using a 10-watt transmitter. However, 100% reliability has not been proven because tripping past faults which are close to terminals is considered somewhat doubtful.

PILOT-WIRE RELAYS

Of all the relaying schemes discussed, far-line protection, carrier-current relaying, most nearly approached the ideal because it assured rapid clearing of faults with simultaneous operation of the circuit breakers at both ends of the faulted line section.

However, the main deterrent to the wire spread use or carrier-current relaying is its cost. The cost is necessarily high compared with other relaying schemes, and in many instances, operating companies have felt that the increased protection afforded by carrier-current relaying did not justify the added cost - particularly where the line sections were short.

Several years ago it was found that a relaying scheme based on the differential or balance principle could be applied to some line sections by using control (pilot) wires between the two stations. From this basic idea, many different schemes of relaying were developed, but all of them require a pilot channel between the terminals of a line over which to compare the current flowing at the ends. This pilot channel may be pilot wires, or it may be a carrier-current pilot channel using the line itself as the conductor.

Typical relays of this kind are the HCB (Westinghouse) and CPD (General Electric Company). The HCB relay operates by comparing the three-phase currents at each of the 2- or 3-line terminals. These are converted by a composite sequence filter into a single phase voltage. The single phase voltages are compared via a pilot wire (pair of wires which may be ordinary No. 18 Awg wires such as may be leased from the telephone company) to determine if the fault is inside the protected line or not.
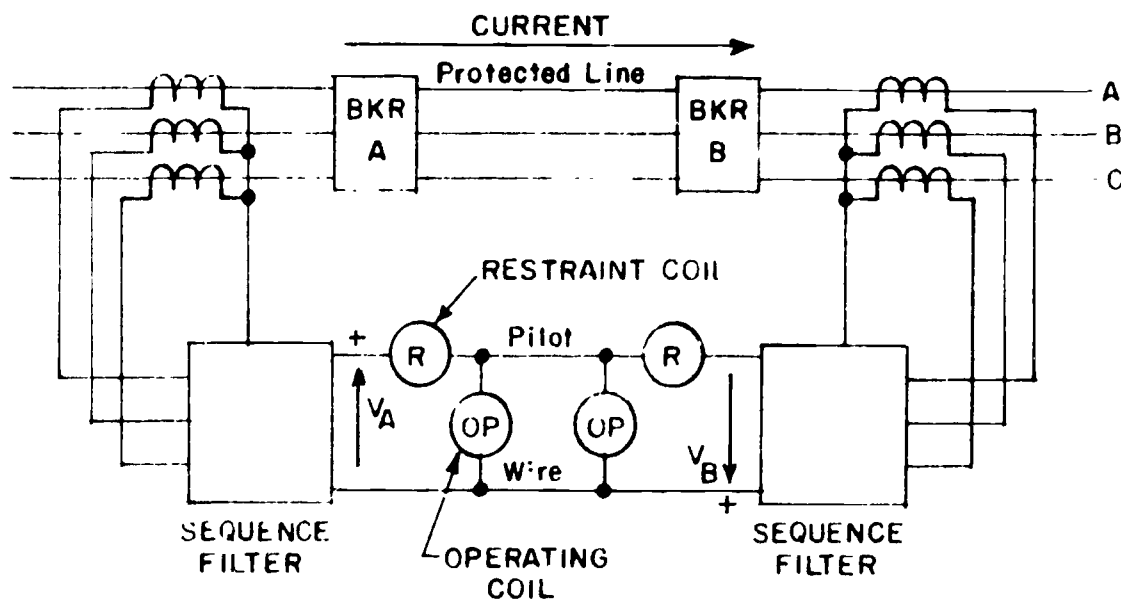
THERMAL RELAYS

The thermal principle is also frequently employed when dealing with rotating machines and transformers. The destructive effects of overloads on

machines depend essentially on the temperature produced in the machine by excessive current. Protective devices, to detect this condition accurately, should be operated not by current nor by a combination of current and time but by actual temperature of the machine or by a thermal element carrying a definite proportion of the machine current and having the same thermal characteristics as the machine. In one scheme of this type, the protective device is not actuated except as both the current and the temperature are high. Even if the predetermined temperature limit is reached, if the current has in the meantime decreased to normal value, the machine will not be disconnected. These schemes by themselves do not give complete protection but must be combined with short-circuit protection.

Type DT thermal relays, essentially a d'Arsonval type instrument of rugged design, are connected to a bridge type circuit to detect excess temperature in generator stator windings. A 10 ohm exploring coil, buried in the machine insulation, is one leg of the bridge. The DT relay is calibrated to close contacts when excess temperatures are encountered. It is intended that these relays be calibrated to manufacturer's specifications. These relays may be connected to sound alarms in attended stations. They may be connected to trip in unattended stations.

Bearing thermostats are similarly installed in unattended stations to detect excess bearing temperature and shut down machines.

HOW RELAYS ARE CONNECTED TO BREAKERS

Large circuit breakers, with few exceptions, are electrically operated and are closed by a closing coil and opened by a trip coil that trips a latch trigger. The breaker is operated by a control switch that closes the circuit leading to the closing or the tripping mechanism. The protective relays associated with such a breaker operate to close the circuit connected to the trip coil.

Protective relays ordinarily are used to control circuit breakers that do not have within themselves means for determining when they should operate to protect the service. Many small circuit breakers contain instantaneous or time-delay overcurrent trip coils, or thermal devices for tripping if the current becomes great enough or persists for long enough to operate the device.

An elementary diagram of a protective relay connected to a circuit breaker follows. When the breaker opens, the auxiliary "a" switch of the breaker interrupts the trip circuit.

In most generating stations and substations, a 125-volt, direct-current source is used for all control work. This source of power is usually a storage battery with provision for a battery charger set floating across the battery. Smaller breakers are usually closed by hand, but they are often equipped with trip coils so they may be opened by means of protective relays.
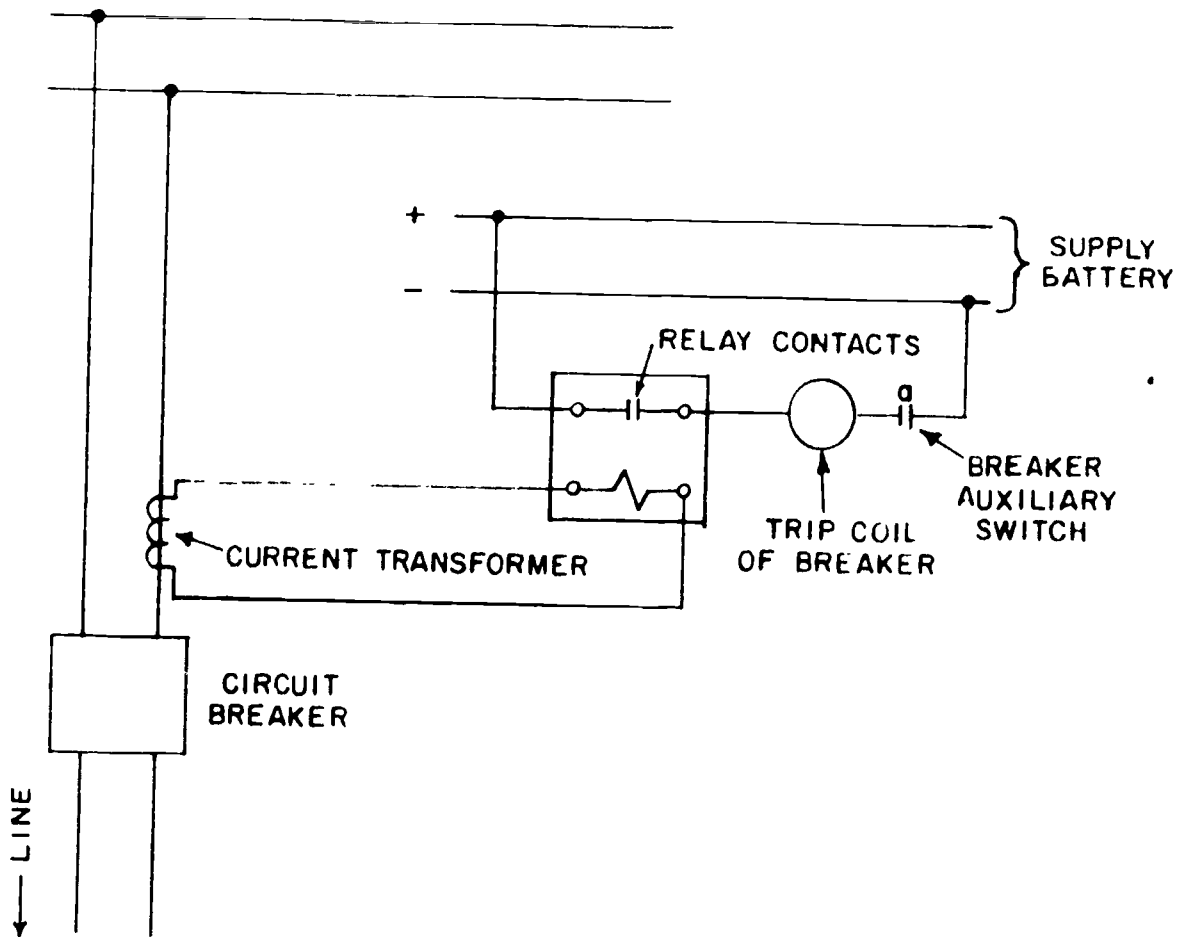
ELEMENTARY DIAGRAM OF A PROTECTIVE RELAY AND CIRCUIT BREAKER

When the breaker opens, the auxiliary switch interrupts the trip circuit to prevent burning of the relay contacts.

Sometimes small breakers are tripped from a small storage battery, but trouble is often encountered with low voltage because of bad connections or high voltage drop across the relay contacts. Twenty-four volt batteries give less trouble than 6-volt or 12-volt storage batteries, but it is recommended that a battery having a voltage of forty-eight volts or higher be given preference.

Several other schemes have been developed for tripping. These schemes are used to a limited extent in small or low voltage stations. One scheme consists in the use of series trip coils energized from current transformers. The protective relays used to operate such breakers are arranged to normally short circuit their respective trip coils. This requires the use of three trip coils to protect a system where there is an overcurrent relay in each of the three-phase wires. Another scheme sometimes used is the capacitor trip scheme. A combination of a copper-oxide rectifier in series with a

capacitor is energized from a potential transformer. The charged capacitor furnishes current in the same way that a battery does when the trip circuit is closed, but it is quickly discharged and must be recharged before it again can be used to trip a breaker. It is not considered good practice to use energy direct from a potential transformer to trip a circuit breaker. During faults, the voltage could be reduced so low that there would be insufficient energy to operate the trip coil.

TRIP COILS OF BREAKER

CURRENT TRIPPING SCHEME USING CIRCUIT
OPENING RELAYS
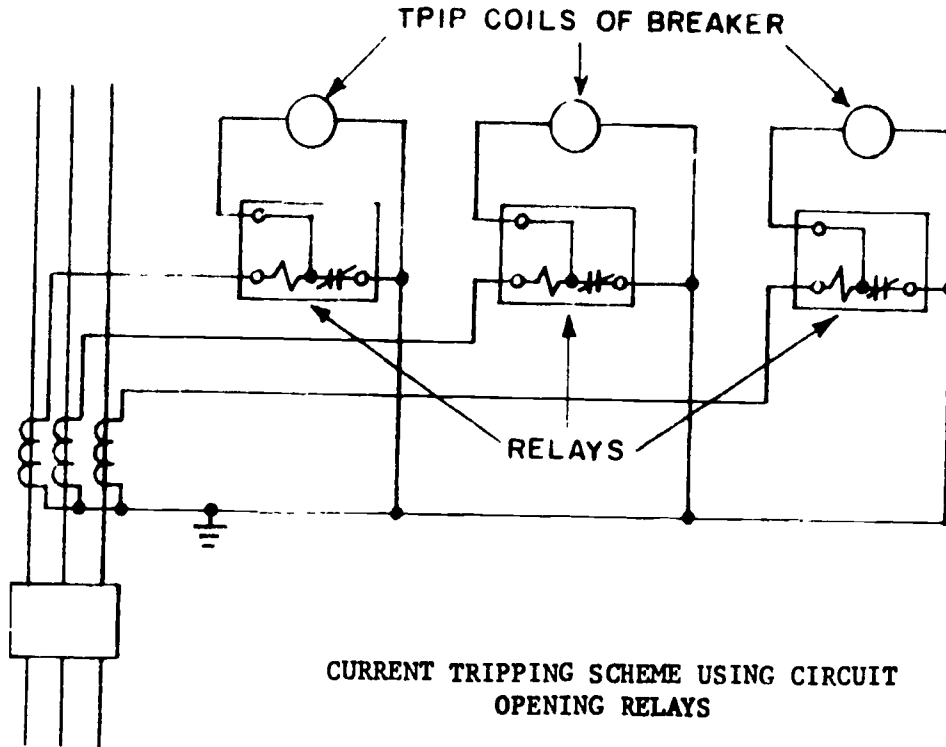
It is often necessary to trip several breakers simultaneously from one set of protective relays. With manual control of each breaker, it is impossible to connect the breaker trip coils together. The usual requirements are to have the circuit breakers operate independently under normal conditions and to be operated simultaneously only by the relays. It is necessary, therefore, to keep the trip coils separated. Where it is desired to trip more than one breaker it is customary to use an auxiliary multicontact relay between the protective relay and the group of circuit breaker trip coils.

Still another method makes use of half-wave silicon type rectifiers connected so that tripping of two or more circuits can be obtained with one set of relay contacts, and at the same time keep the control circuits from the control switches to the individual breakers independent. This is done by making use of the high ratio between forward and backward resistance inherent in the silicon type rectifier.

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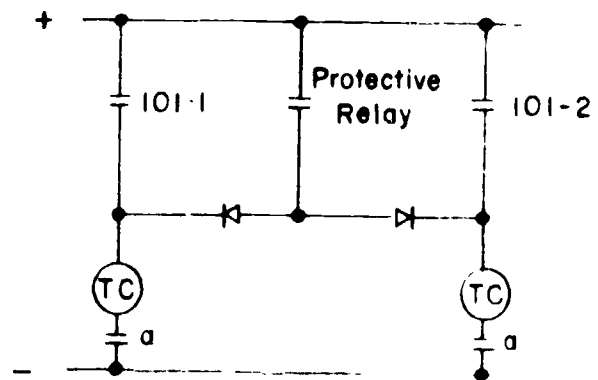
SINGLE LINE DIAGRAM OF SYSTEM CONNECTIONS SHOWING OVERLAPPING OF PROTECTED ZONES

GENERATOR PROTECTION

LOW TENSION BUS PROTECTION

POWER TRANSFORMER PROTECTION

HIGH TENSION BUS PROTECTION

TRANSMISSION LINE PROTECTION

HIGH TENSION BUS PROTECTION

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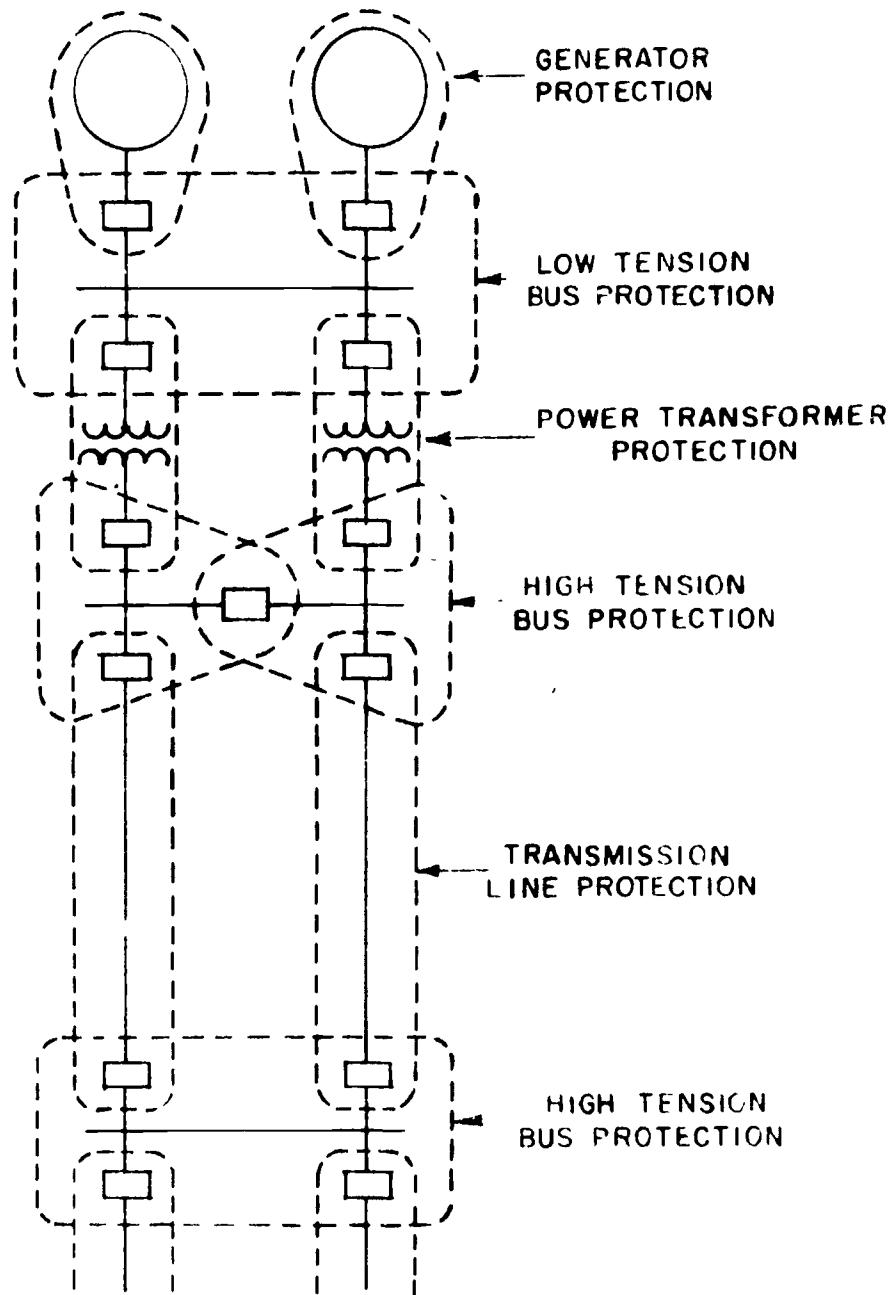
ELECTRICAL POWER STATION THEORY

UNIT V

INSULATING OIL

This unit contains the following lesson:

Lesson 3-5-1: Transformer Oil Care and Maintenance

MAINTENANCE OF INSULATING OIL

Preventive Maintenance

Vast sums of money have been spent for insulating oils thus making it expensive to discard very much bad oil. It is essential that insulating oils be kept in the best possible condition to reduce maintenance costs, to increase the life of equipment, and to decrease electrical failures and costly shutdowns.

A great deal of emphasis should be placed on the importance of regular inspection and testing of insulating oil both in service and in storage. Considerable care must be exercised in taking samples and in testing.

Routine tests should be made annually or more often for dielectric strength. Occasional chemical tests should be made to determine accurately the condition of the oil. The severity of the services should be considered when determining the length of time between taking samples.

Types of Tests

When insulating oil is sent to a chemical laboratory for analysis, six important tests are generally made on a sample. These tests are for -
Dielectric strength
Neutralization number
Steam emulsion
Power factor
Interfacial tension
Pour point

From these analyses, a chemist can tell if the oil should be filtered by mechanical process, reconditioned by chemical treatment, or used as is. No one test is satisfactory for determination of the quality of oil. All these tests must be made and evaluated before the true condition of the oil can be determined.

The dielectric strength of insulating oil may be defined as the minimum voltage at which electrical failure or breakdown occurs under prescribed test conditions. It is important as a measure of its ability to withstand electrical stress and to indicate the presence of impurities such as water, dirt, or conducting particles. A high dielectric strength indicates the absence of moisture but does not indicate whether the oil is oxidized or is forming sludge.

The reliability of dielectric tests of electrical insulating oils is dependent upon the cleanness of sampling equipment and the care with which the samples are taken and tested. It takes a lot of experience to consistently take a good oil sample and make a good oil test. Carelessness when

taking samples sometimes results in needless filtering. Make certain that you are using clean sample containers, clean sampling methods, and clean test equipment.

To be satisfactory, an insulating oil must have a minimum voltage break-down value of 22,000 under the standard oil tester. Most power companies prefer to supply their maintenance crews with a portable oil tester so this test can be performed in the field. The test cup is provided with two 1.0 inch diameter electrodes adjusted to a spacing of 0.1 inch.

The neutralization number test gives the number of milligrams of KOH (potassium hydro-oxide) required to neutralize the acid in one gram of oil. This number is generally proportional to the amount of the oxidation products in the oil. If the neutral number is above .5, the oil is in a sluuging stage. It may sludge at any point between .2 and .5, depending on the type of contaminants in the oil.

Acidity is due to oxidation and may be accompanied by a darkening of the oil due to oxidation of compounds in the oil.

The steam emulsion test indicates the ability of oil to separate from an emulsion (mixture of oil and water) under prescribed conditions and is measured in seconds. New oil has perhaps a value of 20 to 30 seconds; moderately used oils may be 30 to 50 seconds.

We believe that oil with a low steam emulsion value will allow moisture that enters the top of a transformer to settle quickly to the bottom rather than being held in suspension and absorbed by the winding insulation.

A power factor test, when used with other tests, gives an indication of the nature of contaminants present. An increasing power factor indicates an increase of current leakage through the oil. This is due to a decrease in the resistance of the oil. This decrease is caused by the addition of moisture, a mixture of asphalt compounds and oil, carbon in suspension, solutions of other insulating compounds, or oil soluble varnish.

Interfacial tension tests measure the total oxidation products in the oil. As an oil oxidizes, it has a tendency to spread over the surface of water. This spreading or wetting indicates a decrease in its ability to remain as an individual droplet. This property of oil is measured in dynes. The higher the number of dynes the better the oil. A good oil has a value between 35 and 45 dynes. As the interfacial tension drops, the oil will approach the sludging stage at about 18 dynes. Most oil below this value is unsatisfactory.

The pour point of an insulating oil is the temperature below which the oil will not flow. Oils of high pour point are likely to limit free circu-lation of oil in the ducts of a transformer, thus causing heating. Likewise, oil with too high a pour point will prevent the correct operation of a circuit breaker during cold weather. The pour point test is, therefore, a critical one.

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Moisture in Oil

The amount of water that oil will hold is determined by its temperature, its state of deterioration, the type of refining, and the type of crude oil. If there is carbon in the oil, it may absorb water to form a partial conductor which may: decrease the dielectric strength, affect the power factor, and ultimately cause failure.

Sludge

Moisture and oxygen are the worst enemies of oil. Moisture reduces the dielectric strength. It will precipitate sludge from the compounds formed in the oil. Oxygen combines chemically with oil, darkening the oil to form a sludge. This sludge forms an undesirable deposit of solid material on the windings and iron. This sludge deposit acts as a heat insulator slowing up the transfer of heat from the coils and iron to the oil. It also reduces the cross-sectional area of the oil ducts thus preventing the proper circulation of the oil. Some types of sludge attract and hold moisture, reducing the dielectric strength of the insulation. Sludge is also caused by excessive temperature.

Oxygen is closely associated with the formation of sludge in oil so anything that can be done to reduce the exposure of the oil to air should reduce sludge. Thus, an oil conservator, nitrogen above the oil in a transformer, or a sealed type transformer, all help reduce sludge. Compounds that retard oxidation of oil are now available. They are called inhibitors.

Testing Procedures

Identify each sample with the serial number of the apparatus or drum from which it was obtained and the location from which taken (top or bottom). Dielectric tests can be made from a one-pint sample. Complete liquid tests require a one-quart sample.

The sample is then poured into the clean test cup. Rock the test cup gently, then allow it to stand three minutes to permit air bubbles to escape before the first voltage application. Apply voltage uniformly at a rate of about 3 kv per second. Disregard occasional momentary discharges which do not result in a permanent breakdown. Oil testing lower than 22 kv should be filtered to raise the dielectric strength at least to 25 kv.

Oil can be dried rapidly and thoroughly in a filter press if the filter paper is carefully dried, transferred to the press without reabsorbing moisture, and replaced when its effectiveness is exhausted. The paper should be dried in an oven from 6 to 12 hours, depending on the condition of the paper and the separation of the individual sheets in the oven, at a temperature of 85 to 100 degrees. After drying, transfer the paper directly to the filter, or store it under dry oil in a sealed container for future use. If exposed in normal atmosphere, paper will absorb; in as little as ten minutes, two-thirds of the moisture will ultimately absorb from the air.

The most efficient temperature for filtering is between 20 and 40 degrees centigrade. Below 20 degrees, the viscosity increases rapidly; above 40 degrees, the moisture is more difficult to separate.

Sampling Oil

Take samples from outdoor aparatus only on a clear day and when the liquid is at least as warm as the surrounding air to prevent consensation of moisture. Before taking a sample from an opening such as a valve, allow enough liquid to run out so that any moisture or foreign material is removed. Rinse the sample container several times with the same liquid as the sample. Then drain thoroughly before taking the sample. Fill the container with the sample allowing space at the top for expansion. Seal the container tightly with its own stopper.

Clear-glass, small-neck bottles are best for sample containers. They can be inspected readily for cleanness and for free water or solid impurities in the sample. Containers should be rinsed with oil-free gasoline, dried, washed with strong detergent, thoroughly rinsed with water, and dried. Never use rubber or compositions of rubber for gaskets or stoppers. Use a glass stopper or a clean cork protected by clean aluminum foil.

Apparatus for Reconditioning Oil

The filter press method is suitable for reconditioning oil containing small quantities of water and will remove finely divided carbon and sludge. It will not remove acidity. It is quite slow and expensive for wet oils.

A combination of centrifuge and filter press will remove large quantities of water and carbon. This is the most convenient equipment for removing water from oil.

Oil may also be reconditioned by chemical process - use of trisodium phosphate followed by fuller's earth treatment.

Askarel

Askarel is a chlorinated hydrocarbon known under various trade names such as Pyranol (G.E.), Inerteen (Westinghouse), and Chlorextol (A.C.)

Askarel is nonoxidizing and noncorrosive at normal operating temperatures. It will not form sludge under any conditions. Avoid mixing oil and askarel as it will probably ruin both of them.

Askarel cannot be used with ordinary transformer insulations such as varnish and paint. It is only used in transformers having special insulation made of cellulose, cotton, paper, or porcelain. The dielectric strength of askarel is about the same as oil. It should be kept free of moisture, lint, and dirt.

Askarel has an irritating effect upon the skin, eyes, nose, and lips. When working with askarel, apply caster oil to hands for protection. Also,

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put it in the eyes if askarel has accidently been splashed in them. In case askarel comes in contact with the skin, the part should be thoroughly washed and cleaned.

If the liquid is spilled on clothing, it should be changed as soon as possible and the soiled clothing laundered before it is worn again.

Containers, pipes, and all-metal hose used for handling askarel must be free from oil, grease pitch, or other foreign materials. Such equipment preferably should be maintained for exclusive use with askarel.

ELECTRICAL POWER STATION THEORY

UNIT VI

SYSTEM VOLTAGE REGULATION AND POWER CAPACITORS

This unit contains the following lessons:

Lesson 3-6-1: A-C Voltage Regulators
Lesson 3-6-2: Step-Voltage Regulators
Lesson 3-6-3: Power Capacitors

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A-C VOLTAGE REGULATORS

Devices used by power companies to regulate system voltage play an essential part in distribution of electrical energy, so it is important that station wiremen understand how they operate. This lesson will acquaint you with a basic concept of voltage regulation and the necessity of becoming thoroughly familiar with such devices. The emphasis is on the procedure for by-passing or switching of induction and step type voltage regulators.

Required reference:

Information Sheet No. 13

Directions:

Read Information Sheet No. 13. Read any additional references that you may find. Many manufacturers publish excellent booklets on the theory and operation of voltage regulators. Ask your supervisor if you may borrow any of the instruction books on typical voltage regulating equipment in your area.

Write out the best answer that you can for the check-up questions.

Be neat in your work, and when you have completed the lesson, hand it to your instructor.

Check-up: (3-6-1)

1. Why is voltage regulation important?

2. Name two types of regulators.

3. What is an induction-voltage regulator?

4. What does the operation of a single-phase regulator depend upon?

5. The core of the induction regulator rotor is built upon a steel shaft and fits down inside the stator. Which winding is on the rotor?

6. What is the effect of turning the secondary coil to the neutral position at right angles with the primary coil?

7. What are the effects of revolving the primary coil from the neutral position first in one direction, then in the other?

8. Compare the wire size used on the primary as compared to the secondary.

9. What action is taking place when a regulator is said to be "hunting"?

10. Why are breaking systems used on induction-voltage regulators?

11. What is the purpose of the short-circuited winding which is placed at 90 electrical degrees to the primary winding?

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A-C VOLTAGE REGULATORS

A-c voltage regulators have been used on numerous utility distribution systems for many years. Voltage regulation is essential for satisfactory electrical service. Poor voltage regulation affects the quality of service and may seriously impair its commercial value.

With recent customer demands for increased and improved voltage, there is renewed interest in regulators and their applications. Service continuity and good voltage regulation are the normal yardsticks consumers use to measure the quality of their electric service. Heavy air conditioning and heating loads, plus a general trend toward all-electric living, can tax electric systems beyond their design limitations. Because all equipment is designed for use within the narrow limits of its nameplate voltage, poor voltage conditions mean only one thing - poor equipment performance. No one enjoys distorted television reception or flickering lights.

Some other results of poor voltage regulation may be low candle power or high lamp breakage; insufficient development of heat in electrical household appliances; or unsatisfactory motor capacity, speed, temperature, and starting torque. Voltages higher than normal result in increased transformer core losses and lamp renewals. Voltages lower than normal result in revenue losses and dissatisfied customers. Electrical household appliances are designed for most efficient operation at a definite predetermined voltage. Their operation at a voltage other than normal impairs the service, increases the cost to the consumer, and reduces the revenue to the power company.

There are two types of voltage regulator: the induction voltage regulator and the step voltage regulator or load-ratio control transformer.

The induction voltage regulator is a variable-ratio autotransformer having two separate and distinct windings: a primary and a secondary. The primary winding is connected across the feeder to be controlled, and the secondary winding is connected in series with the feeder. Operation of a single-phase regulator depends upon a change of mutual inductance between primary and secondary windings. Small changes of voltage can be made at any point within its range.

The construction of an induction regulator somewhat resembles that of a vertical induction motor. The secondary or series winding is on the stator and the primary winding is on the rotor, along with a short-circuited winding placed at 90 electrical degrees to it. This short-circuited winding counteracts the reactive voltage drop of the secondary winding when the regulator is in the neutral position. The secondary voltage varies with the position of the rotor, being zero when the gear segment is in the mid-position.

When the primary coil is turned to various positions the magnetic flux sent through the secondary coil varies in value causing a corresponding

variation in the secondary voltage, the character of which depends upon the value and direction of the flux. Turning the primary in one direction increases the feeder voltage like the action of a booster. Turning the primary in the opposite direction from the neutral position correspondingly decreases the feeder voltage.

In the construction of the regulator, both primary and secondary cores are circular, the coils are assembled in slots similar to those of an induction motor. The primary coil, consisting of many turns of fine wire, is connected across the source. The secondary coil, consisting of turns of heavy wire, is connected in series with the line or load. The product of the volts and amperes on the source side, less the small loss in the regulator itself, is equal to the product of the volts and amperes on the load side.

PRIMARY
WINDING

SECONDARY
WINDING

FROM
SOURCE

4150 V
60 hz

4300 V
60 hz

TO
LOAD
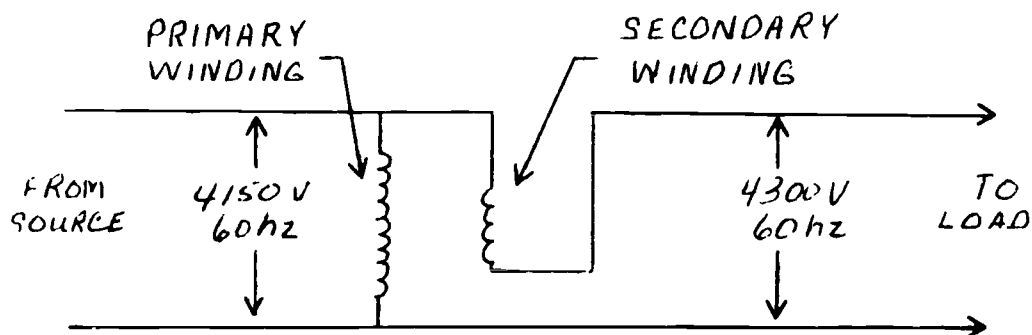
SINGLE-PHASE INDUCTION REGULATOR
BOOSTING VOLTAGE OF A DISTRIBUTION CIRCUIT

In the three-phase regulator, the arrangement of the primary and secondary core windings is similar to the single-phase, in that one primary and one series winding is provided for each phase. The three-phase induction voltage regulator controls the three-phase voltage of a distribution circuit. The primary windings may be connected in either wye or delta. Each of the three secondary windings is connected in series with one of the three line wires. The primary windings are stationary while the secondary windings are movable. The current in each winding is single-phase, but the magnetization of the core is produced by the combined action of all the primary windings.

Induction voltage regulators may be operated by hand either directly or through a sprocket wheel and chain, by a hand controlled motor, or automatically. Generally they are automatically controlled by a contact making voltmeter and an operating motor. The voltmeter is primarily an a-c relay so arranged that the moving member is held in a balanced position at any predetermined voltage, that is, normal line voltage.

If motor operated with hand control, the motor may be of the single-phase, a-c type although the three-phase, a-c motor is preferred. If the motor is automatically operated, it is even more advisable to use the three-phase type. The single-phase motor is not well adapted for this purpose,

since, for the same characteristics, the armature of a single-phase motor has approximately twice the weight and twice the inertia of an armature on a three-phase motor. This increases the overruning of the regulator and also its tendency to hunt. Furthermore, the commutator and brushes of a single phase motor require considerable attention.

All induction regulators for motor or automatic operation are provided with a break to stop the motor as soon as the voltage has been properly adjusted.

This motor which turns a wormgear mechanism is normally controlled by relays energized by a contact-making voltmeter. When the voltage decreases, one set of contactors closes causing the motor to turn in a given direction which boosts the voltage back to normal value. If the voltage goes too high, another set of contactors is activated by the contact-making voltmeter causing the motor on the regulator to turn in a reverse direction. Thus, the primary is moved to a new position which results in the voltage decreasing to its normal level. Usually a two- or three-volt band, which is the most that is tolerated, usually amounts to a line-voltage variation of 1% either way from normal.

The brake for all standard size regulators is a magnetcially released type which is noiseless in its operation and prevents any other running of the motor. The brake pressure is released simultaneously with the closing of the operating motor circuit, consequently releasing the motor from any load due to braking action. The opening of the motor circuit applies the brake preventing any further operation of the adjusting mechanism after the proper voltage has been obtained. The motor power on some regulators is supplied from an external source, but on submerged units, the motor circuit is brought from a transformer with its primary connected to the regulated output of the regulator.

The motor control contactor is used for handling the motor current inasmuch as this current is too great to be handled by the contact-making voltmeter. Also, it is necessary that the contactor have a forward and reverse position for reversing the regulator motor. The motor is caused to rotate in one direction or the other, depending on whether the voltage of the feeder is to be raised or lowered, as determined by the closing of the main contacts on the contact-making voltmeter which controls the excitation of the contactor coils.

A potential transformer is used for energizing the control coil of the contact-making voltmeter. It will normally have such a ratio as to give 110 volts on the secondary with the primary connected across the line and the regulator in the neutral position.

In order that the actual voltage at a distant point on a distribution system may be read at the station, some provision must be made to compensate for the line drop - the difference in voltage between the station bus and the center of distribution. A device known as a line-drop compensator is placed in the voltmeter circuit for this purpose. A line-drop compensator consists of a variable resistance and reactance (each independently adjustable) by means of which, when used with the regulator, correct line-drop compensation can be obtained at some predetermined point on the feeder regardless of load or the power factor of the load.

The line-drop compensator is used to reproduce in minature the resist-
ance and reactance drops to a predetermined point in the line. The function
of the compensator is to lower the impressed voltage on the contact-making
voltmeter thereby causing the regulator to maintain normal voltage at this
predetermined point. It consists of a resistance in series with a reactance
in series with a current transformer. By adjusting the ohmic and reactive
voltage drops across the compensator by dial switches so that they will
correspond to the ohmic and reactive drops in the feeder, the voltage
impressed on the contact-making voltmeter will correspond to the feeder volt-
age at the load center. The regulator, therefore, will be caused to raise or
lower the voltage in the station in accordance with variations on the line.
A means for holding the voltage at the point on the feeder distant from the
station for all conditions of voltage, load, and power factor within the
limits of the capacity of the regulating equipment will thus be provided.

In any distribution system, it is desirable to read the active voltage
at the point of distribution by means of voltmeters in the station. The
voltmeter instead of being wired directly across the secondaries of a poten-
tial transformer has inserted, in series with it, portions of the resistance
and inductance of the compensator. These are so connected that the drop in
pressure across them will combine so that the voltmeter reading indicates
the voltage at the load center.
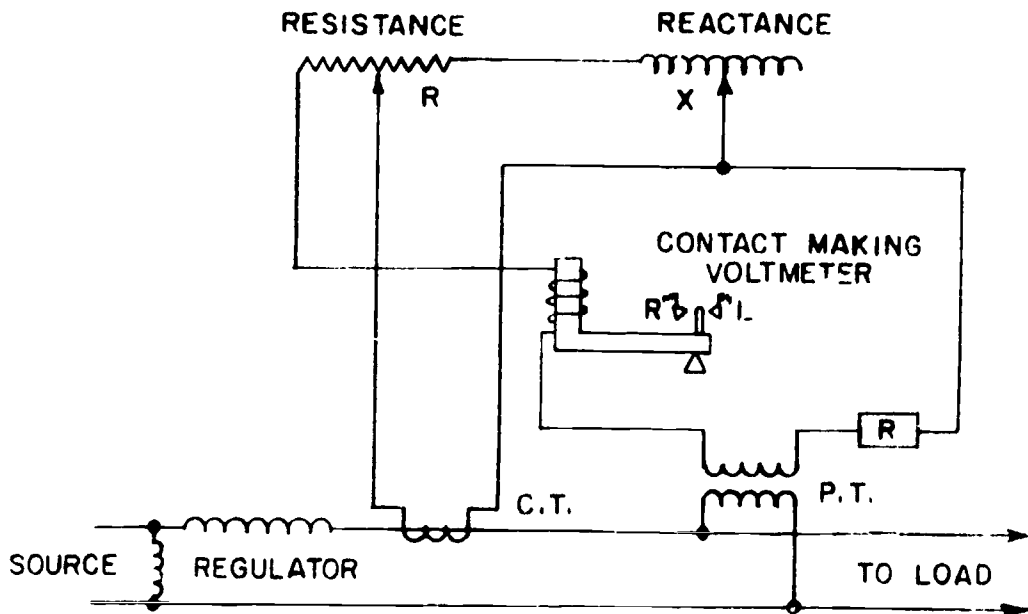
The electrical neutral of an induction regulator is the mid-position of
the mechanical travel of the rotor, thus insuring the same percentage of
regulation in either bucking or boosting the line voltage. The position
indicator should read zero at this position. Limit switches are provided in
the motor circuit to limit the travel of the mechanism. The position indi-
cator will point to 10 on the dial in the boost or 10 on the dial in the buck
position.

A low-voltage cutout is usually applied in conjunction with the contact-making voltmeter and the motor circuit so that, if for any reason the feeder circuit should be opened, the regulator will remain in the same position which it is occupying at the time the feeder is opened. In this way, the possibility is avoided of impressing a higher voltage on the feeder than desired when it is again placed in service.

When you studied about transformers, you found that they usually had two sets of terminals - high-voltage terminals and low-voltage terminals. In voltage regulators, it might be said that all terminals are high-voltage terminals. They are identified as source terminals, load terminals, and common terminals. For example, the single-phase regulator has one source terminal, one load terminal, and a common terminal. Induction regulators and step regulators are connected in much the same way whether they are station-type or pole-mounted type.

Three-phase regulators have one source terminal and one load terminal for each phase or a total of three source terminals and three load terminals. A neutral terminal may also be included if the regulator is designed for a four-wire system. There are no common terminals on three-phase regulators. The three-phase regulator is internally connected to make bringing out the common terminal unnecessary.

Voltage regulators are taken out of service for inspection and mainte-nance at periodic intervals. To maintain continuity of service while the voltage regulator is being connected or disconnected a by-pass switch is provided. The by-pass switch is connected between the load side and the source side. It remains open while the regulator is in service. A disconnect switch must also be provided for each lead to the regulator terminals. The disconnect switches are closed while the regulator is in service. If the common terminal is the neutral of a grounded wye system, its disconnect switch may be omitted.

Single-phase induction and step regulators, and three-phase step regu-lators present no problem when by-passing if the proper sequence of opera-tion is followed. It is necessary that the voltage regulator be on neutral so that no voltage appears across the series winding; otherwise, when the by-pass switch is closed, a high circulating current will result. This circulating current can be several times nameplate rating, depending upon the voltage induced in the series winding and the type of voltage regulator. The high current could cause considerable damage to the voltage regulator and possibly to the operator closing the by-pass disconnect switch.

To remove a regulator from service there is a definite order of steps -

1. Set the automatic-manual switch for manual operation.
2. Operate the regulator to the neutral position.
3. De-energize the control power.
4. Close each by-pass switch.
5. Open the disconnect switches in the source and load leads.
6. Open the disconnect switch in the lead to the common terminal (when provided).

BY-PASS
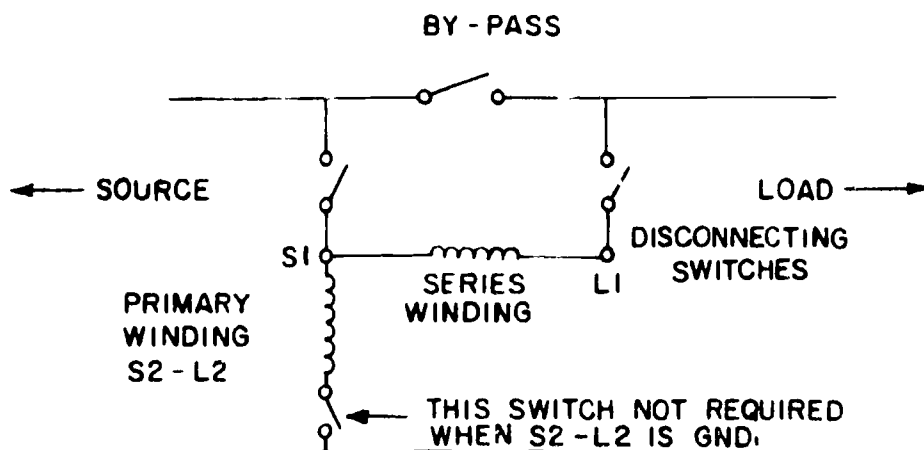
There is a definite order of steps, also, when it becomes necessary to put a regulator into service -

1. Be sure the regulator is in the neutral position. If not operate, by hand or from an external control source, the regulator to the neutral position.
2. Be sure the control switch is in the manual operating position.
3. Close the disconnect switch in the lead to the common terminal.
4. Close the disconnect switches in the source and load terminals.
5. Open the by-pass disconnect.
6. Turn the control switch from manual to automatic. The voltage regulator will then operate to satisfy voltage requirements if necessary.

There are several types of equipment which can be used for by-passing regulators. Some are circuit breakers, combinations of circuit breakers and interlocking switches, open-type disconnect switches, or cutouts with disconnecting blades. Standard voltage regulator by-pass switches are also available. In substations, for economic reasons, the open type disconnects are usually preferred. On primary feeders, pole-mounted cutouts with disconnecting blades are preferred. The special regulator by-pass disconnect switch is a relatively new device and has gained wide acceptance as it helps eliminate some of the possible errors which can occur.

In three-phase circuits, voltage regulators can be applied using various types of connections. They are wye or delta for three-phase regulators as previously mentioned, and wye, open-delta and closed-delta for single-phase regulators forming a three-phase bank. Each connection has its own characteristics regarding regulator kva rating with respect to circuit kva. The kva nameplate rating of a step or induction voltage regulator is only the kva which is transformed within the regulator and not the carrying kva capability of the regulator or the connected kva load. Most modern regulators have a plus or minus 10 percent range plus the ability to increase their capacity when reducing their regulation range.

For a single-phase regulator applied on a single-phase circuit, the regulator kva rating $= \dfrac{\%R \times E \times I}{100}$; where $\%R$ = Maximum percent regulation range of the regulator in the buck or boost direction, E = the single-phase voltage in kv, and I equals the line current.

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Three-phase regulators for four-wire, three-phase circuits are always connected wye, and the three-phase nameplate kva rating is determined by the following formula.

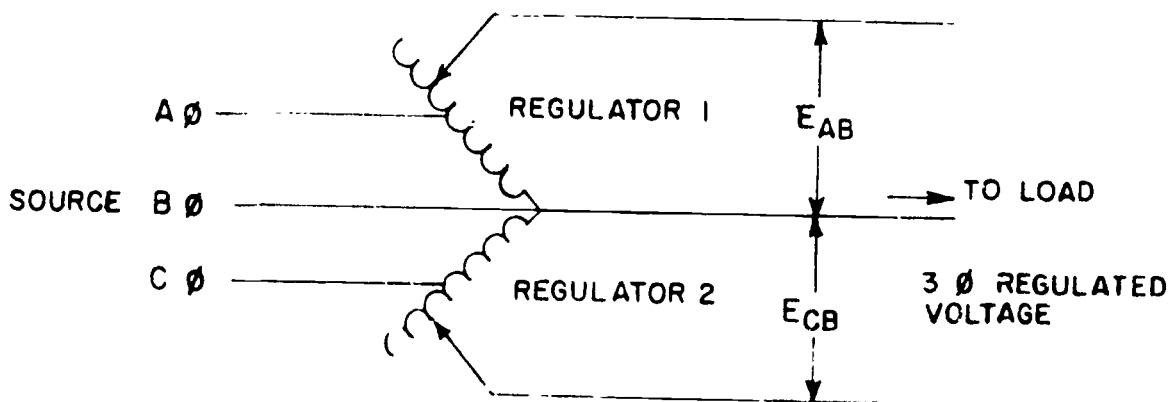$$\text{3-Phase regulator kva rating} = \frac{\%R \ (1.73 \ E \ I)}{100}$$

Where the load is assumed balanced on each of the phases and I equals the line current and E is the three-phase circuit line to line voltage in kv, the kva rating of a single unit in a wye connection is equal to one-third of the rat ng for a three-phase regulator to be applied on the same circuit.

For example, on a 7,200/12,500-volt primary feeder where I (load) = 174 amperes, the regulator range required = ± 10 percent, the regulator nameplate rating would be:

$$\text{Regulator kva rating} = \frac{10 \ x \ 1.732 \ x \ 12.5 \ x \ 174}{100} = 375 \ \text{kva}$$

The kva rating of three-phase regulators applied on three-phase three-wire circuits is determined in the same manner as for four-wire circuits.

A commo.. method of obtaining three-phase regulation in three-wire cir-cuits is to use two single-phase regulators connected open-delta as shown in the following schematic diagram.

You will note that the two regulators are connected from one phase conductor to another; hence, the regulator input voltage is the three-phase, line-to-line voltage and not the line-to-neutral voltage. The three-phase regulator kva r ting would be:

$$\text{Regulator kva rating} = \frac{\%R \ (1.732 \ E \ I)}{(100)(1.732)}$$

Induction regulators were the first automatic voltage regulators used on distribution systems. Their use has lessened due to acceptance of lower cost and equally reliable step regulators. Many induction regulators are presently in use and will be for a good many years.

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STEP-VOLTAGE REGULATORS

Voltage regulation is an important factor in providing satisfactory electrical service. It presents a vital problem to the distribution engineer as well as those who maintain and operate the system.

The study of voltage regulation in this course is limited to an introduction only. To become well versed on the subject requires considerable time and on-the-job experience.

It is the objective of this lesson to help you acquire information pertaining to load ratio control on transformers and step-voltage regulators. This lesson will also acquaint you with a few other types of devices that are commonly used for system voltage regulation.

Required reference:

Information Sheet No. 14

Directions:

Study Information Sheet No. 14. Read any additional references that your instructor may provide. Read any instruction booklets on voltage regulators to which you may have access.

Study any schematic drawings for the control of step regulators or tap changing transformers that may be availalbe.

When you have read the material, answer the check-up questions. Write the best answer that you can. See that every question is answered, check your work, and hand it to your instructor.

Check-up: (3-6-2)

1. When an autotransformer is modified to make a regulator, why are taps put into the secordary winding?

2. What purpose does the preventive autotransformer serve?

3. Why is there a reversing swi+ch on the tap changer?

4. Why is a time-delay device used in the control?

5. Explain band width.

6. Why are moving contacts on the tap changers made in pairs?

7. The reversing switch can only be moved when both moving contacts are on what position?

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8. Assuming a voltage rating of 7,200, and a regulator designed plus or minus 10% in sixteen steps, how much voltage is there between tap positions? How much voltage change in each step?

9. If we assume that the above regulator has a potential transformer with a ratio of 60:1 on a 7,200-volt line, how much secondary voltage change is there in each step?

10. A general rule is to set a band width no smaller than two steps of the tap changer. What would be the minimum band width for the regulator in the problem above?

11. Why is it that a 750 kva step regulator can be applied on a three-phase circuit rated 7,500 kva to regulate the voltage plus or minus 10% and still not exceed the nameplate rating on the regulator?

12. Assume a regulator with a 96 kva nameplate rating and designed for plus or minus 10% to be used on a 2,400-volt single-phase circuit. How many line amperes would be permissable, without exceeding the nameplate rating of the regulator, if in the full boost position?

13. How many line amperes (load) would be permissible if the regulator were limited to plus or minus 5%?

14. We call the voltage drop in a line the line drop. Name three things that cause line drop.

15. What is the purpose of the line-drop compensator used with the voltage regulator control?

16. A voltage regulator is to be taken out of service for inspection and maintenance. Explain, or list in their proper sequence, the steps necessary to maintain continuity of service.

17. Name two methods by which the line-drop compensator settings may be determined.

18. What precautions should be taken when testing regulators electrically?

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INFORMATION SHEET NO. 14   (3-6-2)
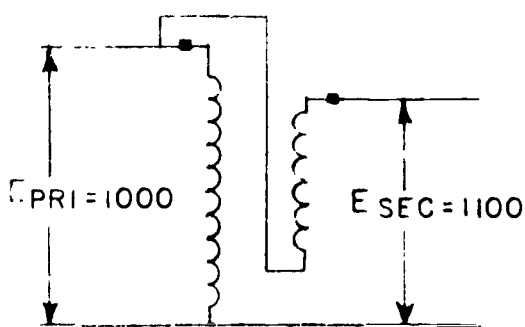
STEP VOLTAGE REGULATORS

To understand the operation of a step-type voltage regulator, it is necessary to understand how an autotransformer works. Regulators vary the voltage by changing the ratio between the primary and secondary windings of an autotransformer.

Possibly the most effective way to show how a regulator operates is to start with a two-winding transformer. The first of the following diagrams shows the basic diagram of a transformer having a turns ratio of 10-to-1. If the primary has 1,000 volts applied, the secondary will have an output of 100 volts.

$E_{PRI} = 1000$ $E_{SEC} = 100$ VOLTS
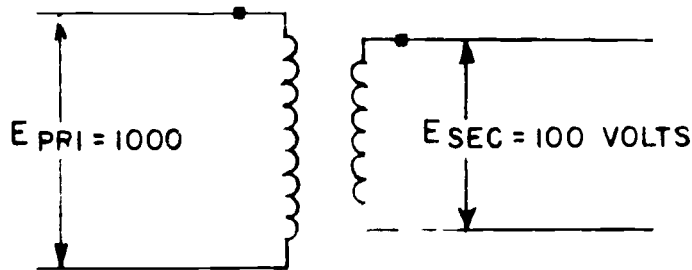
RATIO = 10 : 1

These two independent windings can be connected so that their voltages may aid or oppose one another. A voltmeter connected across the output terminals will measure the sum when connected to aid or the difference of the two voltages when connected to oppose. The transformer becomes an autotransformer with the ability to raise or lower the primary or system voltage by 10%.

$E_{PRI} = 1000$ $E_{SEC} = 1100$

$E_{PRI} = 1000$ $E_{SEC} = 900$

STEP-UP AUTOTRANSFORMER   STEP-DOWN AUTOTRANSFORMER

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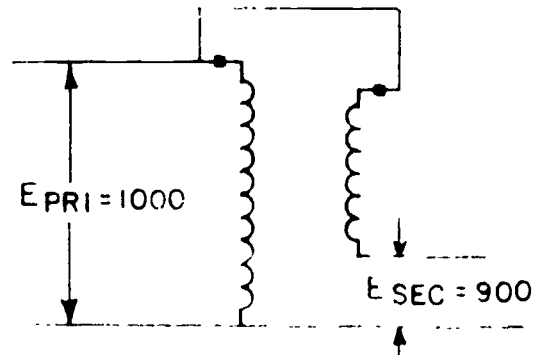
The secondary winding of the autotransformer is connected in series with the line and is commonly referred to as the series winding. A step voltage regulator is an autotransformer which will step-up or step-down a primary voltage depending upon how its series winding is connected to the primary. A step-up autotransformer with a 10-to-1 ratio of primary windings will raise or boost the voltage 10%. A step-down autotransformer with the same winding ratio will step the voltage down 10%.

A sudden voltage change of 10% would have adverse effects on an electrical system. Finer regulation can be obtained by switching the series winding into the circuit in smaller increments. By dividing the series winding into eight equal sections and bringing out the taps, each section will add 1 1/4% voltage to the primary voltage. To change the output voltage of the regulator, you can switch in or switch out sections of the series winding so as to have all, none, or any part, of the series winding in the circuit. This switch is commonly called a tap changer.

If a single moving contact were used, there would be a circuit interruption as the contact moved from tap to tap. Therefore, two contacts are used. They are insulated from each other and connected through a preventive autotransformer. We know that there is a voltage difference between each tap of 1 1/4%. When moving from one tap position to the next, if there is to be no discontinuity, the movable contacts must be physically spaced so that one or the other, or both, must always be on a stationary contact. The preventive autotransformer acts as a bridging reactor so the contacts will not short turns in the series winding at bridging positions. A center tap is made in the preventive auto and is connected to the load bushing of the regulator. Whenever the two moving contacts are on the same stationary contact, there is no voltage difference between them.

On an actual regulator tap changer, the stationary contacts are arranged in a circle. The moving fingers move from stationary contact to contact in a clockwise or counterclockwise direction depending on whether you are raising or lowering the voltage. A reversing switch is provided so the series winding polarity may be reversed and, therefore, either boost or buck the applied voltage. NOTE: In the diagram, to raise the voltage, the reversing switch will move to A. The moving contacts can move from 0 to 8, the maximum boost position. To move from this maximum raise position, the moving contacts will move in the opposite direction - from 8 to 0. To continue lowering the voltage, the reversing switch will move to B, and the moving fingers will then continue to move from 0 to 8 again, the maximum lower position. The

REVERSING SW.

PREVENTIVE AUTO.

16.1

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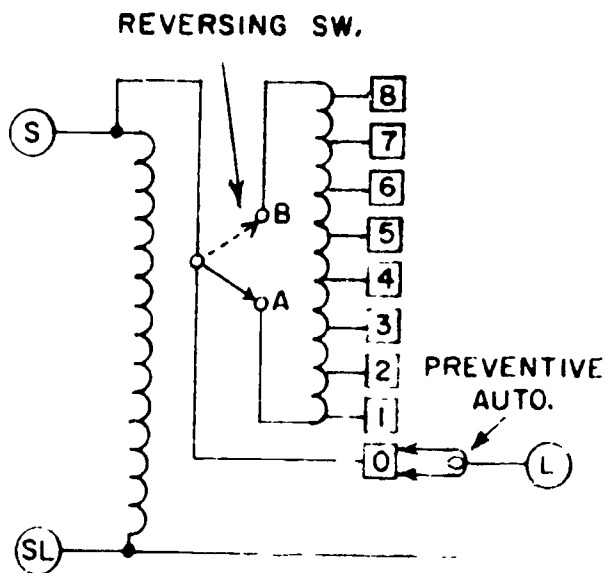
reversing switch can only be moved when both moving contacts are on the 0 or neutral position. Once the moving contacts reach either a maximum lower or maximum raise position, they cannot move any further, being blocked by a limit switch.

Some tap changing devices utilize the preventive autotransformer to obtain additional ratios between taps by operating continuously on two taps with the preventive auto bridging them. Since the difference between taps is 1 1/4%, when the tap changer is on a bridging position, the center tap of the preventive autotransformer will be at a potential half-way between the two moving fingers. 1/2 of 1 1/4% = 5/8% thereby providing the regulator with an even finer voltage control. The moving contacts travel up and down the series winding alternately on the same contact (even position) and then in the bridging position. This then provides for 16 5/8% voltage step to raise the output voltage 10% or a total of 32 5/8% steps from full raise to full lower. Add 1 position for neutral.

The 32-step, plus and minus 10 percent regulation range has such wide acceptance that it is considered standard for most load-tap-changing equipment.

The control of the step or induction voltage regulator receives its intelligence of the circuit voltage from a potential transformer connected to the output or load side of the regulator. This potential transformer steps the line voltage down to a safe control voltage and feeds the control voltage to the voltage regulating relay. It may be either a solenoid-operated balanced beam type or of the induction disc principle. In the induction disc type of relay, the disc maintains a certain position for an applied voltage and rotates in one direction or the other to a different position as voltage changes. The raise and lower contacts are set at the desired band width by simply moving the two pointers associated with the voltage scale of the voltage sensitive element to the upper and lower band-limit respectively. In many modern-station regulators, static relays are replacing the old electro-mechanical relays. Time-delay devices are also being replaced by static timing devices.
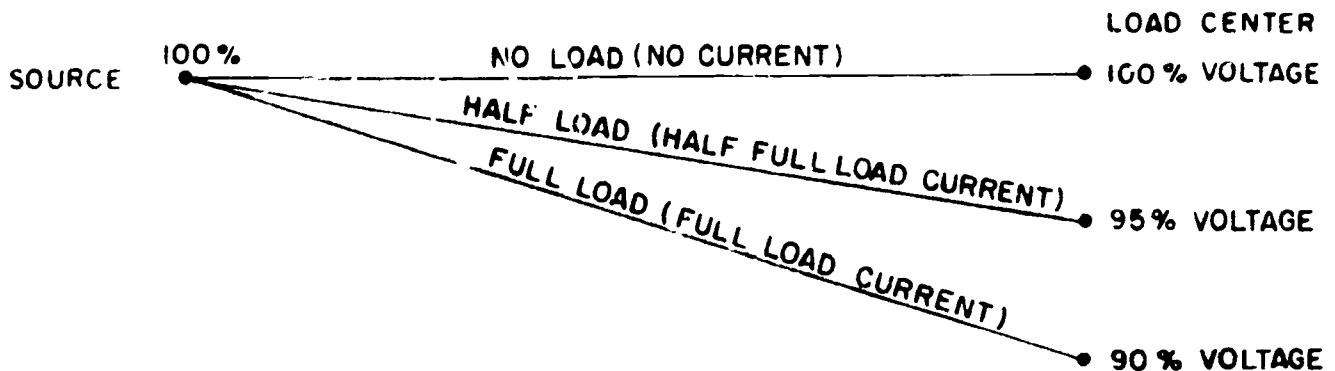
Induction voltage regulators do not use a separate time delay. The only time delay is the inherent mechanical time delay of the operating mechanism.

In substations with one or more primary feeders, the voltage regulating equipment may take the form of an automatic load-tap-changer, built as an integral unit with the transformer. For heavy loaded multi-feeder substations, automatic load-tap-changing equipment on a three-phase transformer provides voltage regulation in the least space and usually at the lowest cost. The load-tap-changing transformer can correct for incoming supply voltage variation and for changes in the magnitude of primary-feeder voltage drop through the use of a line-drop compensator as part of the voltage regulator equipment. Frequently in power systems, load-tap-changing transformers (sometimes called load ratio control) are used to control the flow of reactive kva between two generating stations and to control division of power between branches of the system by shifting the phase-angle position of transformer output voltages.

The theory of operation of the line-drop compensator was simply explained earlier in the lesson. Because the line or feeder is an aluminum or copper conductor, it contains resistance and reactance. A current flowing through this conductor will react with this resistance and reactance to cause a voltage drop. If no current flows between the source and the load, there will be no voltage drop and the source and load voltages will be the same. The following sketch represents a distribution line or feeder connected to a load from a source.

SOURCE ⎯⎯⎯⎯⎯⎯ RESISTANCE (R) ⎯⎯⎯ REACTANCE (X) ⎯⎯⎯⎯⎯⎯ LOAD CENTER
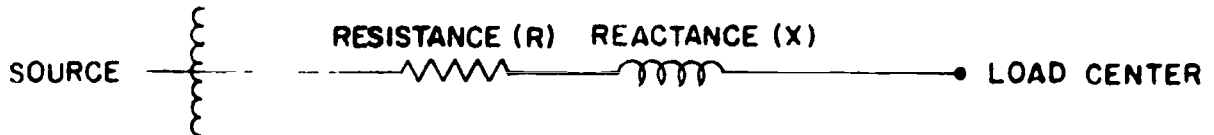
In this diagram, the voltage at the source is maintained at 100%. With no load current, there is no voltage drop between the source and the load center. Therefore, the voltage at the load center is also 100%. If we assume

LOAD CENTER

SOURCE 100%   NO LOAD (NO CURRENT)   100% VOLTAGE

HALF LOAD (HALF FULL LOAD CURRENT)   95% VOLTAGE

FULL LOAD (FULL LOAD CURRENT)   90% VOLTAGE

the full load of this feeder is 600 amperes, at half load (300 amperes), there is a voltage drop between the source and the load center of 5% which makes the voltage at the load center 95%. Full load current (600 amps) causes a greater voltage drop making the voltage at the load center 90%. You can see that there will be a voltage drop between the source and the load center whenever there is a load current. The higher the current the greater will be the voltage drop.

This voltage drop can be minimized by a reduction in the series resistance of the line. A reduction in the resistance is accomplished by stringing larger conductors. A reduction in resistance, however, does not affect the reactance drop but diminishes the total impedance drop. The reactance of the line can be reduced by changing the configuration of the line or by going from overhead lines to underground cables. Changing the configuration of the line may not provide much gain because there are minimum clearances for each voltage level and going from overhead lines to underground cables is very costly.

To compensate for a voltage drop between the source and the load which is usually several miles away, the line-drop compensator is used with the

voltage regulator. The voltage regulator is most often located in the sub-station. The secret of the line-drop compensator is that current can be measured with a current transformer which is connected to the line-drop compensator. The compensator consists of two connected elements, one a resistor and one a reactor. There is a variable control knob for each element because no two distribution lines have the same resistance and reactance characteristics. The reactance and resistance drops of the line must be determined, and each control knob set accordingly.

As load current increases, current in the line-drop compensator increases. This change is passed along to the voltage regulating relay, causing a decrease in the voltage at the relay. This causes the relay to operate the voltage in exactly the same way as it does when there is a decrease in the voltage at the regulator itself. The values of line-drop compensation may be calculated using the instruction book supplied with the regulator or they can be set by experience and trial and error.

INSTALLATION AND MAINTENANCE OF VOLTAGE REGULATORS

Voltage regulators are normally shipped completely assembled, ready to run. Usually the tank is filled with oil at the factory, but occasionally the oil may be shipped in separate containers. The regulator should never be moved by means of the bushings as their porcelain surfaces must not be cracked or damaged. Lifting lugs are provided for this purpose.

Whenever possible, station-type regulators should be handled with a crane, using only the lifting lugs. When a crane is not available, the regulator may be skidded or moved on rollers. When jacks are used to raise the unit, the jack lugs on the tank should be used. A jack should not be used on any other part of the regulator.

Before placing any regulator in service, the oil level should be checked. The oil-level gauge should read 25 degrees at room temperature. All gaskets should be inspected as soon as the regulator is received. It is important, when any cover is off, that no tools or other foreign matter be allowed to drop into the tank because they could cause serious damage.

Many regulators come with the lightning arrester already mounted. The air gap between the arrester and its bushing must have a definite setting, according to the voltage rating of the regulator. This is usually set at the factory, but it may be jarred or knocked out of adjustment during transit.

All regulators should be tested electrically before being put into service, particularly after they have been stored for a period of time. Methods of testing vary according to the type of regulator and are always found in the regulator's instruction book. Before any voltage is applied, crank the tap changer over its entire range with the hand crank to make sure all parts operate freely. There are two kinds of electrical tests. A test voltage may be applied to test the operation of the control system without energizing the regulator itself. Most regulators have separate terminals on the control panel for applying this voltage. Or, the regulator may be

completely energized, providing a complete operational test by applying rated voltage to the bushing terminals.

Safety precautions must be taken whenever applying test voltage. The circuit breaker on the control panel must first be opened to prevent exciting the entire regulator by back-feeding the potential transformer. If the test voltage is being applied to the terminals on the control panel, the circuit breaker should remain open. This is not only important as a good safety practice, but such excitation could overload the control wiring as well as be dangerous to any persons working on the regulator or bus. The bushing terminals would be at full-line voltage.

If the test is being made by applying full-line voltage to the bushing terminals, the circuit breaker must be closed. Methods for isolating the control circuit for testing may vary in different regulators, but they should be explained in the instruction book. Some regulators have two circuit breakers which must be opened, some regulators may have a ground link on the control panel, which must be opened before applying external voltage at the test terminals. Remember, failure to take all the necessary precautions could be dangerous. Be sure to follow accurately all the procedures outlined in the instruction book.

The location and connections of the regulator are usually determined by your engineering department, but you should have some general knowledge on regulator connections. Three-phase regulators are connected in only two ways: one way to a three-wire system and one way to a four-wire system. In the connection to a three-wire system, each phase of the regulator is connected to a phase wire. There is a source and load terminal on the regulator for each phase. The neutral terminal, if there is one, is not used or possibly grounded through a lightning arrester. This is in addition to the usual grounding of the tank at the grounding pad.

On many regulators to be used for connection to a three-wire system, a neutral bushing is omitted. Some types of modern regulators use concentric bushings. These provide one source terminal and one load terminal in a single bushing. These regulators, therefore, include only one bushing for each phase, and possibly a neutral bushing. The terminals are the same and the connections are the same as for other three-phase regulators.

When a three-phase regulator is built to be connected to a four-wire system, the neutral bushing is always present. Connections to the three power wires are the same as in the connection to a three-wire system and the neutral wire of the system is connected to the neutral terminal. The neutral may or may not be grounded. It may occasionally be found that the neutral bushing does not include a grounding strap. In this case, if the system is grounded, the neutral must also be grounded.

The connections for one single-phase regulator involve only two wires. As previously mentioned, single-phase regulators are often used to regulate voltage on three-phase systems. The connection of two single-phase regulators is the most popular way to obtain three-phase regulation on a three-wire system. Because only two regulators are used, it may appear that only two of the three phases are being regulated. Actually, all three phases are

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regulated because, in any three-phase system, the voltage of any one phase is affected by the voltage of the other two phases.
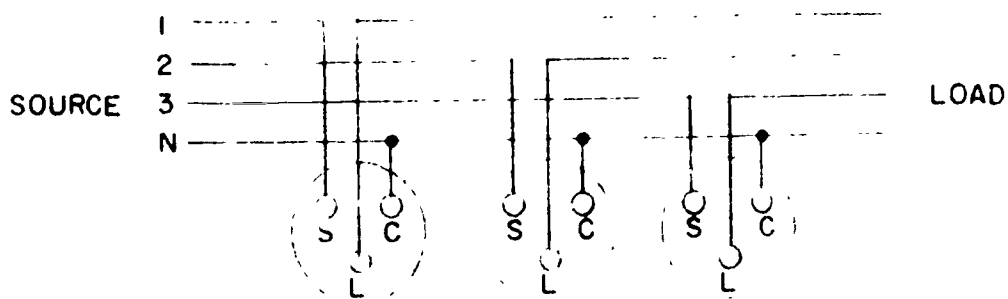
3 SINGLE - PHASE REGULATORS
ON A FOUR-WIRE SYSTEM

Regulators are designed to require a minimum of maintenance and adjustment, but should be given a regular inspection; the frequency of inspection depends upon the severity of the service. The control system should be inspected as a matter of routine. Any relay contacts that are badly burned should be replaced. Usually after a regulator has had 35,000 operations or more, the tap changer should be inspected. The regulator should be taken out of service, the oil drained from the tap changer compartment, and the inspection plates removed. Carbon deposits on the walls of the tap changer compartment should be cleaned off.

The oil in the tap changer compartment of step regulators is subject to more severe service, since there is a natural amount of arcing each time the tap changer operates. Because of this, the tap changer oil requires changing more often than the tank oil. It is preferable that new or clean, dry, filtered oil be used for the refill.

Loss of dielectric strength of the oil is one of the most common causes of regulators going wrong and moisture is the greatest cause of loss of dielectric strength. Thus it is important to keep a close watch on the condition of the oil. Samples of the oil should be taken at periodic intervals for tests of dielectric strength. This is the only reliable way to determine the actual condition of the oil.

Dielectric tests are made by placing a sample of oil in a standard test cup. The voltage at which it breaks down is the measure of its dielectric strength.

GENERATOR VOLTAGE REGULATORS

Another method used for automatic voltage regulation is control of the excitation of synchronous machines. There are a number of different types. Older machines and installations used the direct-acting rheostatic type. The newer more modern machines are most likely equipped with some sort of static network-magnetic amplifier type, amplidyne type, or controlled silicon rectifiers. Each type varies the generator output voltage by changing the exciter field strength.

Automatic voltage regulators operate on the principle of changing the alternator field current to compensate for changes in load current. As the terminal voltage decreases, a relay closes contactors which short a field resistor. This results in an increase in field current and flux and induced voltage. Conversely, an increase in voltage causes the relay to open the contactors across the field resistor. This decreases field current, field flux, and induced voltage.

The following simplified schematic diagram is of an automatic voltage regulator. The voltage regulating relay coil is connected across one phase of the three-phase output of the generator. During normal operation, the voltage regulating relay will cause the contactor to open and close several

TO 3 ∅ LOAD
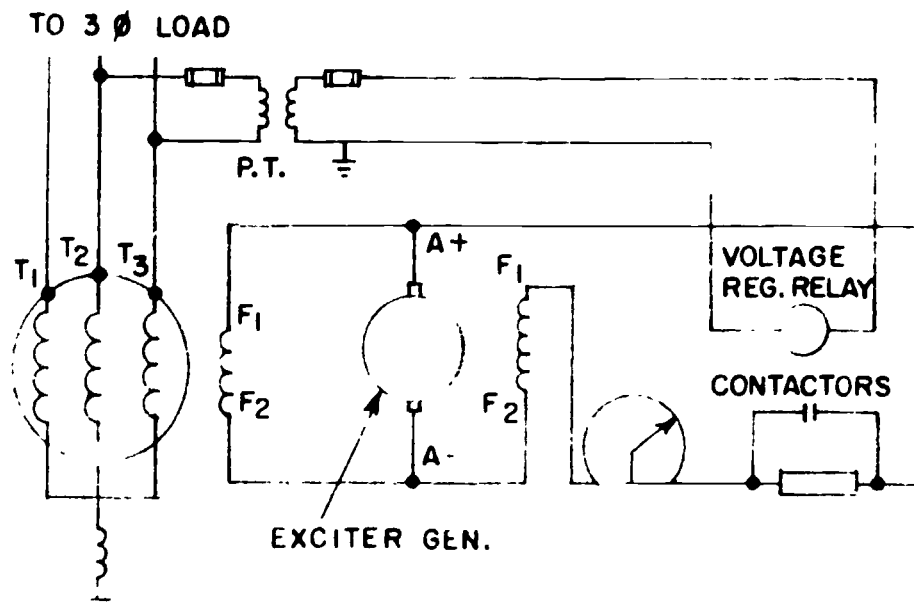
times each second. This results in the exciter generator supplying the alternator field with a relatively fixed value of d-c excitation volts and current. If the generator voltage decreases, the voltage across the relay coil decreases and results in the contactors remaining closed for longer time intervals. As a result, the excitation current supplied to the alternator field increases and the generator output voltage increases, rising to its original value. If changes in the load on the generator cause the voltage to increase, then the contactors will vibrate at a more rapid rate. This means that the time that the resistor in series with the shunt field of the d-c exciter generator is short-circuited is less, and the generator voltage will be lowered to its normal value.

Sometimes it is desirable to regulate so that a constant voltage is maintained at some point on the system external to, or distant from, the station where the generator and its regulator are located. A line-drop compensator is then used in conjunction with the generator or synchronous condenser. The constant voltage at the remote point is accomplished by supplying the generator bus voltage to the regulator after subtracting the line IR and IX drop artificially with the compensator. The generator or

synchronous condenser will then maintain a bus voltage value equal to that point. The wide use of interconnected power systems has eliminated to a large extent the need for line-drop compensators.

Synchronous condensers are usually located in some main distribution substation, particularly those connected with large power systems, to help maintain voltage. A synchronous condenser may be thought of as a kilovar generator. They generate kilovars in the same manner as a conventional generator does. This ability to generate kilovars is a function of excitation. A synchronous condenser is essentially a synchronous motor designed to operate without mechanical load and with a wide range of field control. When they are underexcited they do not generate sufficient kilovars to supply their own needs and consequently must take additional kilovars from the system. When over-excited (normal operation), they can supply all their own kilovar requirements and in addition can supply kilovars to the system. Thus, they may be considered as kilovar generators.

Synchronous condensers have a wide range of field control and are listed having a standard rating from 100 kva at 1,200 rpm to 100,000 kva. Large hydrogen-cooled units have been successfully operated at 3,600 rpm. Hydrogen cooling is particularly applicable to synchronous condensers as the entire unit can be enclosed without shaft seals and, owi g to the high speeds, the reduction of windage losses is an appreciable factor. It is generally not economically advantageous for units smaller than 25,000 to 35,000 kva. Hydrogen cooled units being totally enclosed are readily adaptable for outdoor installation.

Field excitation may be obtained by the same methods as for generators although separate excitation and the fact that generally not more than one or two units are located in a station tend to make direct-connected exciters with pilot exciters more favorable. Direct connected exciters are built within the condenser when the unit is hydrogen-cooled.

A condenser which is required to operate at times underexcited in order to buck the voltage down should be especially designed for this service in order to provide adequate stability and a sufficiently wide range of current.

Automatic voltage control similar to that of generators is frequently provided and has high-speed or quick-response excitation when the condenser is used to increase line or system voltage.

POWER CAPACITORS

A study of this lesson will inform you as to why power companies use power capaci   . You should obtain knowledge of how they are constructed, how they are connected, and how they are applied in substations as well as on lines. Safety procedures when working with, around, or when switching capacitors are stressed. You will learn that these devices may be applied at almost any voltage and may be used in series or connected in shunt with a load.

Directions:

Study the required references and read any additional references that may be assigned by your instructor.

Read each check-up question carefully and write the best answer that you can on all check-up questions.

When you complete your work, examine it carefully, correct any errors that you find, and hand it to your instructor.

Check-up: (3-6-3)

1.   Describe the construction of a power capacitor.

2.   What does the National Electrical Code require for discharging these power capacitors?

3.   How are power capacitors generally rated?

4.   What benefits are obtained by the installation of capacitors on a system?

5.   How may capacitors be applied to high-voltage systems?

6.   Why must disconnect type switches never be used to energize or de-energize large capacitor banks?

7.   How are capacitor banks in substations usually connected?

8.   Explain the difference between shunt-connected capacitors and series capacitors.

9. Are series capacitors ever used on distribution lines? Explain.

10. What is the effect of series capacitors installed in a long transmission line?

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INFORMATION SHEET NO. 15   (3-5-3)

POWER CAPACITORS

From your study of capacitors in previous lessons, you have learned something about the construction of and some of the uses for capacitors and how they are connected. In power stations, capacitors (sometimes called static condensers) are usually assembled in groups made up from individual capacitor cells, commonly called banks. If the capacitor application includes automatic switching equipment, it can also be considered an automatic voltage regulator.

Most switched banks are three-phase and made up of individual capacitor units rated 25, 50, or 100 kvar. Larger banks may be assembled and are directly dependent upon the application. The smaller switched banks are generally factory assembled and come in standard kvar ratings of 225, 300, and 600 kvar and voltage ratings of 2.4 to 13.8 kv. The amount of voltage permissible when switching one step depends largely on the individual utility company. A voltage change of two or three percent is generally acceptable. Often, when a switching operation occurs only two to five times per day, a four or five percent voltage change is permissible.

Both fixed and switched capacitors are used in almost every modern power system. Determining the need for capacitors and their locations in substations and on feeders is usually done by the engineering department. The application of capacitors gives benefits not obtainable by any other method. These include improved voltage levels, elimination or reduction in var transmission with consequent reduction in losses, and release of system capacity plus a var reserve for contingencies.

In order to safely work around these capacitor banks, certain facts and procedures should be kept in mind. The steel frame upon which capacitor cells are mounted is insulated from the metal housing and from ground. It carries the potential of the floating neutral which may be dangerously high if the phases become unbalanced as a result of blown fuses. This frame should be considered energized except when the short and grounding switches at the end of the housing are closed. Although each capacitor cell is normally provided with an internal discharge coil for the purpose of discharging the cells after line potential has been removed, the capacitor may retain a dangerous charge for several minutes.

Capacitor banks must never be energized or de-energized by means of disconnecting switches. Capacitor banks must never be re-energized within less than three minutes after having been de-energized. The three-minute delay is desirable to permit the cells to become completely discharged before they are re-energized. If there is not sufficient delay, excessive transient voltages might be set up in the cells.

The maximum permissible working voltage of power capacitors is 110 percent of rated voltage. Daily operation above this limit will shorten the life of the capacitors.

The function of a shunt capacitor applied as a single unit or in groups of units is to supply lagging kilovars to the system at the point where they are connected. It is connected in shunt and has the same effect as an over-excited synchronous condenser or generator. It supplies the kind of kilovars or current to counteract the out-of-phase component required by an induction motor.

Although previous lessons have covered power factor quite extensively, a brief explanation is added here for the convenience f the student.

By definition, power factor is the ratio of power current to total current flowing in a circuit. When the voltage and current are out of phase, the current may be considered to be made up of the two currents, one in phase with the voltage and the other 90° out of phase with it. The out of phase current is called the reactive or wattless component. It is energy that is being t nsferred back and forth through the circuit with no resulting losses except heat losses due to resistance. This loss occurs in the line and in all current carrying parts.

When the power factor becomes low, large amounts of energy are expended in heating up conductors that, under proper operating conditions, would be available for useful work. An inductance in a circuit will cause the current to lag with respect to voltage, and a capacity will cause it to lead the voltage.
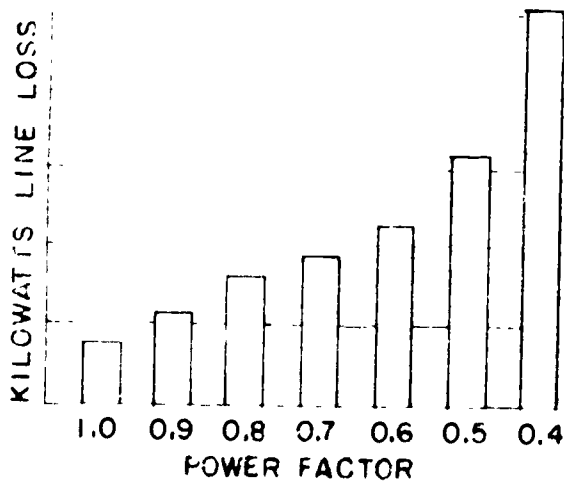
EFFECT ON DISTRIBUTION LOSSES

Energy loss in transporting current increases per kilowatt as the power factor goes down. Line loss varies as the square of the line current.
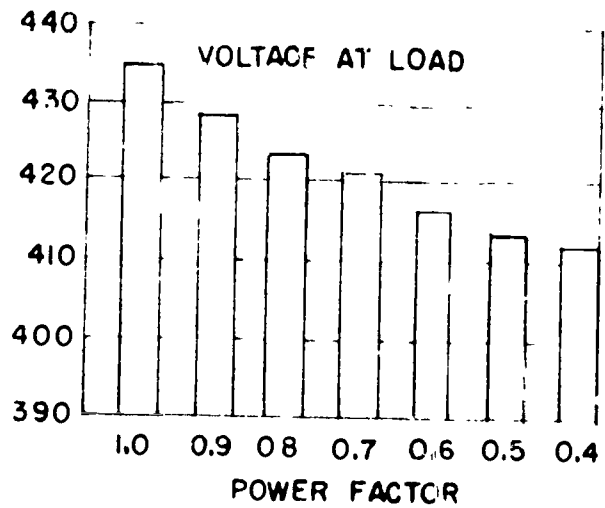
EFFECT ON VOLTAGE REGULATION

Voltage loss in conductors increases with low power factor because of larger current for a given kilowatt load, the g eater lagging phase relati ip.

Apparatus such as transformers, induction furnaces, fluorescent lights, and induction motors having magnetic fields require a magnetizing kva just as a generator requires field excitation. This magnetizing kva is 90° out of phase with the voltage and adds to the wattless component that is carried by the line and is metered in the substations as kilovars. Capacitor banks may be thought of as a kilovar generator. When a capacitor bank is connected in a substation feeding from a bus, it will cause kilovars to flow out of the capacitor bank and into the bus.

The excitation current must be supplied from some type of equipment. Some may be supplied by a-c generators, some by synchronous condensors or motors, and some by capacitors. The desirable solution is usually a combination of all the methods. In each power system, the problem of correcting power factor will be somewhat different as the how much, where, and when depends on many factors.

Capacitors may be applied at almost any voltage. They are a building block type of device by which kvar can be added by adding units in parallel; required voltage can be obtained by units in series. This ability to add capacitors in series to obtain any desired voltage and to add capacitors in shunt to get desired total kvar makes the application of high-voltage capacitor banks a relatively simple matter. High-voltage banks are usually large banks, and more elaborate protection and control schemes can be justified.

Capacitor banks in substations are usually wye connected. On delta systems they are always ungrounded wye connected; on four-wire systems they may be either grounded or ungrounded. Most substation banks are relatively large banks with individual fuses. High-voltage banks are also usually wye connected. The protective scheme of the bank determines whether it is ground or ungrounded.

The control on switched capacitor banks may be preformed manually, but the general trend is to apply automatically switched capacitors where voltage relief is needed and used in conjunction or coordination with step type voltage regulators. Time, voltage, current, or combinations of each are all sources of intelligence used to switch capacitors. Time and voltage are the most common intelligence sources used. With time-switch control the capacitors are switched on at a certain time of day and switched off at a later time. The daily load cycle must be consistent and the daily voltage variations must be known. Voltage control for initiating capacitor switching is very similar to the voltage control method used with feeder voltage regulators. With voltage control, a time delay is also required to prevent unnecessary switching due to momentary disturbances. The use of voltage control requires coordination with other voltage regulating equipment so that the operation of one device (switched capacitor or regulator) will not cause an operation of another device.

It is not the intent for switched capacitor applications on distribution systems to give a fine voltage control. The voltage regulators on the distribution feeders are meant to do this. Current control alone is used only where voltage is not a satisfactory signal. There are several types of voltage-current controls available, however, which are commonly used.

The device to be used for switching capacitors requires special consid-
eration. Capacitance load switching presents some unusual problems. Initial
interruption will occur at current zero. Because the current leads the
voltage by 90 degrees, system voltage at this instant will be peak and the
charge on the capacitor is maximum. Following current zero the voltage on
the source side is equal to the generaced voltage. The trapped charge
remains on the capacitor, the system voltage then decreases toward zero, and
the voltage across the interrupter contacts is that of a sine wave offset by
the charge on the capacitor. It reaches a maximum of approximately two times
the crest of the source voltage in one-half a cycle after current zero. In
certain three-phase switching the maximum voltage across the contacts of the
circuit breaker may reach values as high as 4.12 times phase to neutral
voltage. If the voltage across the contacts exceeds the dielectric strength
of the opening, current flow will be re-established and a restrike may occur.
Restriking in a circuit breaker can lead to the build up of high transient
overvoltages on the power system.

Another characteristic of capacitor switching is the high frequency
transient current which flows into a capacitor bank when it is energized.
For large banks and for higher voltages, it is generally necessary to use
some supplementary means, such as a resistor, in the switching device. Oil
breakers having such resistors are available.

The use of series capacitors has been limited to some extent for many
years. That is, a static capacitor in series with a transmission line,
because it presented problems that, until recently, had been unsolved. A
series capacitor compensates for inductive reactance when inserted in a
transmission line. It is desirable to operate the transmission line in a
manner which keeps the I^2R losses at a minimum. This condition is realized
when the line currents flow into a load which is practically all resistance.
Figuratively, the series capacitor eliminates the element of distance in
power transmission and gives the same voltage condition at the receiving end
of the line as at the sending end, except of course, for the effect of line
resistance. The shunt capacitor gives a constant voltage boost which is
independent of the through current as long as the through current causes no
appreciable voltage change. The series capacitor, on the other hand, gives
a voltage rise which increases as the load increases.

The capacitance on a transmission line increases with the length of the
circuit and the square of the voltage between phases. This is counteracted
with the use of shunt reactors on extremely long lines. Thus, by utilizing
series capacitors on extremely long lines, the characteristics of d-c trans-
mission can be obtained and the advantages of the a-c system retained.

Series capacitors are sometimes used on distribution lines to provide
automatic voltage regulation. However, there is the possibility of undesir-
able phenomena occurring, usually involving some kind of resonance. The
cost of applying series capacitors plus the cost of the protective devices
necessary is more expensive than the use of fixed and switched shunt capaci-
tors or voltage regulators. They are used mainly where excessive voltage
dip and objectionable lamp flicker are encountered. Construction-wise,
shunt and series capacitors are identical.

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When capacitors are located on the load side of the voltage regulator, it is necessary to correct the compensation setting. With the capacitors on the load side, the capacitor current will flow through the line-drop compensator. It is necessary that the voltage drop due to the capacitor current in the compensator be equal to the voltage drop in the line. If the capacitor bank is located on the source side of the regulator, proper regulator operation will occur because the capacitor current does not flow through the regulator in most installations. When capacitors are added on the source side, the input voltage of the regulator changes and, if necessary, the regulator will operate to maintain the desired voltage at the regulation point so proper voltage control is achieved.

A certain percentage of shunt capacitors now in use are installed on the primary feeders. This is because maximum benefit is obtained if the capacitor is located as near the load as practical. Most of these primary feeder applications are in pole-mounted racks. Apparatus such as transformers and induction motors having magnetic fields require a magnetizing kva just as a generator requires field excitation. This mag-kva is 90 degrees out of phase with the voltage and adds to the wattless component that is carried by the line. Lightly loaded transformers or induction motors reduce the power factor to much greater extent than when fully loaded because the wattless component is greater in proportion. Induction motors and other inductive apparatus take a component of current which lags behind the line voltage and thereby lowers the power factor of the system. A noninductive load, such as in incandescent lamps, takes only current in phase with the voltage. As transformers require magnetizing current, they may seriously affect the power factor when unloaded or partially loaded, but when operating at full load, their effect is practically negligible.

Shunt capacitors are sometimes located at the load on the secondary level. A capacitor may be installed in shunt with any load of low power factor to supply the magnetizing current of the load. The load may be a single motor or it may be a large industrial plant.

Power capacitors are generally rated in kilovars. This is related to the farad unit by

$$kvar = \frac{E^2 \; 2\pi f C(10^{-6})}{1000}$$

Where E = rated rms voltage
f = frequency, cycles per second
C = capacitance, microfarads.

The kvar required to correct any given power factor to any desired power factor is entirely dependent on the kw load. A capacitor bank which would correct a 1,000 kw load from 50% power factor to unity power factor would only increase the power factor to 76% if the kw load became 2,000.

The chart on page 4-126 of Croft's American Electricians' Handbook may be used to determine the percentage reactive kva required to raise the power factor to a desired value.

An approximate formula which is sometimes useful when applying capacitors to a feeder or radial line is

$$\text{Percent voltage rise} = \frac{(\text{kvar})(\text{d})(X)}{10 \text{ kv}^2}$$

Where kvar is the total kilovars in a three-phase capacitor bank, d is the distance in miles from the bus to the capacitor bank, X the reactance of the feeder in ohms per mile, and kv the line to line system voltage in kilovolts. This gives the percent voltage rise, caused by the capacitor.

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ELECTRICAL POWER STATION THEORY

UNIT VII

CONTROL ELECTRONICS

This unit contains the following lesson:

Lesson 3-7-1: Introduction to Electronics

INFORMATION SHEET NO. 16   (3-7-1)

INTRODUCTION TO ELECTRONICS

Formerly, the course of study for wiremen and electricians included very little electronics. Because of the steadily increasing part played by the electronics industry in developing new applications and new technics for all forms of control equipment, the modern trend toward solid-state in various forms of supervisory control, computer systems, load controls, and modern high-speed relaying, the wiremen of the future must have training in this field in order to be proficient in their trade.

Semiconductor technology is usuall refe_._d to as "solid-state." This suggests that the material used in the fabrication of the various devices is a solid and that conduction of electricity occurs within a solid material instead of a vacuum or a gas filled tube. Actually the so-called solid is not solid, but only partially so. In the world of the atom, there is mostly space, and scientists have uncovered the basic ingredients that make up our world. From these basic ingredients the semiconductors have been developed.

Transistors and diodes are made from semiconductors, so-called because they lie between the metals and the insulators in their ability to conduct electricity. A transistor is not filled with a vacuum as is the vacuum tube, and electrons are not boiled off a filament c cathode since there is no filament or cathold. Conduction within the transistor is a function of the material of which the transistor is composed and of its composition from an atomic and subatomic standpoint.

There are many semiconductors, but none quite so commonly used as germanium and silicon, both of which are hard, brittle crystals. In the structure of pure germanium and silicon, single crystals, the molecules, are in an ordered array, i.e., a definite and regular pattern exists among the atoms due to space equality. Tubes act as variable conductors in a circuit because the electron flow or current is controlled to the external circuit by various voltages applied to the electrodes. In a semiconductor, the outermost (valence) electrons are neither so tightly bound to the atom as an insulator nor so loosely held as in a conductor. Impurities added to pure germanium or silicon will cause a change in the lattice structure, which might add a free electron or create a hole. A hole is considered as an electron deficiency. The importance of the hole is that it may serve as a carrier of electricity and a free electron from a neighboring atom may drop into it.

If the electrons greatly outnumber the holes in the crystal, the crystal is negative in nature and called an "n-type" semiconductor. Inasmuch as electrons and holes are present in the crystal, both will contribute to the conduction process. In "p-type" material, just as in n-type, both holes and electrons exist, but the predominating holes are the majority carriers. To summarize, solid-state conduction takes place in semiconductor crystals by the movement of charge carriers known as holes and free electrons. A "hole"

can exist only in a semiconductor material. Since it depends for its exist-
ence upon the right type of crystalline structure, a hole cannot exist in a
conductor. The concept of holes is based on actual fact. It is the basis for
understanding transistors and is so presented in all transistor textbooks.

One of the simplest and most commonly used devices is the unidirectional
semiconductor crystal. Certain types of crystals, such as germanium, have
the property of permitting electrons to flow through them in one direction
only and are referred to as diodes. The germanium diode is in the same semi-
conductor class as the transistor, being composed of the basic germanium
element and chemically altered by the addition of another element to form a
P-N junction. A P-N junction is that line of demarcation between P-type
material and N-type material and is essential to its operation. The excess
electrons on one side of the junction combine with holes on the other side
of the junction and cause a depletion region to be formed.

This depletion region is present even if no external battery is applied
to the P-N crystal. It can be made larger by connecting an external battery
of the proper polarity to it. A diode so connected is said to be reverse
biased, and current flow in the circuit is prevented.

If the battery is connected to the crystal so as to reduce the size of
this depletion region, it is said to be forward biased. If the forward bias,
or voltage of the external battery, is great enough to reduce the size of
this depletion region to almost nothing, current flows in the circuit. Thus,
we have the well-known rectifying action of the semiconductor diode.

Diodes of various types are frequently employed in industrial electronic
circuitry. Selenium diodes have been used extensively as rectifiers in power
supplies for converting a-c to d-c. They are made up of stacks of individual
rectifier plates which can be copper, aluminum, or magnesium, on one side of
which is deposited a crystalline semiconductor layer of selenium. They have
been used in battery chargers where they handle several amperes of current.
Many multi-layer, larger types have been employed to provide larger currents
for the solenoid closing coils on power circuit breakers. Since the advent
of the silicon diode with its many advantages, the selenium diode has been
used less frequently in modern equipment.

For handling power from low to very high values, the newer type silicon
junction semiconductor diode is extensively used in the many branches of
industrial electronics. It is not only used in rectification, but for regu-
lation, switching, and blocking of electrical circuits.

For comparable ratings, the silicon rectifiers are much smaller than
selenium types, have greater efficiency, and are able to pass much higher
currents. On the larger types, a threaded mounting stud is provided so that
the unit can be bolted to a chassis called a heat sink. This helps to dis-
sipate the heat and enables the diode to operate at even higher current
ratings.

The construction of diodes is such that the anode is always positive P
material, the cathode is always negative N material and conduction (passing
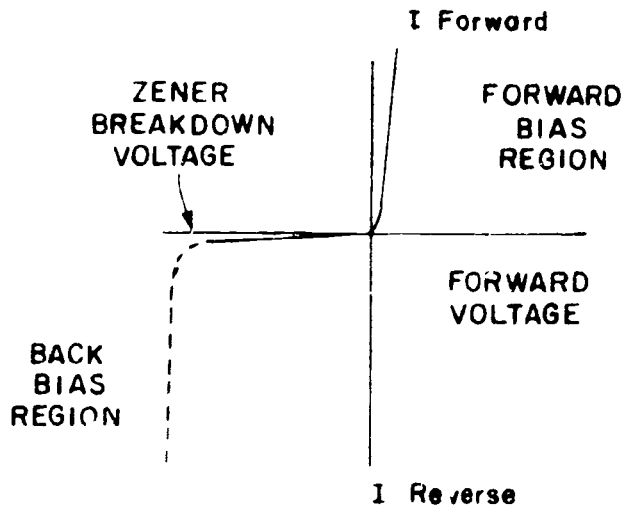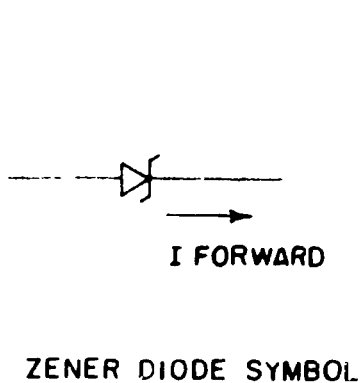
of current) occurs when positive potential is applied to positive P anode
and negative potential to negative N cathode (forward bias). Blocking occurs
when negative potential is applied to positive P anode and positive potential
to negative (reverse bias).

BIAS OF PN JUNCTION
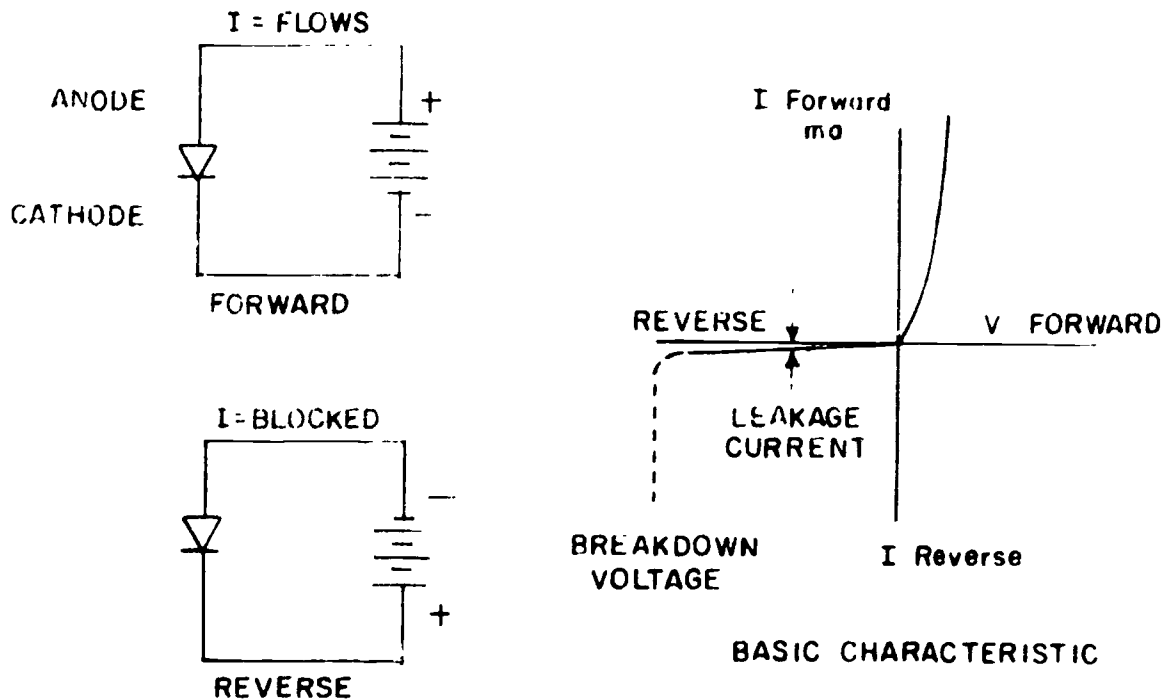
An important feature of the silicon junction diode is the unusual break-
down characteristic of the unit. On the forward bias side, the silicon diode
has very little resistance to the current flow. When reverse voltage is
applied (starting at zero point) the resistance of the unit is high. If the
reverse voltage is increased, a critical point will be reached where suddenly
the resistance will drop to a very low value or "breakdown" which, unless
current flow is limited, will cause the diode to be destroyed. This charac-
teristic is utilized in the zener diodes which are the junction type with a
large cross-section of silicon and, since the breakdown is not damaging, the
diode conducts enough current in the reverse direction to maintain a nearly
constant voltage drop across the diode. The breakdown point is known as the
zener region and zener diodes are available in voltage ratings from 4 to 600
volts.

A single diode inserted in an a-c circuit which results in the current
flowing only every other half cycle is called half-wave rectification. Full-
wave rectification changes both halves of the a-c input into a pulsating d-c
output. Essentially, two half-wave rectifiers are applied to each alternate
half of the a-c input, resulting in both halves of the input being changed in-
stead of just the positive half as with half-wave rectification. A full-wave

ZENER
BREAKDOWN
VOLTAGE

I Forward

FORWARD
BIAS
REGION

FORWARD
VOLTAGE

I FORWARD

ZENER DIODE SYMBOL

BACK
BIAS
REGION

I Reverse

ZENER DIODE CHARACTERISTIC CURVE

rectifier utilizes full a-c voltage, and the half-wave rectifier uses only half the voltage available at the a-c source. The common arrangement for this full-wave is the bridge-type rectifier.

I

R

+

—

A.C. VOLTAGE
INPUT

+

—

TIME

CURRENT 1

TIME

CONVENTIONAL CURRENT
FLOW
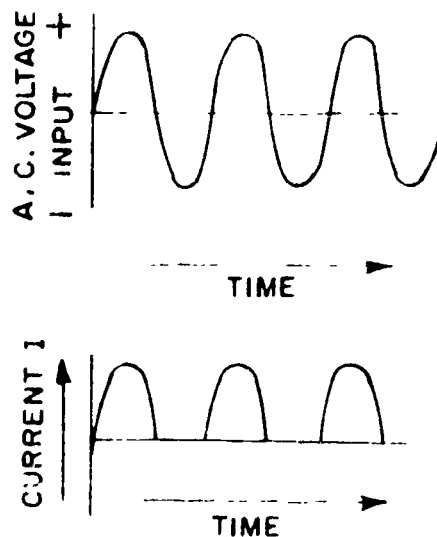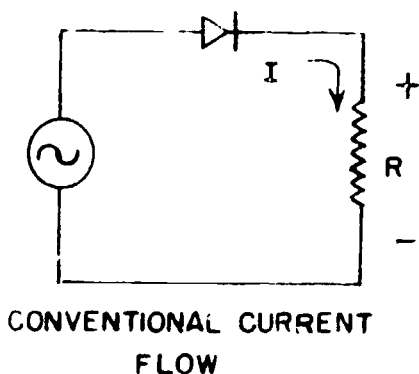
HALF-WAVE RECTIFIER CIRCUIT

INPUT AND OUTPUT WAVEFORM

Output voltages from these rectifier circuits contain significant ripple. A device for eliminating the ripple if the rectifier is to be used as a power supply is called a filter. Ripple is a fluctuation of d-c output that usually contains an a-c component superimposed upon d-c voltage. A capacitor filter has a low value of capacitive reactance and acts as shunt for the ripple-frequency component of the pulsating d-c, thus helping to

produce a ripple-free d-c output. When filtering high-power a-c, the filter
network requirements can be reduced considerably by rectifying from a three-
phase system.

Three diode rectifiers are all that is necessary for full-wave rectifica-
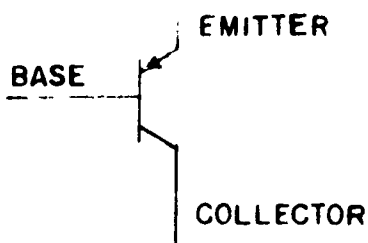tion, because each diode will rectify one segment of the three-phase a-c.

THREE-PHASE RECTIFICATION
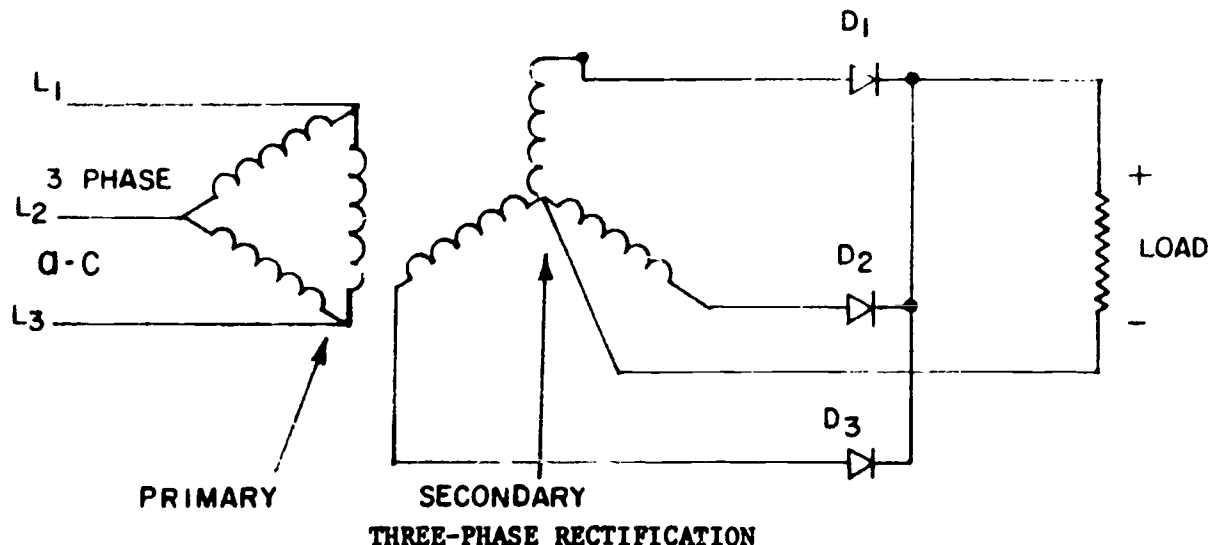
The zener diode is useful in voltage regulations. The zener diode
breakdown characteristic which is not damaging occurs at a specific reverse
pote⁻ᵗial amplitude. A current limiting is chosen to hold the diode in the
zener region. The voltage drop across the diode remains constant even though
current-drain variations caused by the load alter the voltage of the circuit.
The regulated ou_ut voltage will rem. n substantially constant so long as
the diode is operated in the zener region.

Transistors are solid-state devices chemically bonded together to form
a PNP or NPN transistor. If the first and third section of this device is
composed of P-type material and the second, or center section of N-type
material, it is called a PNP transistor. If the first and third section is
composed of N-type material with the center section composed of P-type
material, it is called a NPN transistor. As you can see from the configura-
tion, it has three wires coming out of it, and is composed of three different
sections.
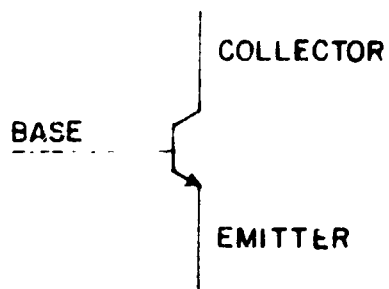
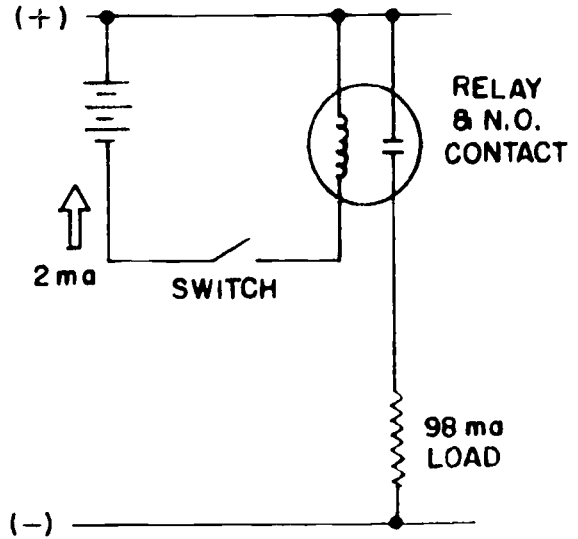NPN TRANSISTOR CONFIGURATION   PNP TRANSISTOR CONFIGURATION

A transistor has a collector, a base, and an emitter. The base is the normal controlling element for the transistor. A collector might be said to collect the current into the transistor. The emitter, which carries current that is common to the base and the collecto., emits the current from the transistor. Note in the configuration that the base lead is shown leaving the body of the transistor at right angles to it, and that the emitter and collector leads leave at an angle. Furthermore, the emitter lead bears an arrowhead, the direction of which differs between the tjo types. This arrowhead points in the direction of conventional current flow - opposite from the direction of the electrons themselves. Normally a transistor is not labeled as being a PNP or NPN transistor; the direction of the arrowhead conveys this information.

A transistor is a variable resistor. Its resistance can vary, depending upon the base current, from zero ohms to infinite ohms. This resistance can vary just about as fast as you wish it to; that is, with exactly the frequency of the input signal. (It will operate at megahertz.) Compared to vacuum tubes, transistors require much less power for operation. They are fairly rugged and have an exceptionally long life. The high value of "off" resist- ance and low value of "on" resistance associated with a transistor make the device valuable for switching applications. It is easily controllable from the base lead. This is because a relatively small current in the base can control a large current in the collector. This switching gain makes the transistor a very versatile device.
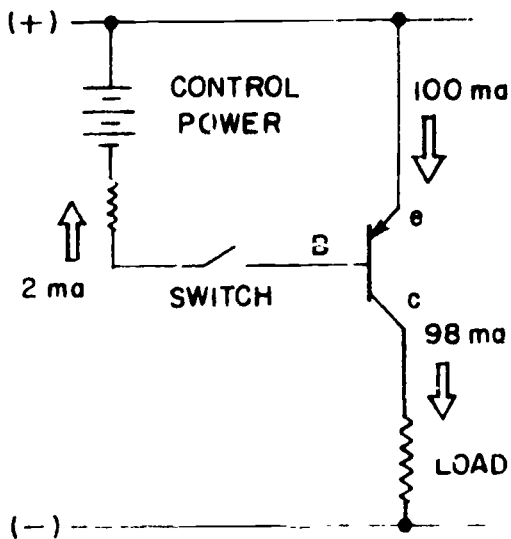

PNP TRANSISTOR CIRCUIT   RELAY ANALOGY

When we use the transistor as a switch we change the resistance from zero ohms to inf` ite ohms in one step - and that's exactly what takes place in any switch or relay contactor. If we take the above circuit with its toggle switch and resistor to the base lead and its resistor load in the collector lead as an example, let us assume that 100 ma flows into the

emitter, 2 ma flows out of the base, and 98 ma flows out of the collector
to the load. If the toggle switch in the base lead is a very delicate con-
struction and it is able to safely interrupt only 2 ma, it is still perfectly
safe in operating as shown. The opening of the toggle switch, and thus the
direct interrupting of 2 ma, will cause to be interrupted the 98 ma collector
current. The resistor in the base lead is simply a protecting resistor.
(The emitter-base junction of a transistor is a simple forward-biased diode,
and unless some sort of resistor is inserted in the circuit the junction will
rapidly destroy itself.)

The silicon-controlled rectifier differs from the ordinary silicon diode
by virtue of its combining some of the characteristics of both the solid-state
diode and the transistor. It has a special "gate" lead placed beside the
usual cathode lead and hence has three terminals as does the transistor. The
silicon-controlled rectifier has characteristics similar to the gas-tube
thyratron discussed in Croft's American Electricians' Handbook on page 6-23;
hence, a signal applied to the gate will cause conduction, and the latter
continues even after the signal is removed and is analagous to a self-
latching relay. Once turned on it remains on until turned off by an external
event.
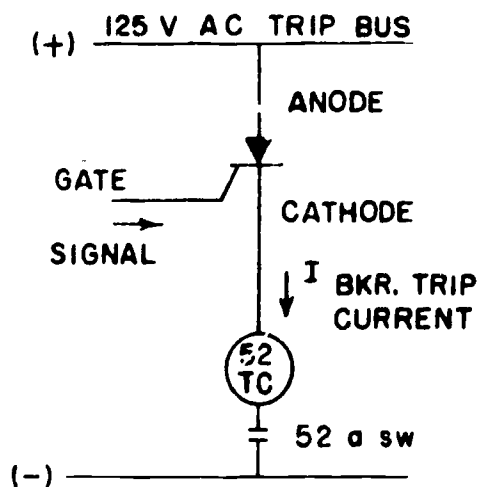
SILICON CONTROLLED RECTIFIER
USED AS A BKR TRIPPING RELAY

Small package size, high efficiencies,
high voltage ratings (up to 1,000 volts)
and high currents (up to 400 amps and
more) make this device very useful in
control applications. In general, the
SCR can withstand extremely large over-
currents for short periods of time.
Transients in the order of ten times
normal full-load currents are possible
without damage. Care must be taken for
the gate circuit, because both over-
voltage and overcurrent can burn out
this element usually resulting in a
short circuit from the cathode to the
anode.

The unijunction transistor is a three
terminal device composed of emitter, base 1,
and base 2. As its name (unijunction)
implies it consists of but one junction;
however, it is still a three-terminal device.
The most usual application for the unijunc-
tion transistor is in trigger circuits. If
zero (or reverse) voltage is at the emitter,
the bar acts as a conventional resistor.
There is no current between the emitter and
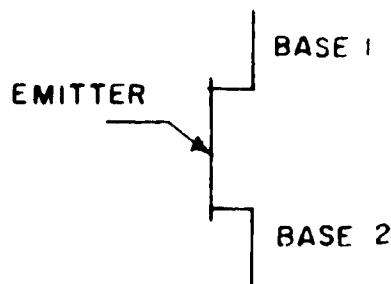
UNIJUNCTION SYMBOL

the semiconducting material until the voltage on the emitter becomes high enough. When the emitter turns on, it is effectively connected to base 1 by the impedance of a forward diode. The impedance between base 2 and the emitter remains high in the order of several thousand ohms.

The semiconductor devices listed here are only a representative few. Researchers will continue to develop more and more of these devices and find ever expanding uses for them.

Transistor means a voltage transferred across a resistor. A transistor is neither a good insulator nor a good conductor. The control feature of the transistor comes from the fact that a small voltage applied at the emitter will cause current to travel in the collector.

Careful attention when soldering transistors in a circuit should be given to avoid overheating the pigtails. If, during soldering, the maximum specified junction temperature of a device is exceeded, the device can be destroyed. Use heat shunts (clips, pliers, etc) connected between the heat source and the device, and a soldering iron of adequate heat delivery for the job to be done cleanly and quickly. Excessive power will also cause exceeding the maximum junction temperature of a transistor and can permanently destroy it. Excessive voltage can also cause damage to solid-state devices. Voltage spikes can rupture (result in punch-through) or internal short from collector to emitter.

When connecting a transistor into a live circuit, the base lead must always be connected first. In disconnecting the transistor from a live circuit, the base lead must be removed last.

Semiconductor material is hard and brittle and can be damaged by high impact shock. Any high impact shock can cause fracture of the semiconductor material, or lead breakage, resulting in complete ruin of the transistor. This is especially true of transistor leads at the point where they enter, or attach to, the header. Some leads when bent during testing and handling may easily break. Excessive bending and twisting of the leads can generate cracks in the transistor housing. Such cracks offer openings for moisture to enter and contaminate the device. To avoid this it is always well to allow at least 3/32" to 1/8" clearance between the header and the start of a lead bend.

If it is at all possible, transistors with short leads should not be soldered directly into the circuit. Several types of sockets will accommodate these short leads. If soldering is necessary, remember to use a heat shunt and solder cleanly and quickly.

When measuring resistance of a transistor with an ohmmeter at least two transistor leads must be disconnected from the circuit. Transistors can generally be checked with an ohmmeter as follows:

PNP - Put the negative meter lead on the base. Connect the positive lead to the collector and then to the emitter. The meter should show a low

resistance. Then reverse the leads by putting the positive lead on the base. The meter now should show a high resistance to both emitter and collector.

NPN - Put the positive meter lead on the base. Connect the negative lead to the collector and then to the emitter. The meter should show a low resistance. Then reverse the leads by putting the negative lead on the base. The meter should show a high resistance to both emitter and collector.

A ohmmeter (ordinary v.o.m.) can also be used to check silicon and selenium diodes by measuring front to back resistance to determine if they are defective or not. Be sure to connect the v.o.m. lead that is positive to the anode of the diode and the negative lead to the cathode for a forward-resistance measurement. Then simply reverse the leads to measure the back resistance. Silicon diodes will have a much greater front-to-back ratio than selenium diodes.

The transistor symbols for both types are shown in your reference book on page 6-65 and show the direction of conventional flow just as in the rectifier symbol. The most popular of the many transistor case styles are shown below. Note that the collector is connected to the case in most transistors.
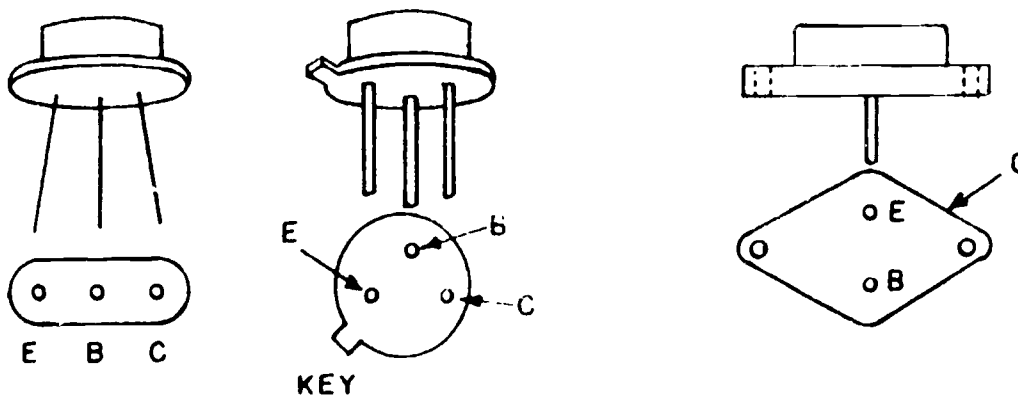

KEY

TRANSISTOR CASE STYLES

	METER TERMINALS	POS.		NEG.	OHMS
A sample test of a		C	to	E	50k ohms
PNP transistor made		E	to	C	3k ohms
with a Simpson v.o.m.		C	to	B	200
having an internal		B	to	C	60k ohms
1 1/2-volt battery		E	to	B	200 ohms
		B	to	E	150k ohms

One example of statics finding great application in protective relaying and circuit breaker control circuits is the tripping diode or "TRB" static tripping unit manufactured by Westinghouse. As advertised, the Westinghouse diodes used in the TRB Static Tripping unit will: (1) carry 30 amperes for one second; (2) are suitable for 48/125 or 250 volt d-c operation; having a

peak inverse voltage of 300 and 600 volts, respectively; (3) easily meet the ASA standard for range of operating temperature of -20° to +40° C. The TRB has no moving parts and requires no maintenance. A typical application is illustrated.

SUBSTATION BUS

LINE POSITION

ONE-LINE DIAGRAM

D. C. TRIP BUS
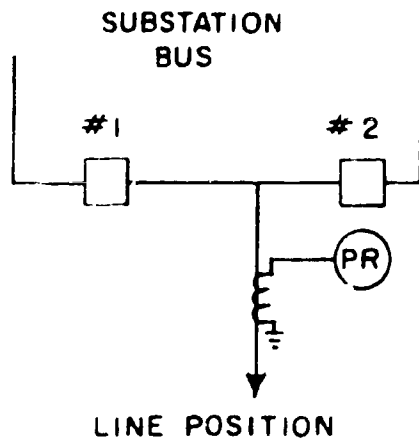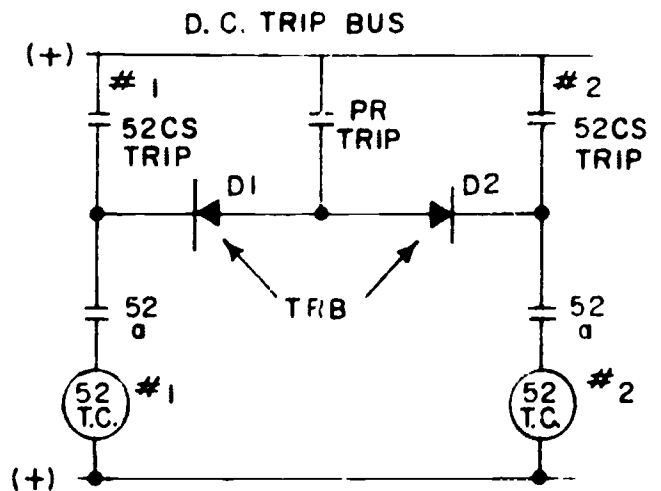
SCHEMATIC DIAGRAM

The use of a tripping diode in this scheme eliminates the one-half cycle of tripping time usually present when an auxiliary electro-mechanical relay is used with high-speed protective relays. Control switch #1 trips breaker #1, and similarly, control switch #2 trips breaker #2. The contact of the protective relay will trip both breakers. The operation of the #1 control switch will trip only breaker #1. Using the TRB unit, current cannot flow from the control switch #1 to breaker trip coil #2 because of the polarity of diode D-1. Controls associated with each particular breaker are isolated from the other breaker, yet both breakers can be tripped by operation of the protective relay. This scheme is often employed where two breakers are often employed to clear a faulted line as would be the case in a ring bus or the breaker and half scheme illustrate\` by the one-line diagram.

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