

5 | Substation Overview

Course Outline

1. Introduction to WECC
2. Fundamentals of Electricity
3. Power System Overview
4. Principles of Generation
5. Substation Overview
6. Transformers
7. Power Transmission
8. System Protection
9. Principles of System Operation

Overview

- Purpose of Substations
- Substation Equipment
- Substation Control House
- Substation Bus Configurations

Purpose of Substations

- In general, a substation is a power system facility that contains power system components such as:
 - circuit breakers and other switchgear
 - transformers
 - reactors
 - capacitors

Purpose of Substations

- A substation usually includes a control house that contains equipment such as:
 - protective relays
 - meters
 - alarm annunciators
 - communications equipment

Purpose of Substations

- An indoor substation houses all electrical equipment within the walls of a building. Indoor substations may either be entirely underground or look similar to other buildings in the neighborhoods that they serve.

Purpose of Substations



Purpose of Substations

- Outdoor substations have the same equipment as indoor substations but the equipment is located outside where it is exposed to natural elements, rather than in a building. The equipment is usually enclosed within a fence.

Purpose of Substations



Purpose of Substations



Purpose of Substations

- **Ground Mat**

- Substations usually include a ground mat. A ***ground mat*** is a system of bare conductors, on or below the surface, connected to a ground to provide protection from high voltages.



Purpose of Substations

- One purpose of a substation is to contain the equipment for changing electric energy from one voltage to another. Substations also enable one or more of the following functions to be accomplished:
- Switching operations
 - Substations connect or disconnect elements of the power system, using circuit breakers and/or switches.

Purpose of Substations

- Reactive power compensation
 - Utilities install synchronous condensers, shunt reactors, shunt capacitors, and static VAR compensators at substations to control voltage.
 - Utilities install series capacitors at substations to reduce line reactance.



Substation Equipment

- In this section we describe the function and operating principles of the following power system components:
 - Switchgear Equipment
 - Capacitors
 - Reactors
 - Ground Switches
 - Lightning Arresters
 - Wave Traps

Switchgear

- ***Switchgear*** is a general term given to switching and interrupting devices. Switchgear equipment is commonly contained in metal-enclosed units. However, at higher voltages, the equipment may or may not be in metal enclosed units.
- Switchgear equipment performs two separate functions.

Switchgear

- Under normal conditions, switchgear equipment enables routine switching operations to occur.
- For example: Switchgear equipment disconnects and isolates a piece of equipment so maintenance work can be performed.
- Under abnormal conditions, switchgear equipment automatically disconnects faulted equipment from the rest of the power system as soon as possible, in order to minimize damage. Under these conditions, switchgear equipment performs a protective function.

Switchgear

- All switchgear operates by pulling apart electric conductors (contacts). As the contacts are drawn apart while power is flowing through the device, an arc forms between the contacts. The arc is drawn out in length as the contacts open. To interrupt current flow, the arc must be extinguished with a dielectric substance, such as air, oil, or sulfur hexafluoride (SF₆).

Switchgear

- We discuss the following types of switchgear equipment:
 - Circuit Breakers
 - Load Break Switches
 - Disconnect Switches
- We examine the function and operating principle for each of these.

Circuit Breakers

- Circuit breakers disconnect circuits or equipment from the power system. A circuit breaker's primary function is to interrupt current flow under load or fault conditions.
- Circuit breakers rapidly isolate faulted portions of the power system. They also provide a means to carry out routine switching operations, such as disconnecting a device to conduct maintenance.

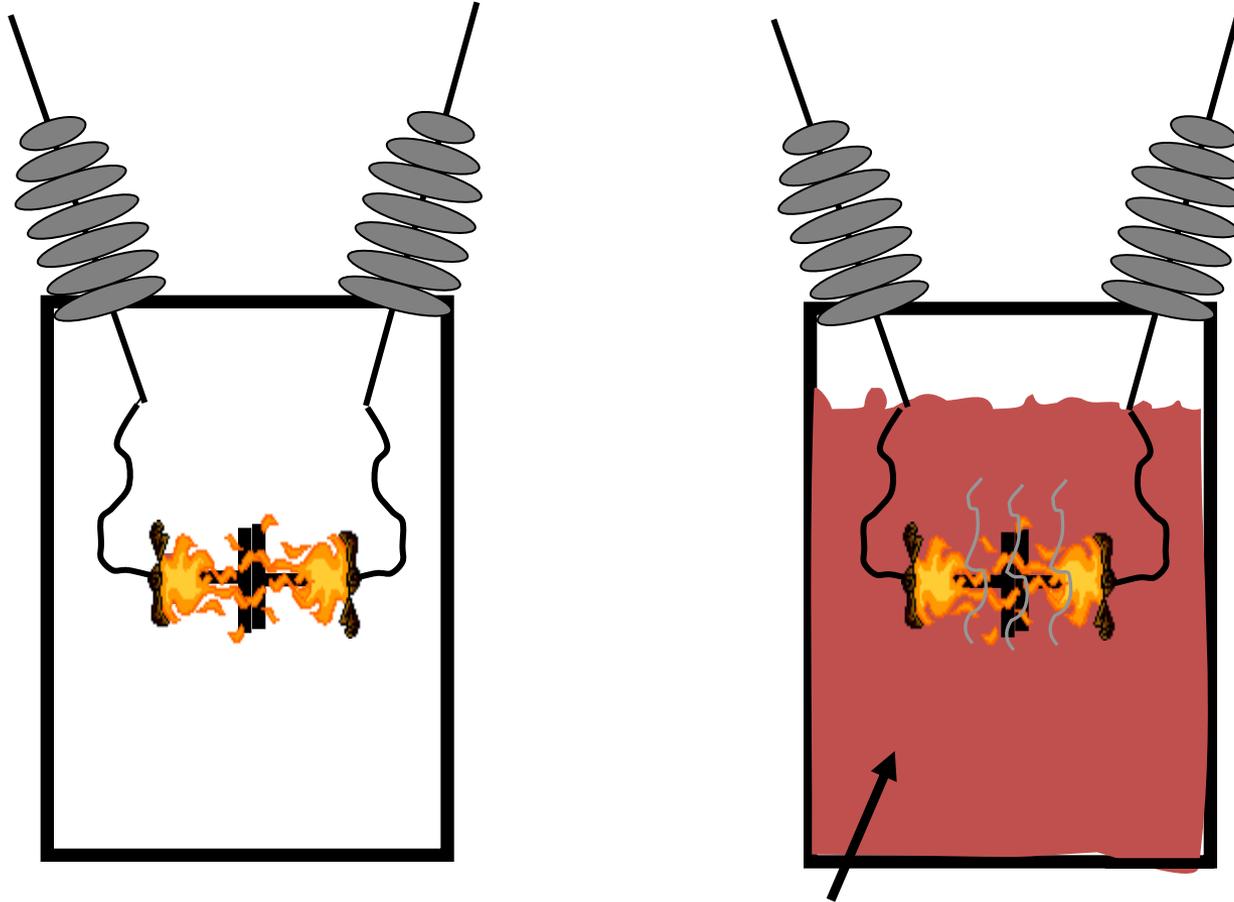
Circuit Breaker Operating Principles

- To interrupt the current, the circuit breaker must trip. Let's examine the mechanics involved in tripping circuit breakers under fault conditions.
- When a fault occurs, relays sense the fault and initiate the opening of the circuit breakers related to the faulted equipment by energizing the circuit breakers' trip coils. ***Module 8: System Protection, presents the details on the operation of relays.***

Circuit Breaker Operating Principles

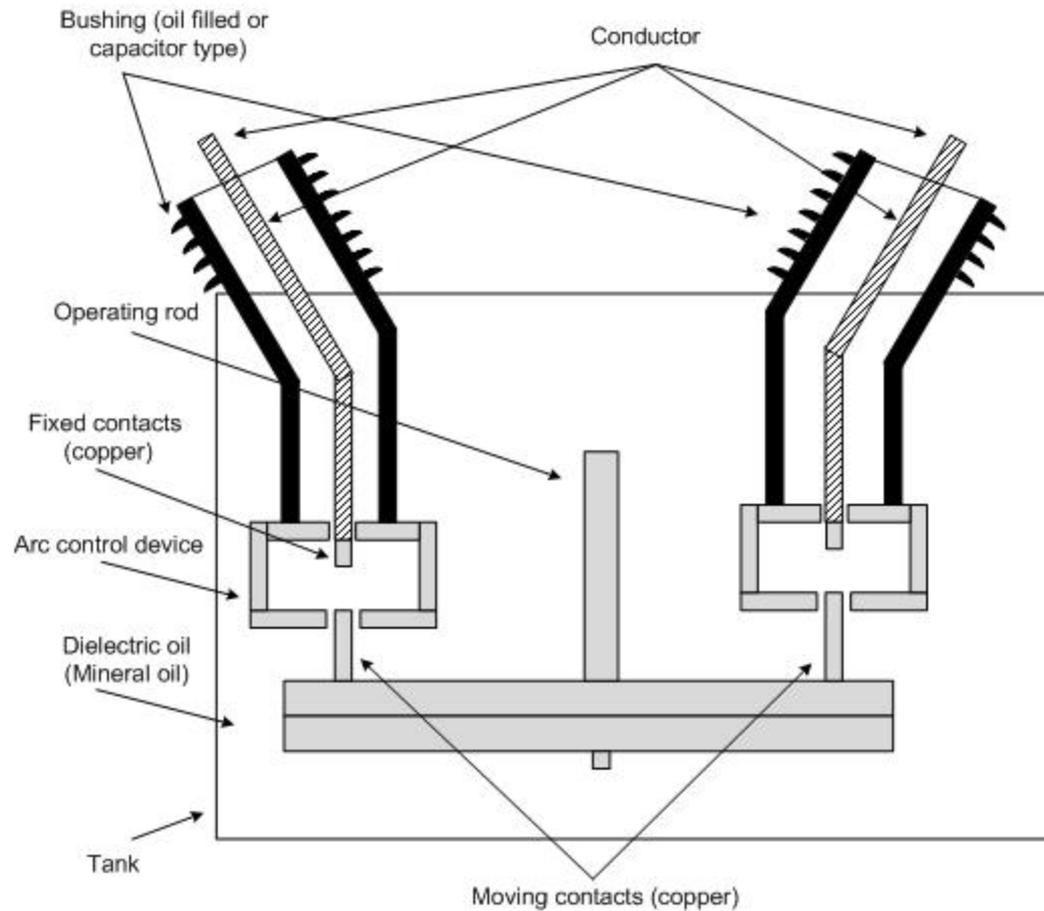
- The circuit breakers open for a pre-determined time period based on the reclosing relays settings. After the pre-determined time period, the reclosing relays signal the close coils to close the circuit breakers. The time delay is sufficient to allow the arc to extinguish.
- If the fault still exists after reclosing (e.g., if it is a permanent fault, such as a conductor touching the ground), then the relays signal the circuit breakers' trip coils to open the circuit breakers again, this time permanently.
- ***Note: Not all circuit relay schemes include reclosing relays.***

How an Oil Breaker Works



Insulating Oil

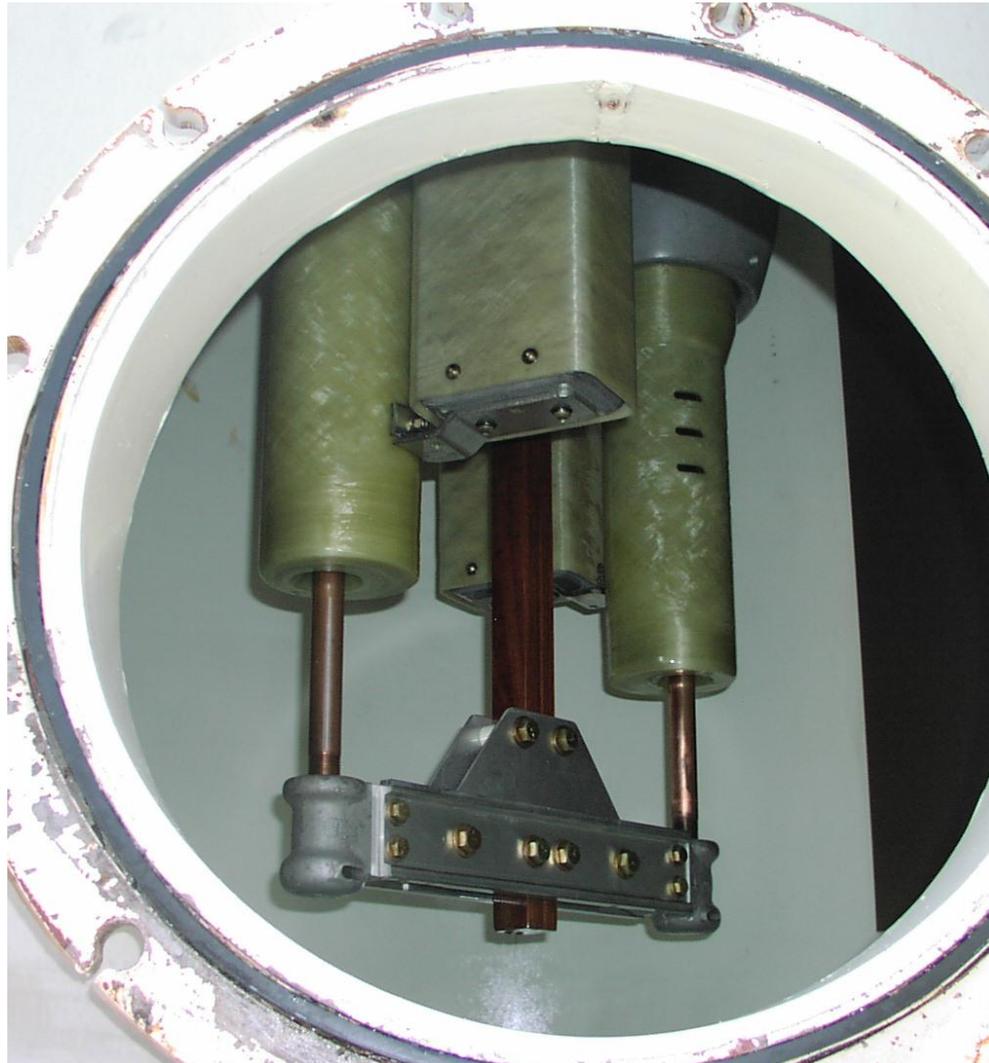
Circuit Breaker Operating Principles



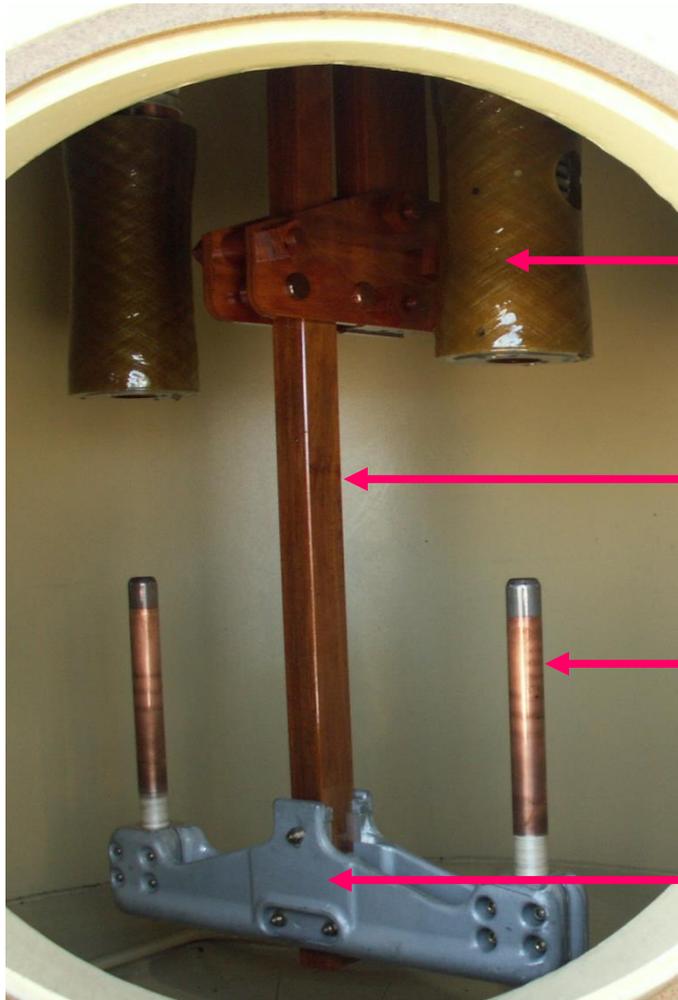
Restriking

- The insulating medium (oil, air, etc.) is still hot from the original arc and includes ionized molecules that form a conducting path. Therefore, when the voltage increases again, the arc usually re-ignites in an action called ***restriking***.
- During restriking, the cross head continues to separate from the contacts. This process repeats itself twice per cycle until the cross head is far enough from the contacts that the arc cannot re-establish itself. At this point, the flow of current is completely interrupted.

Crosshead and Contacts



Crosshead and Contacts



**Open Contacts on
115kV CB**

**Interrupting Device with new Contact
Rod Receptacle installed**

Operating Rod (Movable Member)

New Contact Rod installed

Side Plate (Cross member)

Burnt Contacts from 115kV OCB



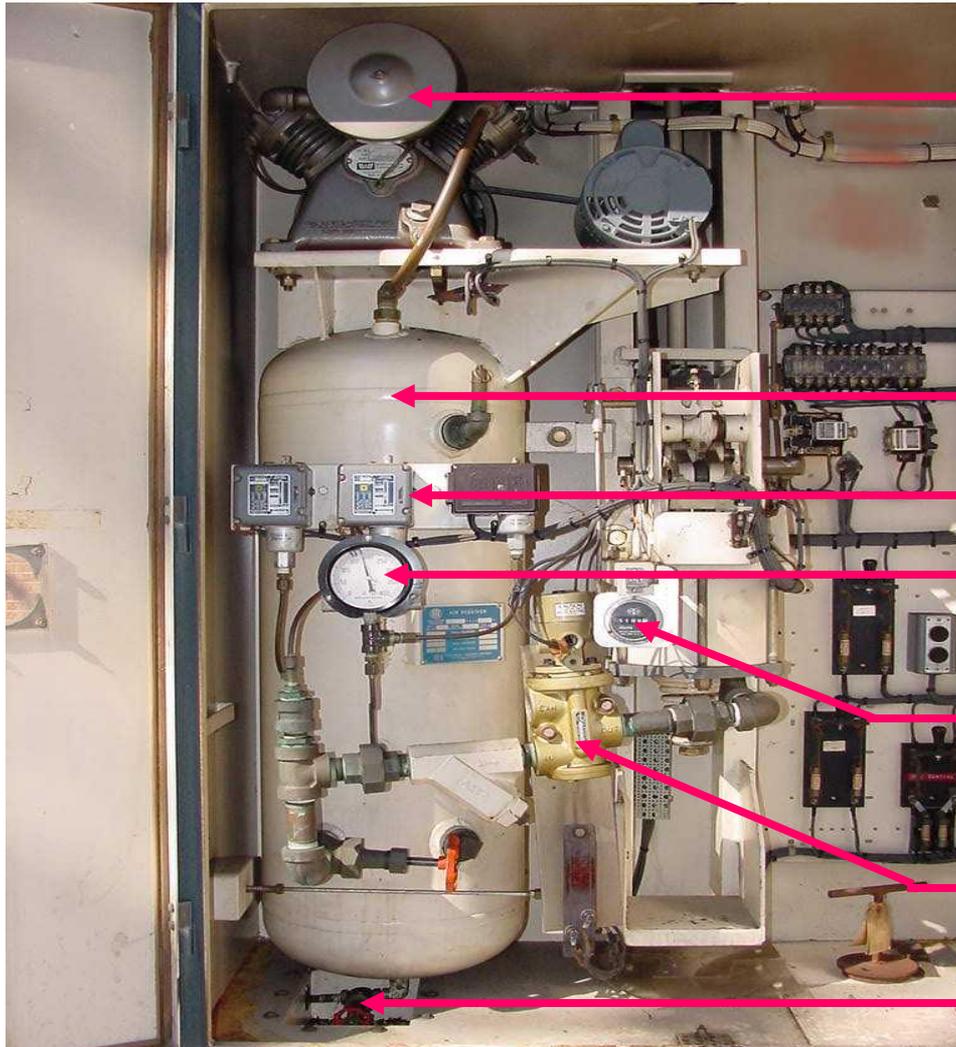
Location of Contact Rod Receptacle inside Interrupting Device 115kV OCB



Operator

- Once the fault has been cleared, the circuit breaker can be closed. The device used to close a circuit breaker is called ***an operator***. The methods of closing a circuit breaker are:
 - An energized solenoid drives the breaker into the closed position.
 - A motor compresses a closing spring that closes the breaker.
 - Compressed air drives a piston that drives the breaker to the closed position. If pressure is lost, only the pneumatic operator closing the breaker is affected; the circuit breaker's tripping or interrupting capability is not affected.

Pneumatic Operating Mechanism



Air compressor

Compressed Air Tank

Pressure Switches

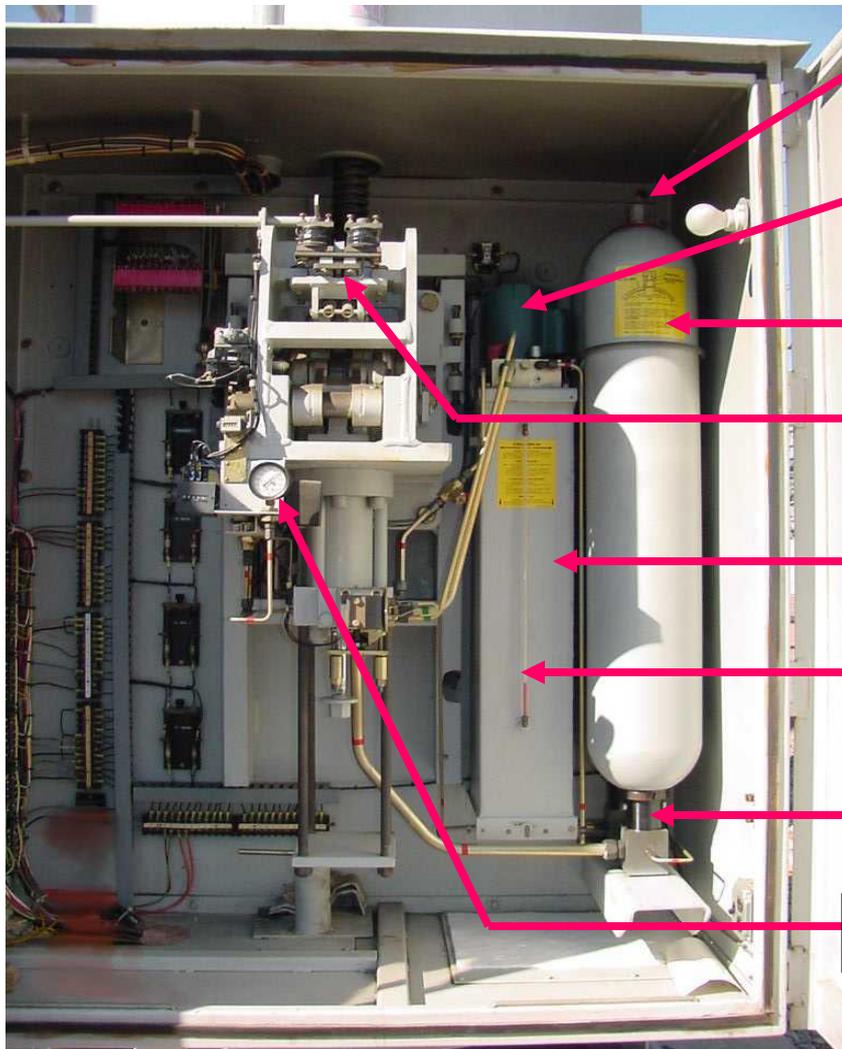
Air pressure gauge

Compressor run time meter

Pressure Regulator

Drain valve

Hydraulic Operating Mechanism



Nitrogen fill valve for accumulator tank

Hydraulic pump motor

Accumulator tank with bladder

Closing Spring

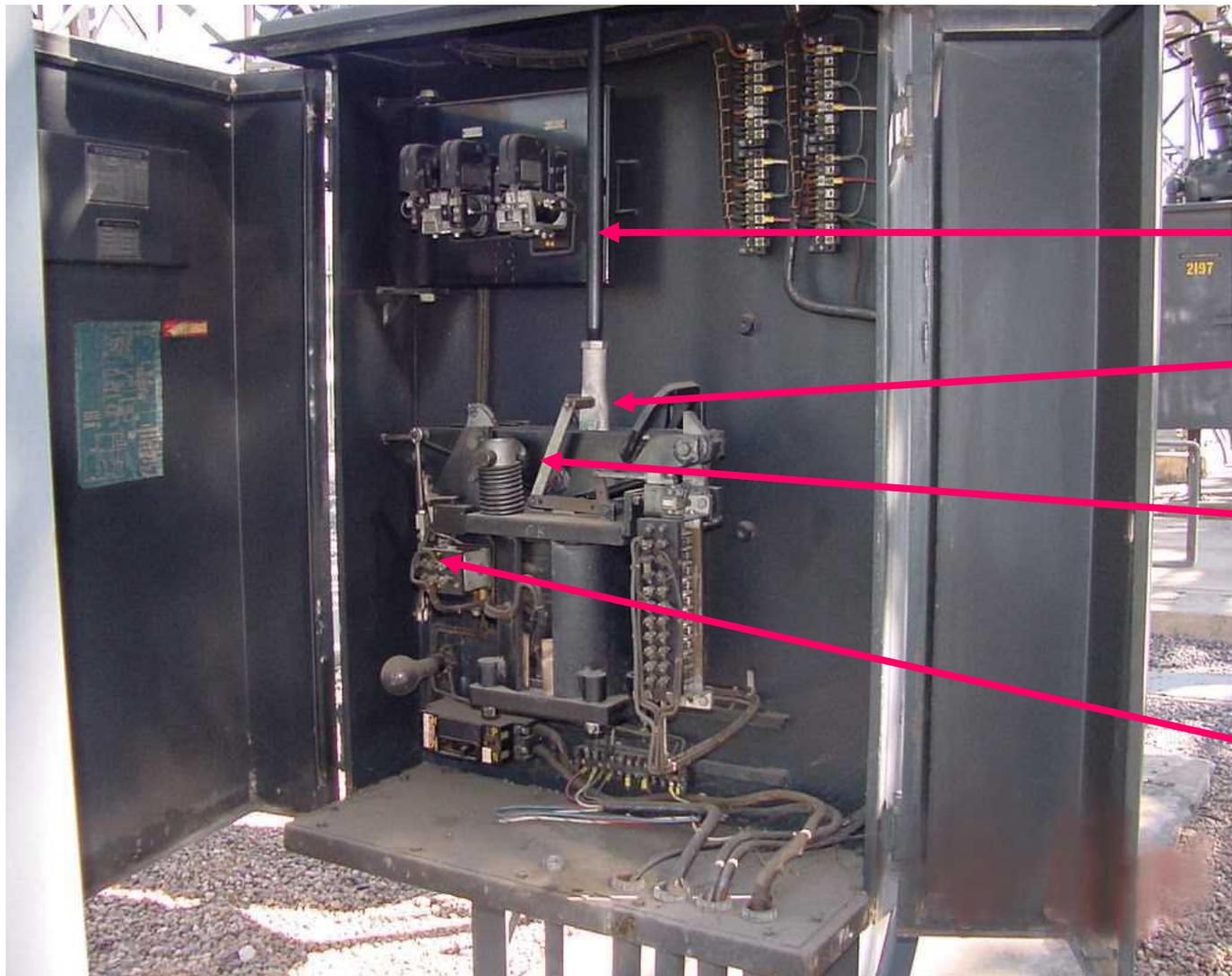
Hydraulic Fluid Reservoir

Hydraulic fluid sight glass

Hydraulic Piston

Pressure Gauge

SOLENOID MECHANISM



Operating Rod

**Plunger located
behind here**

**AB contact
linkage**

Coil

Operator

- Some circuit breakers are equipped with a switch to manually trip in the event of a failure in the electrical controls. Such switches commonly need to be manually reset before the affected circuit breaker can be closed again.
- A common problem that results in failure to trip or close a circuit breaker is an open-circuit in the trip coil itself or in the DC wiring leading to the trip coil.

Operator

- To detect an open-circuit condition before it is necessary to trip the breaker, manufacturers connect a lamp on the circuit breaker's control panel in series with the trip coil and its associated wiring.
 - If the lamp is on, the wiring and coil are intact.
 - If the lamp is off, the wiring and coils are not intact and the circuit breaker may not operate when called on to trip.

Trip Coil Monitor Lights



Circuit Breakers

- We know that one function of a circuit breaker is to interrupt fault current. Tripping the breaker to interrupt fault current creates an internal arc that produces very high temperatures.
- The two most common methods of extinguishing the arc are:
 - increasing the arc's length
 - cooling the insulating medium around the arc (de-ionizes the medium)

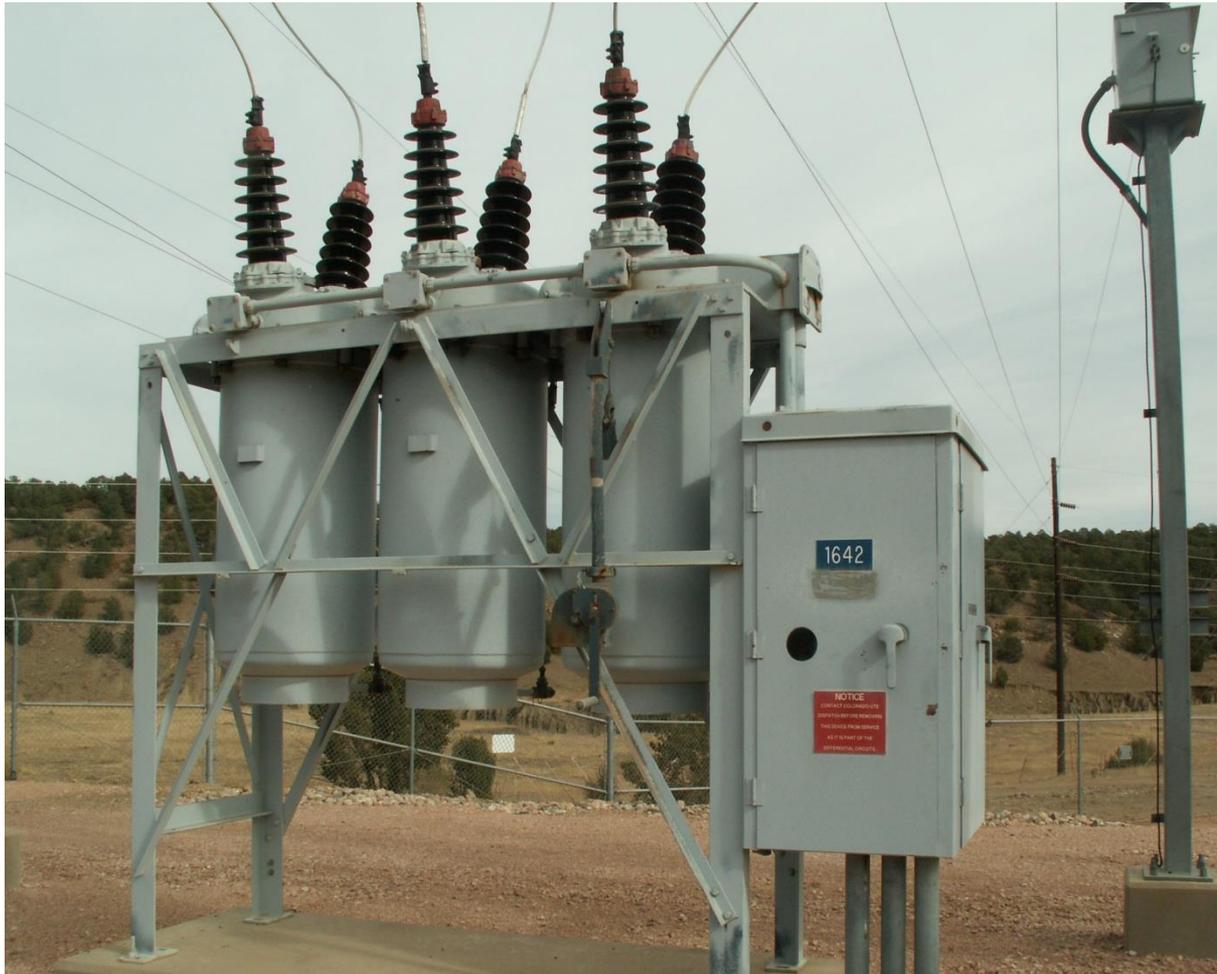
Circuit Breakers

- Circuit breakers use many different insulating media to interrupt the arc.
- The most common insulating media include:
 - air
 - oil
 - SF6
 - vacuum

Types of Circuit Breakers

- There are several different circuit breaker types, including:
 - oil circuit breakers
 - air circuit breakers
 - air blast circuit breakers
 - gas blast circuit breakers
 - gas puffer circuit breakers
 - vacuum circuit breakers
- Each type of circuit breaker indicates a method used to interrupt the arc within the breaker.

Oil Circuit Breakers



46kV CB

3 Phase Single Tank OCB

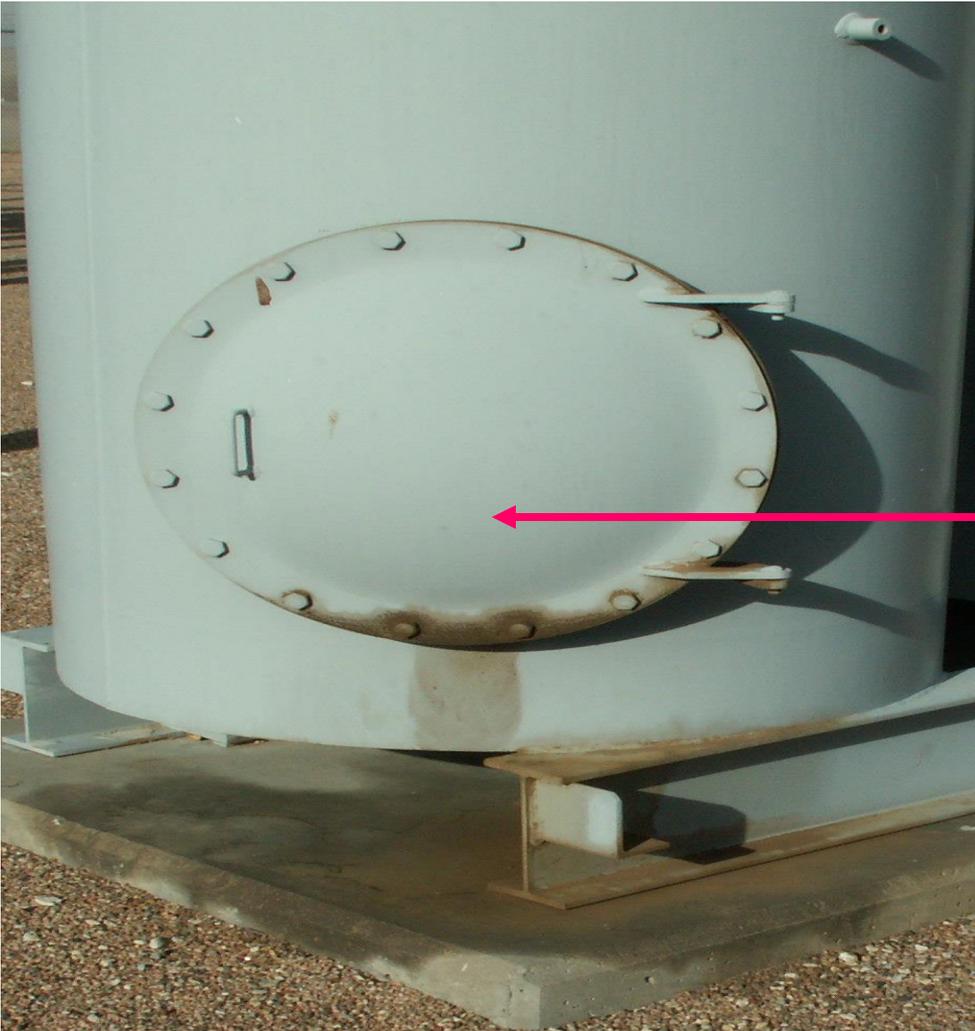


Oil Circuit Breakers



115kV CB

Oil Circuit Breakers



**Inspection/Maintenance Cover
(Manhole)**

Oil Circuit Breakers

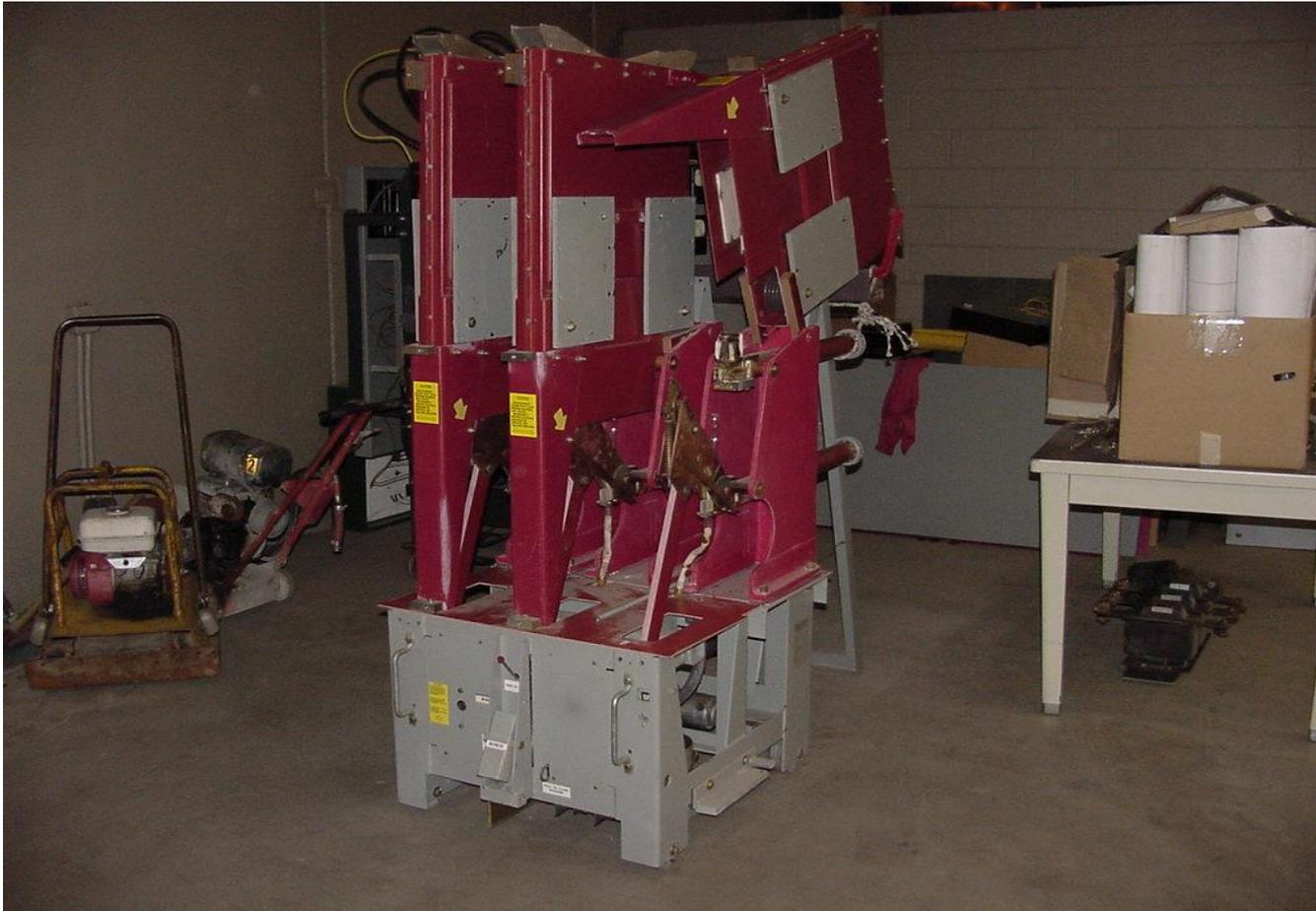


115 kV CB Oil has been drained and major maintenance in progress

**Inspection portals to view and maintain contacts.
(Manhole)**

Location of control rods and contacts.

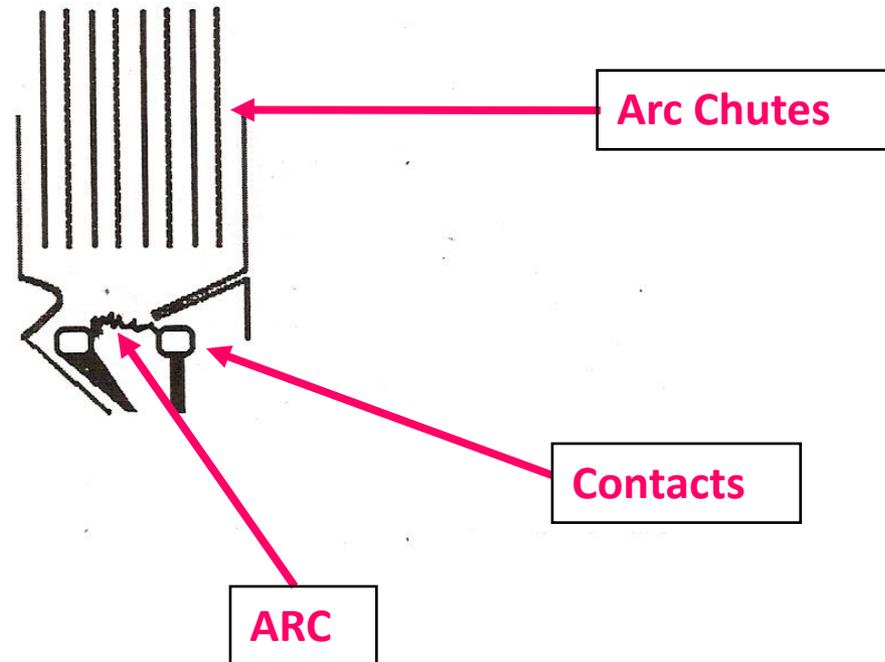
Air Magnetic Circuit Breakers



Air Magnetic Circuit Breaker

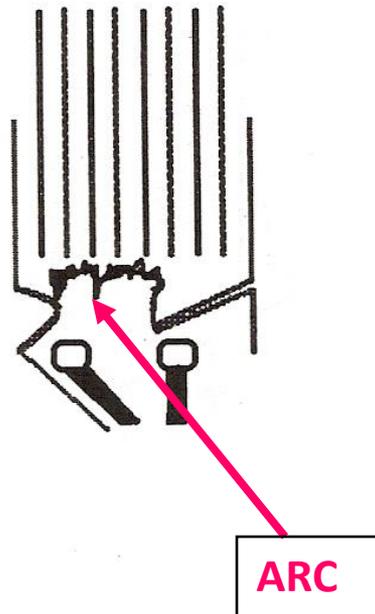
Arc in Air Magnetic Circuit Breaker

Contacts Open and Arc is formed



Arc in Air Magnetic Circuit Breaker

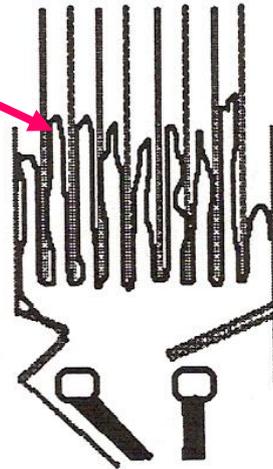
Magnetic field moves arc into chutes



Arc in Air Magnetic Circuit Breaker

Extends the Arc

Fiber baffle plates



Arc in Air Magnetic Circuit Breaker

Metallic baffle plates



Voltage drop across each baffle extinguishes the arc

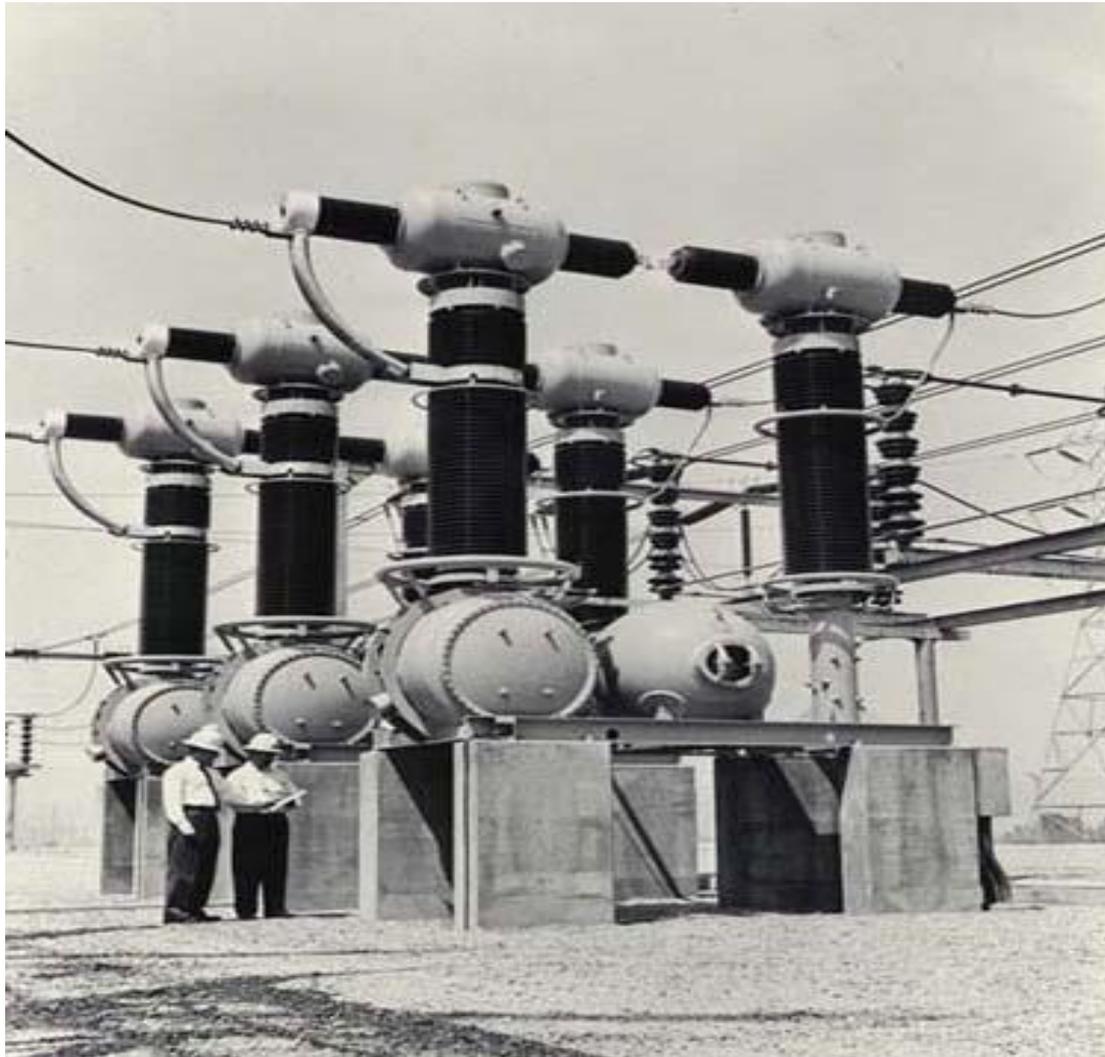
Air Blast Circuit Breakers

- Air Blast Circuit Breaker
 - Interrupts the arc by:
 - A blast of high-pressure air to stretch and cool the arc.
 - At higher voltages pressurized air is the dielectric media
 - Energy breaks down air
 - Opening resistors for some ratings
 - High arc voltage, high current chopping levels

Air Blast Circuit Breakers

- Pressurized porcelain
 - 300 – 600 psig
- Many contacts
- Compressor systems
- Complex
- Noisy
- Still built (very cold climates)(\$\$\$\$)

Air Blast Circuit Breakers



Gas Blast (SF₆) Circuit Breaker

- Interrupts the arc by using:
 - Low-pressure SF₆ gas as a dielectric.
 - A blast of high-pressure SF₆ gas (stored in a reservoir) is used to stretch and cool the arc. In association with a blast of compressed air.
- The expanding gas is allowed to exhaust to the inside of the interrupter head tank through the inside of the hollow stationary contact and moving arc horns.
- These type breakers are also referred to as “Live Tank” breakers as the tank in which the contacts are located is not grounded.

Gas Blast (SF6) Circuit Breaker



Interrupter Head

Access Door

230kV CB
(Live Tank)

Horizontal Pull Rods

High Pressure
SF6 Tank

SF6 Tank Heater

Gas Blast (SF6) Circuit Breaker

Low Pressure
SF6 Gauges

High Pressure
SF6 Gauges

Compressor Cabinet for the Gas
Blast (SF6) Circuit Breaker

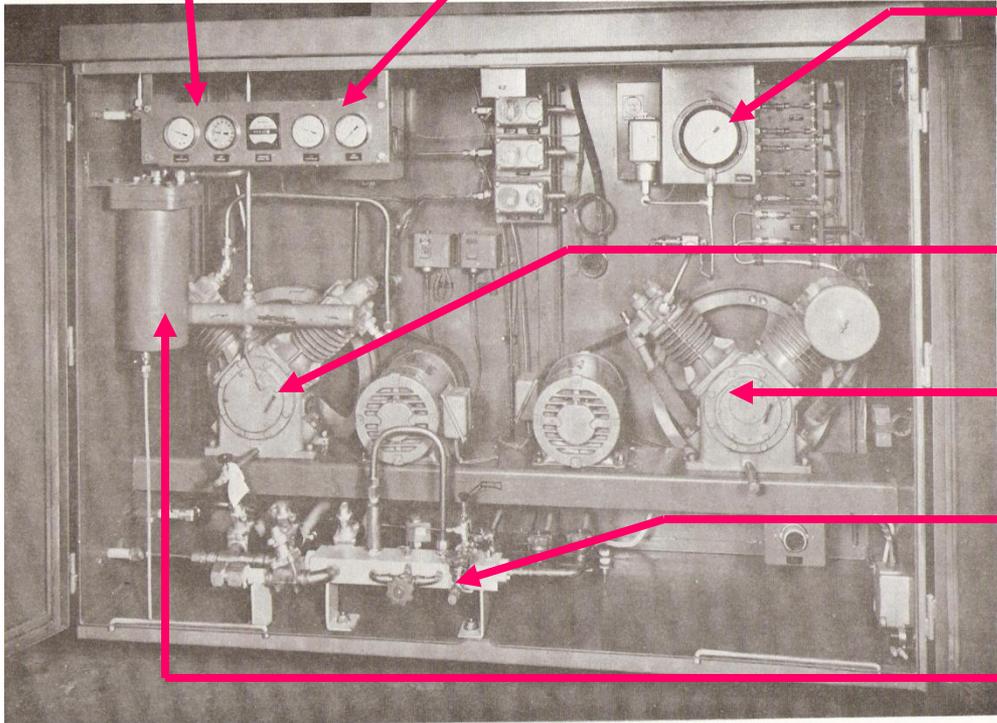
Air Pressure Gauge

SF6 Gas Compressor

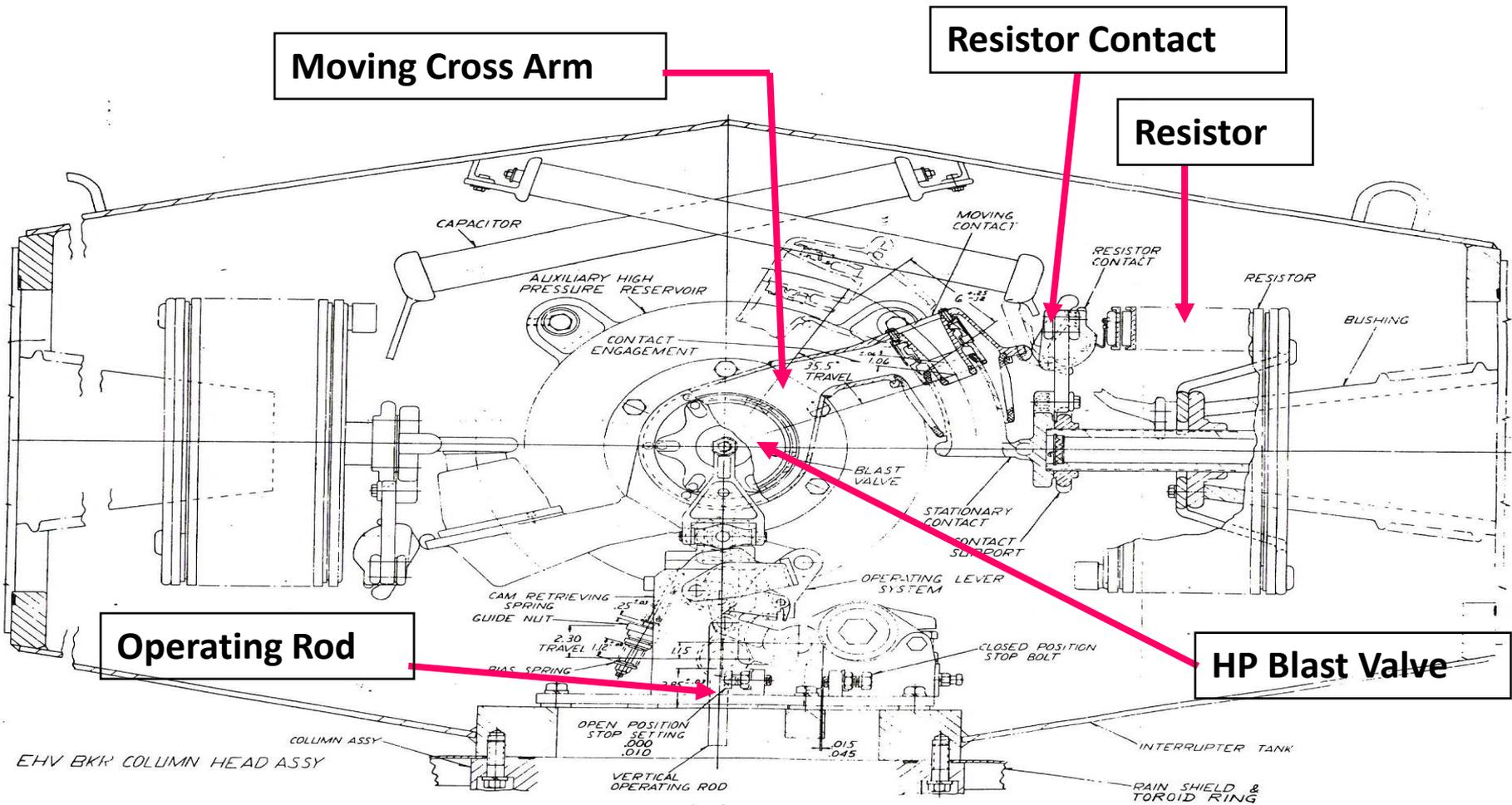
Air Compressor

SF6 Filling Connection

SF6 Filter/Dryer

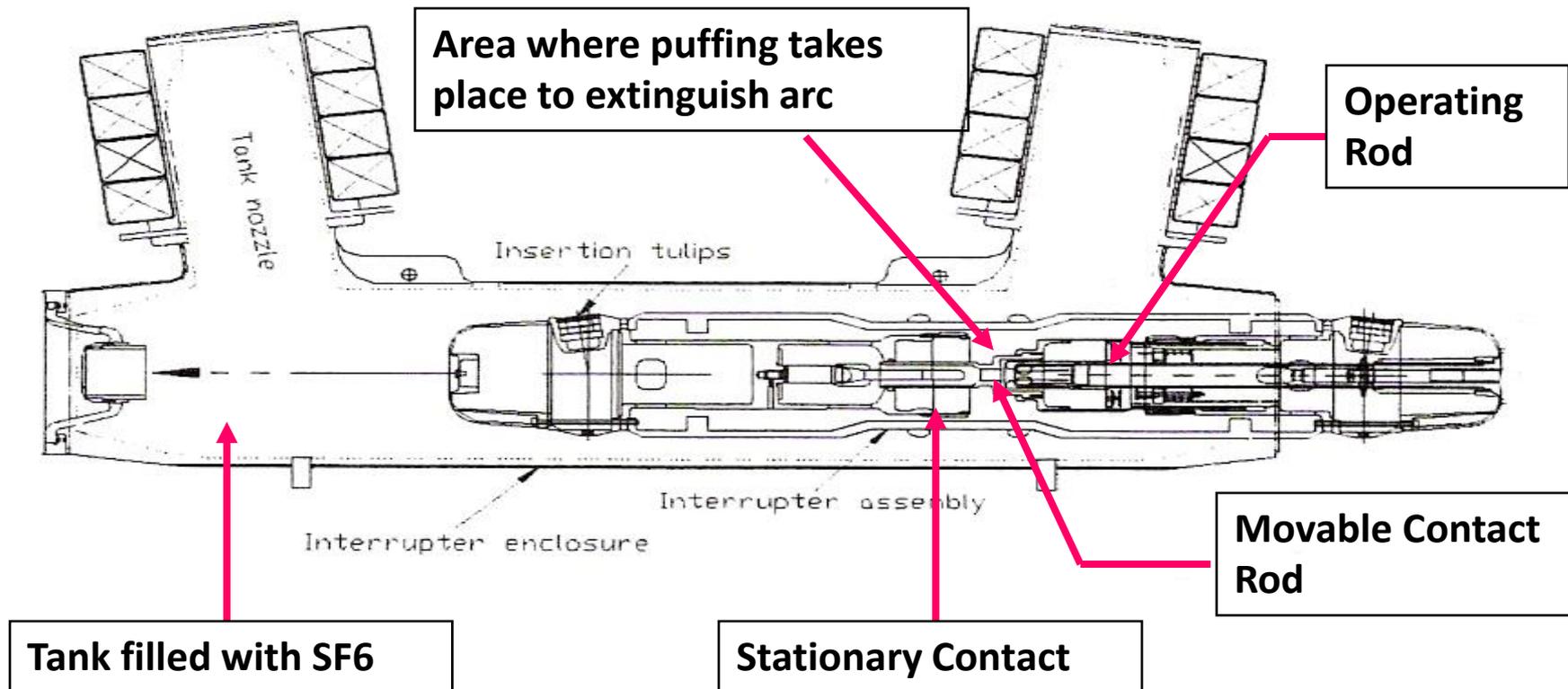


Gas Blast (SF6) Circuit Breaker



Side View of Gas Blast Breaker Interrupter Head

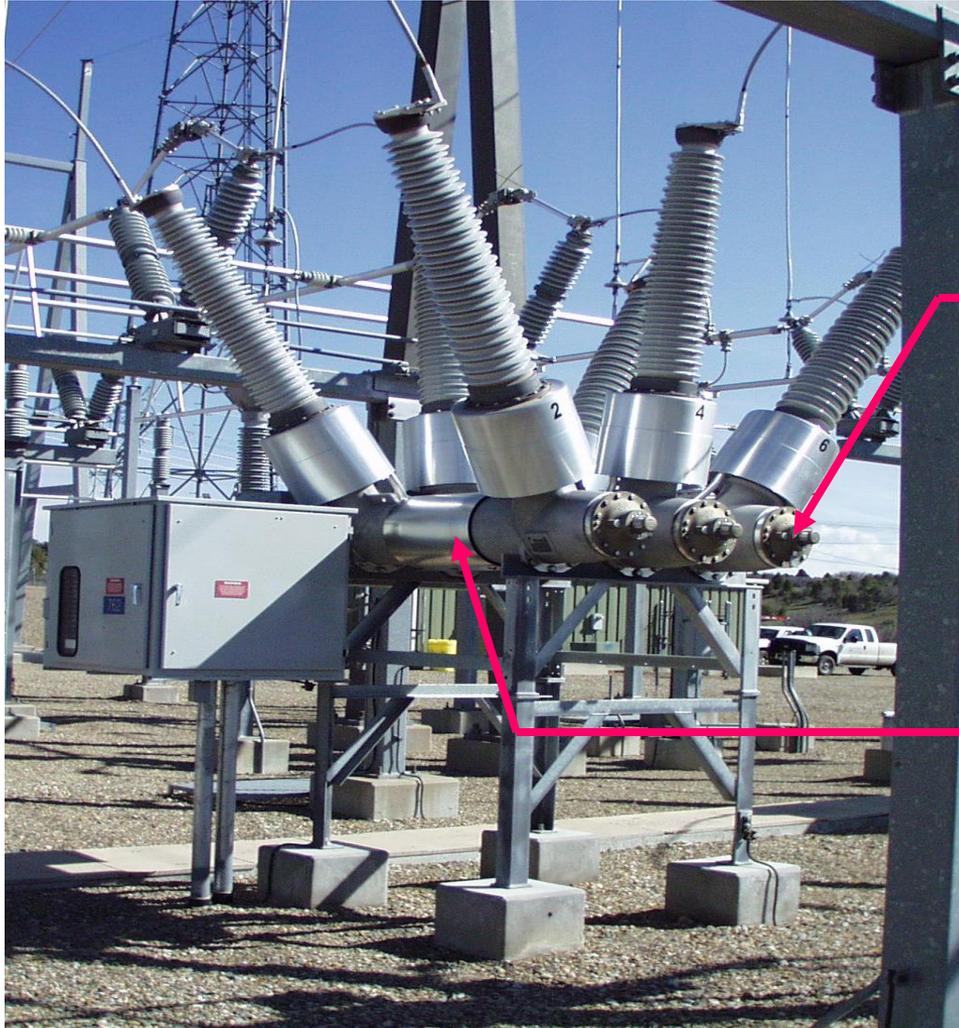
Gas-Puffer (SF6) Circuit Breaker Interrupter



Gas-Puffer (SF₆) Circuit Breaker

- Interrupts the arc by using:
 - Low-Pressure SF₆ gas as a dielectric.
 - SF₆ gas is compressed in a chamber as the main contacts open. The compressed high-pressure gas is then directed toward the arc to stretch and cool it.

Gas-Puffer (SF6) Circuit Breaker



115kV CB

Interrupters are located inside these tanks (these tanks are referred to as "Dead Tank" breakers as the outside of the tank is grounded)

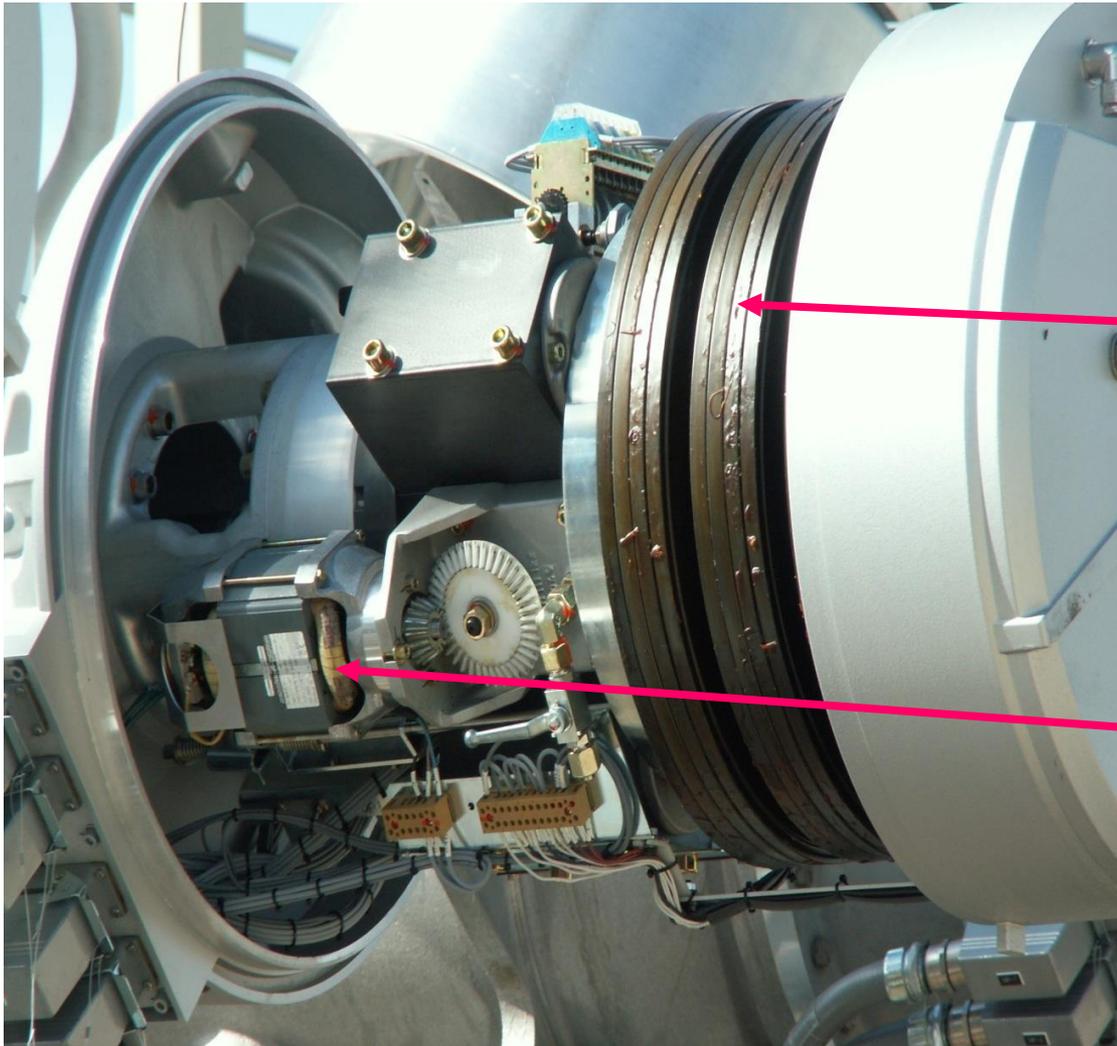
SF6 Tank heaters

Gas-Puffer (SF6) Circuit Breaker



**345kV CB as it
is being installed**

Gas-Puffer (SF6) Circuit Breaker



**New 345kV CB
ABB Puffer CB**

**Hydraulic Spring Operating
Mechanism**

Spring Charging Motor

Gas-Puffer (SF6) Circuit Breaker



**SF6 pressure gauge on
115kV CB (Alstom)**

Gas-Puffer (SF6) Circuit Breaker



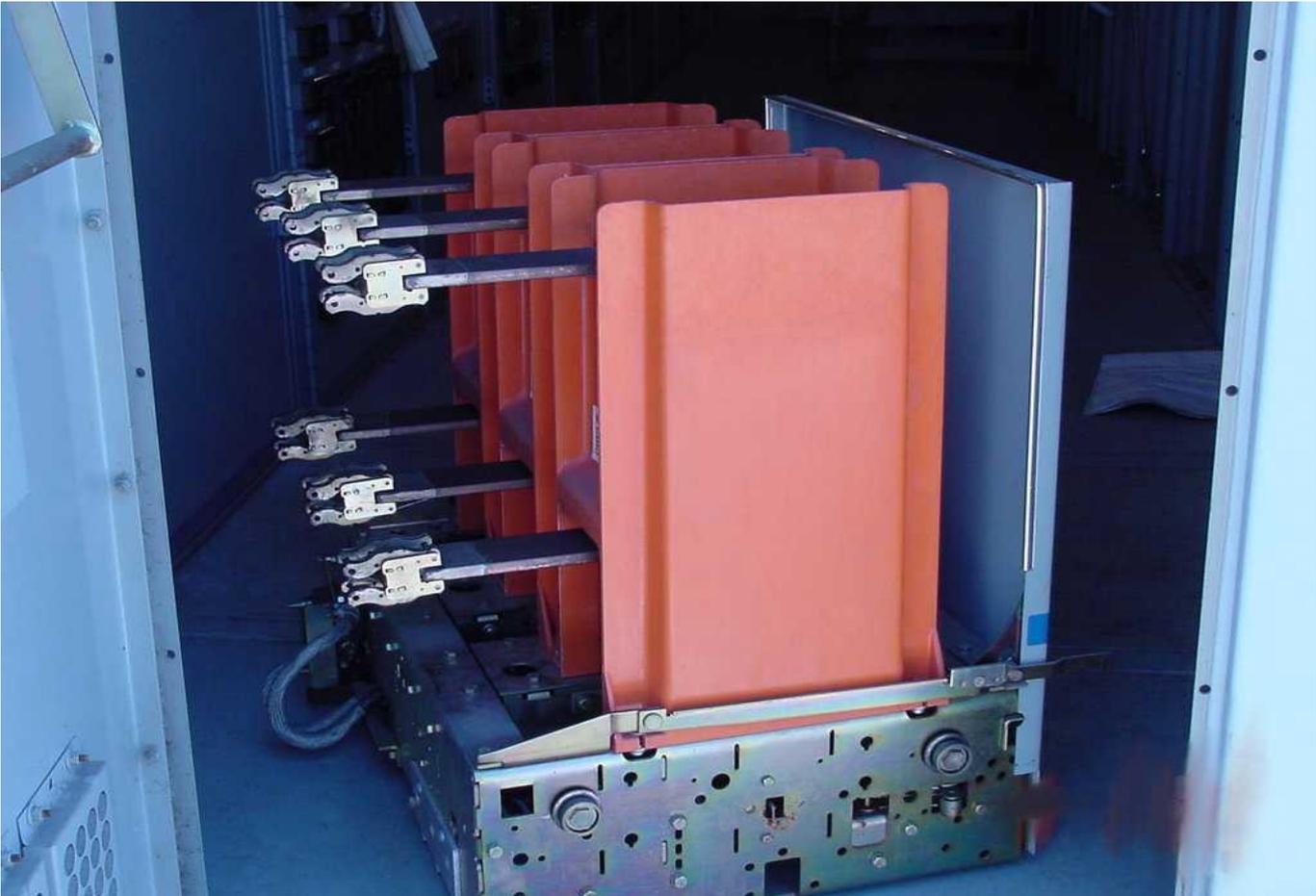
**Annunciator Panel located on the breaker.
115kV CB (Alstom)**

Vacuum Circuit Breakers

- Interrupts the arc by using:

The vacuum interrupters use a moving contact and a stationary contact both housed in a sealed, metal envelope. An actuator outside the envelope triggers the movement of the moveable contact. Inside the envelope, a metal or glass condensing shield surrounds the contacts to collect the evaporated contact material that is released when an arc is drawn. Since a vacuum contains no conducting material, the arc is immediately extinguished.

Vacuum Circuit Breaker



Ratings & Operating Considerations

- The operating voltage and the amount of current the circuit breaker can interrupt determine a circuit breaker's rating. A circuit breaker is rated based on the following parameters:
 - maximum voltage
 - continuous current
 - interrupting current capabilities
- For example:
 - A circuit breaker may be rated as 765 kV maximum voltage, 3 kA continuous current, and current interrupting capability of 63 kA.

Ratings & Operating Considerations

- Circuit breakers have a ***maximum continuous*** current carrying capability, which is the highest load current that the circuit breaker is designed to carry for extended time periods.
- Exceeding this rating may result in overheating that could damage the circuit breaker contacts and insulation.

Ratings & Operating Considerations

- Circuit breakers are also rated according to the maximum fault current that they are capable of interrupting. This is called ***maximum interrupting*** current.
- Fault currents exceeding the breaker rating may produce arcs with more energy than the circuit breaker can extinguish. In this case, the breaker may fail to interrupt the fault current.

Ratings & Operating Considerations

- ***Interrupting time*** is the period from the instant current begins to flow through the trip coil until the circuit breaker interrupts the fault.
- Typical interruptions are measured in cycles and vary in time. On high-voltage transmission lines, interruptions vary from two to eight cycles.
- ***Closing time*** is the time it takes to close a breaker from the instant the close coil is energized until current begins to flow through the breaker.
- Typical closing times vary from two to 40 cycles.

Ratings & Operating Considerations

- ***Independent pole*** operation uses a separate mechanism for each breaker phase. Independent pole operation allows the tripping of independent poles (phases) which reduce the possibility of a three-pole stuck breaker for a three-phase fault. It also reduces the impact on the system that occurs when three phases are interrupted.
- Two types of independent pole operation are:
 - single pole
 - selective pole

Ratings & Operating Considerations

- Single pole operation trips one pole for each phase-to-ground fault and trips all poles for all other types of faults.
- Selective pole operation clears only the faulted phase or phases for all types of faults.

Ratings & Operating Considerations

- Another use of independent pole operation is realized by the addition of a Synchronous Control Unit (SCU).
- The SCU is a microprocessor-based control device that enables synchronized closing or opening of the independent poles of a circuit breaker.
- For example; when used with a capacitor circuit breaker, the SCU can be programmed to open or close the poles when the respective phases' voltage waveform is at exactly zero, thereby minimizing potentially damaging transient overvoltage's caused by capacitor switching operations.

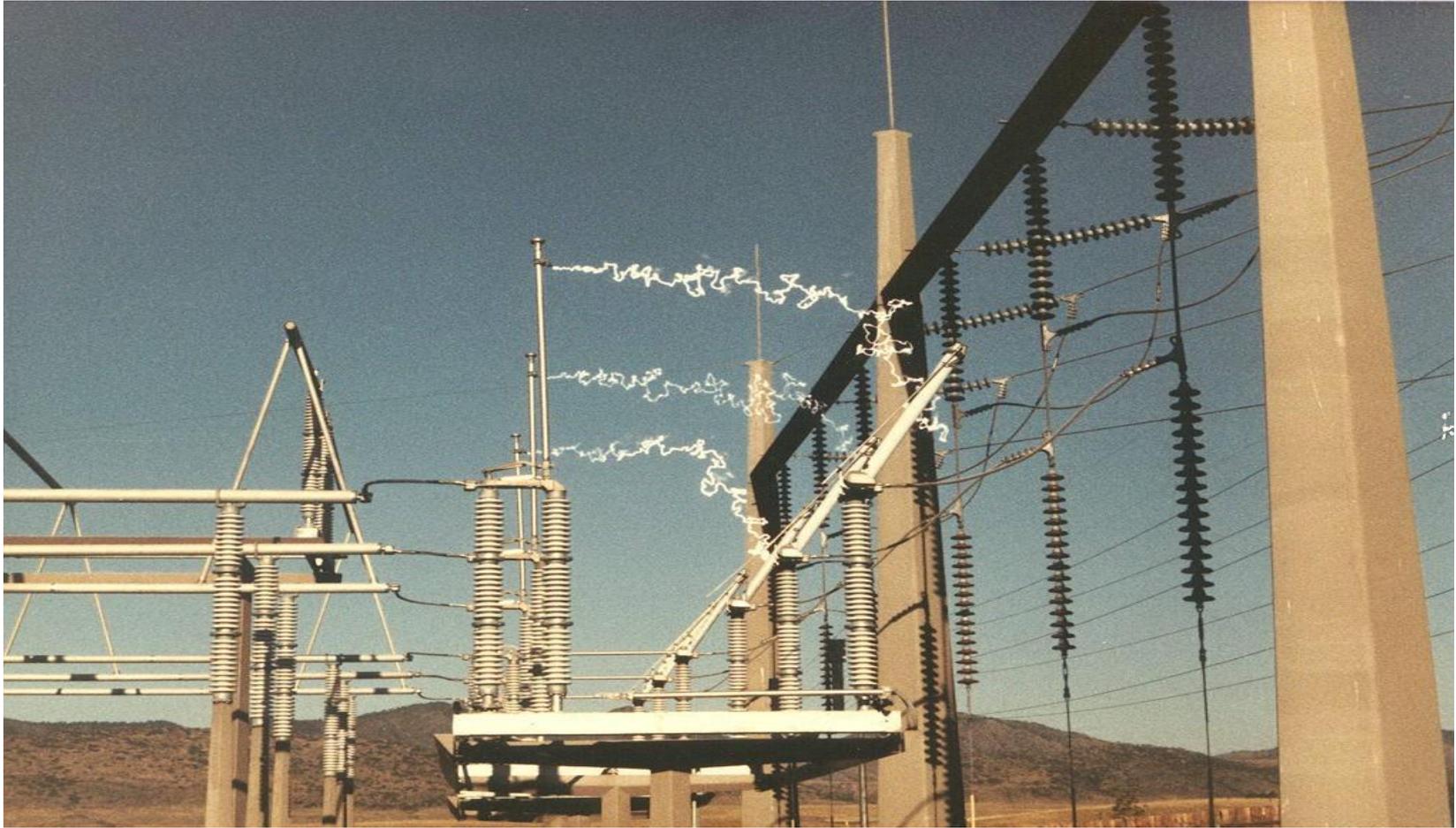
Load Break Switches

- Load break switches interrupt normal load current but cannot interrupt fault current. Utilities install load break switches when they need a method for disconnecting a device for scheduled maintenance, but they cannot justify the expense of a circuit breaker.
- For example:
- A utility may install a load break switch on either side of a transformer. If a fault occurs in the transformer, isolating the fault requires opening the circuit breakers for the line feeding the transformer.

Load Break Switches

- Breaking current with a load break switch forms a long arc through the air. The arc may rise many feet and last several seconds before it stretches out far enough to be cooled and extinguished. During this time, the switch blade moves far from the stationary contact. This prevents the arc from restriking.
- A simple example of a load break switch is the light switch on a wall in a home.

Load Break Switches



Load Break Switches



Disconnect Switches

- Disconnect switches are not typically used to interrupt normal load currents. Disconnect switches isolate lines and other equipment, such as transformers or circuit breakers, after circuit breakers or load break switches have interrupted the current. They may interrupt charging currents to the unloaded devices being disconnected.
- Disconnect switches can be operated manually, but some may be operated automatically by remote control or by protective relays.

Disconnect Switches

- The disconnect switch may be a horizontal- or a vertical-type switch. Breaking current with this device forms an arc in the air. The arc may extend many feet and last several seconds before it stretches far enough to be extinguished. During this time, a blade is moving away from a stationary contact. The blade eventually is moved far enough away from the stationary contact to prevent the arc from restriking.

Disconnect Switches



Disconnect Switches



Disconnect Switches

- A special type of high-voltage disconnect switch is the ground switch. Ground switches are disconnect switches that provide a solid ground to a power line or piece of station equipment such as a bank or a bus. The general function of a ground switch is to provide a safety ground.

Disconnect Switches

- Ground switches provide a convenient way to apply a safety ground to a de-energized piece of equipment. They protect maintenance personnel from accidental re-energizing of the equipment.
- They also provide some protection from stored charge in the equipment or the induced charge from nearby energized equipment. This protection is generally considered inadequate, however, and crews use personal grounds at the work site.

Disconnect Switches

- A circuit switcher is a type of disconnect switch that has a limited interrupting capability and is used primarily for switching capacitors and reactors. It can also be used to isolate sections of a line.

Circuit Switcher

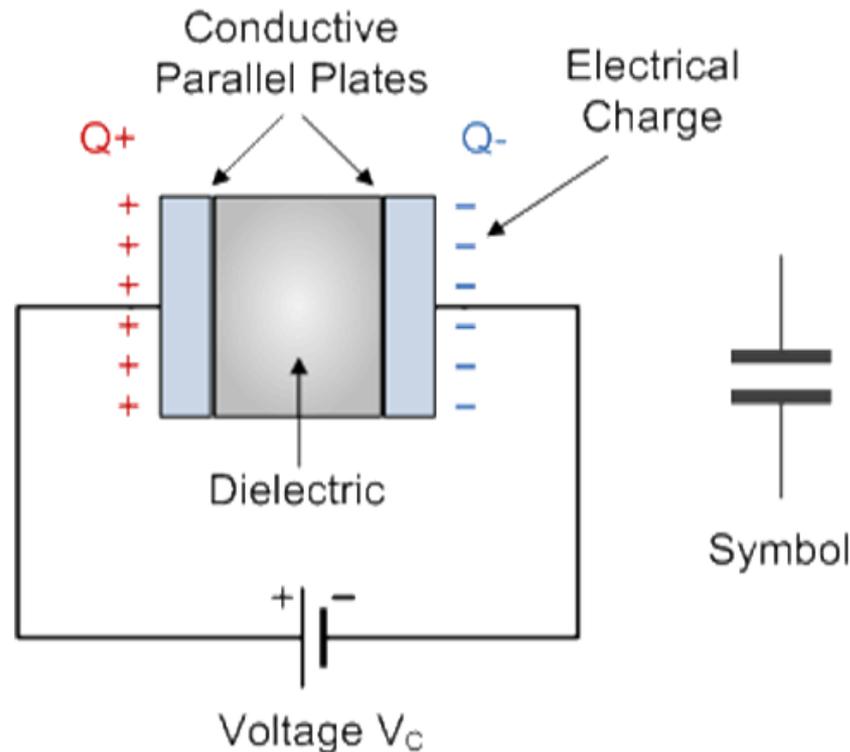


Circuit Switcher Failure



Capacitors

- A capacitor is a set of metal plates separated by an insulating material, called a dielectric. Capacitors introduce capacitance into a circuit.

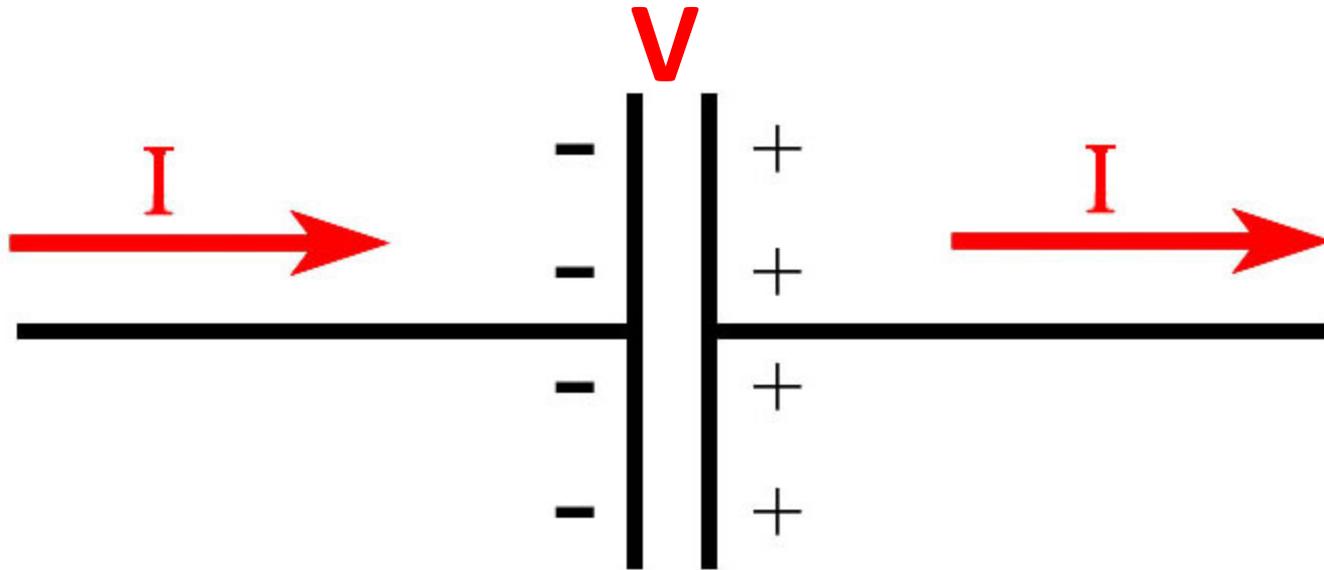


Capacitors

- Recall from reading ***Module 2: Fundamentals of Electricity***, that capacitance is the ability to oppose change in voltage by using energy stored in an electrical field.
 - Capacitance, measured in farads, increases as the plate area increases.
 - The capacitance decreases as the plate spacing increases.

Remembering

Current leads the Voltage in a capacitive circuit.



The current flows immediately to the other side, but the voltage builds across the capacitor.

Capacitors

- Vars flowing over a transmission line or distribution feeder cause voltage drops between the source and the load. The current associated with the Var flow also lowers the circuit's capacity to carry watts and increases the power loss. If there were a way to generate Vars at each load, we could eliminate excessive Var flow.
- Generally, utilities use capacitors in banks (groups of capacitors). Since it is not physically or economically practical to generate Vars at each load, utilities install shunt capacitor banks as close to the load as is practical to generate Vars.

Capacitors

- Because it takes time to discharge a stored charge from a capacitor, there is usually an enforced minimum time between capacitor switching operations to allow the capacitor to discharge.

Capacitors

- Capacitors have many uses on the power system, including:
 - Voltage Regulation — Utilities install capacitors to maintain voltage within preset limits by generating Vars.
 - Power Factor Correction — Utilities install shunt capacitors on distribution circuits to improve the power factor.

Capacitors

- Inductance Reduction — Utilities install capacitors in series with long high-voltage transmission lines to offset the series inductance. This improves stability and increases power transfer capability. We discuss stability in ***Module 9: Principles of Power System Operation***.
- Measuring Devices for Protection System — Coupling capacitance voltage transformers (CCVTs) are stacks of capacitors and resistors. CCVTs measure voltage on transmission lines 100 kV and greater. We discuss CCVTs in more detail in ***Module 8: System Protection***.

Capacitors

- Communications for Power Line Carrier — Capacitors are ideally suited for coupling high-frequency power line carrier signals to the power line because of the capacitor's low impedance to high-frequency signals. Recall from ***Module 2: Fundamentals of Electricity***, that the magnitude of the impedance of a capacitor is $1/(2\pi fC)$, so the higher the frequency, the lower the capacitive reactance (impedance).
- Filters for Undesirable High-Frequency Signals — Capacitors filter out high-frequency signals from the power line voltages. This application is particularly important at high-voltage direct current (HVDC) line converter terminals where the converters create harmonic frequencies.

Capacitors

- Utilities install shunt capacitor banks, typically connected in an either grounded or ungrounded WYE (star) configuration, with fuse protection for individual phases, or individual capacitor units, depending on the type of installation.

Capacitors



Capacitors



Reactors

- A shunt reactor is an inductor (or a coil) connected from conductor to ground. Shunt reactors absorb Vars, producing the opposite effect of shunt capacitors.
- Utilities use reactors to perform the following functions:
 - Cancel Effects of Transmission Lines' Shunt Capacitance — Utilities install shunt reactors at the terminals of long transmission lines to reduce the voltage rise effects of the lines' shunt capacitance. Installing shunt reactors may affect normal switching procedures.

Reactors

- Limit Fault Current Magnitude — Utilities may insert reactors in series with operating bus sections and often insert reactors in series with distribution circuits to limit fault current magnitude. This is particularly useful at substations that are close to generating stations and on major transmission facilities, where fault current magnitude may exceed the circuit breaker's interrupting rating. Utilities also insert reactors in the distribution substation transformer neutral to limit the ground fault current flow.

Reactors

- Filter for Undesirable High-Frequency Signals — Utilities use reactors in conjunction with capacitors to filter out high-frequency signals from the power line voltages. This application is particularly important at HVDC line converter terminals in filtering the harmonic frequencies created by the converter equipment.
- Voltage Regulation — Utilities use reactors to maintain voltage within preset limits by absorbing Vars.

Reactors

- Shunt reactor banks for high-voltage applications are usually immersed in oil-filled tanks similar to power transformers. The operating considerations identified for transformers also apply to oil-immersed reactor banks. (See to ***Module 6: Transformers, for more information.***)
- For low-voltage applications (e.g., distribution applications), utilities use dry-type air-cooled units. These units require little or no maintenance.

Line Reactor



Low Voltage Tertiary Reactor (13.8kV)



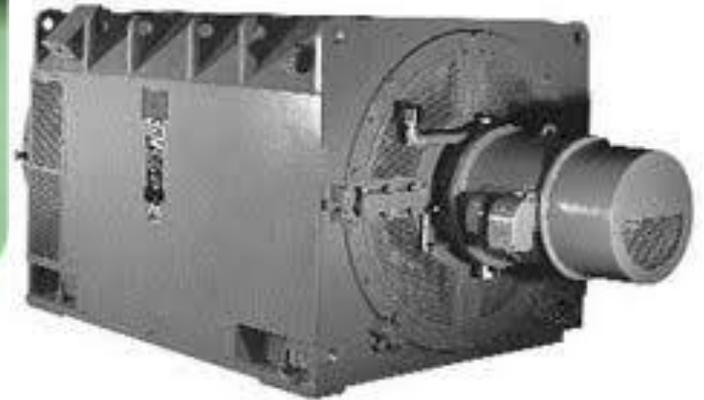
Low Voltage Tertiary Reactor



Synchronous Condenser

- A ***synchronous condenser*** changes the power factor of the system by generating or absorbing VARs.
- A synchronous condenser is basically a synchronous motor with no mechanical load or a synchronous generator with no prime mover. The condenser has a control circuit that provides voltage control by controlling the field excitation.

Synchronous Condenser



Synchronous Condenser

- If the system voltage decreases below a specified value, the control circuit increases the field excitation. This causes the synchronous condenser to supply Vars to the system, acting like a capacitor or overexcited generator.
- If the system voltage increases above a specified value, the control circuit decreases the field excitation. This causes the synchronous condenser to absorb VARs from the system, acting like a reactor or underexcited generator.

Lightning Arresters

- Lightning arresters protect transformers and other power system equipment from voltage surges by shunting over-voltage to ground. Lightning arresters prevent flashovers and serious damage to equipment.
- Lightning arresters, also called ***surge arresters***, conduct high-voltage current to ground without producing an excessive voltage. The arrester begins to conduct electricity at a specified voltage level well above the operating voltage. Then, the arrester becomes an open circuit when the over-voltage subsides and the current flowing through the arrester drops to a low value.

Lightning Arresters

Lightning Arrester

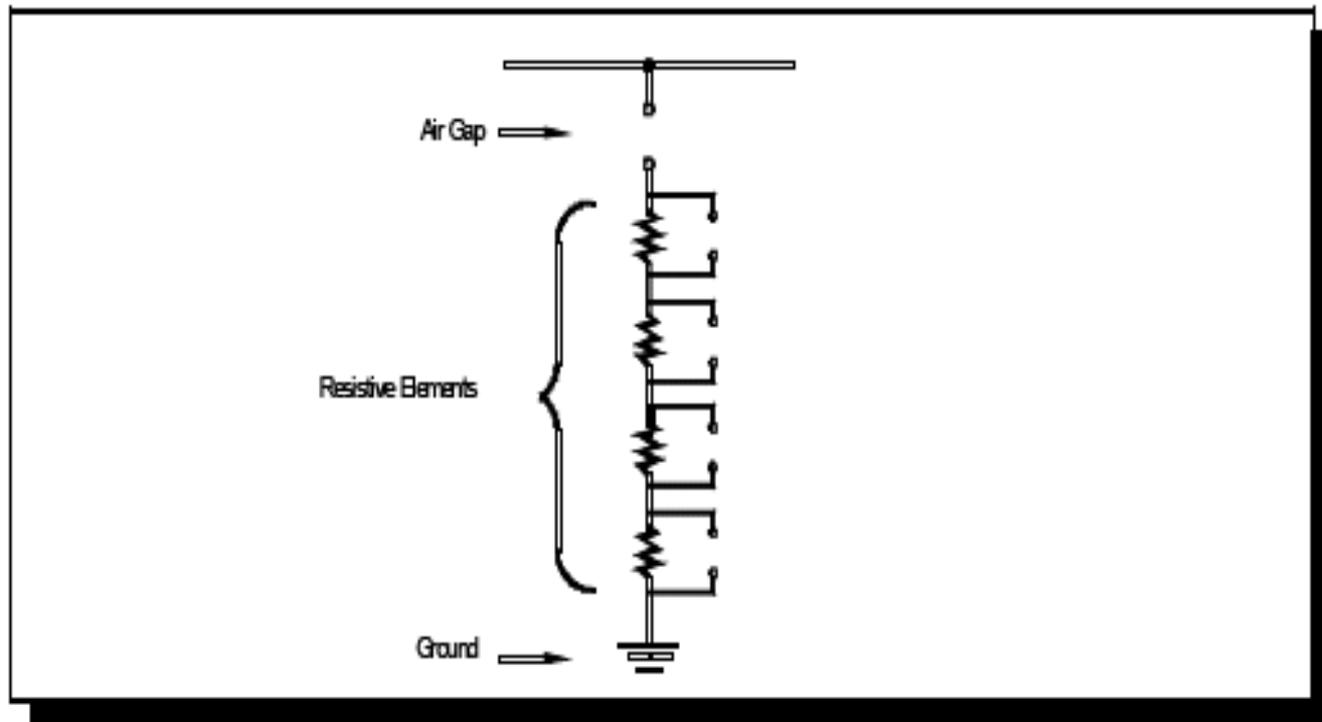


Lightning Arresters

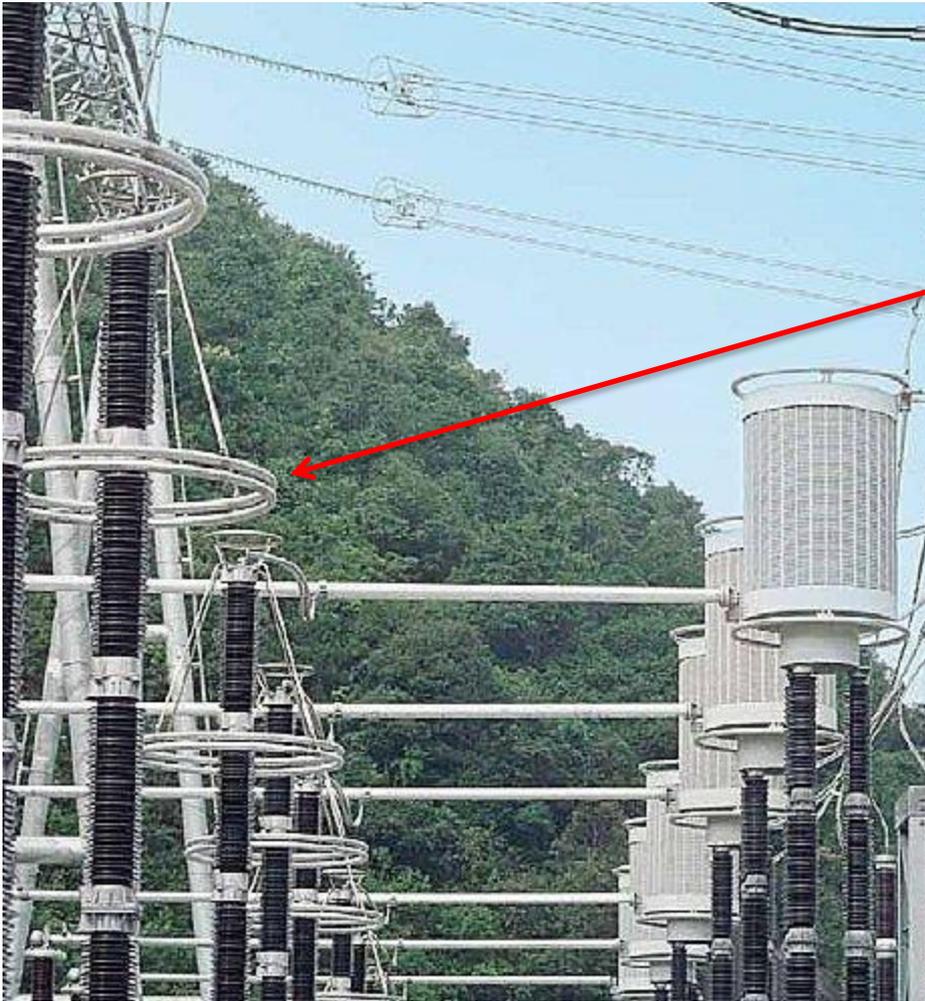
- A lightning arrester includes the following elements:
 - air gap
 - resistive elements
 - ground connection

Lightning Arresters

- The air gap allows a high-voltage surge to jump across the gap to ground.
- Resistive elements allow high-voltage current to flow, but prevent current flow at line voltage.

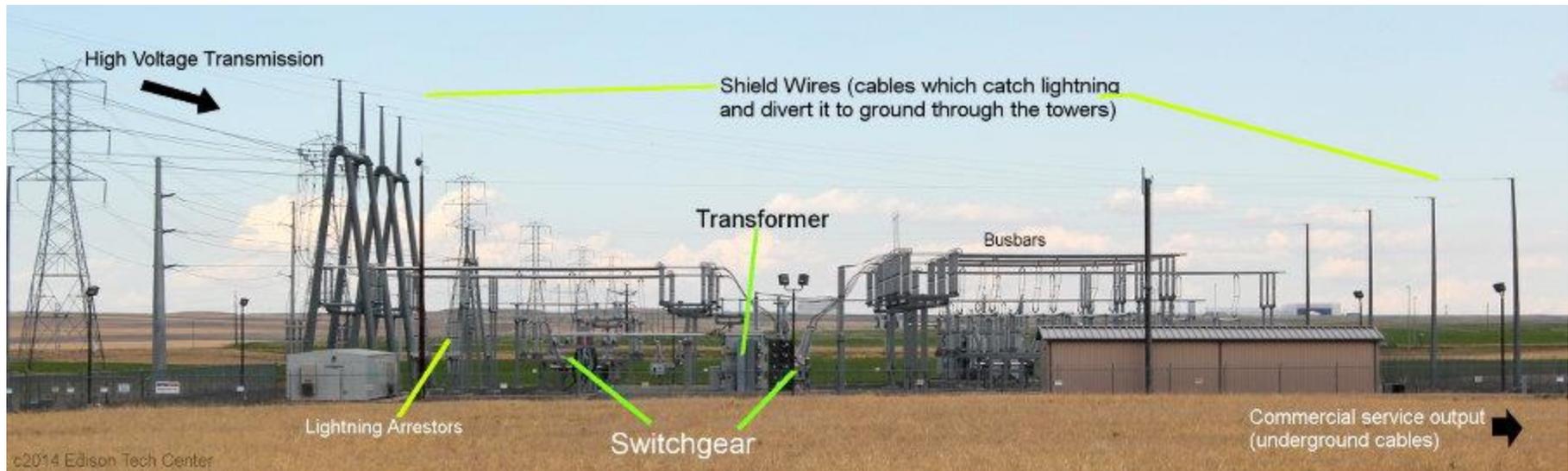


Lightning Arresters



Lightning Arrester

Lightning Arresters



Wave Traps

- A ***wave trap***, also called a line trap, is a device that presents:
 - a very high impedance to high-frequency signals
 - a negligible impedance to power system frequencies
- Wave traps perform the following two functions:
- Prevents the communication system's energy from flowing into the substation bus. Without wave traps, the carriers on one line may interfere with power line carriers on other lines connected to the bus. This would compromise the integrity of the protection system. We discuss protection systems in detail in ***Module 8: System Protection***.

Wave Traps

- Prevents an external ground fault behind the protection relays from short circuiting the carrier signal on the unfaulted line. In ***Module 8: System Protection***, we examine how the protection system sends a blocking signal to prevent tripping during such faults. If the carrier short circuits, false tripping might occur.

Wave Traps



Substation Control House

- Recall from reading ***Section 5-1: Purpose of Substations***, that a substation includes a building that houses protection, control, metering, communications, and other equipment. This building is the substation control house.
- The relays and meters in the control house receive information from power system equipment in the substation via cabling in an underground conduit. The information received includes:
 - CT currents
 - PT voltages
 - circuit breaker statuses

Substation Control House

- Protection relays, supervisory control, programmable logic controllers, and/or manual control switches send control signals to power equipment in the substation.

Control Panels

- Utilities mount control house equipment on vertical panels. The front covers of protection relays and meters are visible through the panel. This provides a way for substation operators to obtain relay targets and read meters easily. Access to the wiring for each device is behind the panel.

Control Panels

- The transformer control panel typically includes the following elements:
 - Protection relays.
 - Meters that display the high- and low-side current and other transformer quantities.
 - Control switches that operate load-tap changers.
 - Alarm annunciators that provide warnings of abnormal conditions, such as a transformer overload, high temperature, or high gas pressure.
(Communications systems send these alarm indications to control centers.)

Upper Half of Transformer Relay Panel



Bottom Half of Transformer Relay Panel



Relay & Transformer Relay Panel



Transmission Line Control Panel

- A transmission line control panel typically includes the following elements:
 - control switches that manually operate the circuit breakers associated with the line
 - status lamps that indicate the circuit breaker's status
 - status lamps that indicate the circuit breaker's trip coil status
 - status lamps that indicate whether the line is energized
 - meters that indicate line voltage, current, and power flow
 - communication transmitters and receivers for the protection systems associated with the line
 - alarm annunciators that indicate abnormal conditions, such as low voltage or low circuit breaker pressure

Transmission Line Relay Panel



Other Equipment

- In addition to the equipment found on the control panels, control houses contain the following equipment:
 - station batteries and motor-generator battery chargers
 - EMS/SCADA remote terminal units
 - Human-Machine Interface/Programmable Logic Controller
 - fault and sequence-of-events recorders
- We examine each of these separately in the next few pages, beginning with the station battery.

Station Battery

- The station battery provides DC power to the station control circuitry, which operates other equipment such as a circuit breaker's trip coils.
- The number of cells in the station battery determines what the appropriate battery voltage will be. For example, a 60-cell battery system will have a nominal voltage of 125 V DC.
- The batteries must provide sufficient voltage for operating circuit breakers and other vital substation equipment for a limited time period. The substation's AC maintains the charge on the batteries through the battery charger.

Station Battery

- At critical high-voltage substations, utilities may install two separate batteries: a primary and a backup. A separate source charges each battery.
- Utilities periodically check substation batteries for low voltage or dead cells. They correct any problems immediately since circuit breakers need DC power to trip.

Station Battery



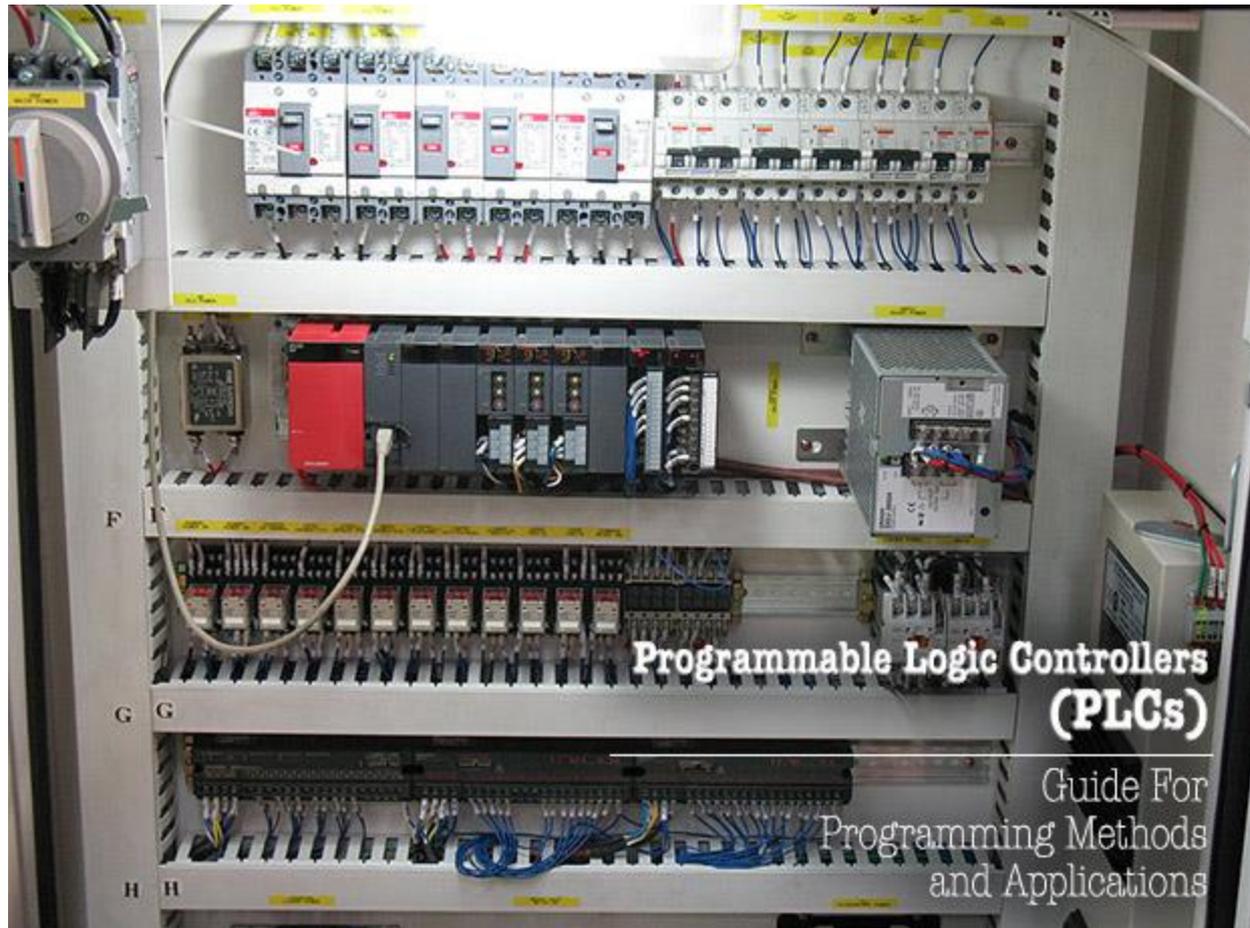
EMS/SCADA RTU's

- Remote terminal units (RTUs) provide an interface between the substation equipment and the EMS/SCADA system at the control center. RTUs receive signals of important substation quantities (voltages, currents, equipment statuses, and alarms) and transmit them to a master station at the control center.
- Conversely, system operators send control signals to substation equipment via the RTUs. We discuss EMS software functions in more detail in ***Module 9: Principles of Power System Operation.***

Programmable Logic Controller/HMI

- With the advent of affordable microprocessor-based relays and Programmable Logic Controllers, new equipment is beginning to populate substations.
- ***Programmable Logic Controllers (PLC)*** perform all bank and line reclosing operations in place of a conventional electro-mechanical recloser. In addition to standard reclosing operations, the PLC can be programmed to perform conditional reclosing such as only reclosing a line circuit breaker upon detection of an energized line and then only after a predetermined period of time.

Programmable Logic Controller



Programmable Logic Controller/HMI

- ***Human-Machine Interfaces (HMI)*** contain the database of information collected from the PLC as well as any electronic protection relays connected to the HMI and acts as the intermediary between the PLC and RTU. Most of the remote and manual switching operations are performed through the HMI.

HMI Touch-Screen Panel



Orion #1
Orion #2
Hardened PC
Touch-Screen
Display
Keyboard
Ethernet Router
Satellite Clock

HMI controls and metering screen

Empire SubStation

File Logic Debug Special Development!

CB 462 CONTROL

A KV (L-N)	A PHASE AMPS
69.2	48.0
B KV (L-N)	B PHASE AMPS
69.2	50.0
C KV (L-N)	C PHASE AMPS
69.4	46.0
MWATTS	MVARs
9.95	-2.65

74DC TC#1 74DC TC#2 74DC CLOSE COIL

CB 462
BREAKER CONTROL SWITCH

OPEN CLOSED

TRIP CLOSE

CB 462
CS 200 SUPY CONTROL SWITCH

(SUPY) ON (LOCAL) OFF

CB 462
RECLOSER CONTROL SWITCH

(ENABLED) ON (BLOCKED) OFF

RETURN

10:28:29 AM
5/9/2007

ALARM SEE ANNUNCIATOR

EVENT VIEWER

HMI Touch Screen General Annunciator

Empire SubStation
File Logic Debug Special Development!

ALL ALARMS ACKNOWLEDGED

CIRCUIT BREAKER #266 ALARMS	CIRCUIT BREAKER #342 ALARMS *
CIRCUIT BREAKER #462 ALARMS *	CIRCUIT BREAKER #442 ALARMS *
CIRCUIT BREAKER #562 ALARMS *	CIRCUIT BREAKER #542 ALARMS *
CIRCUIT BREAKER #662 ALARMS *	CIRCUIT BREAKER #646 ALARMS *

TRANSFORMER
#1
ALARMS *

RTU
MISCELLANEOUS
ALARMS *

GLOBAL
ACKNOWLEDGE

RETURN

10:30:15 AM
5/9/2007

ALARM SEE ANNUNCIATOR

EVENT VIEWER

Remember back in the old days?

Control Handles

52CS Breaker Control Switch

79CS Reclosing Relay Control Switch

200CS Supervisory Control Switch



Push-Buttons have replaced the control handles.

- Push the OPEN button to open the circuit breaker.
- Push the CLOSE button to close the circuit breaker.
- Push the Recloser Relay button ON/OFF.
- Push the Supervisory Control button ON/OFF.
- Same functions - less wiring.



All-in-one control box

Panel metering
 Open Indication
 Close Indication
 Recloser Off Indication
 Supervisory Off Indication
 Hot Line Order Indication
 Comm Fail 21P



Fault & Sequence of Events Recorder

- Critical substations typically include subsystems that gather and store information needed to analyze abnormal events. Two of these subsystems are fault recorders and sequence-of-events recorders. ***Fault recorders*** log, on paper or in computer memory, critical current and voltage waveforms at the time of any fault. System engineers analyze the results.

Fault Recorder



Fault Recorder



Digital Fault Recorder mounted in a 225kV station.

Fault & Sequence of Events Recorder

- ***Sequence-of-Events (SOE)*** recorders track the order in which events occur, such as the events in a relay operation or a circuit breaker opening. If we observe these events, they would appear to happen at the same instant. However, SOE recorders identify the correct order of events down to one-millisecond resolution. This information is often useful in determining whether protection systems operated as expected.

Substation Bus Configurations

- There are five basic methods for connecting buses, circuit breakers, and circuits. Utilities may vary their method to meet their individual requirements based upon the following factors: cost, application, and required degree of service continuity and reliability.

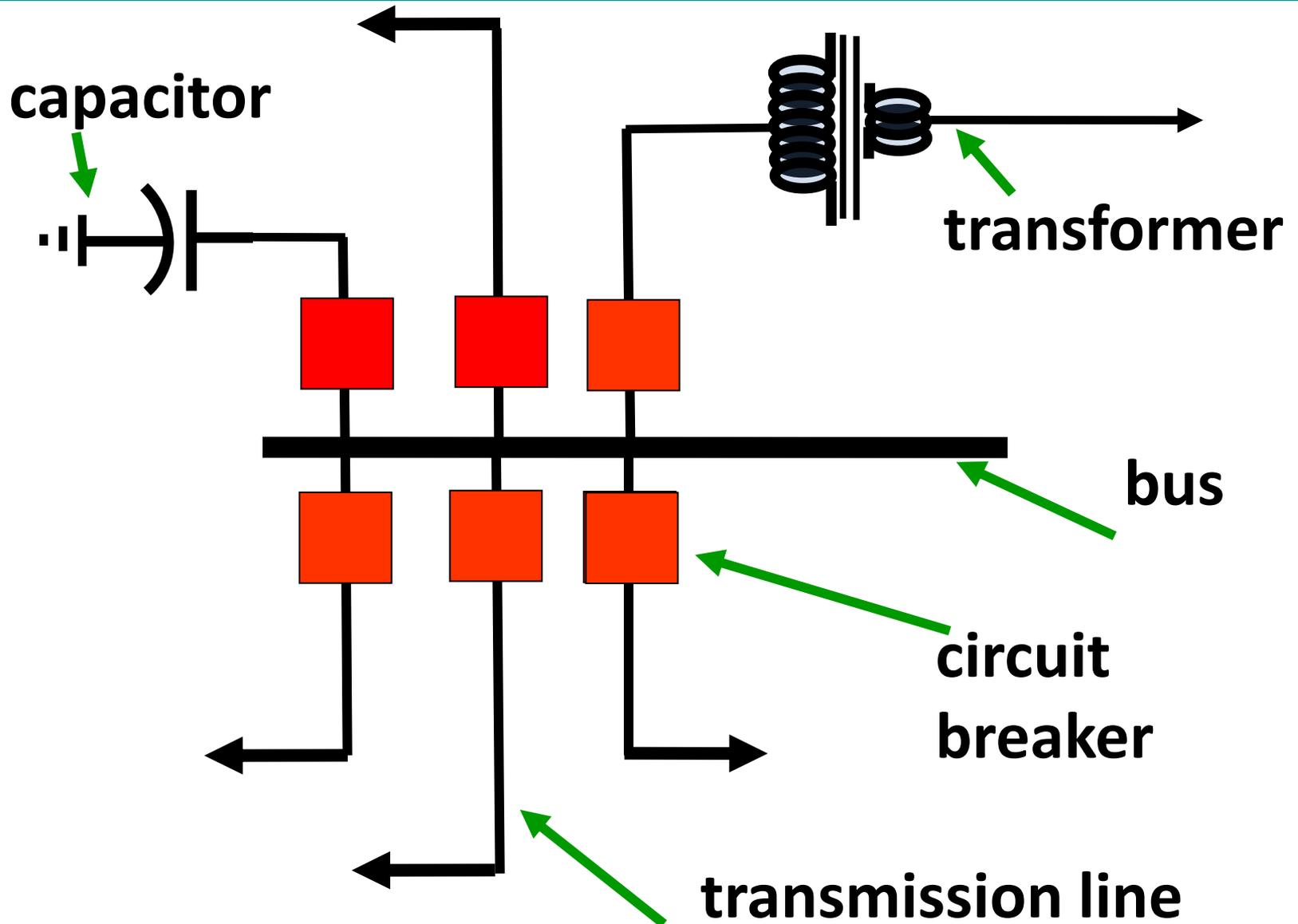
Substation Bus Configurations

- The five basic arrangements are:
 - Single Bus
 - Main and Transfer Bus
 - Ring Bus
 - Breaker-and-a-Half Arrangement
 - Double Bus-Double Breaker Arrangement
- We examine each of these arrangements in the next few pages.

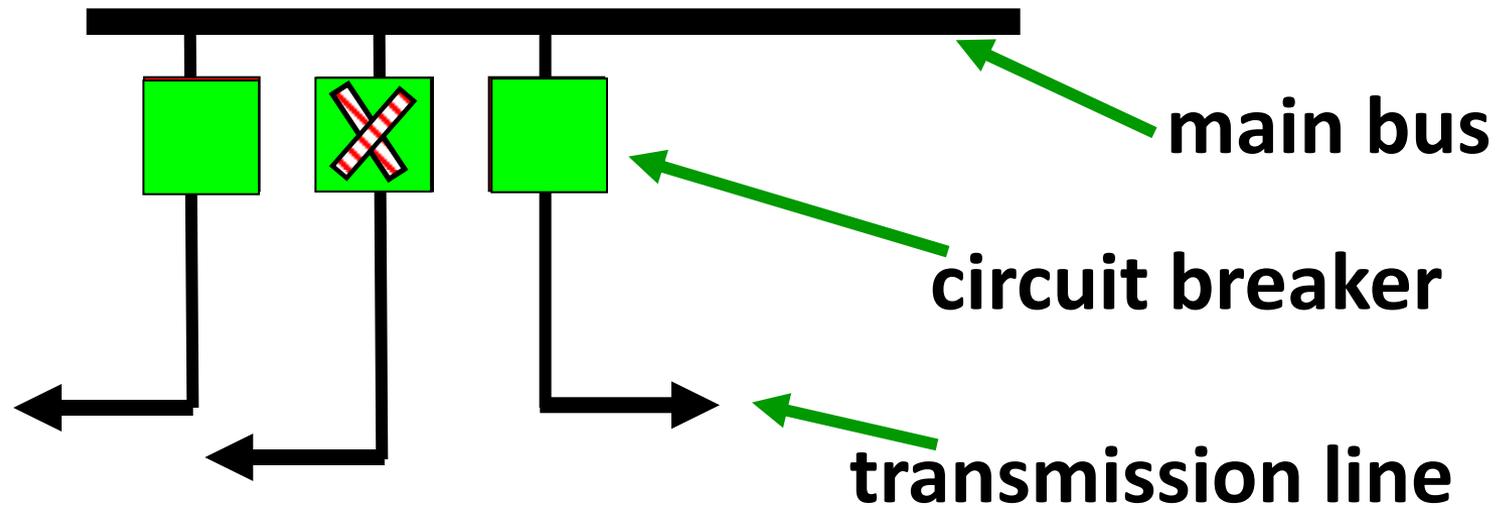
What is a Bus or Bus Bar?



How a Bus Works



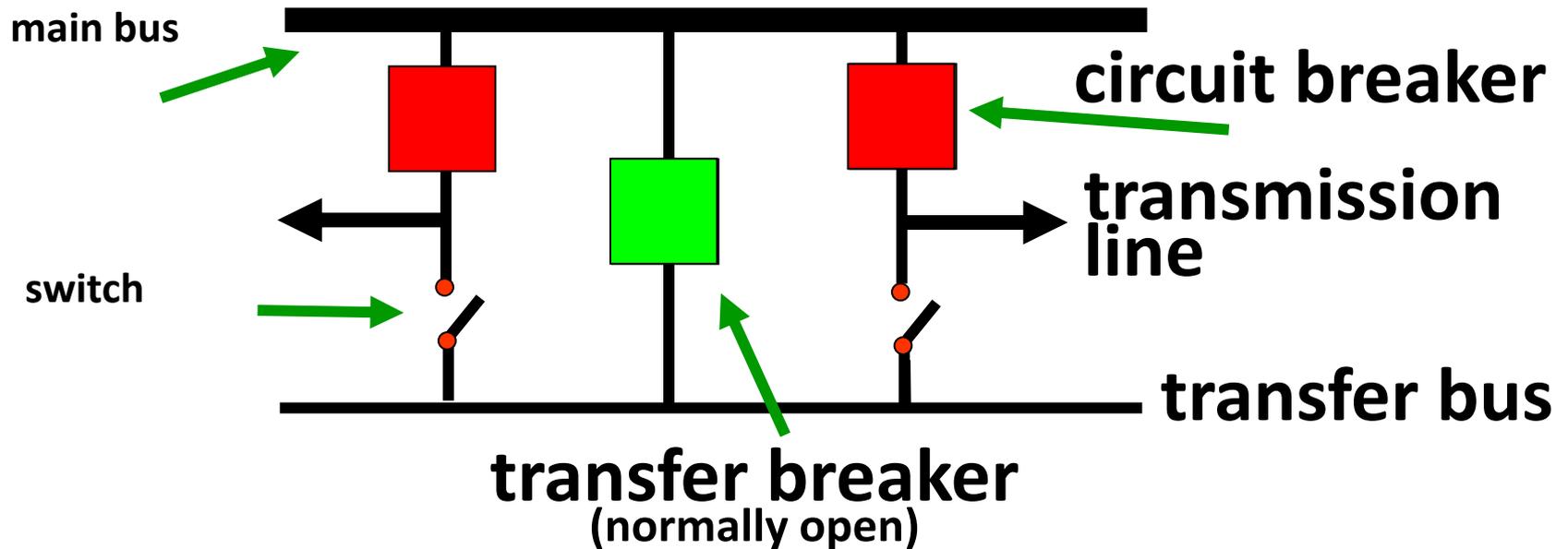
Single Bus – Single Breaker



Each line is protected by a single circuit breaker. Breaker outage isolates line

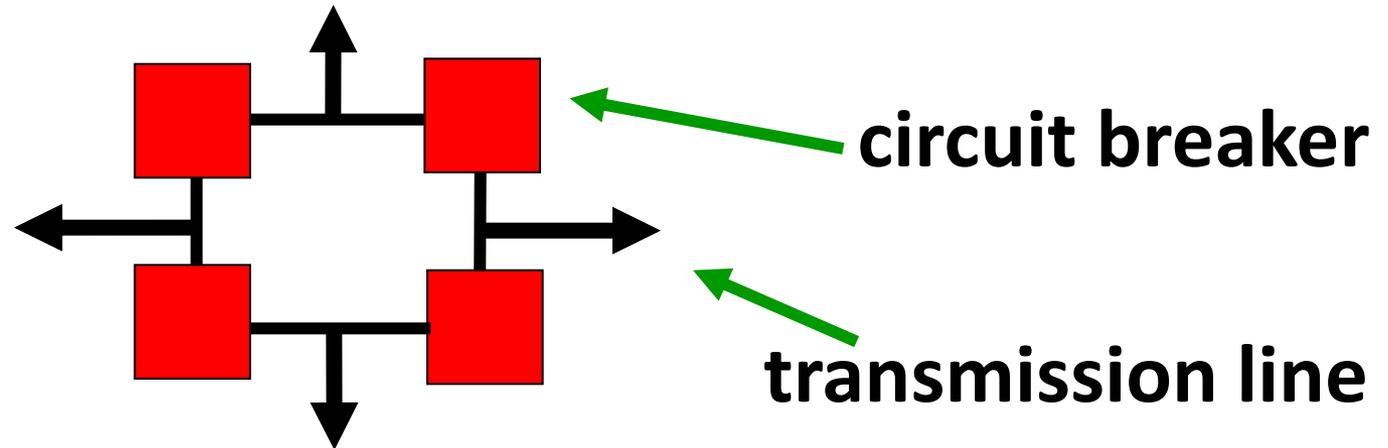
An outage of the bus opens all lines at this station

Main and Transfer Bus



Transfer breaker & switch allows either line to remain energized while its normal breaker is out for maintenance...

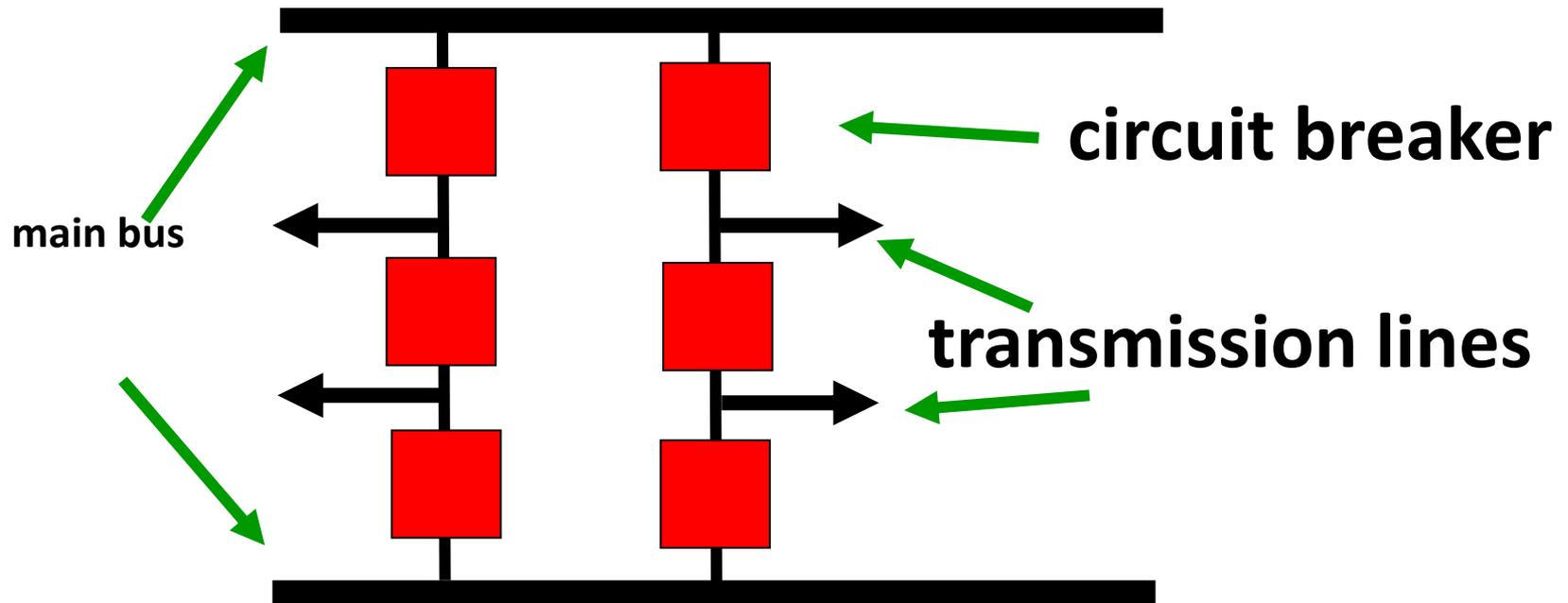
Ring Bus



One circuit breaker per element

An outage of any breaker does not outage any lines.

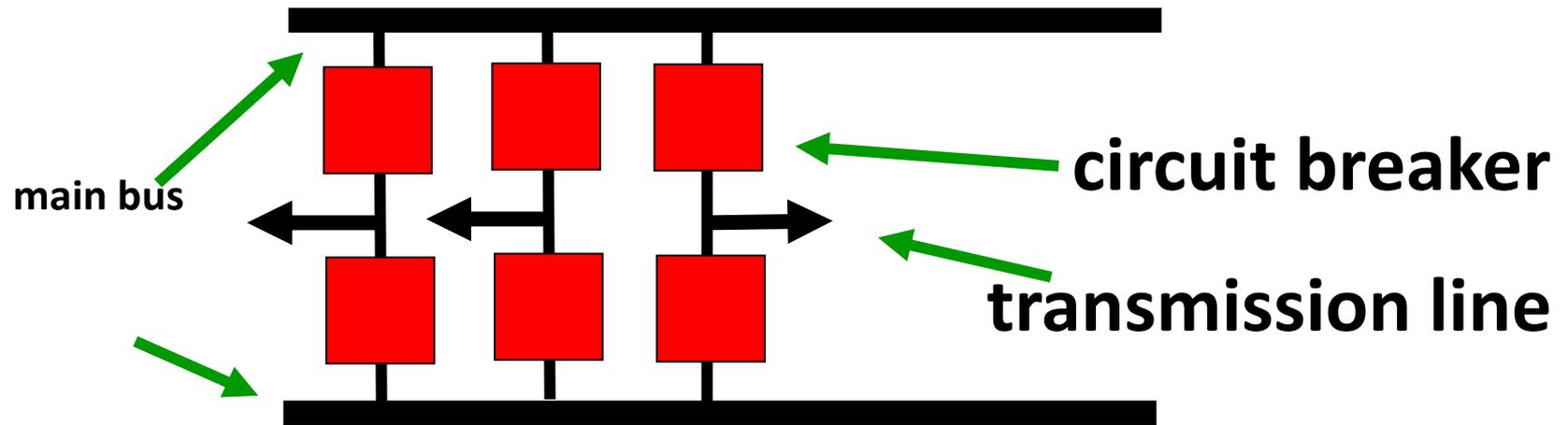
Breaker and a Half



Each line is protected by “1-1/2” circuit breakers.

An outage of any bus or any breaker does not outage any lines.

Double Bus – Double Breaker



Each line is protected by two circuit breakers.

An outage of either bus or any breaker does not outage any lines.

Recap