Power System Fundamentals

Relay Applications

PJM State & Member Training Dept.

Objectives

At the end of this presentation the Student will be able to:

- Describe the purpose of protective relays
- Identify relay protection scheme characteristics and components
- Describe the impact of the loss of components on system protection
- Identify the types of transmission line protection and their characteristics
- Identify the types of transformer protection and their characteristics
- Identify the types of bus protection and their characteristics
- Identify the types of generator protection and their characteristics

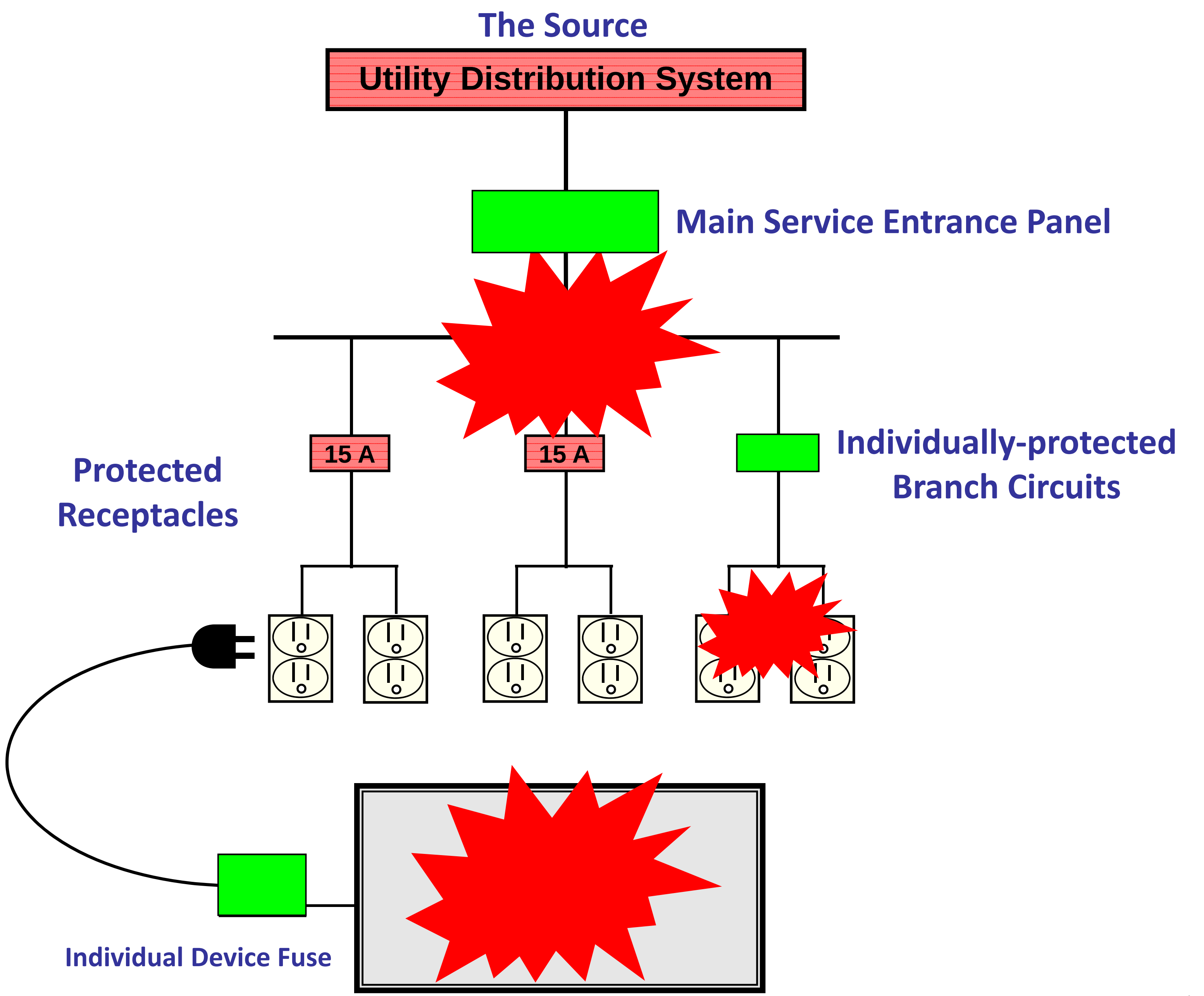
Basic Concepts in Protection

Purpose of Protective Relaying

- To detect and isolate faulted or malfunctioning equipment in order to:

1) limit the extent of the system disturbance and

2) maintain system reliability


The Source
Utility Distribution System
Main Service Entrance Panel
15 A
15 A
Individually-protected
Branch Circuits
Protected
Receptacles
Individual Device Fuse

Basic Concepts

- Relays are the intelligence in a Protective Scheme
  - They monitor system “inputs” and operate when the monitored quantity exceeds a predefined limit
  - Relay response will initiate a desirable system event that will aid in maintaining system reliability (i.e. trip a circuit breaker, throttle back a unit, etc)

Basic Concepts

- Other devices which are used in conjunction with Protective Relays are:
  - Current Transformer (CTs)
  - Potential Transformers (PTs)
  - Other Sensing Devices (e.g. Temperature, Oil Level, Pressure, etc.)
  - Logic Circuits (Analog or Microprocessor)
  - Three Pole Interrupting Devices (CBs, Circuit Switchers, Motor Operated Disc)

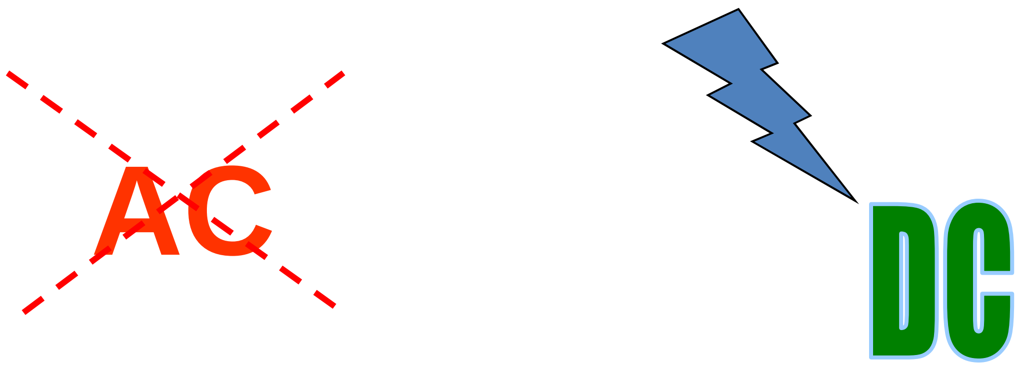
Basic Concepts

- Most Relay schemes work to control a DC system
  - DC System usually has rack of Batteries and a battery charger
  - Generally controls the tripping of CBs
  - This why NERC compliance includes DC Control Circuitry and Batteries as part of the Relay Standards

Relay Scheme Components

DC Control Systems

- The power source used for controlling power system equipment must be highly reliable and not subject to interruption by power system transients or outages



- Protection and control circuits are individually fused to guard against disrupting the entire DC system for problems on a particular branch circuit
- Amber lights often monitor the DC supply to individual branch circuits, giving a visual indication that the circuit is energized

DC Control Systems

- With few special exceptions, DC systems operate ungrounded
- Power plants and most substations have some battery ground detection, very often including *ground indicating lamps* that visually alert personnel to inadvertent DC system grounds

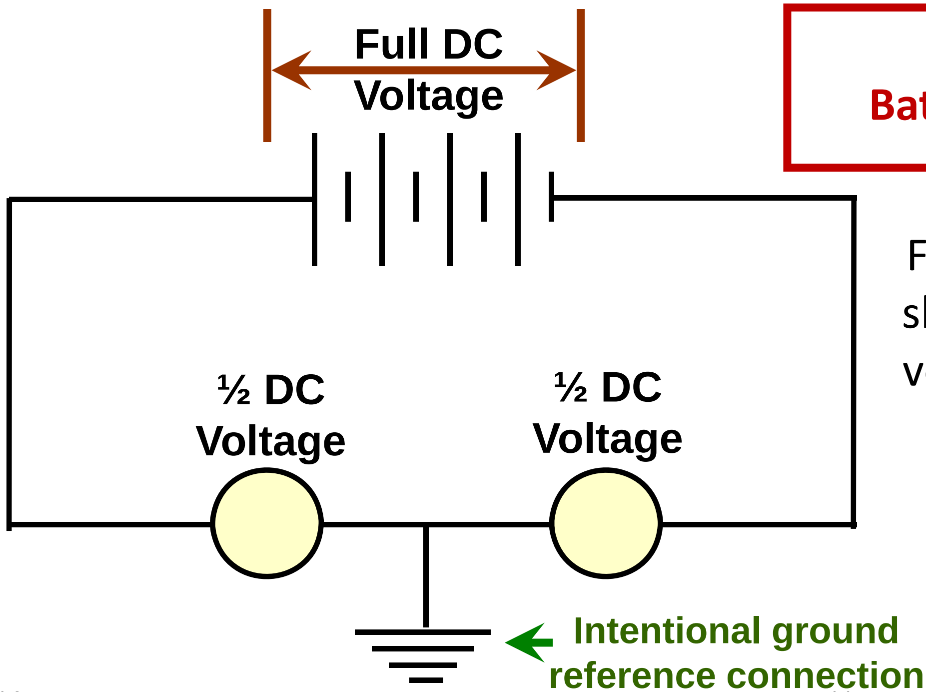
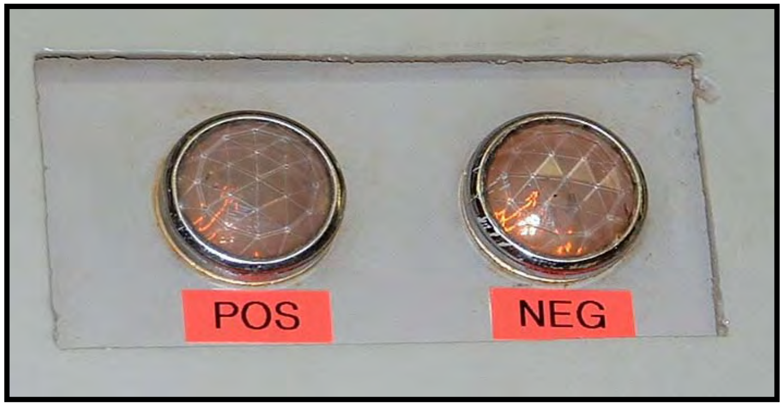


Illustration Of
Battery Ground Detection Lamps

For the normal, ungrounded condition shown, the two lamps each have equal voltage dropped across them and glow with equal brilliance

DC Control Systems

Illustration Of Actual Battery Ground Indicating Lamps



Normal Battery Ground Lamps Approximately Equal Brilliance

Battery Ground Lamps Indicate A Solid Ground On The Positive Side Of The DC System

- This same principal of DC ground detection is used in more sophisticated devices that provide an alarm contact instead of just a visual indication
- A single inadvertent ground on an ungrounded DC system is not catastrophic…the danger is that a second inadvertent ground could occur on the *opposite side of the DC supply* and short out the battery!

DC Control Systems

- **COMMON CAUSES OF BATTERY GROUNDS**

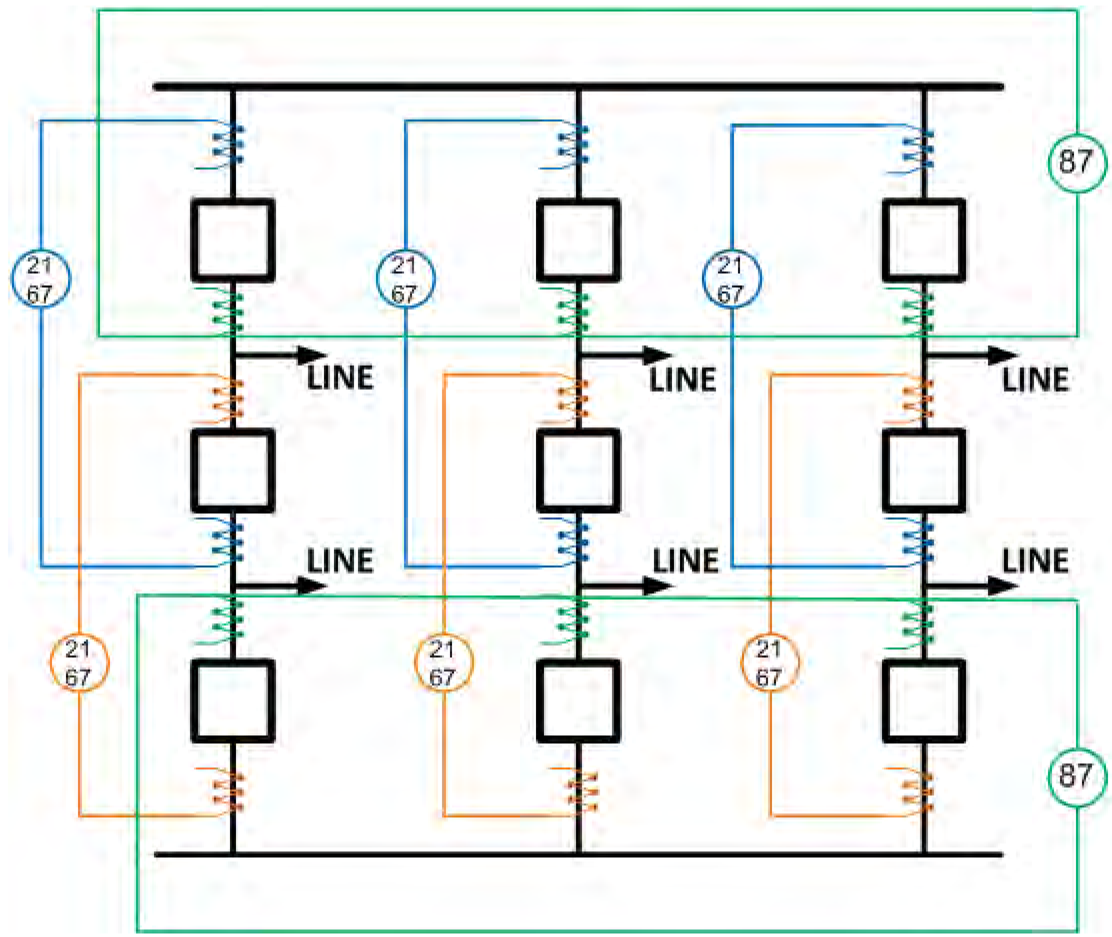
Overview of Power System Protection

Overview of Power System Protection

- Key element to remember
  - Protective Schemes are designed to have:

OVERLAPPING ZONES
OF PROTECTION!

Overlapping Zones of Protection

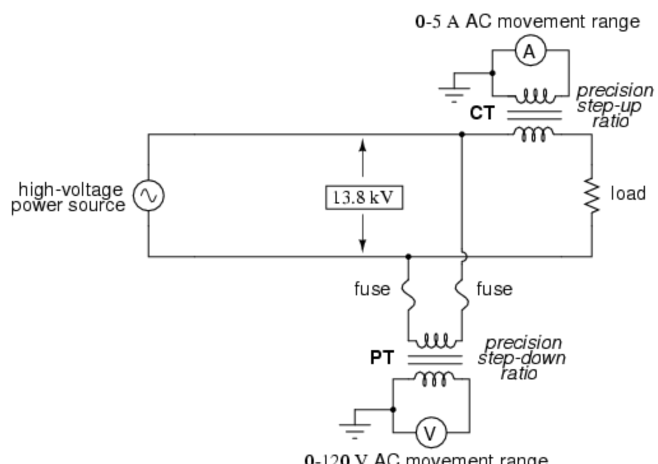


Overview of Power System Protection

- Critical elements of the power system are protected by "Primary" and "Backup" relay systems
  - Primary Schemes are generally high speed schemes (operate speed = 1 cycle)
  - Backup Schemes can also be high speed but don't have to be. System conditions dictate if this scheme has to be as fast as the primary scheme

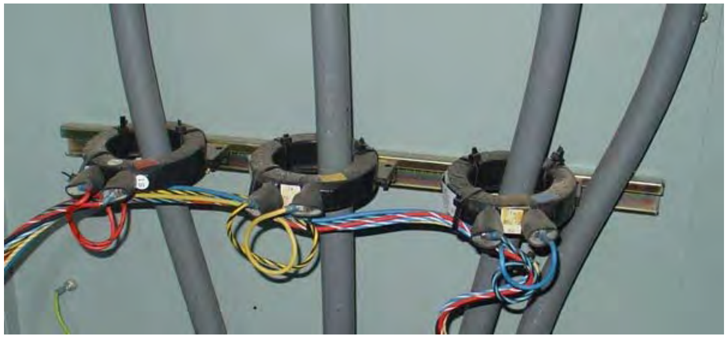
Instrument Transformers

- Instrument Transformers change *primary* voltages and currents into *secondary* quantities having proportional magnitudes and identical phase angle relationships
  - Primary current is transformed by CTs (Current Transformers) and LCs (Linear Couplers)
  - Primary voltage is transformed by PTs (Potential Transformers) and CCVTs (Coupling Capacitor Voltage Transformers)



Current Transformers (CTs)

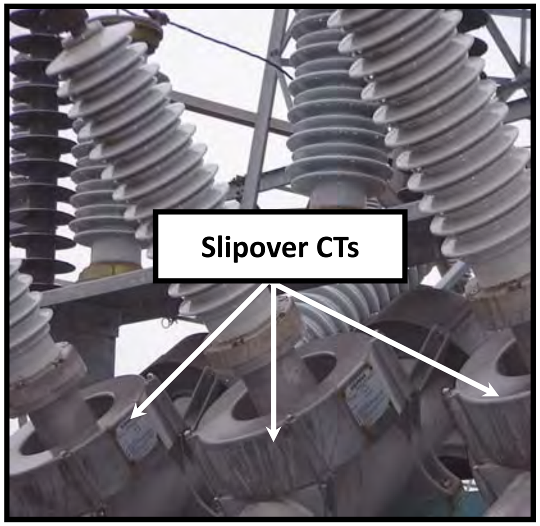
- CTs transform high magnitude primary amps to secondary amp quantities within the current ratings of relays and meters
- CT ratios are typically expressed as Primary Amps/5
  - For example, a generator CT ratio expressed as 25000/5 means that 5000 amps flowing in the primary circuit results in 1 amp flowing in the secondary circuits
  - CTs that fit around breaker, generator, or transformer bushings are called bushing CTs; these are the most common type of CTs

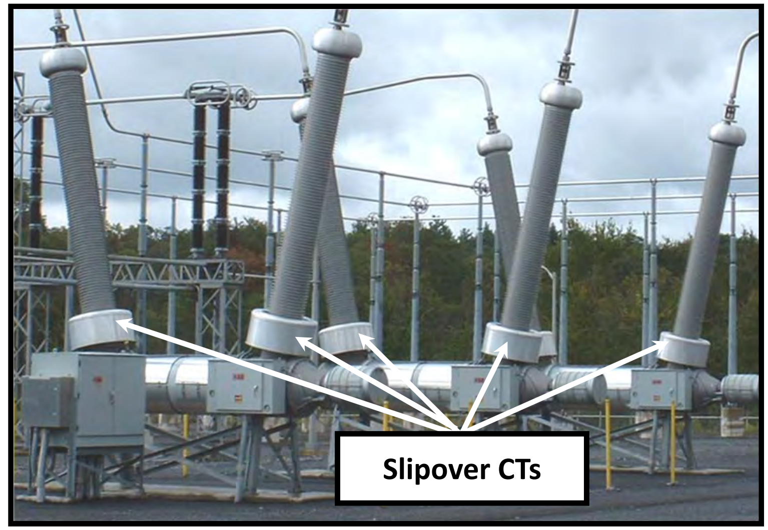


Current Transformers (CTs)

- A CT is a nearly ideal current source...within the limits of its construction, a CT produces as much voltage as necessary to push secondary current proportional to the primary current through a connected load, no matter how large the load impedance
- Ohm's Law, V = Z x I, describes how much voltage, V, a CT must produce to drive its current, I, through connected load impedance, Z...as Z gets bigger, V must also increase to satisfy the equation!

If the secondary circuit of a load-carrying CT is open-circuited, the CT can produce high enough voltage to injure or kill personnel





Illustrations Of Externally Applied Current Transformers

ABOVE LEFT

Slipover CTs installed on a 69kV circuit breaker

ABOVE RIGHT

Slipover CTs installed on a 500kV circuit breaker

BELOW

Similar to the bushing CTs pictured above, the window CTs below have a single turn primary winding comprised of the primary current conductor passing through the center of the CT

Linear Couplers (LCs)

- LCs transform high magnitude primary amps to secondary voltages within the voltage ratings of relays and meters
- Linear Couplers can be *thought of* as having an air core instead of iron, like a CT. This conceptualization isn't *technically* correct, but unless you plan to actually build a linear coupler it's good enough to distinguish between CT and LC construction

Potential Transformer (PTs)

- PTs transform primary voltages to the 115 VAC or 69 VAC secondary voltages used in relay and metering circuits
- Large generators usually have two sets of PTs, sometimes referred to as the metering PTs and the regulator PTs. These designations don't necessarily identify function, since both sets of PTs provide voltage to various protective relays and meters
- Although one set of PTs (the *regulator* PTs) is the preferred source of voltage to the generator voltage regulator, either set is usually capable of serving this function
- With a few exceptions, PTs aren't used at transmission voltage levels…most higher voltage applications use a derivative of the PT, the Capacitance Potential Device

Capacitance Potential Devices

- Known as CCPDs (Coupling Capacitor Potential Devices) or CCVTs (Coupling Capacitor Voltage Transformers)
- These devices use voltage division to reduce primary voltages to the 115 or 69 VAC needed by relays and metering equipment:
  - Primary voltage divides across porcelain capacitance stacks, the higher the voltage the more units in the stack. A transformer in the CCVT base does the final transformation from several thousand volts to 115/69 VAC
- Due to voltage division, a failure in one stack can act as a row of dominoes resulting in more failures

Diagram Of CCVT Construction

- Primary voltage divides across capacitance stacks C1, C2, and C3
    - Voltage across C3 equals approximately 20 kV

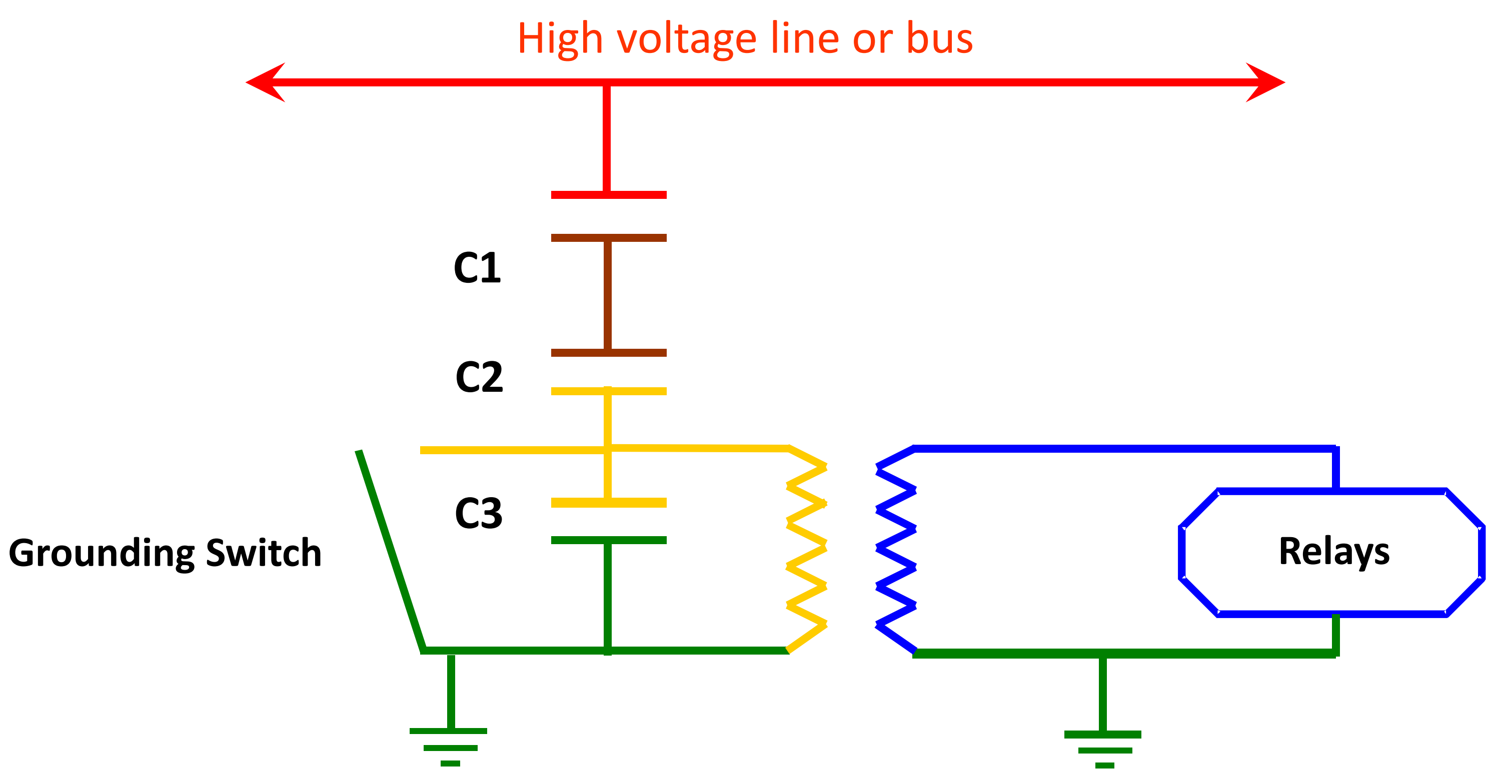


Illustration Of 230kV CCVT

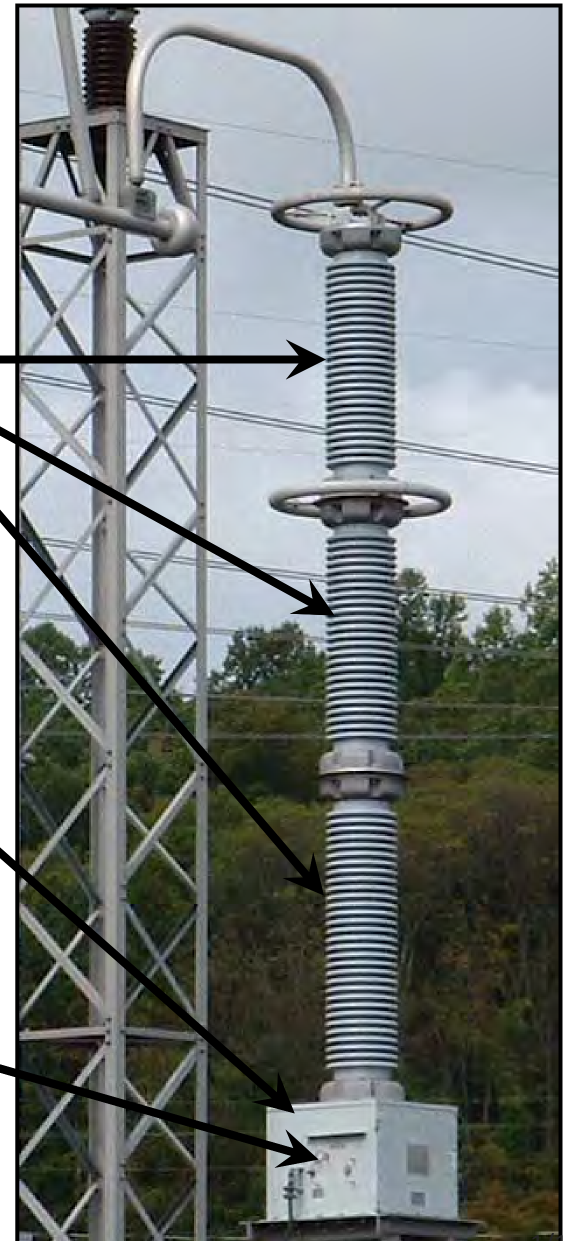
Notice that the 230kV CCVT has 2 capacitor stacks, while the 500kV CCVT needs 3 stacks to divide the higher primary voltage

Capacitor Stacks

Transformer Enclosure

Grounding Switch

Illustration Of 500kV CCVT



Overview of Power System Protection

- As with most things, there is a balance between preserving system reliability and economics
- Must review the cost of the protective scheme against the probability of a particular event occurring

Relay Scheme Design Considerations

- **Sensitivity** - can scheme detect all "events" that it is supposed to?
- **Selectivity** - will it remove only the "faulted" piece of equipment?
- **Speed** - can the scheme clear the fault fast enough to maintain or insure system integrity?
- **Reliability** - will the scheme be secure and dependable?
    - **Security** - no misoperations
    - **Dependability** - operate when it should
- **Economy** - Provide the desired level of protection for the least cost
- **Simplicity** - Attempt to keep designs straightforward

Relay Devices

Definition

- A relay is a device that will change its output contact status due to the excursion of a monitored system input beyond a preset value
- Examples:
  - Current exceeds preset value
  - Oil level below required spec
  - Temperature above required spec

General Functions:

- Protective
  - remove a system disturbance from the power system
- Regulating
  - insures system is operated within proper guidelines
- Auxiliary
  - Other less critical functions (i.e. alarms, reclosing. etc.)

Electromechanical

Solid State

Microprocessor

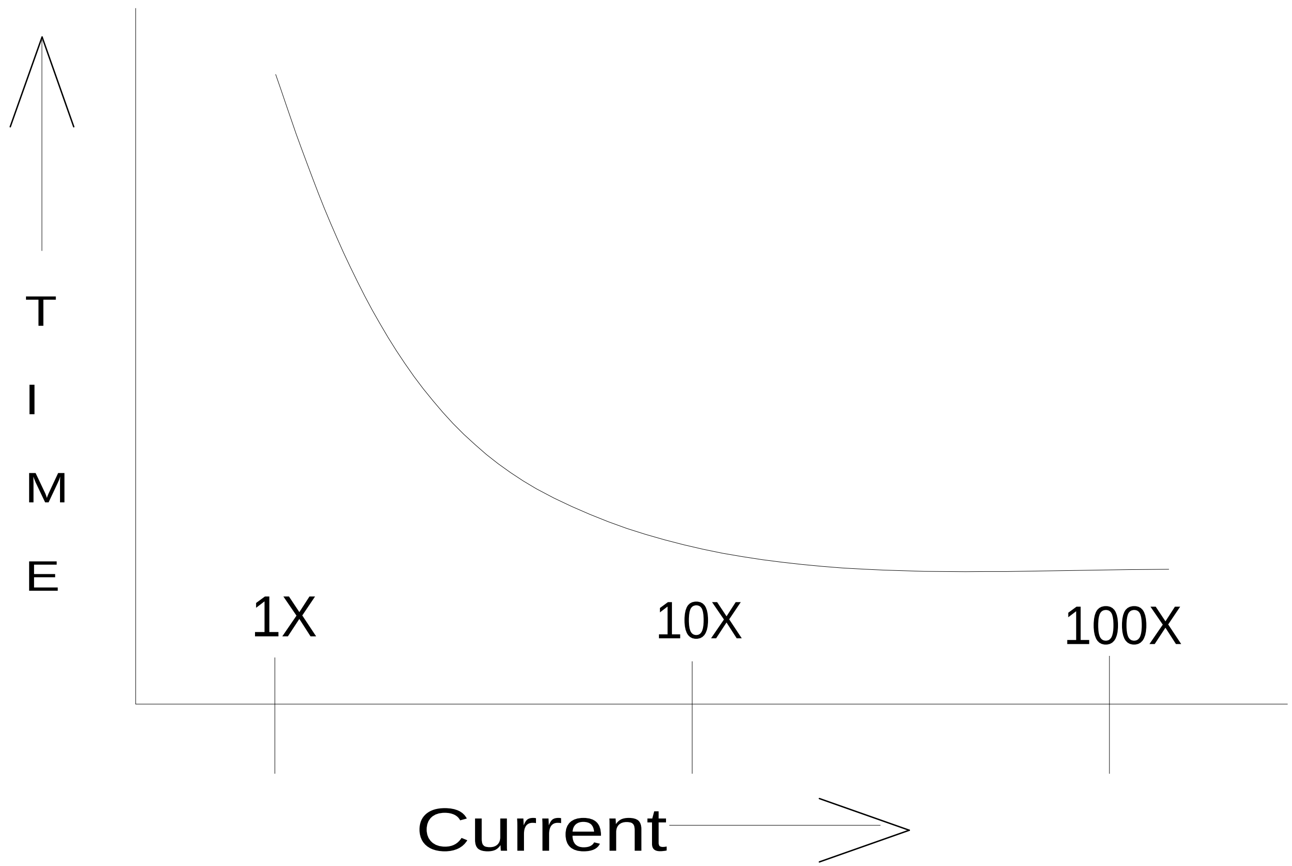
Universal Numbering System for Protective Relays

IEEE #	Device	Relay Function	IEEE #	Device	Relay Function
21	Distance Relay	Requires a combination of high current and low voltage to operate. The various zones of the distance scheme (Z1, Z2, etc.) assist with determining the location of the fault	63	Pressure Relay	Operates on low or high pressure of a liquid or gas (oil or SF6) or on a rate-of change of pressure (sudden pressure)
25	Synchronizing Relay	Checks voltage magnitude, phase angle, and frequency to verify synchronism across a CB before allowing a close	67	Directional Overcurrent	Operates if current is above a set value and flowing in the designated direction
27	Undervoltage Relay	Operates when voltage falls below a set value	78	Out-of-Step	Detects loss of synchronism.
49	Thermal Relay	Operates when the temperature (usually a winding) rises above a set level	79	Reclosing Relay	Initiates an automatic closing of a circuit breaker following a trip condition
50	Instantaneous Overcurrent	Operates with no time delay when current rises above a set level	81	Frequency Relay	Operates if frequency goes above or below a set limit
51	Time Overcurrent	Operates on a time-delayed basis depending on the amount of current above a set level	86	Lockout Relay	An auxiliary relay that can perform many functions (including tripping of breakers) and prevents closing of circuit breakers until it is reset either by hand or electrically
52	Circuit Breaker	Circuit Breaker	87	Differential Relay	Senses a difference in currents entering and leaving power system equipment
59	Overvoltage Relay	Operate when voltage exceeds a set limit	94	Tripping Relay	Auxiliary relay which is activated by a protective relay and which initiates tripping of appropriate breakers

Typical Performance Parameters:

Overcurrent

- Required input: Current from CTs
- Instantaneous - No intentional time delay
- Time delayed - Inverse time/current curve
- Can protect for both Phase and Ground faults. The physical connection determines what current (phase or ground) the relay will respond to



Inverse Curve Characteristic

Typical Performance Parameters:

Over/Under Voltage:

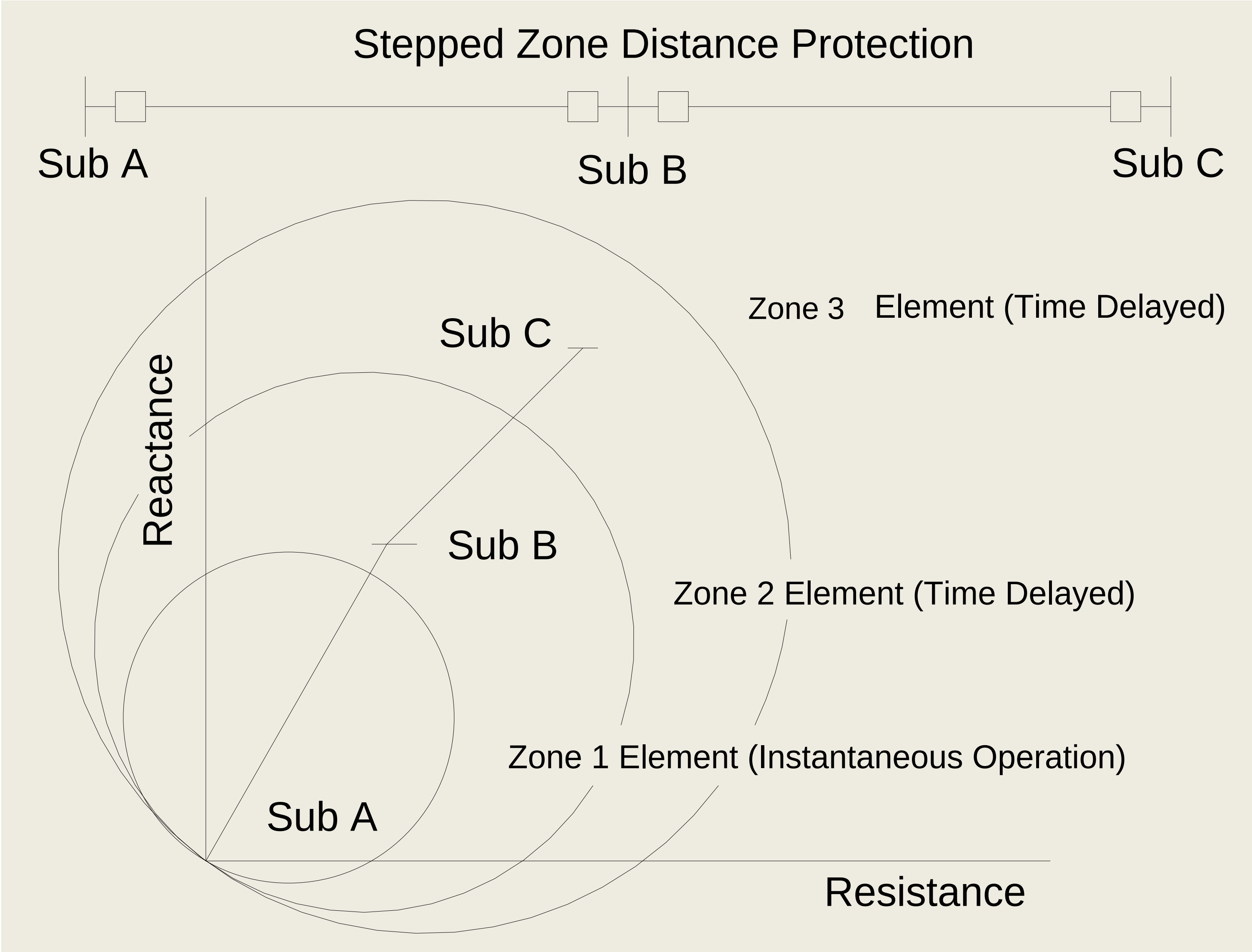
- Required input: Voltage from PTs
- Instantaneous - No intentional time delay
- Time delayed - Generally a fixed delay
- Generally used for automatic sectionalizing control (i.e. auto transfer schemes, etc.)

Typical Performance Parameters:

- Directional Capability
  - Required Inputs: Current and Voltage
  - Can be a stand alone relay or associated with another relay element
  - Directionality makes the life of a protection engineer much easier from a relay coordination point of view

Typical Performance Parameters

- Stepped Distance Relaying
  - Requires Current and Voltage inputs
  - Operates on the V/I = Z (impedance) principle
  - Constant reach regardless of system
  - Less susceptible to misoperating on load current (when compared to simple phase overcurrent relays)
  - Usually provides three Zones of Protection:
    - Zone 1 - Instantaneous Operation
      Set for approximately 90% of line
    - Zone 2 - Fixed Time Delay Operation
      Set to see entire line + margin
    - Zone 3 - Fixed Time Delay Operation
      Set greater than Zone 2



Stepped Zone Distance Protection
Sub A
Sub B
Sub C
Zone 3 Element (Time Delayed)
Sub C
Reactance
Sub B
Zone 2 Element (Time Delayed)
Zone 1 Element (Instantaneous Operation)
Sub A
Resistance

Backup Transmission Line Protection

- Note that Zone 1 can only be set to see, at most, 90% of the protected line
- Cannot be set to see 100% of the line
  - Relay would not be able to distinguish between an internal or external fault
  - Setting relay to see 100% of line to obtain instantaneous clearing would most likely result in an overtrip
- This is one major disadvantage of a Stepped Distance scheme

Transient Load Limits

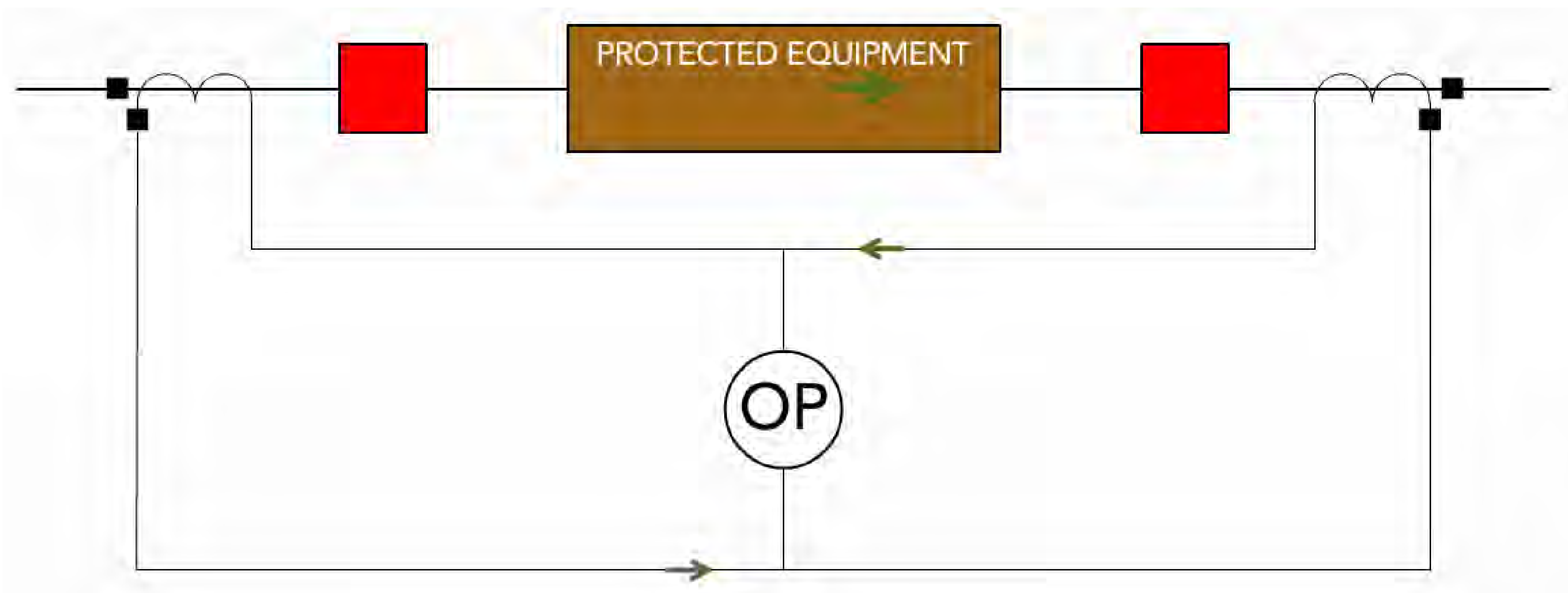
- Load carrying capability is another concern with distance relays
- Transient limit represents the maximum secure load carrying capability of the protective relays during actual operating conditions
  - As loading increases the “Z” viewed by the relay may cross into the “Z” trip area of the relay setting
  - Operators must be aware of any lines that are restricted not due to their thermal capability, but by the relays themselves.

Typical Performance Parameters:

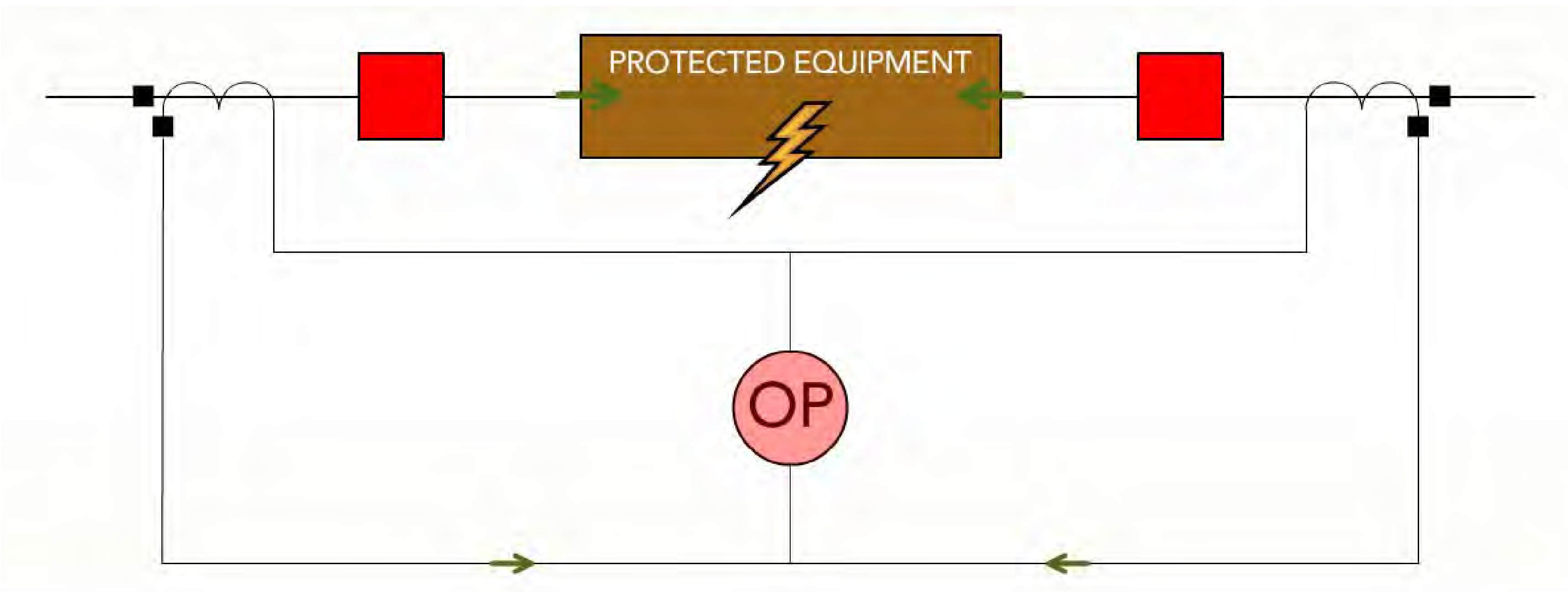
Differential

- Required input: Current from CTs
- Relay generally operates very fast (1 cycle)
- Normal protection for Generators, Transformers and Bus sections
- CTs supplying the relay should be matched so that currents into the “zone of protection” are equal to those currents that leave
- The difference/mismatch in current is observed in the relays operate coil

Differential Relay



Differential Operation



Typical Performance Parameters:

- Other Types (not all inclusive):
  - Frequency - Typically uses voltage
  - Reclosing - Single or Multi-shot
  - Thermal - Transformer Protection
  - Auxiliary - Master Trip, 52X, etc

Lockout Relays

- Lockout Relays
  - Special devices operated by dozens of functions that protect generators, transformers, busses and various other pieces of switchyard equipment
  - Relay itself doesn't *protect* anything; instead, it has multiple contacts that cause multiple devices, like circuit breakers, to operate in order to de-energize or isolate failed equipment
  - Serve an important function: if they failed to trip for a fault, for example, the switchyard GCB would stay closed and the equipment would remain energized
  - Because it's so important, the electrical coil that trips the lockout relay is monitored continuously by an amber lamp located immediately above the relay

Generator Lockouts

- The amber lamp is normally lit to indicate three important things about the Lockout Relay:
  1) There is DC control power available to the lockout relay
  2) The lockout relay operating coil is electrically intact
  3) The lockout relay is reset and ready to trip
- If the lamp *isn't* lit, it means there's no DC power available or that the lockout coil has burned open…in either case the lockout wouldn't be able to trip, making this a very serious situation that has to be resolved *immediately*
- The Lockout Relay target is an orange semaphore directly above the relay handle. When the lockout operates, the amber light goes out and this colored target appears
- The Lockout relay handle being at an angle instead of being perpendicular to the floor is another indicator of lockout operation

Illustrations Of A Lockout Relay

CAUTION
NEVER HOLD THESE RELAYS IN THE RESET POSITION…
this can burn up the operate coil and make the relay useless!

RESET

TRIPPED

Relay Basics Exercises / Review

The purpose of relay protection is to detect and isolate faulted equipment to:

1) Limit extent of disturbance
2) Preserve customer service
3) Maintain reliability

1. 1 and 2
2. 2 and 3
3. 1 and 3

One of the primary functions of protective relays is to ensure continuity of service to customers.

A. True

B. False

What parameters are used as inputs to relays?

Rank	Responses
1	
2	
3	
4	
5	
6	

Relays convert system parameters into electrical signals and when these signals reach a set point, the relay:

A. Initiates a trip
B. Waits for operator instructions
C. Triggers an alarm
D. Resets its counter

What is a desirable characteristic of relay systems?

Rank	Responses
1	
2	
3	
4	
5	
6	

Which of the following are input devices for relay schemes?

A. CTs
B. PTs
C. BLTs
D. Wavetraps

In most applications, current transformers scale down full load currents to a value of:

A. 1 ampere
B. 2 amperes
C. 4 amperes
D. 5 amperes

In most applications, potential transformers reduce primary system voltage to approximately:

A. 100 volts
B. 115 volts
C. 208 volts
D. 240 volts

How many turns would be required on a CT to achieve the 5 amp relay current if the full load current was 400 amps?

A. 40
B. 80
C. 100
D. 200

Current and voltage quantities can be combined in a relay circuit to determine the impedance of a line.

A. True
B. False

Which of the following are major design classifications of relays:

A. Electromechanical
B. Solid State
C. Virtual
D. Microprocessor based

Transmission Line Protection

Transmission Line Protection

- A typical power system utilizes three types of lines to deliver power to the end user. They are:
    1) Transmission Lines
    2) Sub-transmission Lines
    3) Distribution Lines
- We will be focusing on the Transmission lines which are defined as lines operating at 100kv and above

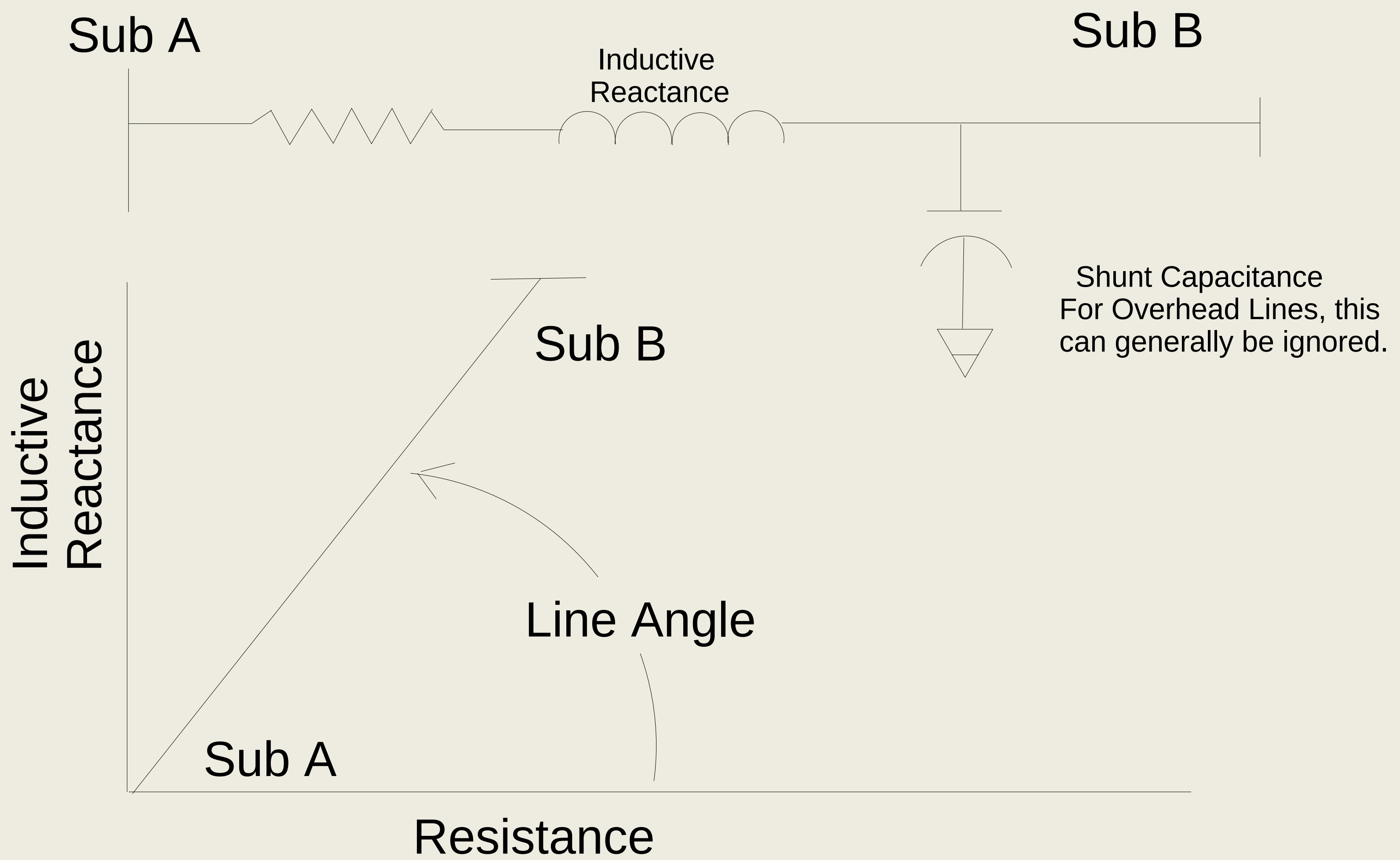
Transmission Line Protection

- Because these lines carry large amounts of energy and are extremely important to the operation of a power system, it is necessary to use the most advanced relaying methods to insure their integrity
- Being that important, it is desirable to have instantaneous clearing for all faults on the transmission line under normal operating conditions

Quick Review

- A Transmission Line has Impedance **(Z)** that is composed of resistance **(R)** and Reactance **(X)**
- It can symbolically be represented as: **Z = R +j X**
- Consequently, on an R-X impedance diagram, any line can be graphically represented
- See example

Graphical Representation of a Line Impedance



Transmission Line Protection

- For reliability, transmission lines utilize **Primary** and **Backup** protective schemes

- The criticality of each line is evaluated to determine if backup protection should be equivalent to primary protection. The factors which influence the decision are:
  - System Stability Concerns
  - Relay Coordination Concerns

Transmission Line Protection

System Stability

- If stability studies indicate that delayed clearing of faults on a transmission line cause a Generator to go unstable, it indicates that both the primary and backup protective schemes must clear all faults instantaneously

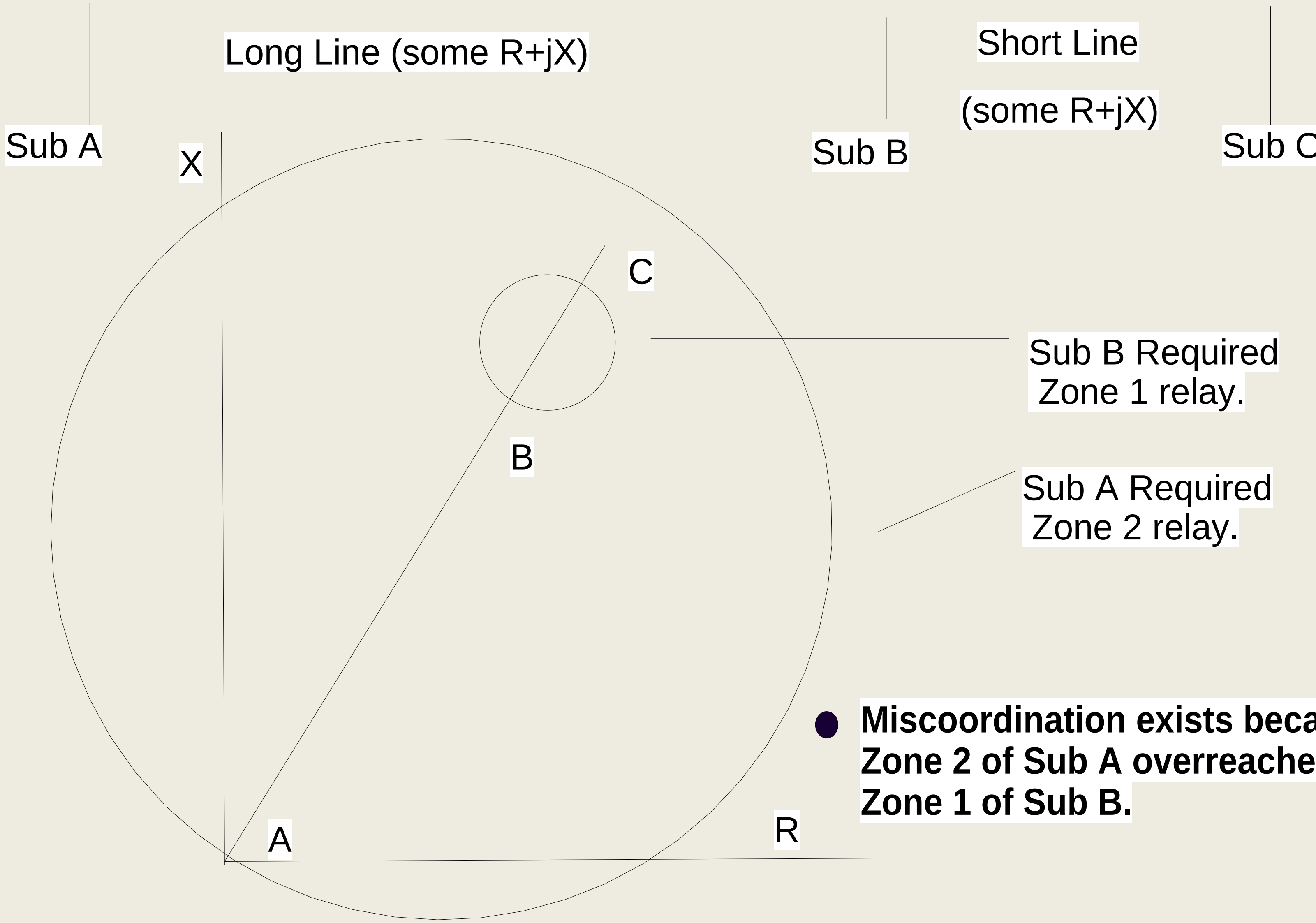
- These studies are done as part of the initial engineering process

Transmission Line Protection

Relay Coordination:

- If protection studies determine that coordination of backup relay schemes can not be achieved, dual **pilot protection** schemes must be employed on the line to be protected
- Typically happens on Long Line/Short Line situations. See example

Relay Coordination: Long Line/Short Line



- **Miscoordination exists because Zone 2 of Sub A overreaches Zone 1 of Sub B.**

Primary Transmission Line Protection

- To obtain instantaneous clearing for all faults, **Pilot Relaying** is utilized
  - The term “pilot” implies that a communication channel exists between all terminals of the protected line
    - Power Line Carrier
    - Telephone pair
    - Fiber Optic
    - Microwave

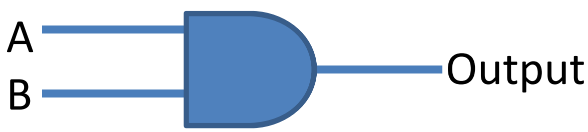
Primary Transmission Line Protection

- Several types of “pilot” protection schemes exist. The ones we will review are:
    1) Directional Comparison
    2) Direct Under-reaching Transferred Trip
    3) Permissive (Over & Under-reaching)
    4) Phase Comparison
    5) AC Pilot Wire
    6) Optical Fiber Differential

Logic Gates Overview

AND Gate

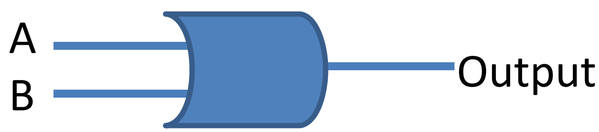
Needs 2 inputs to get an output



A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

OR Gate

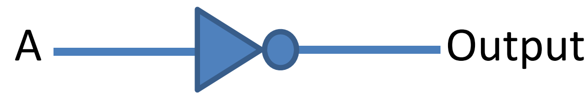
Needs 1 input to get an output



A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

NOT Gate

Output is the inverse of the input



A	Output
0	1
1	0

Directional Comparison Blocking

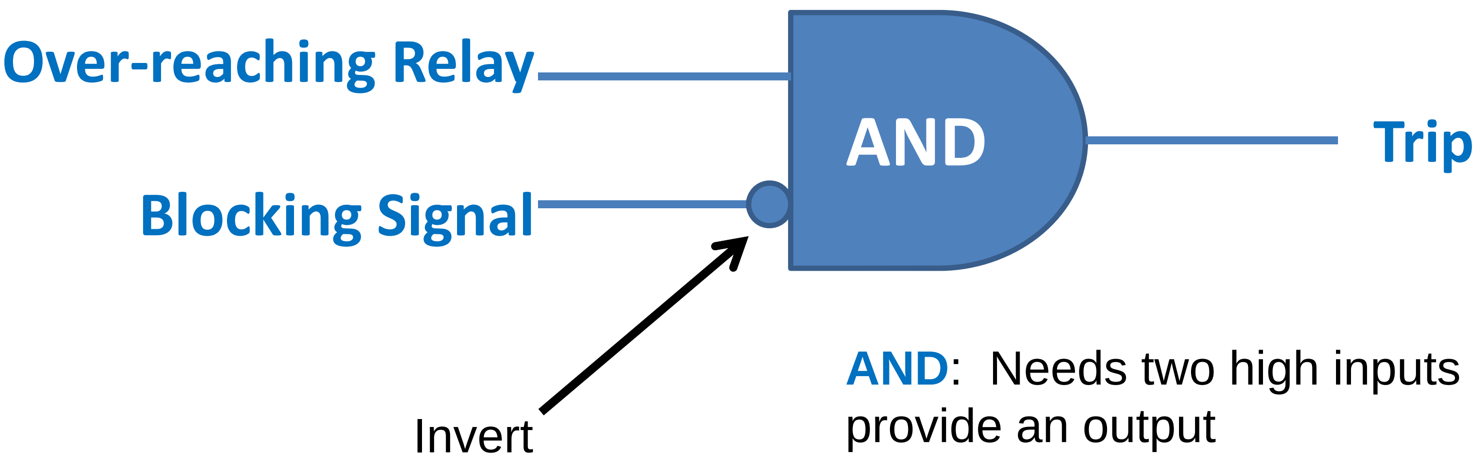
- Relays set to see beyond remote terminals
- Under non-fault conditions, no signal is sent between the terminals of the line
- To initiate a breaker trip, two conditions must be met:
  - Operation of a local tripping relay

  AND

  - Absence of a blocking signal from remote end
- Testing of communication path is done by Carrier Checkback Scheme

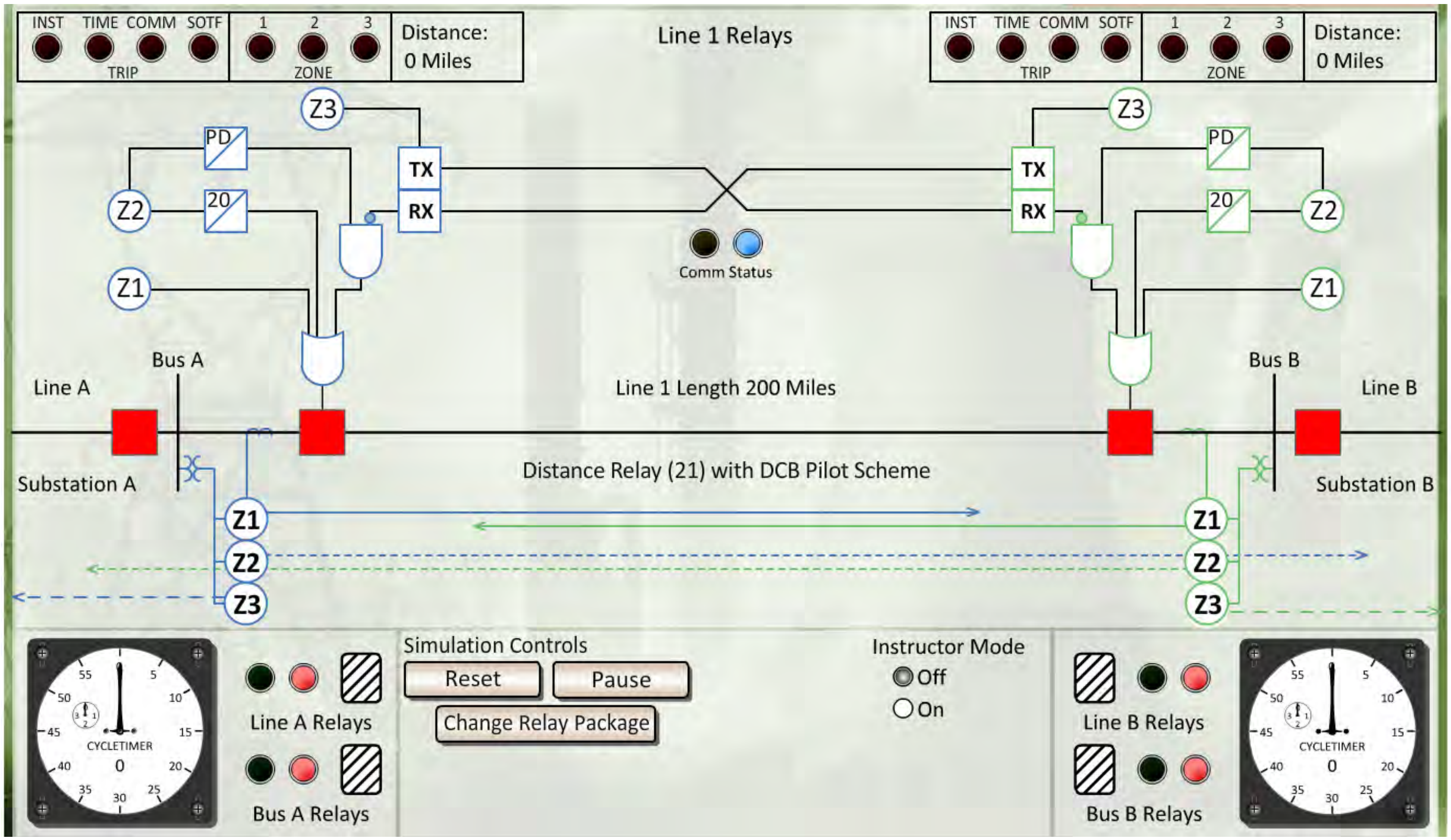
Directional Comparison Blocking Scheme

- To Initiate Trip:
  - Over-reaching Relay must operate
  - Absence of Blocking Signal from remote end
- In digital logic:



AND: Needs two high inputs in order to provide an output

Directional Comparison Blocking



Wave Trap and CCVT

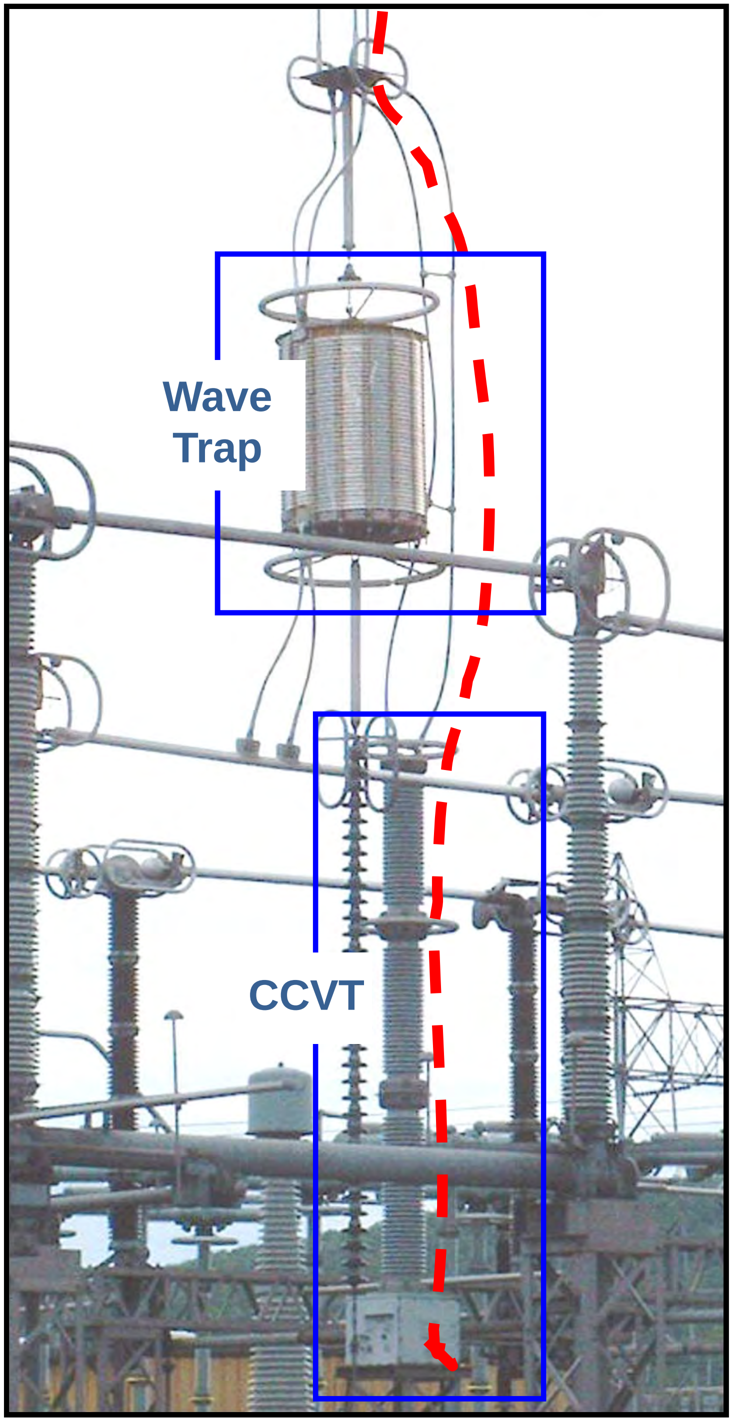


Illustration Of
500kV Wave Trap & CCVT

The carrier signal couples to the transmission line through the CCVT

The signal enters and exits the base of the CCVT, then connects to a nearby impedance-matching tuning box and then to the transmitter/receiver equipment located inside the substation control house

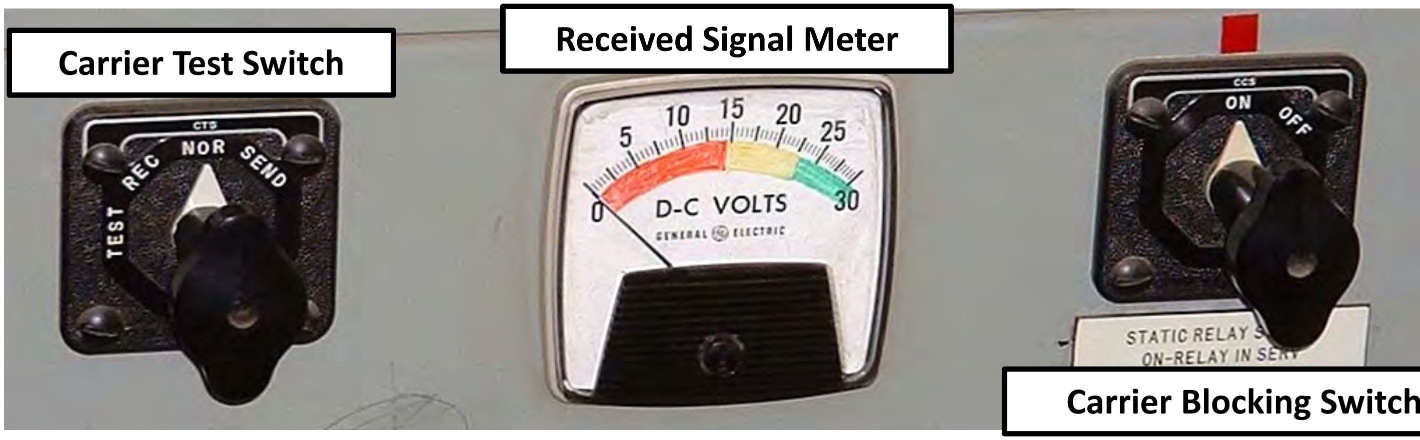
The carrier signal traffic is bi-directional: the local terminal both transmits a signal to the remote terminal and receives a signal from it, all through the same path shown in the illustration

The wave trap blocks the carrier signal from exiting the transmission line through any path other than through the CCVT

Typical Blocking Carrier Controls

Carrier Test Switch

Received Signal Meter



Carrier Blocking Switch

Note the red-yellow-green segments on the Received Signal Meters… the received carrier signal is strong enough if it appears in the green region, so-so in the yellow region, and bad enough to warrant blocking the carrier relaying if in the red region

Direct Under-reaching Transfer Trip

- Relays set to under reach the remote terminal
- Under non-fault conditions, a continuous GUARD signal is sent by the local transmitter and monitored by the remote receiver
- To initiate a breaker trip, one of the following must occur:
  - Local under-reaching relay must operate

  OR

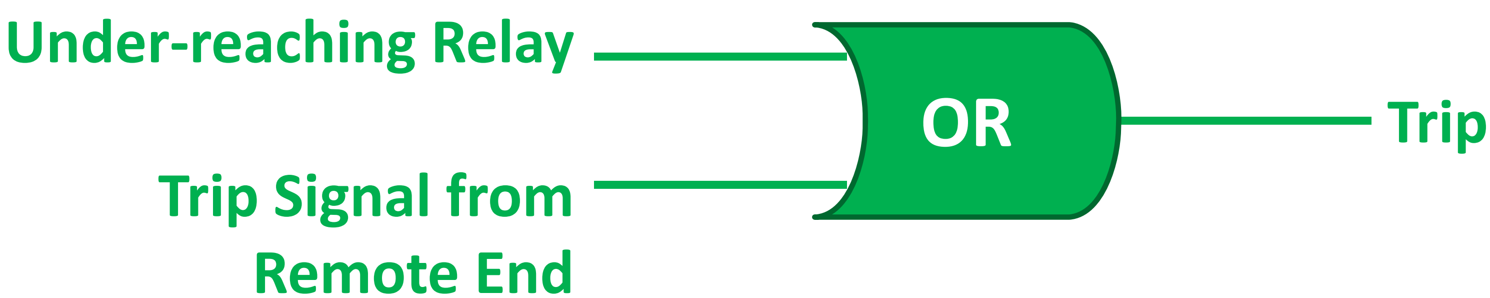
  - Reception of a TRIP signal from the remote end must e received
- Testing of communication path is continuous via GUARD signal. Loss of guard will generate alarm

Direct Under-reaching Transfer Trip Scheme

- To Initiate Trip:
  - Under-reaching Relay must operate

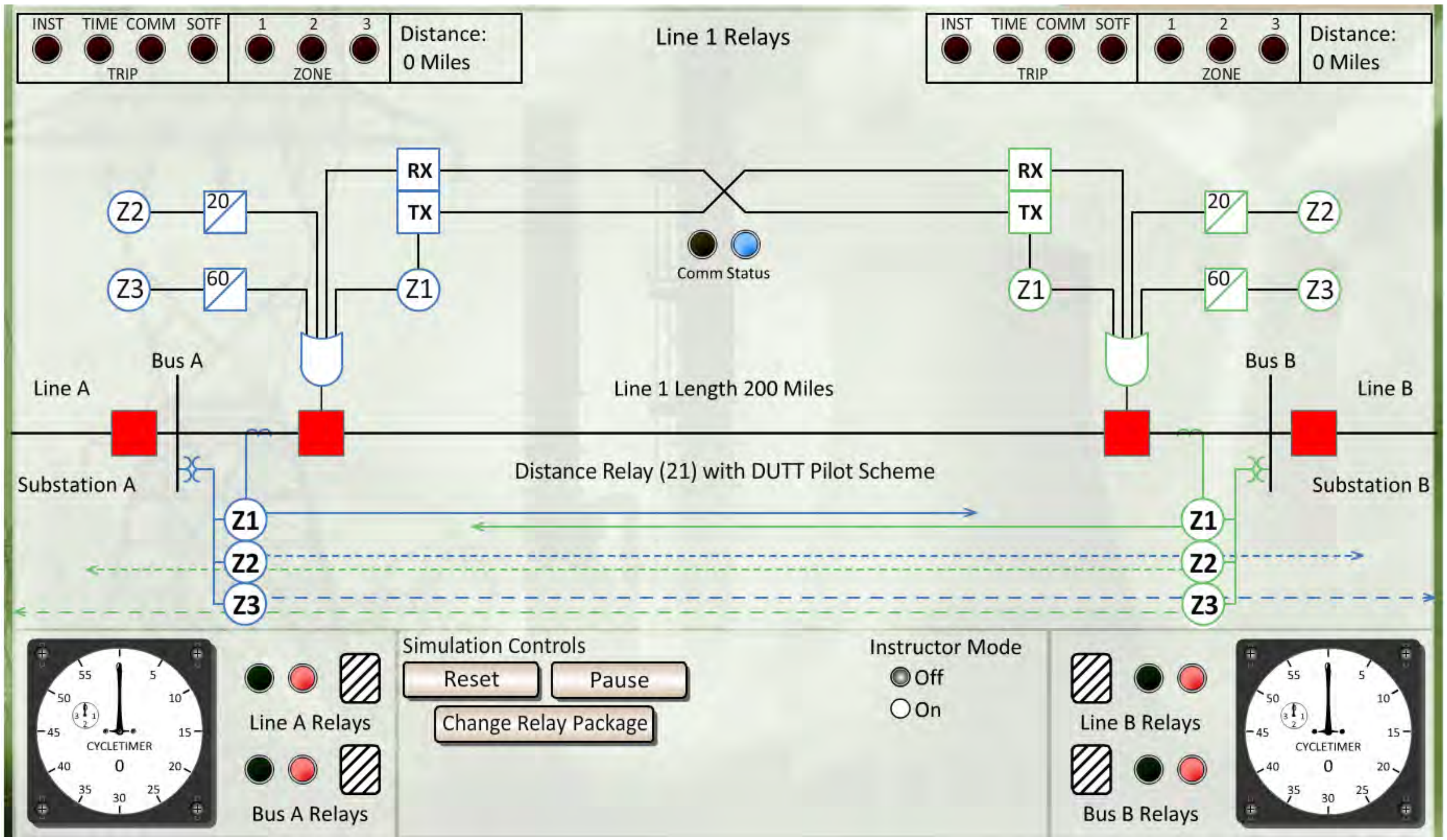
  OR

  - Receive a trip signal from the remote end
- In digital logic:



OR: Needs one high input in order to provide an output

Direct Under-reaching Transfer Trip



Permissive Under-reaching Transfer Trip

- Direct tripping relays set to under reach remote end
- Fault detector relays set to overreach remote end
- Under non-fault conditions, continuous GUARD signal is sent to remote end
- To initiate a breaker trip, one of the following must occur:
  - The under-reaching relay must operate

  OR

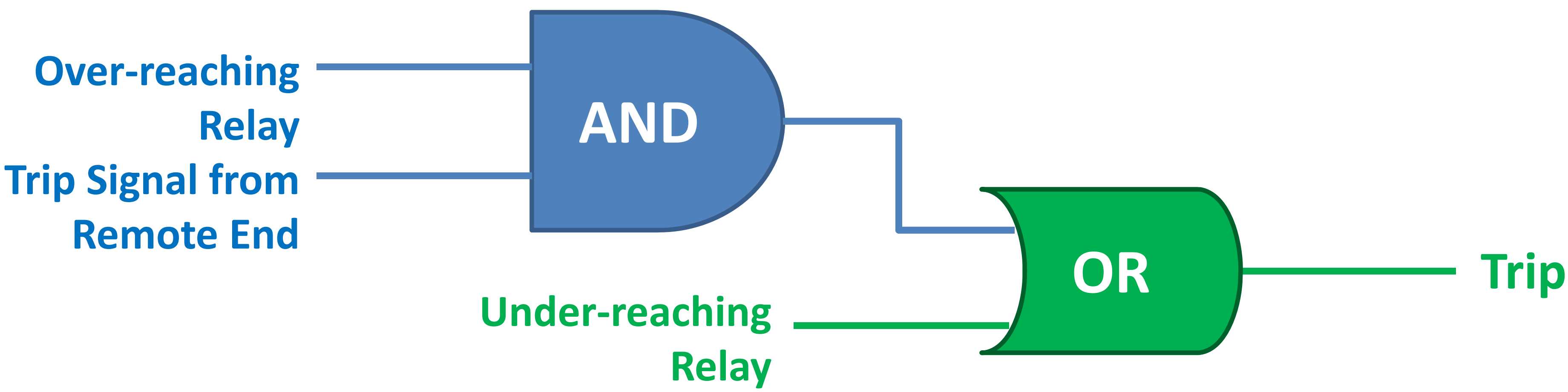
  - The overreaching relay must respond **AND** a TRIP signal must be received from remote end
- Communication path testing is continuous via GUARD signal. Loss of Guard will generate an alarm

Permissive Under-reaching Transfer Trip Scheme

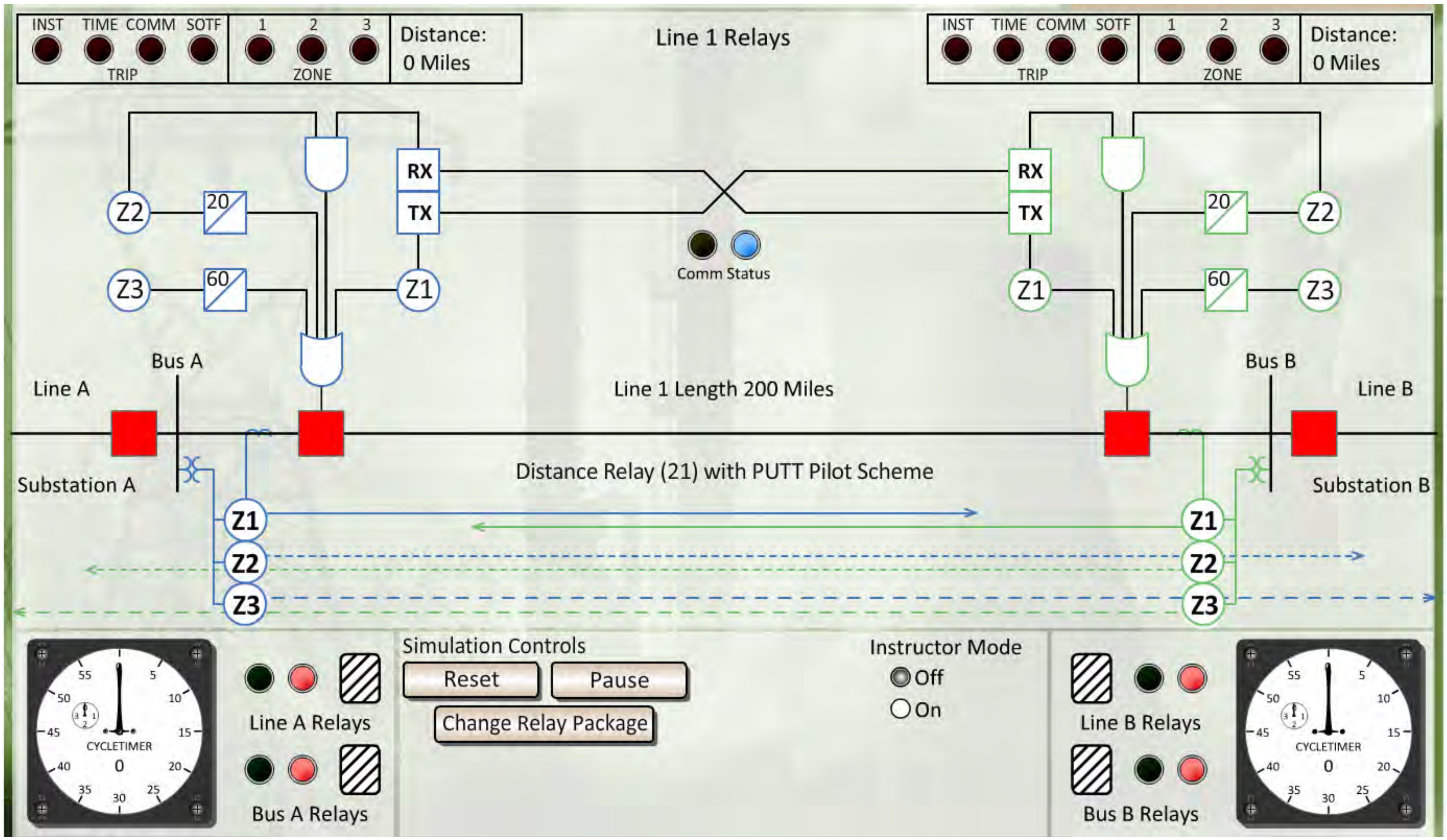
- To Initiate Trip:
  - Under-reaching Relay must operate

  OR

  - Over-reaching relay must operate **AND** receive a trip signal from the remote end
- In digital logic:



Permissive Under-reaching Transfer Trip



Permissive Over-reaching Transfer Trip

- Relays set to see beyond remote terminals
- Under non-fault conditions, a continuous GUARD signal is sent
- To initiate a breaker trip, two conditions must be met:
  - Operation of local tripping relay

  AND

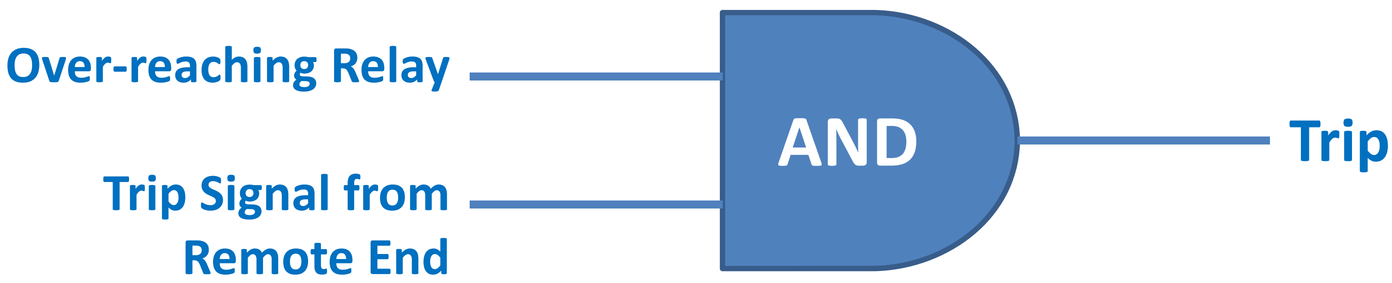
  - Receipt of TRIP signal from remote end
- Testing of communication path is continuous via GUARD signal. Loss of Guard generates alarm

Permissive Over-reaching Transfer Trip

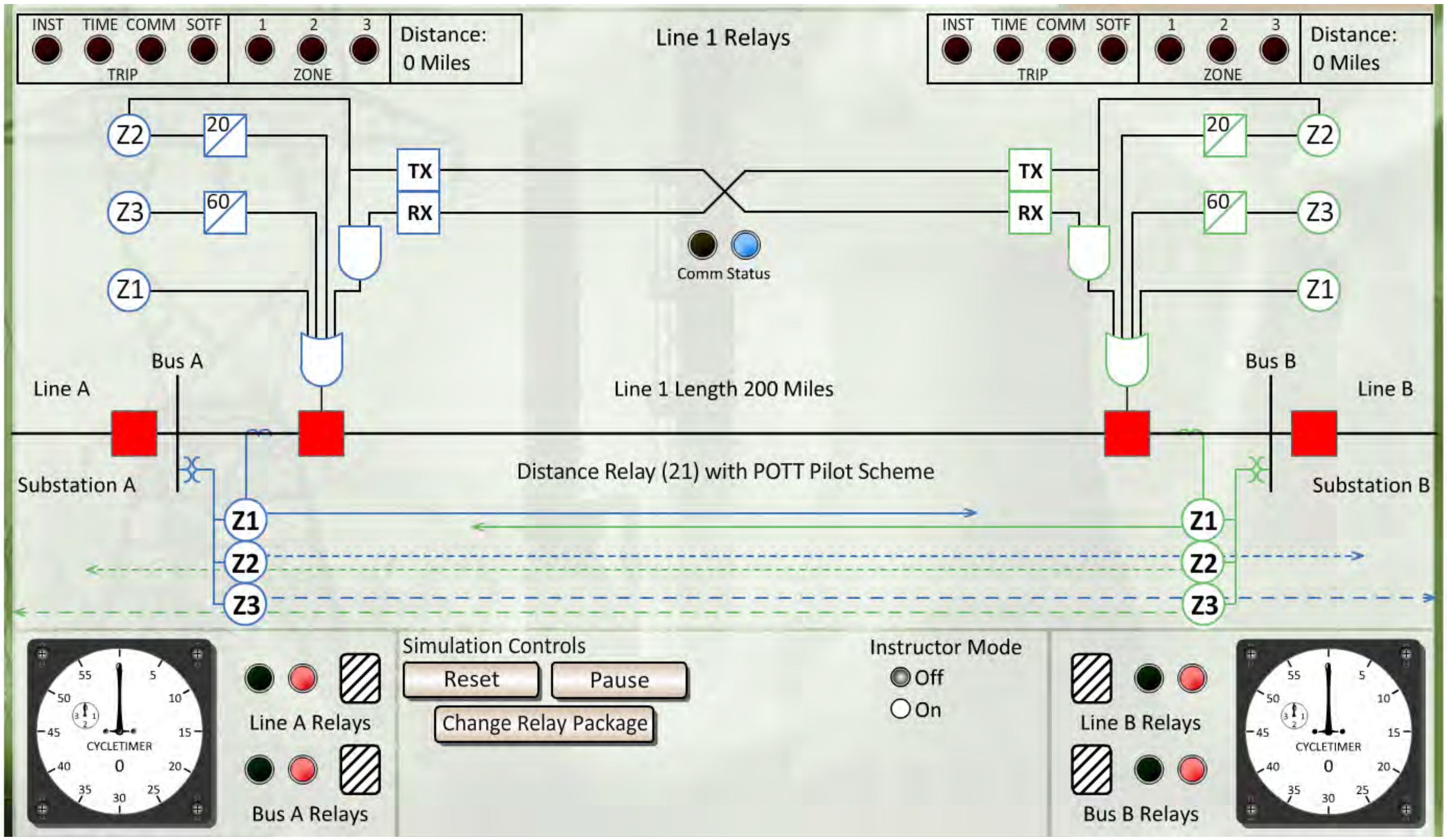
- To Initiate Trip:
  - Over-reaching Relay must operate

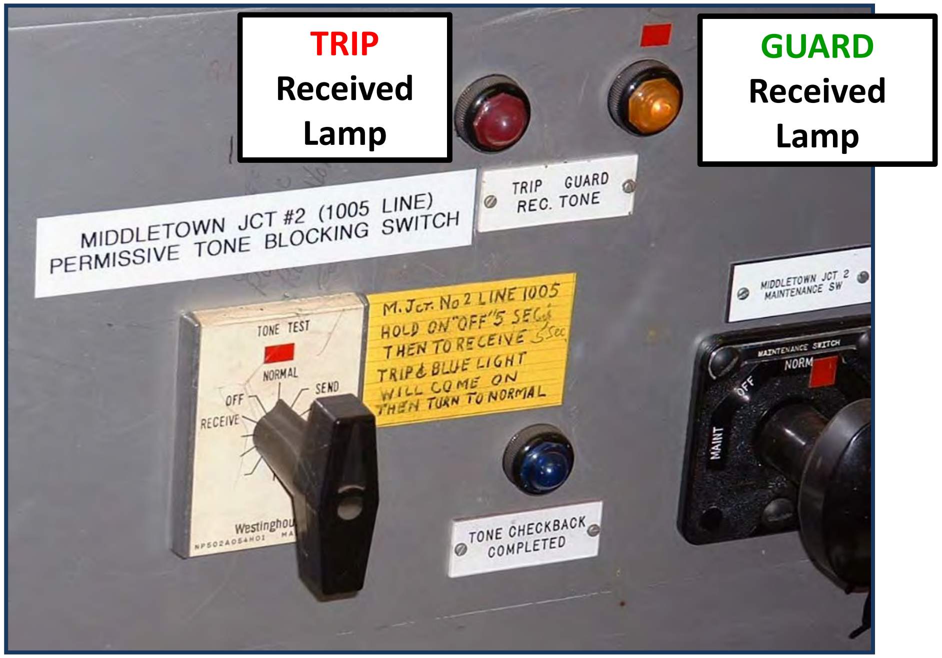
  AND

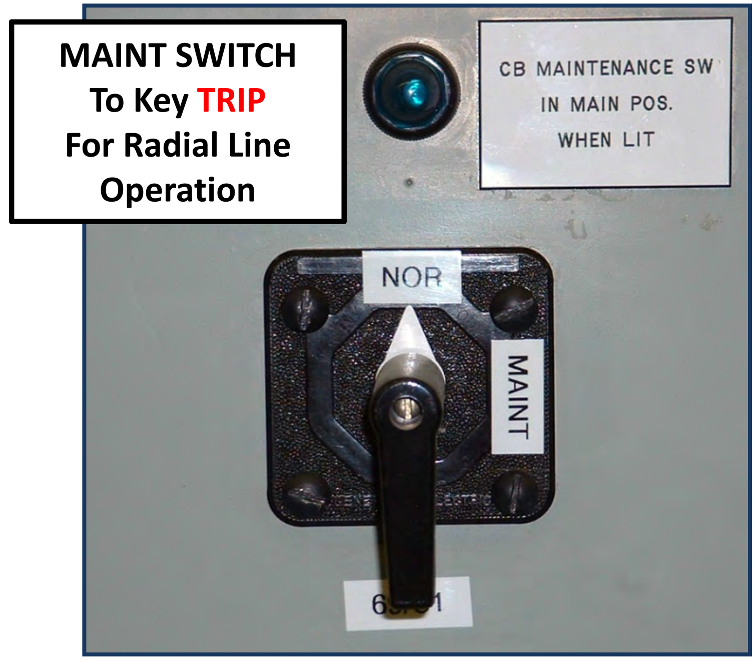
  - Receive a trip signal from the remote end
- In digital logic:



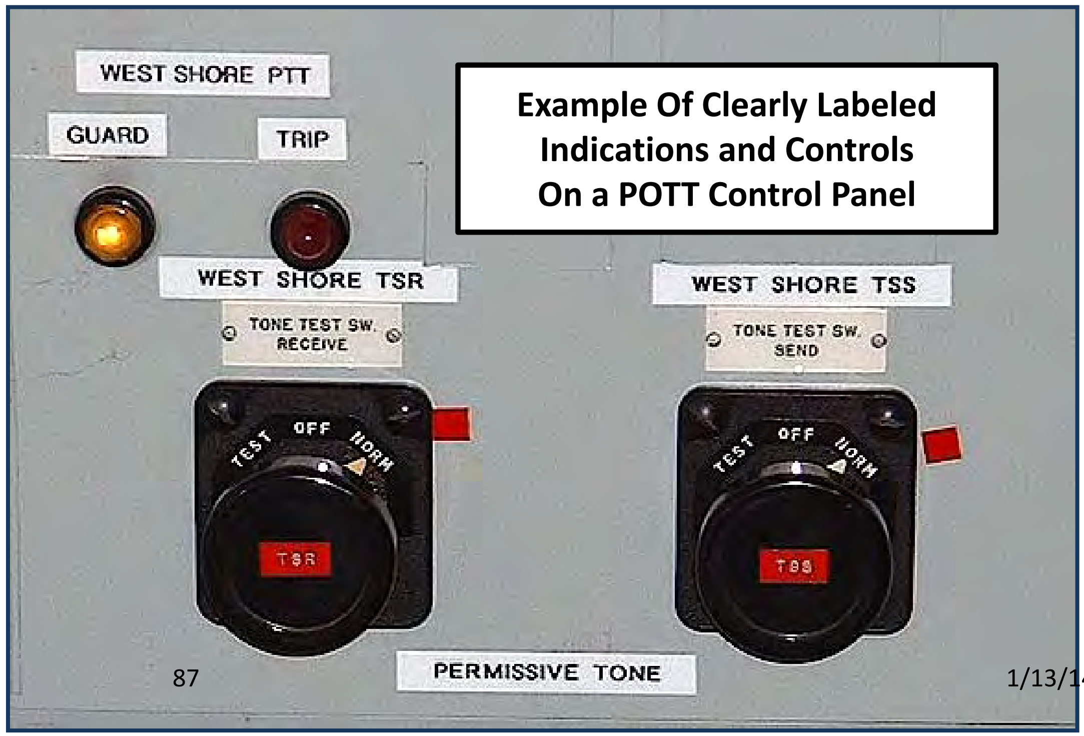
Permissive Over-reaching Transfer Trip







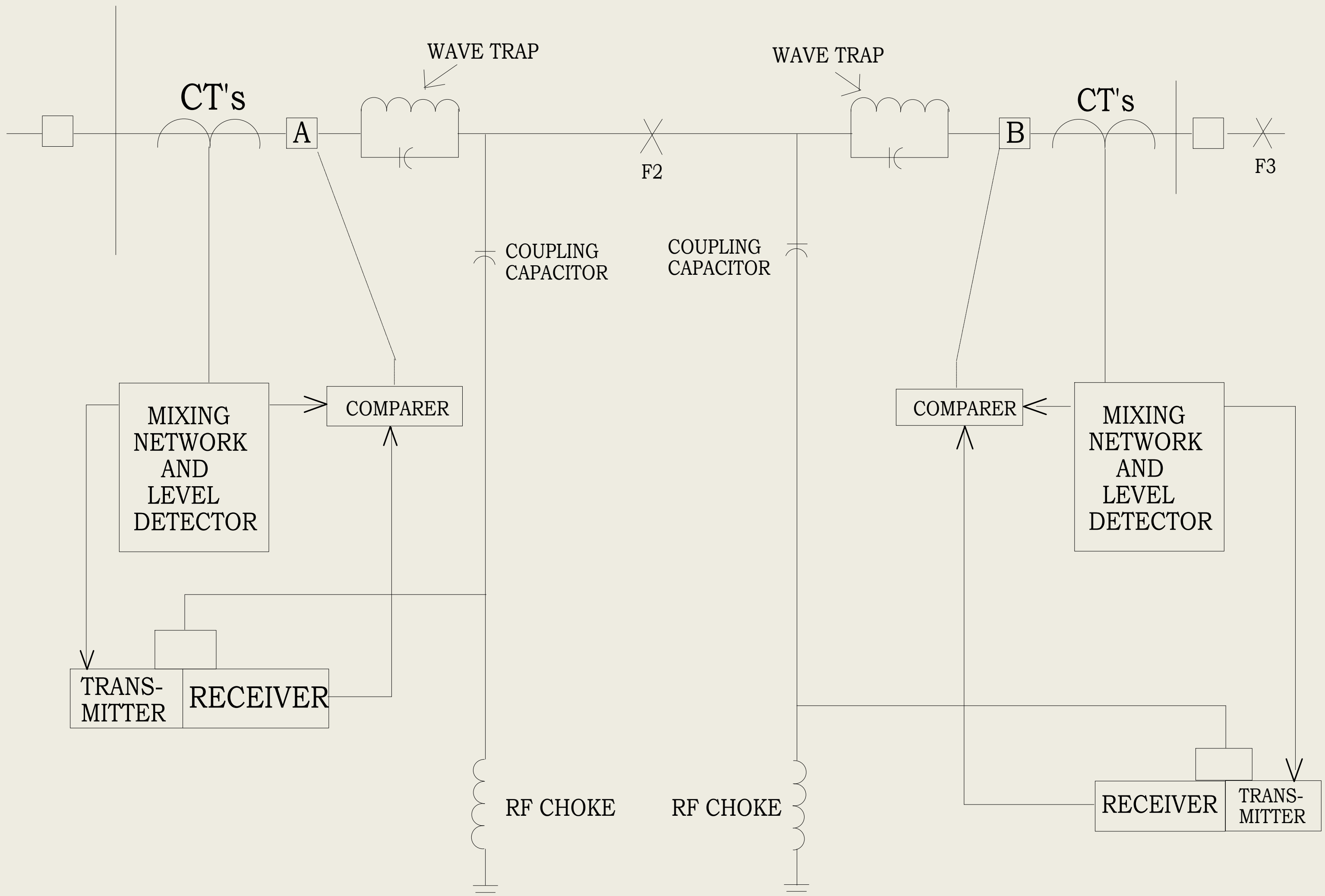
Illustrations Of Typical POTT Scheme Indications and Controls



Phase Comparison

- This is a differential scheme that compares the phase angle difference between the currents at the terminals of a transmission line
- If currents are “in-phase”, no fault is present on this line section
- If currents are “out-of-phase” by about 180 degrees, an internal fault is present
- Equipment used is same as Directional Comparison scheme
- Scheme was typically used on the 500 kV system

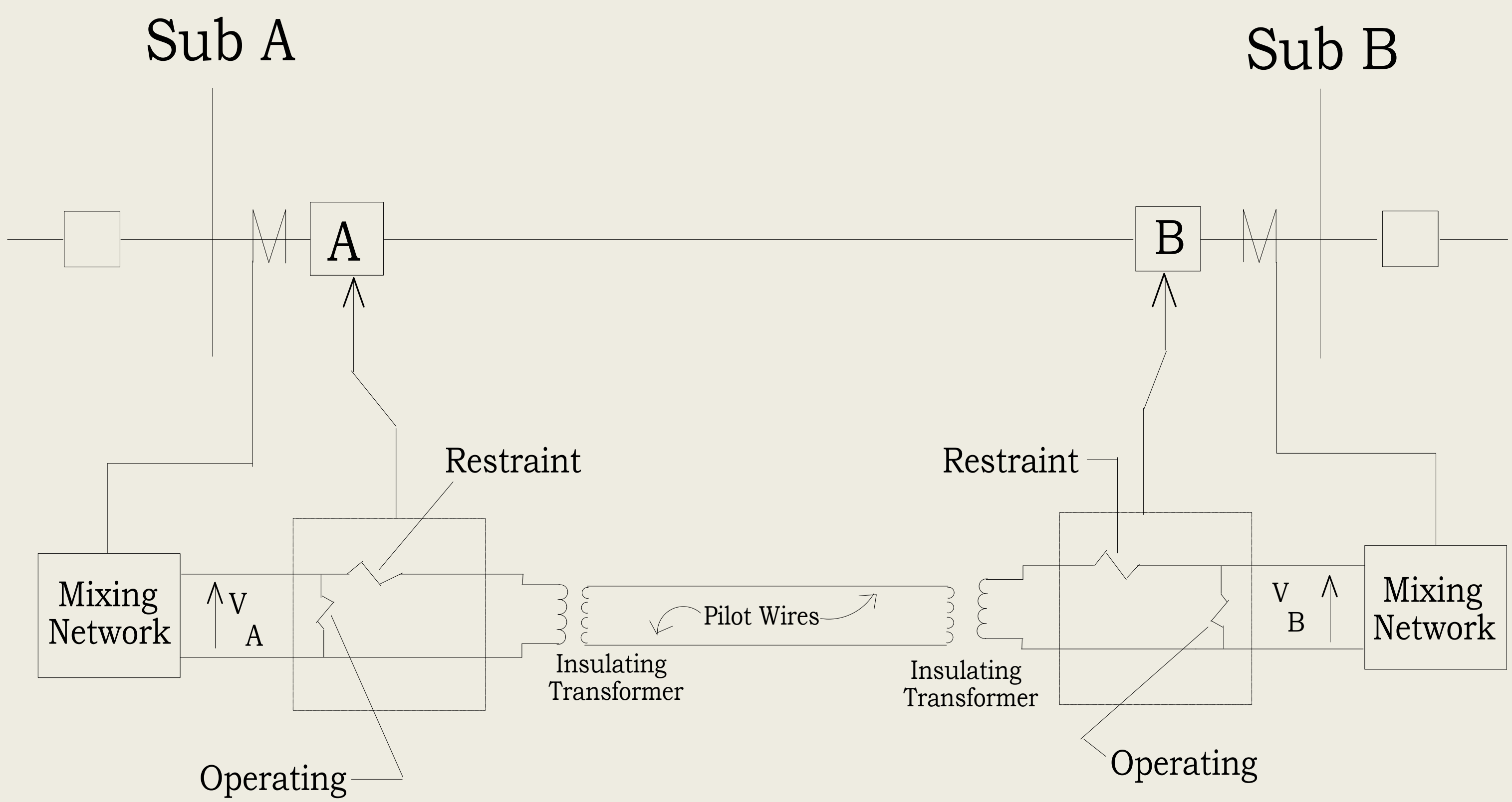
Phase Comparison Relaying



AC Pilot Wire

- Form of differential line protection where phase currents are compared to determine if a fault is internal or external to the protected line segment (similar to phase comparison)
- Requires a pair of wires between terminals to operate. Economical for short lines
- Operation is similar to a bus or transformer differential scheme
- Loss of two wire pair will defeat tripping scheme. No automatic testing of P.W. exists

Pilot Wire Relaying (Current Differential)



Optical Fiber Differential

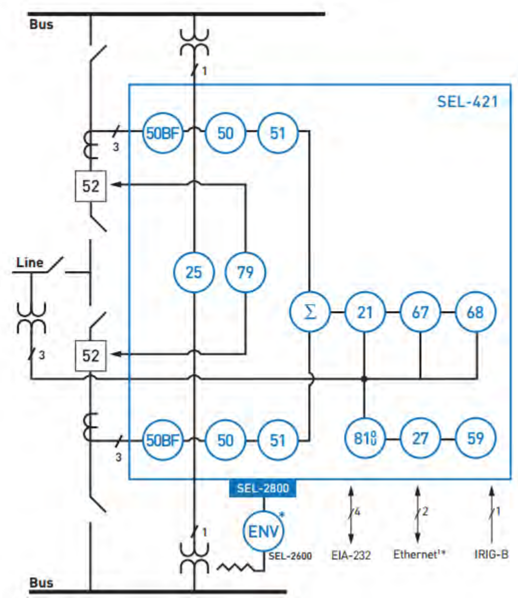
- Relays operate on a current differential basis
- Requires the use of optical fiber to transit digital information
- The digital information contains the current magnitudes and other diagnostic parameters and is transmitted continuously between connected stations
- Tripping is initiated when differential relay exceed the relays restraint characteristic
- Failure of the fiber communication path will automatically block the scheme and initiate an alarm

Backup Transmission Line Protection

- Can be exactly like primary protection. Depends upon stability or coordination concerns
- If stability and coordination are not a concern, non-pilot relaying can be applied as a backup scheme

Backup Transmission Line Protection

- In non-pilot applications, line protection generally consists of the following:
  - Stepped Distance for Phase Protection
  - Directional Time and Instantaneous Overcurrent for Ground Protection
- Due to the recent introduction of microprocessor based relays, additional relay functions are available for use. The more common functions include:
  - Ground Stepped Distance elements
  - Negative Sequence Overcurrent elements



Backup Transmission Line Protection

- Directional Overcurrent Ground Relay
  - Equipped with Time & Instantaneous elements
  - Time Element must be coordinated with other ground relays in the system
  - Instantaneous relays must be set short of remote terminal (just like Zone 1 phase relays)
  - Non-directional relays can also be applied if they can be coordinated. However, with the new microprocessor relays, directionality is available - so might as well use it
  - Aids in coordination

Backup Transmission Line Protection

- Directionality - how is it achieved?
  - The directional unit of a relay uses the current from the line being protected (i.e. phase current for a phase relay and residual current for a ground relay) in conjunction with a “polarizing” quantity to determine “power” flow direction
    - The polarizing quantity is typically voltage

Other Functions Performed:

- When either a primary or backup relay responds, the relay scheme will initiate:

  1) Tripping of the line terminal CB(s)
  2) Stop sending carrier blocking, send trip signal, etc. Depends upon relay scheme
  3) Initiate Breaker failure relay scheme/DTT
  4) Automatic reclosing (if applicable)

Breaker Failure Relaying - Short Discussion

- If a stuck breaker condition occurs, a breaker failure scheme will be initiated that will trip the necessary local CBs needed to isolate the failed CB
- In addition, Direct Transfer Trip may be initiated to trip any remote CBs that could supply the fault. DTT will temporarily block auto-reclosing
- If the failed CB can be automatically isolated by the opening of motor operated disconnects, this will occur and allow reclosing of remote CBs. If there are no MOD’s, reclosing remains blocked

Direct Transfer Trip

- Can be used for the following purposes:
  - Insure tripping of remote terminal for transformer faults
  - Clear the remote terminal for stuck breaker condition at the local station
- Generally, high security is achieved by using two transmitter/receiver pairs
- To initiate a trip, both receivers must detect their unique trip signal from the respective transmitter

Reclosing Practices

- Just as it is advantageous to clear a fault as fast as possible to minimize the shock to the electrical system, it is also advantageous to return the transmission path to service as soon as possible
- Since most faults on transmission lines are transient in nature (i.e. disappear when circuit is de-energized), automatic reclosing provides the means for returning the power system to a more stable state

Reclosing Practices

- On the 230 kV system, multi-shot reclosing may be employed. However, this can differ among PJM member companies
- On the 500 kV system, it is a standard policy to utilize single shot reclosing for lines. The reclosure attempt will take place 5 seconds after the line trips

Reclosing Practices

- Where is automatic reclosing not desirable?
  1) If protected line is an underground cable
  2) If line has a tapped transformer that cannot be automatically disconnected from the line
  3) If line is just being returned to service and trips

- All situations are usually taken care of by the control scheme during design stage

Reclosing Practices

- Manual Reclosing
  - This includes supervisory (SCADA) control in addition to control handle closures
  - Used when switching equipment in or out of service. (SCADA is typically used instead of control handle in order to confirm its availability
  - Should fault occur as soon as a CB energizes a piece of equipment, no automatic reclosing will take place

Reclosing Practices

- Manual Reclosing
  - Also used for "Try Back" (testing) of a line after a fault
  - Company policy should be followed when fault testing is being considered
  - The operator should consider the effects that testing may have on the electrical system (shocking the system again)
  - If possible, it is always better to request a patrol of line before trying to restore it to service

Reclosing Practices

- In general, reclosing of transmission line CBs is supervised by **Synchro-check relays**
  - Insures that the two systems being ties together are in synchronism with each other (or close to it)
  - If the systems are synchronized such that the angle between the two are within defined limits, reclosing will occur. If they are outside the predefined limits, the relay will block reclosing

Protective Relay Alarms Via SCADA

- Depending upon design, receiving of an alarm could mean:
  1) Low signal levels on Power Line Carrier Equipment
  2) Loss of Guard on one or more Permissive or DTT schemes

Risks Involved

Directional or Phase Comparison Schemes

- With low signal levels, there is a good chance that the protected line could overtrip for a fault

Permissive Transferred Trip Schemes

- With a continuous loss of guard, the scheme will shut itself down. Little risk of overtripping exists
- With a sporadic loss of guard, noise is being introduced into communication channel. Fair chance of incorrect tripping exists
- Momentary loss of guard and return to normal has little risk of overtripping

Risks Involved

Direct Transfer Tripping Schemes

- A continuous loss of guard will shut down scheme. Little risk of overtripping exists
- Sporadic loss of guard is indication of noisy communication channel. There is a good chance that an overtrip will occur
- Momentary loss of guard and return to normal is of little concern. Low risk of overtripping

Ranking of Risks (Most to Lease Critical)

1) Sporadic Loss of Guard - Direct Transferred Trip Schemes
2) Low Signal Levels - Directional or Phase Comparison
3) Sporadic Loss of Guard - Permissive Transferred Trip Schemes
4) Continuous Loss of Guard - Direct Transferred Trip Schemes
5) Continuous Loss of Guard - Permissive Transferred Trip Schemes
6) Momentary Loss of Guard - Direct Transferred Trip Schemes
7) Momentary Loss of Guard - Permissive Transferred Trip Schemes

Special Relay Schemes

- Load Shedding via Underfrequency
- Close-In Fault Protection

Underfrequency Load Shed

- Used to match load with available generation
- In this program, PJM Member companies must shed 30% of their base load. Done in 10% steps
- UF load shedding is coordinated with UF relays at generating stations

Close in Fault Protection

- In service for a short period of time after a transmission line has been re-energized (i.e. one terminal closed)
- Simple instantaneous overcurrent relays are utilized to trip the line if a fault (i.e. grounds) exist on the line. The relays are removed from service after a short time delay

Transmission Line Protection Exercises/Review

The two categories of relay schemes commonly used for transmission line protection are:

A. Stepped distance & Overcurrent
B. Pilot based and Overcurrent
C. Pilot based and Stepped Distance
D. Under voltage and Overcurrent

Distance relay schemes employ Ohm's law and divide what two quantities to obtain line impedance?

A. Voltage/Resistance
B. Voltage/Current
C. Current/Resistance
D. Current/Voltage

What is the primary disadvantage of Stepped time distance relay scheme?

A. Doesn’t cover the entire line
B. Delayed clearing for certain faults
C. No overlapping zones of protection
D. Lack of coordination

Identify a means of communication used in pilot relay schemes.

A. Microwave
B. Telephone pair
C. Power Line Carrier
D. Fiber Optic

One of the primary advantages of using an impedance (distance) relay for backup transmission line protection rather than overcurrent relay is:

A. It has a constant reach
B. There is no time delay
C. Not susceptible to load current trips
D. Non-directional protection

Which of the following are features of Stepped-Time Distance relay schemes?

1. Uses Impedance relays
2. Relays are directional
3. All relays have a small time delay
4. Relays are typically grouped in three zones

A. 1, 2 and 3

B. 1, 2 and 4

C. 1, 3 and 4

D. 2, 3 and 4

A Zone 1 impedance relay is set on both ends of the line and allows instantaneous tripping to protect what percentage of the line?

A. 100%
B. 90%
C. 75%
D. 50%

Pilot relay schemes allow instantaneous tripping for what percentage of the protected line?

A. 100 %
B. 90%
C. 75 %
D. 50%

Directional Phase Comparison schemes protect for a fault on the line because the fault will cause what?

A. Max current flow out of the line
B. Current flow at both ends into the fault
C. High voltage spikes in the fault area
D. Voltage flow towards the fault

Relay Testing - Considerations and Concerns

Relay Testing

- Relay testing is important to insure Relays and Relay Schemes are functioning as designed
- Because testing is usually done when primary equipment is energized, there is a risk that unwanted operation of relay schemes may occur

Why can tripping occur?

- Close working conditions
- Wiring errors
- Improper “Blocking” or “Isolating” of equipment
- Inexperience (lack of training)
- Accidental (bump panel or relay)

Considerations and Concerns for S.O.'s:

- When a request is received from a person doing testing, think about:
  - What could it do to the system? Is the system being operated in a manner that the loss of the equipment protected by the relay scheme will cause serious problems (stability, voltage, overloads etc.)
  - Would the removal of relay scheme go beyond the setting criteria for other relay schemes

Protection Practice:

- Protection and Coordination are typically based upon the electrical system being **normal** or altered by any **single contingency**
- A single contingency is the outage of a piece of equipment such as a line, transformer or relay scheme
- If more than one piece of equipment is outaged at a station, protection or coordination can be compromised
- The relay engineers should be contacted to insure protection and coordination will still exist

General Considerations for Dispatchers Following a Relay Operation

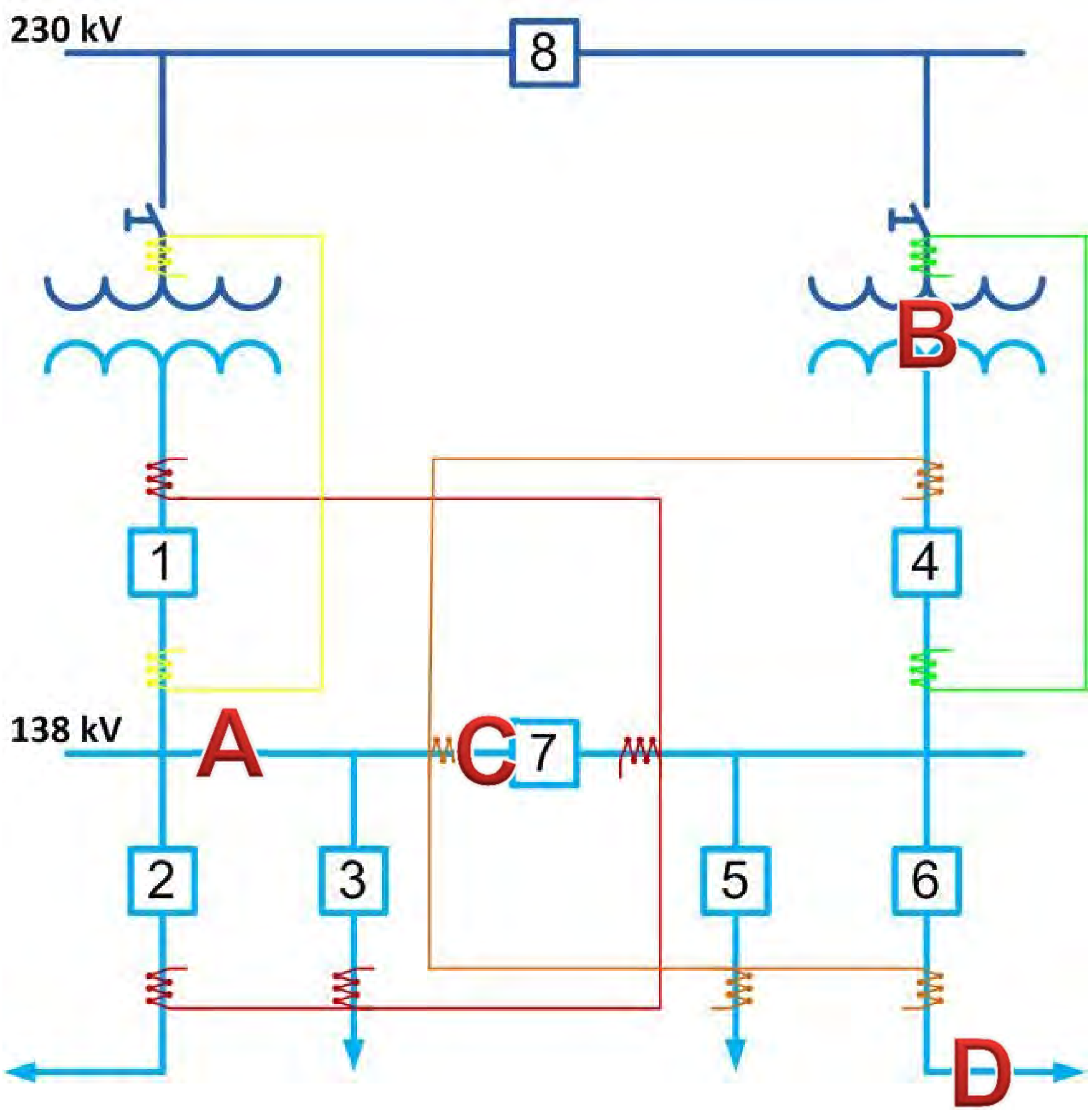
Know your companies policy regarding Dispatcher response to a relay trip

- Who do you notify?
- Who to call to initiate repairs
- Who to call to perform line patrols, substation inspections, etc.
- Inter-company response & notifications

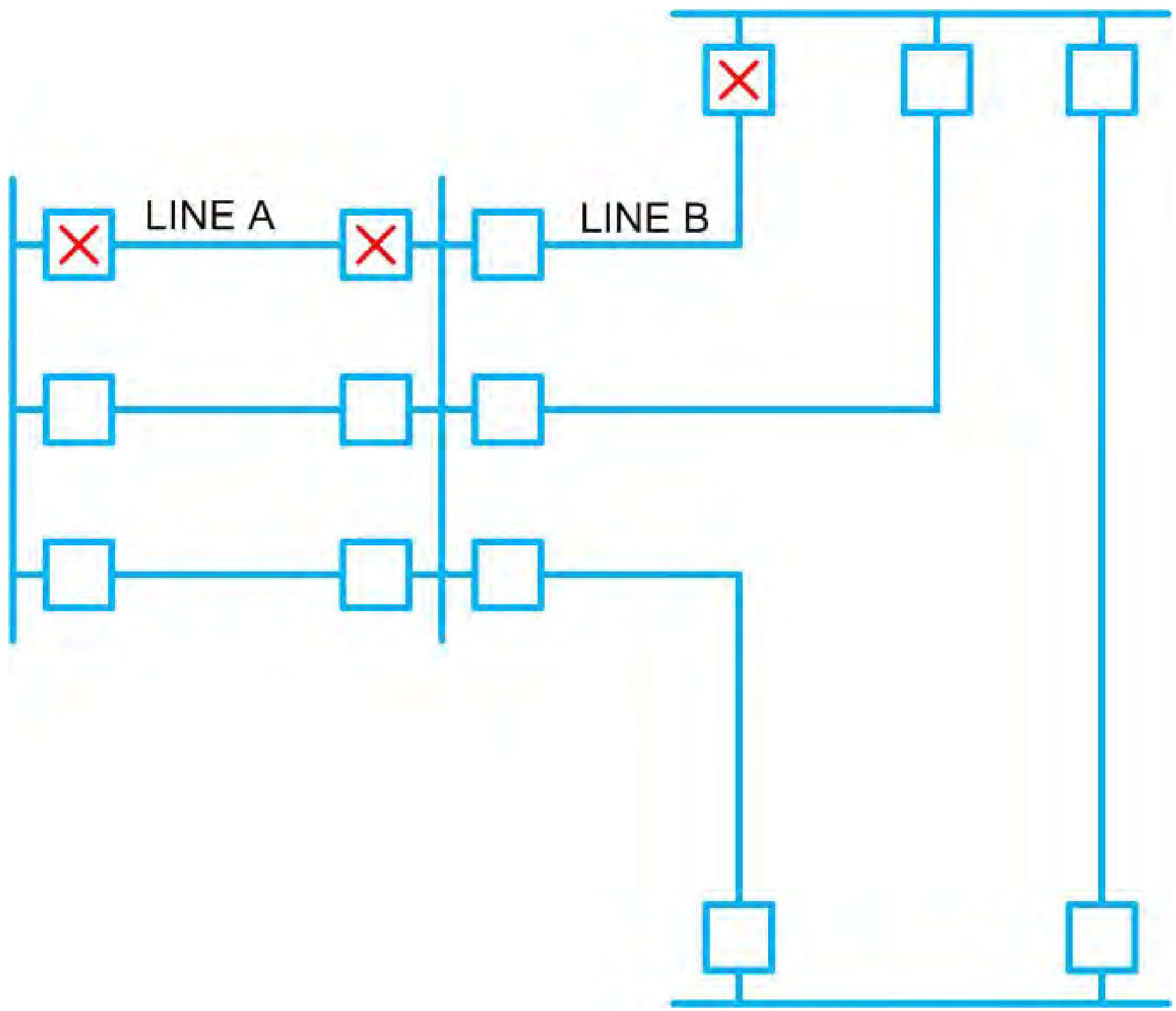
- Data collection and fault analysis
  - Try to obtain as much data as possible for future detailed analysis (i.e. relay targets, Digital fault recorder information, system conditions)
  - Real time analysis comes with experience
  - Often knowing what has tripped may lead to a determination of the faulted piece of equipment or potential relay problem
  - (See examples)

Fault analysis

Breakers 1 thru 7 trip open. Where is the likely fault location?



Fault analysis



Exercise prudence before "Trying Back"

- 500 kV lines have a single shot reclosing attempt after 5.0 seconds
- Testing after 5 minutes is possible with concurrence from PJM and others
- No "Try Back" should occur on:
    1) Generator SU transformers
    2) Underground Cable (Bus Work)
    3) Indoor equipment

Transformer Protection

Transformers:

- At the heart of the Transmission System
- They make the transport of large amounts of electrical energy economically possible
- Because of their criticality to the Bulk Power System, high speed clearing for faults is desirable

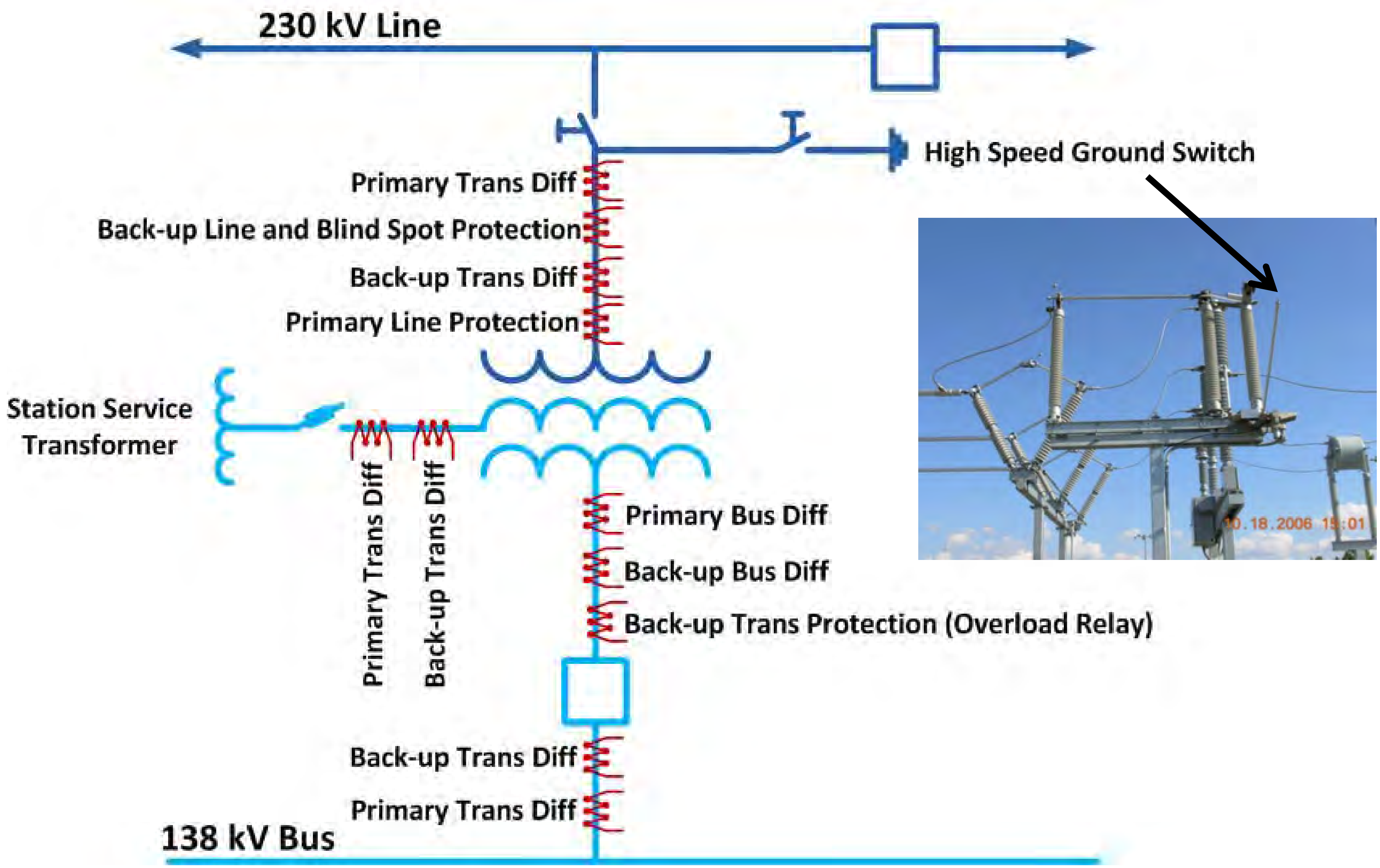
Transformer Protection

- Typical Problems that can occur:
  - Inside the Tank
    1) Winding Faults to Ground
    2) Winding Turn to Turn Shorts
    3) Excessive Winding and/or Oil Temperature
    4) Overloads (i.e. winding/oil temperature
  - External to Tank
    1) Bushing Lead Failure
    2) Bushing Flashover
    3) Lightning Arrester Failure
    4) “Through Faults”

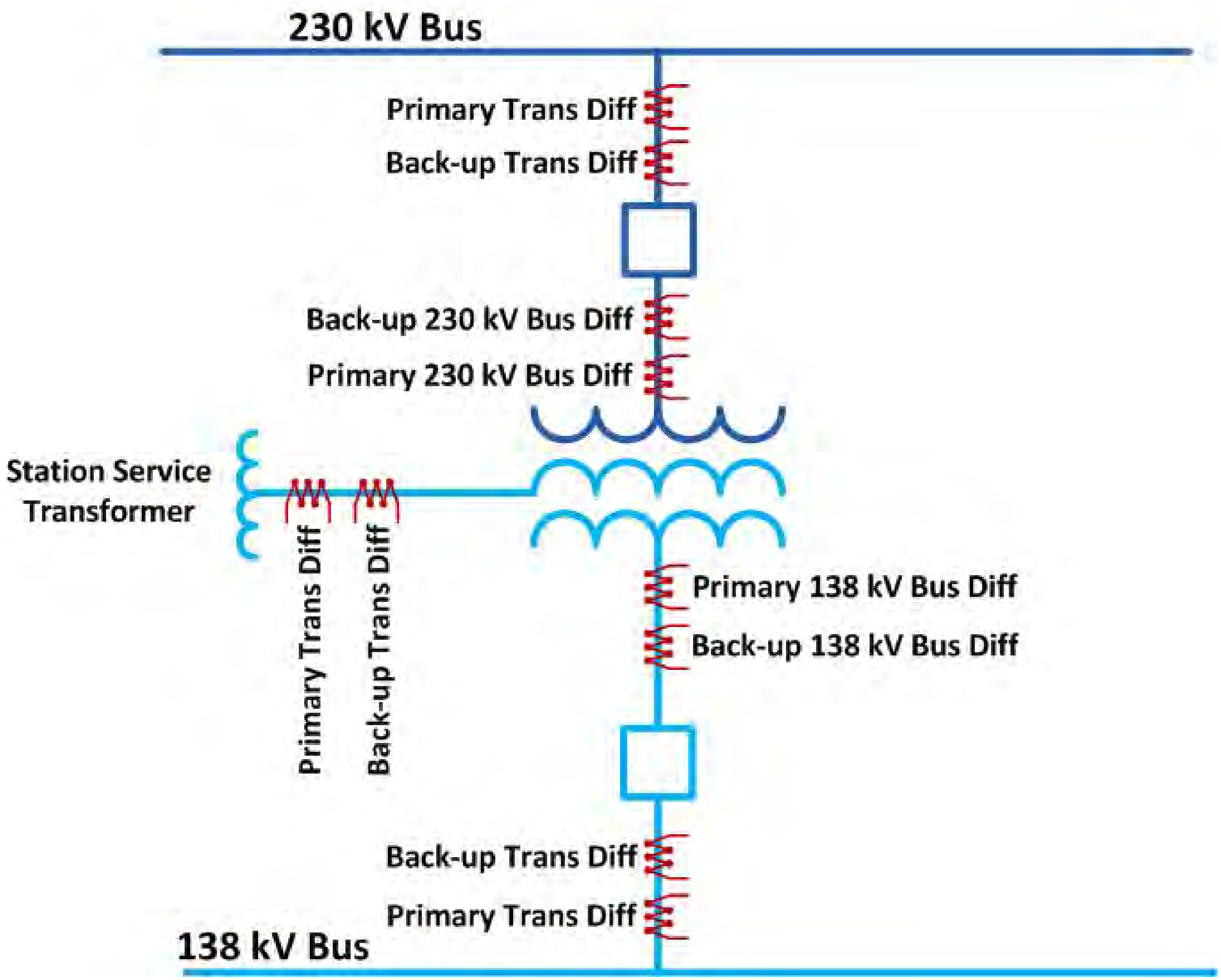
Transformer Protection

- Transformer Protection is typically provided by **differential relaying**
- Transformers provide unique problems for differential relaying that must be accounted for:
  1) Different voltage levels (i.e. different current magnitudes)
  2) Automatic Tap Changers (LTC's or TCUL's) associated with transformers cause further mismatch between high side and low side currents
  3) Energizing a transformer causes magnetizing inrush current which appears as an internal fault to the differential relay
  4) Because of Delta-Wye connections, the transformer introduces a 30 degree phase angle shift that must be accounted for

CT Connections for Tapped Transformer



CT Connections for Bus Connected Transformer



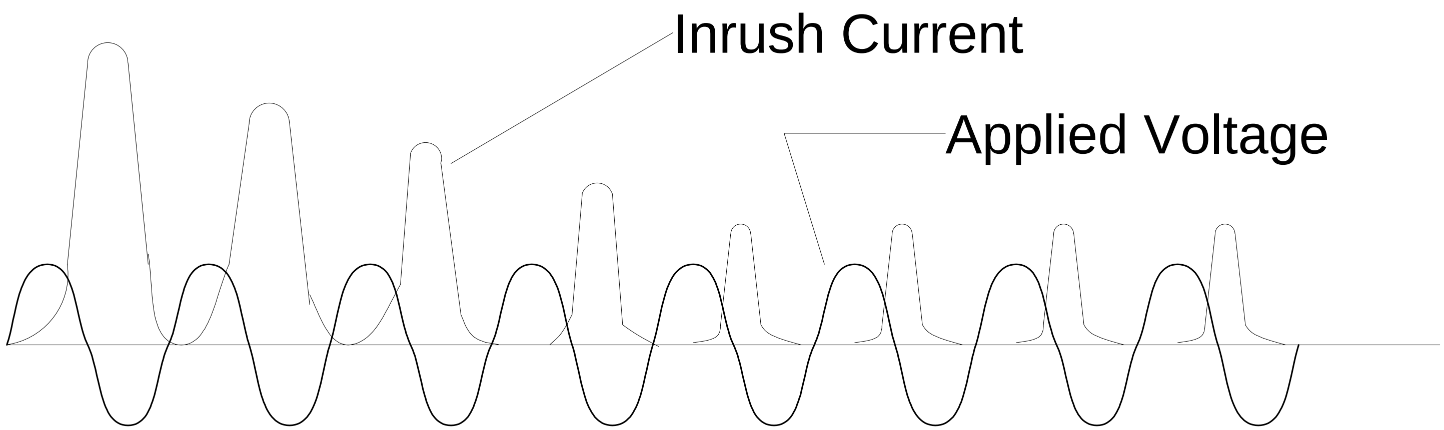
Transformer Protection

- It was recognized early that a perfect match of CT ratios, necessary for the differential relay, was practically impossible
- Mismatch of CT secondary currents can be overcome with a **Percentage Differential Characteristic** relay
- This type of relay has **operate** and **restraint** coils which are connected in a manner that allows for a certain amount of CT mismatch

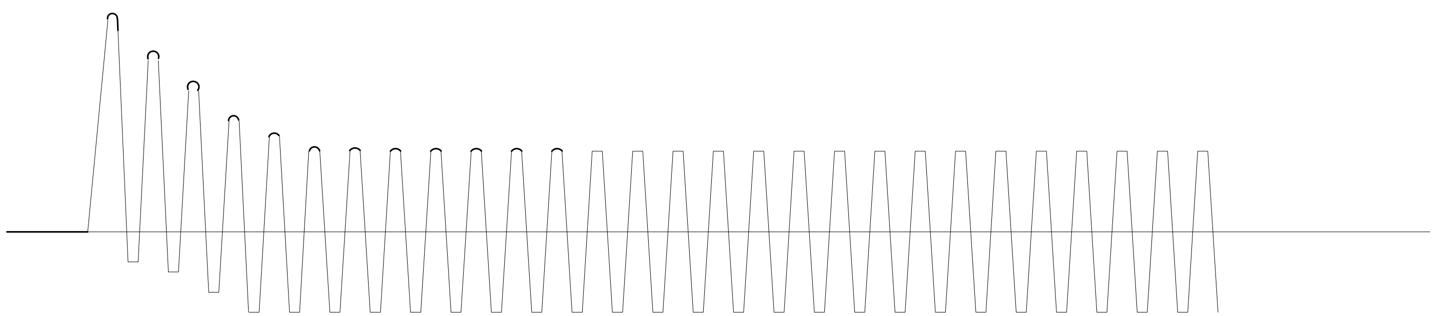
Transformer Protection

- The inrush current that exists when a transformer is energized is high in harmonics, particularly the second harmonic

- The use of a **Harmonic Restraint** element can de-sensitize the differential relay to these harmonics and provide the necessary security required



Typical Magnetizing Inrush Current Wave



Typical Offset Fault Current Wave

Transformer Protection

- The 30 degree phase shift that is introduced when protecting wye-delta transformer banks can be overcome with the proper connection of the CTs supplying the differential relay

- The general rule of thumb:
  - CTs on wye side of transformer should be connected in delta, while CTs on the delta side should be connected in wye

Transformer Protection

- Bottom Line:
  - The differential relay is the ideal device for transformer protection in that it takes advantage of the zone type of protection to provide sensitive high speed clearing of transformer faults

Transformer Protection

- Since high voltage transformers are critical to the Bulk Power System, generally primary and back-up differential relays are used for protection
- Beyond using two discrete differential relays, additional devices are used to protect the transformer

Transformer Protection

Sudden Pressure Relays:

- If an arcing fault occurs inside the transformer tank, gases are generated which can be detected by a pressure relay
- Operation of this relay will initiate tripping of the transformer
- This protection provides back up to the differential relays

Transformer Protection

- Gas Analyzers (Combustible Gas Relay):
  - Low magnitude faults produce gases as they breakdown the oil and insulation in the transformer tank
  - The gas analyzer relay constantly monitors the gas space above the transformer oil and will actuate an alarm if gas levels exceed a predetermined level
  - An Alarm provides warning of a possible internal fault which could be catastrophic

Transformer Protection

Winding Temperature Relays:

- Winding Temperature (referred to as “Hot Spot” protection) inside the transformer is simulated by using a CT to drive a heating element under oil
- As the transformer becomes loaded, the heating element produces more heat
- As the heat increases and predetermined temperature levels are reached, a temperature sensing device will:
    1) Start additional cooling groups (if possible)
    2) Alarm if temperature continues to increase
    3) Trip the transformer

Oil Temperature Relays:

- Oil temperature is monitored by a "Top Oil" device inside the tank.
- Similar to the "Hot Spot" protection, when predetermined temperature levels are reached, a temperature sensing device will:
    1) Start additional cooling groups (if possible)
    2) Alarm
    3) Trip the transformer

Illustrations Of Analog Gauge Style Winding Temperature and Liquid Temperature Thermal Devices

Illustration Of Microprocessor Based Thermal Device

Liquid Temperature is the upper unit

Winding Temperature is the lower unit

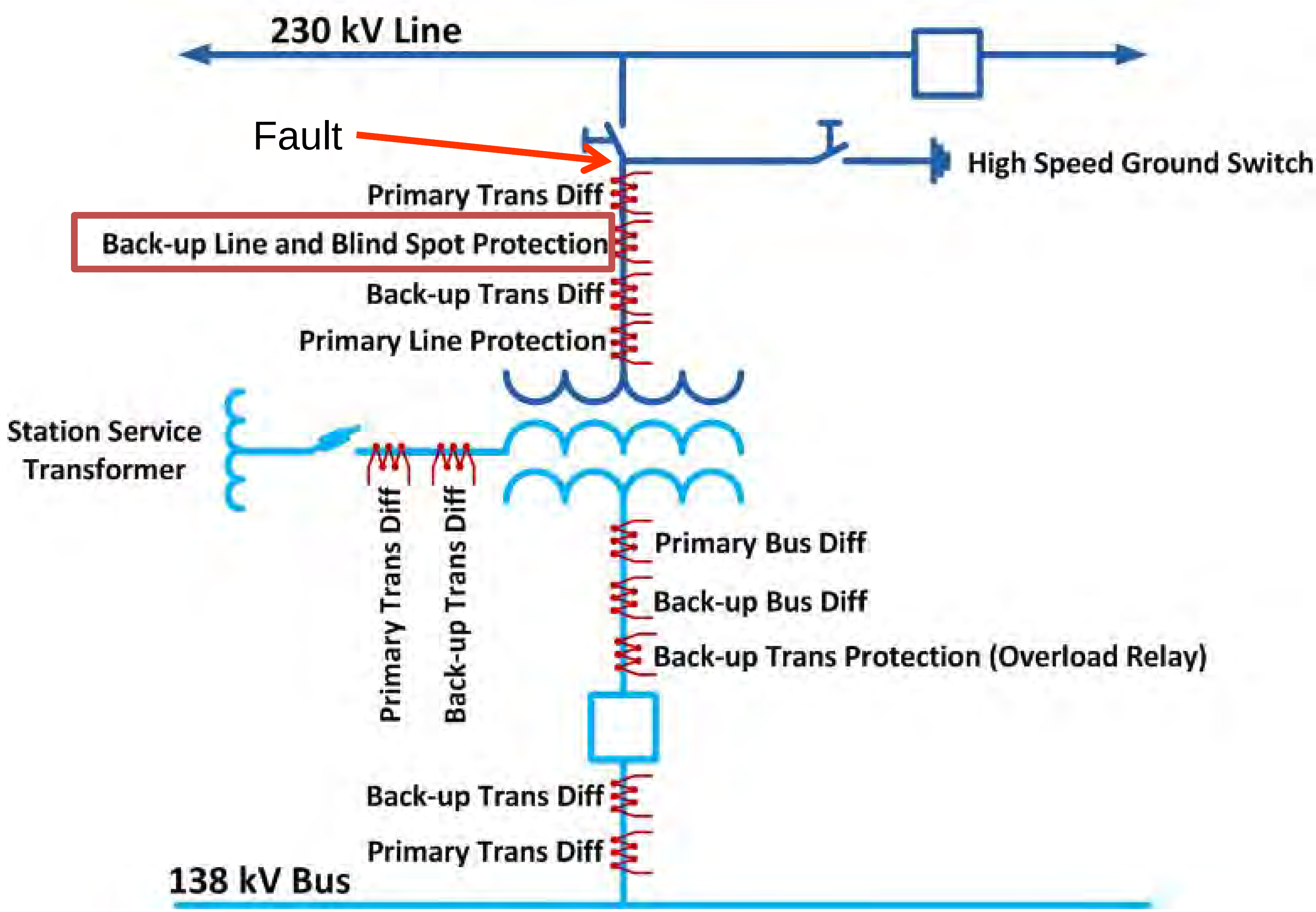
Transformer Neutral Overcurrent Relay:

- Relay is connected to a CT located on the neutral connection of a WYE-Grounded transformer
- Used as Back-Up protection for “Through Faults”
- Must be coordinated with other system ground relays
- Operation of this relay will trip the transformer

Blind Spot Overcurrent Relay:

- On occasion, tapped transformers are energized from the low side only (i.e. high side MOAB is open). This is typically done to maintain station service
- Line Relaying may not respond to a fault that could occur between the Transformer Diff. CTs and the MOAB
- A Blind Spot relay is used to detect this condition
- It is in service only when the high side MOAB is open
- Will trip the low side circuit breakers to isolate the fault

CT Connections for Tapped Transformer



Transformer Protection

- Other Protective Devices:
  - Loss of Cooling Relay - If all fans and/or oil pumps are lost for any reason, the transformer will be tripped if temperature is above a predetermined level
  - Low Oil Level - Lack of proper oil level compromises transformer cooling. This device will alarm and eventually trip the transformer if oil level drops below a certain threshold

Transformer Protection

- Operation of any of the above relay schemes will initiate other protective functions
- The physical design of the electrical system will define what additional actions are taken
- Some actions include:
    1) Initiate Direct Transferred Trip to remote terminals
    2) Initiate breaker failure relaying
    3) Block reclosing of CBs that are tripped (until transformer is isolated)
    4) Close the high speed ground switch
    5) Initiate permissive trip/stop sending blocking signal, etc

Transformer Protection

- Turn to Turn shorts (non-fault condition)
  - Have not discussed this abnormal condition much
  - In general, this condition is very difficult to detect - initially
  - As more and more insulation deteriorates, this condition may cause the gas analyzer relay to respond
  - Otherwise, could go undetected until winding flashes over to ground. At that point, normal transformer protection will respond to clear the fault

Transformer Protection

- Because a Bulk Power Transformer is a high cost piece of equipment, automatic testing of the transformer is generally not included in the control scheme design
- If the differential relay responds, a master trip auxiliary relay will trip and block closing of devices which could re-energize the transformer
- To reclose the locked out devices, this master trip relay must be hand reset

Operator's role if Transformer Protection Operates

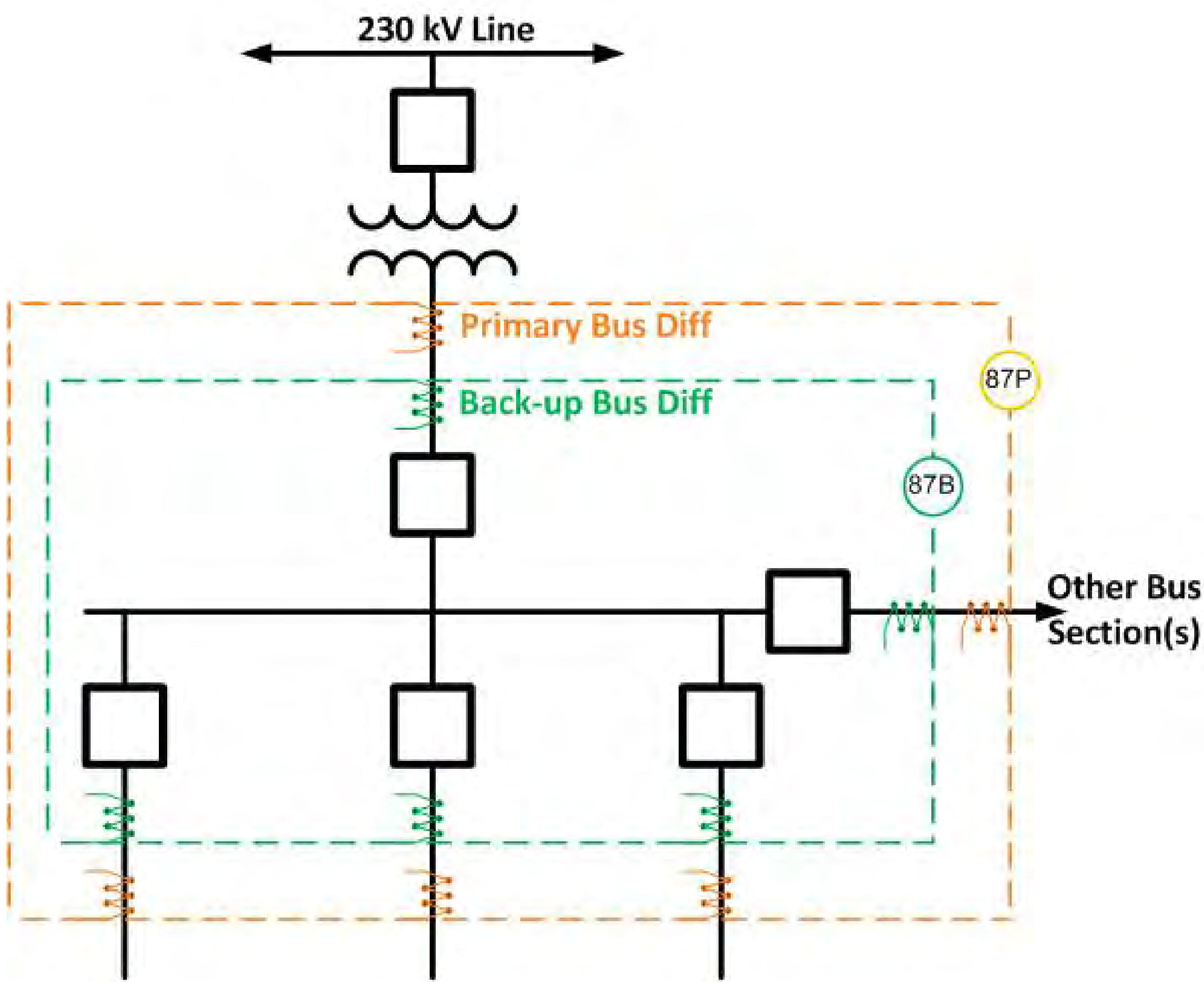
- Know your company policy!
  - Alert all that need to be informed of the operation
  - Be aware of steps required to alleviate possible system overloads, low voltage concerns, etc.
- In general, do not test (try-back) the transformer until it is inspected by qualified individuals

Bus Protection

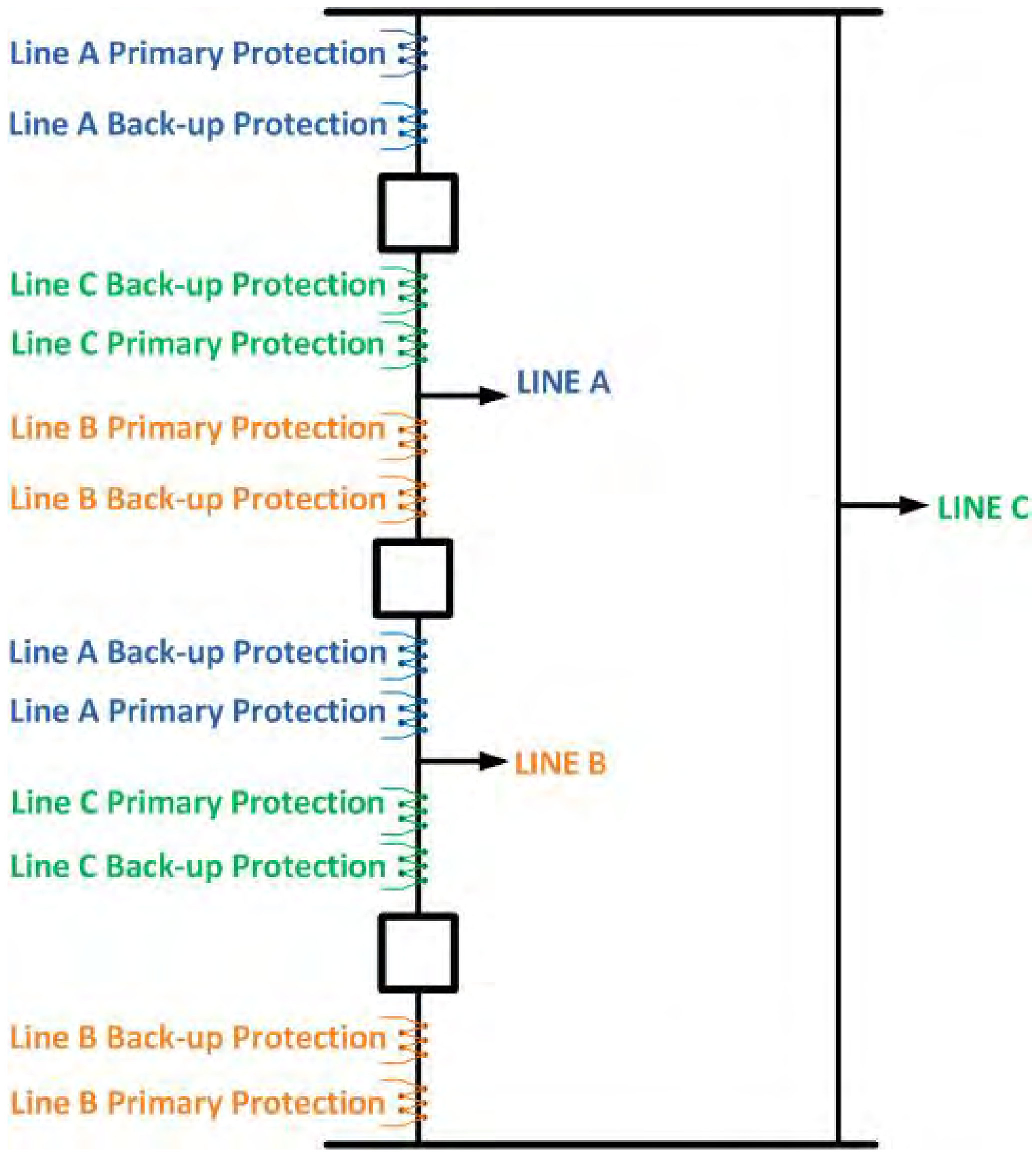
Typical Bus Designs

- Single Bus - Single Breaker
  - Least flexible of sub designs, but low cost
- Ring Bus
  - Improved Flexibility, may be difficult to relay.
- Breaker and a Half
  - Offers most flexibility, but more expensive
- Double Bus-Double Breaker
  - Similar to Breaker and a Half

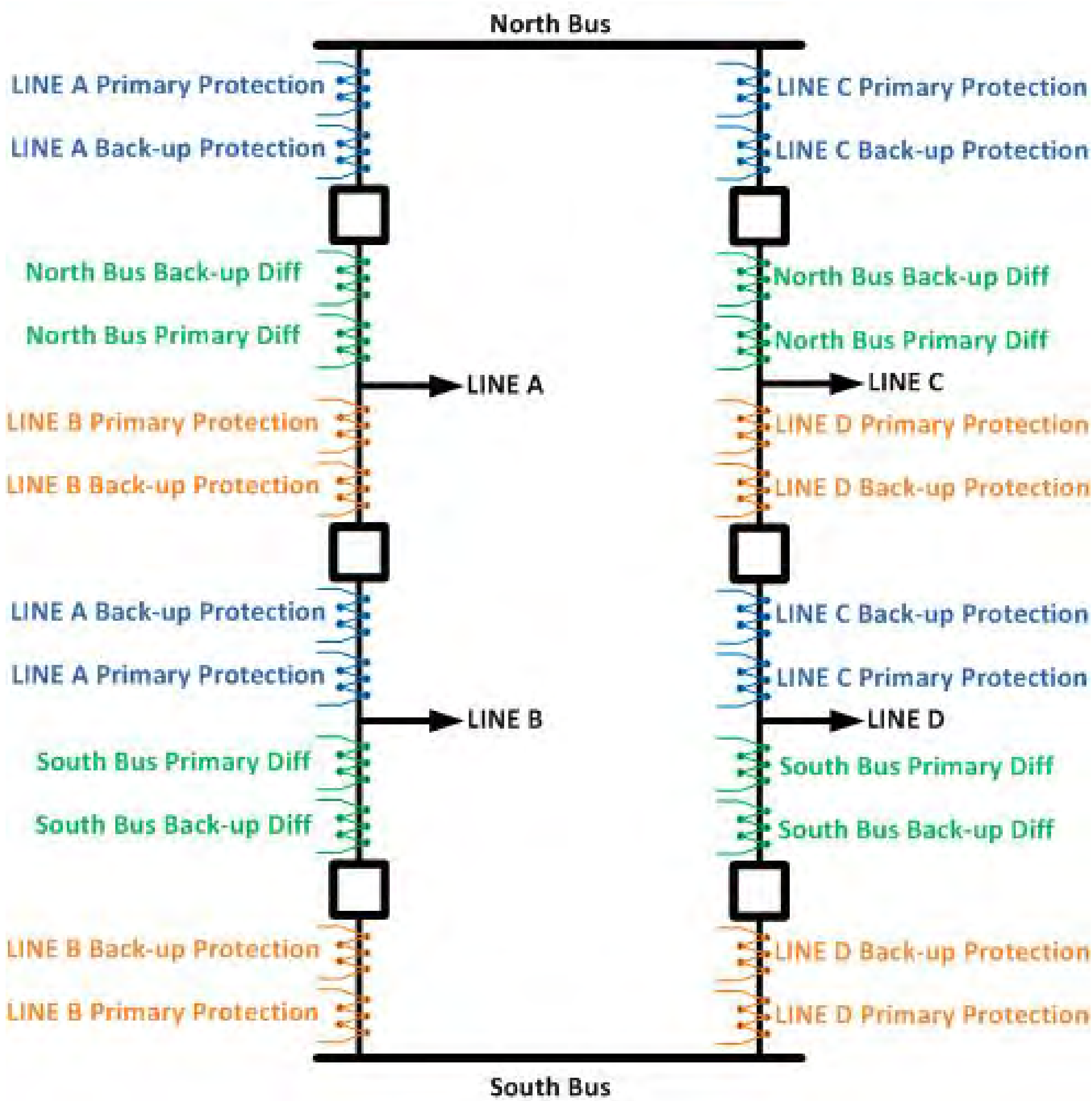
Single Bus – Single Breaker Arrangement



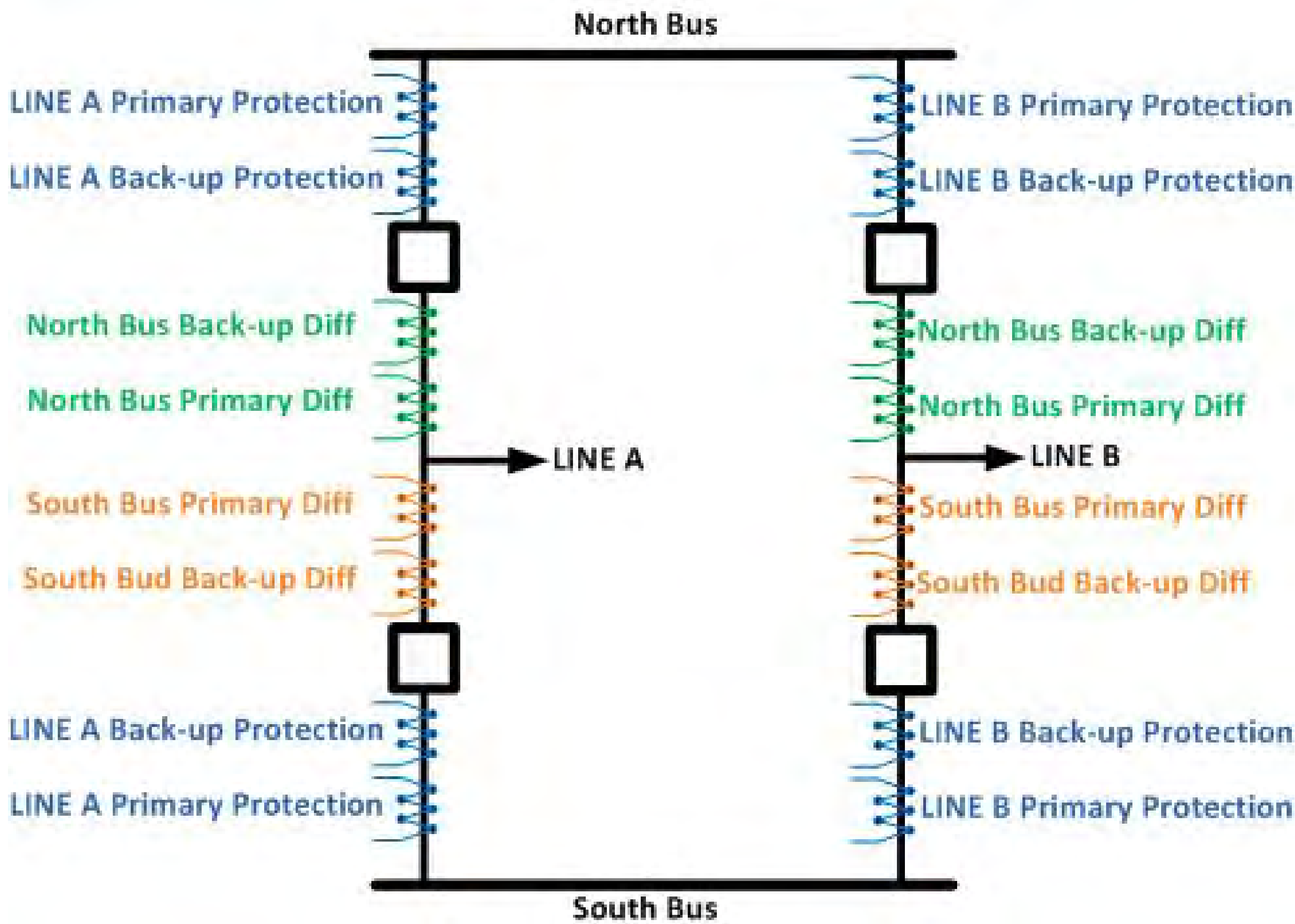
Ring Bus Arrangement



Breaker-and-a-Half Bus Arrangement



Double Breaker – Double Bus Arrangement



Bus Protection

- On the Bulk Power System, the most common protection practice to insure high speed clearing of faults on bus work is to use **Differential Relays**
- Older, less critical stations may employ Time and Instantaneous Overcurrent relays connected in a differential scheme. These schemes can be less sensitive, slower or both

Bus Protection

- Generally, the CTs used for Bus Protection are located on the line or equipment side of the circuit breaker. Consequently, the CB is within the protection zone of the bus differential and the line or piece of equipment **(overlapping zones of protection)**
- CTs that are connected in the differential scheme should be of an accuracy class that can withstand maximum expected fault currents (i.e. CTs should not saturate). Failure of application engineers to insure this could lead to a misoperation

Bus Protection

- If a bus differential relay operates, the relay will typically do the following:
  1) Energize a Master Trip Auxiliary Relay
  2) Trip all sources to that bus section (via the Master Trip)
  3) Setup the Reset of the Master Trip Relay if bus testing is to occur
  4) Block reclosing of all CBs except that of the automatic testing source (if so equipped)
  5) Initiate Breaker Failure
  6) Initiate an Alarm

Bus Protection

- On the 500kv System, automatic bus testing does not occur
- In general, on voltage levels below 500kv, a single automatic test of the bus might occur. This can vary across the PJM territory

Bus Protection

- If the particular station is equipped with bus testing and a successful test occurs, all remaining CBs that were tripped will automatically reclose
- If the bus test was unsuccessful, all CBs, including the testing CB, will be locked out
- Although automatic reclosing is blocked, the operator <u>may</u> have the ability to close a CB via supervisory control (SCADA)

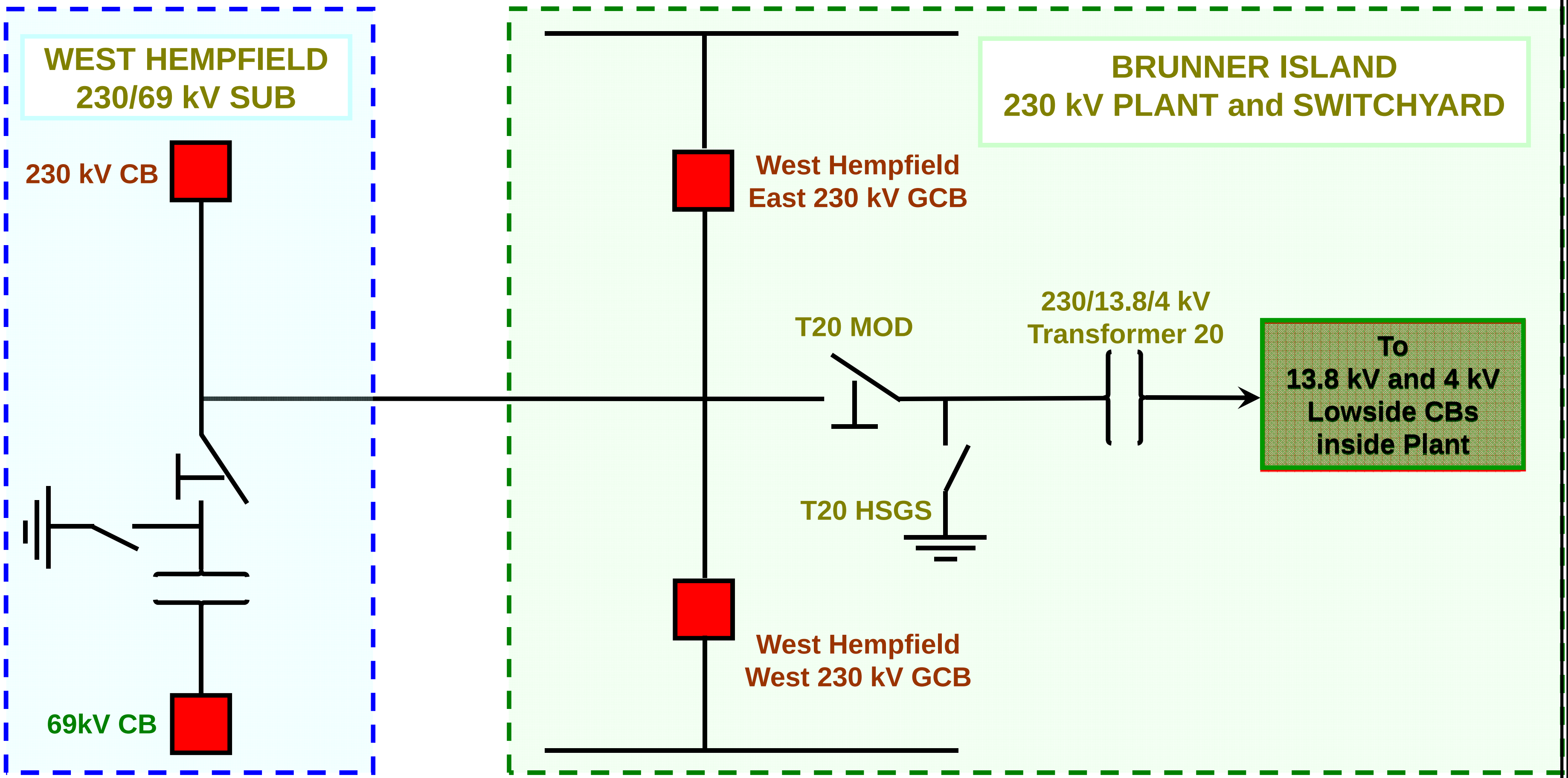
Operator Role is Bus Protection Operates to de-energize a Bus

- Know your company policy!
  - Alert all that need to be informed of operation
  - Be aware of steps required to alleviate possible system overloads, low voltage concerns, etc. (sound familiar?)

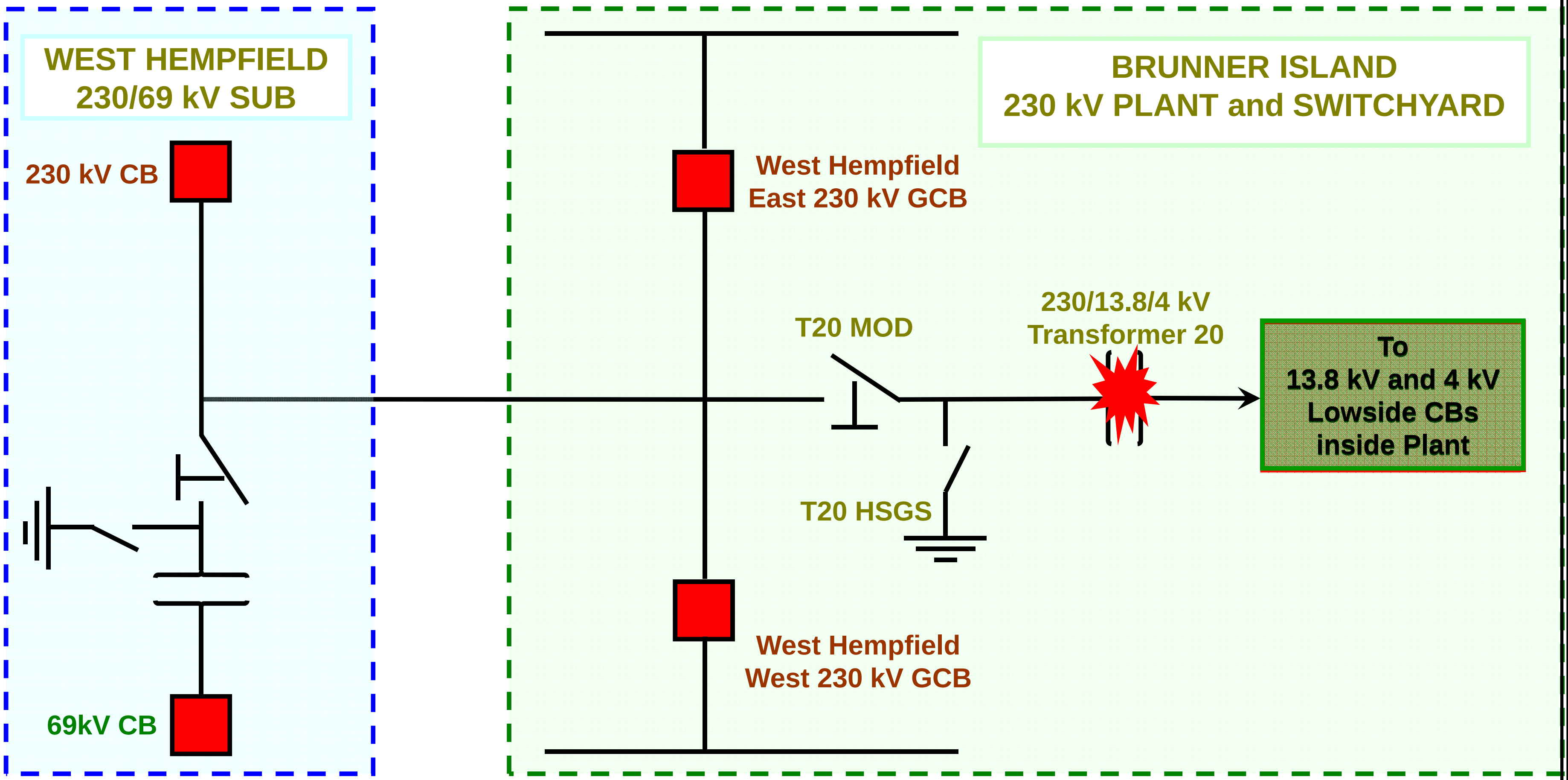
- If the bus trips and locks out, no testing via SCADA should occur until the station is inspected by authorized personnel

Direct Transferred Trip (DTT) Relaying

Clearing Sequence For A Fault On Brunner Island Transformer 20

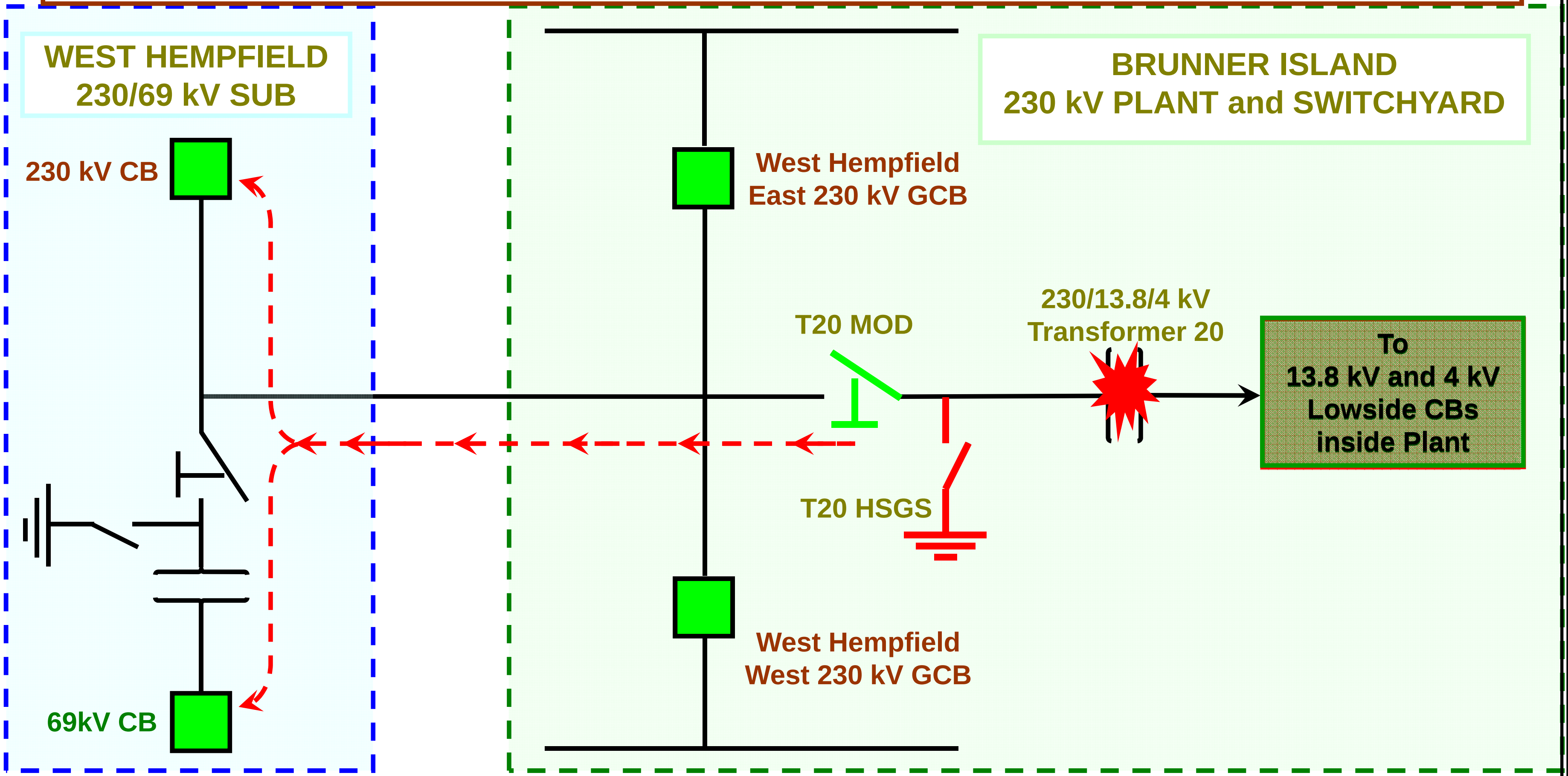


1) A fault occurs inside Transformer 20 at Brunner Island

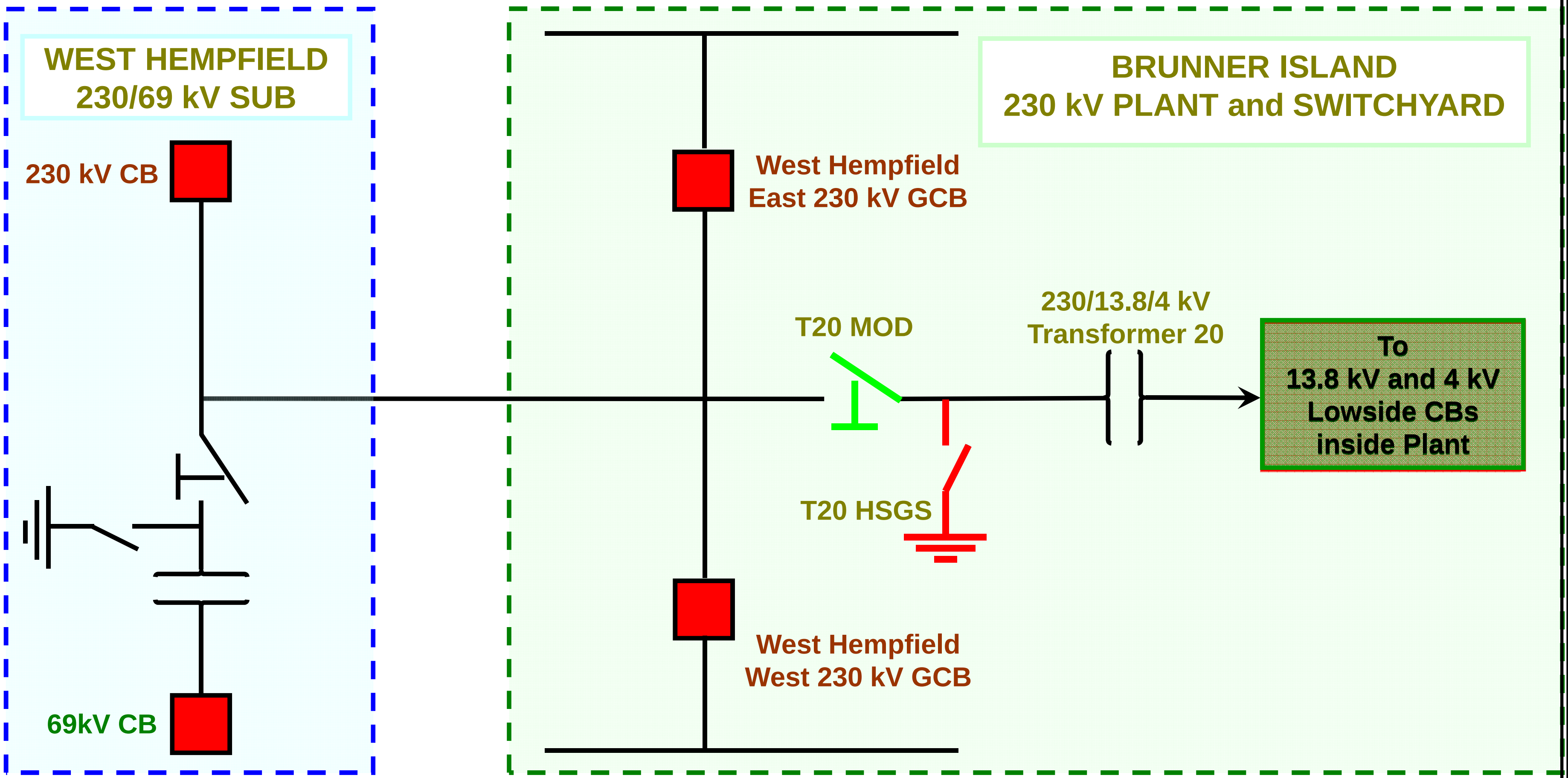


2) At Brunner Island, Transformer 20 protection operates to immediately trip the West Hempfield East and West 230kV circuit breakers and the 13.8kV and 4kV Transformer 20 lowside circuit breakers. Simultaneously, a DTT TRIP signal is initiated to West Hempfield Sub, the T20 HSGS closes and the T20 MOD starts to open

3) At West Hempfield, the 230kV line and 69kV transformer lowside breakers open immediately upon receipt of the DTT TRIP signal…all circuit breakers at West Hempfield are open before the HSGS at Brunner Island closes fully into the transmission line

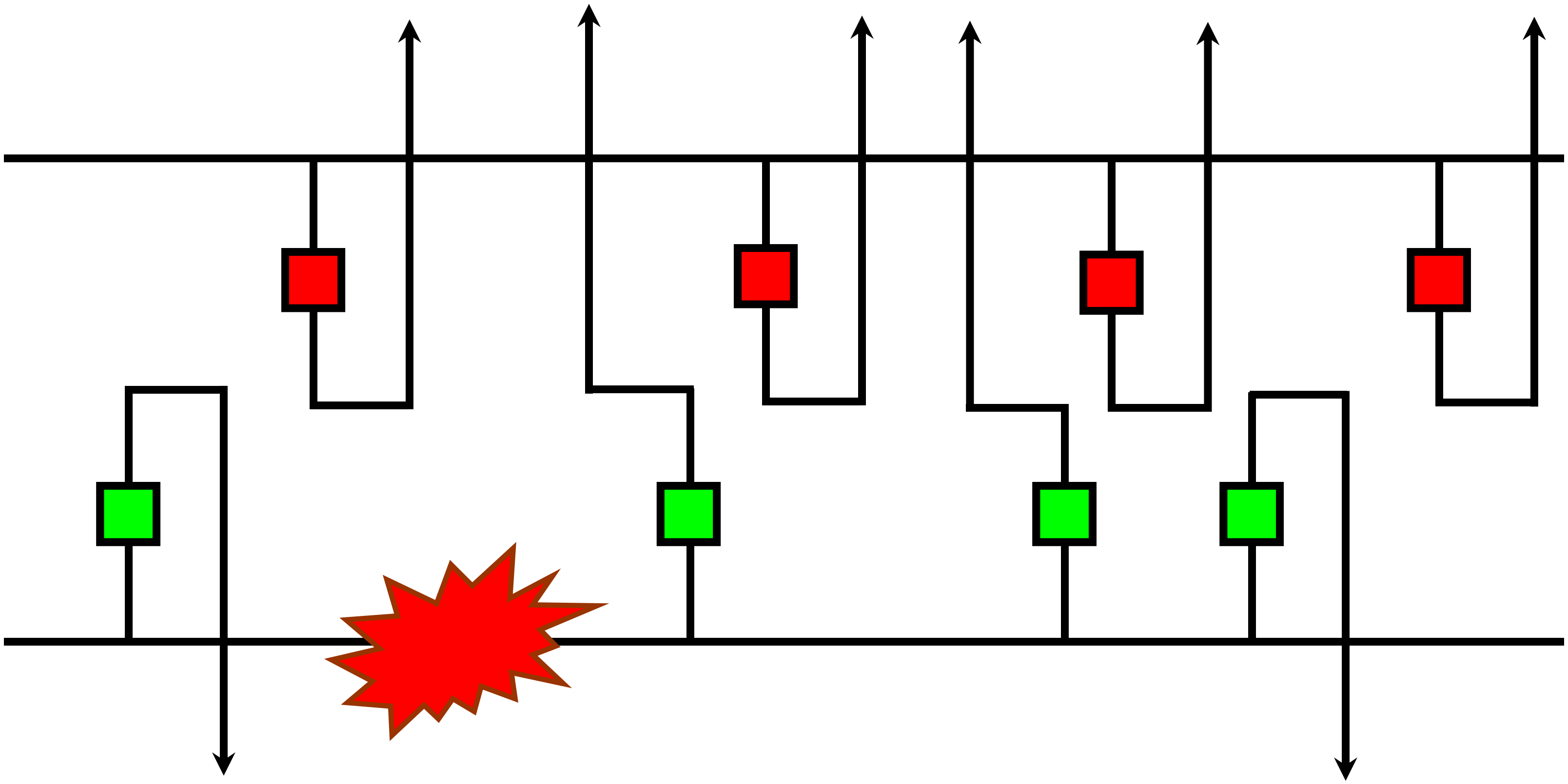


4) At Brunner Island, the T20 MOD opens fully to physically isolate the fault and stops the DTT TRIP signal to West Hempfield…all circuit breakers at West Hempfield reclose automatically. The transmission line breakers at Brunner Island also reclose automatically after the failed transformer is isolated, but the T20 lowside breakers are designed to stay open.



Bus Protection

Illustration Of Automatic Bus Testing In a Transmission Switchyard



Following a bus differential operation, a preselected circuit breaker automatically recloses to test the bus

Illustration Of Automatic Bus Testing In a Transmission Switchyard

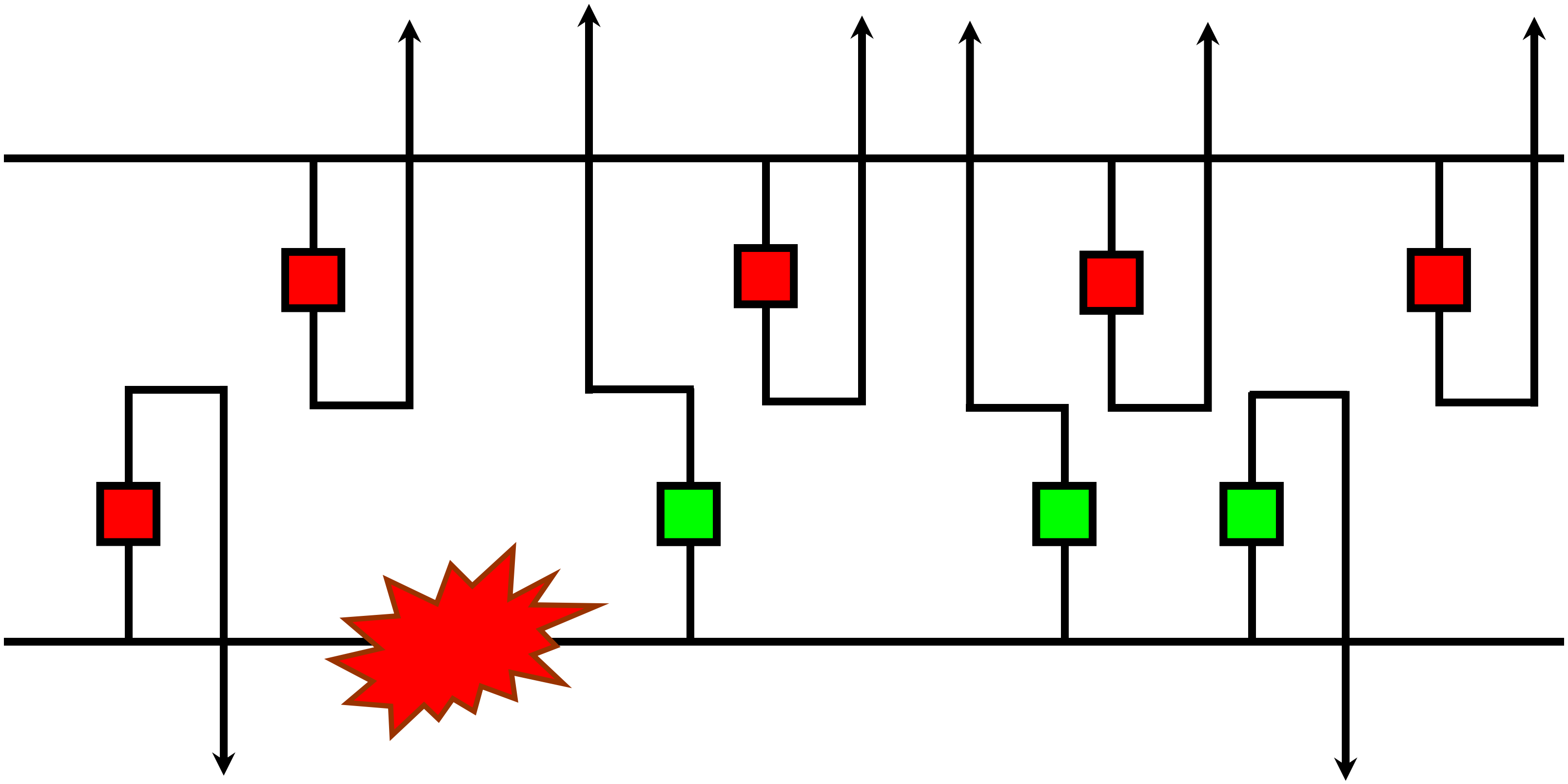


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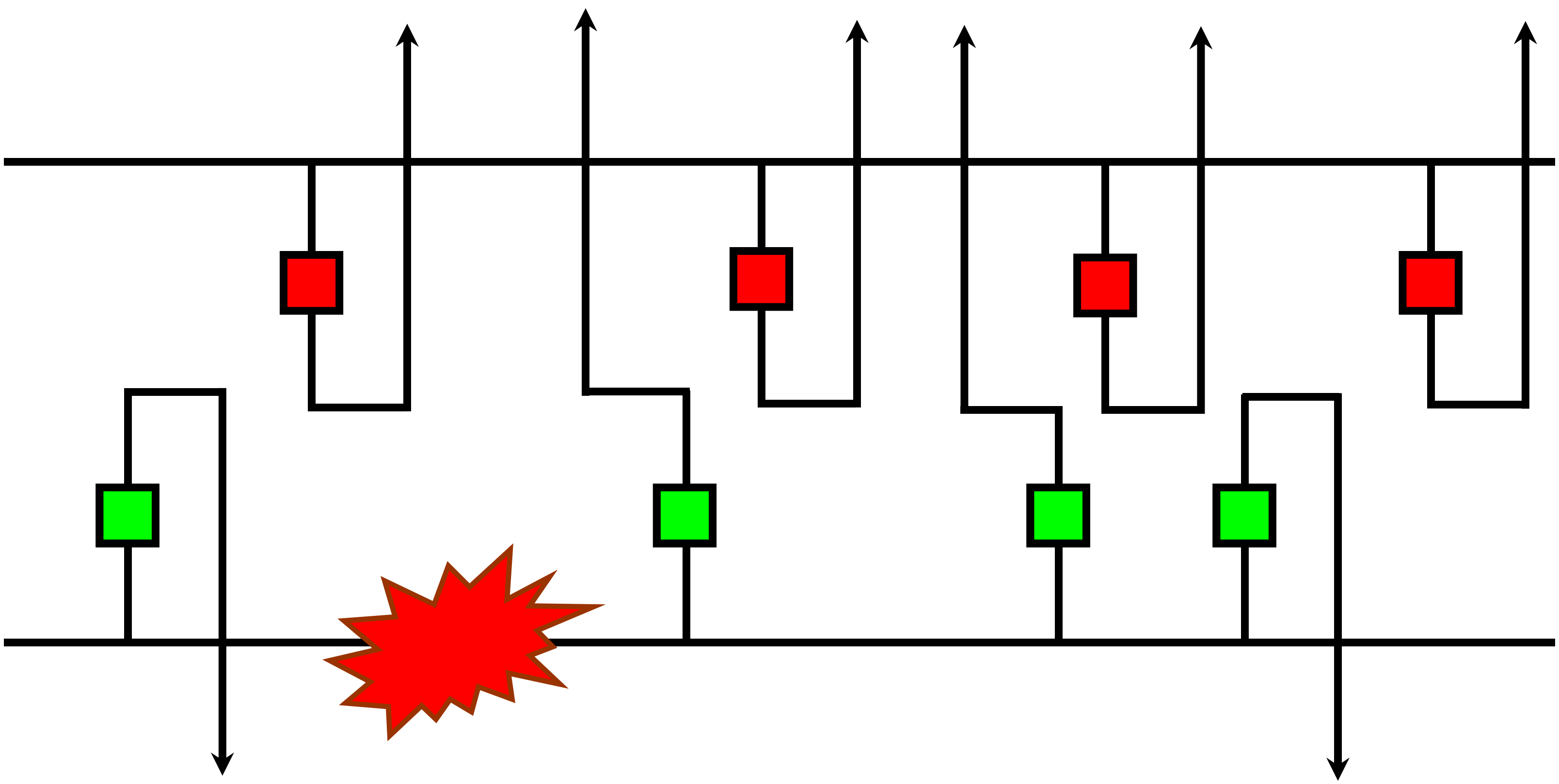
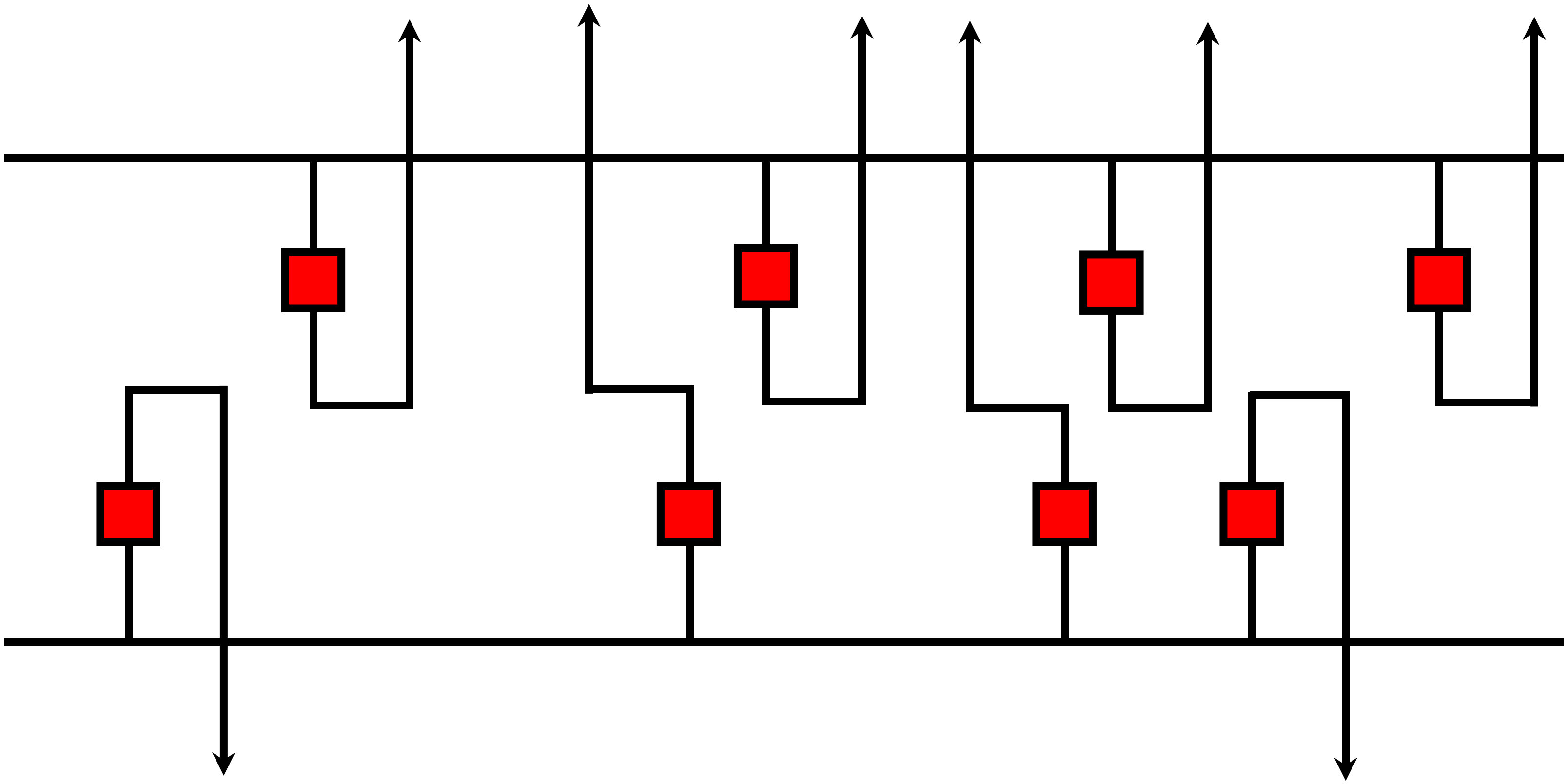
Illustration Of Automatic Bus Testing In a Transmission Switchyard



If the bus test is unsuccessful, all circuit breakers lock out and must be closed manually or by SCADA

Illustration Of Automatic Bus Testing In a Transmission Switchyard

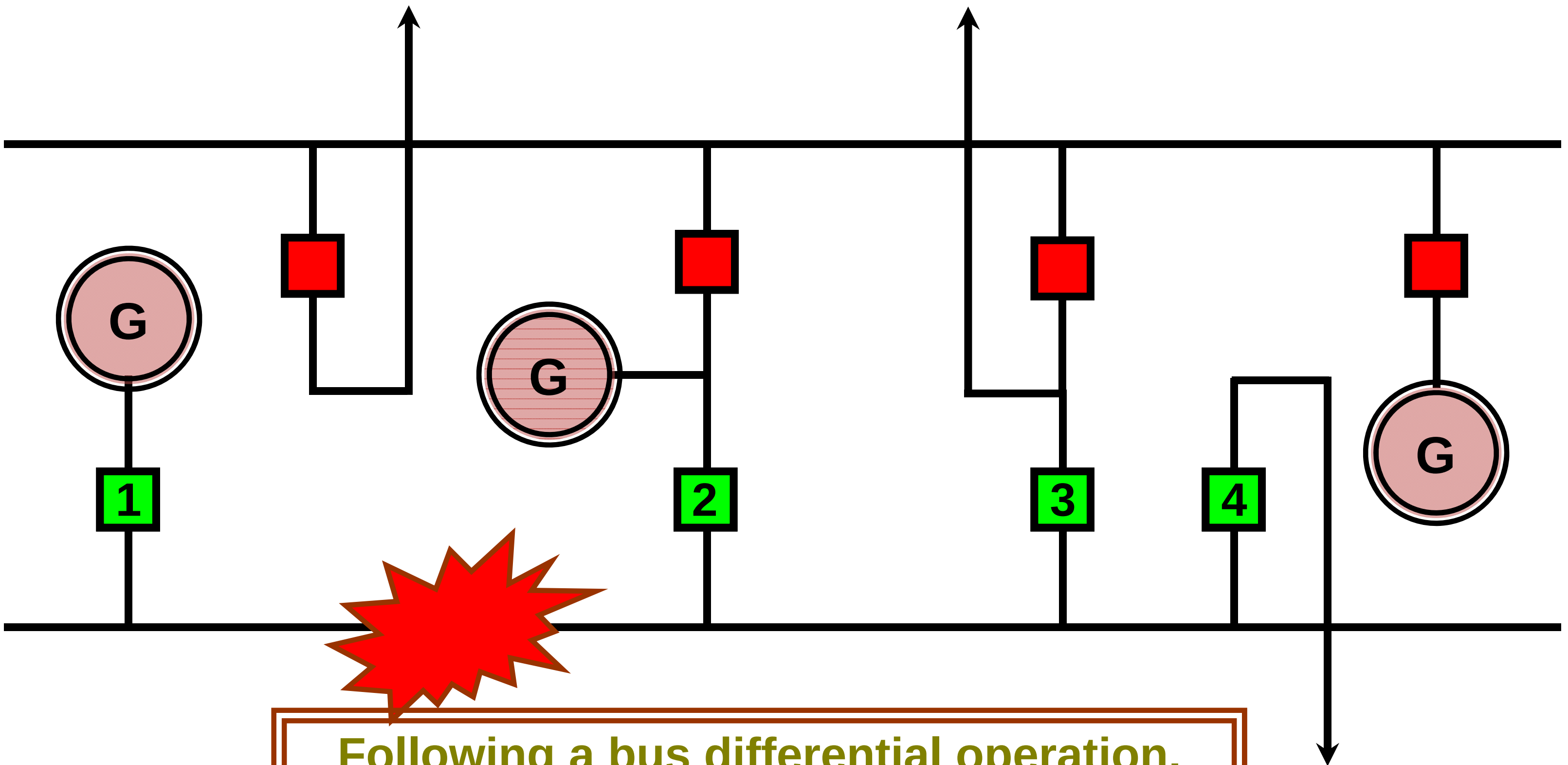


On the other hand, if the bus test is successful, all the other circuit breaker automatically reclose after a time delay to ensure the bus is stable.

Bus Testing At Generating Stations

- **Automatic bus testing following a bus differential operation at a generating station is given special consideration because of the severe mechanical stresses placed on turbine-generator couplings by a close-in bus fault…**
- **…normally the impedance between the generator terminals and a fault on a power line "cushions" the mechanical impact on the turbine-generator…**
- **…a bus fault, however, is essentially right at the terminals of the GSU transformer, so we want to limit exposure of the generator to such close-in faults as much as possible…**
- **…for this reason, a tripped bus at a generating station should be tested *only with a transmission line energized from a remote substation*…**
- **…this technique puts the testing source as far away as possible so that the impedance of the transmission line limits the current available to a persistent bus fault and thus minimizes added stress on the local generators**

Illustration Of Automatic Bus Testing At a Generating Station



Following a bus differential operation,
a preselected circuit breaker must
be closed to test the bus…
which one is preferred here and why?

Transformer and Bus Protection Exercises/Review

The most commonly used relay scheme for transformer and bus protection is:

A. Overcurrent
B. Undervoltage
C. Differential
D. Distance

Differential relay schemes compare the total current flowing into a device to __________.

A. A reference current
B. Total current leaving the device
C. Total voltage drop across the device
D. Voltage flow through the device

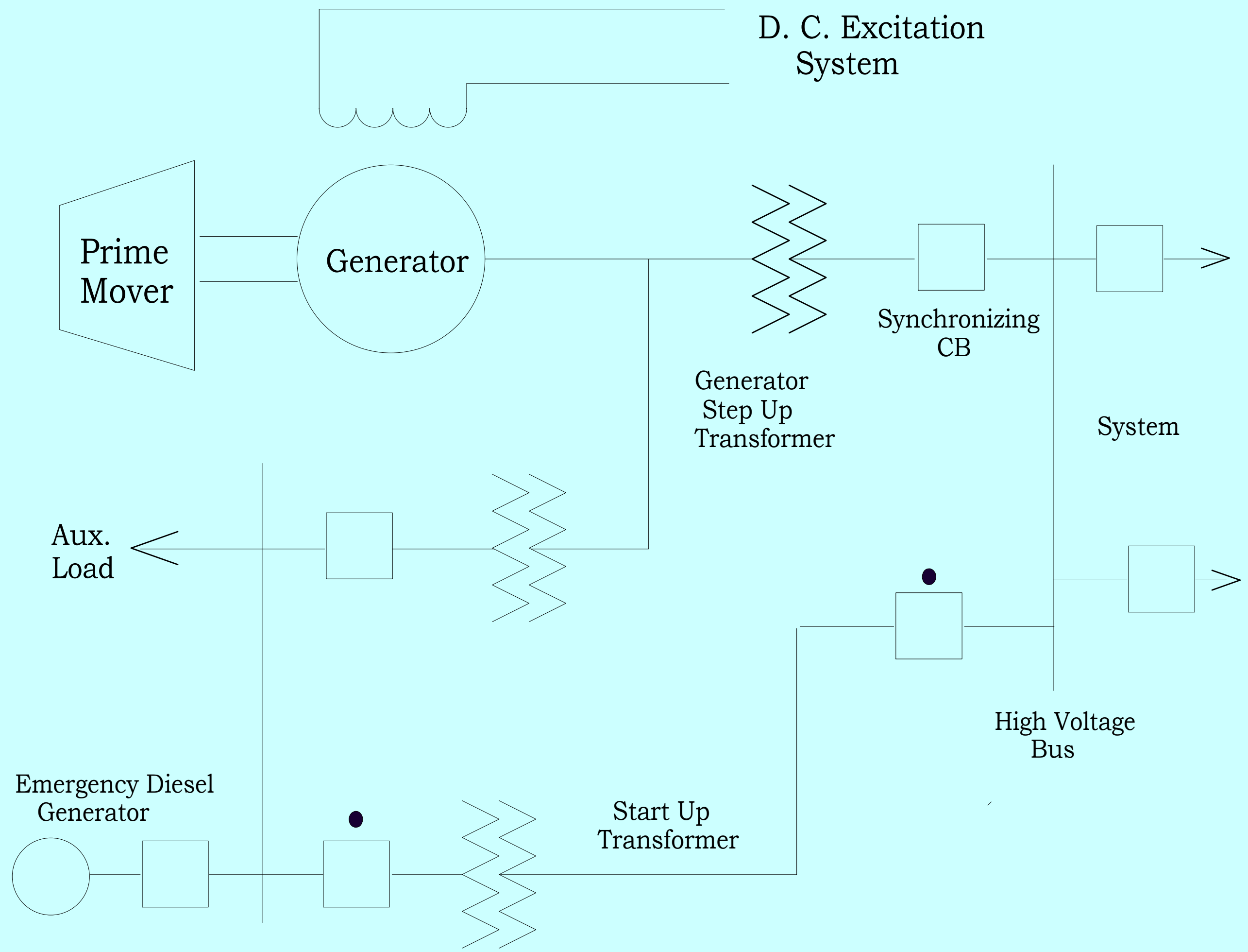
A differential relay scheme across a transformer must compensate for ______________________.

A. Voltage ratio across the transformer
B. Impedance ratio of the transformer
C. Current ratio across the transformer
D. Resistance ratio of the transformer

Automatic reclosure availability on some relay schemes serves to improve overall reliability by restoring circuits after a fault has been cleared.

A. True
B. False

Generator Protection



Typical Generating Plant Arrangement

Station Arrangement

- A Generator is usually connected to the power system through a wye-delta transformer (wye on the high voltage side, delta on the generator side)
- Generator itself is connected wye with its neutral grounded through a high impedance
- Purpose of this generator connection is to limit the high magnitude currents which could flow for a ground fault

Station Arrangement

- Generator In-Service
  - Startup Transformer is out of service
  - Plant auxiliary loads are supplied from the station service transformer
- Generator Out of Service
  - Since Generator is off line, the station service transformer is out of service
  - Plant auxiliary loads are supplied from the Startup Transformer

Station Arrangement

- Station Blackout
  - Generator has just tripped or was already off line
  - The startup transformer can provide no help because this portion of the high voltage system is interrupted
  - Emergency generators (diesel) are used to supply the plant auxiliary load until the system is restored

Generator Unit Tripping

Generator Unit Tripping:

- The frequency of failures in Rotating Machines is low, however failures can and do occur
- Beyond actual failures, certain abnormal conditions can cause generator failure if not corrected quickly
- Some of these harmful conditions are:
  - Winding Faults
  - Overheating
  - Loss of Field
  - Single Phasing
  - Overloading
  - Overspeed
  - Motoring (turbine)
  - Overexcitation

Generator Unit Tripping:

- Not all of the problems mentioned necessarily have to cause a unit trip. If detected quickly, measures can be taken to mitigate the problem

- Consequently, some relay schemes will first produce an alarm to alert operators of the problem. If the problem worsens before corrective action can be taken, the scheme will initiate a unit trip

Generator Unit Tripping:

- If protective devices do cause a unit trip, the following actions will occur:
  1) Generator Synchronizing CB is tripped and locked out
  2) Normal Station Service supply CB is tripped
  3) Generator DC field CB is tripped
  4) Prime Mover is tripped

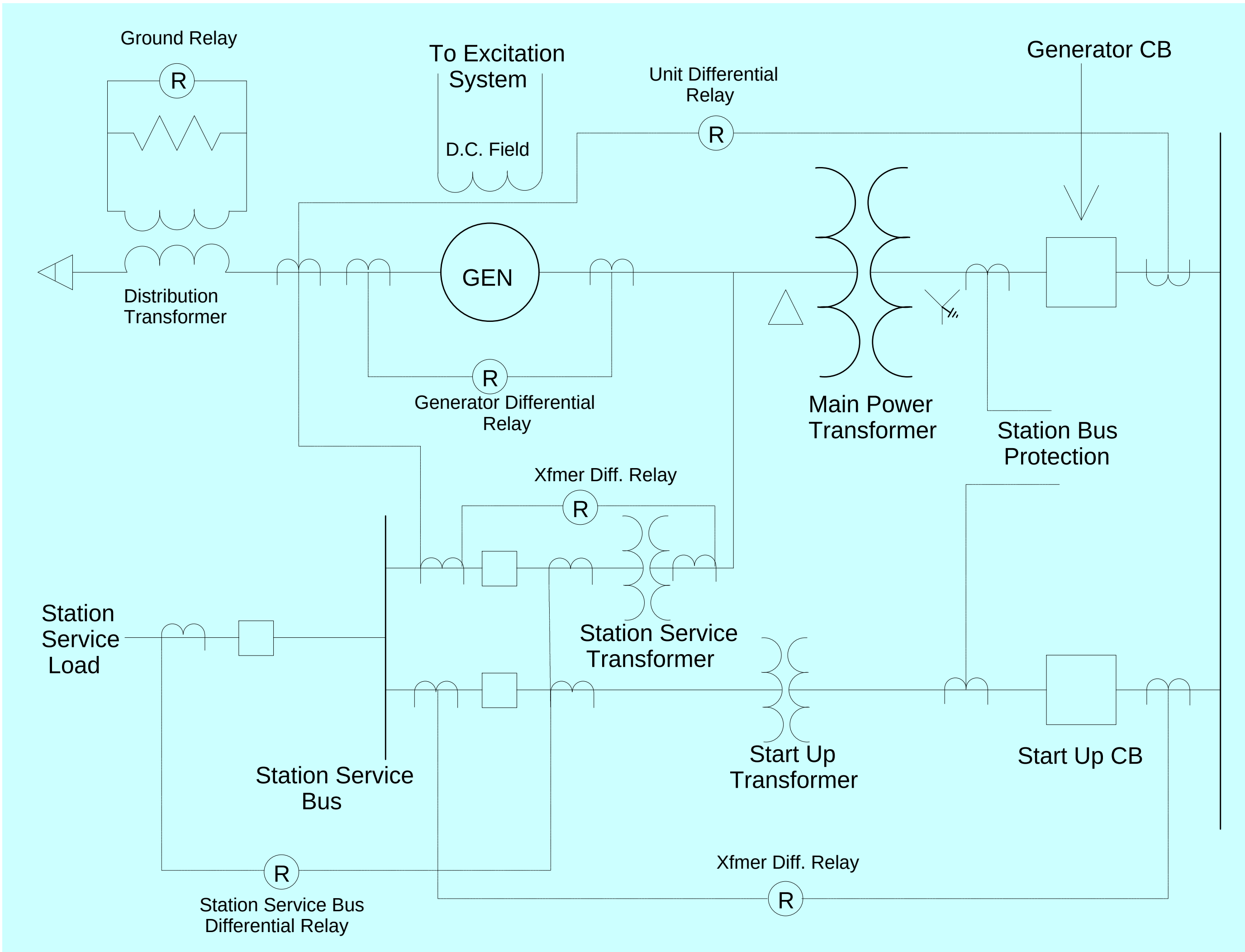
Generator Unit Tripping:

- When a unit trips, the function of the plant operator is to stabilize the prime mover and auxiliary systems to insure a controlled shut down
- The generation dispatcher’s purpose is dependent upon individual company procedures. This could involve negotiation for additional generation or notifying that company’s energy marketing function

Overall
Unit Protection

Areas to be protected and concerns:

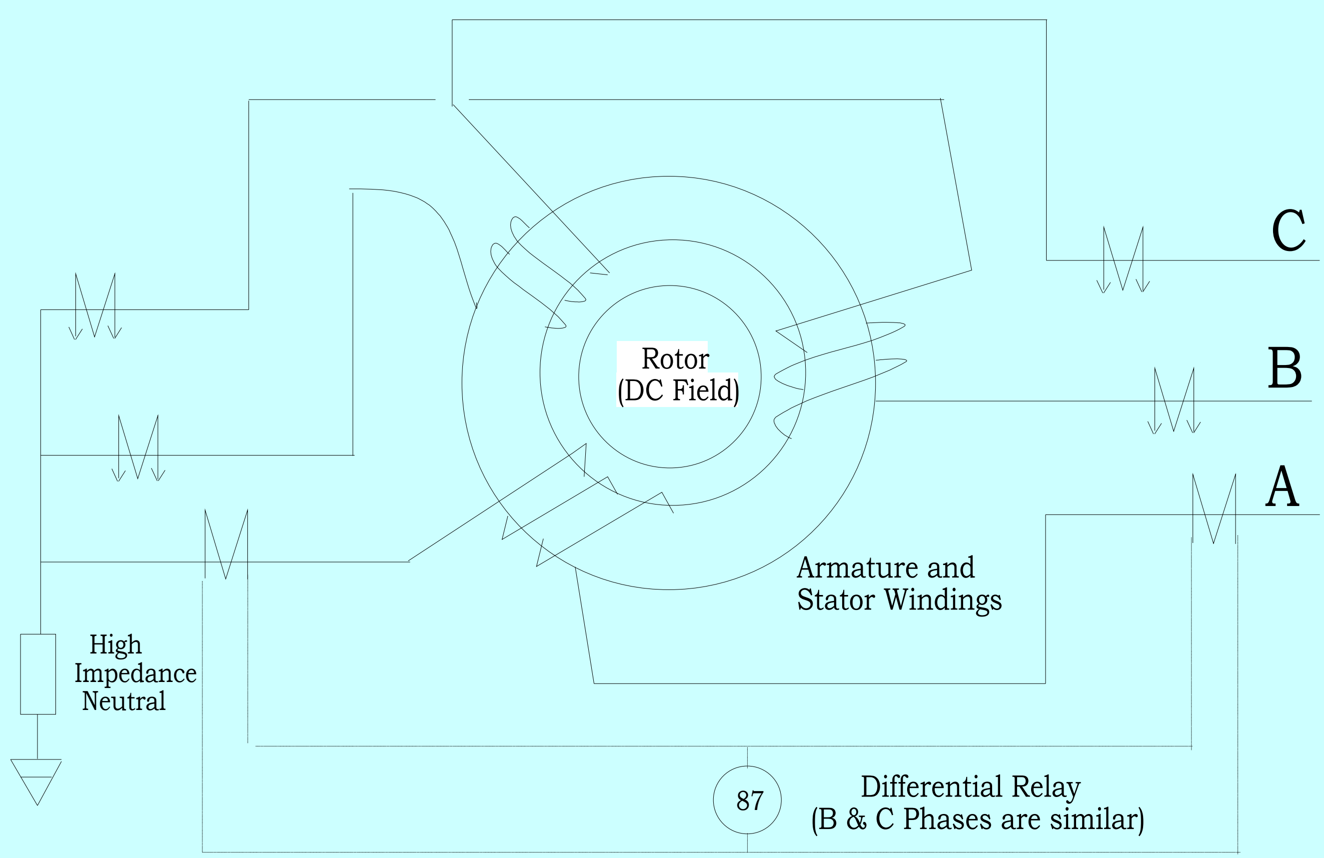
1) Generator - Winding Fault, Overloading, Overheating, Overspeed, Underfrequency, Loss of Excitation, Motoring, Phase Unbalance, Out of Step
2) Turbine - Overspeed, Underspeed, Vibration, Temperature
3) Auxiliaries - Cable Faults, Grounds on System
4) Station Service - Transformer Faults, Lead faults, etc


Ground Relay
R
To Excitation System
D.C. Field
Unit Differential Relay
R
Generator CB
GEN
Distribution Transformer
R
Generator Differential Relay
Main Power Transformer
Station Bus Protection
Xfmer Diff. Relay
R
Station Service Load
Station Service Transformer
Start Up Transformer
Start Up CB
Station Service Bus
Xfmer Diff. Relay
R
R
Station Service Bus Differential Relay

Protective Relay Schemes for the Generator:

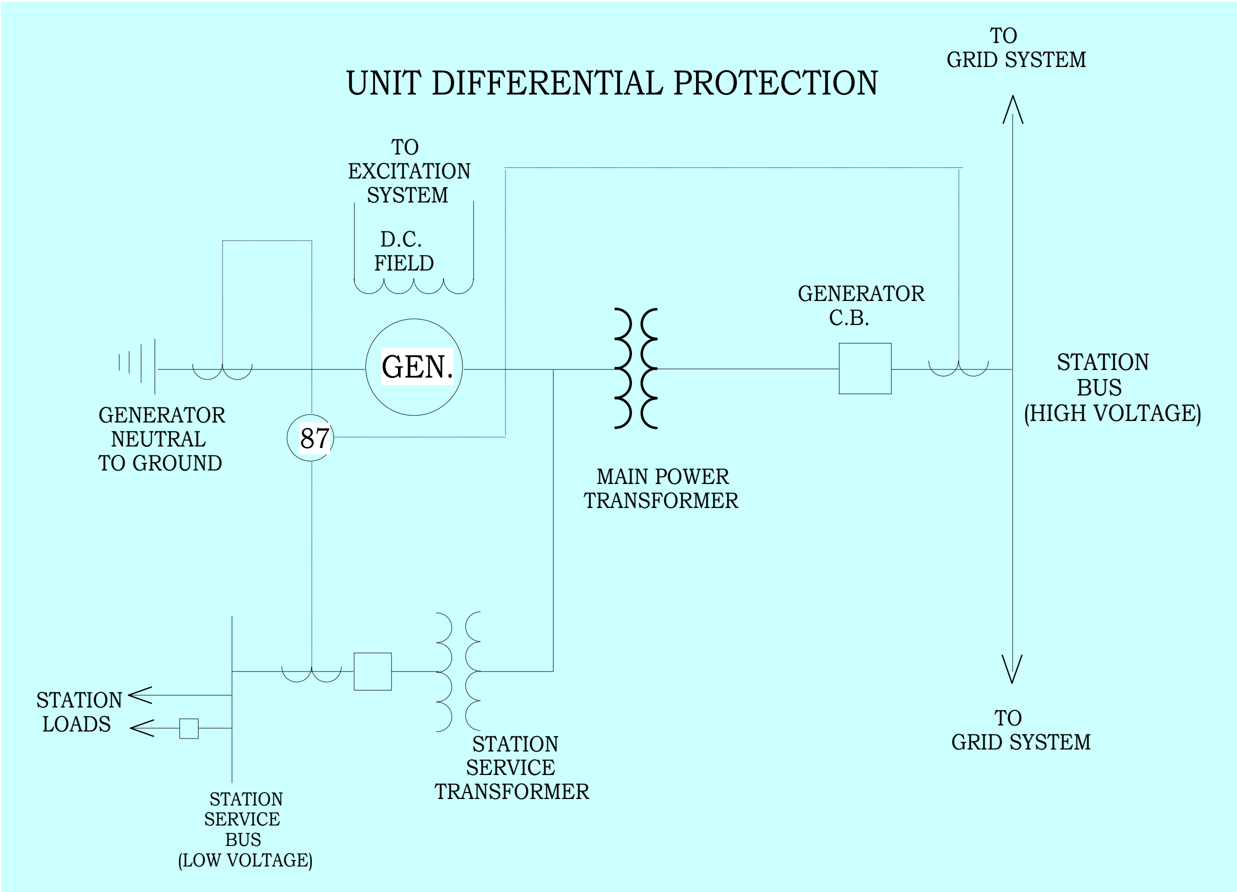
- Generator Differential
  - Wraps only the Stator Windings of the Generator
  - Sensitive to phase and some ground faults
  - Operation of this relay will initiate a unit trip

Generator Differential



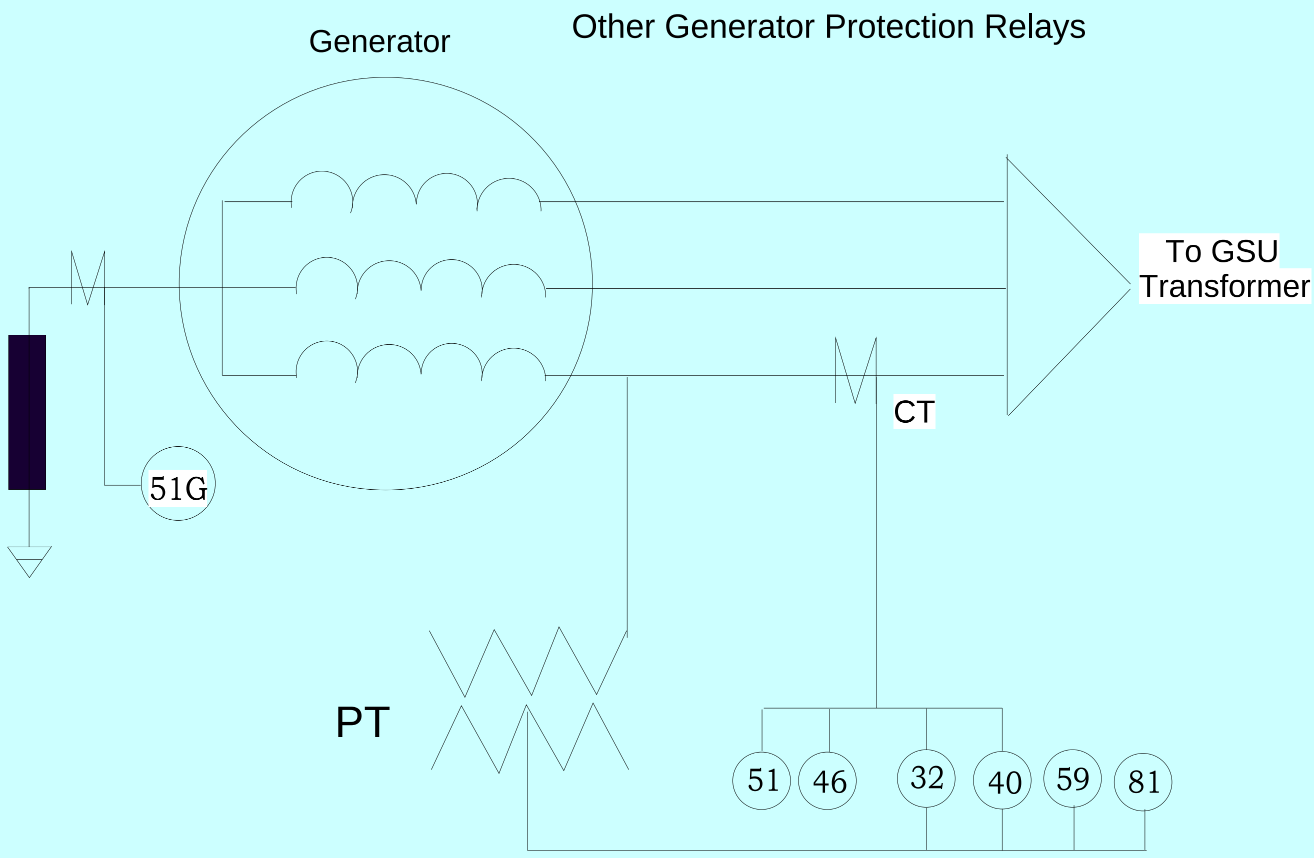
Protective Relay Schemes for the Generator:

- Overall Differential
  - Wraps the Generator, Gen. Step-up Transformer & Station Service Transformer
  - Sensitive to phase & some ground faults
  - Backs up the Gen. Diff, GSU Diff., Station Service Diff, etc
  - Less sensitive than the Gen. Diff
  - Operation of this relay will initiate a unit trip


UNIT DIFFERENTIAL PROTECTION
TO
GRID SYSTEM
TO
EXCITATION
SYSTEM
D.C.
FIELD
GENERATOR
C.B.
GEN.
STATION
BUS
(HIGH VOLTAGE)
GENERATOR
NEUTRAL
TO GROUND
87
MAIN POWER
TRANSFORMER
STATION
LOADS
STATION
SERVICE
TRANSFORMER
TO
GRID SYSTEM
STATION
SERVICE
BUS
(LOW VOLTAGE)

Protective Relay Schemes for the Generator:

- Overcurrent Protection
  - Provide Backup Protection for Gen. Diff Scheme
  - Protects the generator from system faults that are not cleared within a predetermined time interval
  - Coordinated with System Overcurrent schemes
  - Usually time delayed to minimize tripping for transient surges or synchronizing
  - Will initiate a unit trip



51 - Backup Overcurrent
46 - Negative Sequence
40 - Loss of Field
81 - Underfrequency

32 - Reverse Power (Anti-motoring)
51G - Generator Ground Overcurrent
59 - Overexcitation

Protective Relay Schemes for the Generator:

- Anti-motoring or Reverse Power Protection:
  - Actually used to protect the Turbine instead of the generator
    - When Generator takes in power, it is essentially a synchronous motor (non-harmful to generator)
    - This mode of operation, if sustained could lead to turbine blade failure
  - This is one standard method for taking unit off line
  - May cause alarm, but will initiate a unit trip

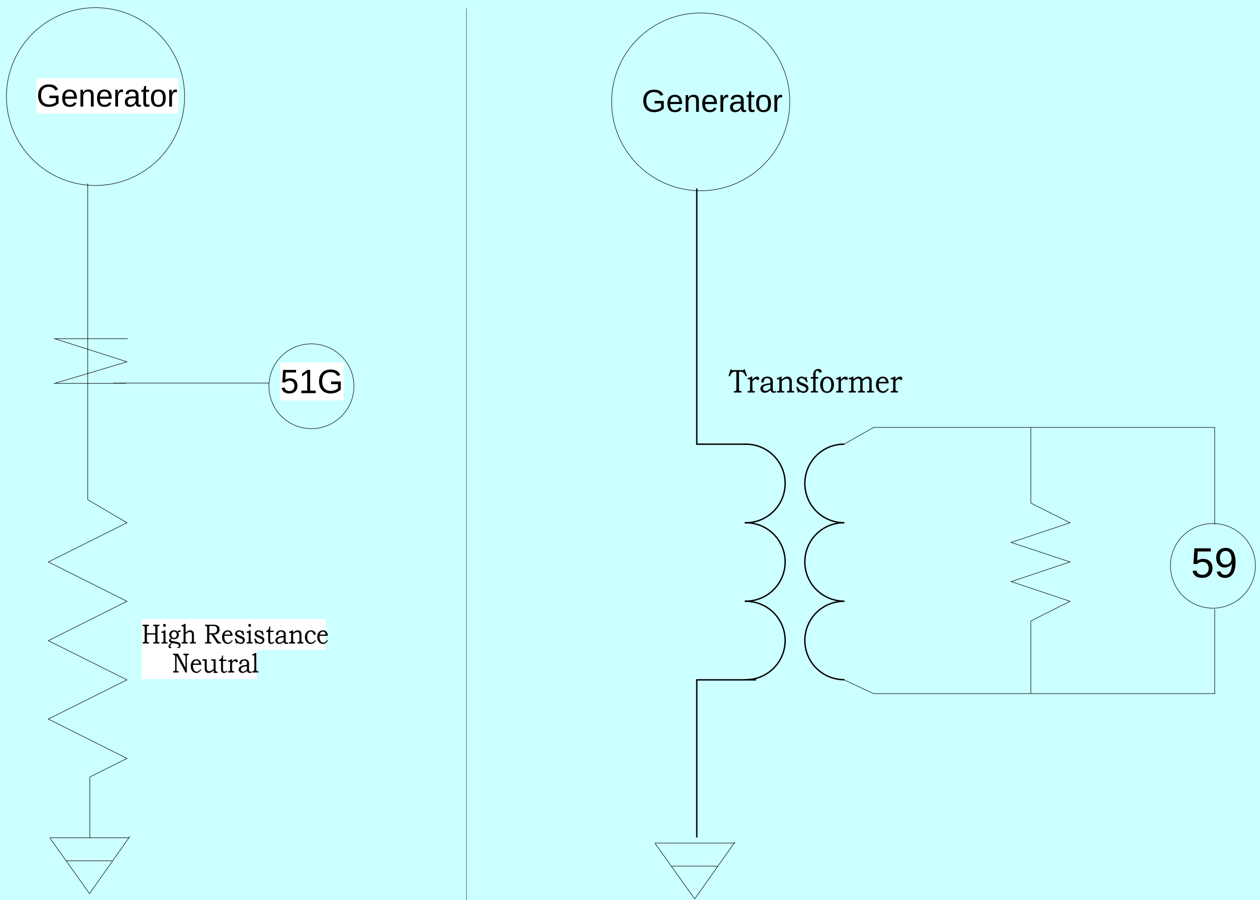
Protective Relay Schemes for the Generator

- Negative Sequence Protection
  - During unbalanced faults, "Negative Sequence" currents will flow
    - Physically, 120 cycle rotor currents are induced in the solid rotor forgings, non-magnetic rotor wedges and retaining rings.
    - The I^2R loss quickly raises temperature of the rotor and would eventually cause serious rotor damage
  - Will initiate an alarm and trip unit

Protective Relay Schemes for the Generator:

- Generator Ground Fault Protection
  - Method of Generator Grounding affects the protection provided by the differential relays
    - The higher the grounding impedance, the lower the ground fault current magnitude
  - To detect these low magnitude faults, Neutral Overcurrent or an Overvoltage relay scheme is employed
  - Operation of this relay scheme will initiate a unit trip

Types of Generator Grounding Used



Resistored Neutral with an Overcurrent Relay

High Impedance Neutral with Overvoltage Relay

Protective Relay Schemes for the Generator:

- Loss of Field Protection
  - When loss of field occurs in a synchronous machine, reactive power flows from the system into the machine
  - The reactive flow can be 2 to 3 times the generators rated load (i.e. thermal damage)
  - Relays monitor reverse var flow or low voltage
  - Operation of this relay will alarm and initiate a unit trip

Protective Relay Schemes for the Generator:

- Loss of Field Protection
  - Loss of Field indicates that trouble exists in:
    1) Main Exciter
    2) Field Winding
    3) Operating Error when machine is in Manual mode

Protective Relay Schemes for the Generator:

- Overexcitation Protection
  - Concern is for the Generator Field and main GSU transformer since overexcitation can cause damaging overheating due to core saturation in a very short time
  - For GSU transformer protection, a Volts/Hertz relay is applied
    - Operation of relay will trip unit
  - For Field Overexcitation, Voltage or Current relays are employed
    - Relay will alarm or automatically reduce field to allowable limits

Protective Relay Schemes for the Generator:

- Underfrequency Protection
  - If System Load exceeds the capability of the machine, the frequency will decay
  - In PJM, machines are typically set for 57.5 hz with a 5.0 second time delay
  - System load shedding schemes are used to dump load as required
    - If not enough load is disconnected and frequency drops, relay will initiate a unit trip
  - If unit tripping occurs, pull out your “Black Start Restoration” guide because it will be needed!

Generator Protection Exercises/Review

List the associated actions that typically occur when a generator trips:

Which relay scheme protects the generator from stator winding faults?

1. Loss of field
2. Generator Differential
3. Overspeed
4. Neutral overcurrent

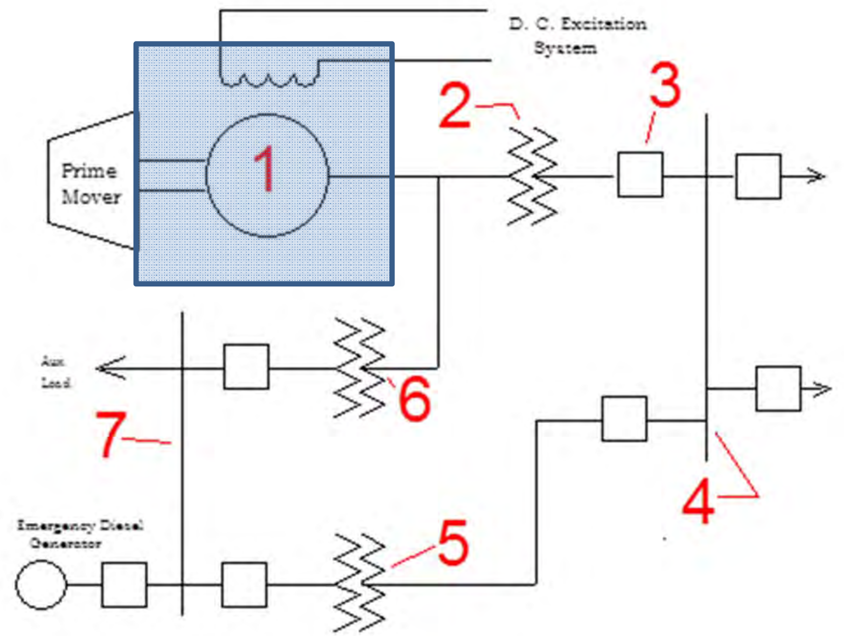
What type of relay is used to protect the generator from a loss of synchronization resulting from excessive VAR absorption?

A. Overexcitation
B. Loss of Field
C. Negative Sequence
D. Differential

What major component of a generator is protected by a generator field over-excitation relay?

A. Turbine
B. GSU
C. Field windings
D. Isophase bus

What is the name of this major component of a generating unit?



Typical Generating Plant Arrangement

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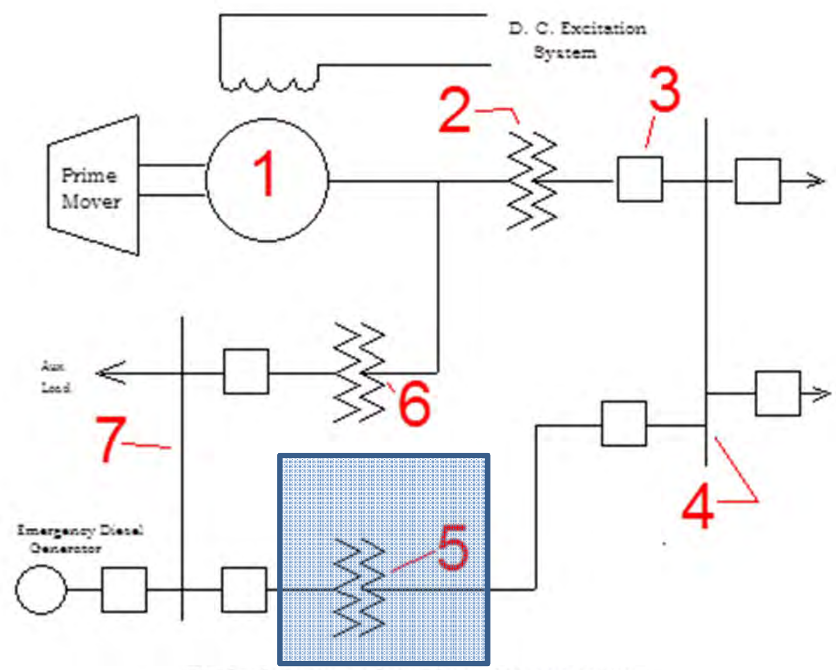

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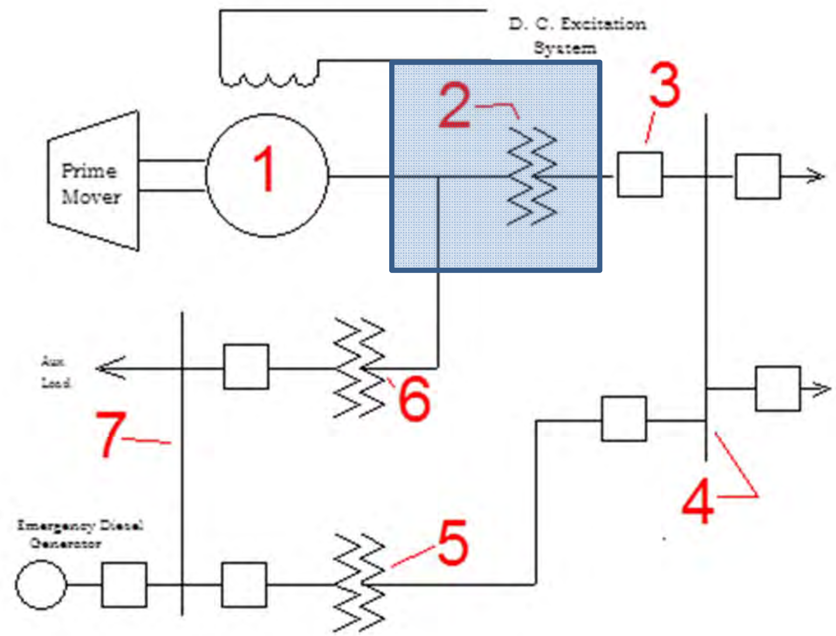

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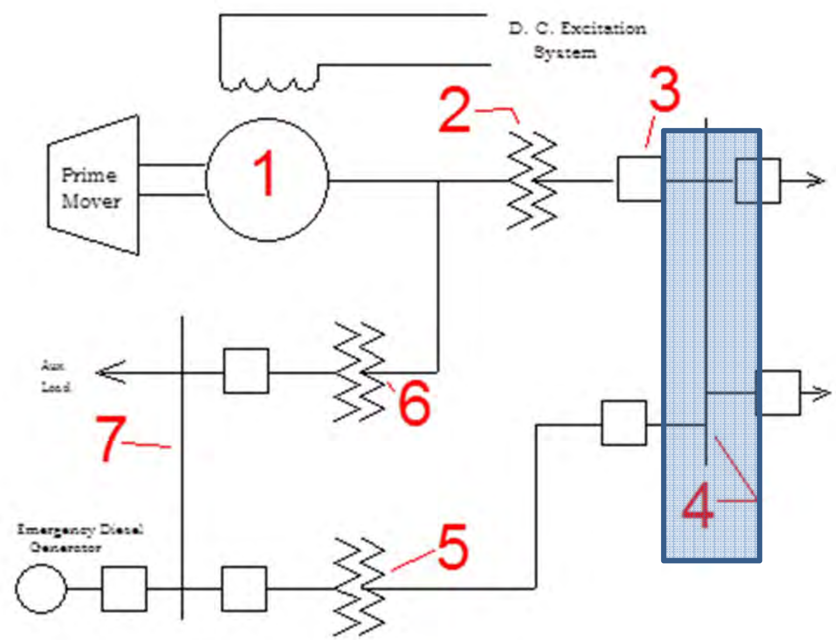

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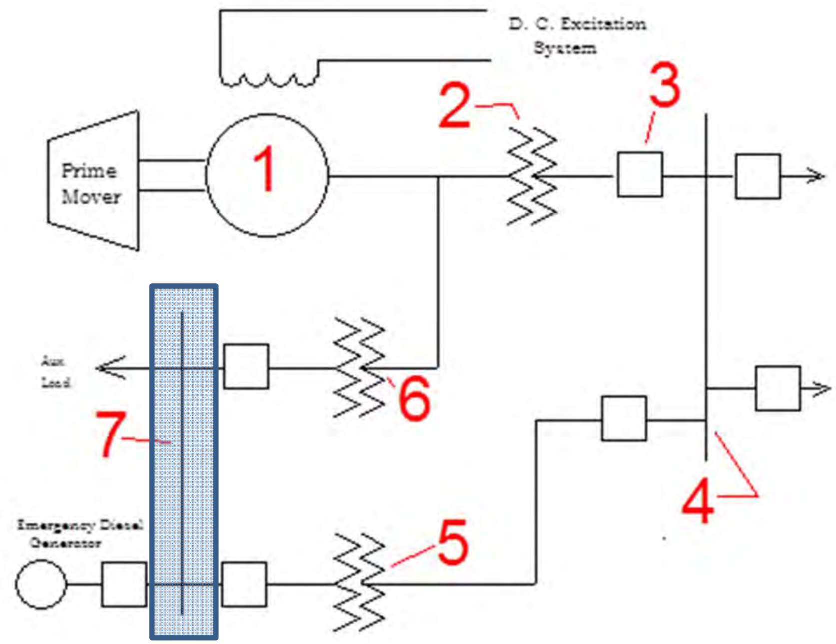

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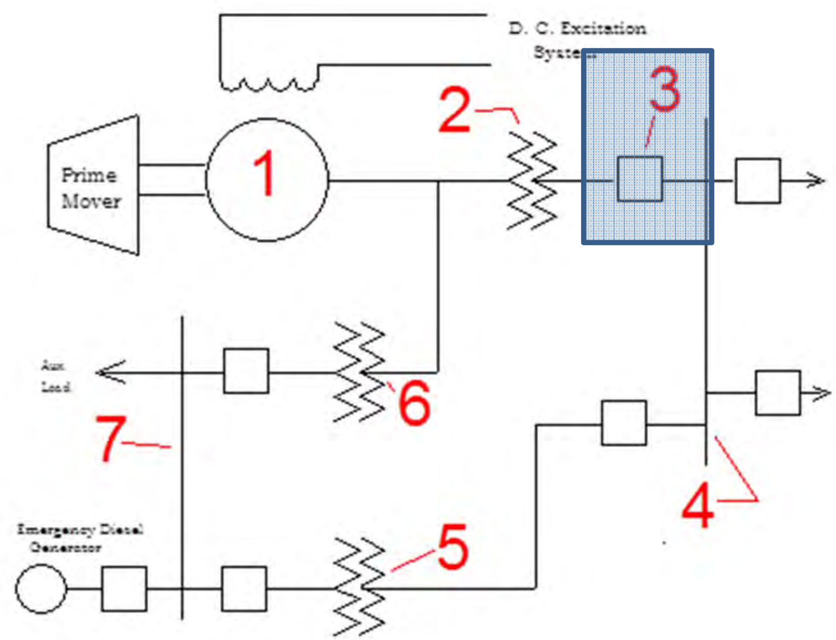

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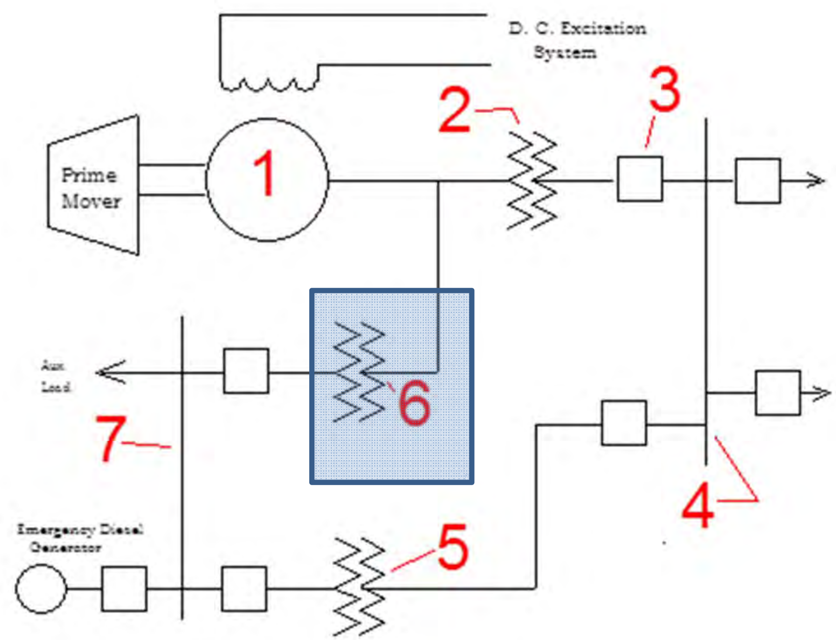

Typical Generating Plant Arrangement

Summary

- Describe the purpose of protective relays
- Identify relay protection scheme characteristics and components
- Describe the impact of the loss of components on system protection
- Identify the types of transmission line protection and their characteristics
- Identify the types of transformer protection and their characteristics
- Identify the types of bus protection and their characteristics
- Identify the types of generator protection and their characteristics

Questions?

Disclaimer:

PJM has made all efforts possible to accurately document all information in this presentation. The information seen here does not supersede the PJM Operating Agreement or the PJM Tariff both of which can be found by accessing: http://www.pjm.com/documents/agreements/pjm-agreements.aspx

For additional detailed information on any of the topics discussed, please refer to the appropriate PJM manual which can be found by accessing: http://www.pjm.com/documents/manuals.aspx

Resources and References

- PJM. (2013). *PJM Manual 3: Transmission Operations (rev 43)*. Retrieved from http://www.pjm.com/~/media/documents/manuals/m03.ashx
- PJM. (2011). *PJM Manual 7: PJM Protection Standards (rev 0).* Retrieved from http://www.pjm.com/~/media/documents/manuals/m07.ashx
- Miller, R. & Malinowski, J. (1994). *Power System Operation*. (3rd ed.). Boston, MA. McGraw-Hill.