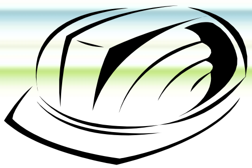
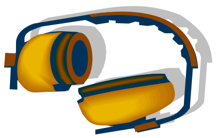
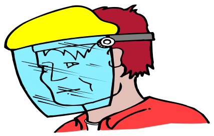


INTRODUCTION TO SYSTEM PROTECTION





Hands-On Relay School 2012

CONGRATULATIONS

On choosing the field of system protection. It is an exciting, challenging profession.

System protection has changed considerably in the past 20 years.

Many learning and growth “opportunities” will come your way in the future.

What is System Protection?

System protection is the art and science of detecting problems with power system components and isolating these components.

Problems on the power system include:

1. **Short circuits**
2. **Abnormal conditions**
3. **Equipment failures**

NERC defines the protection system as:

Current Approved Definition:

Protective relays, associated communication systems, voltage and current sensing devices, station batteries and DC control circuitry.

Purpose of System Protection

- Protect the public
- Improve system stability
- Minimize damage to equipment
- Protect against overloads
- Employ relay techs and engineers

What Components (Equipment) Do We Protect?

What Components (Equipment) Do We Protect?

•Generators

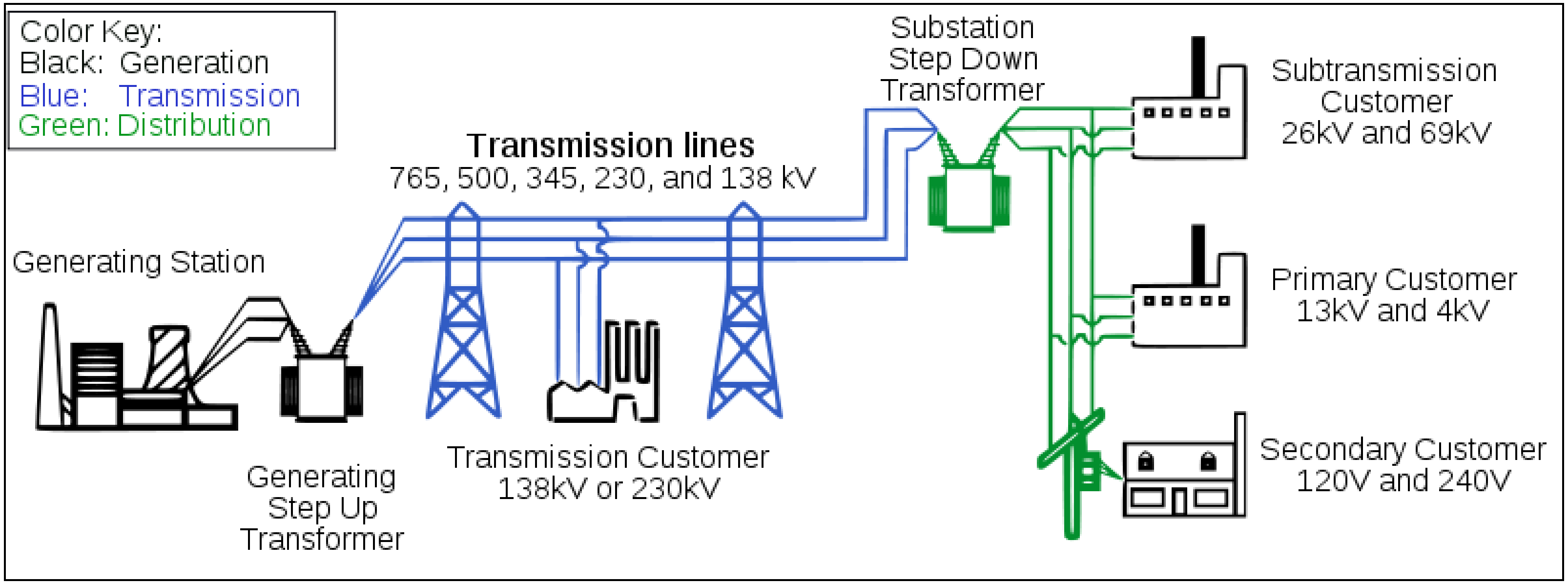
•Transformers, Reactors

•Lines

•Buses

•Capacitors

What Components (Equipment) Do We Protect?

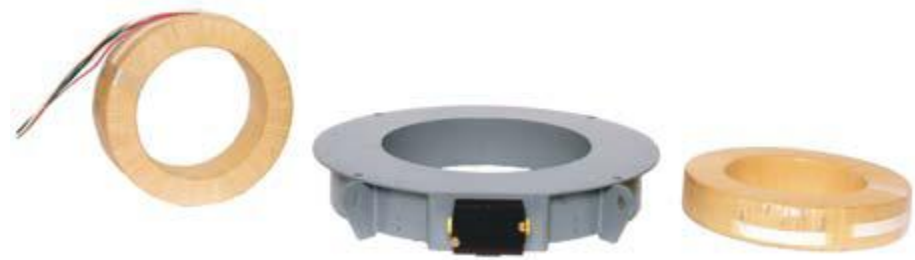


Some Basics

Protective relays monitor the current and/or voltage of the power system to detect problems with the power system. Currents and voltages to relays are supplied via CT's and PT's.

Some Basics

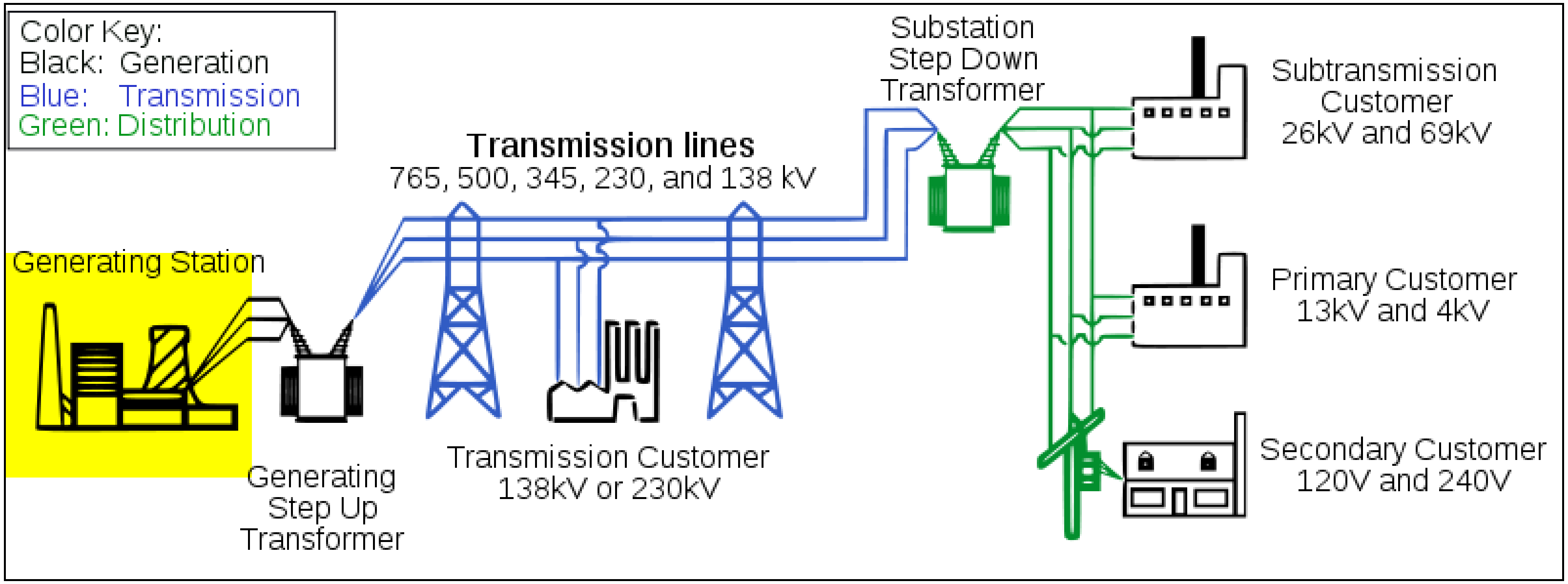
Current Transformer (CT)
A device which transforms the current on the power system from large primary values to safe secondary values. The secondary current will be proportional (as per the ratio) to the primary current.



Some Basics

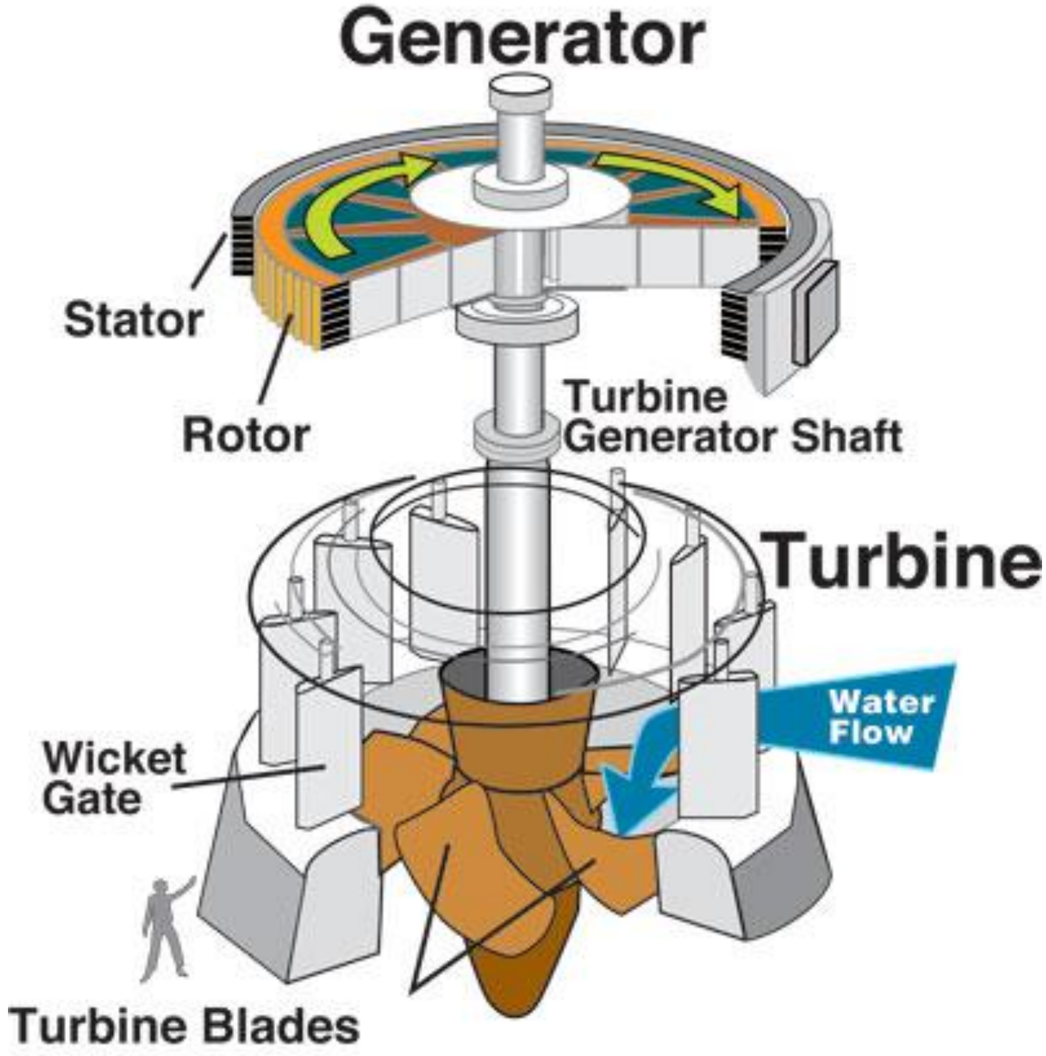
Potential Transformer (PT)
A device which transforms the voltage on the power system from primary values to safe secondary values, in a ratio proportional to the primary value.

What Components (Equipment) Do We Protect?



I. Generator Protection

A. Construction & Theory of Operation

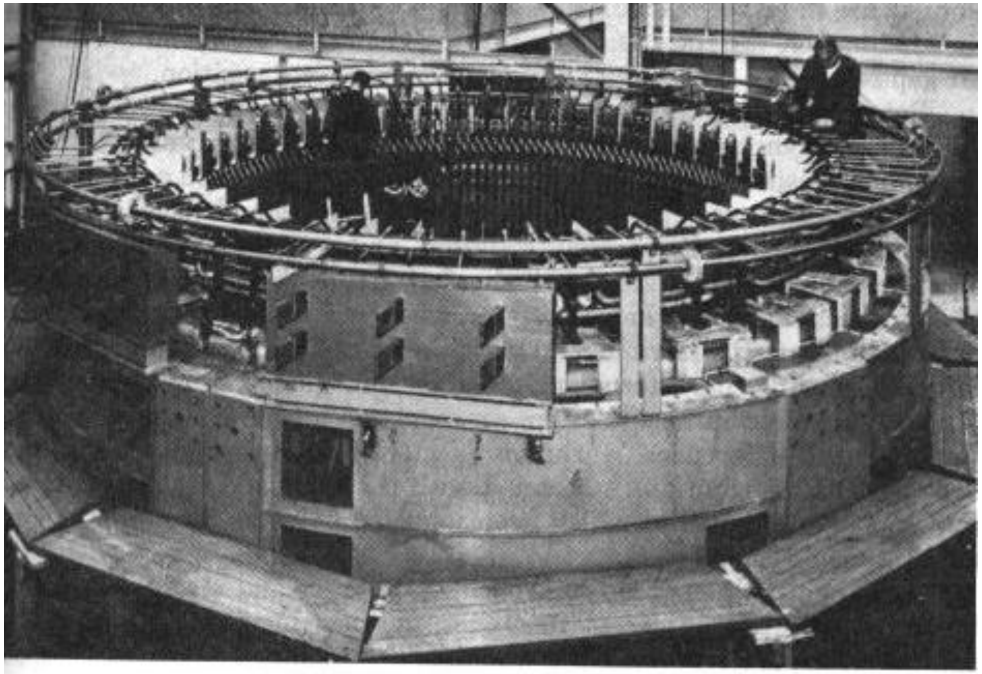


Three Gorges Dam in China Largest in the world (22,000MW, 26 Generators)

I. Generator Protection

What can go wrong?

A. Stator Winding Problems
   1. Winding-winding short
   2. Stator ground

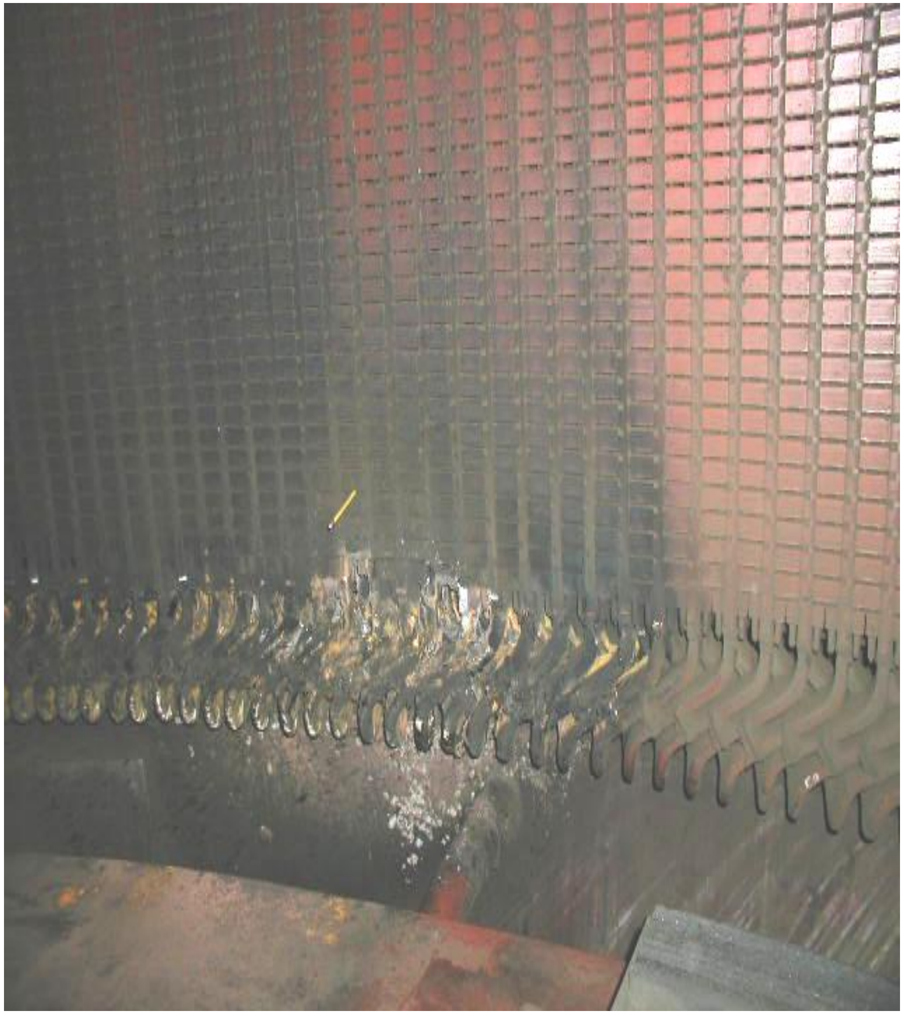


Stator of a 190-MVA three-phase 12-kV 375-r/min hydroelectric generator. The conductors have hollow passages through which cooling water is circulated. (*Brown Boveri Corporation.*)

I. Generator Protection

What can go wrong?

A. Stator Winding Problems



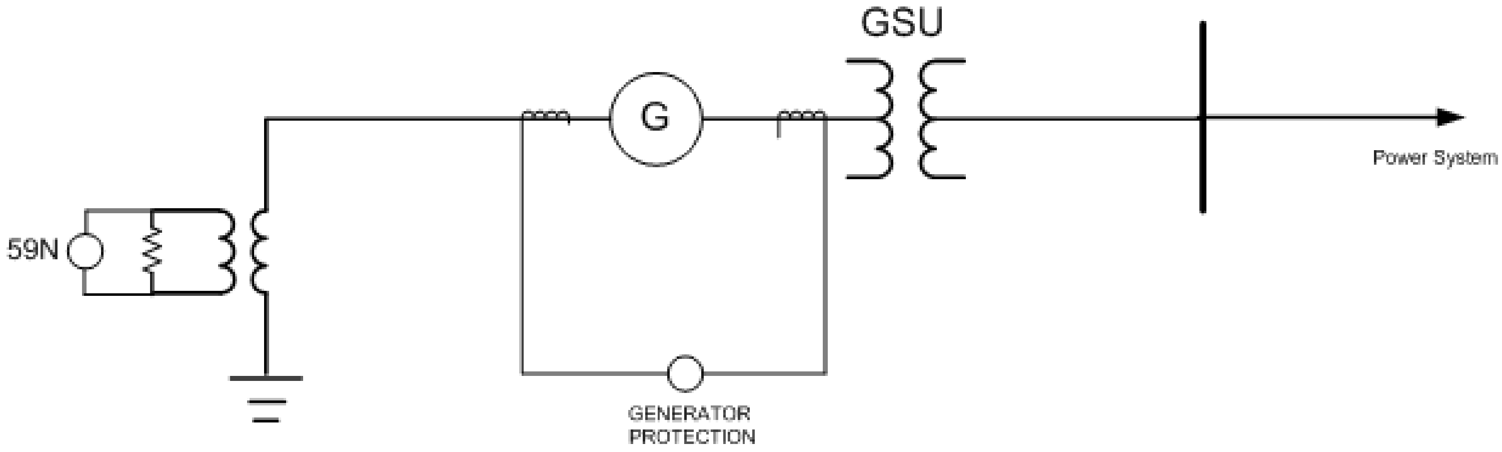
How Do We Protect the Stator?

A. Differential Protection (what goes in must come out)

1. Detects phase-phase faults

B. Stator Ground Protection

1. 59N (95% of Stator)
2. Third Harmonic Voltage Method (100% of Stator)
3. Signal Injection (100% of Stator)



Generator Protection

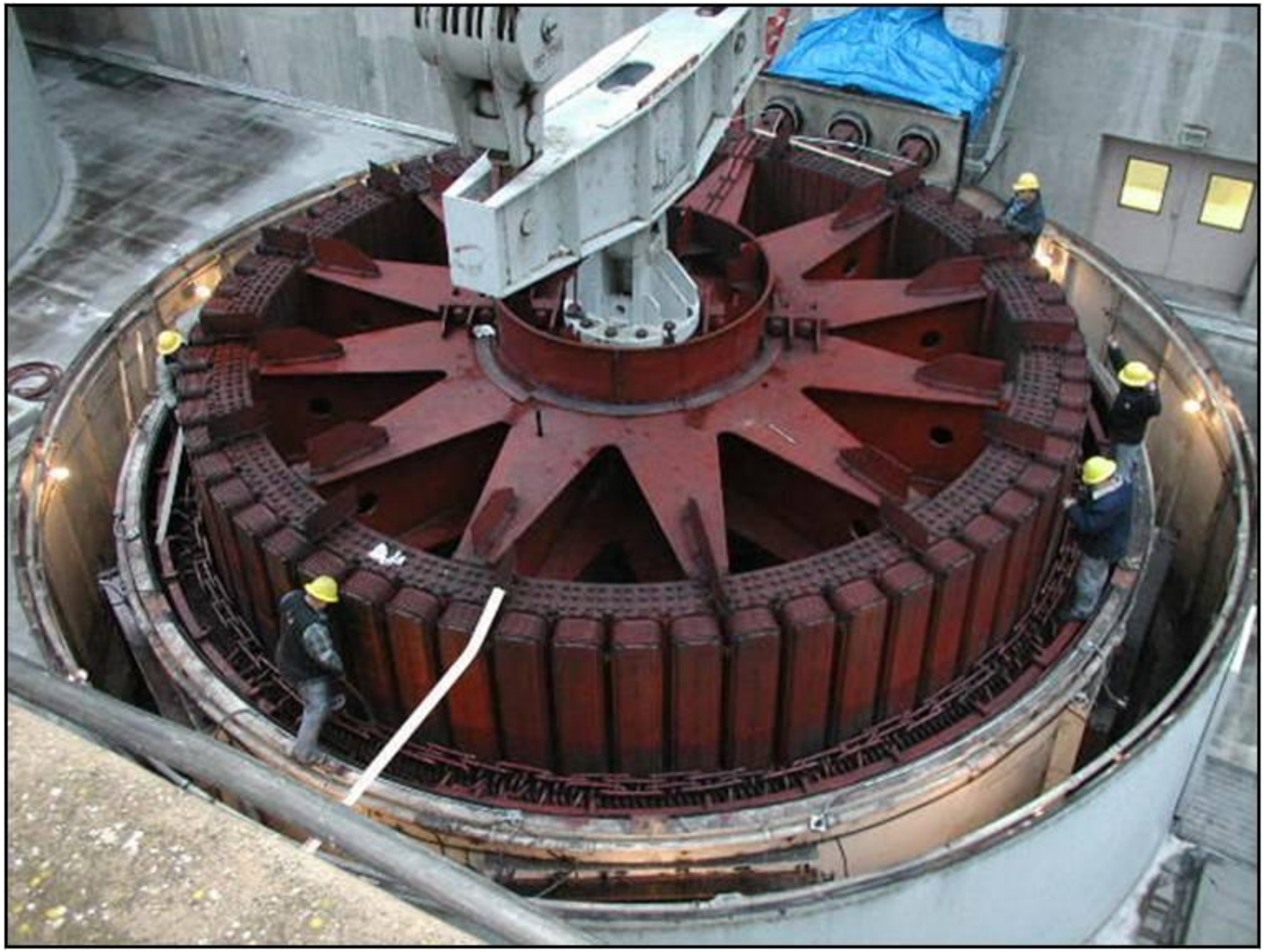
What can go wrong?

B. Rotor Problems

1. Loss of field
2. Field ground
    a. First ground
    b. Second ground
    =TROUBLE

Generator Protection

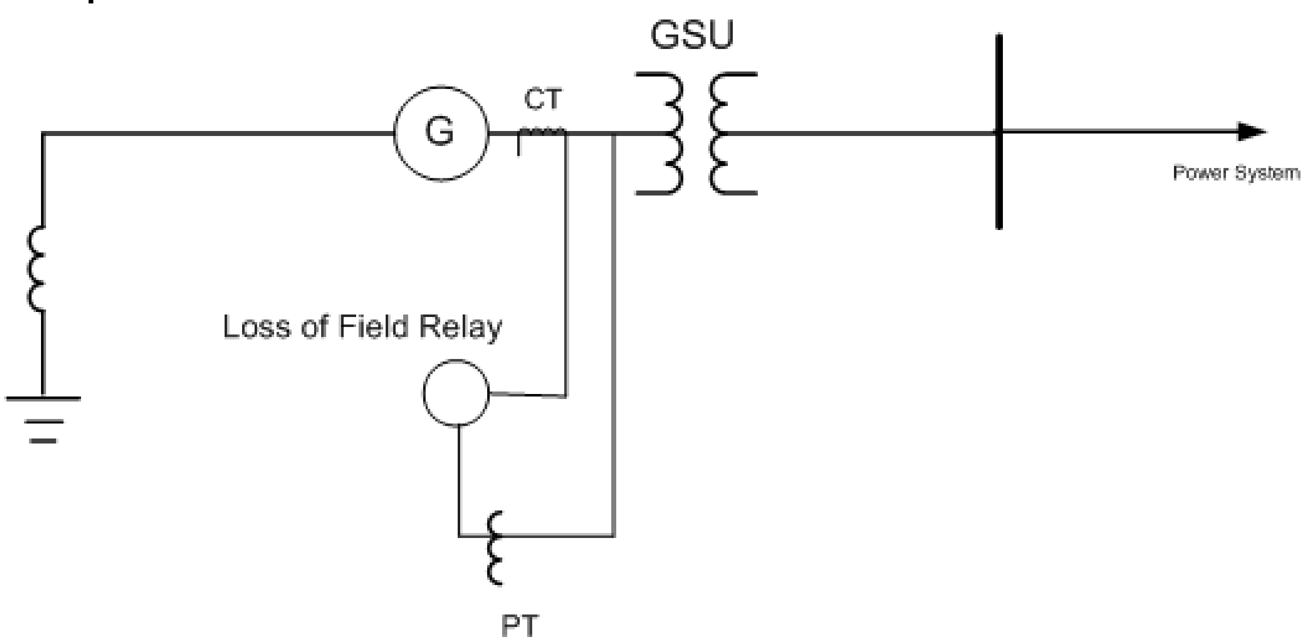
Rotor



Generator Protection

How Do We Protect the Rotor?

1. Loss of Field
   a. Impedance



Generator Protection

How Do We Protect the Rotor?

2. Field ground
    a. DC voltage relay (64F)

The field ground relay is connected from the negative side of the field to DC ground. Detects voltage from the field to ground.

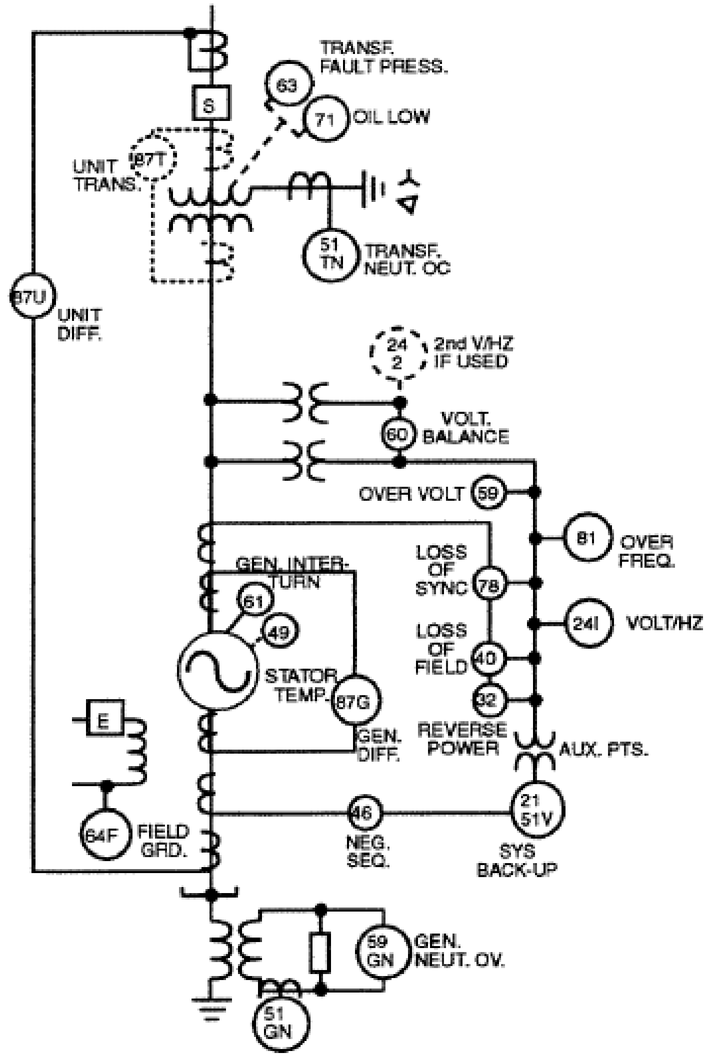
Generator Protection

What else can go wrong?

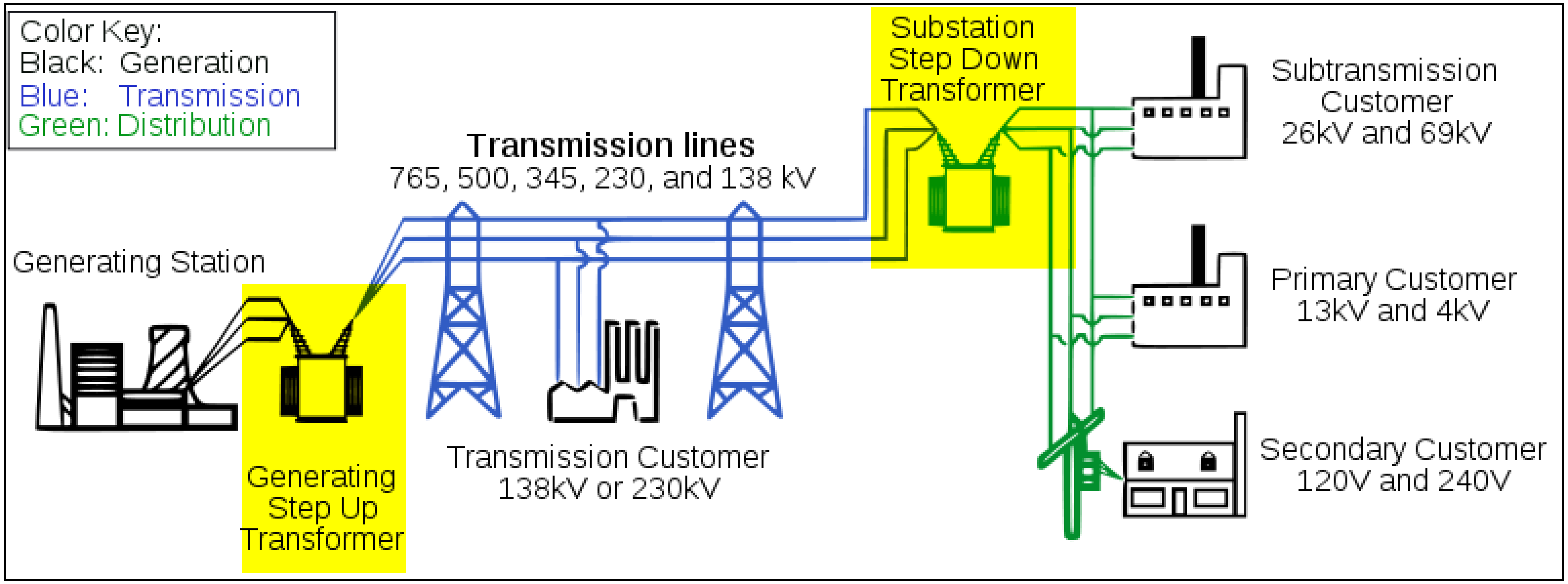
C. Abnormal Conditions

1. Over/Under Frequency
2. Over Excitation
3. Reverse Power
4. Out of Step
5. Unbalance Current

Generator Protection



Transformer Protection



XFMR PROTECTION

Power transformers are expensive, and are a long lead-time item (1 year or longer) so protection must be effective

Transformer Protection

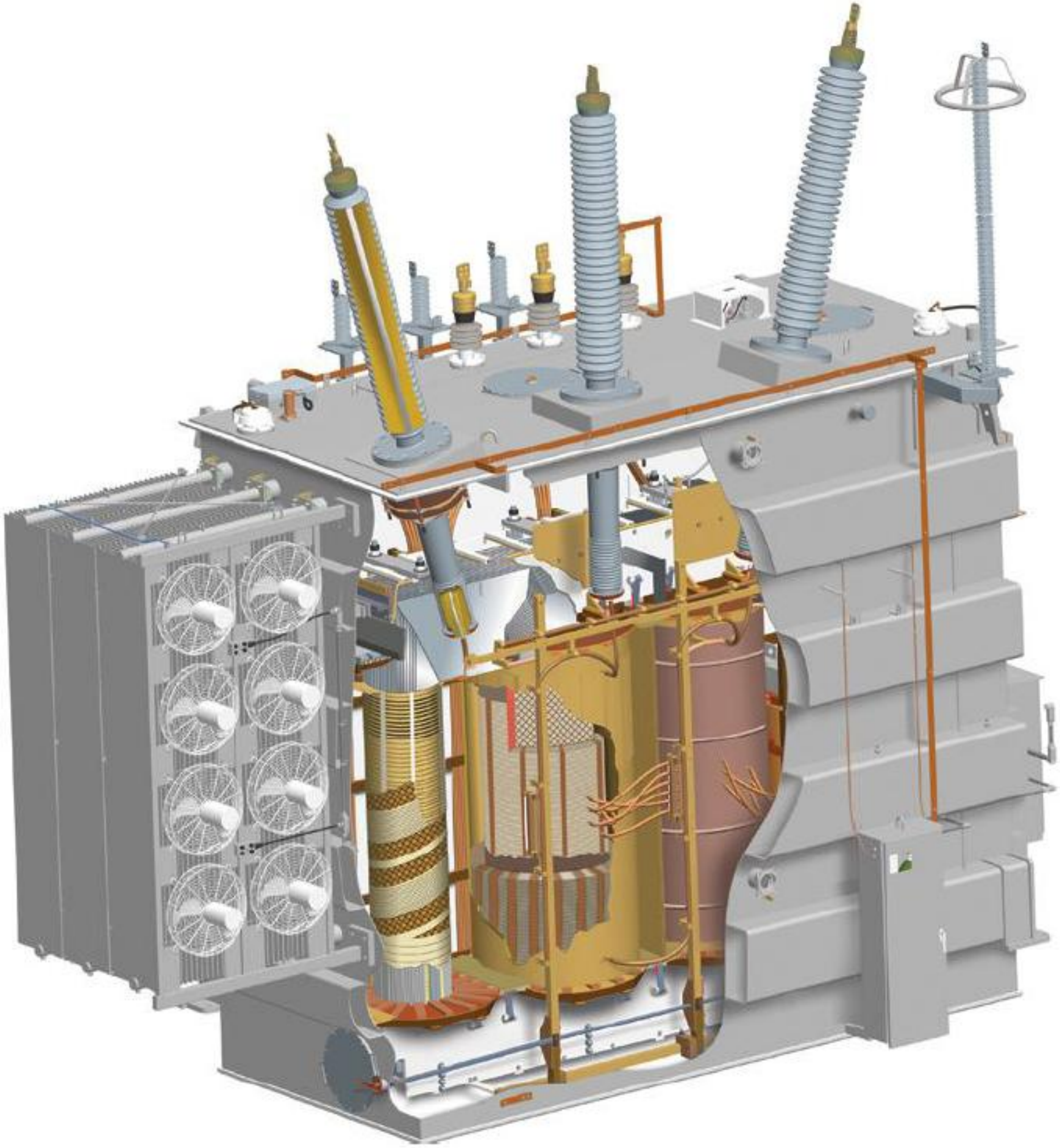
Construction

Transformer Protection

Construction

Transformer Protection

Construction



Transformer Protection

Transformer size and rating

● MVA: the capacity of the transformer in terms of million volt-amps. Size can range from less than 1 MVA to 500 MVA and higher.

● Transformer rating (MVA) is determined in part by the amount of cooling employed. MVA rating increases with more cooling. OA, FOA (stage 1), FOA (stage 2)

Transformer Protection

What can go wrong?

- Winding-to-winding faults
- Winding-to-ground faults
- Bushing faults

Transformer Protection

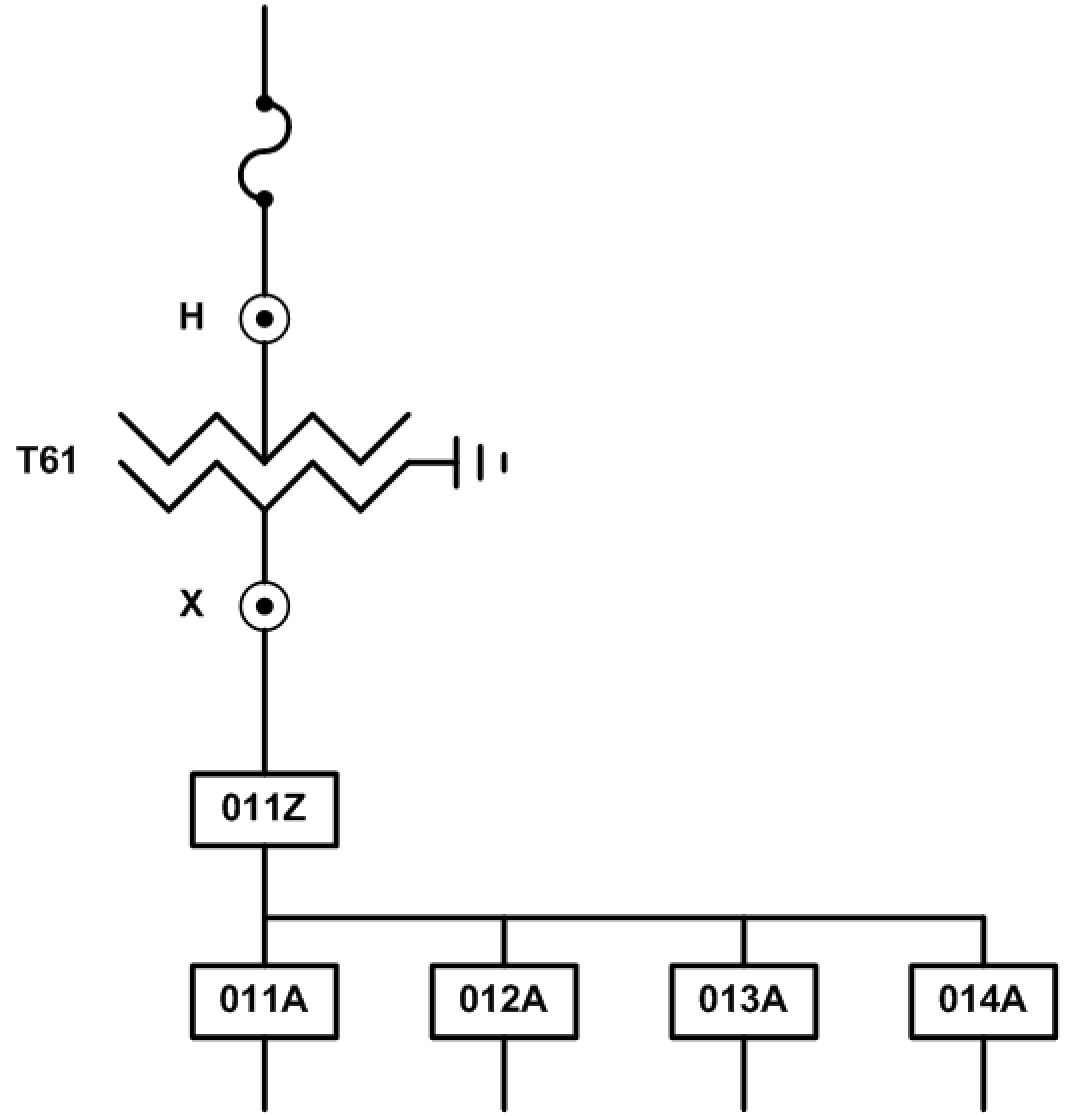
Transformer Protection

Protection Methods

- Fuse
- Overcurrent
- Differential

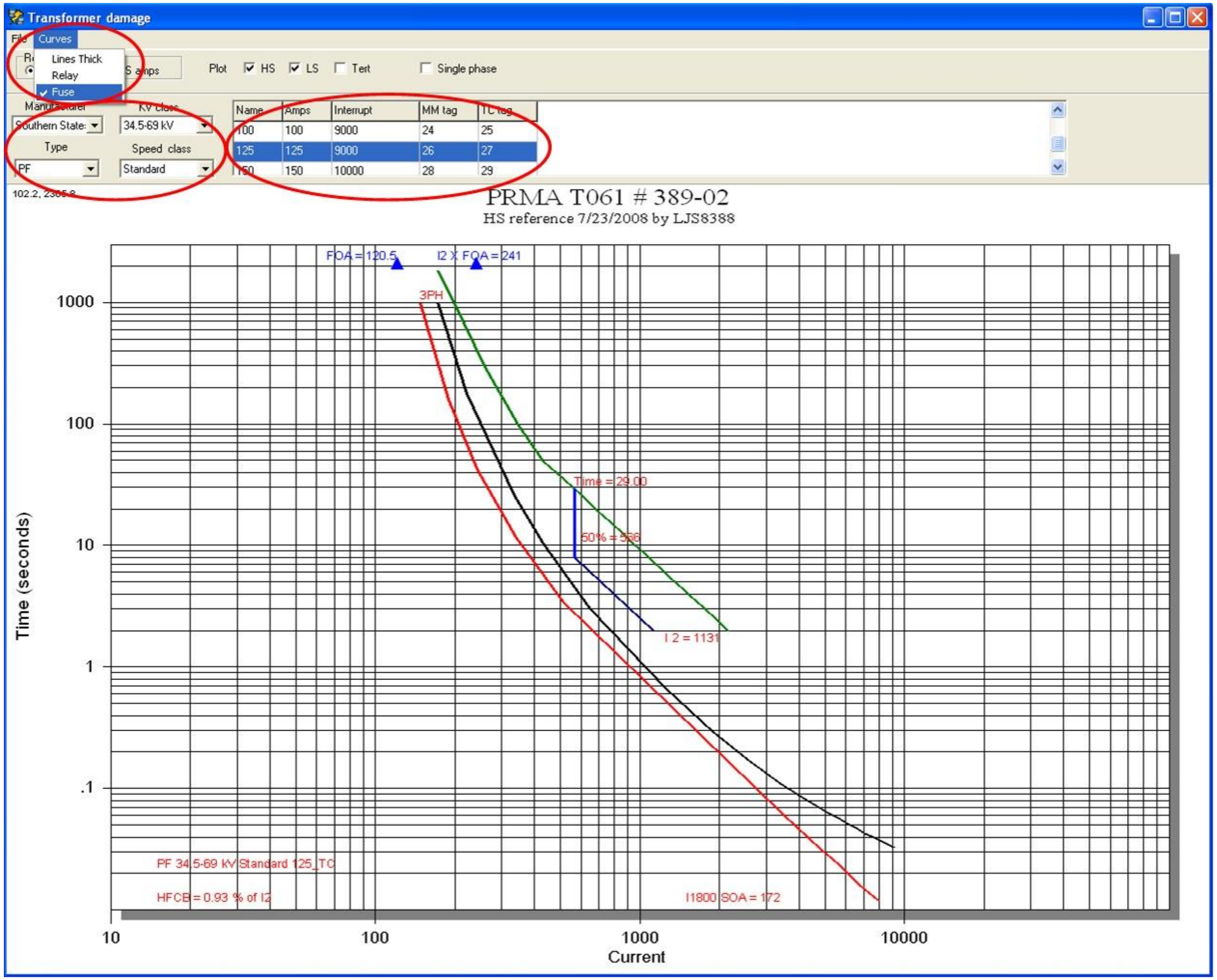
Transformer Protection

High Side Fuse



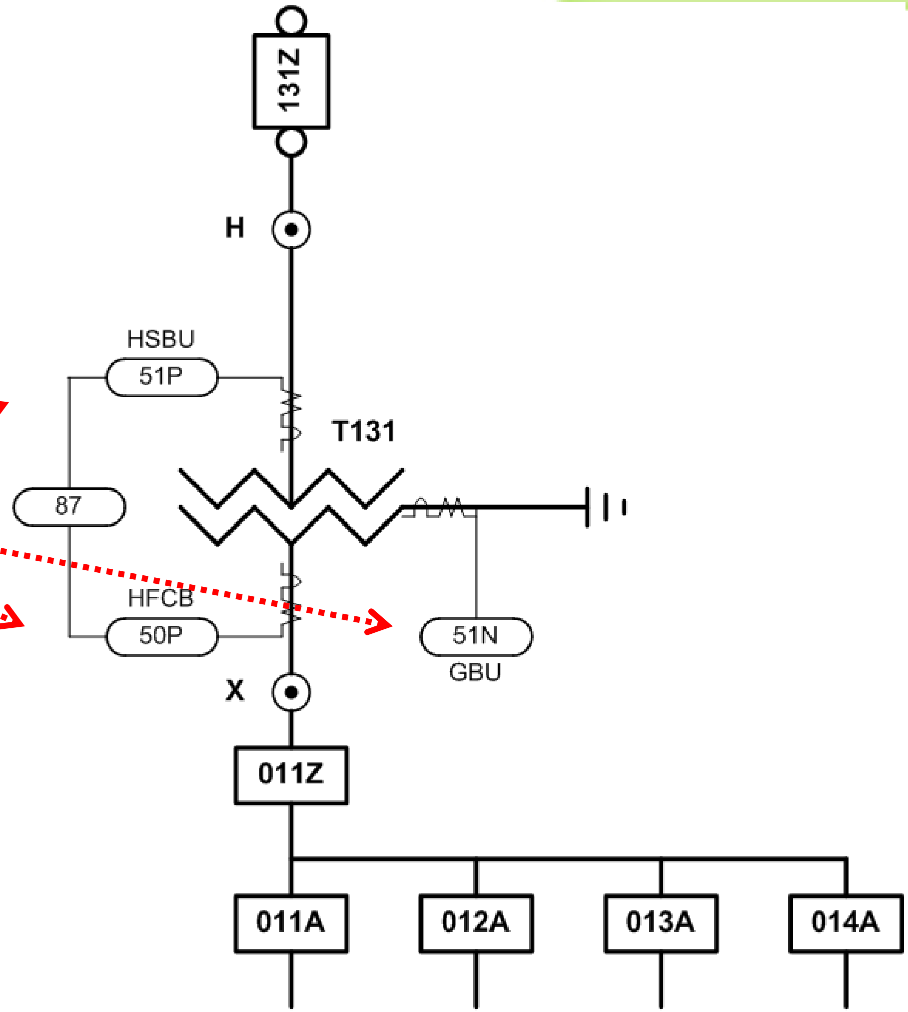
Transformer Protection

Transformer Damage Curve



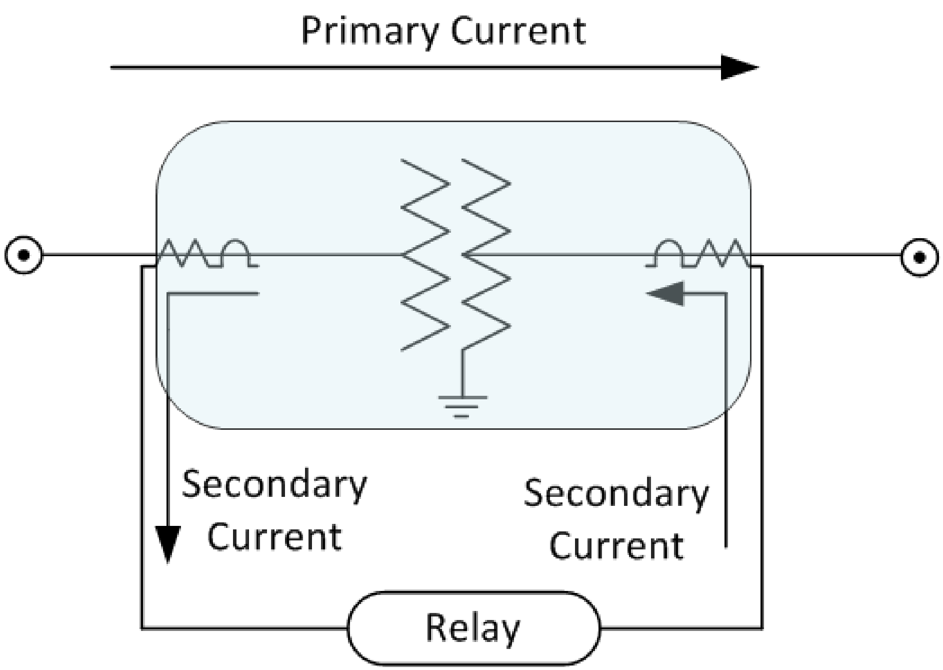
Transformer Protection

Overcurrent Relays



Transformer Protection

Differential Protection:
What goes in must come out….. P-in = P-out

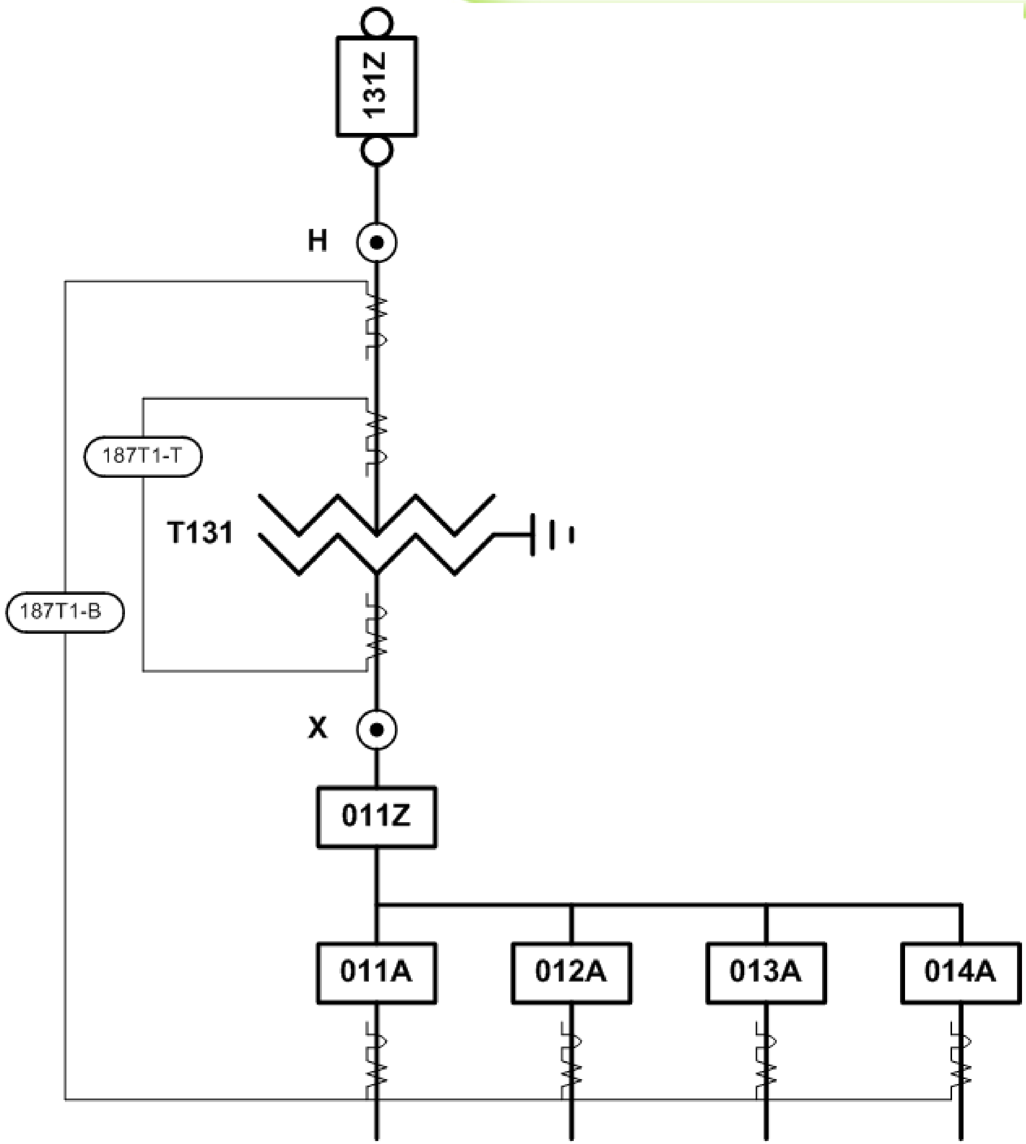


Transformer Protection

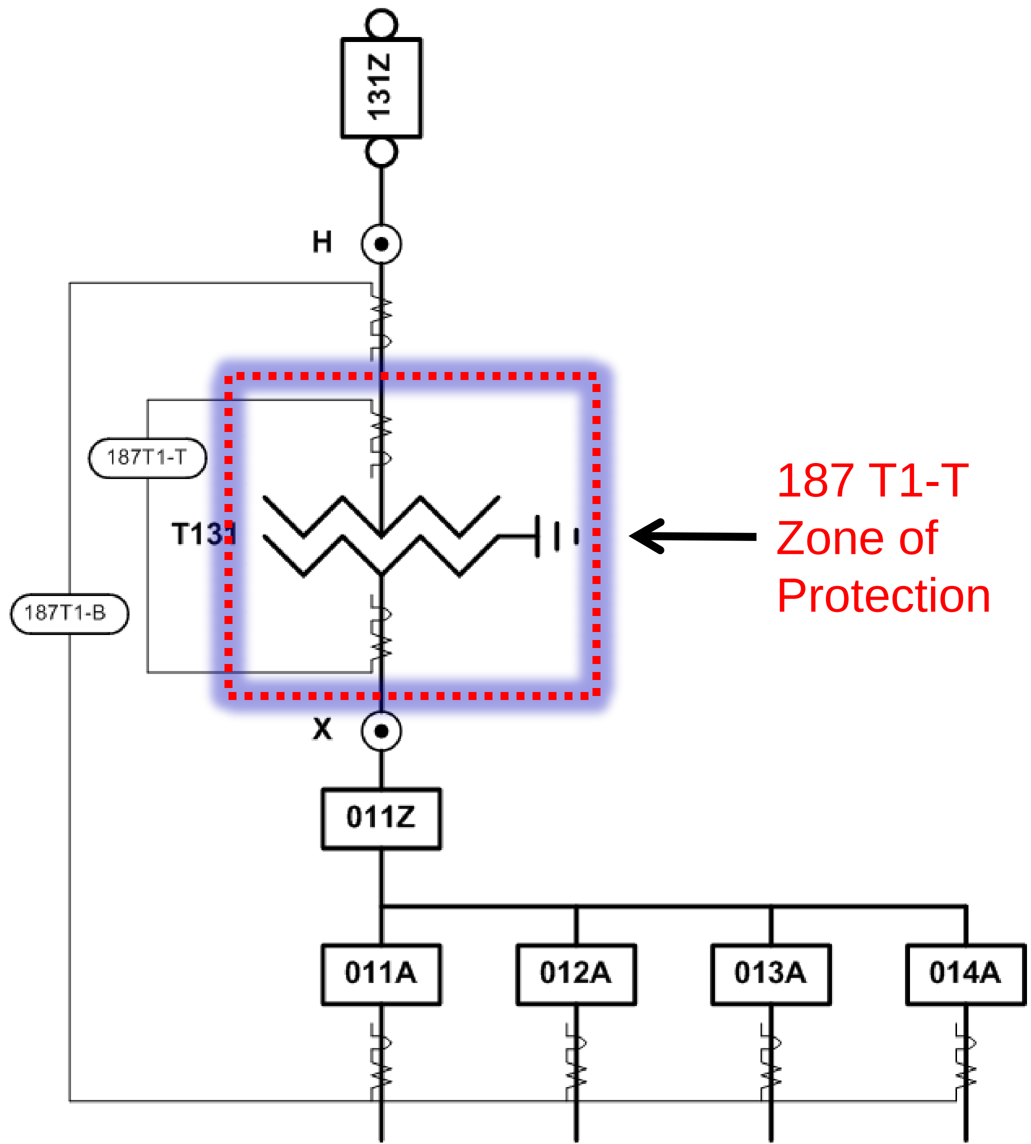
Microprocessor Relays

187T1-T
Wraps transformer

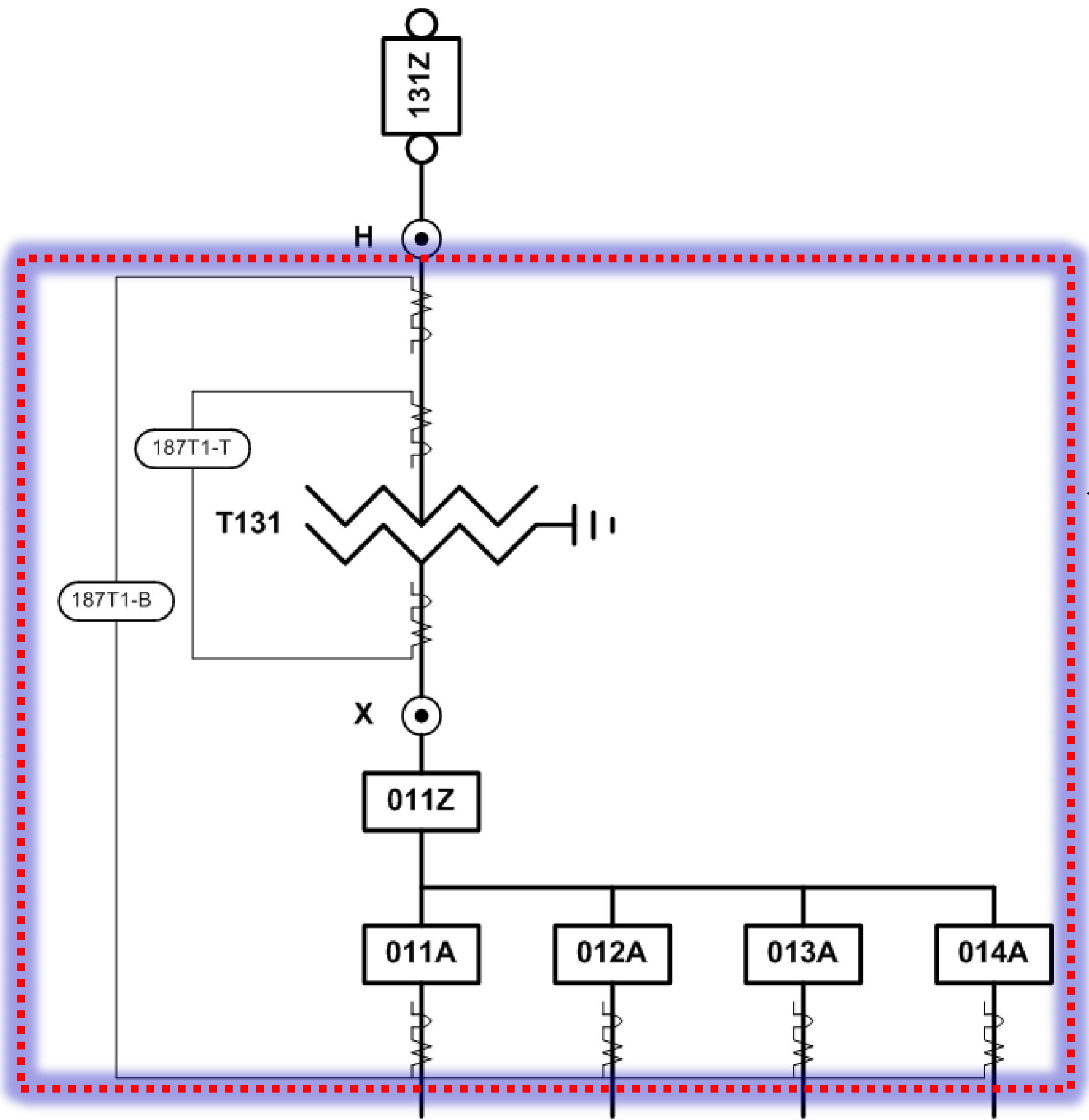
187T1-B
Wraps transformer and bus



Transformer Protection



Transformer Protection



187 T1-B
Zone of
Protection

Transformer Protection

Some terms you will be learning about this week:

Restraint

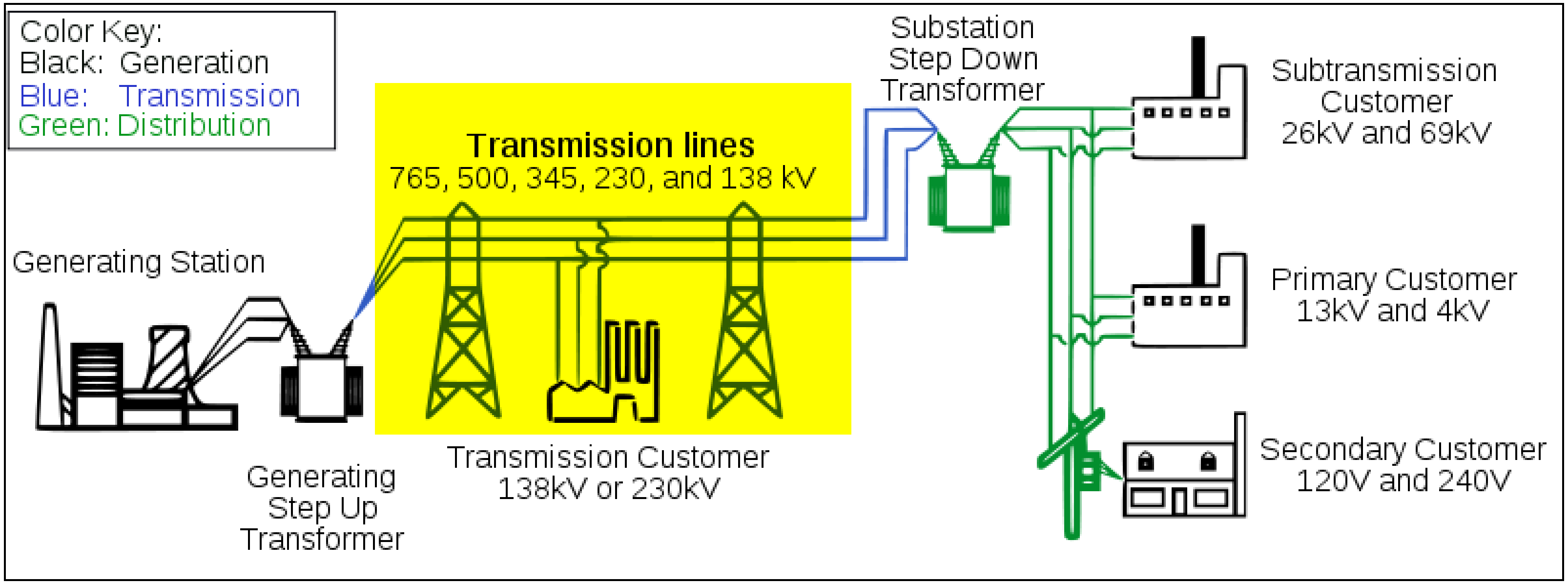
Operate

Slope

Inrush

2nd Harmonic

LINE PROTECTION

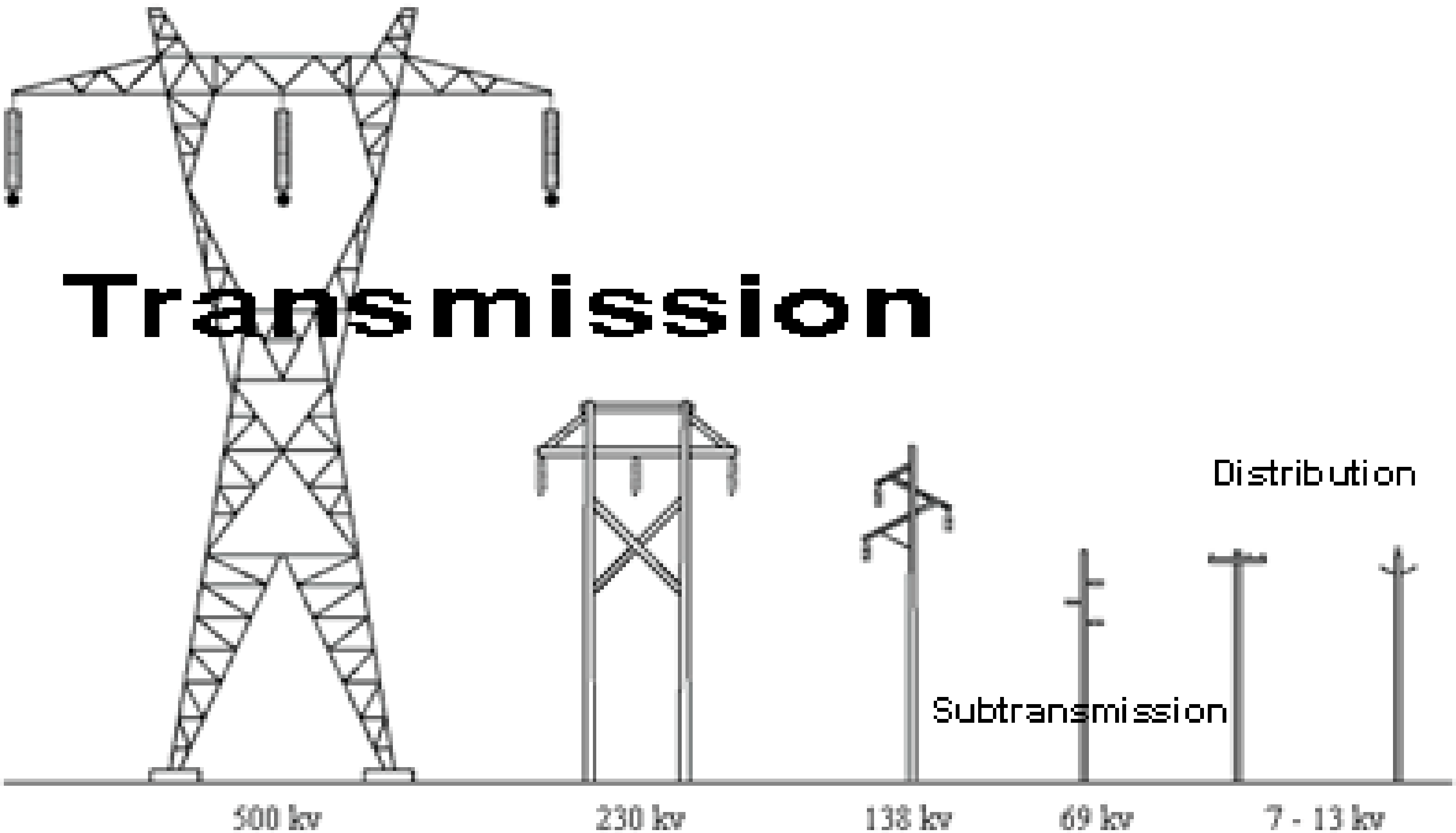


Transmission Line Protection

Transmission lines can vary in length from several hundred feet to several hundred miles, and in voltage (line-to-line) from 46KV to 750KV.

Construction can be simple, such as a single wood pole with insulators atop a crossarm, with little spacing between the conductors and from the conductors to ground. At the other end of the scale are metal lattice structures with bundled conductors (2 or more conductors per phase) with large spacing between conductors and between conductors and ground.

Transmission Line Protection



Transmission Line Protection

Transmission Line Protection

Ice Storm

What Can Go Wrong?

FAULTS (Short Circuits)

Some causes of faults:
- Trees
- Lightning
- Animals (birds, squirrels, snakes)
- Weather (wind, snow, ice)
- Natural Disasters (earthquakes, floods)
- Faulty equipment (switches, insulators, clamps, etc.)

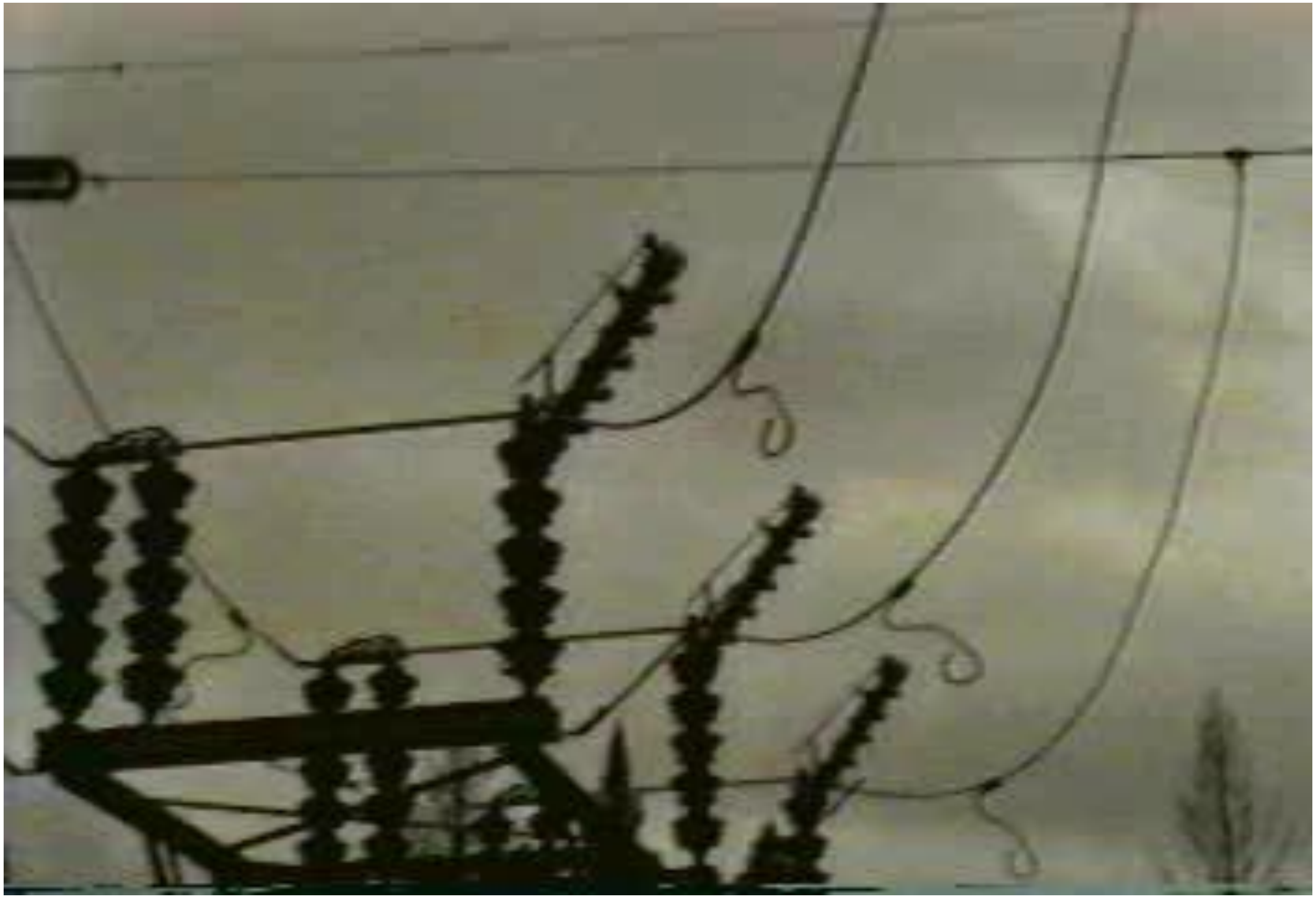
345kV_SWITCH.mpg

RoundMountainStagedFault1.mpg

Transmission Line Protection

345kV_SWITCH.mpg

Transmission Line Protection



Faults

“Faults come uninvited and seldom go away voluntarily.”

Fault Types:

- Single line-to-ground
- Line-to-line
- Three Phase
- Line-to-line-to-ground

Transmission Line Protection

How Do We Protect Transmission Lines?

A. Overcurrent
B. Directional Overcurrent
C. Distance (Impedance)
D. Pilot
   1. DCB (Directional Comparison Blocking
   2. POTT (Permissive Overreaching Transfer Trip)
E. Line Current Differential

Overcurrent Protection

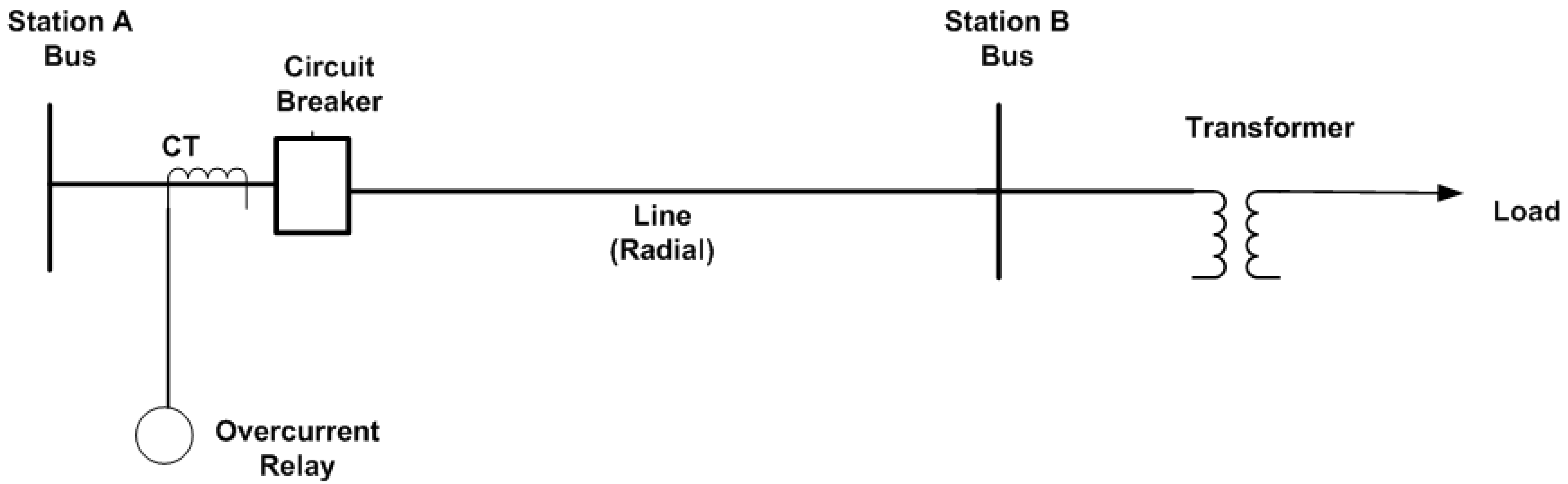
Non-Directional
Relay responds to overcurrent condition

Instantaneous (IOC) device #50
- No intentional time delay

Time Overcurrent (TOC) device #51
- Various curve types, including inverse, very inverse, extremely inverse

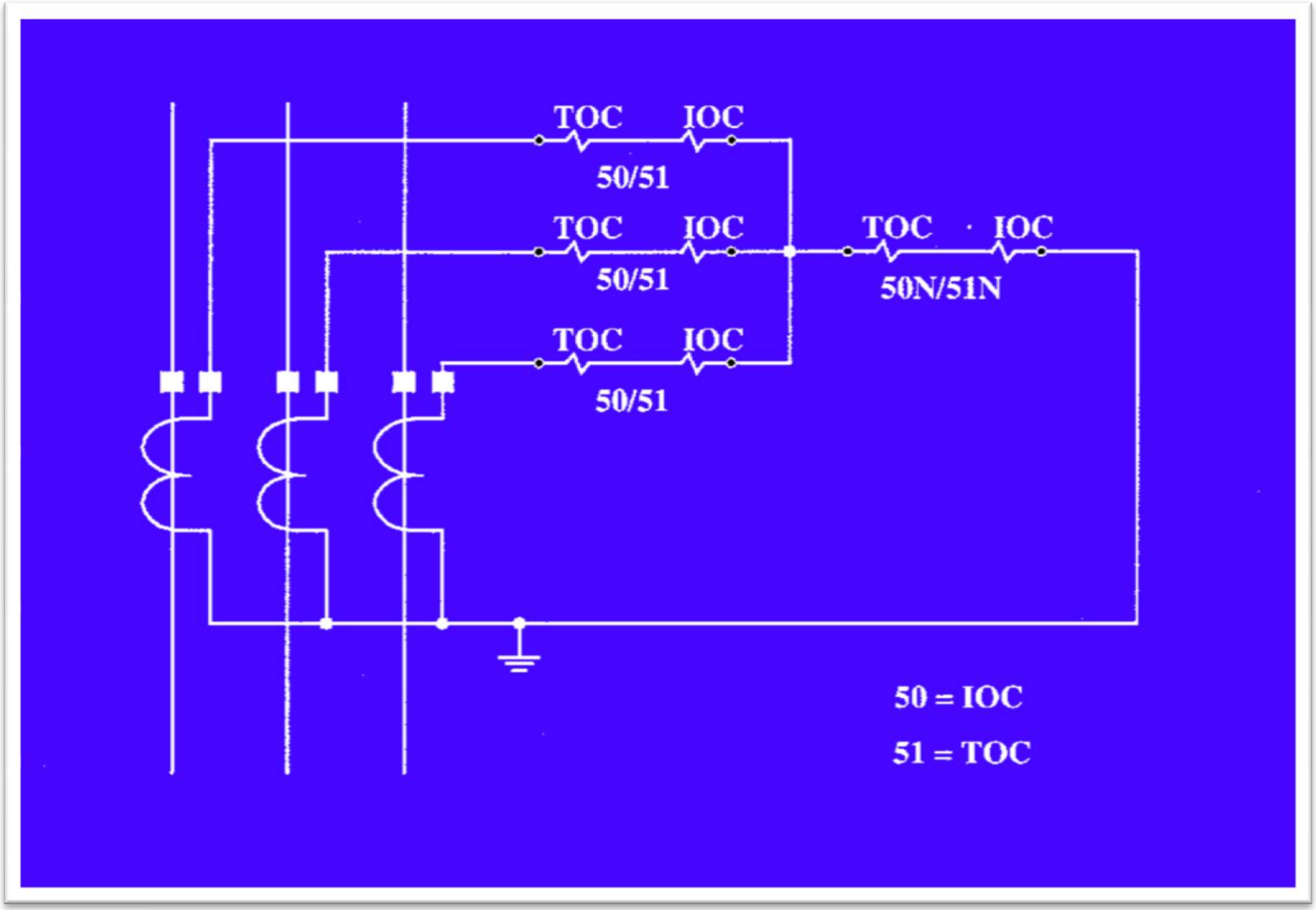
Transmission Line Protection

Overcurrent Line Protection



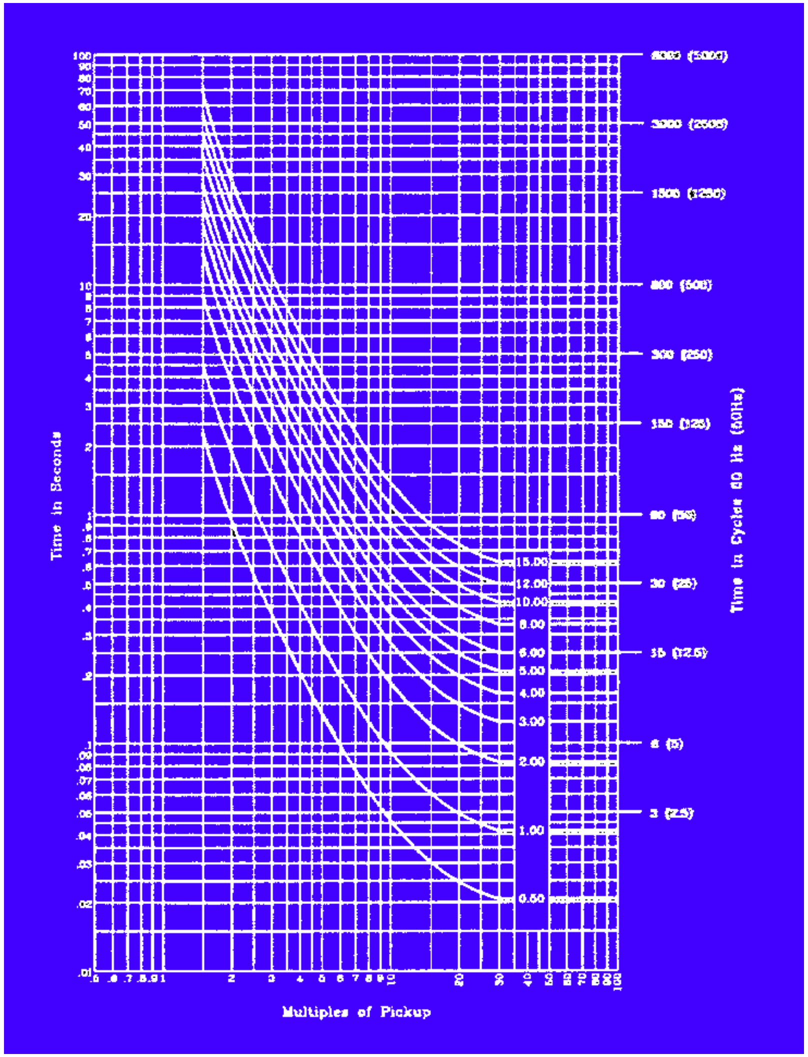
Transmission Line Protection

AC Schematic



Transmission Line Protection

Time Overcurrent Curves



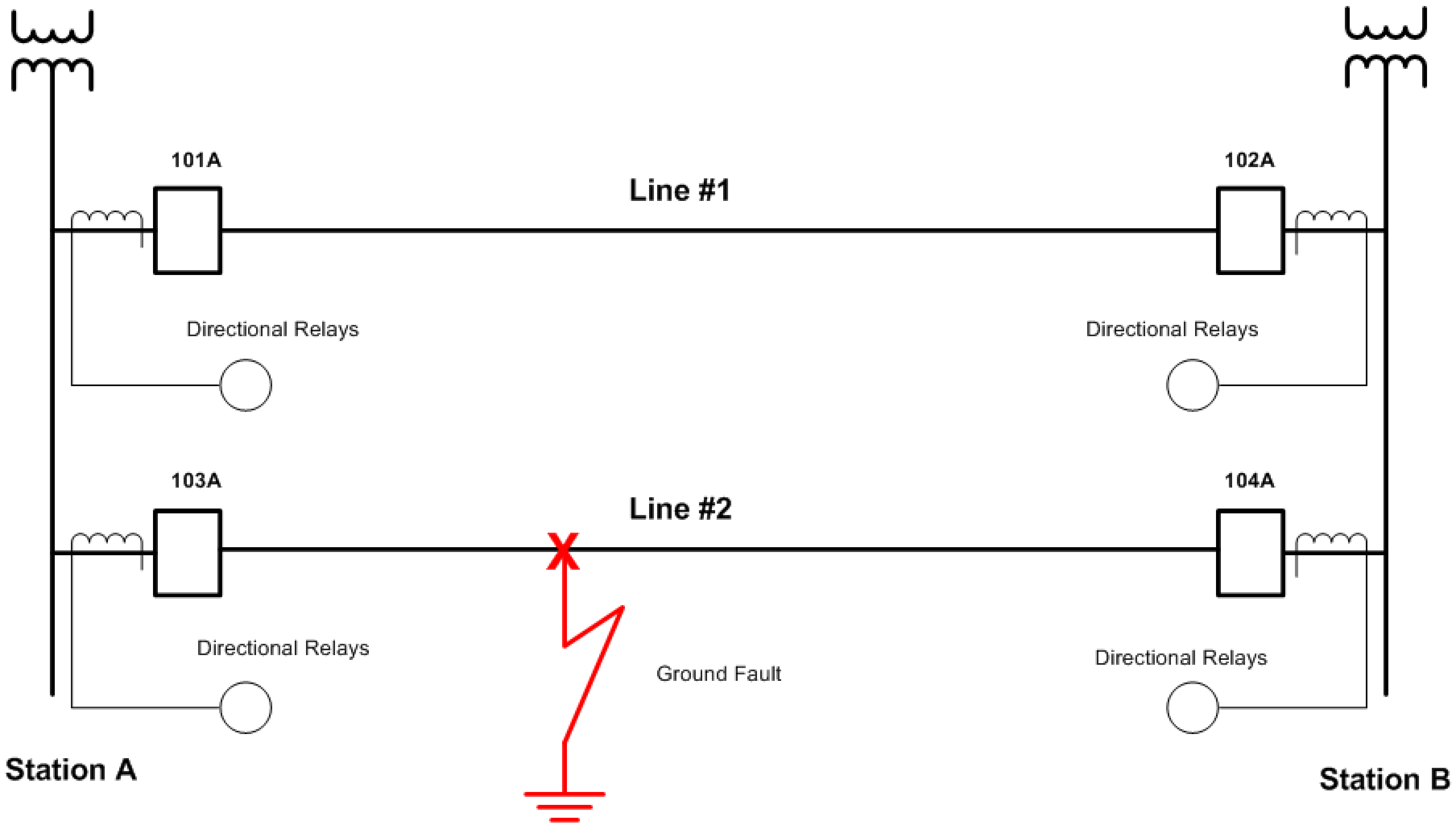
Directional Overcurrent Protection

Relay responds to overcurrent condition in the forward direction only (device #67, 67N, 67NT)

Will not respond to reverse faults

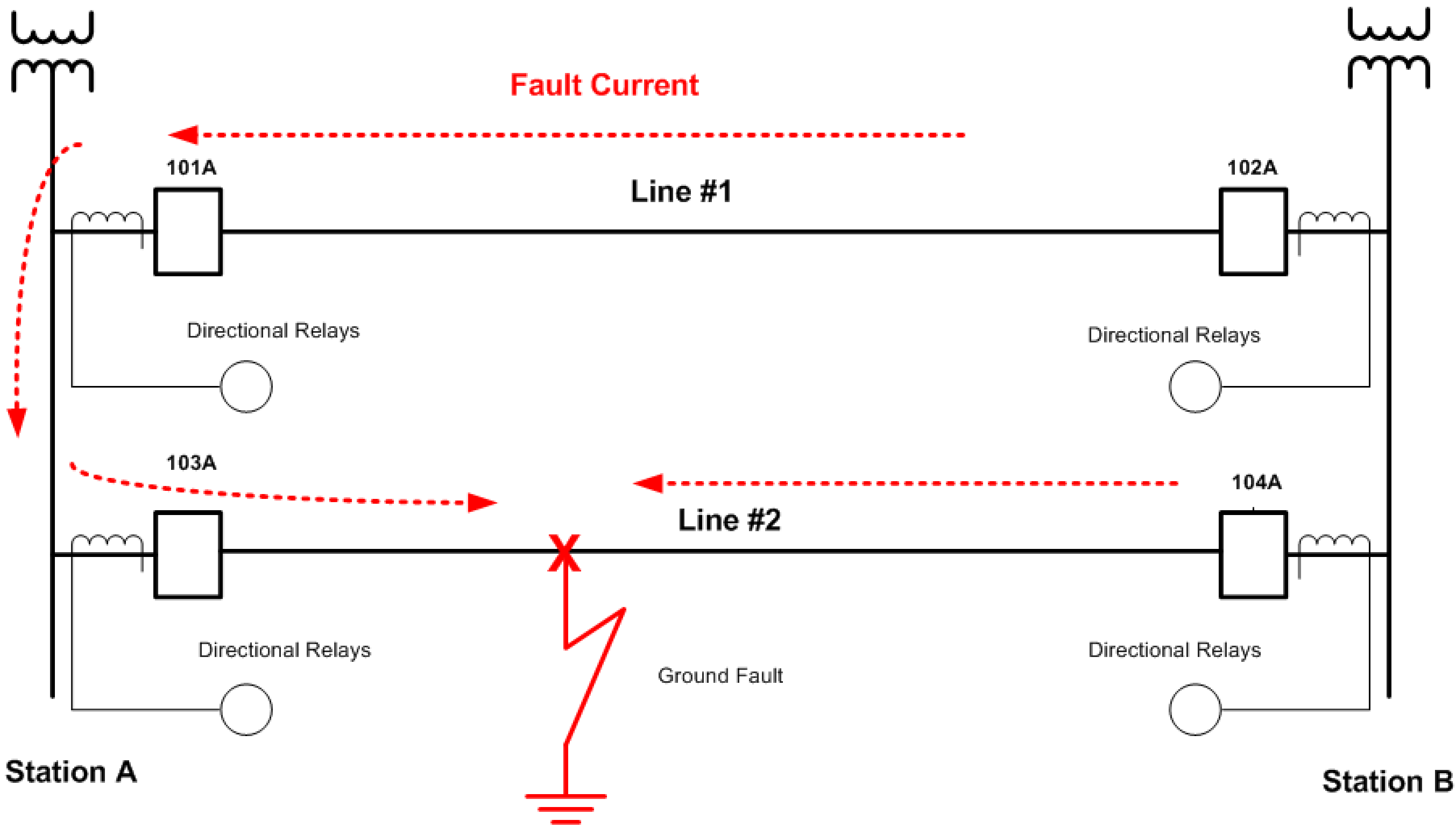
Compares the current in the line versus a known reference that will always be the same (such as a voltage or polarizing current source)

Transmission Line Protection



Transmission Line Protection

Directional Overcurrent Example



Distance Protection

A distance relay measures the impedance of a line using the voltage applied to the relay and the current applied to the relay.

When a fault occurs on a line, the current rises significantly and the voltage collapses significantly.

The distance relay (also known as impedance relay) determines the impedance by Z = V/I. If the impedance is within the reach setting of the relay, it will operate.

Distance Protection

Electromechanical distance relays use torque to restrain or operate

KD, GCY, etc. Device #21

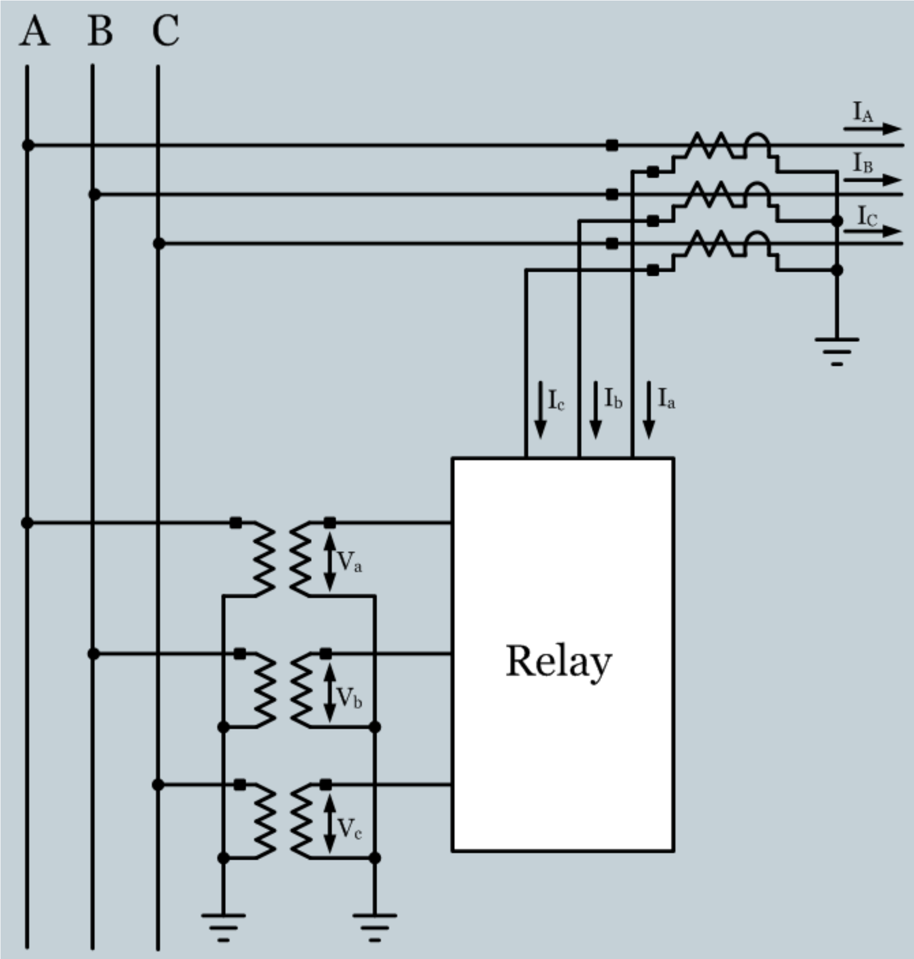
Microprocessor distance relays use equations to restrain or operate

SEL, ABB, GE, Areva, etc. Device #11

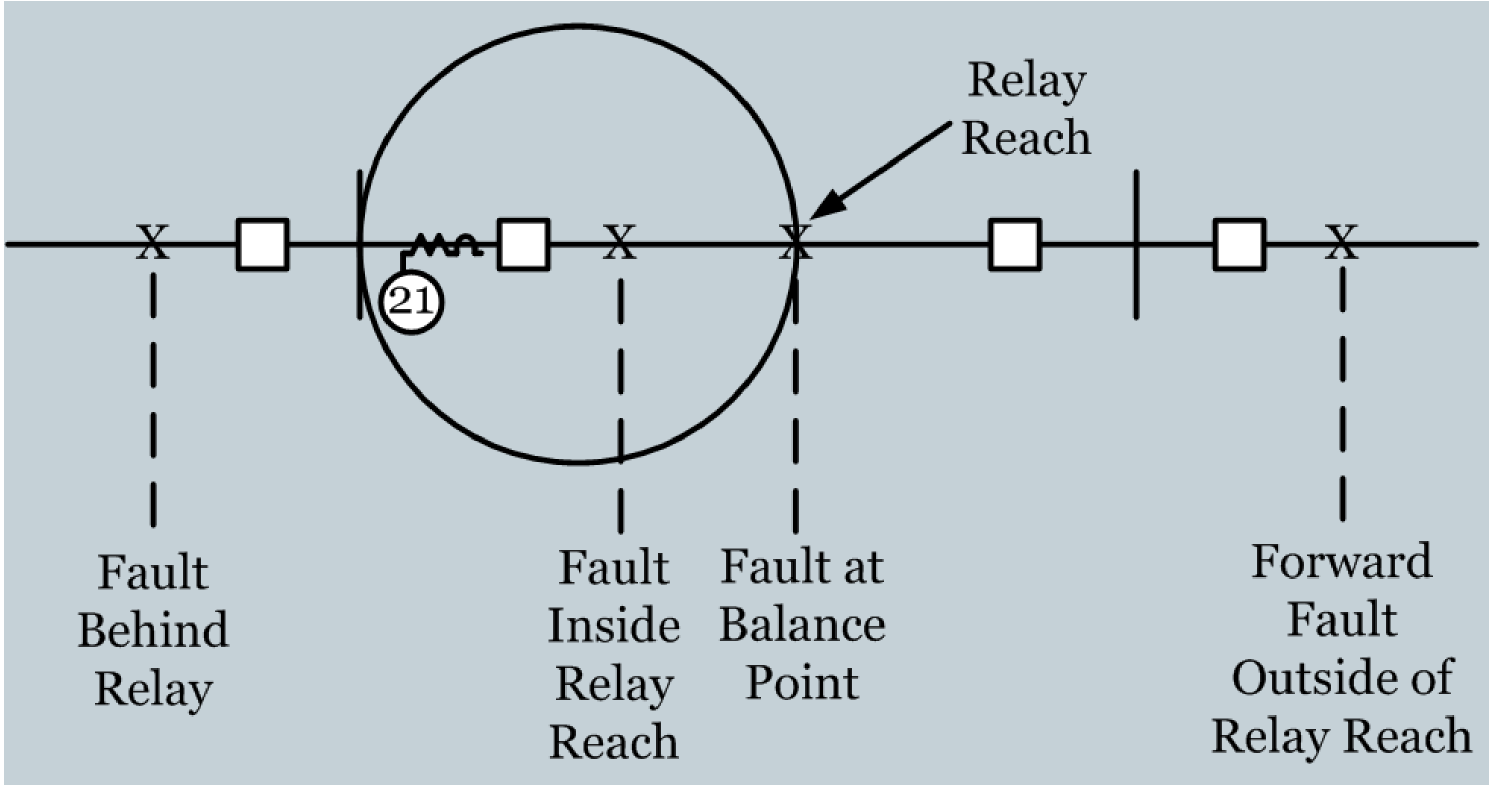
Transmission Line Protection

Distance Relay

CT and PT Connections



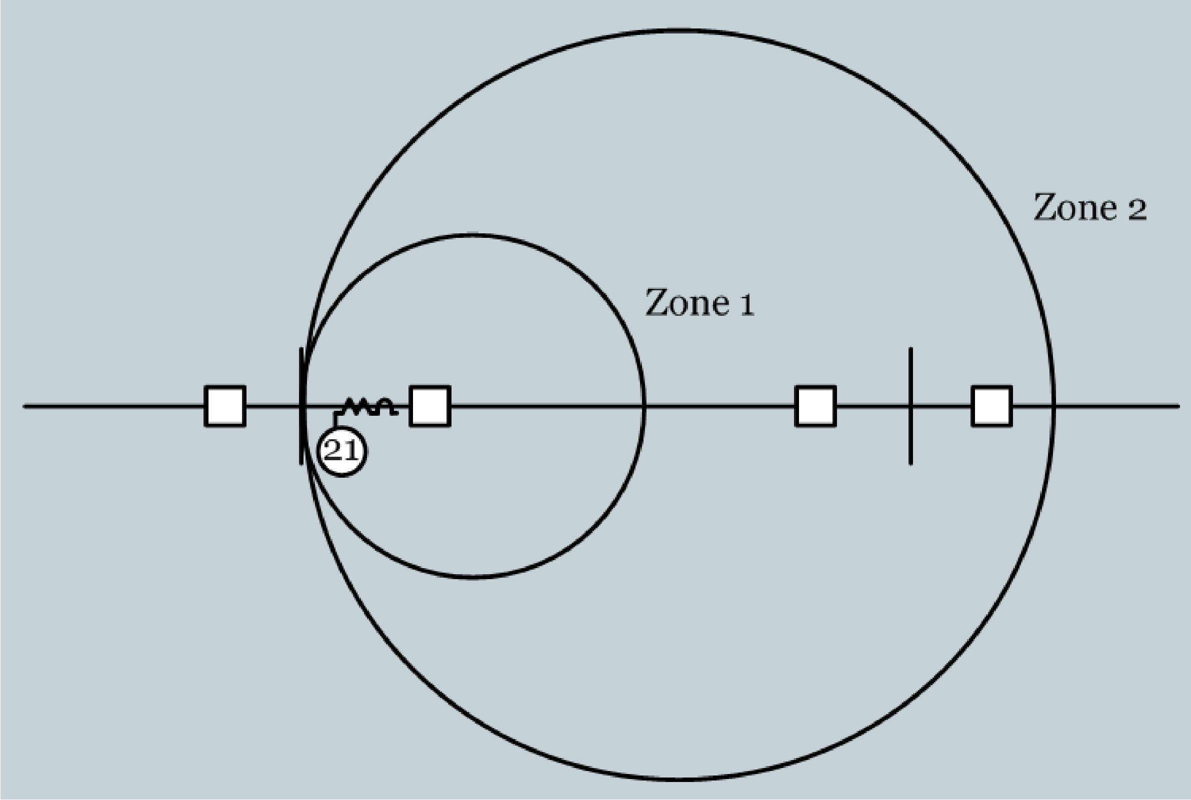
Transmission Line Protection



Transmission Line Protection

Distance Protection

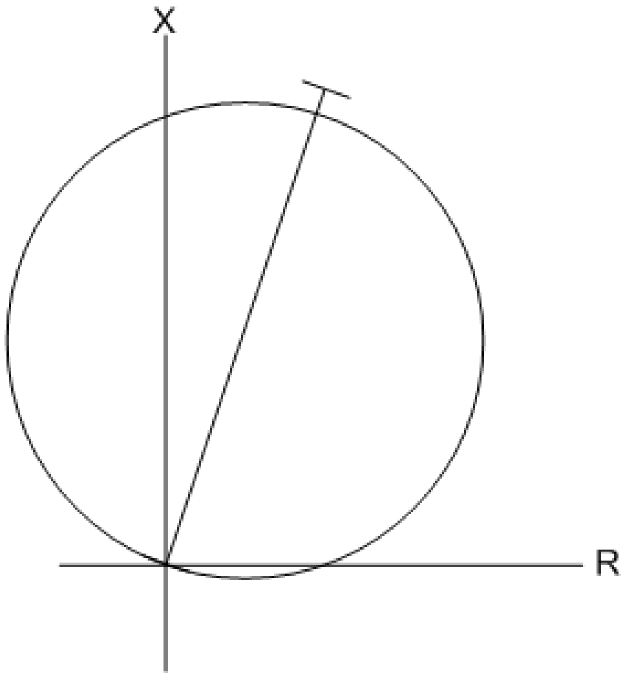
Typical zone reach settings



Transmission Line Protection

Distance Protection

When a fault occurs on a transmission line, the current increases and the angle of the current with respect to the voltage changes to a lagging angle, usually between 60 to 85 degrees.

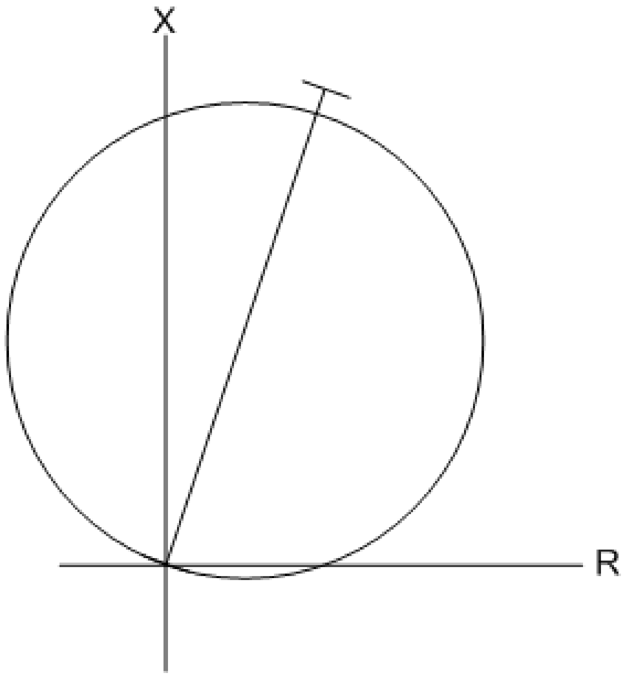


Transmission Line Protection

Distance Protection

The most common characteristic (or protection shape) of distance relays is the mho characteristic, a circular type reach characteristic.

Distance relays have a settable maximum torque angle (mta), which is the angle of the current compared to the angle of the voltage at which the relay is most sensitive. In the drawing on the right, the mta is approximately 75 degrees.



Introduction to System Protection

Terminology

Dependability: the certainty that a protection system will operate when it is supposed to

Security: the certainty that a protection system will not operate when it is not supposed to

Reliability = Dependability + Security

Pilot Relaying Scheme

A protection scheme which employs communications to send a signal from one station to another to allow high speed tripping (permission) or to prevent high speed tripping (blocking).

Pilot protection allows over-reaching zones of protection to ensure full protection of the line as well as high speed tripping.

Pilot Relaying Scheme

<u>Directional Comparison Blocking (DCB)</u>

A communications based protection scheme where high speed over-reaching tripping is allowed unless a block signal is received.

Pilot Relaying Scheme

Permissive over-reaching transfer trip (POTT)

A communications based protection scheme where high speed over-reaching tripping is allowed only if a permissive signal is received

Transmission Line Protection

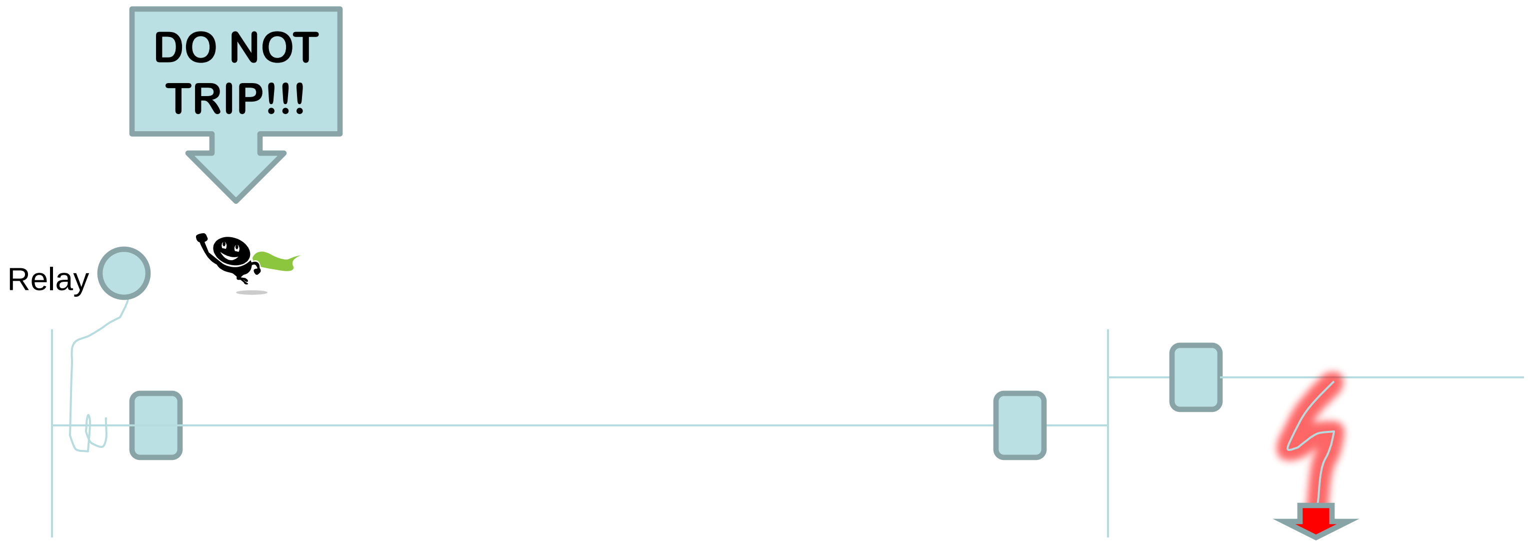
BLOCKING SCHEME OPERATING PRINCIPLE


Relay

Transmission Line Protection

BLOCKING SCHEME OPERATING PRINCIPLE

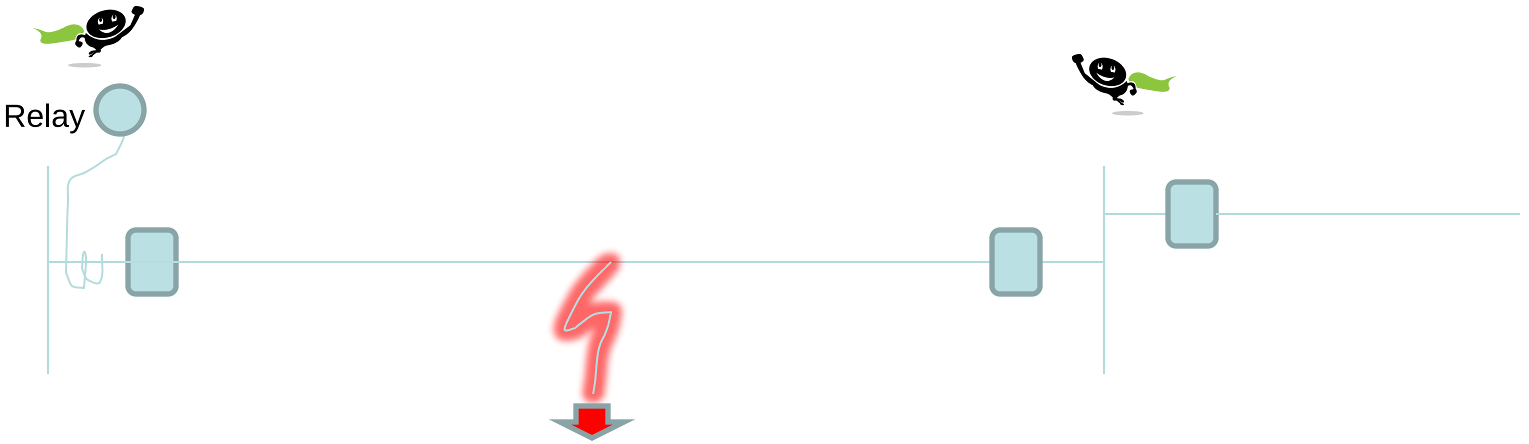
External Fault



Transmission Line Protection

BLOCKING SCHEME OPERATING PRINCIPLE

Internal Fault
No block signal is sent

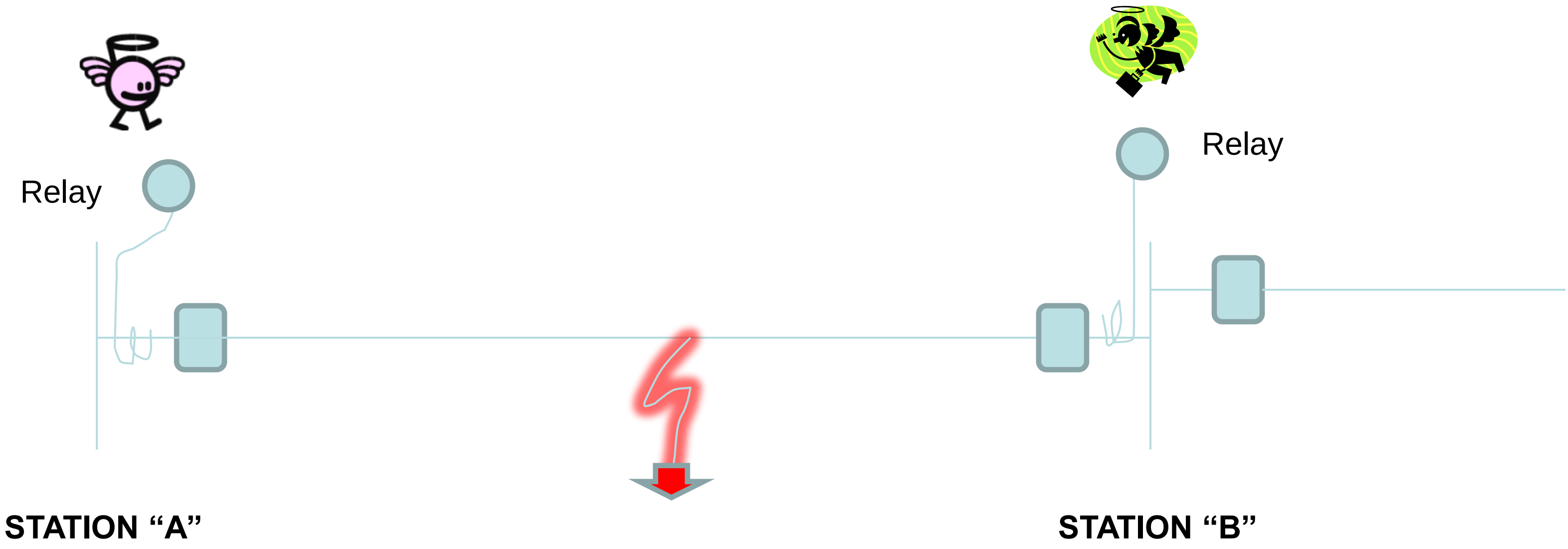


Transmission Line Protection

Permissive Scheme

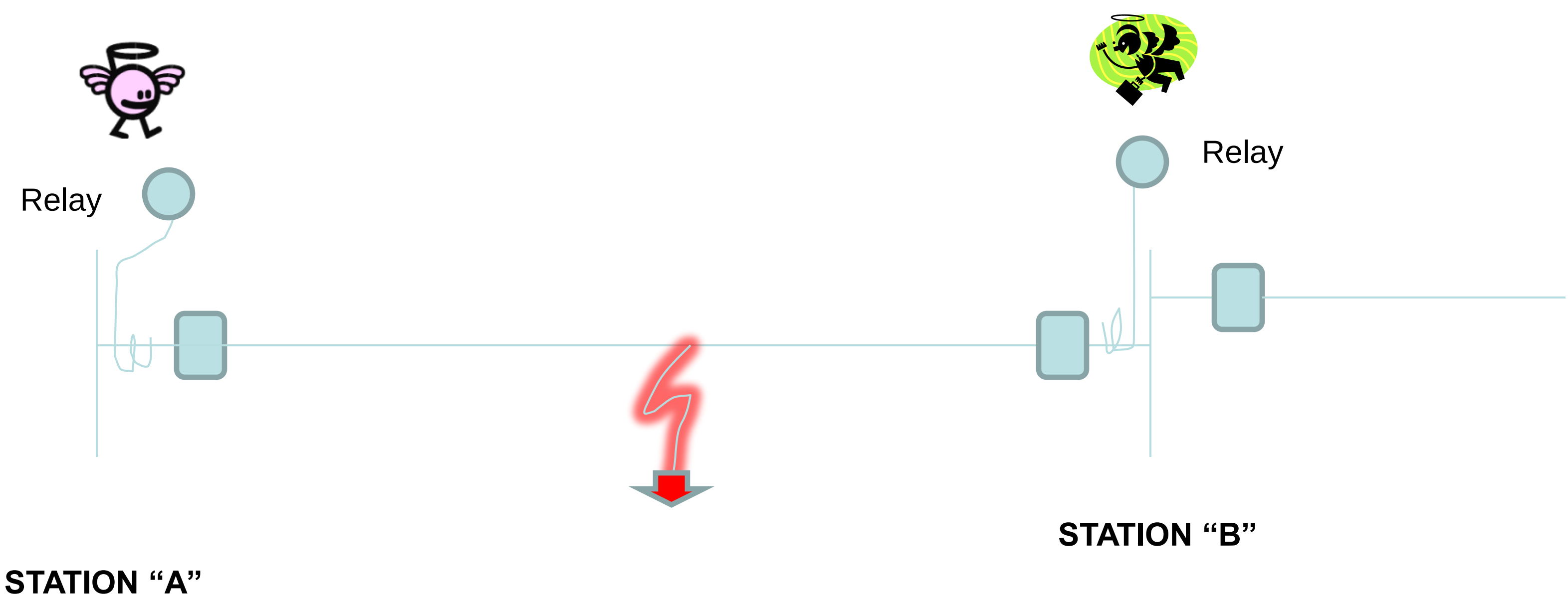
Transmission Line Protection

Permissive scheme internal fault



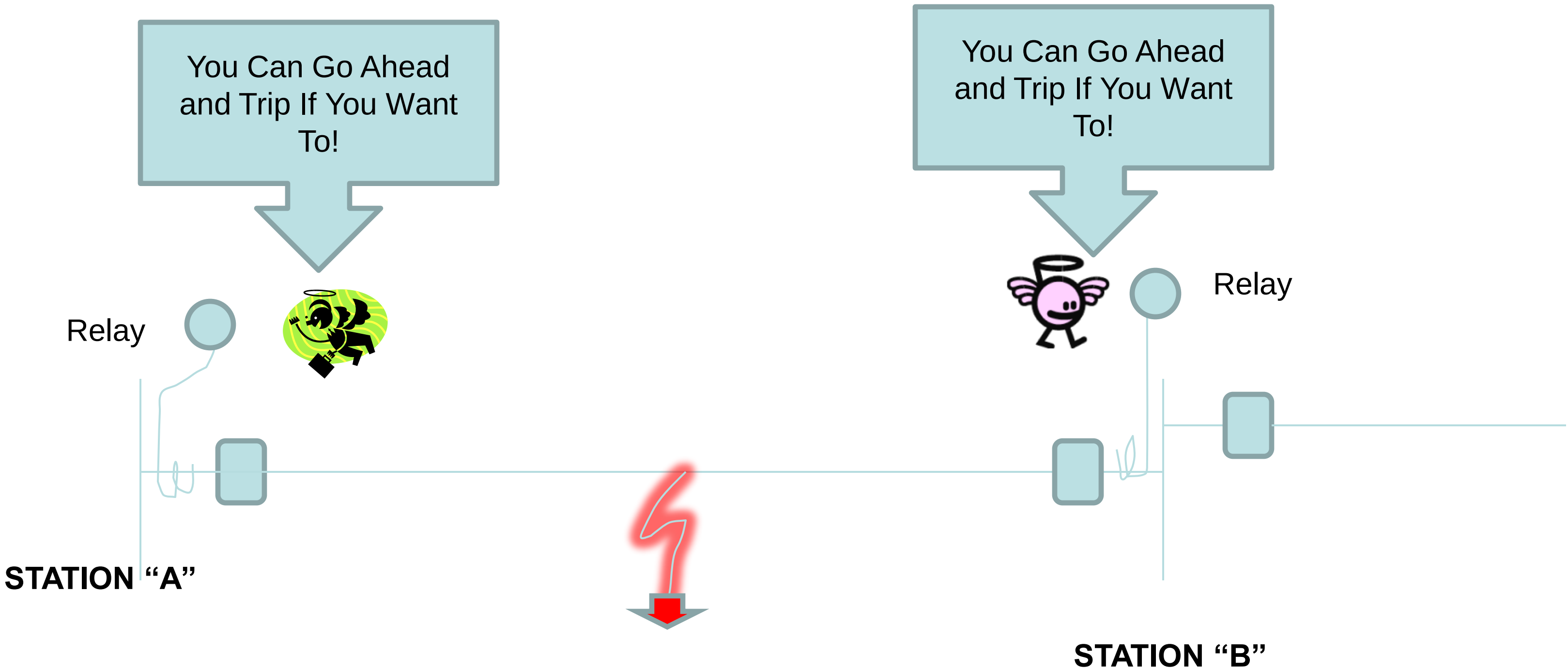
Transmission Line Protection

Permissive scheme internal fault



Transmission Line Protection

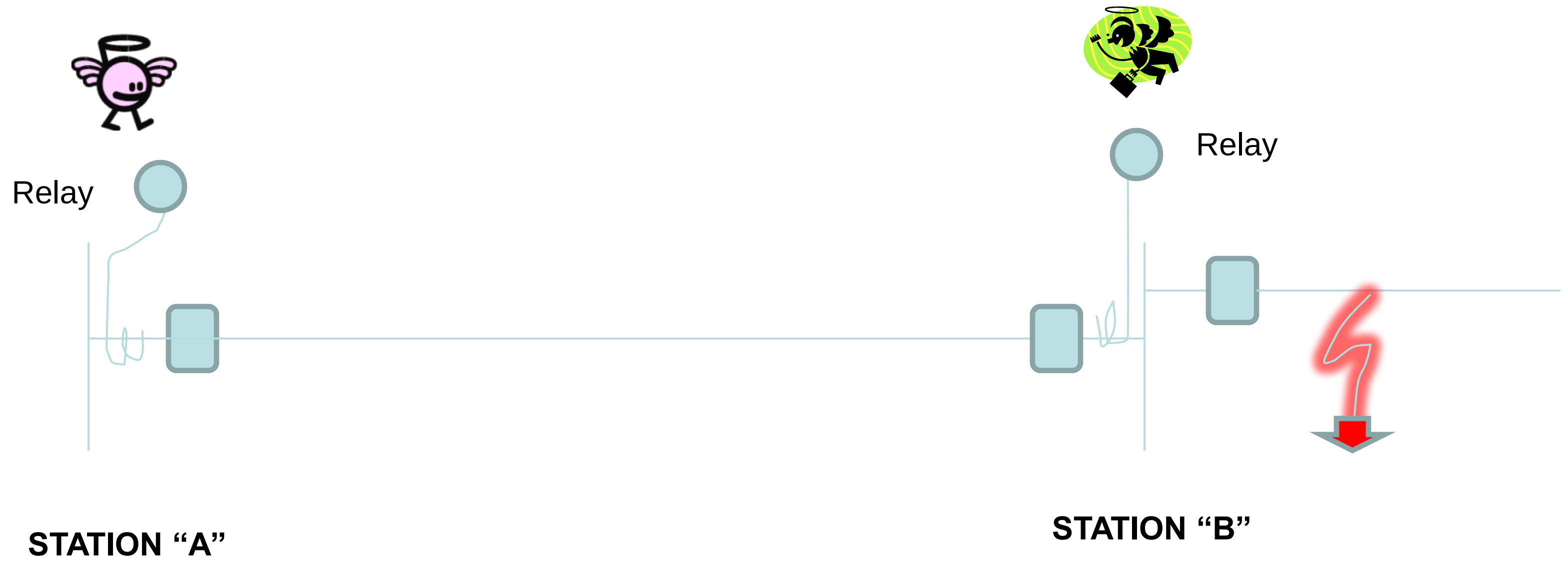
Permissive scheme internal fault



High Speed Tripping Takes Place at Station A and B

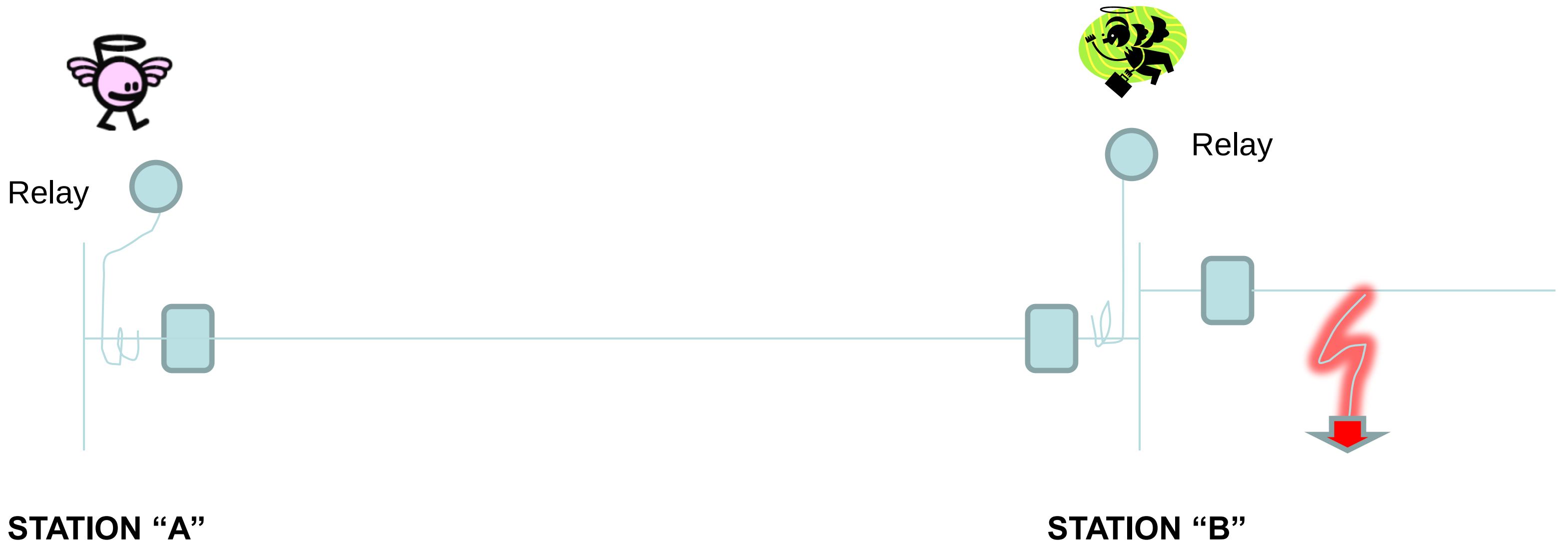
Transmission Line Protection

Permissive scheme external fault



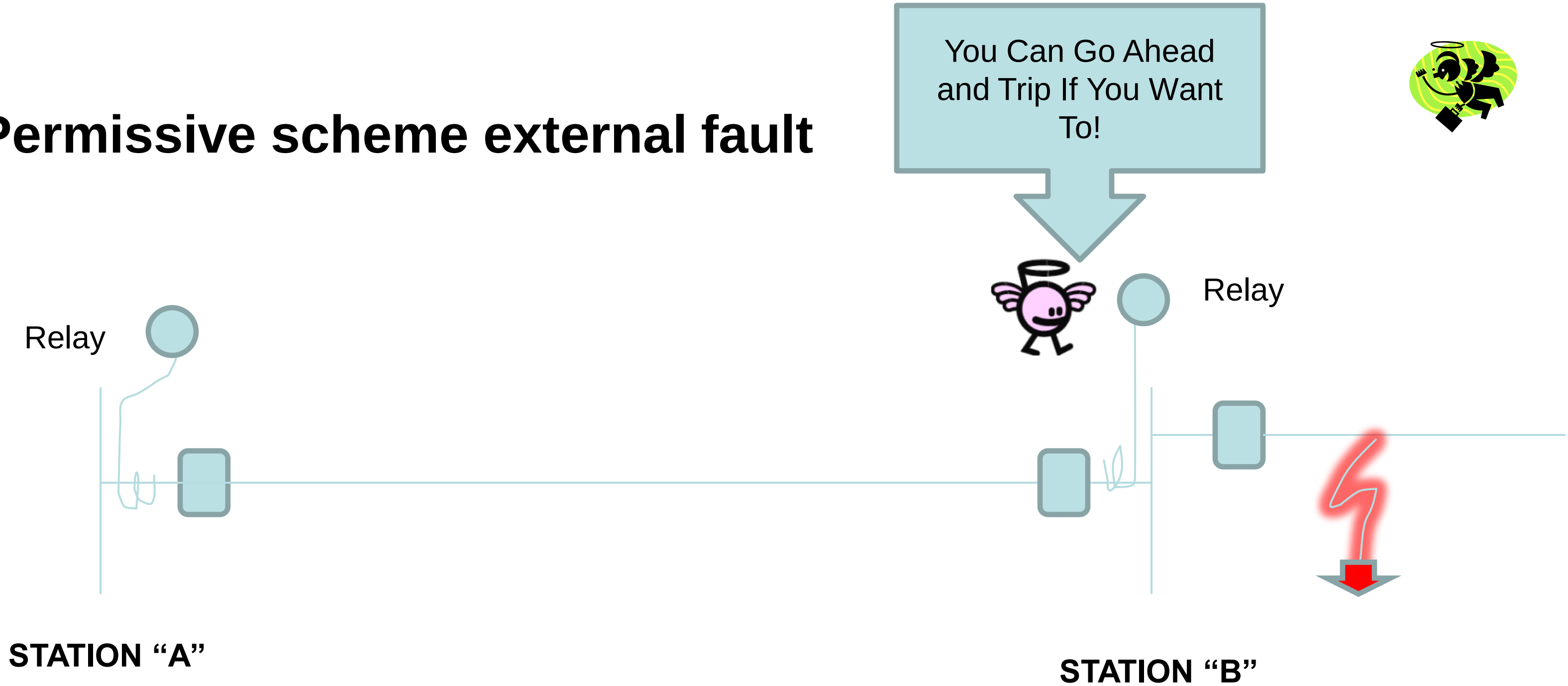
Transmission Line Protection

Permissive scheme external fault



Transmission Line Protection

Permissive scheme external fault



No High Speed Tripping Takes Place Because the Fault Is Reverse to the Relay at Station B.

Transmission Line Protection

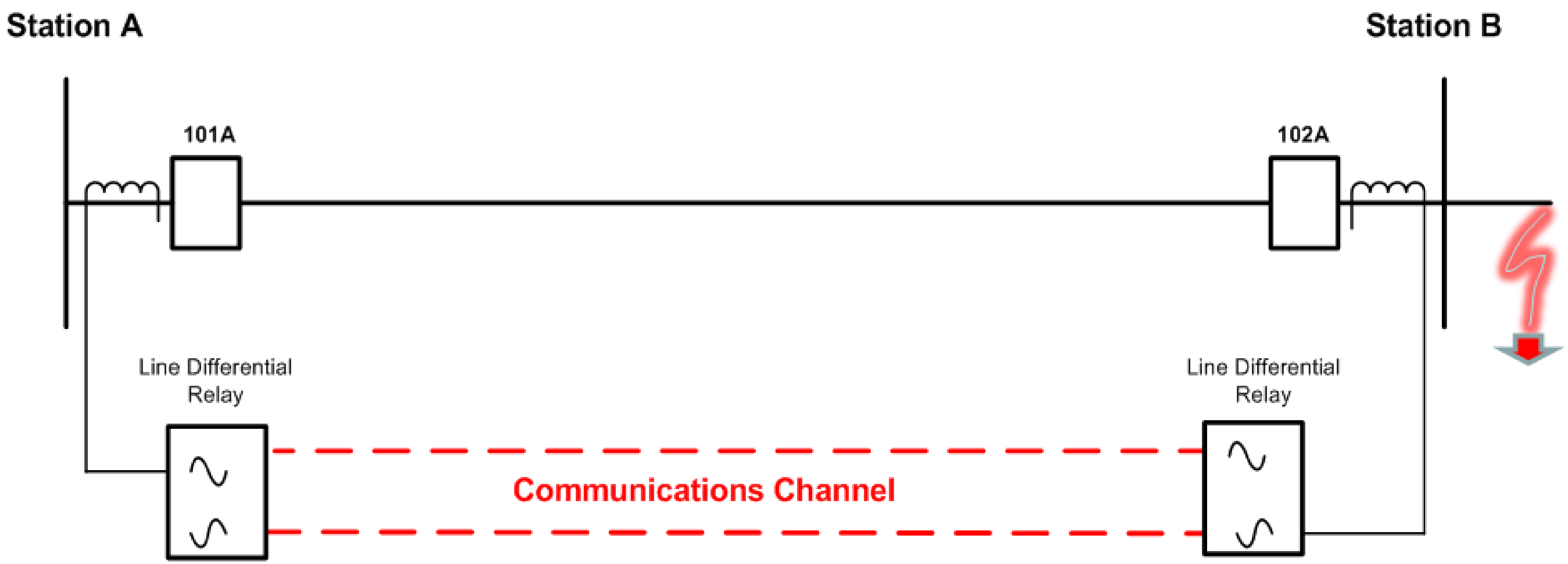
BLOCKING VS. PERMISSIVE

- **Blocking**
- Increased dependability because if the carrier fails, the protection will trip anyway.
- Decreased security because if the carrier fails, the protection will trip for an out of section fault.
- **Permissive**
- Increased security because if the communication fails, the protection will not trip high speed.
- Decreased dependability because if the comm fails, the protection will not trip high speed for an in section fault.

Transmission Line Protection

LINE DIFFERENTIAL

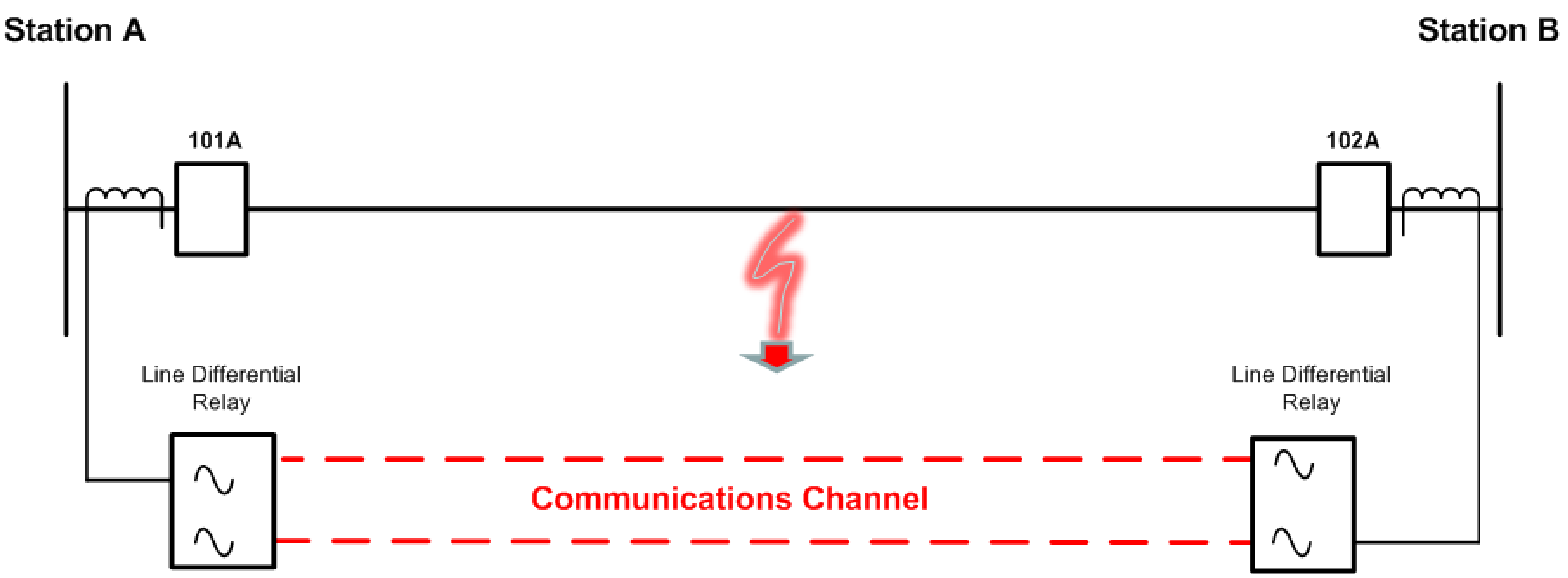
No fault or external fault, current at each end is balanced
The current going into the line is going out at other end



Transmission Line Protection

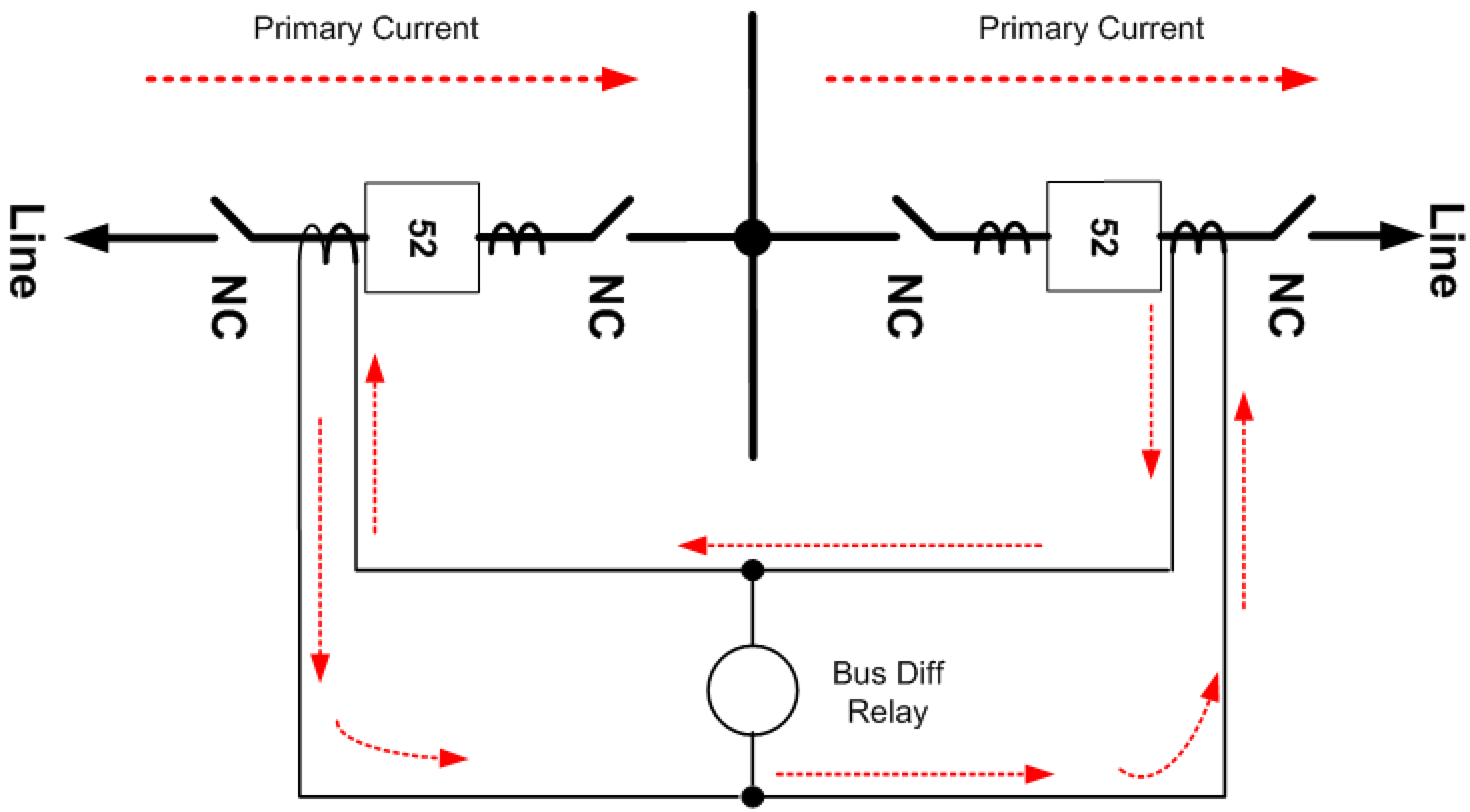
Line differential

Internal fault, relay trip is processed



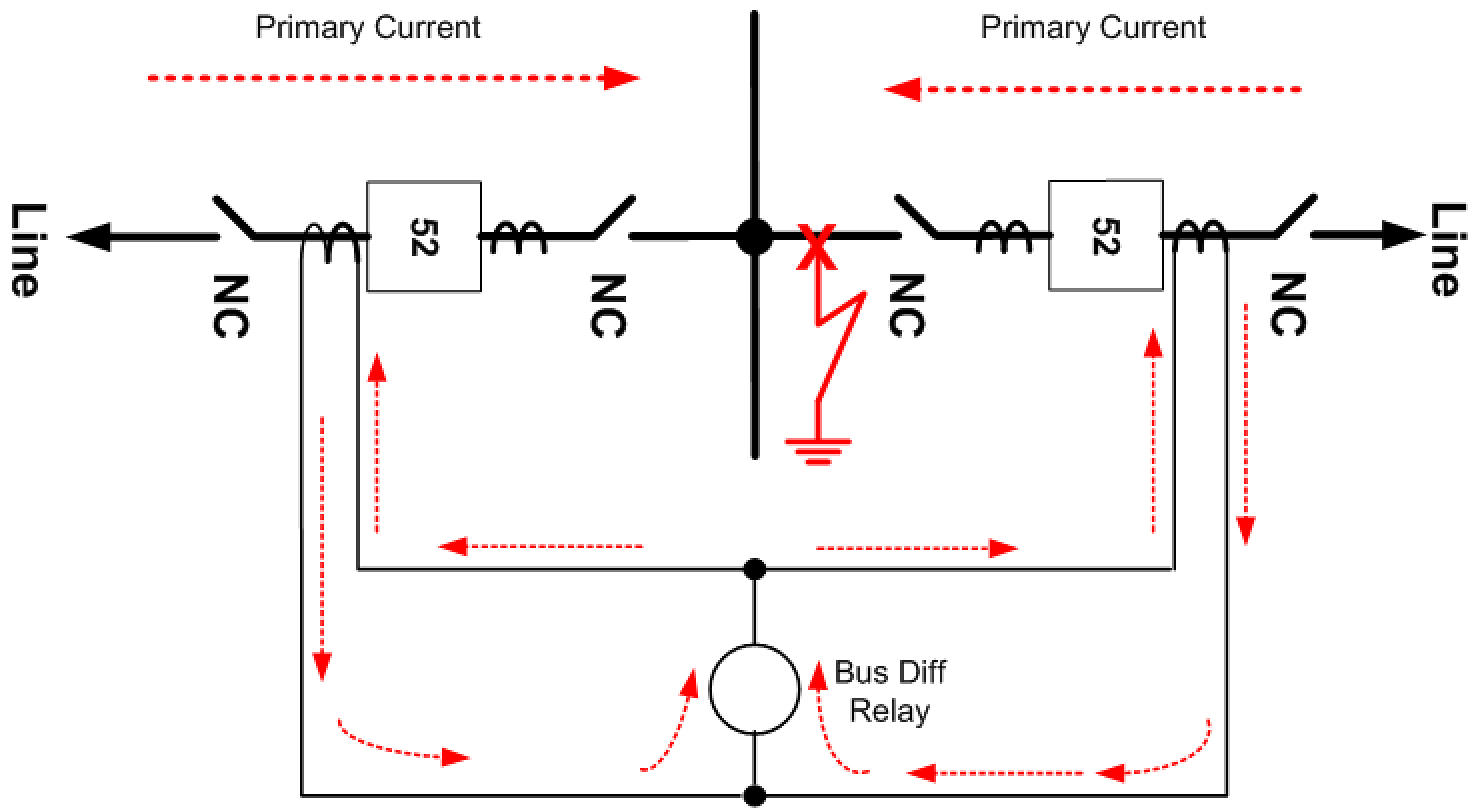
Bus Protection

Bus Differential:
Current into bus must equal current out of bus



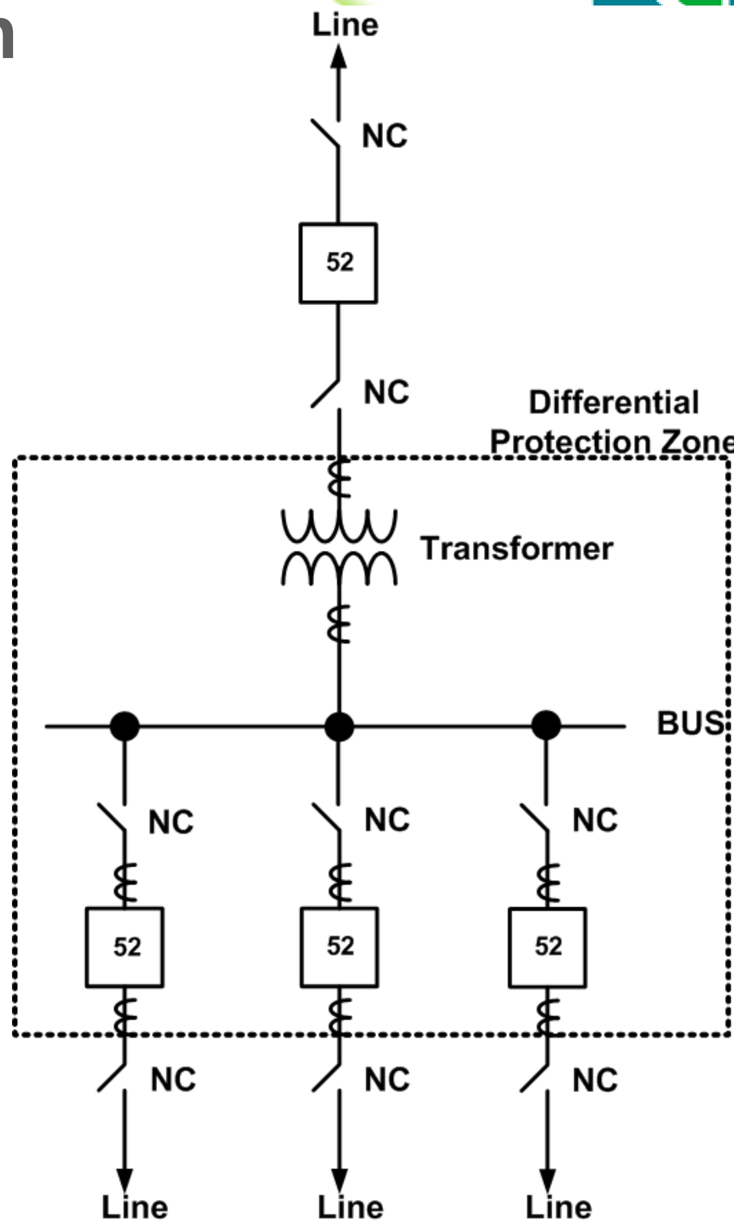
Bus Protection

Bus Fault



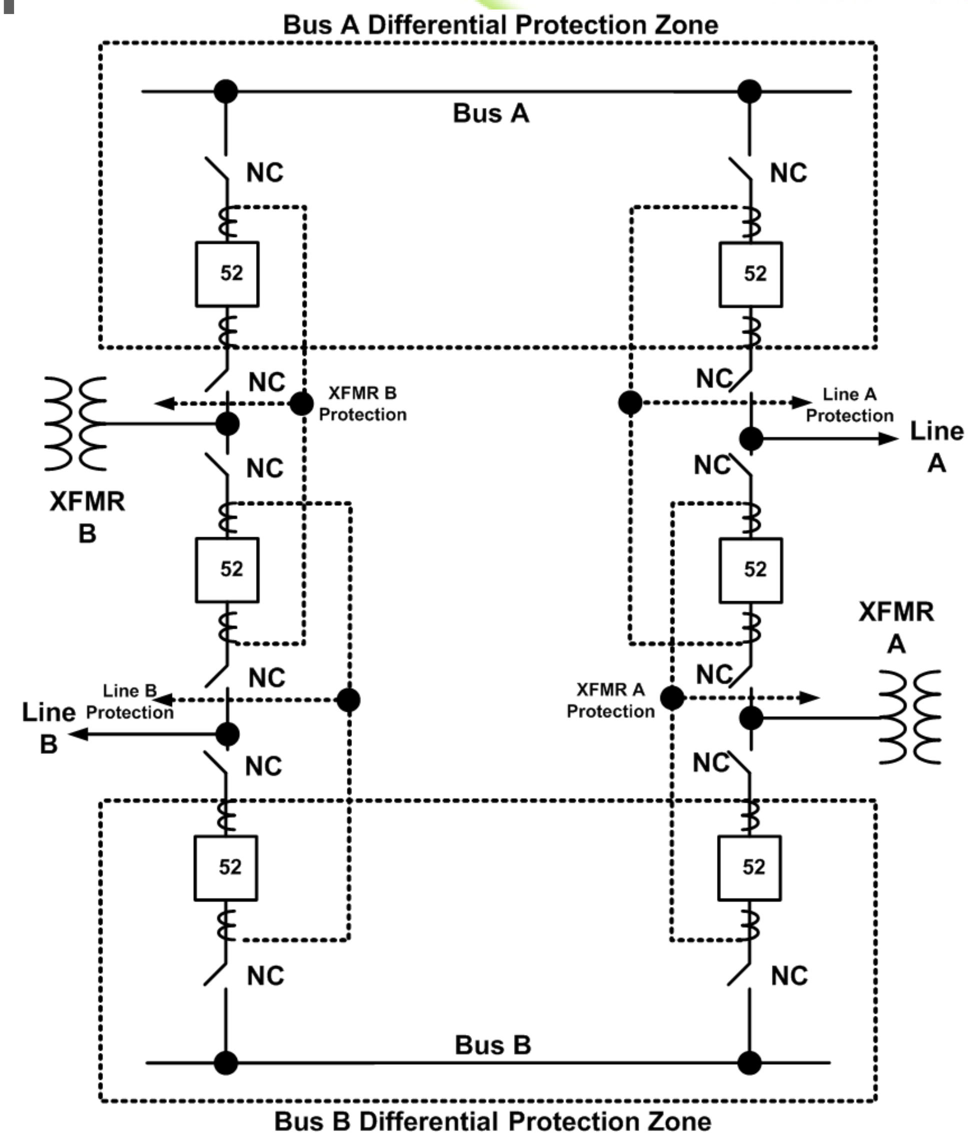
Bus Protection

Single bus with XFMR



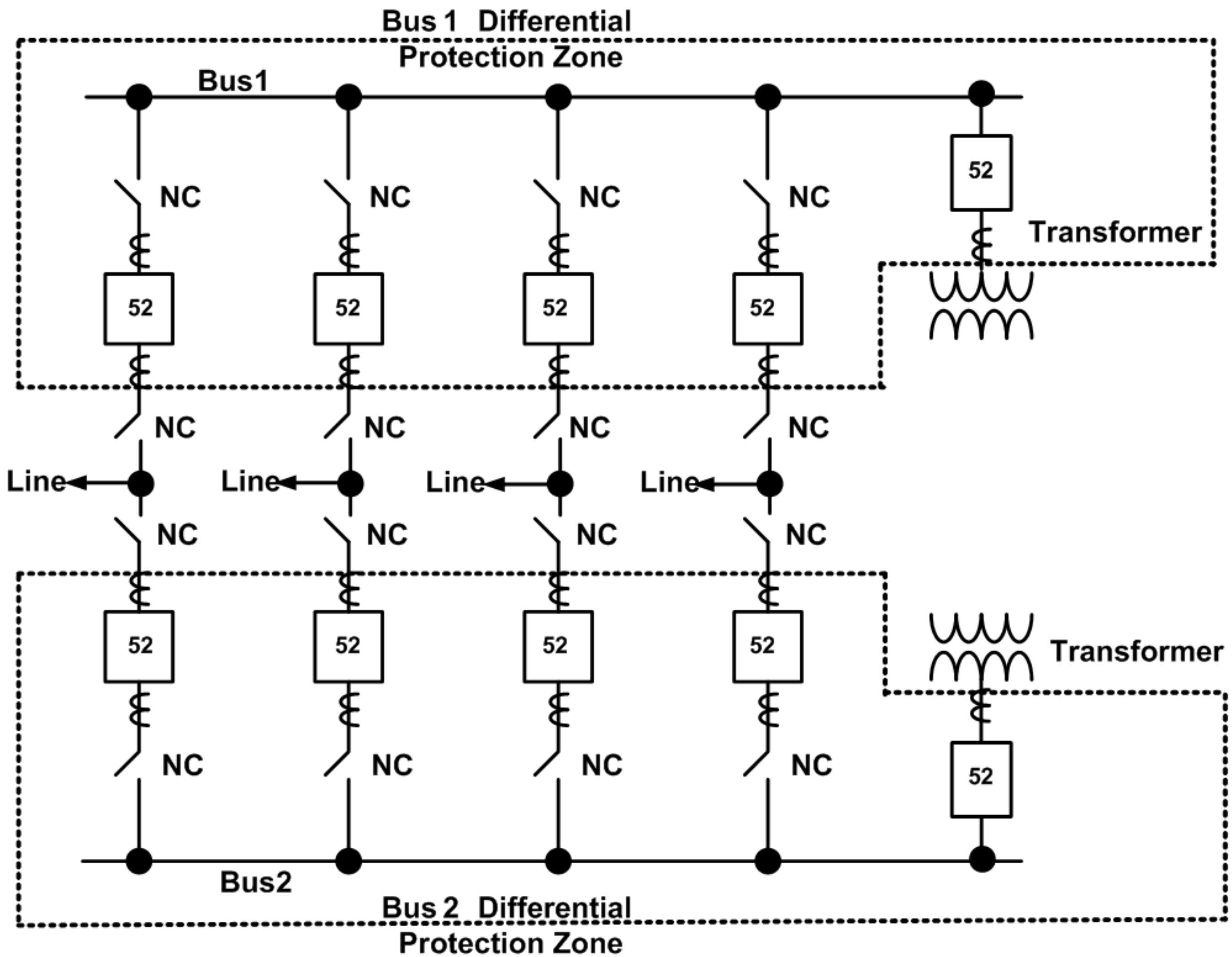
Bus Protection

Double bus, breaker-and-a-half



Bus Protection

Double bus, double breaker



Capacitor Protection

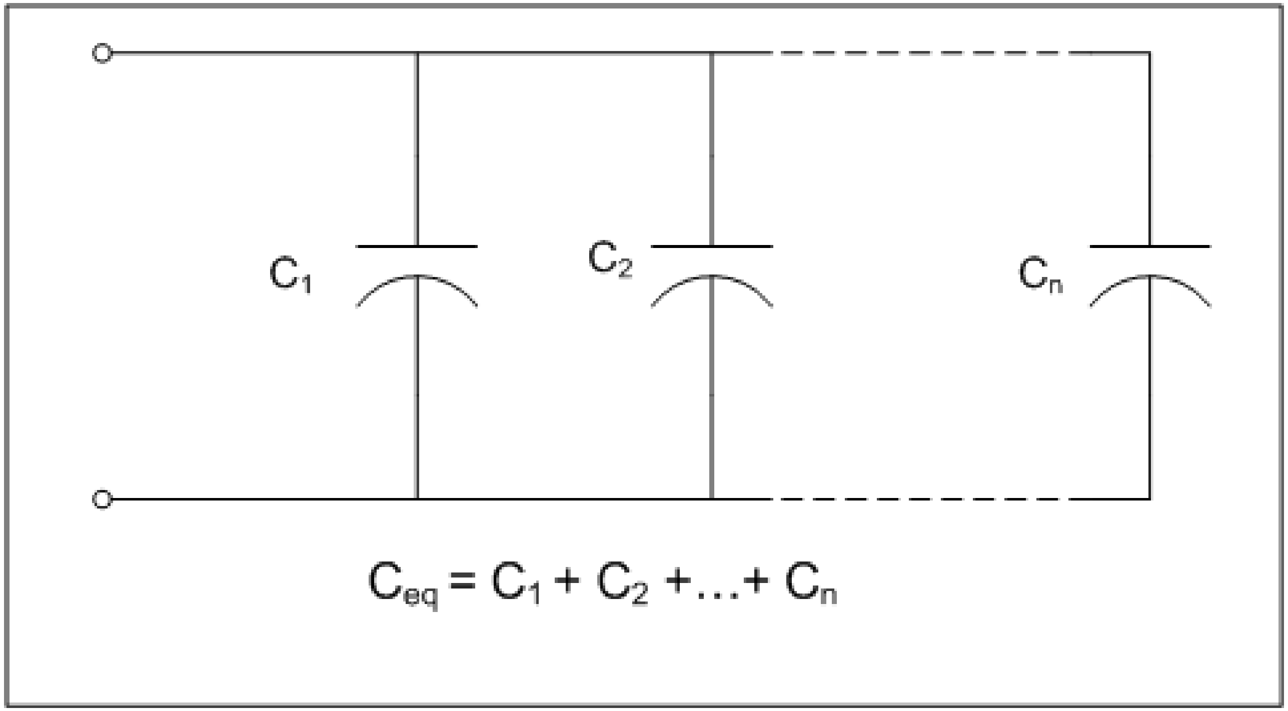
Purpose of capacitors:

Shunt capacitors raise the voltage on a bus or line to a higher level, thus helping keep the voltage at desired level

Series capacitors cancel out the inductive reactance of a line, thus making the line appear shorter increasing load flow on the line.

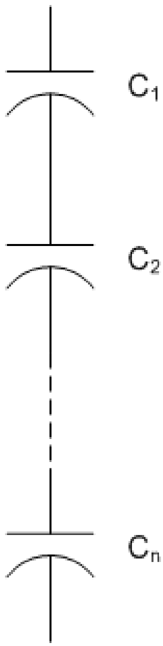
Capacitor Protection

Capacitors connected in parallel add



Capacitor Protection

Capacitors connected in series sum like they are in parallel

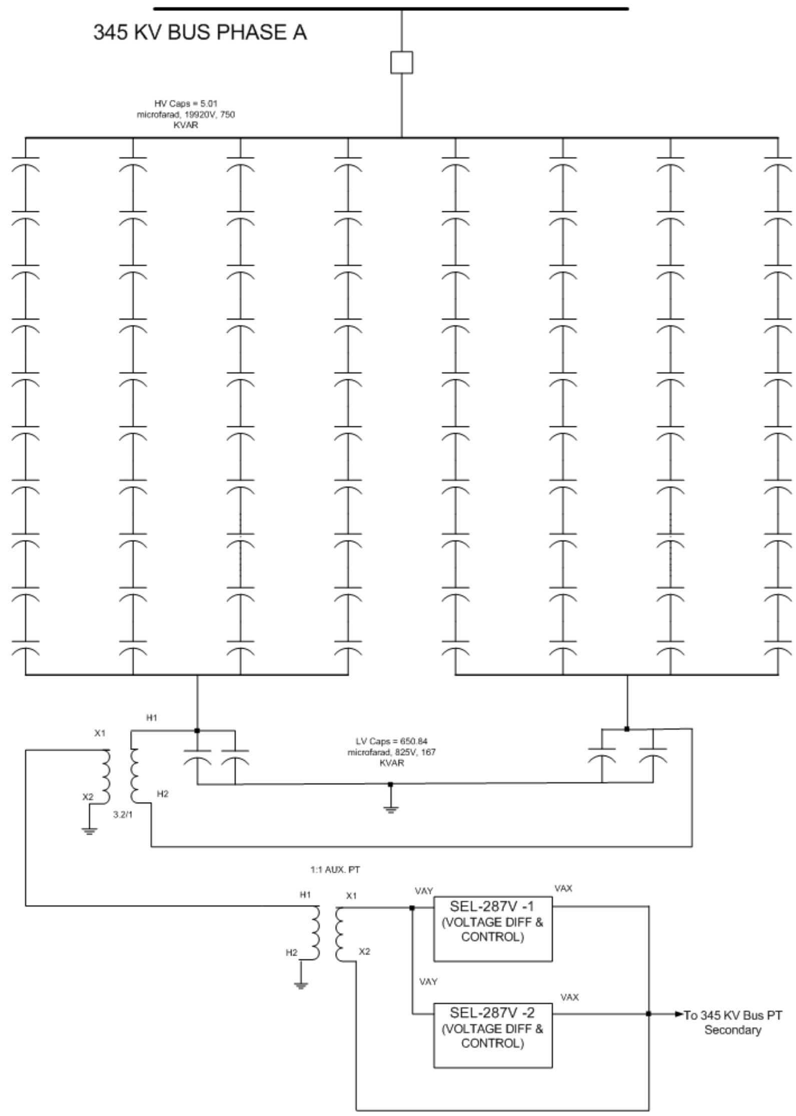


$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}$$

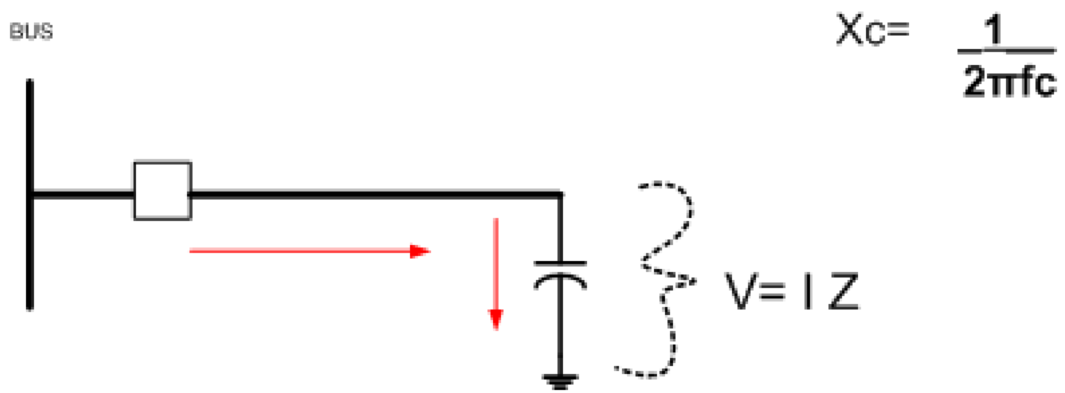
Capacitor Protection

Capacitors are connected in series and parallel combination to obtain the desired total capacitance for the bank

Capacitor Protection



Capacitor Protection

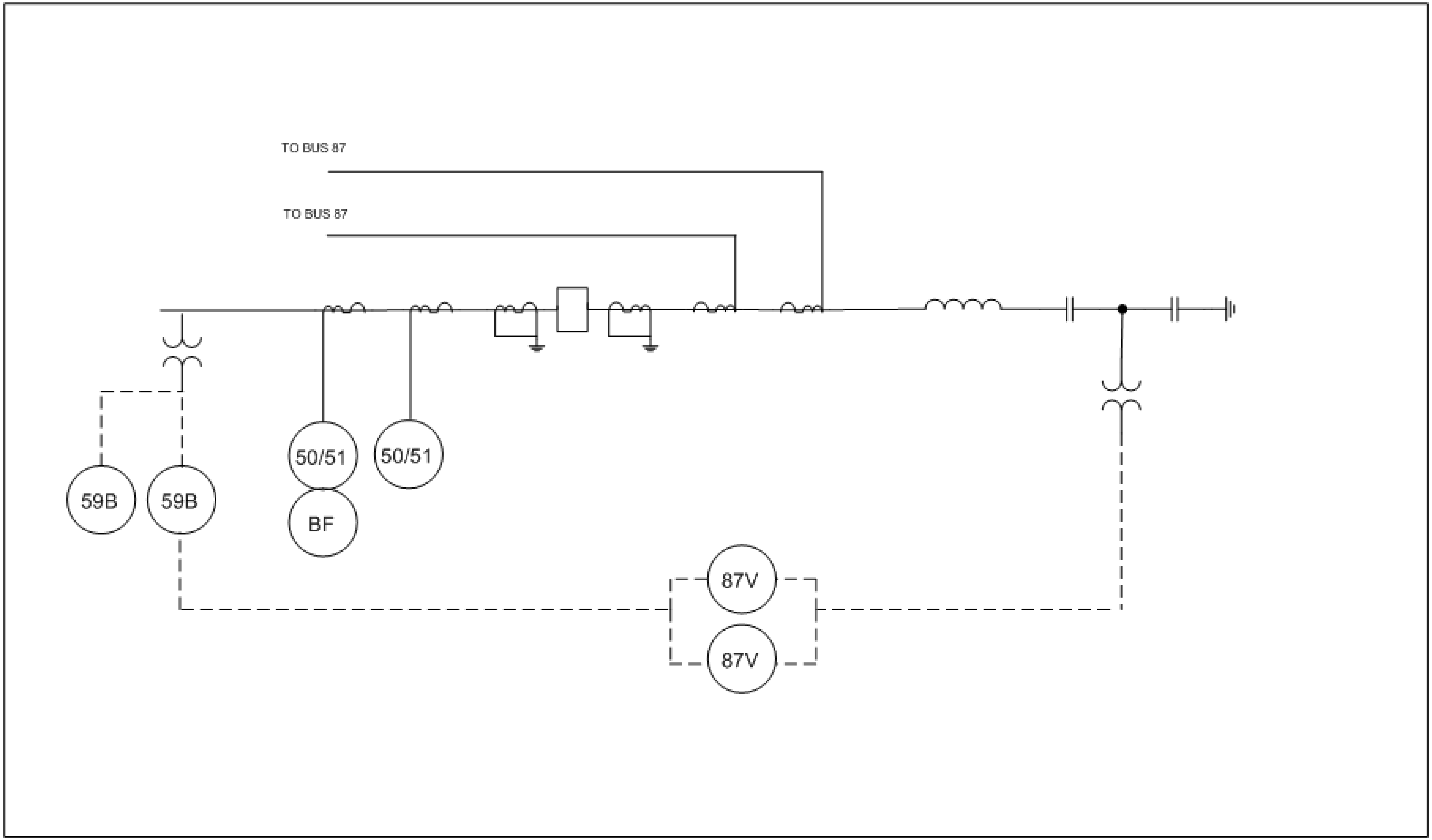


Voltage across cap bank is determined by current flow and impedance (capacitive reactance) of bank.

If a capacitor fuse blows or if a capacitor shorts, the voltage drop across the bank changes due to a change in capacitive reactance of the bank.

A voltage relay detects the higher voltage and trips the breaker

Capacitor Protection



Introduction to System Protection

????? QUESTIONS ?????

If you are still awake, nudge your sleeping neighbor and tell him/her that the lecture is over and it is almost time for the next lecture, which may actually prove to be an interesting and informative lecture (unlike this one).

If you are not awake, may you dream that you are on a Hawaiian beach…
And then wake up in Pullman!