Utility Protection Practices in PJM

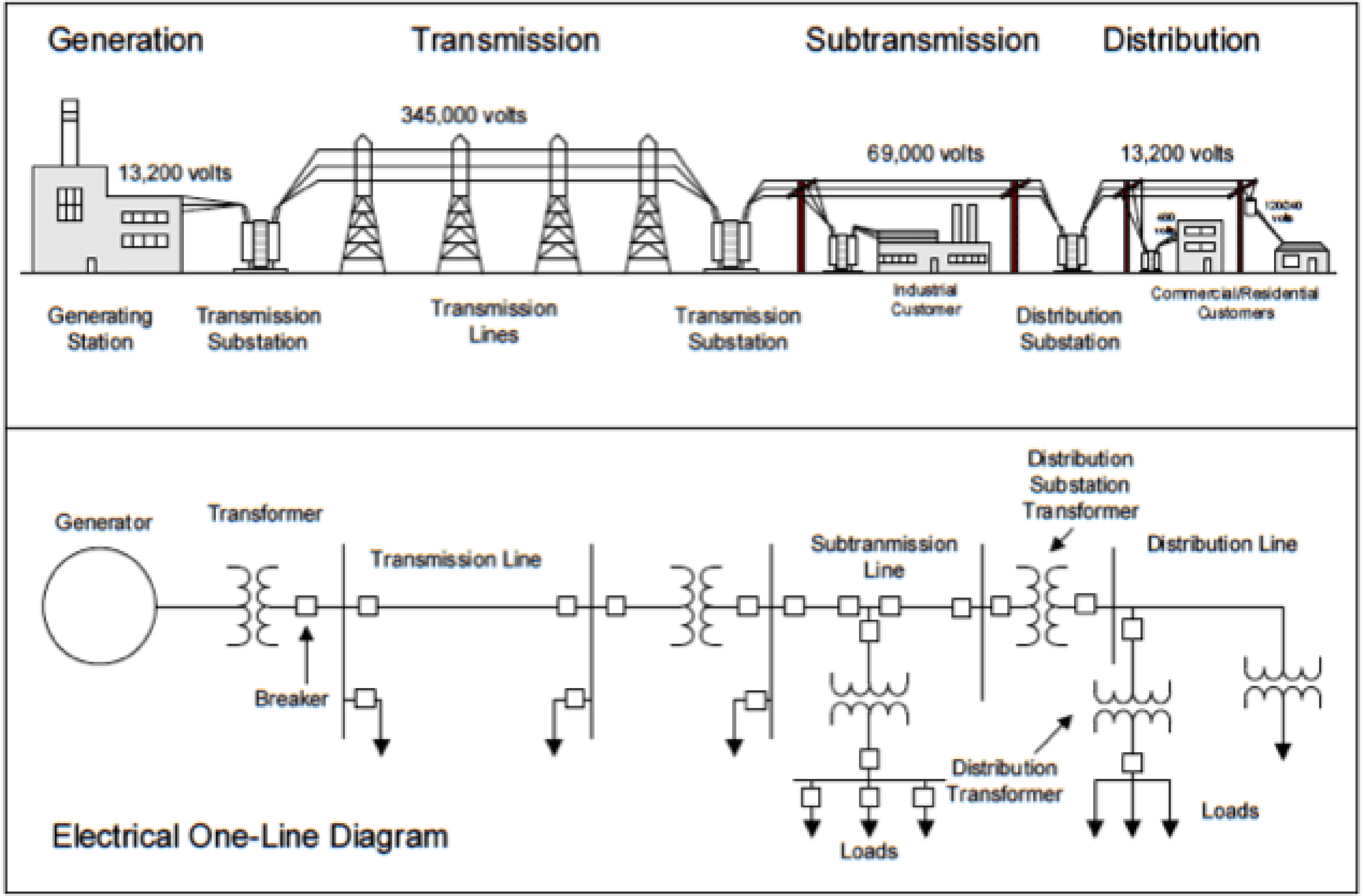
Terry Fix

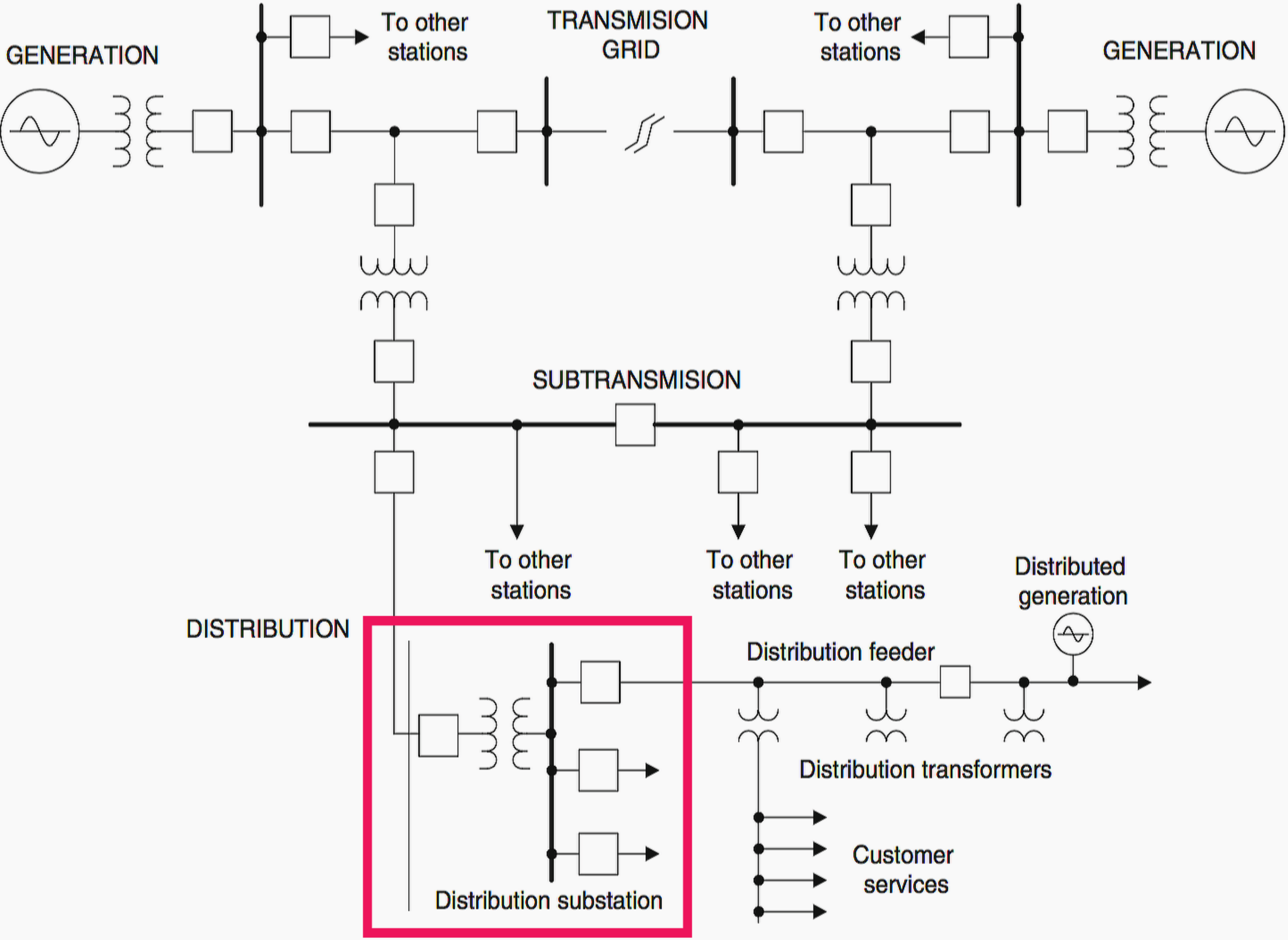
Protective Relay Systems Consultant

Dominion Energy

Past Chair of PJM Relay Subcommittee

Typical Electrical Power System Single-Line Diagram




GENERATION
To other stations
TRANSMISION GRID
To other stations
GENERATION
SUBTRANSMISION
To other stations
To other stations
To other stations
Distributed generation
DISTRIBUTION
Distribution feeder
Distribution transformers
Customer services
Distribution substation

Decentralized Power System

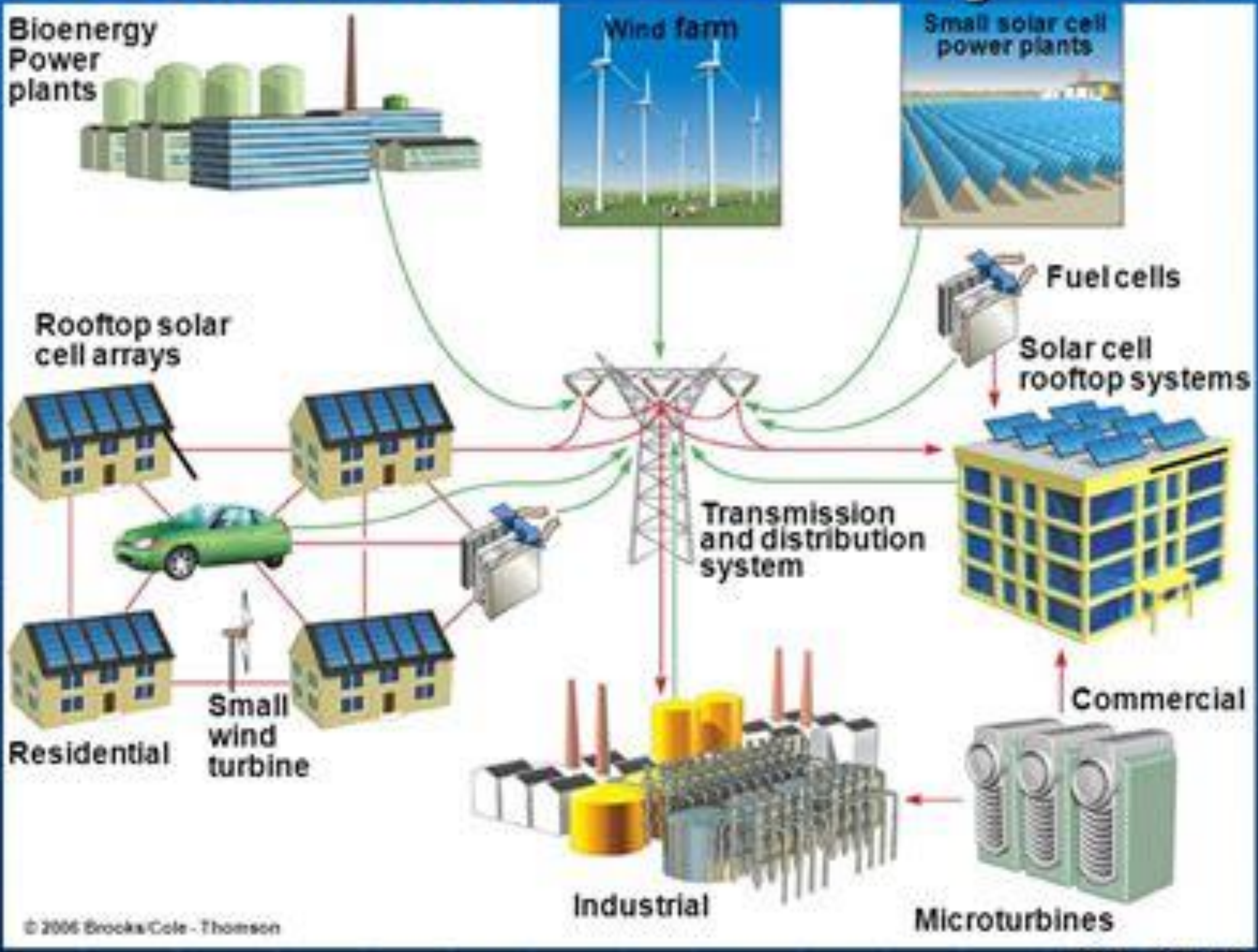
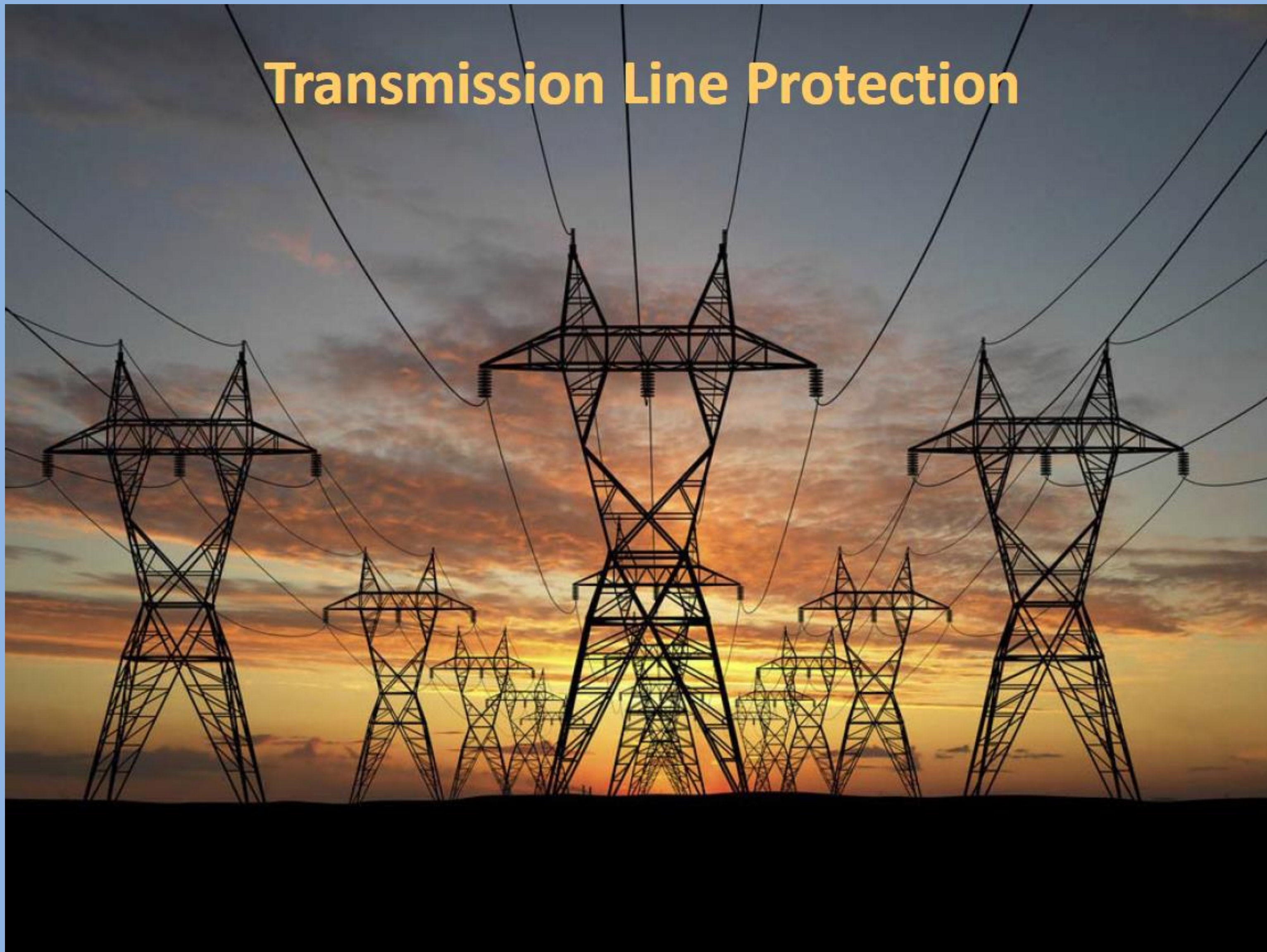


Fig. 13-46, p. 324

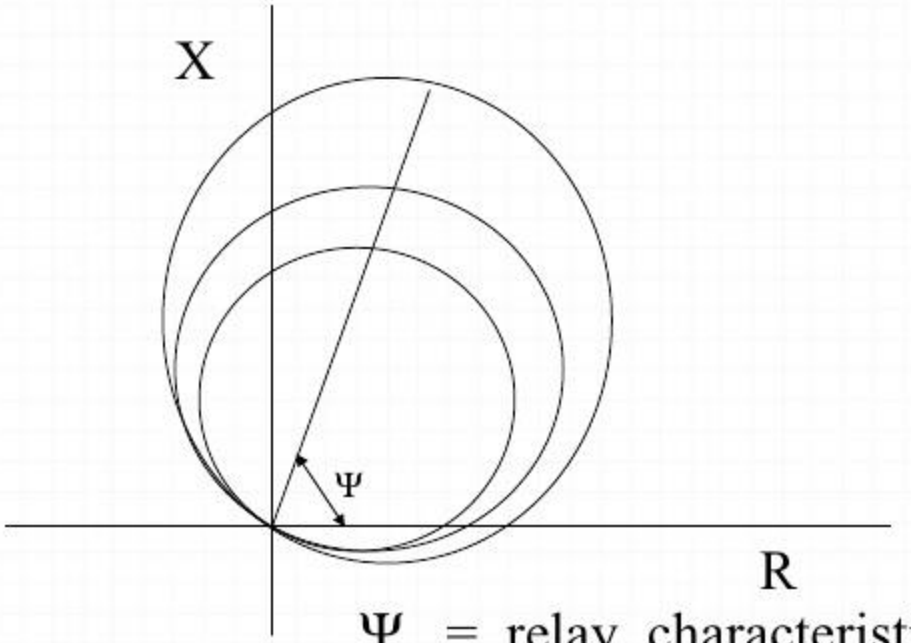
Transmission Line Protection



Transmission Protection Characteristic

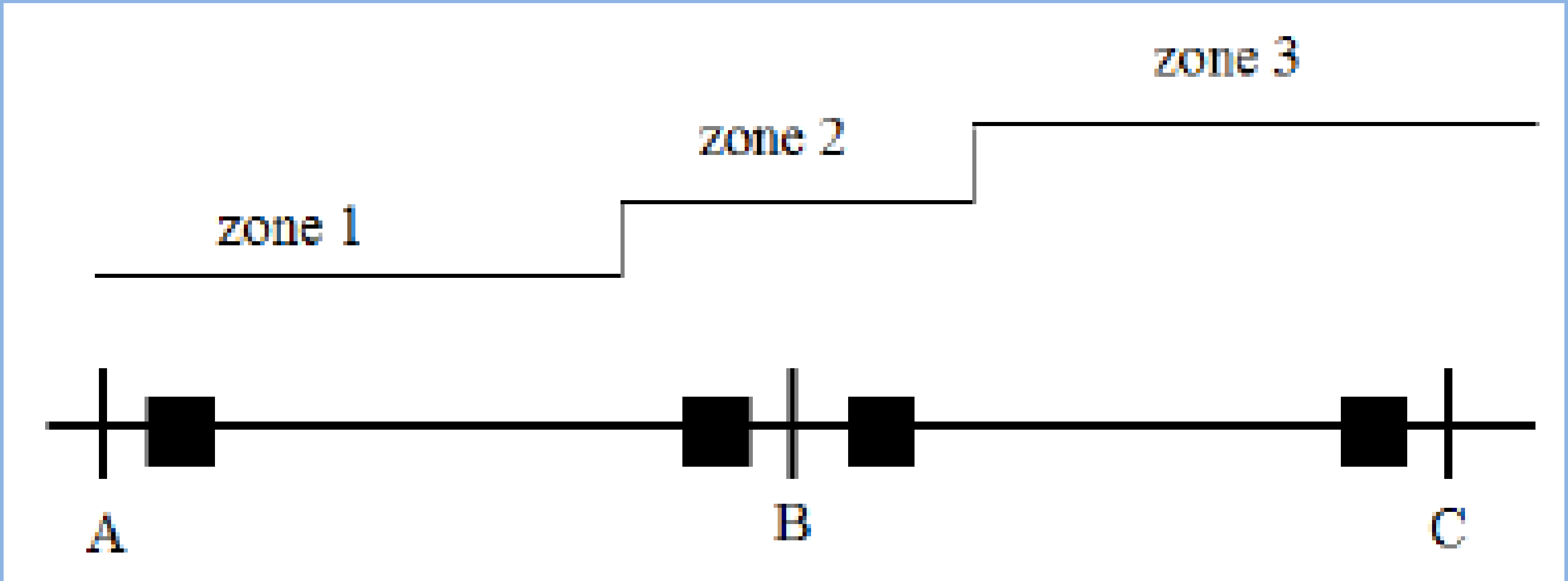
MHO relay characteristic

The characteristic of a mho impedance element , when plotted on a R/X diagram, is a circle whose circumference pass through the origin .

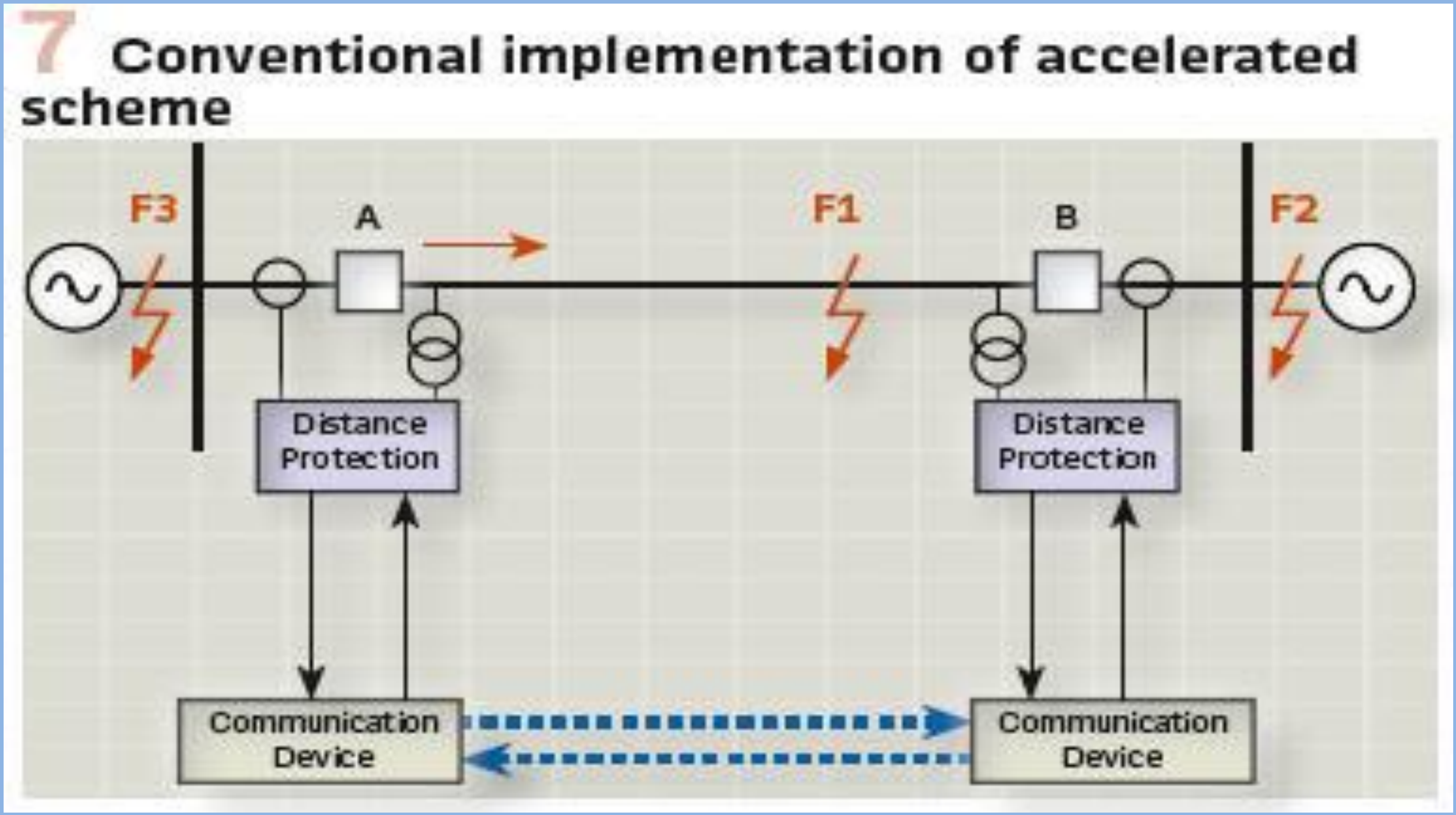


Ψ = relay characteristic angle

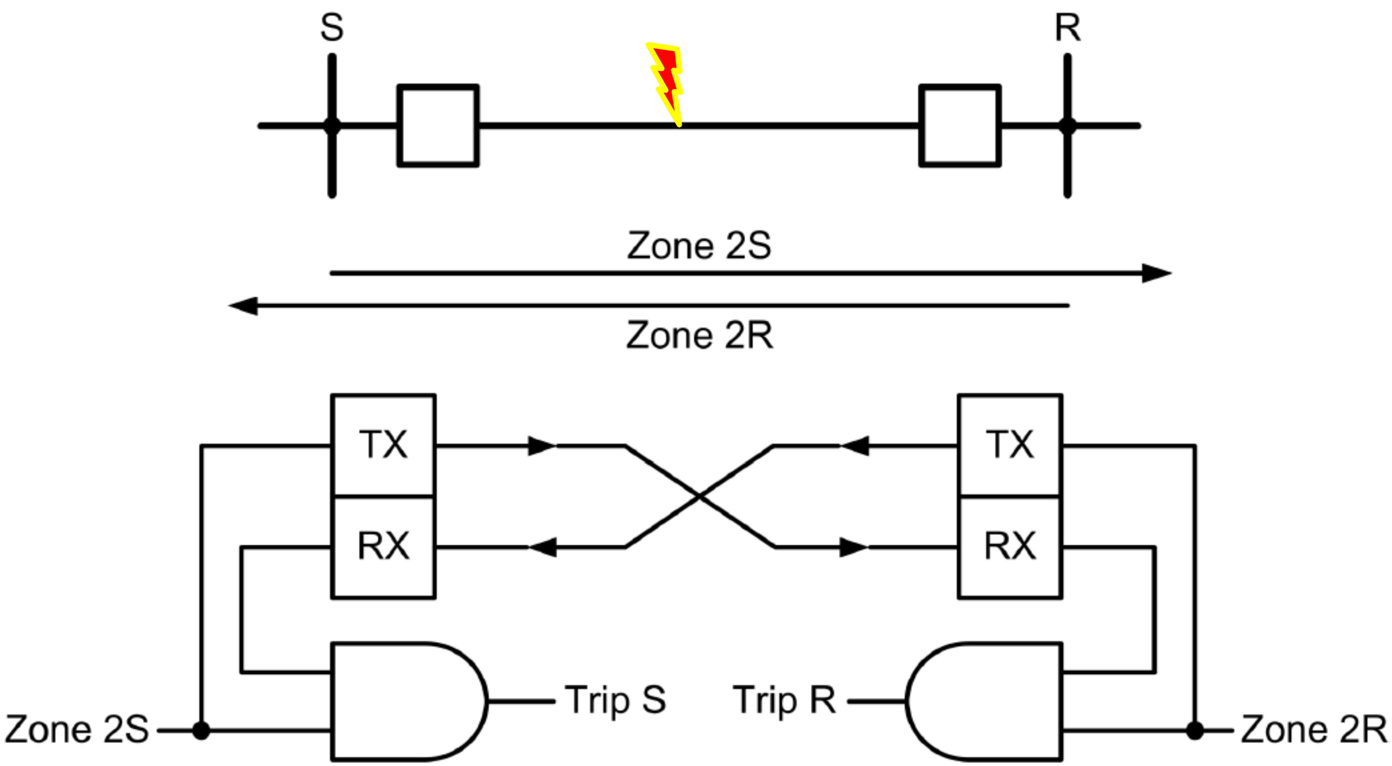
Transmission Protection Characteristic



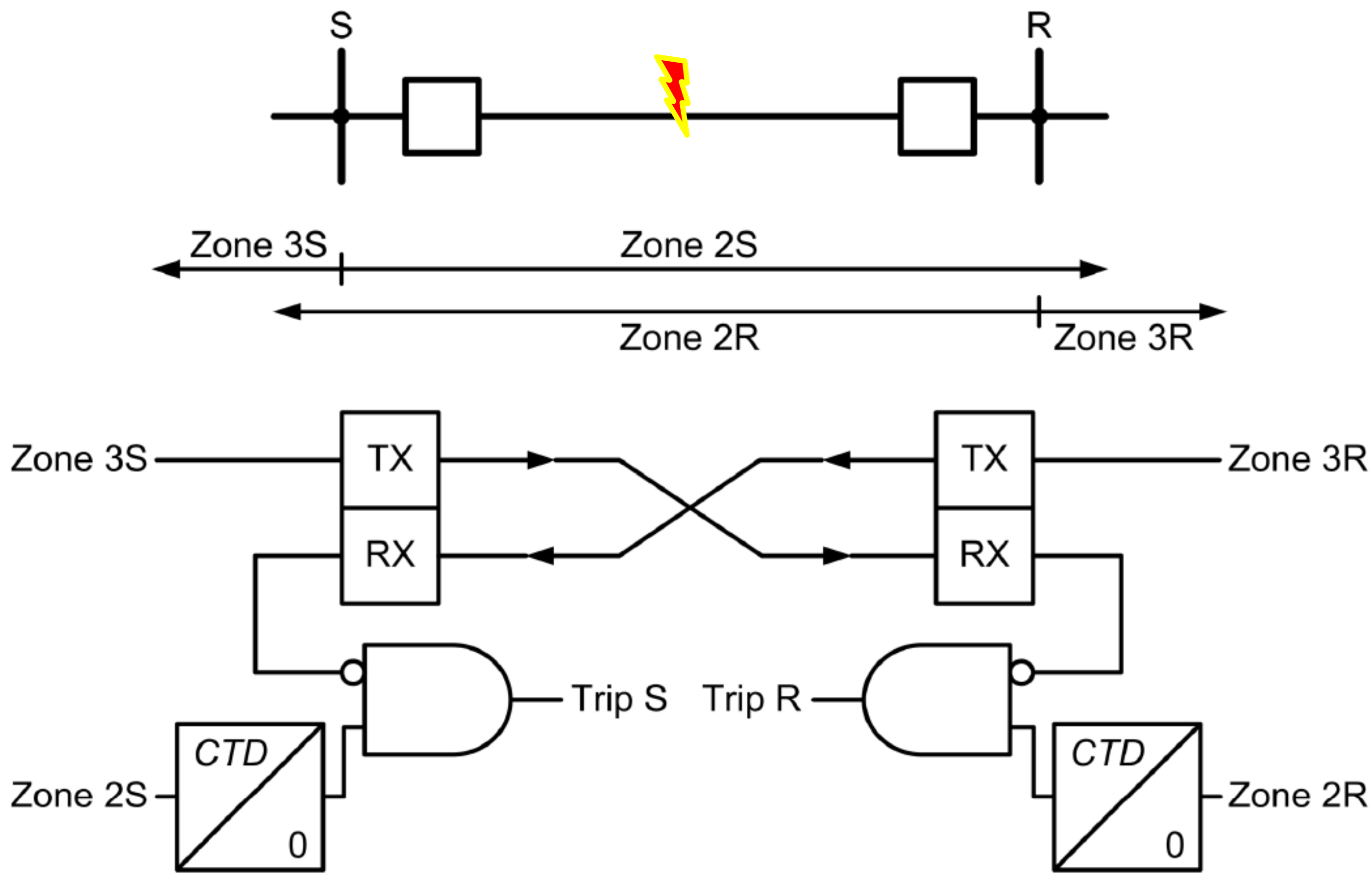
Pilot Protection Scheme with Communication



POTT Logic

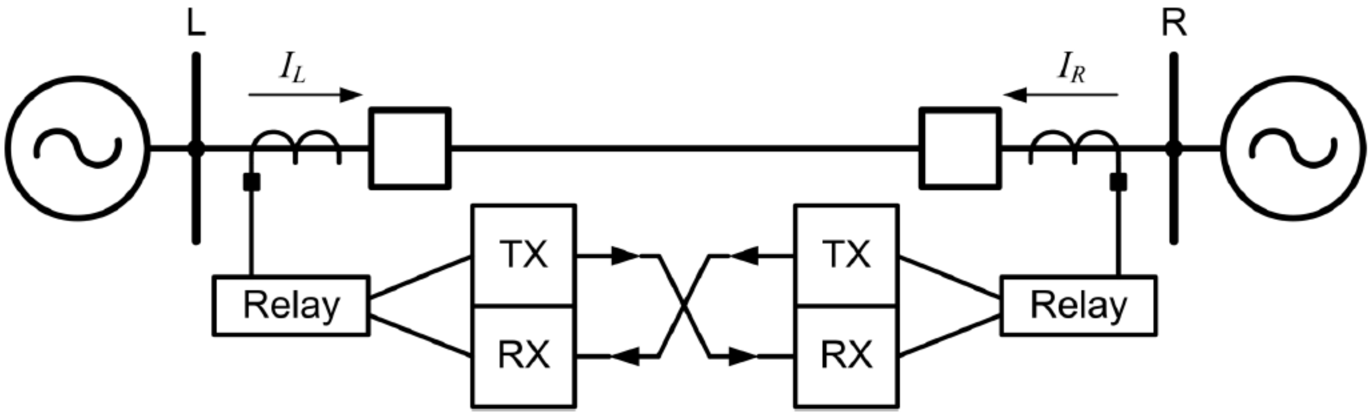


DCB Logic



S
R
Zone 3S
Zone 2S
Zone 2R
Zone 3R
Zone 3S
TX
RX
TX
RX
Zone 3R
Trip S
Trip R
CTD
0
Zone 2S
CTD
0
Zone 2R

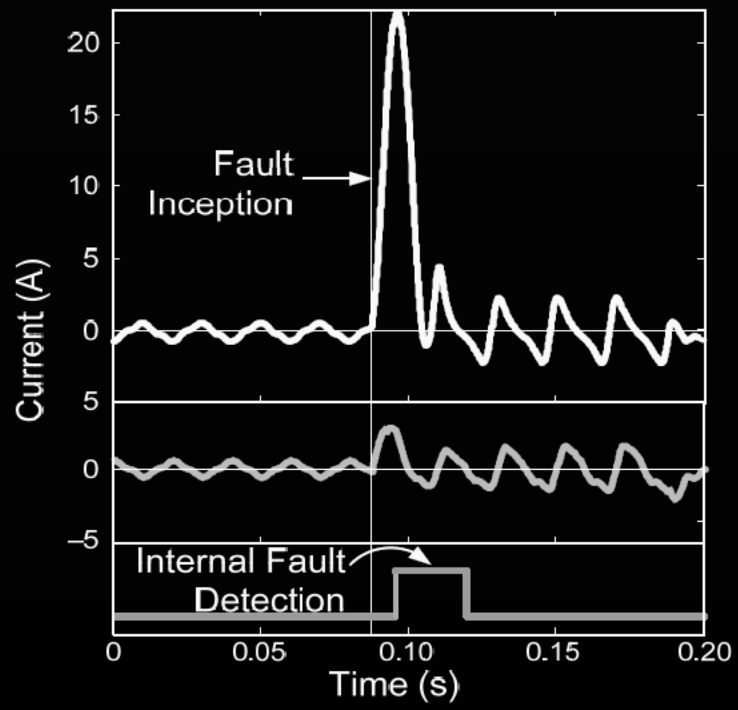
Current-Only Pilot Schemes



Compare current information

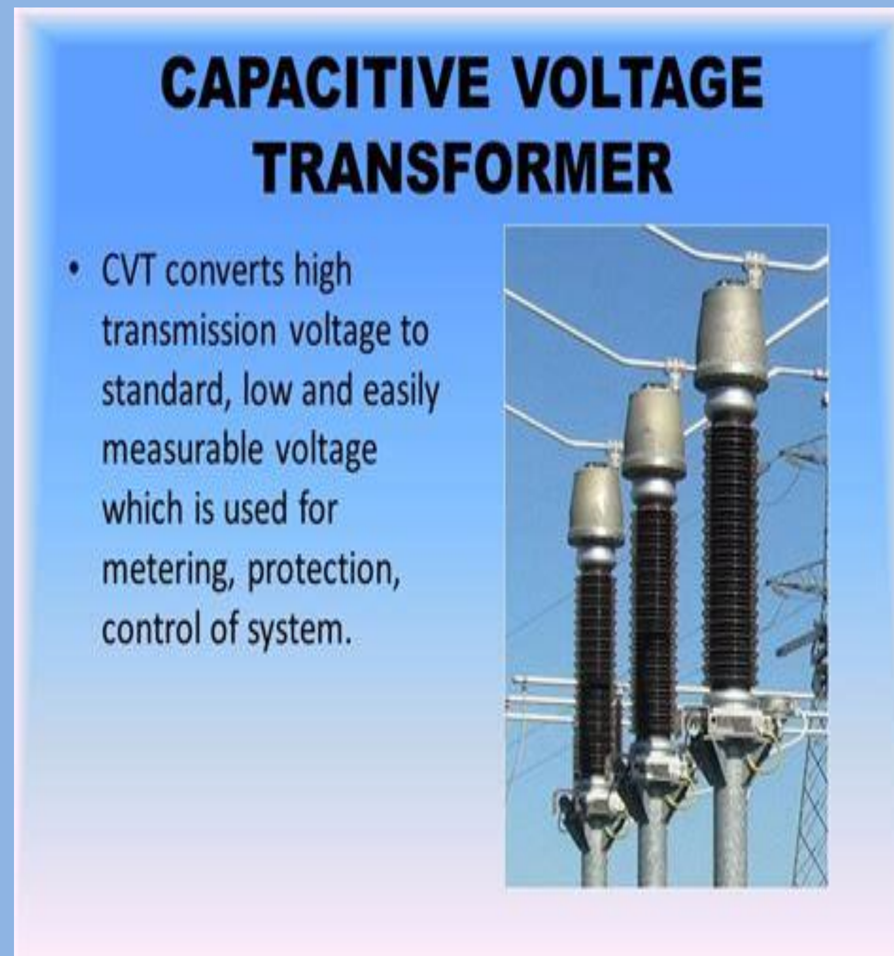
- Phase comparison
- Differential

Subcycle Operation Minimizes Equipment Damage, Improves Stability Margins



Transmission Breaker

Transmission Current and Voltage Sensing Devices



Transmission Protective Relays

Substation Control House

Transmission Substation

Lightning Strikes

Transmission Power Transformer

Windings of a Power Transformer

Winding Damage due to Fault Current

Equipment Damage

Large Power Plants

2003 Northeast Blackout

NERC Common Failure Modes

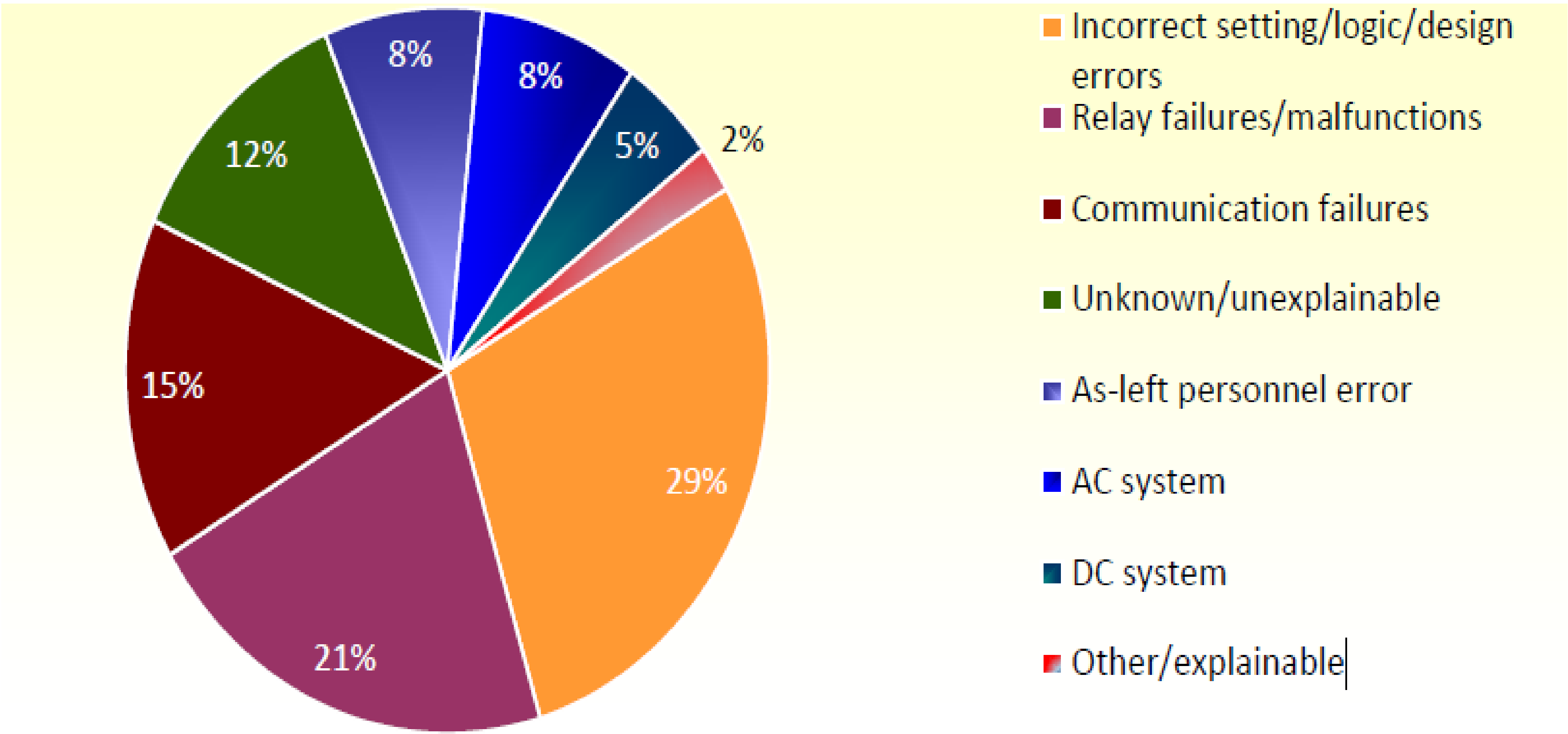


Figure 4.11: NERC Misoperations by Cause Code from 2011Q2 to 2013Q3[70]

Common Equipment Failures

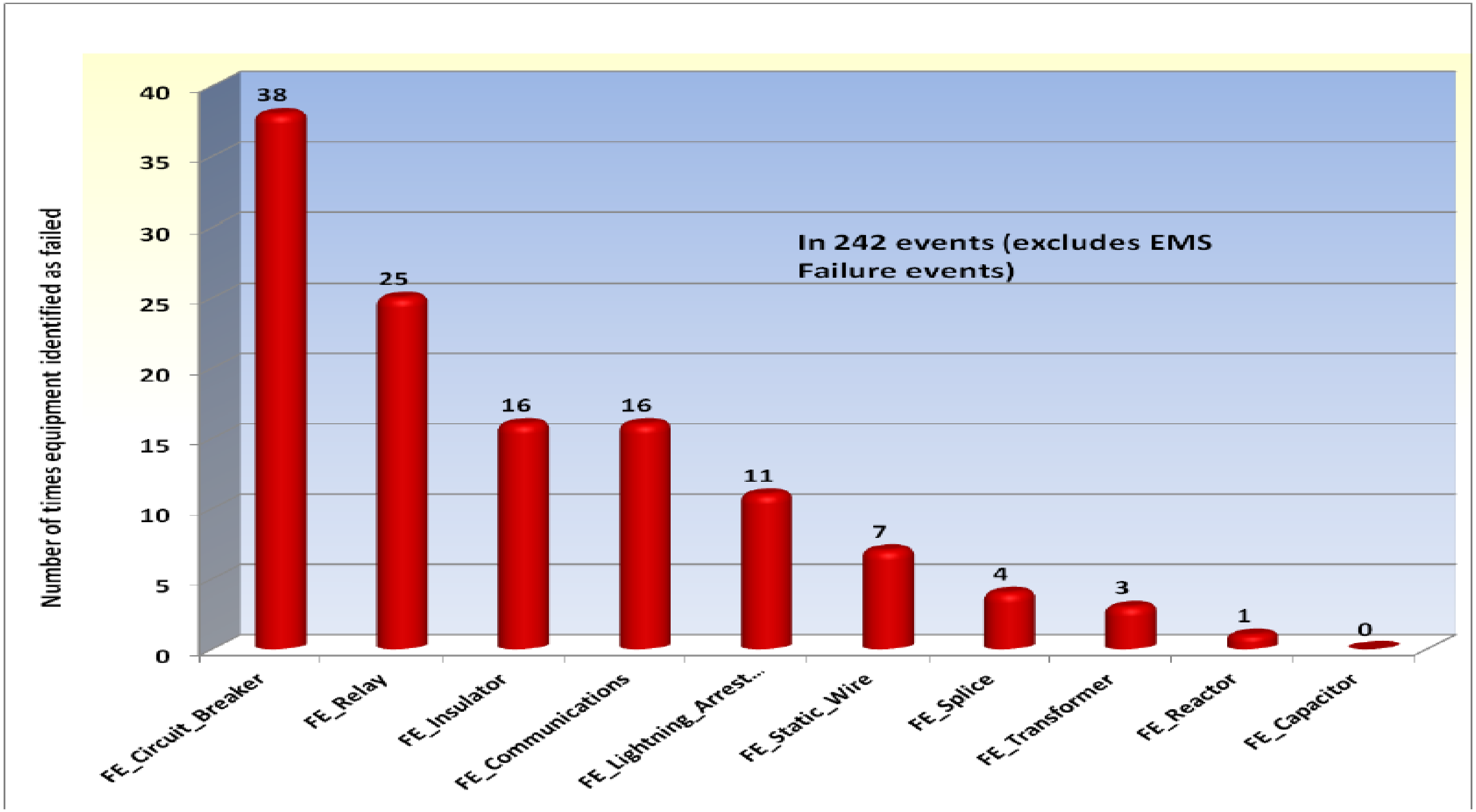
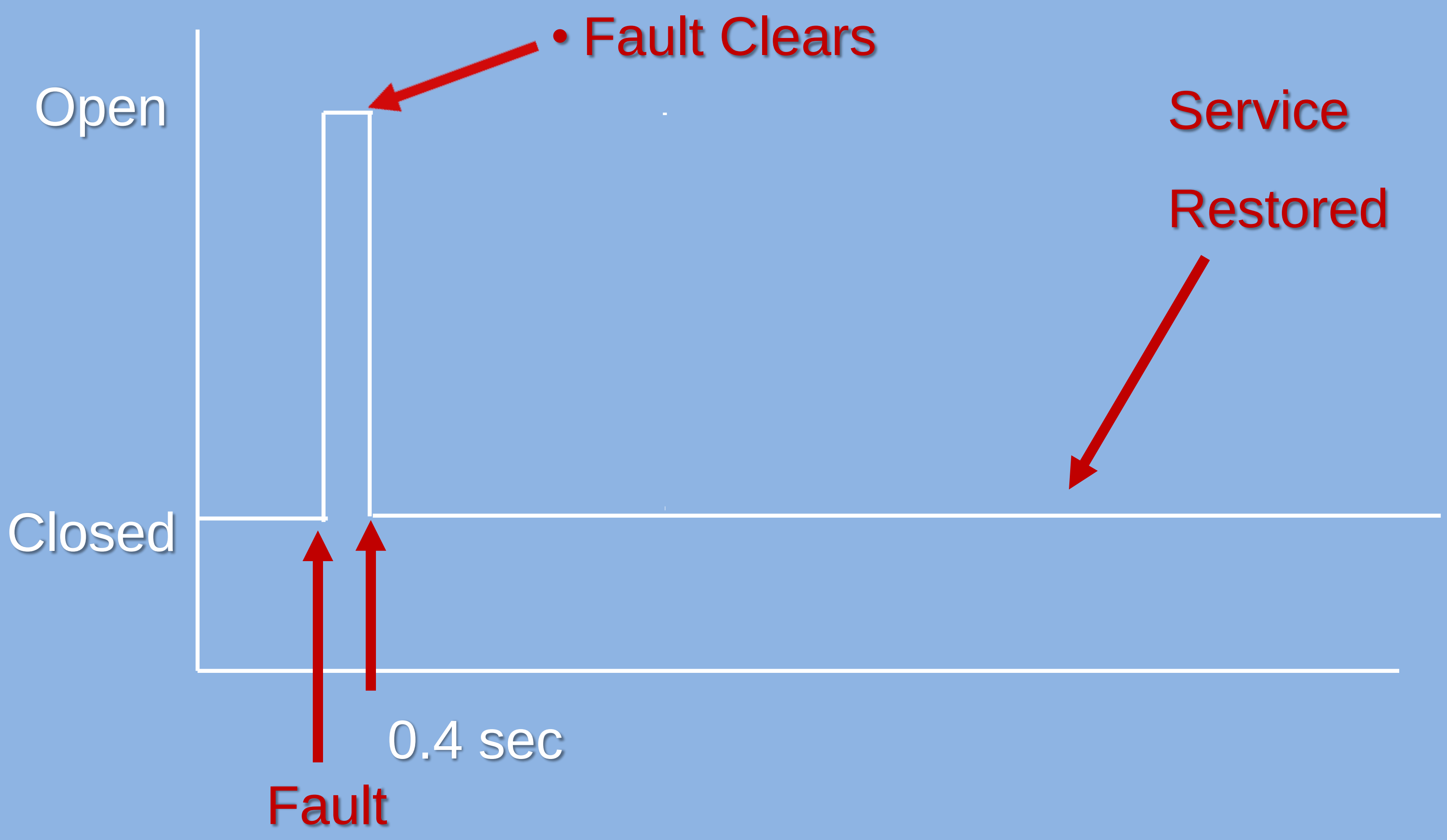


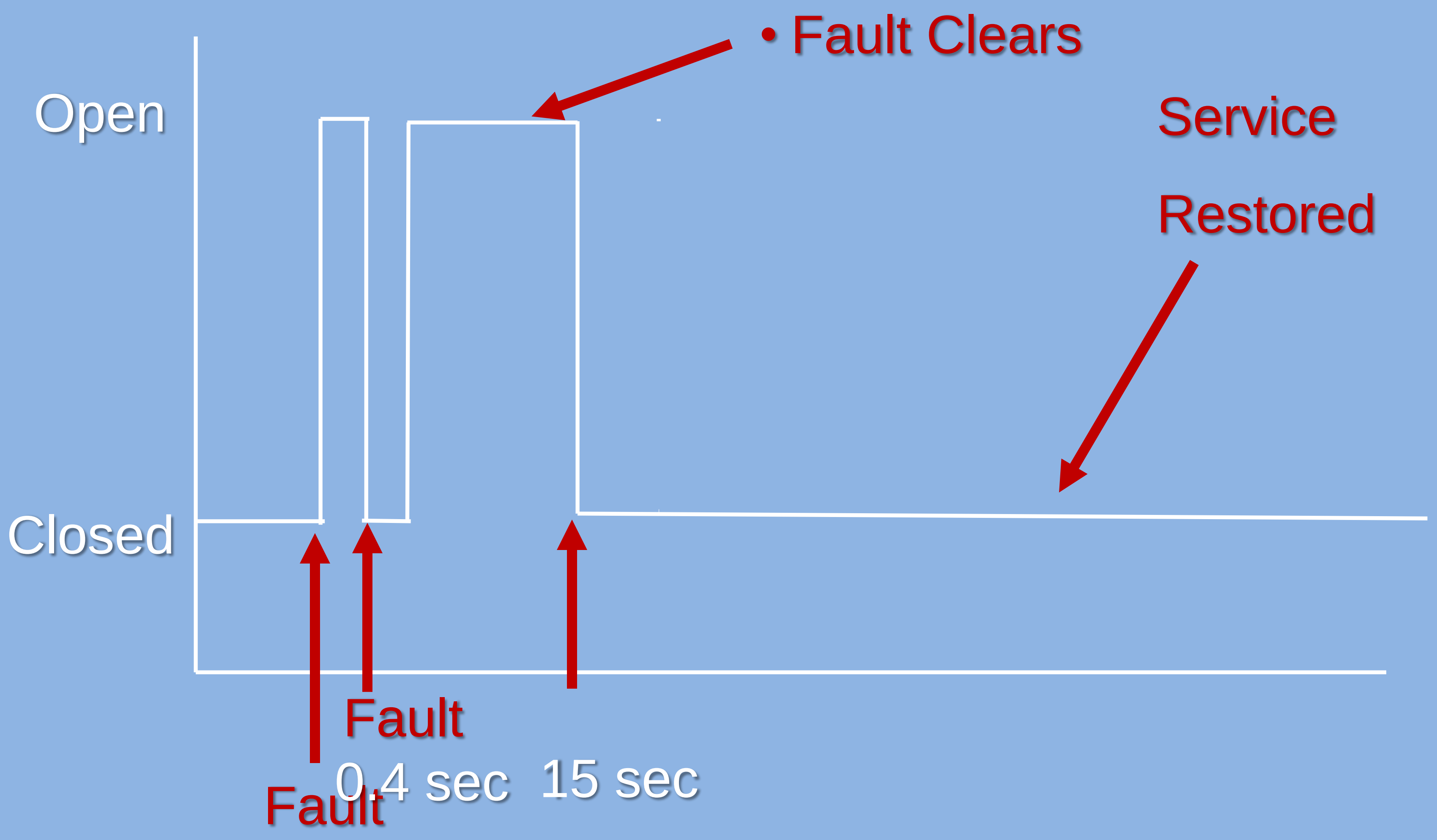
Figure 5.4: Failed Equipment Identified during Review of Event Reports

Transmission Reclosing Practices

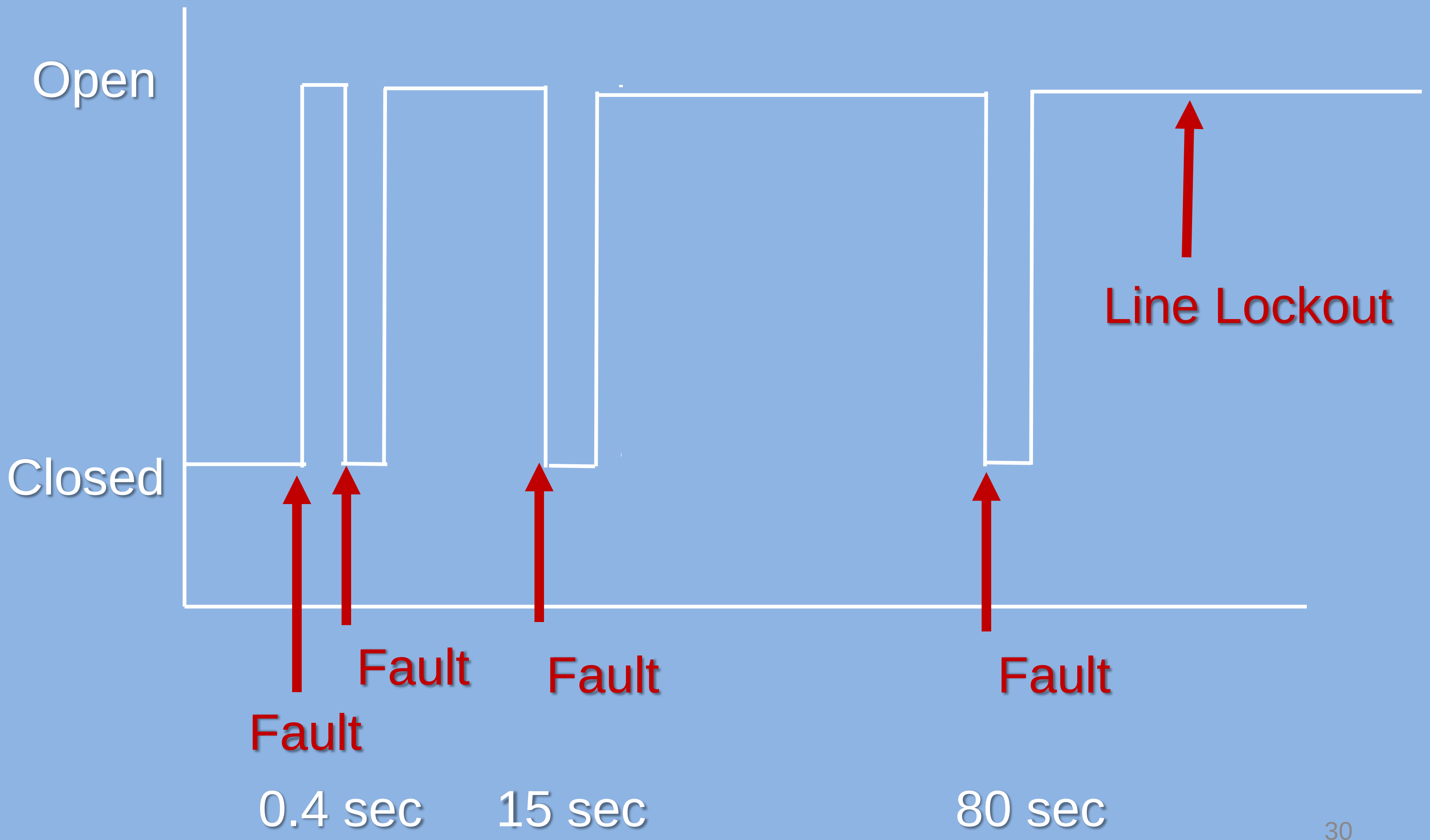
Breaker Reclosing Cycle
Temporary Transmission Fault



Breaker Reclosing Cycle
Temporary Transmission Fault

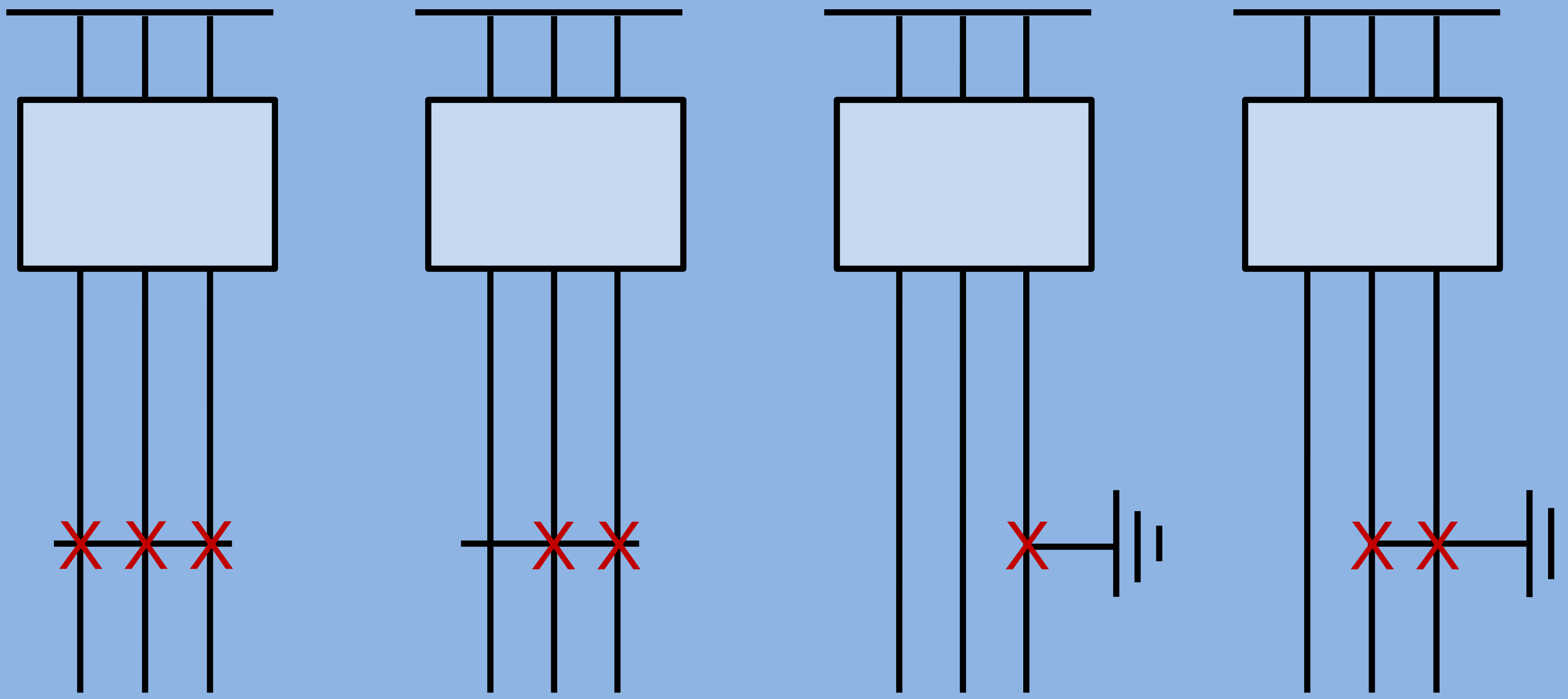


Breaker Reclosing Cycle
Permanent Transmission Fault



Distribution Feeder Protection

Fault Types



3 Phase

Phase to Phase

Phase to Ground

2 Phase to Ground

Basic Protective Devices

Fuse

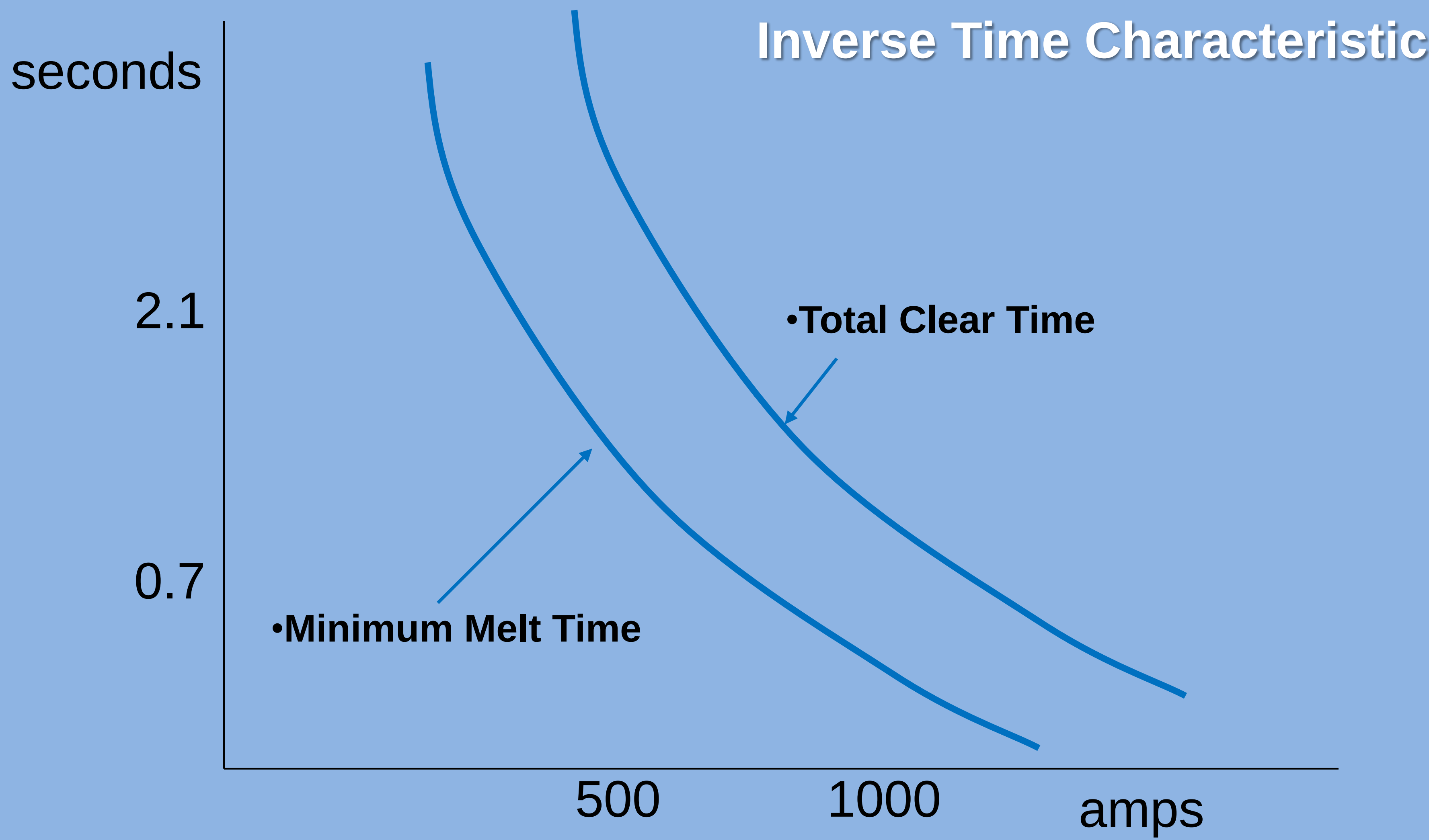
Recloser

Overcurrent Relay

Fuses

- Basic sectionalizing device
- One time operation
- Needs to be replaced
- Inverse time characteristic
- Minimum melt time
- Total clear time

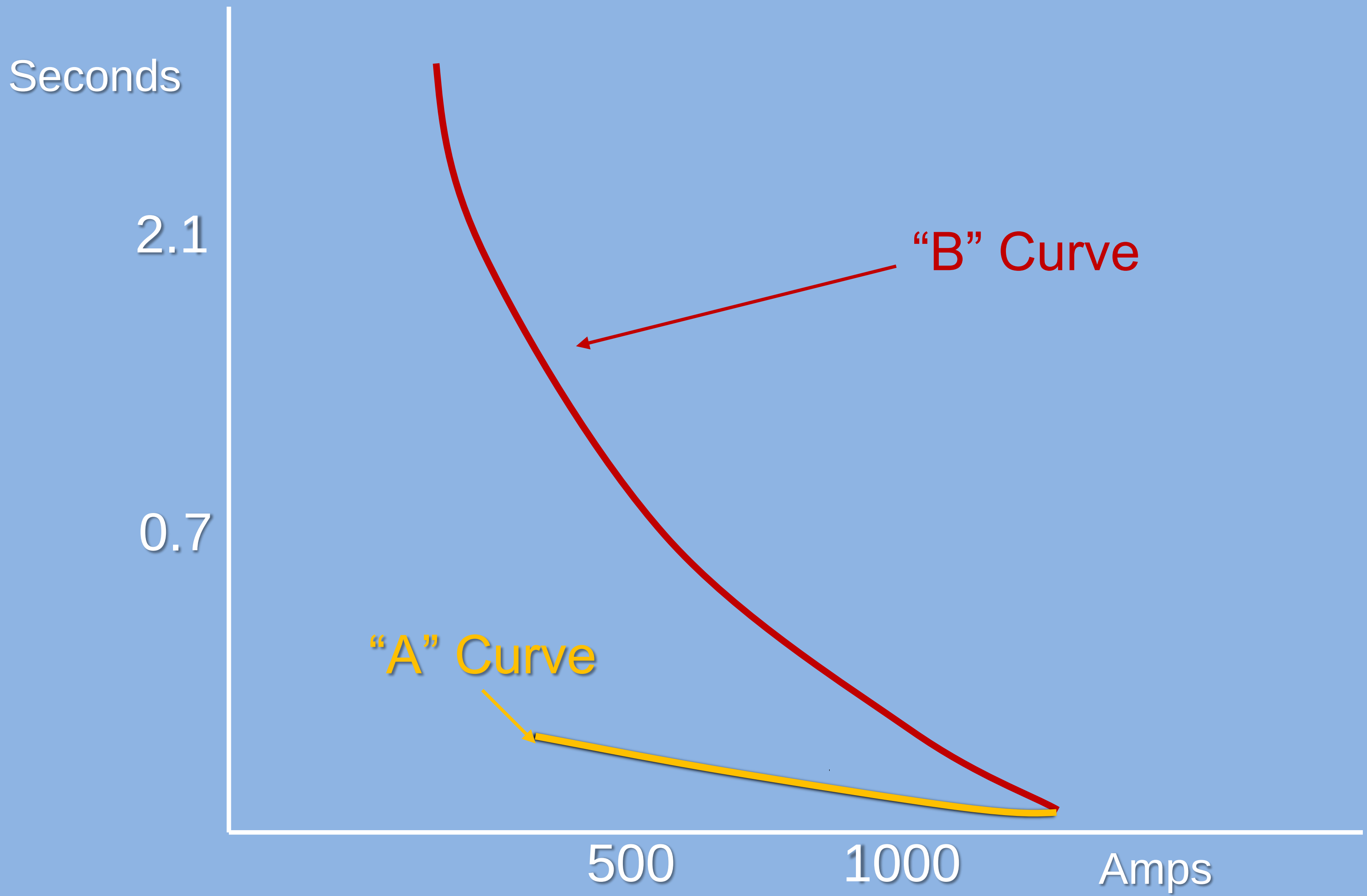
Fuse Time vs. Current Curve



Reclosers

- Basic sectionalizing device
- Multiple operations
- Inverse time characteristic
- Fast “A” curve
- Time delayed “B” curve

Recloser Time vs. Current Curve

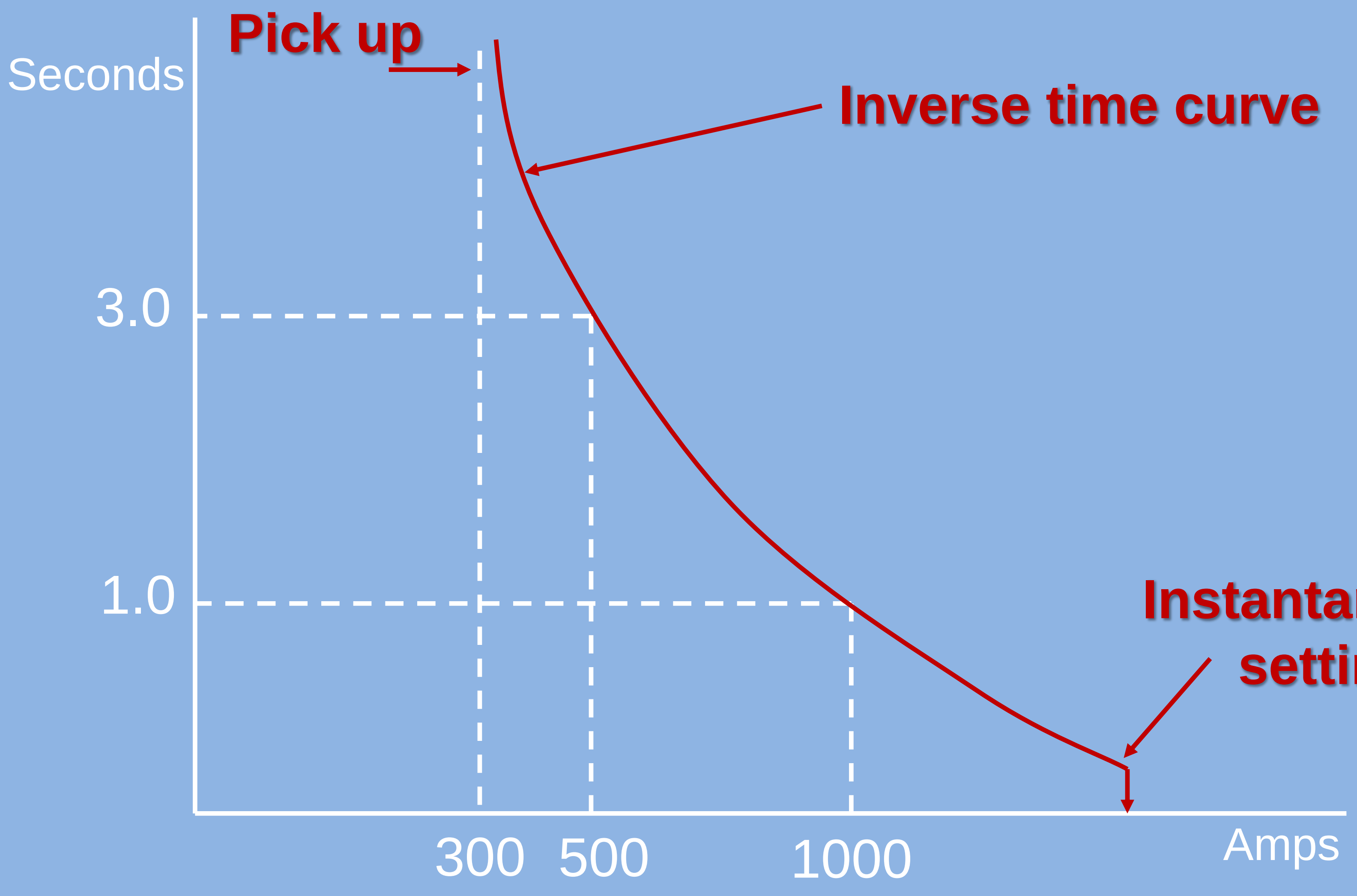


Types of Relays

Electromechanical

Microprocessor (Schweitzer Relay

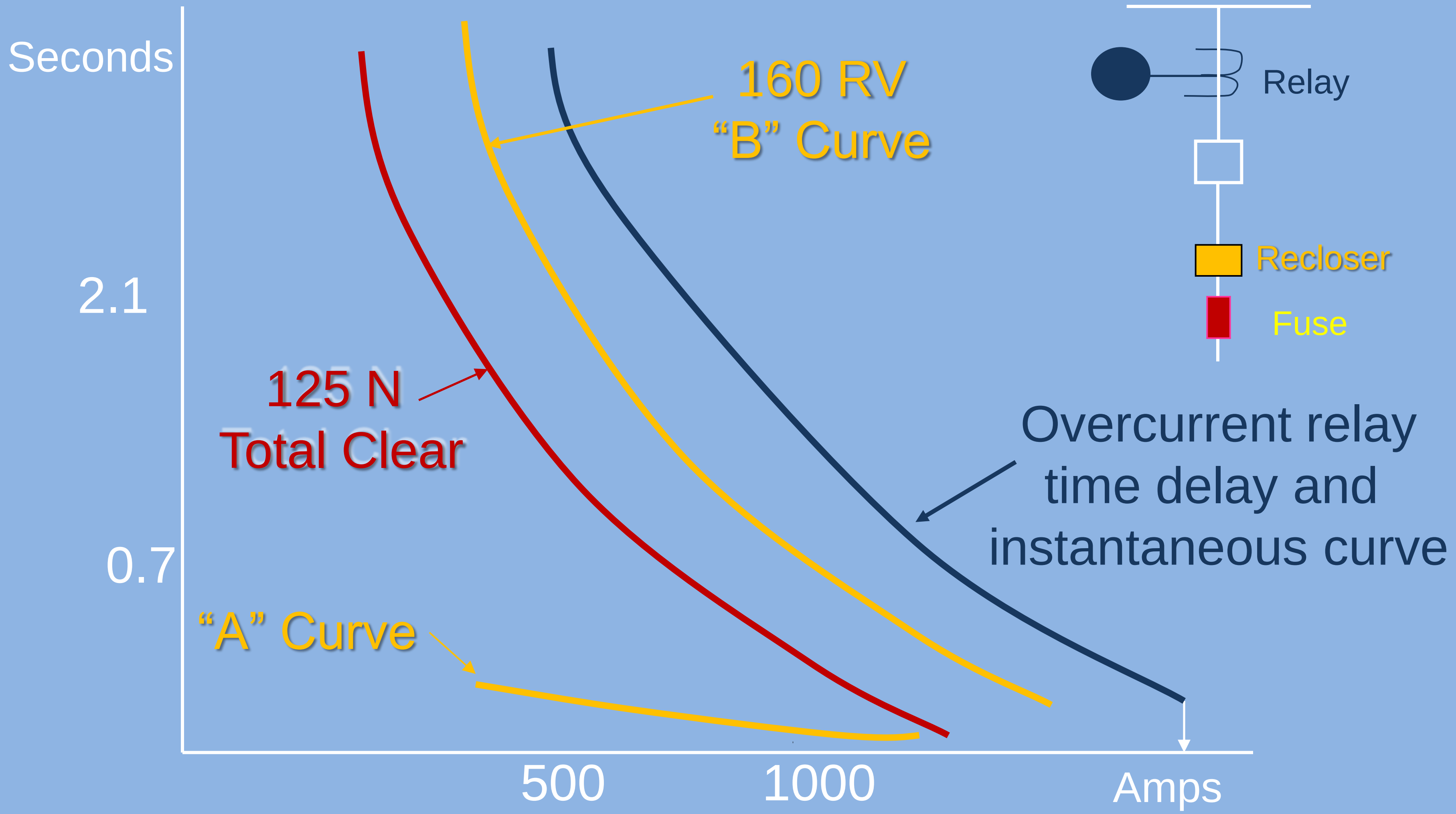
Relay Time vs. Current Curve



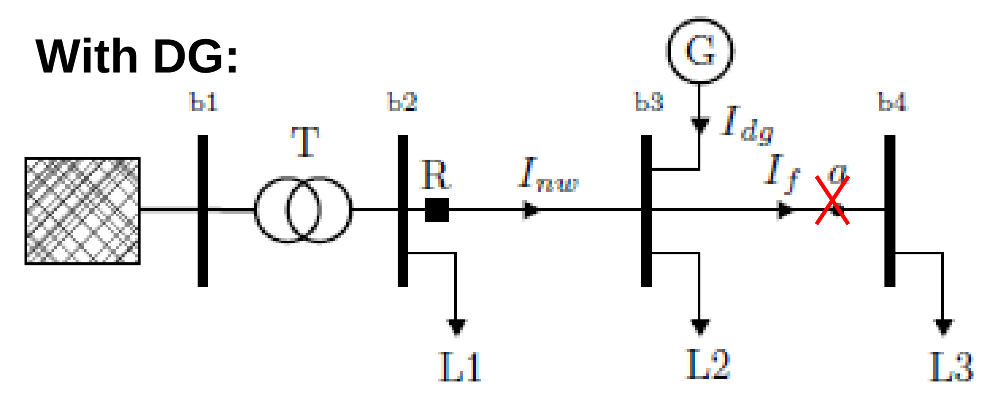
Protective Device Coordination

- Proper timing and operational sequencing of protective devices
- Coordination minimizes customer outages while clearing circuit faults

Coordination Curve
Fuse, Recloser, Relay



DG Protection Issues
Reduction of Reach



$$V_r = I_{nw} Z_{23} + (I_{nw} + I_{dg}) Z_{3a}$$

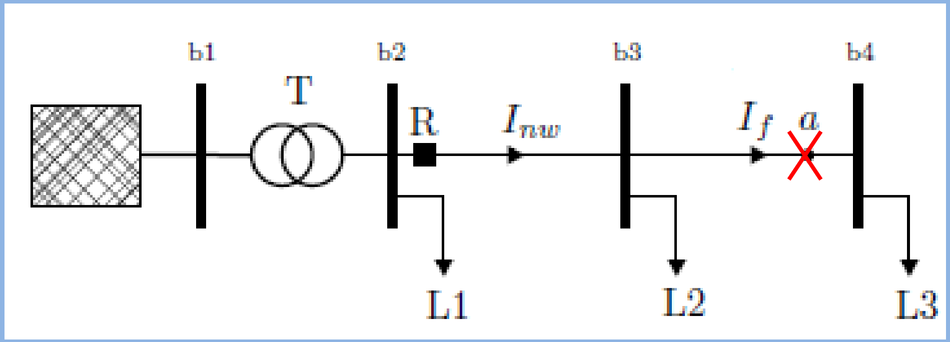
The impedance measured by the relay R:

$$Z_r = \frac{V_r}{I_{nw}} = Z_{23} + Z_{3a} + \underbrace{\frac{I_{dg}}{I_{nw}} Z_{3a}}_{\text{disturbance}}$$

REDUCES THE REACH!

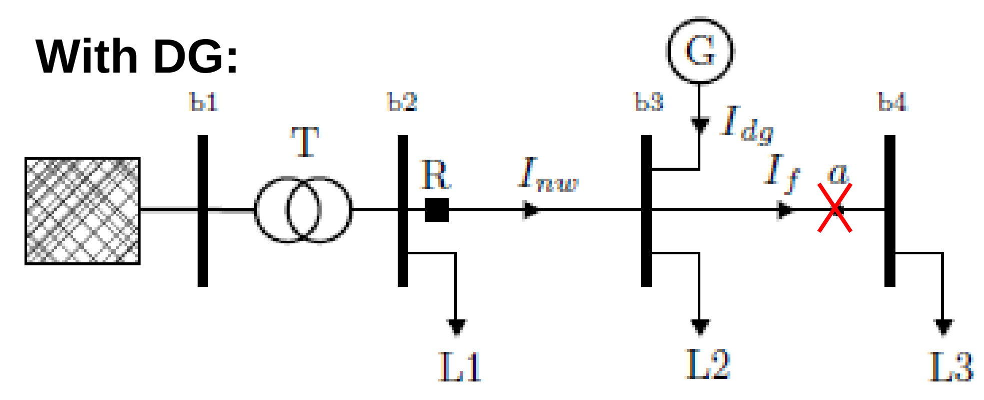
DG Protection Issues
Short-Circuit Current

❖SCENARIO 1: Fault at point 'a'



$$I_f = I_{nw} = \frac{1}{|Z_{th}|}$$

Z_{th} is the inner impedance of the Thevenin representation of the network in p.u.



$$I_f = I_{nw} + I_{dg}$$

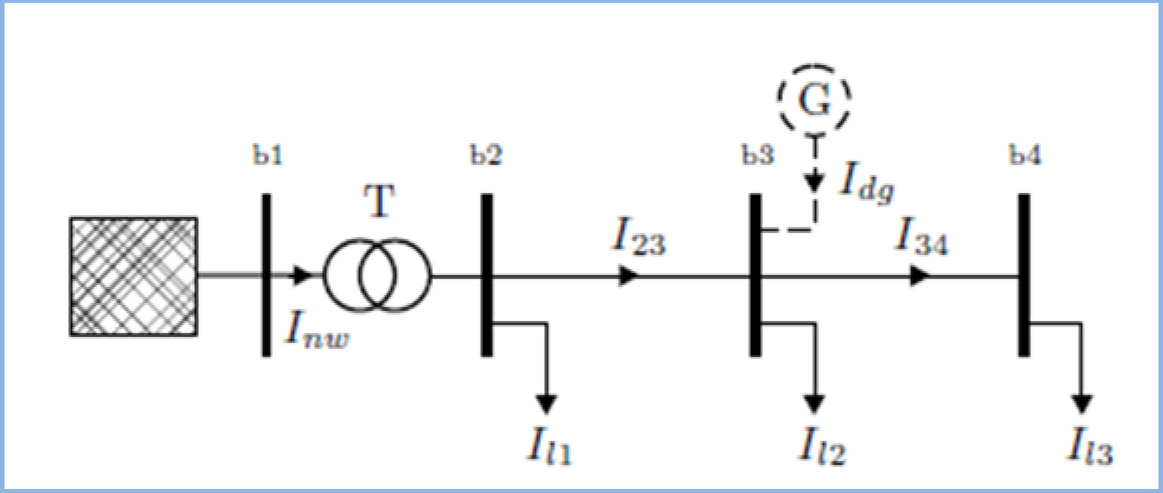
AMPLITUDE!

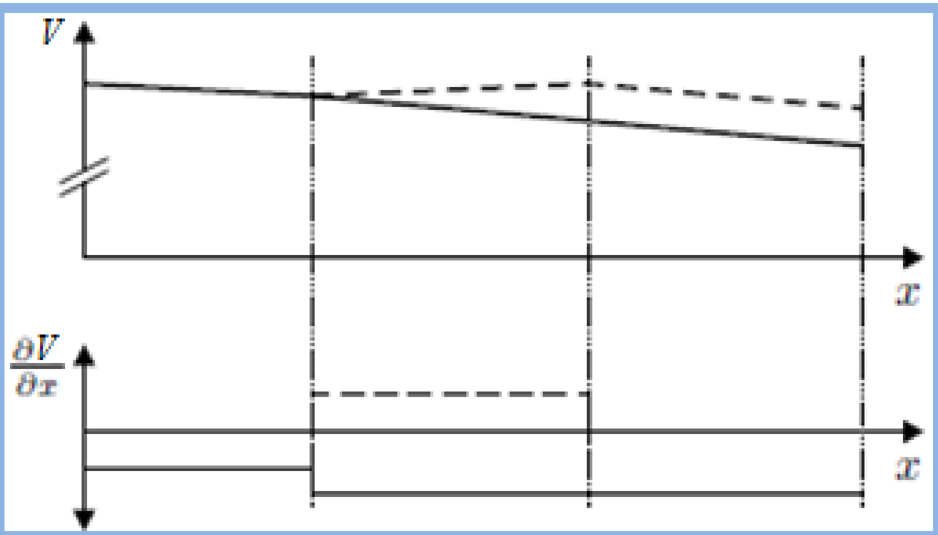
❖SCENARIO 2: Fault at 'b2'

With DG: Reverse current flow at the directional relay 'R'

DIRECTION!

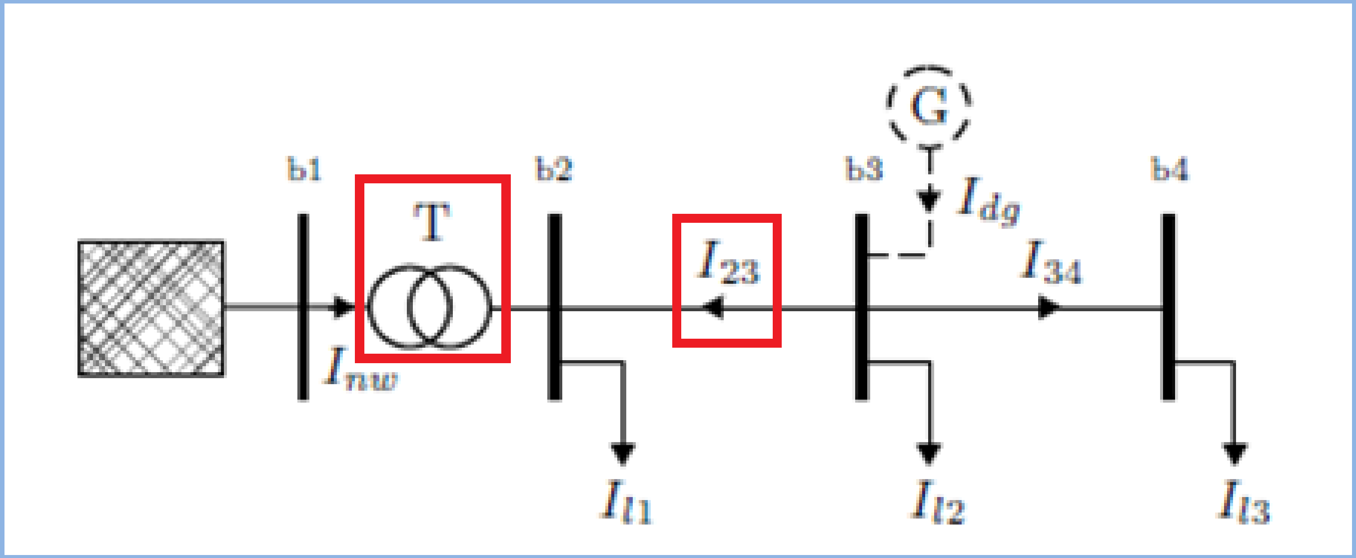
DG Protection Issues
Voltage Profile





Distributed generation impacts the voltage profile at local buses.

DG Protection Issues
Reverse Power Flow



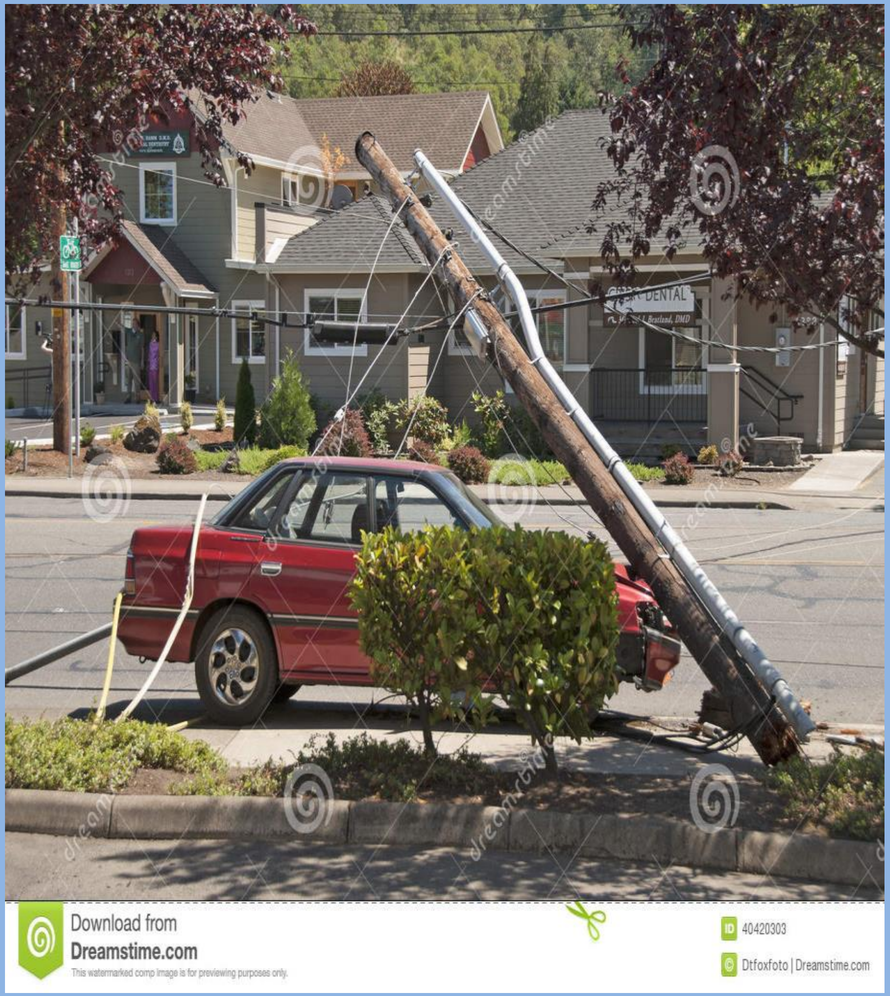
Reverse Power Flows cause issues with automatic tap changers.

Typical Distribution Substation Construction

Equipment Damage

Equipment Damage

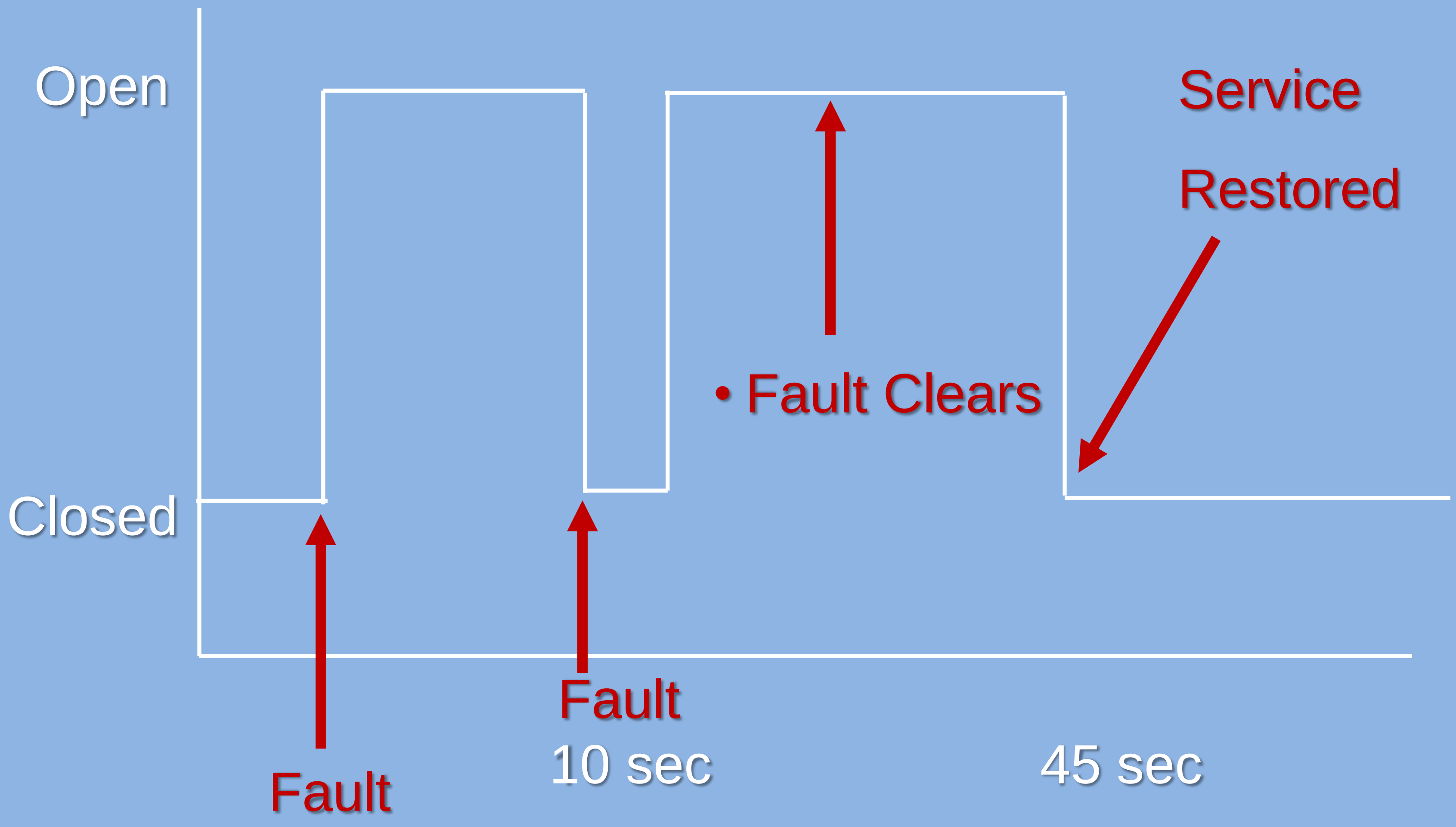
Personal Safety



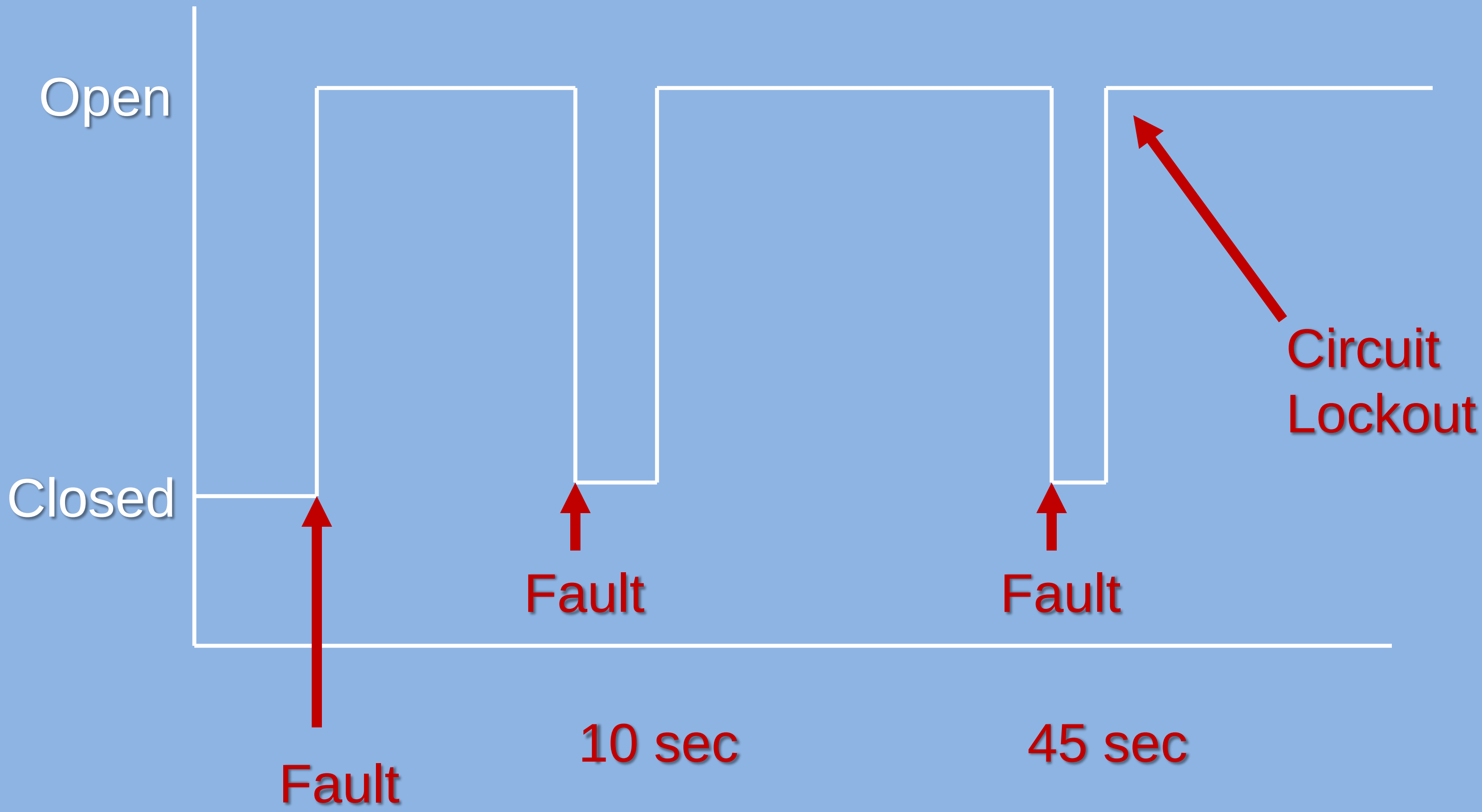
Personal Safety

Distribution Reclosing Practices

Breaker Reclosing Cycle
Temporary Distribution Fault



Breaker Reclosing Cycle
Permanent Distribution Fault



How Does DER Integrate into This System

Std 1547: Interconnection Is The Focus

IEEE Std 1547: Interconnection system requirements & specifications, and test requirements & specifications

OVERVIEW

- IEEE 1547 series are standards for interconnecting distribution resources with electric power systems which helps utilities tap surplus electricity from alternative sources.

- The standard establishes technical requirements for electric power systems interconnecting with distributed generators such as fuel cells, photovoltaic, micro-turbine, reciprocating engines, wind generators, large turbines, and other local generators.

IEEE 1547: What's in it?

- Interconnection technical specifications:
  - General requirements
  - Response to Area EPS
  - Abnormal conditions
  - Power Quality
  - Islanding

UL 1741: A Companion to IEEE 1547

- UL 1741 is a standard for inverters
- Provides a basis for certification of inverter-based systems, sometimes called “pre-certified”
- Goes beyond IEEE 1547 to include:
  - Construction, materials, wiring, component spacing, etc.
  - Protection against risks of injury to persons
  - Output characteristics and utility compatibility
  - Ratings and labeling
  - Specific DR Tests for various technologies (PV, Wind, microturbines, fuel cells and engines)

Questions?