"Power System Protection" – Where Are We Today?

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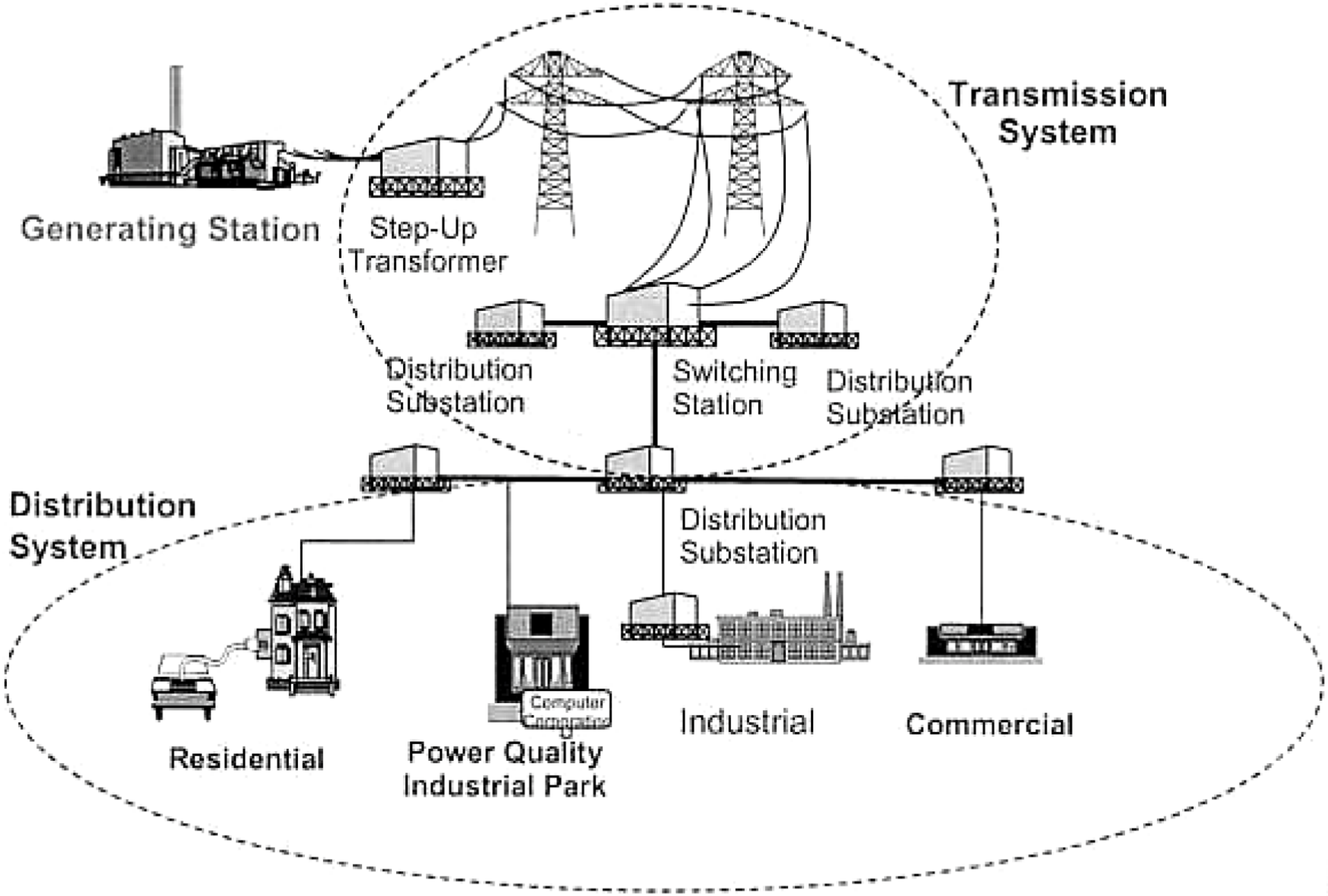
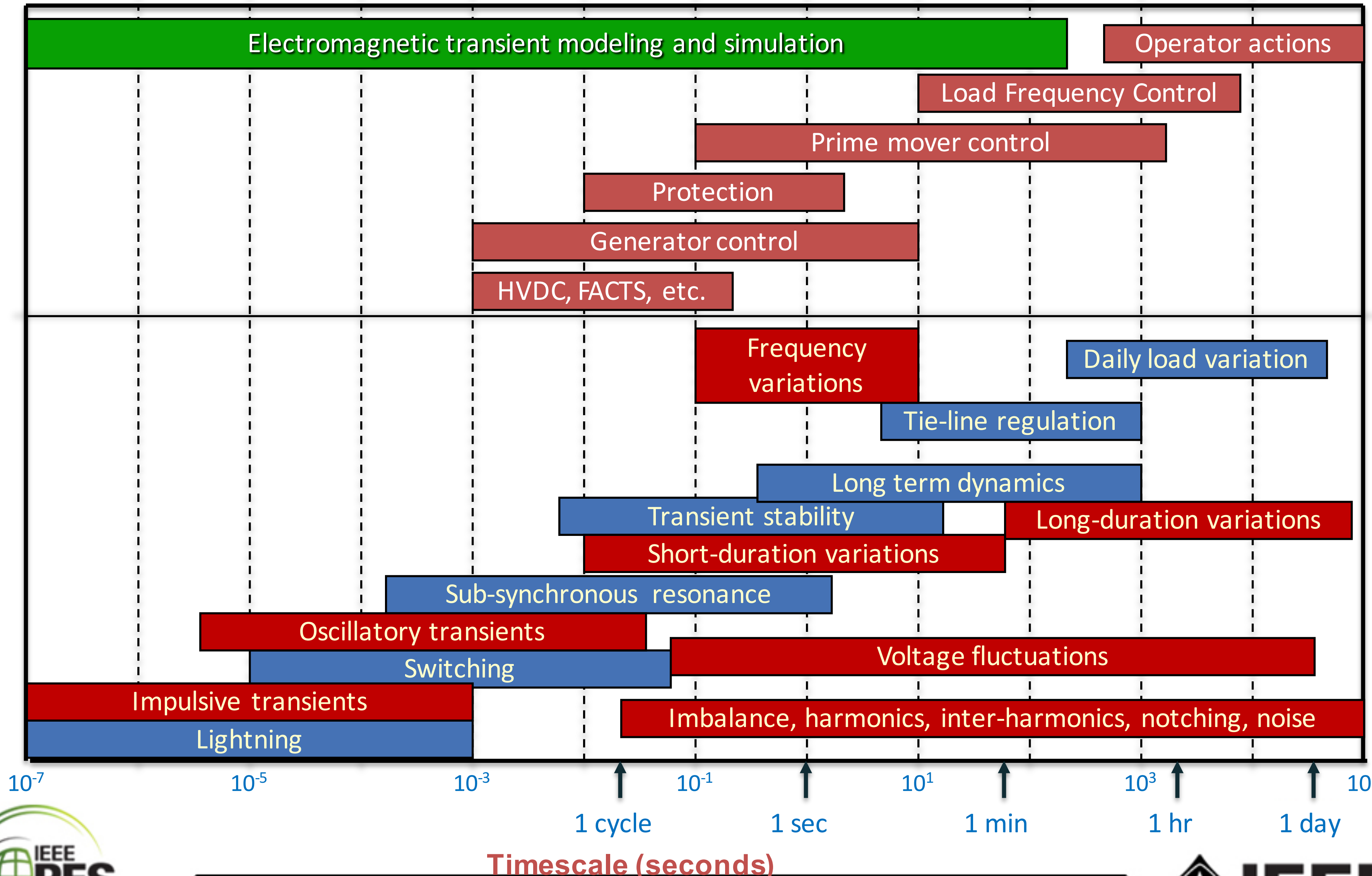
Electrical Power System Components



Time Scales of Power System Phenomena



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System Studies and Outputs

- **Steady State**

  Short Circuit Fault Level

  - ✓ Equipment Selection (isolation level)
  - ✓ Reference for Protection Settings

- **Dynamic State Simulation**

  Speed of the fault clearing time

  - ✓ Non-communication assisted scheme
  - ✓ Communication assisted scheme

- **Transients Simulation**

  Tripping Priority regarding to:

  - ✓ Overvoltage's conditions
  - ✓ Power Quality (harmonics)

Power System Transmission

How to Model Transmission Line?

➤ **Electrical Behavior of Transmission Line**

-[dV/dx]=[Z][I]

-[dI/dx] = jω[C][V]

➤ **Series impedance matrix *[Z]***

$$\lfloor Z \rfloor = \lfloor R(\omega) \rfloor + j\omega \lfloor L(\omega) \rfloor$$

$$Z_{ii} = R_{ii}^{c} + j\omega\overline{L}_{ii}$$

$$Z_{ik} = j\omega\overline{L}_{ik}$$

Transmission Line Inductance

$$\overline{L}_{ii} = \left(\frac{\mu_o}{2\pi}\right)\ln\left(\frac{2\cdot\left(h_i + \overline{P}\right)}{r_i}\right) = a - jb$$

$$\overline{L}_{ik} = \left(\frac{\mu_o}{2\pi}\right)\ln\left(\frac{D'_{ik}}{d_{ik}}\right) = c - jd$$

$$\overline{P} = \sqrt{\frac{\rho_o}{j\omega\mu_o}}$$

Formula Quantities

$R_{ii}^{c} =$ a.c. resistance of conductor *i*,

$\omega = 2\pi f$, angular frequency,

$f =$ frequency in Hz,

$h_i =$ average height above ground of conductor *i*,

$r_i =$ radius of conductor *i*,

$d_{ik} =$ direct distance between conductors *i* and *k*,

$D_{ik}^{'} =$ distance between conductor *i* and image

at complex depth of conductor *k*,

$\rho_o =$ earth resistivity,

$\mu_o =$ earth permeability.

$$Z_{ii} = R_{ii}^{c} + j\omega(a - jb) = (R_{ii}^{c} + \omega b) + j\omega a = R_{ii} + j\omega L_{ii},$$

$$Z_{ik} = j\omega(c - jd) = \omega d + j\omega c = R_{ik} + L_{ik}.$$

Power System Disturbances and Faults

- **Inadequate supply equipment**
  - ***Result of inadequate planning or unexpected rapid load demand***
  - ***Exceeding supply capability results in load losses***
- **Many blackouts caused by operating systems too close to stability limits**

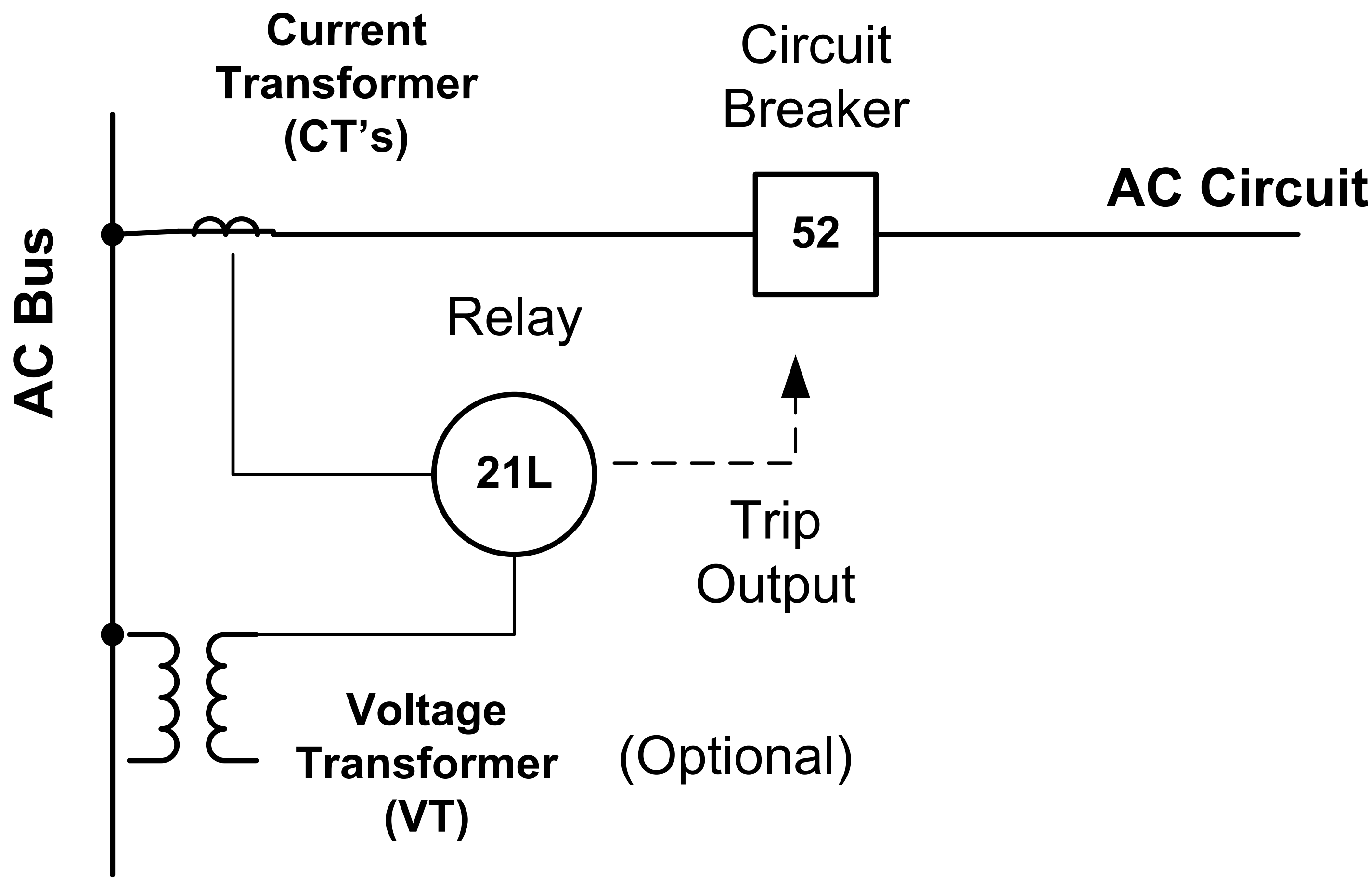
Power System Protection

Protective relays provide the "brains" to sense trouble, but they are not able to open and isolate the problem area of power system.

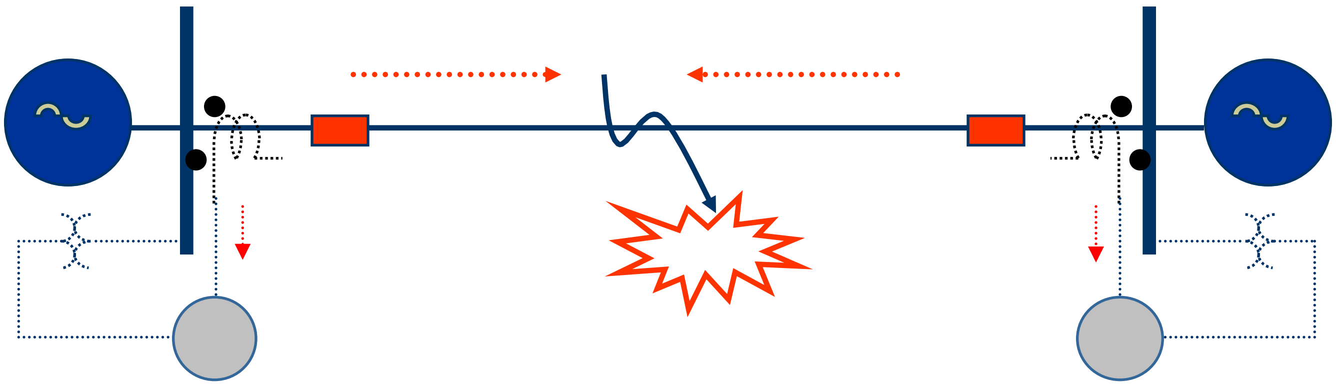
#

Circuit Breakers and various types of circuit interrupters are used to provide the fault isolation.

Relaying Fundamentals



Protection Duties



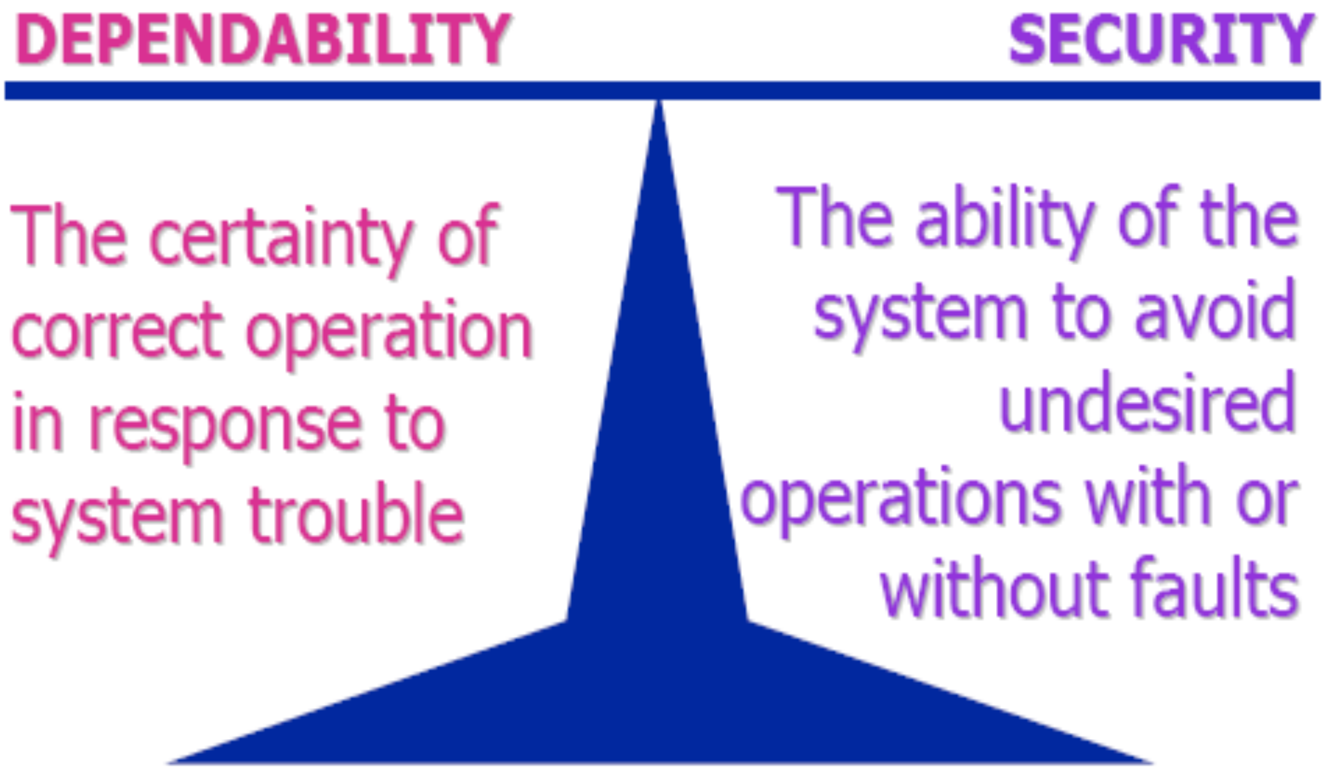
- *Protection system or relay must detect the fault and signal circuit breaker to isolate the fault reliably and as fast as possible.*

Protection Scheme Design Criteria

PERFORMANCE	ECONOMICS
Speed	$
Functionality	$
Reliability	$
Longevity	$
Simplicity	$

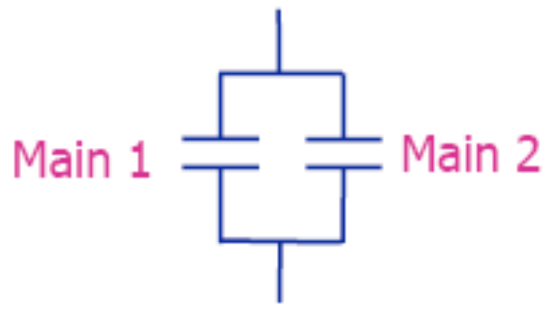
Reliability

The protection systems should be dependable and secure



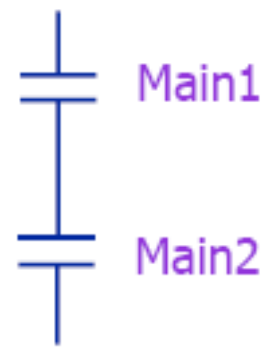
Reliability

DEPENDABILITY



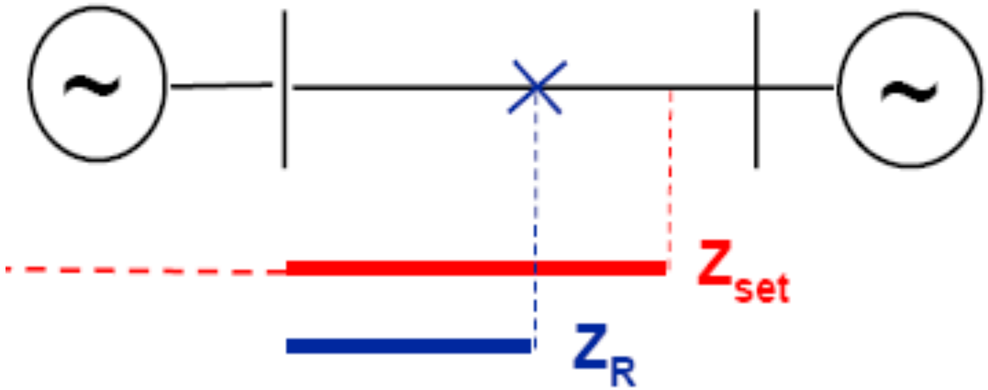
The certainty of operation in response to system trouble

SECURITY

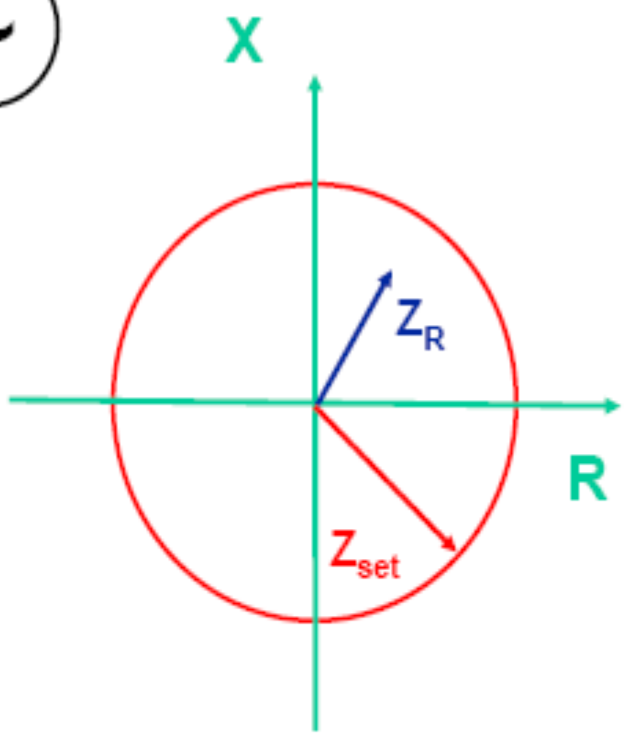


The ability of the system to avoid misoperation with or without faults

Impedance measurement

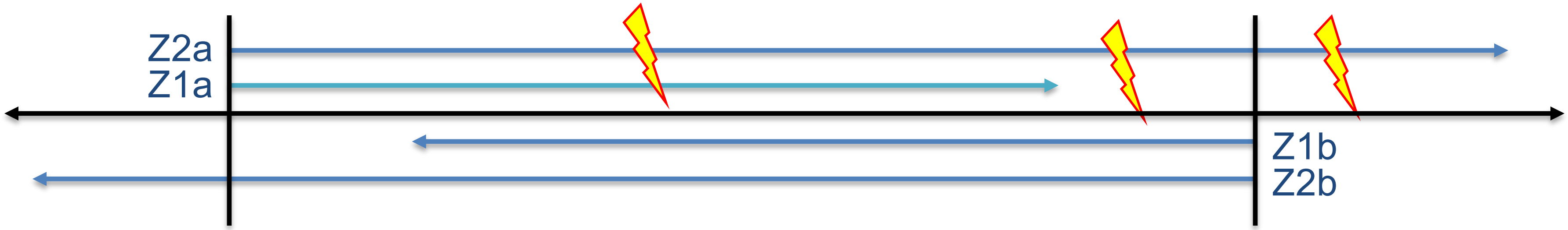


$$Z_R = \frac{V_R}{I_R} < Z_{set}$$

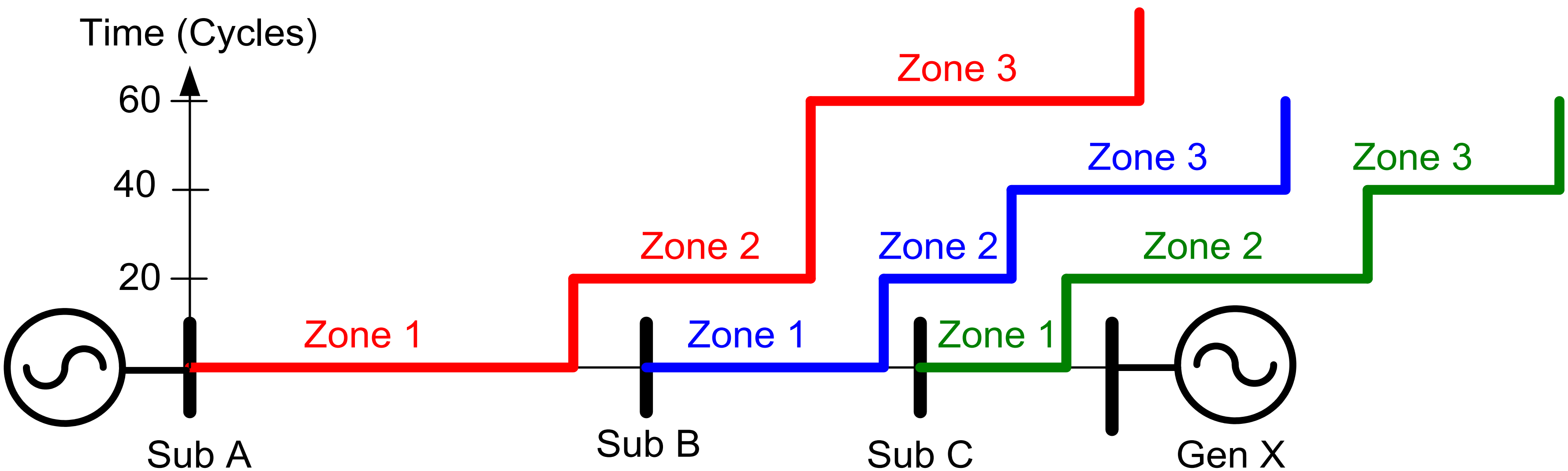


Stepped Distance

- **Note: NOT communications assisted, but good background for other schemes**



Example reaches and time coordination



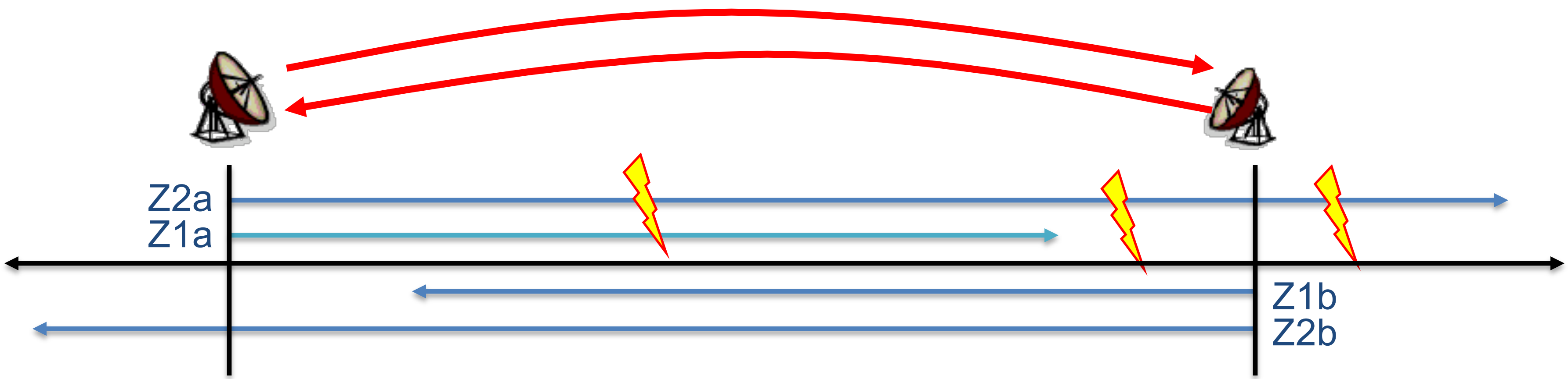
Line Protection Reaches

- **Reaches:**
  - ✓ *Zone 1 shall not overreach protected line.*
  - ✓ *Zone 2 elements shall be set as far as possible without overreaching remote instantaneous elements.*
  - ✓ *Zone 3 elements shall be set to cover longest remote line, or as far as possible without risk of tripping under emergency load conditions*
- **Speed:**
  - ✓ *Zone 1 instantaneous*
  - ✓ *Zone 2 time delayed to coordinate with remote protection*
  - ✓ *Zone 3 time delayed to coordinate with remote protection*

Communication assisted line protection?

- ***Speed, speed, speed…***
- ***Selectivity problem (ie: is the fault between the two ends of the line?)***
- ***Adding communications allows cooperation between both line terminals, which improves speed by improving selectivity***

Permissive Overreaching Transfer Trip



- Sending Permissive Trip = “fault is in front of me”
- Received Permissive Trip + local Zone 2 = local trip

Protection concept

- Protections are provided by redundant ***designated primary and standby protection***, or PYPN and SYPN using ***identical* or different manufacturer *multifunctional* relays.**
- Each, PYPN and SYPN are connected to ***separate current transformer cores and voltage transformer windings***.
- Dependability of the single circuit breakers are provided by ***breaker failure protection*** and primary and standby breaker trip coils
- **Line protection using telecommunications** are equipped with functions that operate to provide fault clearing independent of the telecomm
-

Telecommunication

Telecommunication is provided with modernized network infrastructure (Digital Microwaves) which, together with multifunctional protection devices allow optimizing the existing /new power system operation.

Automatic Reclosing

- Automatic single-shot reclosing is provided for all air insulated transmission lines.
- Automatic reclosing is not provided for lines that are all cable.

Power Quality

This protection consist of

- Over-frequency,
- Under frequency,
- Over-voltage
- Under-voltage elements

Security

- **Security is achieved**

(Secure protection system should not operate for normal system operation or when not required to operate to clear a fault)

  - **with appropriate operating levels for fault detection functions (current, voltage and impedance),**
  - **with selective protection systems,**
  - **with supervision by voltage, impedance, load- blinding and directional functions.**

Selectivity

- **Selectivity is achieved**
- ***(Protection systems remove from service the minimum number of system elements necessary to clear a fault)***
  - **with closed zone protection,**
  - **with appropriate operating levels for fault detection functions (current, voltage and impedance), and**
  - **with time coordination of fault detection functions.**

Speed

- Protection systems provide fault clearing in a minimum time, considering time delays required to achieve security and selectivity.
- High speed fault clearing without time delay is sometime required, in which case security and selectivity must still be maintained.

Loadability

- Protection is not limit the load carrying capability of major equipment such as transmission lines, transformers, circuit breakers, disconnect switches
- Loadability requirements of NERC Standard are applied for transmission lines and transformers

Special application issues

- Sync Check
- Out of step (OOS) protection

The OOS logic determines whether a power swing is stable and

- ✓ Generates the set points of Zone 6 and Zone 7 associated to OOS protection
- ✓ Set the relay logic to block distance protection longer than the OOS tripping delay

- Overload protection

"Summer" and "winter" settings account for the variation of rated circuit capacity with ambient temperature and is applied in the line protection devices.

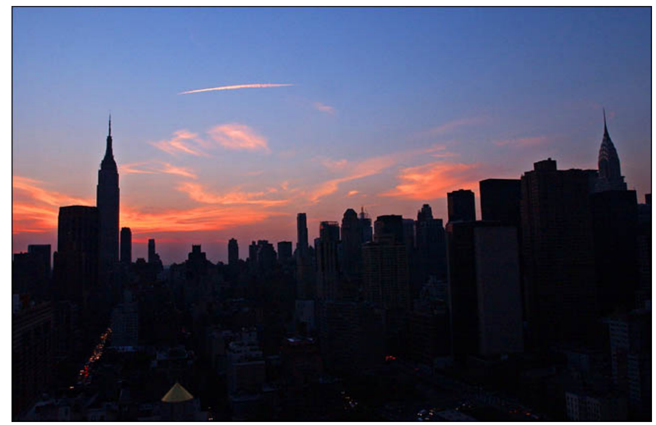
- ✓ Local "Summer" / "Winter" settings are "ENABLE/DISABLE" on the relay.
- ✓ "Summer" / "Winter" settings are automatically switched by the analog quantity DDOY "Time and Data Management".
- ✓ Settings automatically switch to the Summer Over Load protection setting on selected day depend of region (i.e. April 1) of each year then switch back to the Winter setting in winter period (i.e. Nov 1).

Remedial Action Schemes (RAS)

Remedial Action Schemes

(special protection schemes designed to prevent cascading outages, unacceptable operating performance or to support system operating limits)

- **RAS are designed to detect the system condition that can cause**
  - ✓ **Instability**
  - ✓ **Overload**
  - ✓ **Voltage collapse**



- **RAS Include**
  - **protection sensing facilities**
  - **arming facilities under the control of the system control centres**
  - **action sites where generation shedding**
  - **load shedding**
  - **reactive switching**

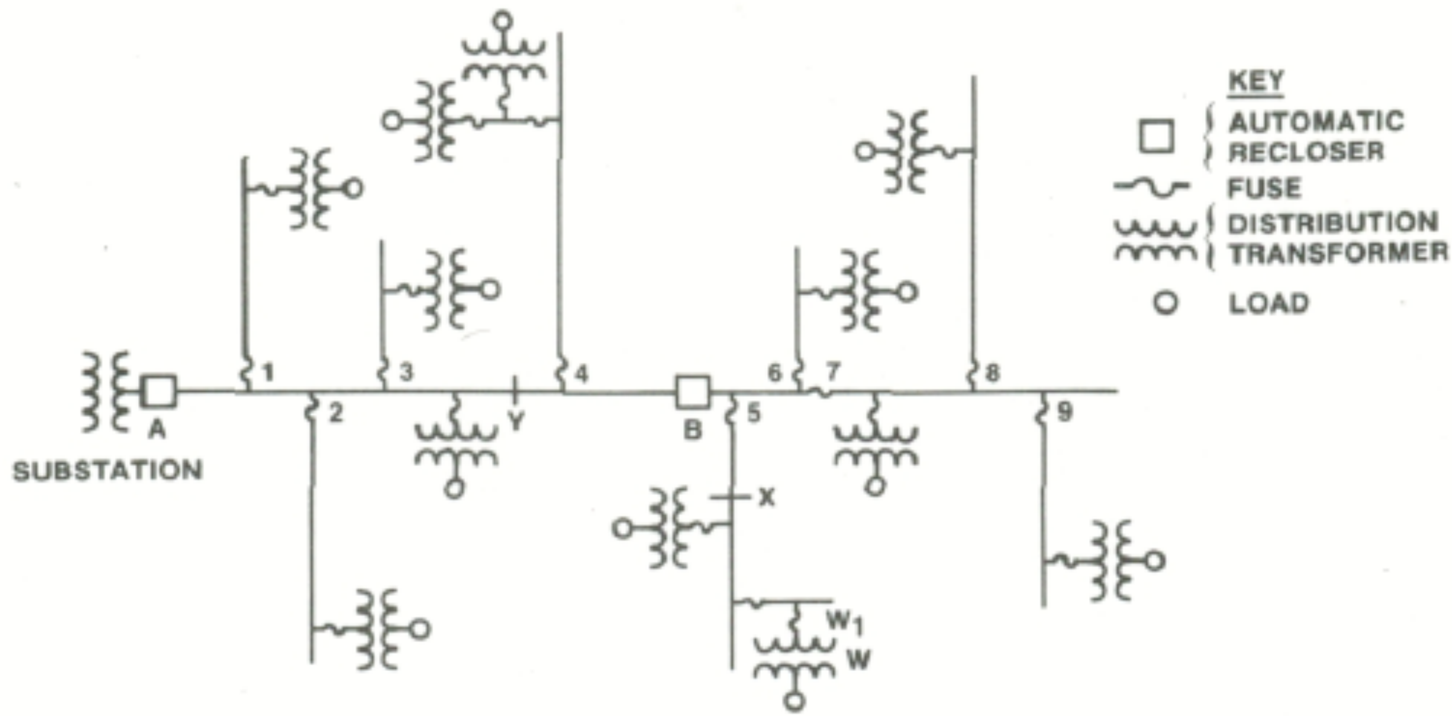
Multifunctional Relay Devices

Multifunctional numerical relays are used in majority protection schemes

- **allow an implementation of almost all the functionalities needed to protect and control the power system components more efficiently:**
  - ✓ Fundamental protections (*Over Current, Over Voltage, Over Frequency, Distance, Differential Protections)*
  - ✓ Breaker Failure protection (BFPN)
  - ✓ Autoreclose (AR)
  - ✓ Automatic switching of protection settings
  - ✓ Overload protection
  - ✓ Wide area special protection schemes (SPS) or remedial action scheme (RAS)
  - ✓ Synchronized Phasor Measurement

Power Distribution System

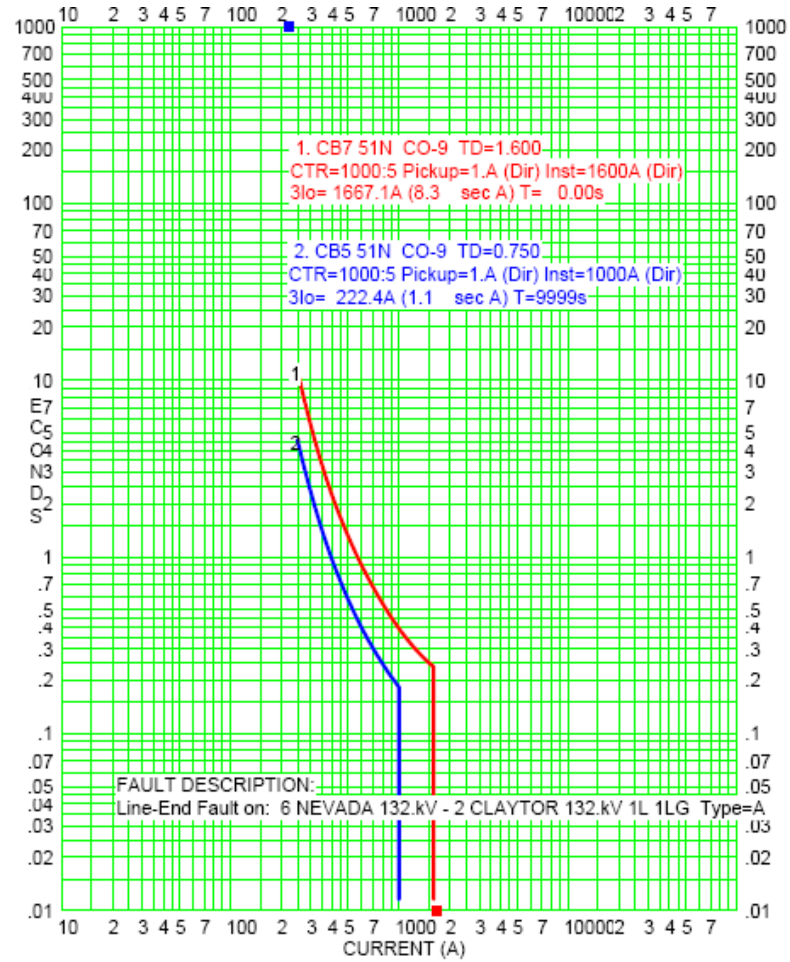
Distribution system is designed to serve radial load
(Power flows from higher voltage levels down to customers)



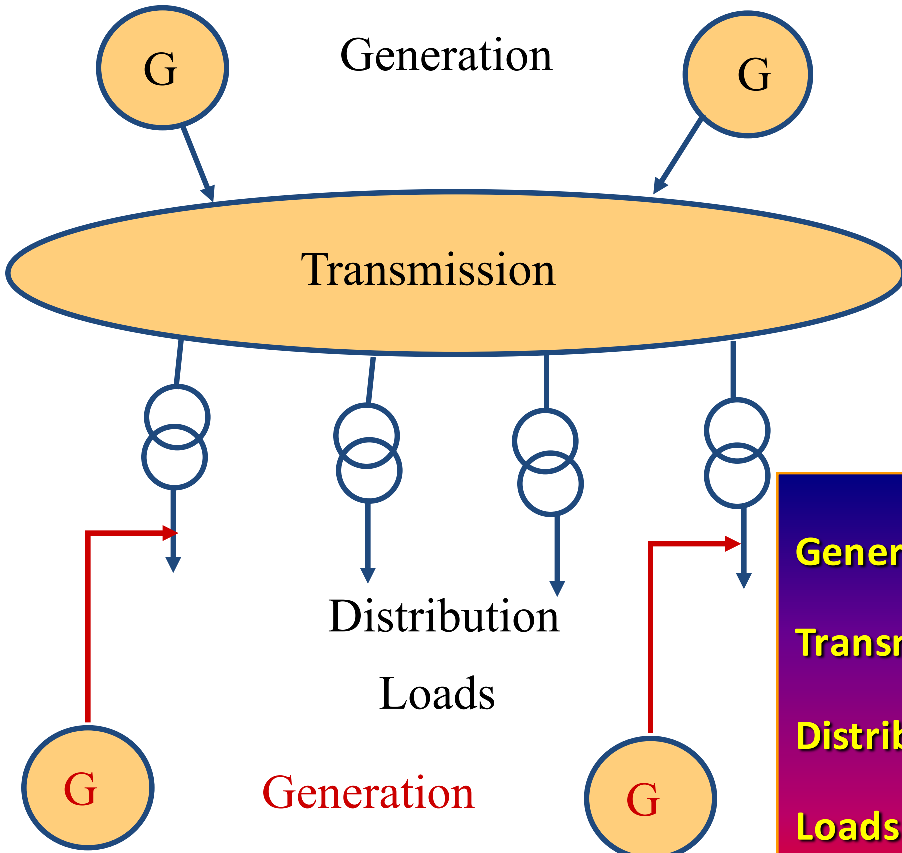
DISTRIBUTION FEEDER WITH AUTOMATIC RECLOSERS AND FUSE CUTOUTS

Distribution Protection

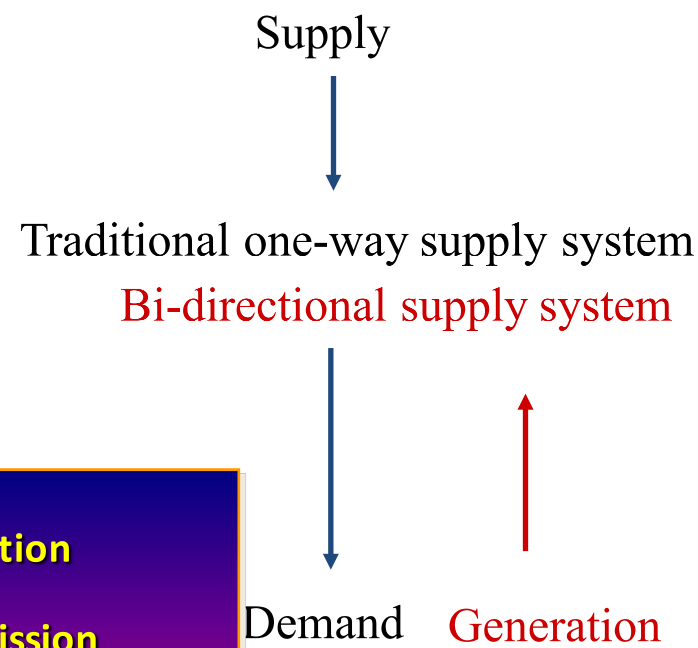
- Relay characteristics are plotted on a time current characteristic (TCC) diagram.
- Non directional protection is needed because of radial system configuration



Power System Design Today



- **Generation**
- **Transmission**
- **Distribution**
- **Loads**
- **Interconnections**



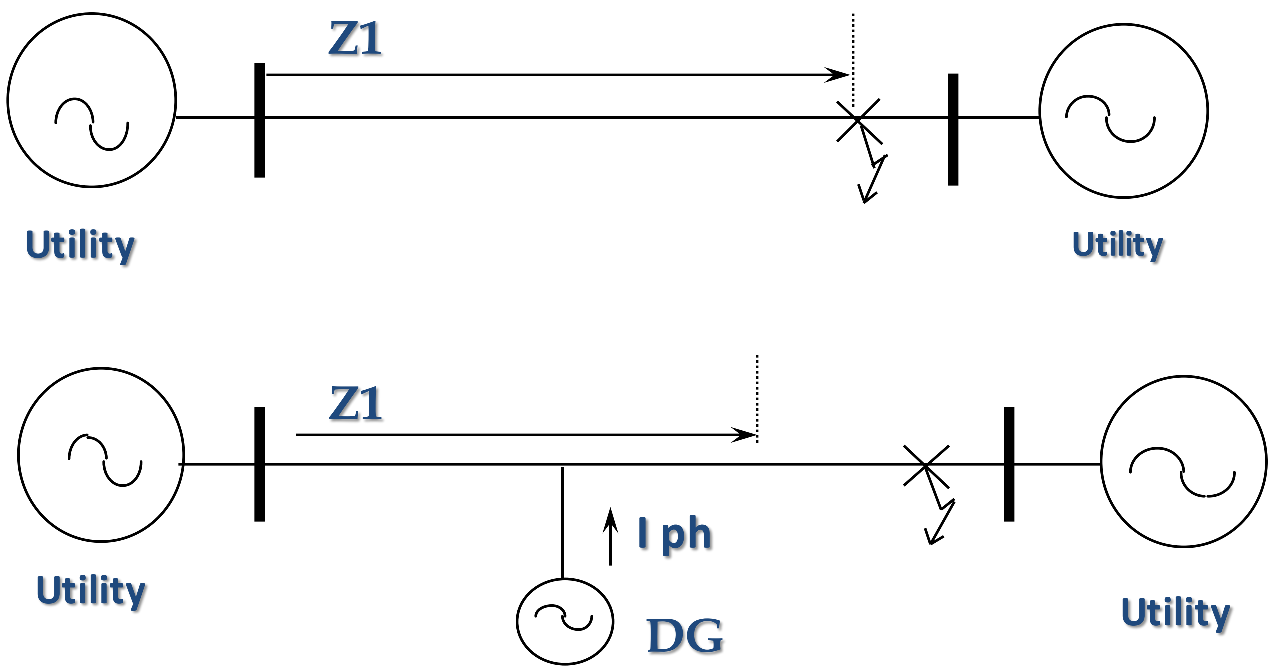
Concerns related to the distribution system operation and planning

With DG increases, Distribution System is becoming more like transmission system:

- **double or multiple feed circuits having significant changes in operation**
- **protection system becomes more complex due to changes in system behavior and power flow under short-circuit conditions**
  - ✓ ***Protection have to accommodate bi-directional power flows***
- **safety of public and equipment**
  - ✓ ***as the network was not designed to accommodate larger numbers of DG***

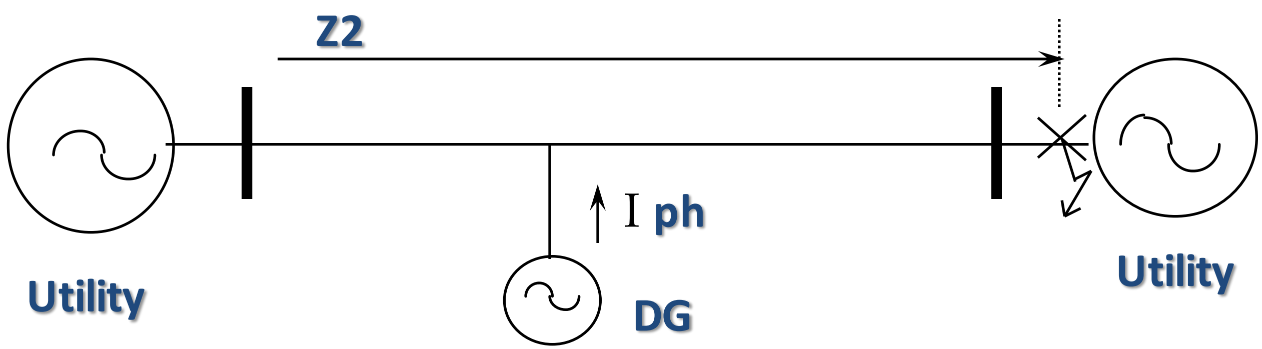
Impedance Settings

✓ Reduced Z1 coverage

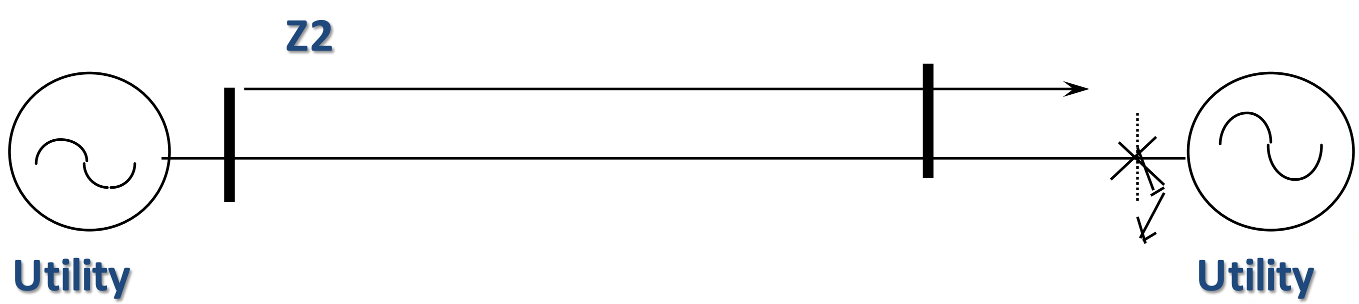


Impedance Settings with DG

- ✓ *Must increase Z2 coverage to deal with infeed*



- ✓ *Consequence: longer reach if IPP is out of service*



A Fork In The Road

DG's Transformer connection

?

HV Grounded star connected

- ✓ no overvoltage problems

but, ground relaying desensitization

HV Delta connected

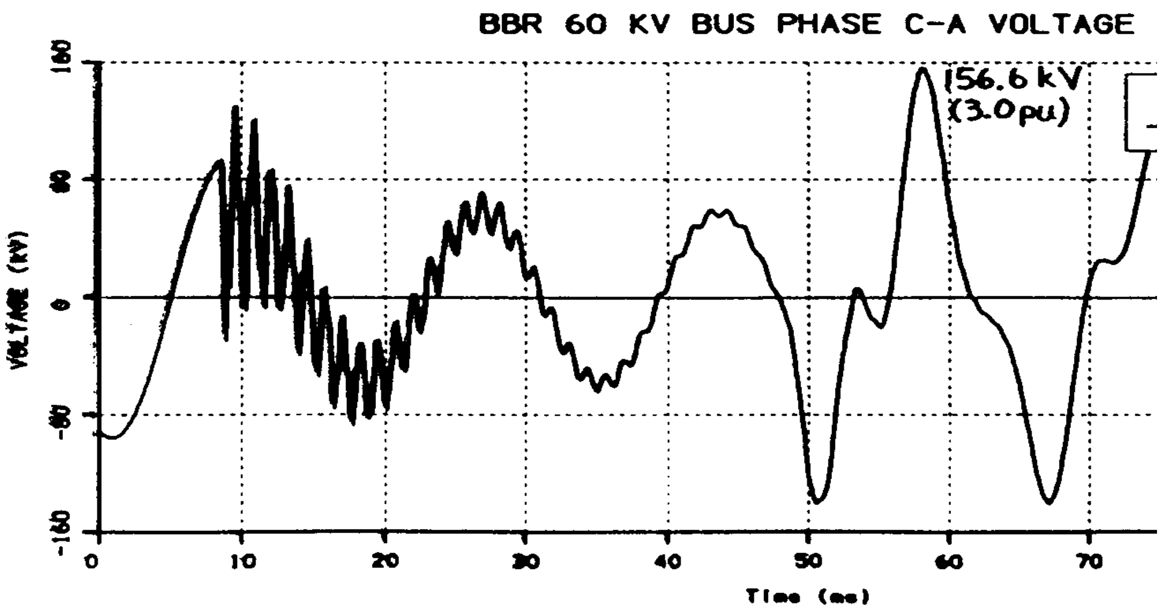
(not a source of ground fault current)

- ✓ no ground relay sensitivity problems

but, overvoltage problems

Transient Overvoltages

- ✓ ***Problem - non 60 Hz basis***
- ✓ ***EMTP analysis***



Overvoltages approaching 3 pu

Ground Relay Desensitization

Why is Ground Relay Sensitivity So Important?

- ✓ *High soil resistivity*
- ✓ *High impedance faults due to impedance in fault path*

My remark

Although Telecommunication (provided with modernized network infrastructure) which, together with multifunctional protection devices allow optimizing the existing /new power system operation, the *expertize in Power System Operation is MAIN KEY in providing Reliable Power System Operation.*