HV Shunt Reactor Intelligence Protection Scheme- How it Makes Grid Smarter

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OUTLINE

- Power System Components Introduction
- HV Shunt Reactors & Connections
- Circuit Breakers (CB)
- Issues Associatied with Reactor Switching
- Switching Shunt Reactors
- Turn to turn faults in reactors
- Making sensitive elements secure
- BC Hydro Reactor PN Scheme
- Conclution-Smart Solution

Power System Transmission

Selection of Appropriate Simulation Tool

Power Flow / Transient Stability Solution

- *Valid for steady-state and low-frequency swings*
- *Simplified control blocks (approximate transfer functions)*
- *Suitable for studying large systems, when transients are not concerned*

EMT-Type Solution

- *Valid over a wide range of frequencies*
- *Detailed control system models*
- *Detailed switching models for power electronic devices*
- *Harmonics Studies*
- *Simulation of transient over-voltages, lightning impulses, etc.*
- *Modelling of machine dynamics*

Behavior of Transmission Line

- **Electrical Behavior of Transmission Line**

$$-[dV/dx]=[Z][I]$$
$$-[dI/dx] = j\omega[C][V]$$

- **Series impedance matrix *[Z]***

$$[Z]=[R(\omega)]+j\omega[L(\omega)]$$

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

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

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*,

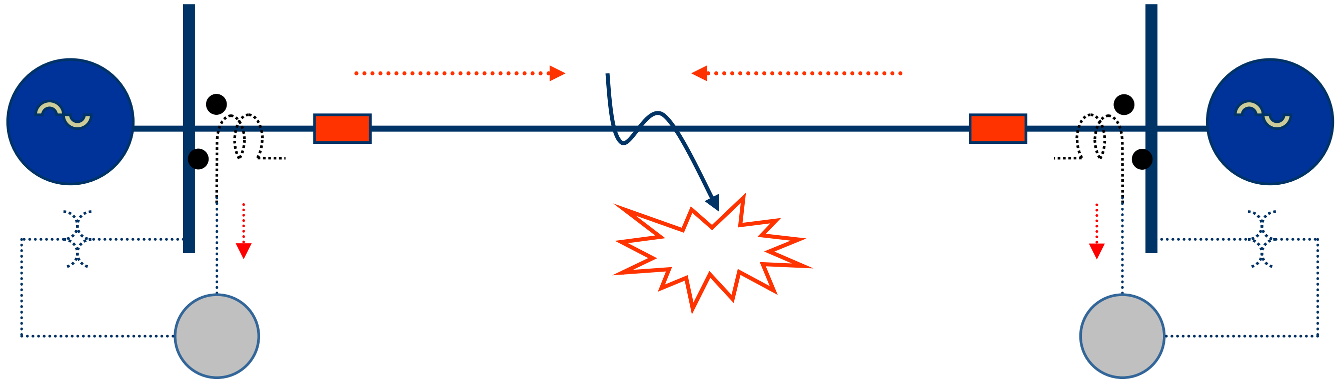
$\rho_o =$ **earth resistivity,**

$\mu_o =$ **earth permeability.**

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

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

Protection Duties



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

Reliability versus Speed

Reliability of protection system or relay includes two competing attributes:

Dependability:

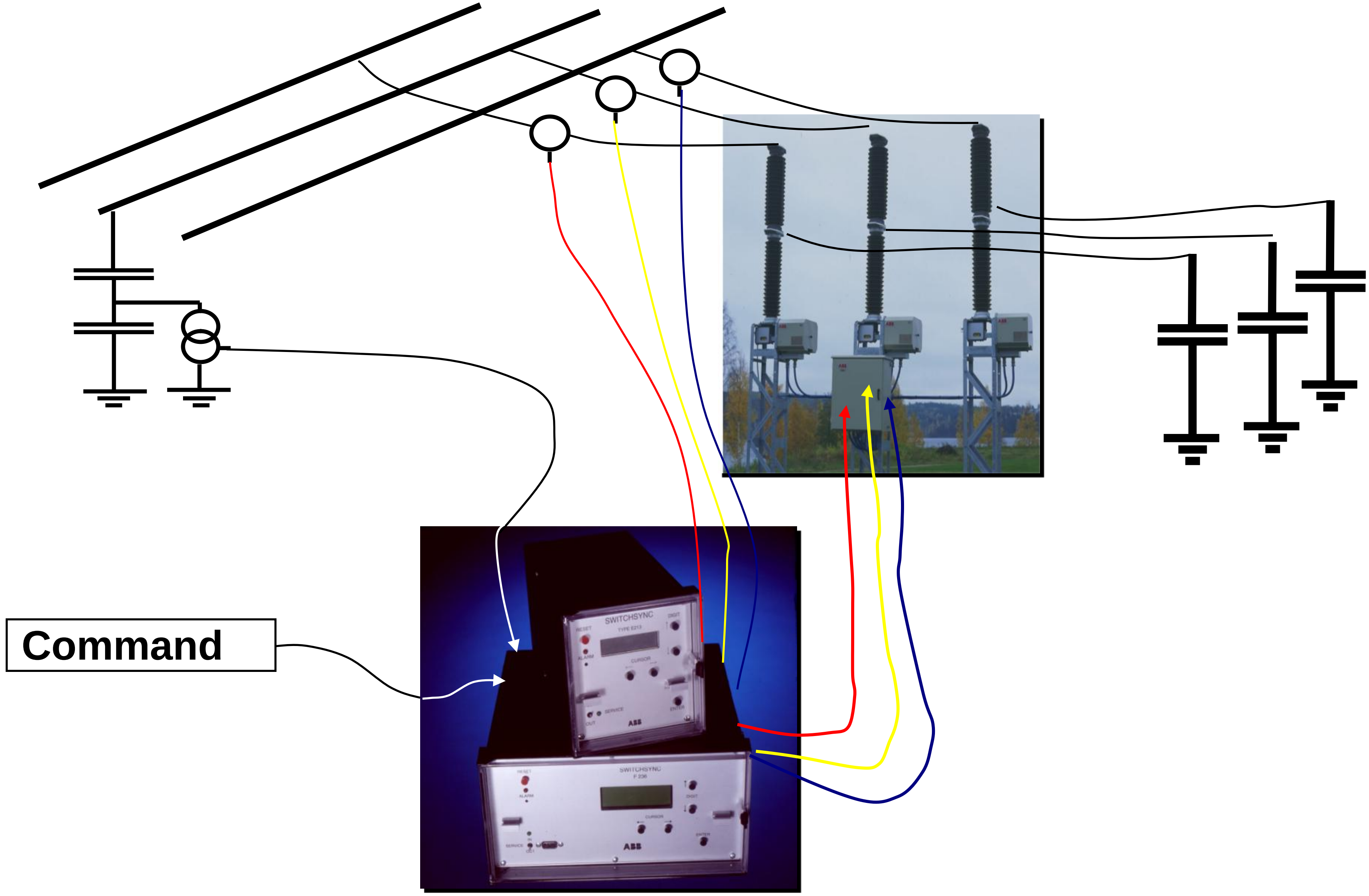
To operate correctly for situations in which it is designed to operate.

Security:

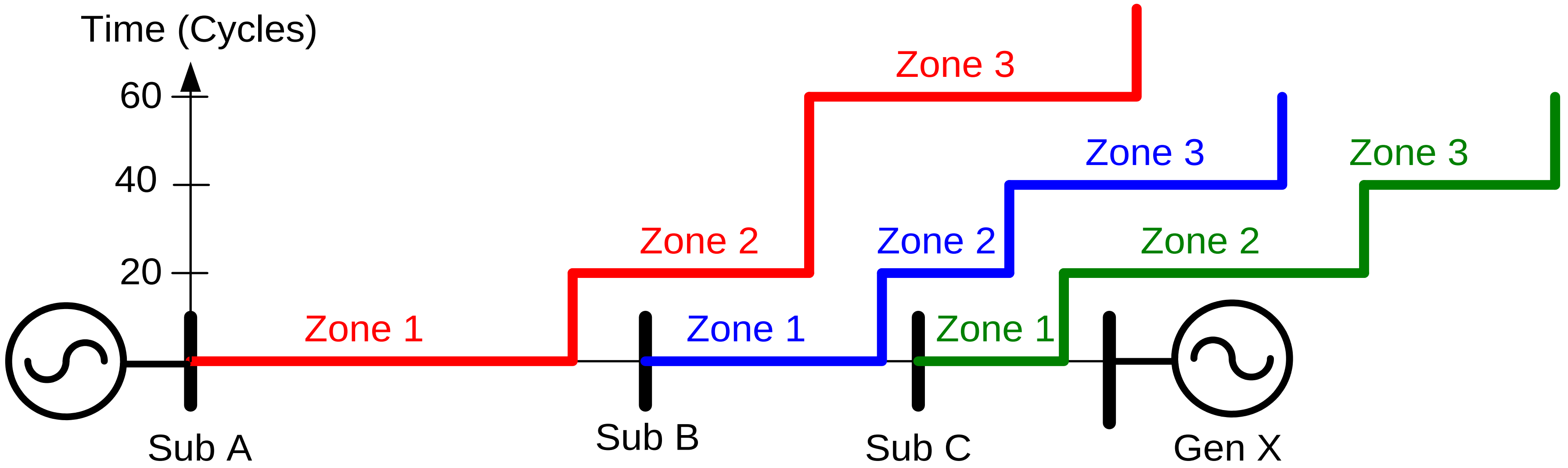
Not operating incorrectly in all other situations.

To minimise the damage from fault, the protection system must operate as fast as possible. But high speed of protection system may threaten its reliability. Thus there is a trade-off between reliability and speed.

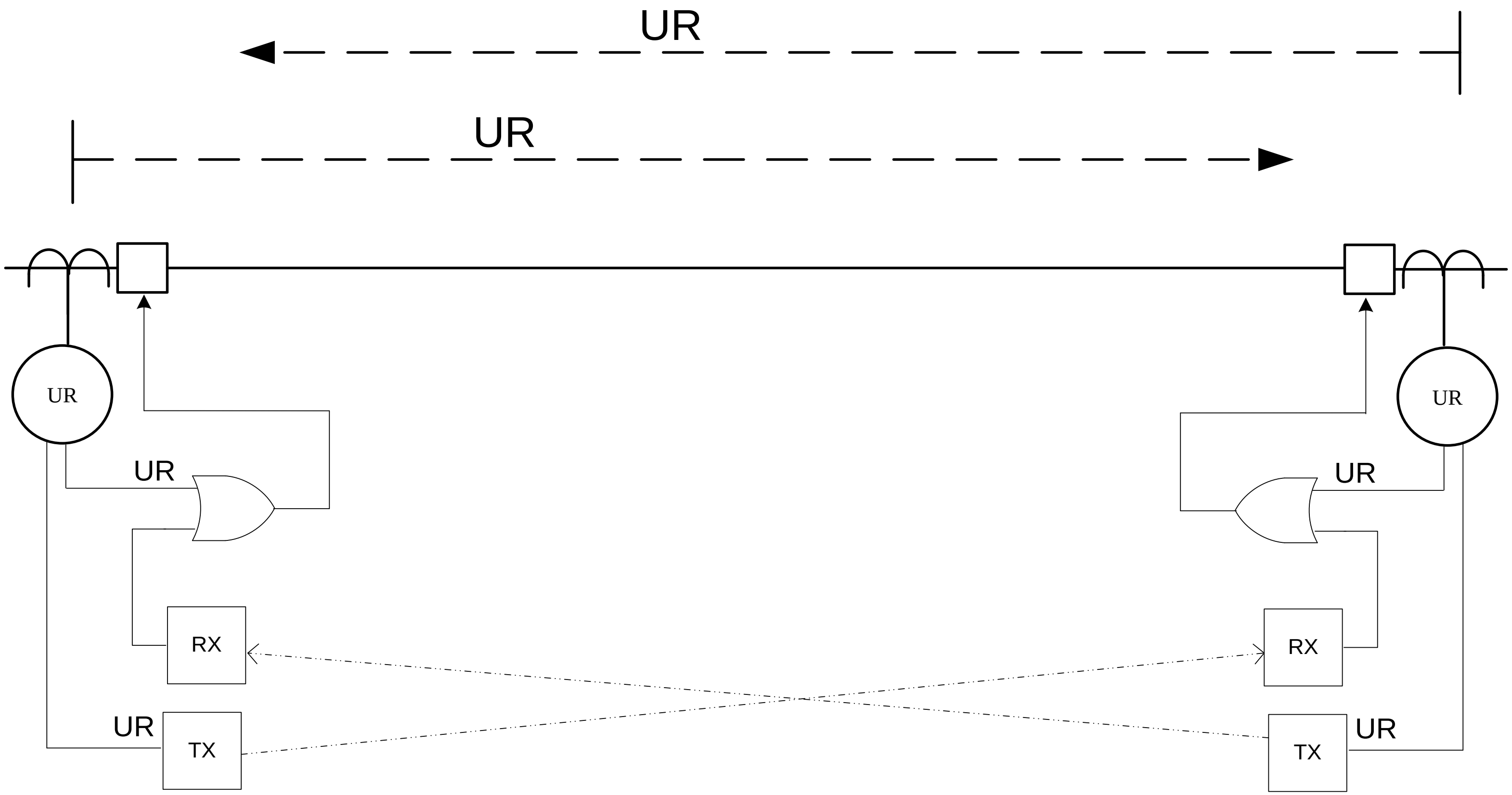
Protection Device Connected to the Line



Example reaches and time coordination



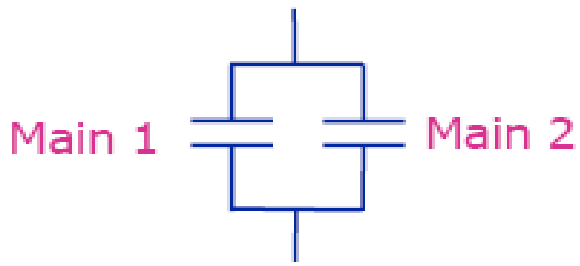
Direct Underreach Transfer trip



Underreaching elements at each end must overlap each other.
Requires very secure communications

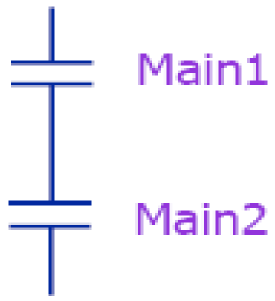
Reliability

DEPENDABILITY



The certainty of operation in response to system trouble

SECURITY



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

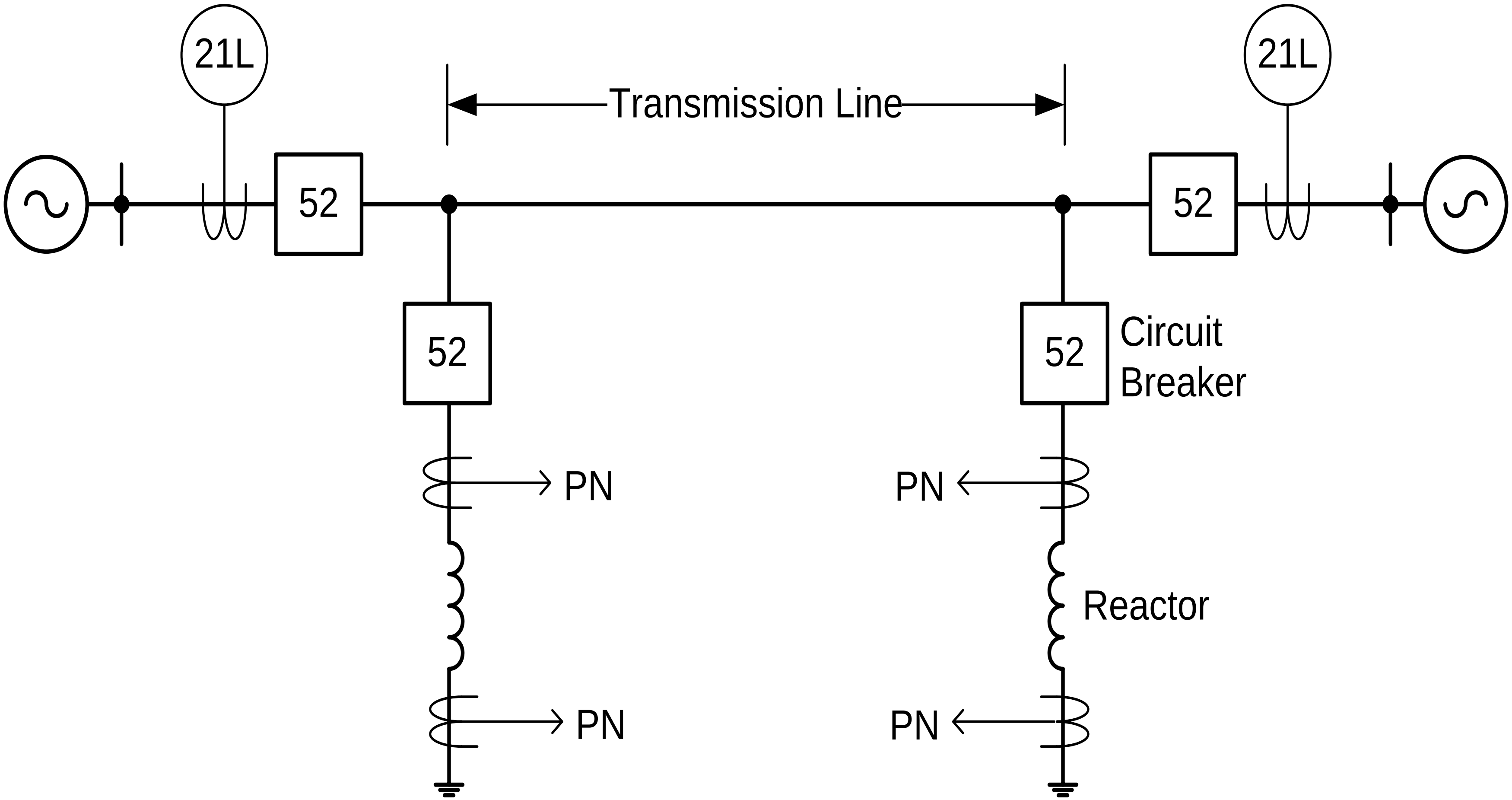
Power System Transmission Issues

- ***High charging currents of long transmission lines and cables.***

The shunt reactor as a component of the power system is used to compensate for the effects of high charging currents of long transmission lines and cables.

500 kV Shunt Reactor

Line Connected Shunt Reactor



CBs that requirement can not be standardized

The other 10% includes:

- ***Shunt Reactor switching***
- ***Capacitive Current switching***
- ***Transformer secondary fault interruption***

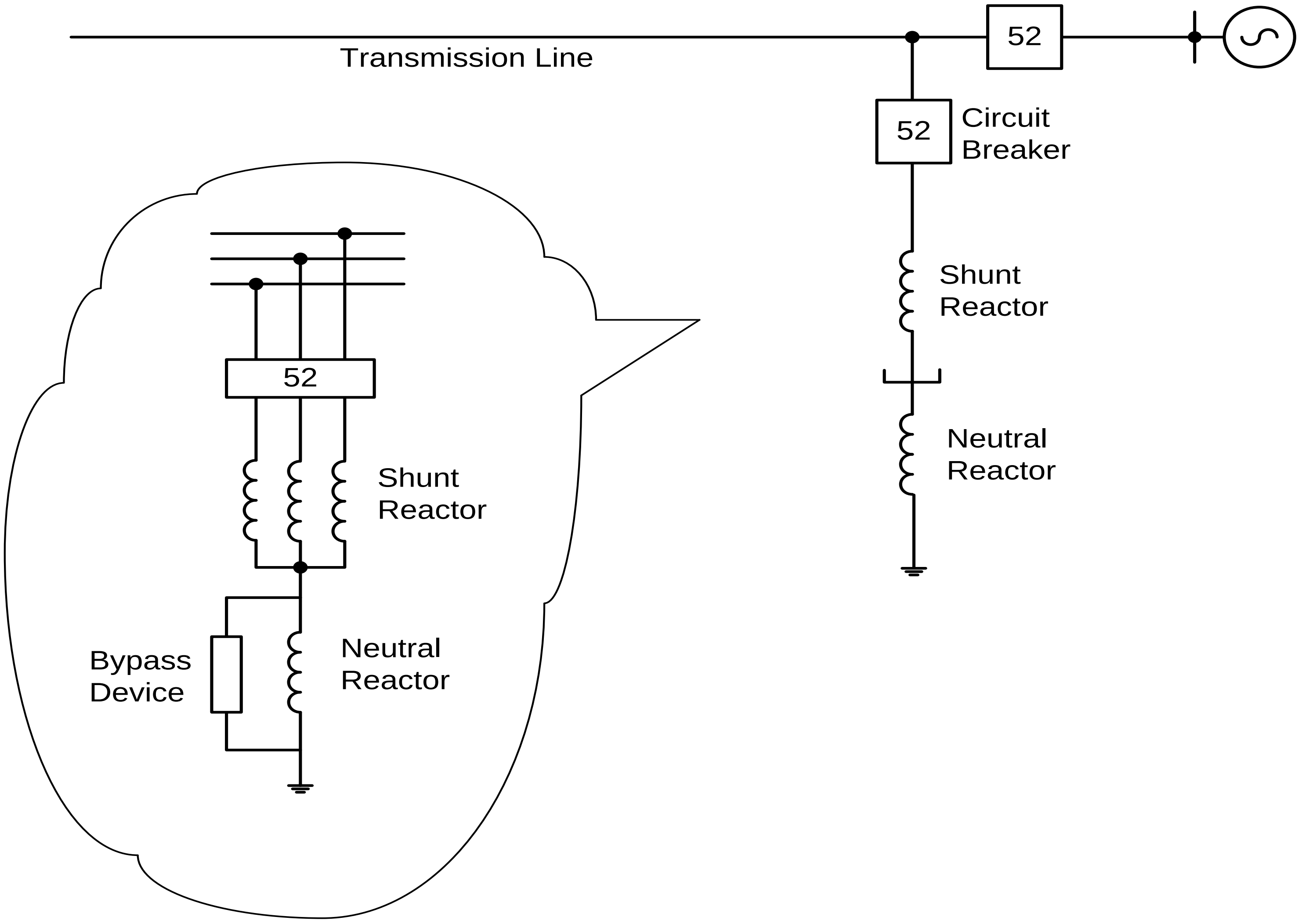
Application of CBs in HV System:

- ***Fundamental considerations***
- ***Oscillating circuits and damping***
- ***Amplitude and first-pole-to clear factors***
- ***Traveling waves***

Reactor Connections

- Reactors are wye-connected with a solidly grounded neutral, or fourth reactor connected between the reactor-bank neutral and ground (for SPT and Reclosing of CBs)

Shunt Reactor with Neutral Reactor



Neutral Reactor

- Reactors are wye-connected with a solidly grounded neutral, or fourth reactor connected between the reactor-bank neutral and ground (for SPT and Reclosing of CBs

- Shunt Reactor Current is mainly inductive and it is small (10%-15% of nominal currents)
- Shunt Reactor are frequently switched and during the periods of the system operations with low loads it is energized and with the rise of load it is de-energized again.
- Switching operations results in EMT and some mechanical effects.
    - At closing, high, unsymmetrical currents with long time constant can occur
    - During opening

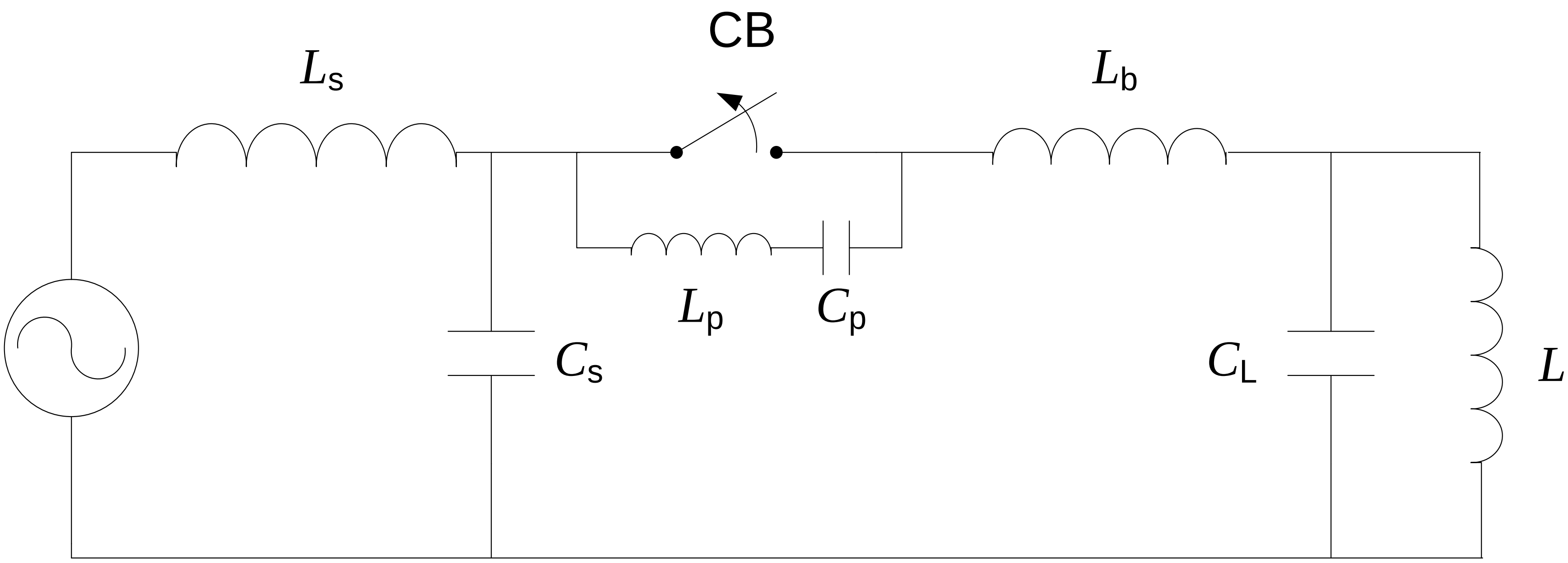
Shunt Reactor Connections to 500 kV

- Most shunt reactors in the BC Hydro system are permanently connected through a switching device (a disconnect switch or a circuit breaker) at the ends of 500 kV transmission lines to limit fundamental-frequency temporary overvoltages and energization overvoltages (switching transients).

Neutral Reactors (NR) for secondary arc extinction on SPT lines.

(Impedance & Voltage Rating of NR are based on the shunt capacitance of Transmission Line and determined by EMTP)

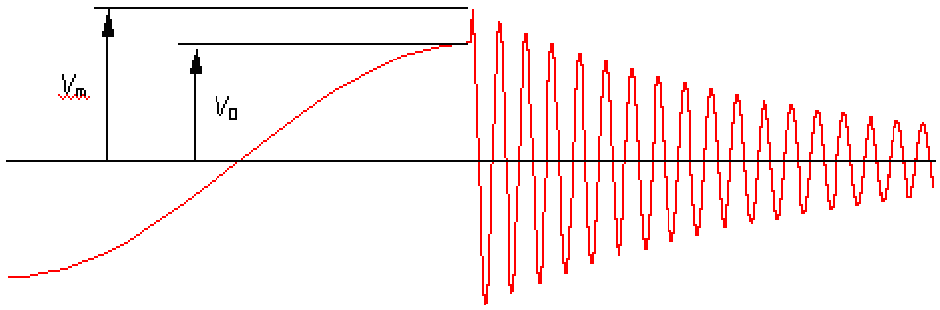
Inductive – Shunt Reactor De-energisation



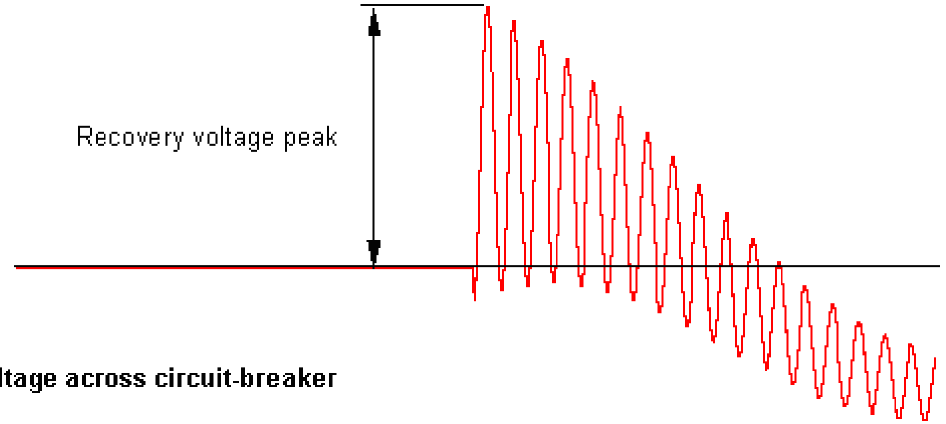
Interactive process characterised by:

- **Current chopping (interaction of arc with capacitance in parallel with the CB)**
- **Relatively high frequency recovery voltage on load side**
- **Reignitions (can normally not be avoided)**

Shunt Reactor De-energisation - Voltages

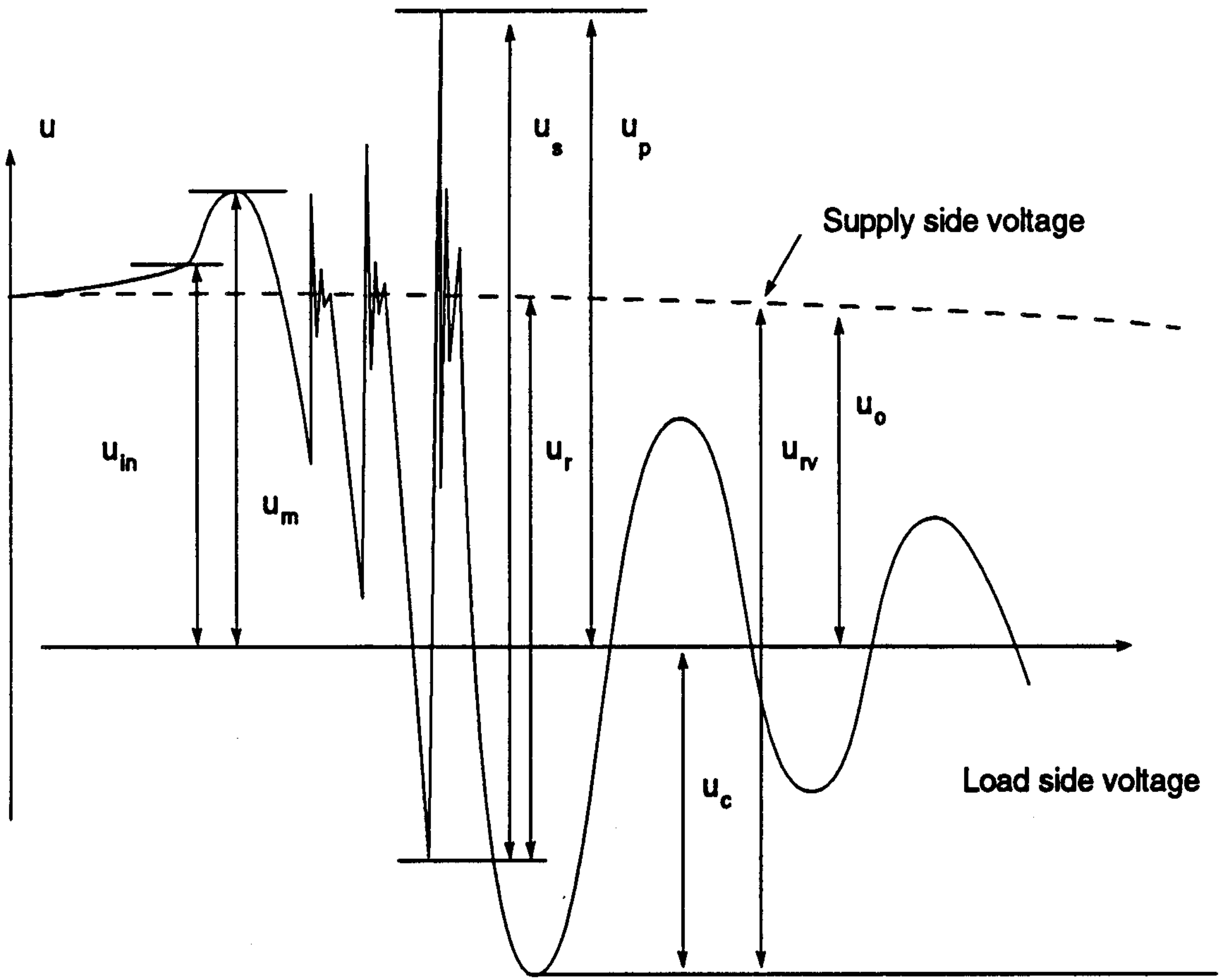


Load side voltage



Voltage across circuit-breaker

Shunt Reactor De-energisation - Reignitions



Inductive Load Switching - General

- **Overvoltages generated during switching should be kept low**
  - ***Circuit-breaker with a low number of series connected breaks***
  - ***Circuit-breaker with a low chopping number (short minimum arcing time for gas circuit-breakers)***
  - ***Circuit-breaker having low parallel capacitance***

Inductive Load Switching - Testing

- **Establishes whether or not the circuit-breaker meets certain performance criteria**
  - *Used to derive the chopping number*
  - *Chopping number is used to predict performance in the field*
  - *Used to determine the reignition behaviour of the circuit-breaker*

Inductive Load Switching - Testing

- **CBs are designed and intended to:**
  - ***Withstand voltage***
  - ***Carry and make/break normal load currents***
  - ***Interrupt fault currents***

- **Standards are intended to cover 90% of all applications**
- **The other 10%: where the user's requirements are beyond the scope of the standard or application variations are such that requirements can not be standardized**

- Under "The Other 10%" are CBs for the Reactors.
- It is a complex issue to select appropriate CBs for the Shunt Reactor switching and fault current interruption capability.

Hazards to a Reactor

- **The principal hazards to a reactor are similar to that for a transformer:**
  - ***Bushing and Isolation failures***

(resulting in large changes in the magnitude of phase current)

  - ***Turn-to Turn faults within winding,***

(resulting in small changes in the magnitude of phase current),

  - ***Miscellaneous failures***

(such as low oil, loss of cooling, pole disagreement, ...)

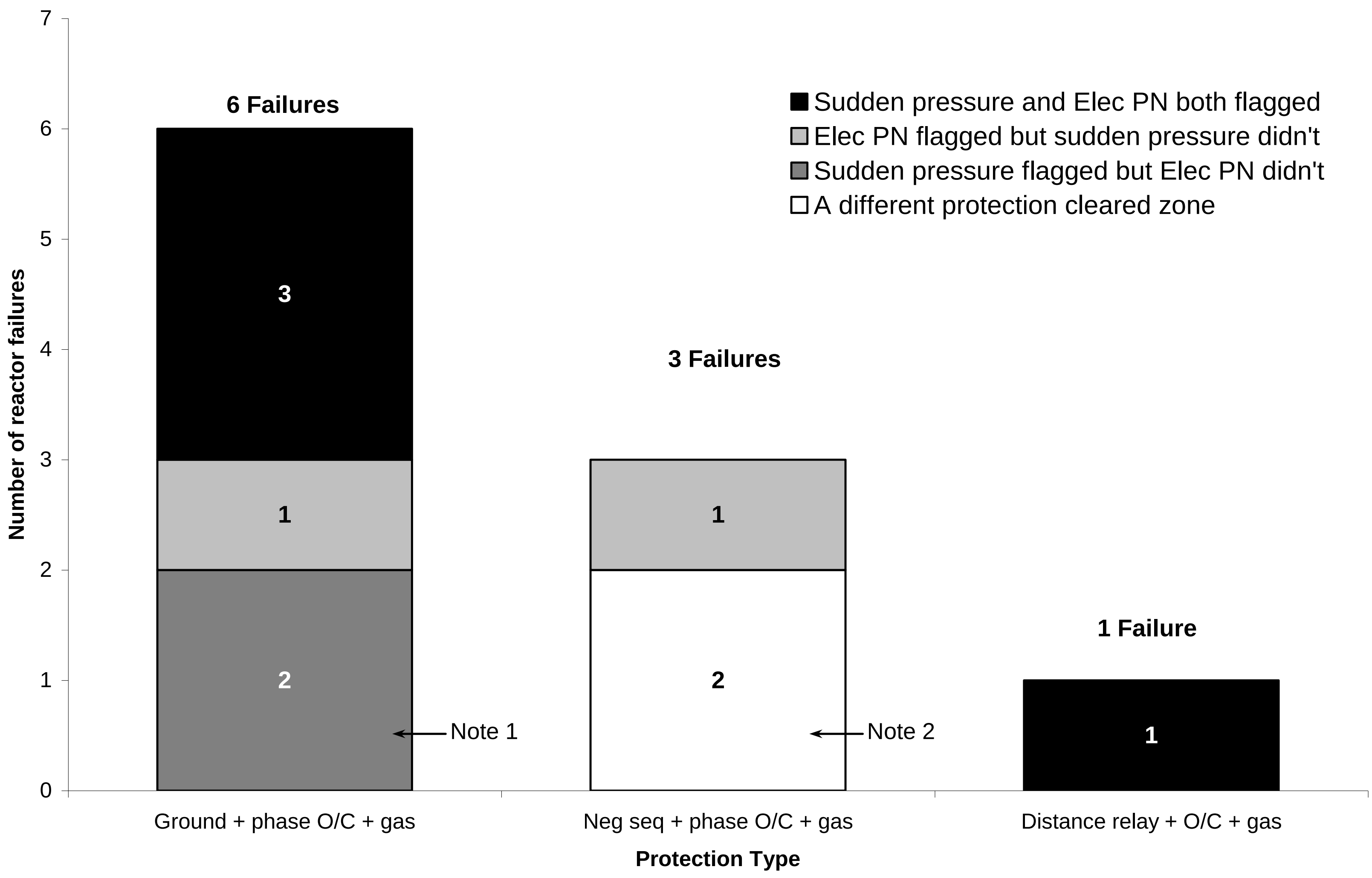
Reactor Protection

Protection of reactors is basically the same as for transformers with the size and importance to the system including:

- ***Electrical protection***
- ***A non-electrical protection***

(BC Hydro system is to provide protection for all possible faults using both electrical and non-electrical devices)

Response of Electrical and Non-electrical Protections on Reactor Faults within the BC Hydro



Turn to Turn Faults in Reactors

- Possibly small fault current
- Can’t be seen with differential relay
- BCH practice is to use ground directional relay

Security Problems

- Reactor inrush
- CT saturation and false neutral currents
- Many mis-operations in early years

Protection for Large-Magnitude Faults

- **Differential Scheme**

  Differential protection connected to reactor supply-side and neutral-end CTs has been applied as a primary protection for faults between windings of different phases, winding-to-core or winding-to-tank faults.

  Several factors must be considered:

  - ***Magnetizing inrush current***
  - ***Current transformers unequal performance and saturation***

Protection for Turn-to-Turn Faults

Since *"turn-to-turn"* faults result in through fault currents that can not be detected by differential protection, BC Hydro's preference is to detect turn-to-turn faults using a directional neutral current relay in addition to "non-electrical protection".

Protection for Turn-to-Turn Faults

Neutral ground protection controlled by a directional relay (67N) and supervised by Inrush Tripping Suppression (ITS)

(Instantaneous Neutral Ground Overcurrent element in Multifunctional relay connected to the neutral CT).

Turn-to-Turn Protection Scheme

- **Directionalzed to see zero sequence current flow into the reactor.**

  (This device should not operate for external faults)

- **The setting is about 5-10 % of reactor rating**

  (This setting could be slightly desensitized because of the directional element's sensitivity).

- **Inrush Tripping Suppression (ITS)**

  (to avoid false tripping by sensitive protection elements on energizing the reactor)

- **Tripping is time delayed by 15 cycles**

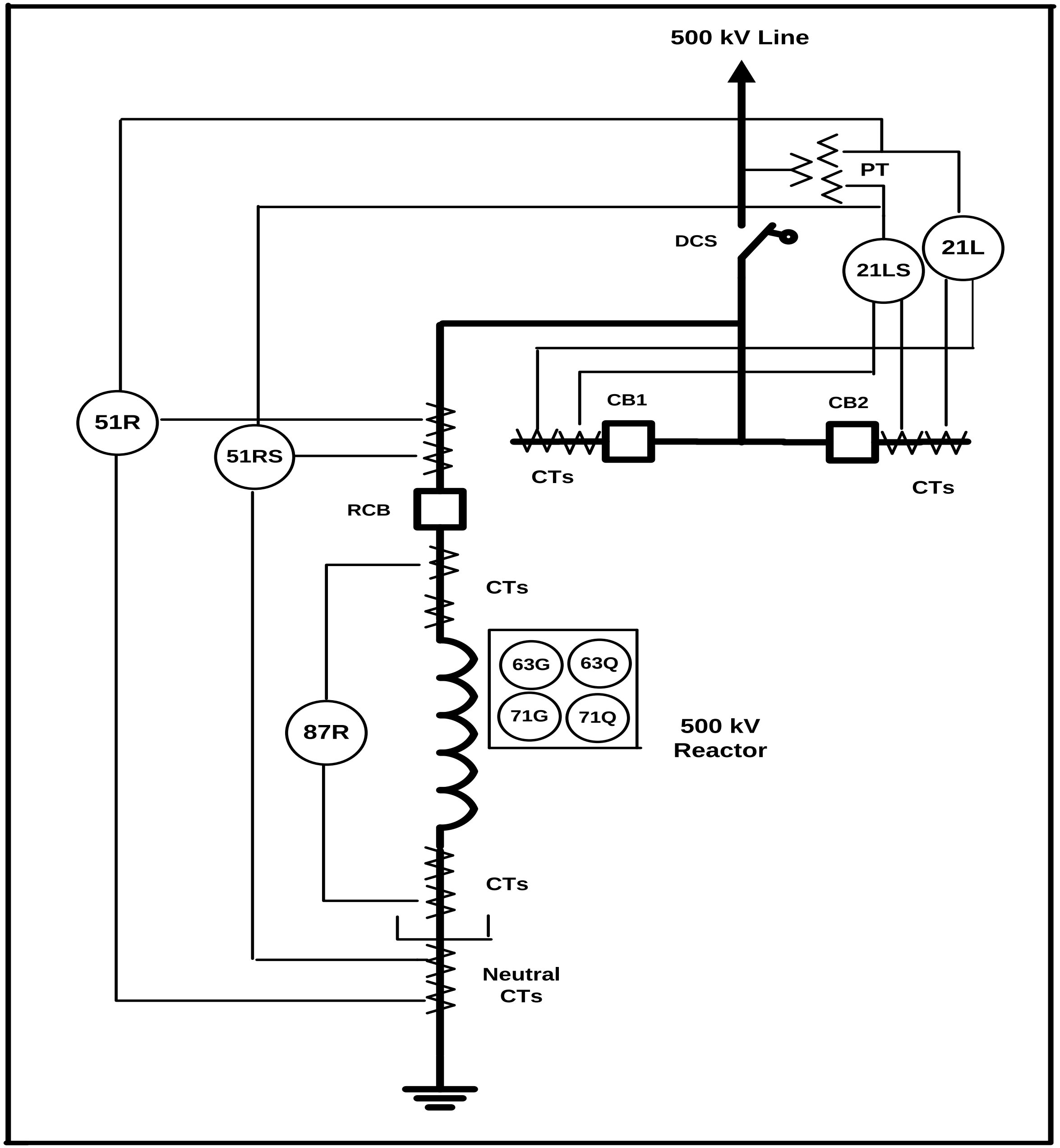
  (Time delay is necessary to avoid race between reset of ITS logic and transient pick up of the 67N element).

Inrush Tripping Suppression Logic

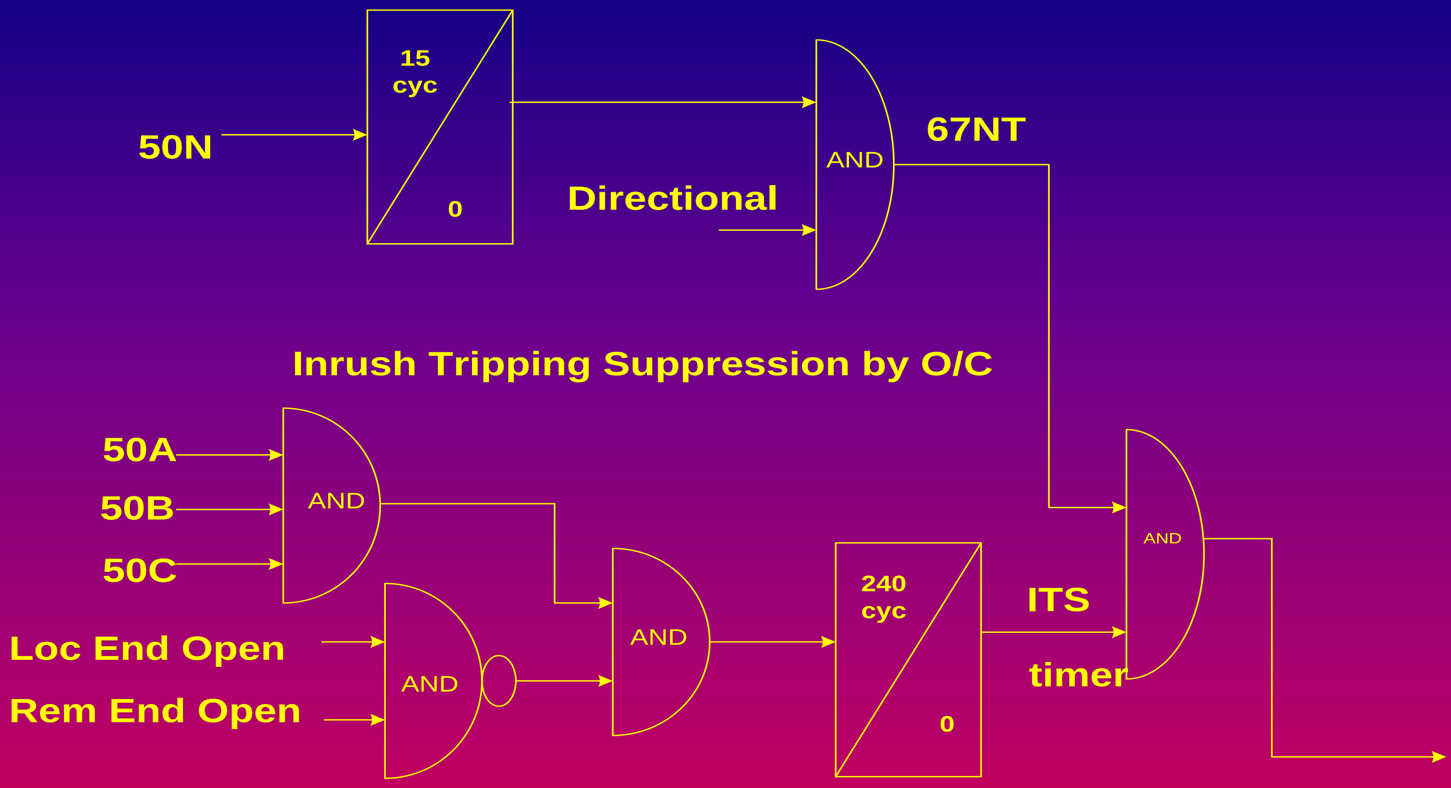
Inrush Tripping Suppression ***(ITS)*** **is to avoid false tripping by sensitive protection elements on energizing the reactor**

(will block the ground overcurrent tripping on de-energization of the reactor and will retain the blocking function for a few seconds after energization).

Present BCH 500 kV Shunt Reactor One Line Diagram

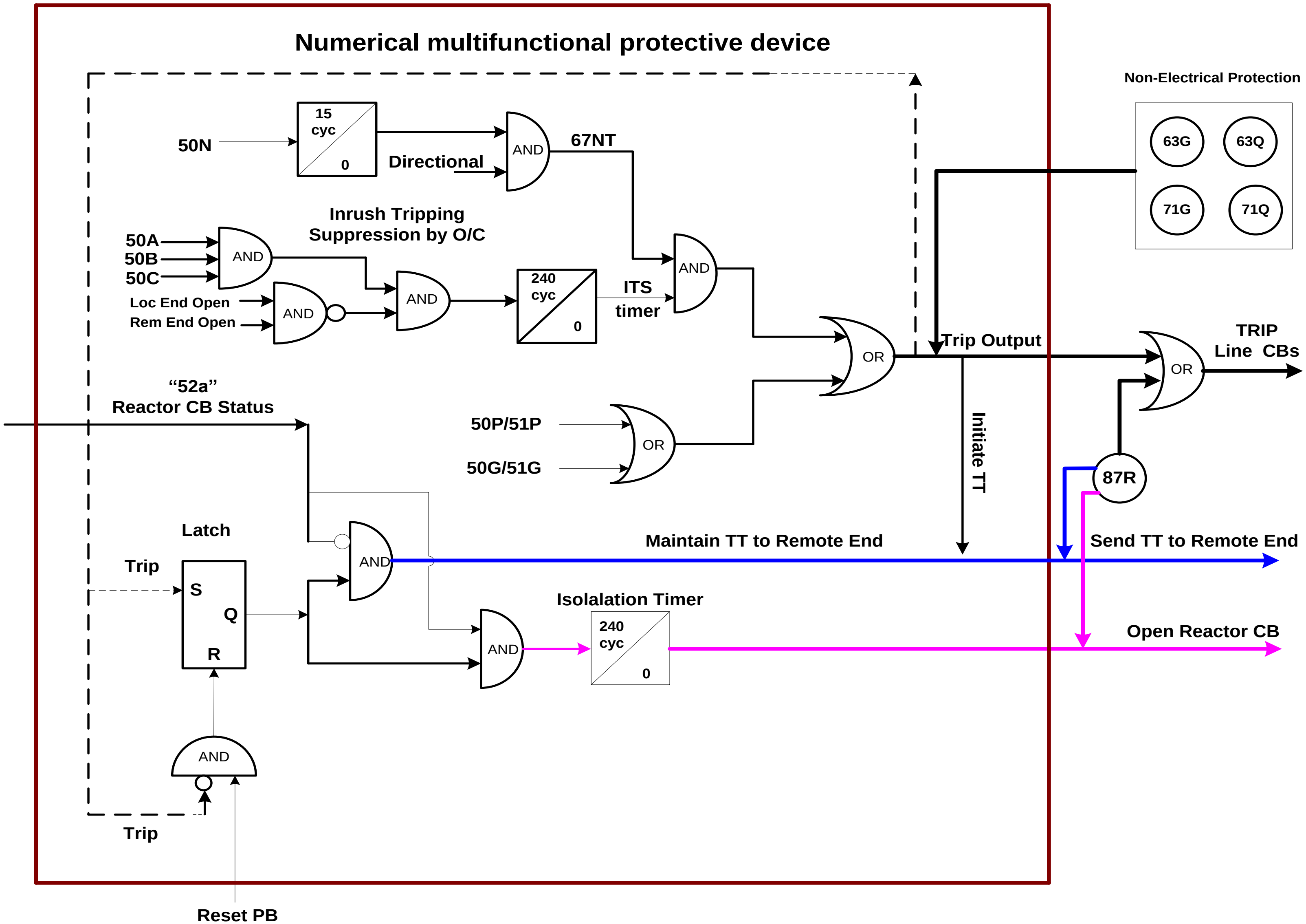


Inrush Tripping Suppression Logic



As reactor position in BCH system is shared with the lines, local tripping will no longer be sufficient to clear the fault and a direct transfer trip (DTT) from the reactor terminal will be required to trip the remote terminal of the associated line.

BC Hydro Reactor Protection Scheme



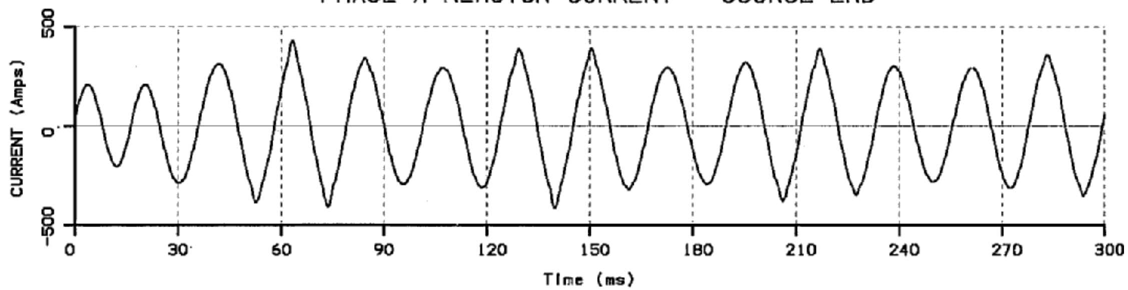
Note: 50 elements measure reactor current

500 kV Shunt Reactor De-energization Currents

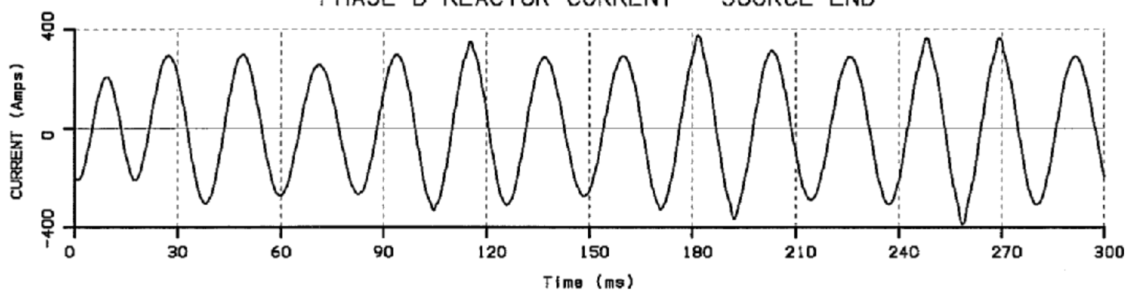
500 kV SHUNT REACTOR SWITCHING

500 kV LINE HAS SHUNT REACTORS AT EACH END
REMOTE LINE END IS ALREADY OPEN
OPEN SOURCE END OF LINE

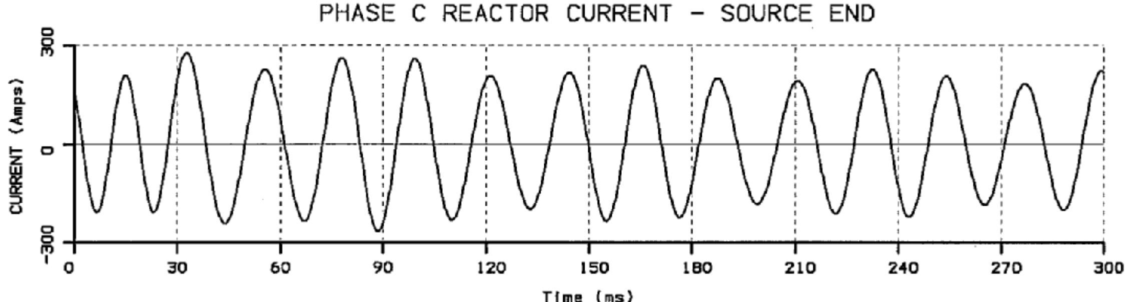
PHASE A REACTOR CURRENT - SOURCE END



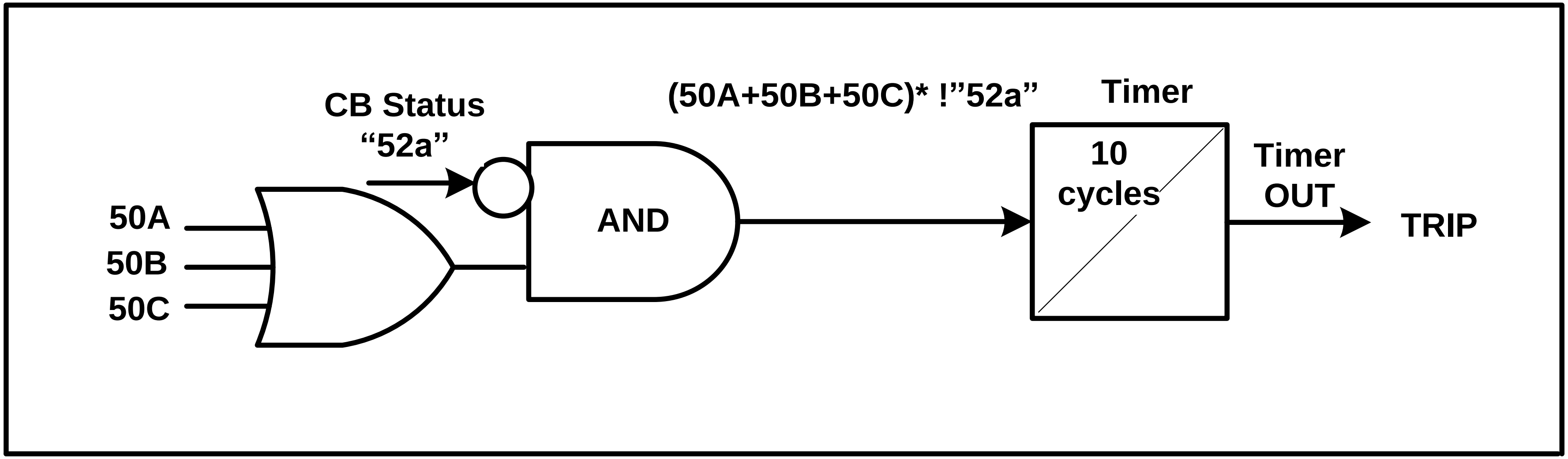
PHASE B REACTOR CURRENT - SOURCE END



PHASE C REACTOR CURRENT - SOURCE END



Additional Function- Flashover PN Logic



Finally - Why do we have protection?

Summary

- ***Developing a sensitive electrical protection is necessary to complement the non-electrical protection devices supplied with the reactor***
- ***Done mainly with the development of the inrush tripping suppression logic***
- ***BC Hydro sees advantages in using modern protective devices because of the flexibility they offer in providing additional protective functionalities.***

Summary

- **Tele-communication**
- **Saved the CBs that are beyond the scope of the standard for the user's requirements.**
- **Except unpredictable phenomena during Shunt Reactor switching that could cause disaster if interrupting devices (CBs or DSs)**