Directional Overcurrent Protection

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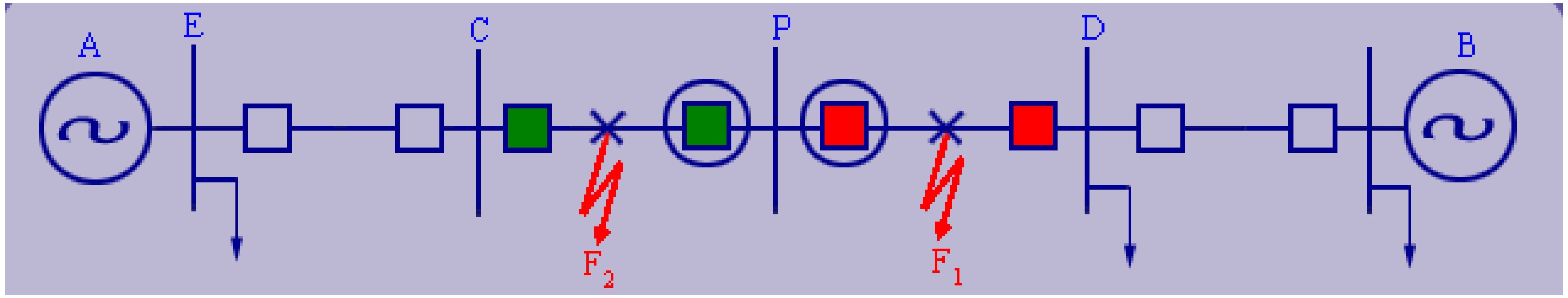
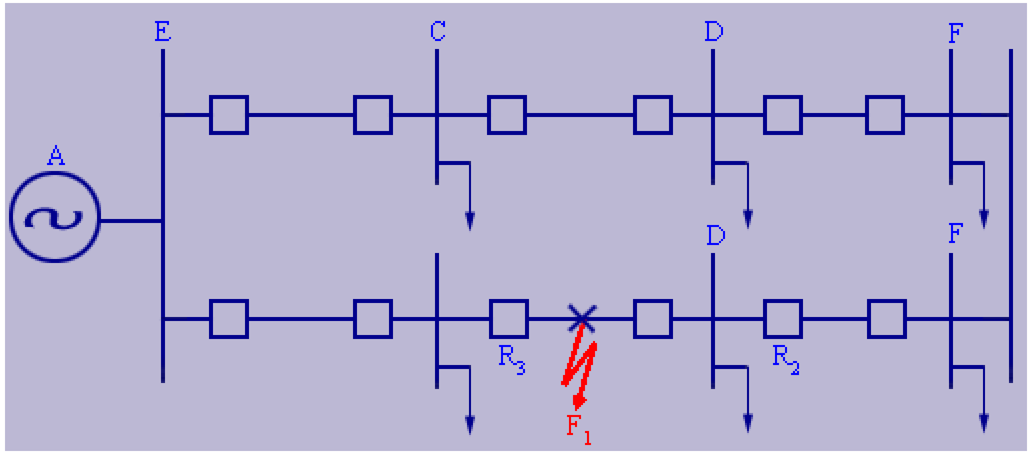
Necessity

- In overcurrent protection scheme it was assumed that
  - System is radial and single sourced.
- True for traditional distribution systems but it does not hold true for sub-transmission or transmission system with multiple sources.
- Radial system with two sources connected require relays on both end of line to detect fault and disconnect transmission line from both ends
  - If relays for protection are installed only at one end of transmission line say towards source A end, it is obvious that after opening of relay in red, the fault will continue to be fed from source B.



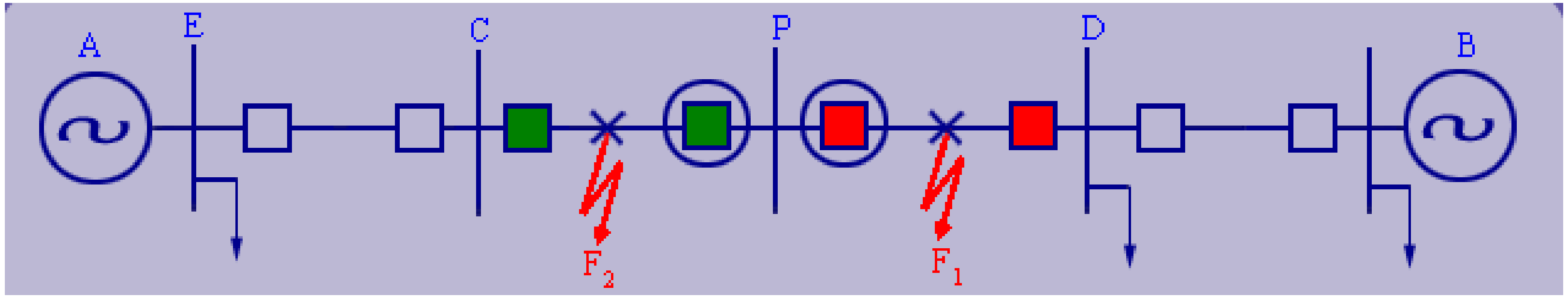
Necessity

- Similar situation will exist even for a single source system if parallel paths exist.
- Hence, system which have multiple paths to source require relays at both ends. However, installing relays at both ends does not provide a complete relaying solution



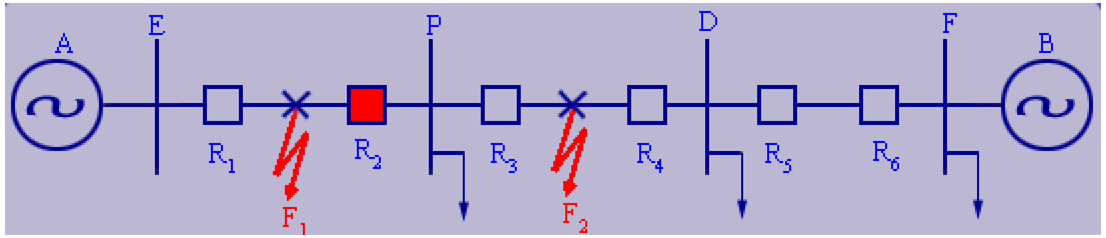
Necessity

- Consider the action of red relay with respect to two likely faults F1 & F2
- If the fault is at F1 then it is responsibility of red relays to open. If fault is at F2, then it is the green relays which should trip the line.
  - However, it is quite likely that for fault F2, the circled red relay may trip before circled green relay opens to disconnect feed from the source B, the reason being that both relays are subjected to same fault current.
  - In other words, circled red relay competes with circled green relay to clear fault. Opening of circled red relay unnecessarily causes loss of service to load at bus P and it should be classified as wrong operation



Necessity

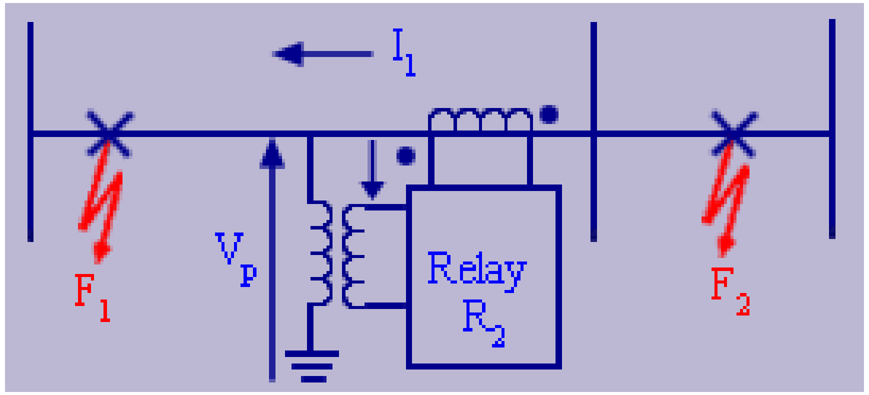
- Relay element has to be provided with additional discrimination feature to distinguish between faults.
  - Further, this 'selectivity' will not be sufficient if it is based upon magnitude of pick up current (or fault currents).
  - For overcurrent protection the discrimination is provided as R1 > R3 > R5 and R6 > R4 > R2



- not possible to provide such time discrimination between relays like R2 and R3

Necessity

- Two possible fault locations
  - Relay R_2 should operate if fault is at F_1 because it is on primary feeder but not behind i.e. at F_2.
- With polarity of CT connection, it is apparent that for fault F_1 current I_1 seen by the relay lags V_p by 90 degrees. This is under the assumption of bolted fault and reactive nature of circuit impedance. However, when the fault is in the position F_2, then relay current leads the bus voltage 'V_p'.



Fundamental Principle

- **Selectivity logic:** measure the bus voltage phasor Vp and compute the phase angle of relay current with respect to bus voltage
  - If the relay 'detects fault' and current lags VR (= Vp), then permit relay tripping. If the relay 'detects fault' and current leads VR (= Vp), then inhibit the relay tripping.
  - The relays with 'discrimination principle' based on phase angle comparison are called **directional relays**
- Overcurrent relays can be made directional by adding above discrimination logic to well known overcurrent logic. Such relays are called as directional overcurrent relays.
  - Used in distribution system or sub transmission system where 'ring main' configuration is used to provide more reliability of service and has higher cost due to additional cost of VT.

Fundamental Principle

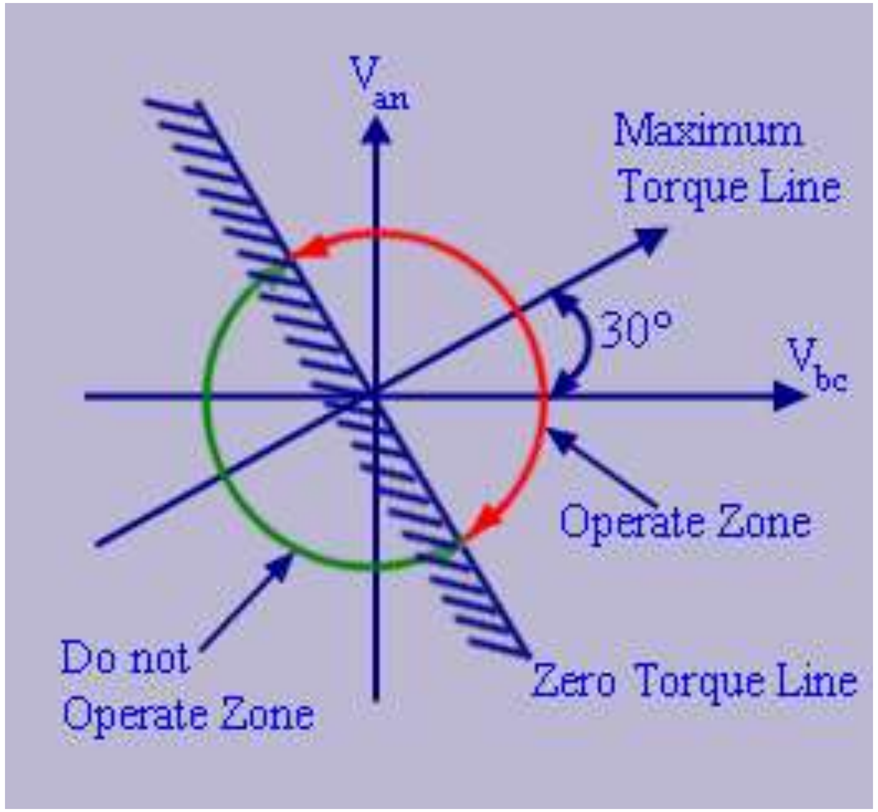
- Directional overcurrent relay can be visualized as a cascade connection of 'one directional unit' and one overcurrent unit.
  - If the polarity of the current is appropriate, then directional unit picks up. If the current magnitude is above pickup, then the overcurrent unit also picks up and when both units pickup, the trip coil is energized and CB tripping is ensured. In a numerical relay, this can be programmed by a simple 'AND' logic.
- Any fault involving ground is called a ground fault. Traditionally, three phase relays and one ground relay have been used to protect a feeder or a transmission line. However, in a numerical relay, all these functions can be integrated into a single relay which acquires 3-phase voltages and 3-phase currents.

Fundamental Principle

- For electromechanical relays, with respect to reference phase 'Va', we can draw operating line (zero torque line) which separates the plane into two regions marked as 'operate' and 'Do not operate'.
    - If the fault is in the operating region, then Ia lags Va and we issue trip decision.
    - In case, fault is behind the relay, the fault current leads Va and hence lies in the "do not operate" region.
- Maximum torque line, i.e. line perpendicular to the zero torque line can be placed at an angle with respect to Va also.
    - adds complexity to electromechanical relay design.
    - But simple programming job in a numerical relay.
    - Common practice is to place the maximum torque line at an angle of 60 degrees lag or 45 degrees with respect to ' Va'

Fundamental Principle

since V_{bc} is in phase quadrature with V_a, it is possible to use V_{bc} as the reference phasor and locate the maximum torque line at 30 degrees leading it. This is what traditionally practiced in legacy directional overcurrent relays. With this placement we now show that directional unit will pickup for both 3-phase and L-L faults.



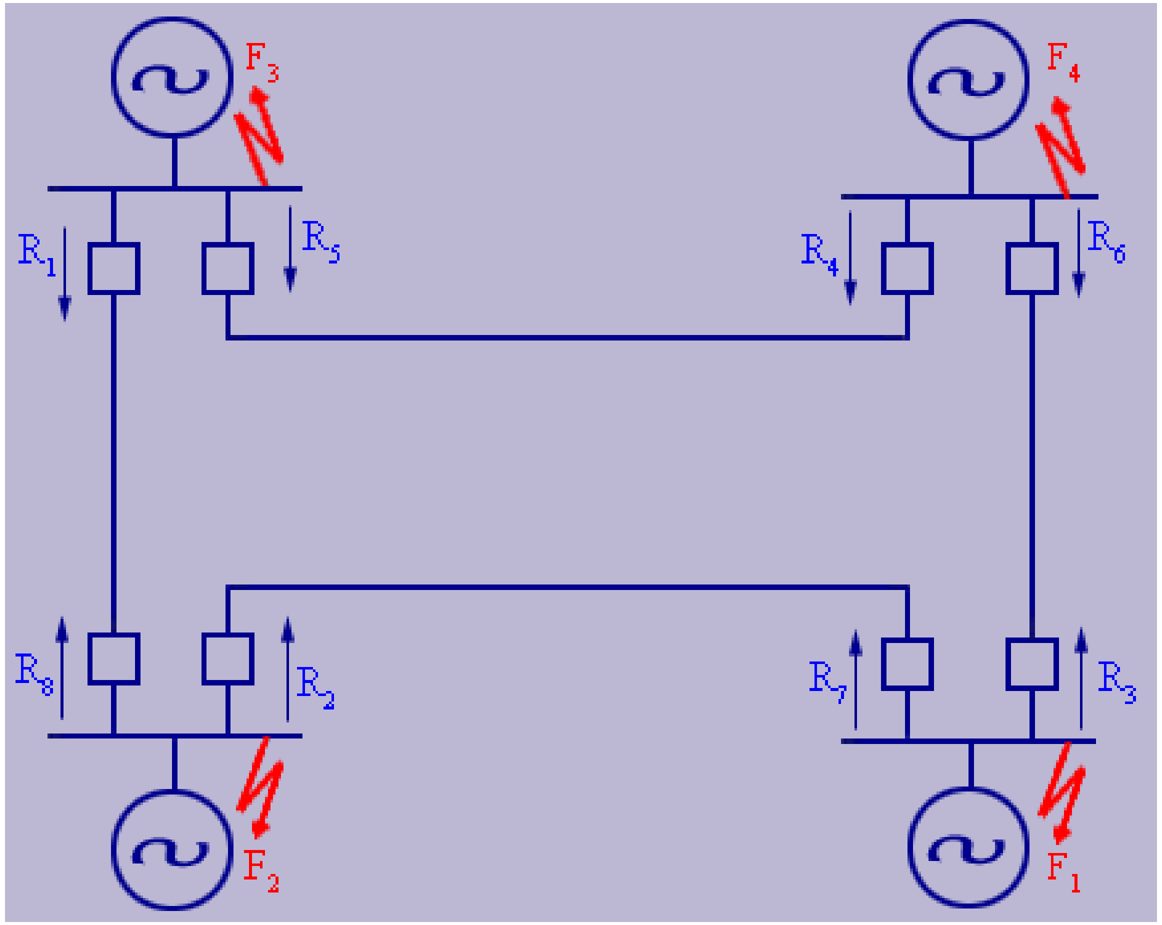
Directional Overcurrent Relay Coordination

Overcurrent & Directional Overcurrent Protection

Directional Relay Coordination

- Coordination of directional overcurrent relays involves setting of relays one by one so that at each stage the relay coordinates with its primary relay.
- In a loop, the last relay to be set is the very first, in which initial setting were assumed.
  - Relay coordination activity in a mesh system is iterative.
  - Contrast with a radial system where the relay coordination is completed in one pass.
  - The iterative nature of relay setting and coordination converges when on revisiting the same relay, if we do not have to change the relay settings and TMS.

Directional Relay Coordination



Typical transmission line is protected by directional relays at both ends. Hence we have to consider two loops, i.e. one loop formed in clockwise direction and the another in anticlockwise direction.

In this case clockwise loop is given by R5 > R6 > R7 > R8 > R5 and anti clockwise loop is given by R1 > R2 > R3 > R4 > R1 where arrow should be read as ‘backs up'

Directional Relay Coordination

- Consider anticlockwise loop for setting starting setting from any one of the four relays, i.e. R1, R2, R3 and R4.
    - Let us start from R2, i.e. setting in relay R2 is assumed appropriately.
    - R1 will be set to coordinate with R2, since R1 has to back up R2. Now R4 has to coordinate with R1, R3 with R4 and R2 with R3. Thus we can see that the setting of R2 has changed from what it was initially to coordinate with R3.
    - After first iteration, we update the setting of R2 to the corresponding new setting, to coordinate with R3, thus closing the loop. If the setting of the R2 has changed significantly, then we repeat the above process by fine tuning the settings of all the relays in the loop again.
- As every iteration improvises the relay settings (TMS), we expect the settings to converge in a few iterations. We have to repeat the same process with the clockwise loop also. Then all the relays will be set and relay coordination activity is complete.

Example

- Consider the system shown in above figure

Fault Current seen by Primary - Back up Relay Pairs				
	Anti clockwise loop		Clockwise loop	
Remote Bus Fault at	Current seen by primary relay	Current seen by back up relay	Current seen by primary relay	Current seen by back up relay
F_1	R_2 (639A)	R_1 (152A)	R_6 (1365A)	R_5 (272A)
F_2	R_1 (1652A)	R_4 (391A)	R_7(868A)	R_6 (240A)
F_3	R_4 (1097A)	R_3 (140A)	R_8 (1764A)	R_7 (287A)
F_4	R_3 (937A)	R_2 (142A)	R_5 (553A)	R_8 (197A)

Pick up Values of Relays								
Relay	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Pick up setting (A)	60	80	60	160	80	160	128	100