RELAY LOADABILITY CHALLENGES EXPERIENCED IN LONG LINES

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Presentation Outline

- Blocking Trip
  - Block Overload by Load Encroachment
  - Block Power Swing by Out-of-step
- NERC PRC-023-3
- Setting Calculation Verification
  - Load Encroachment
  - Out-of-step
- Challenge of Long Line Case
  - Solution
  - Example

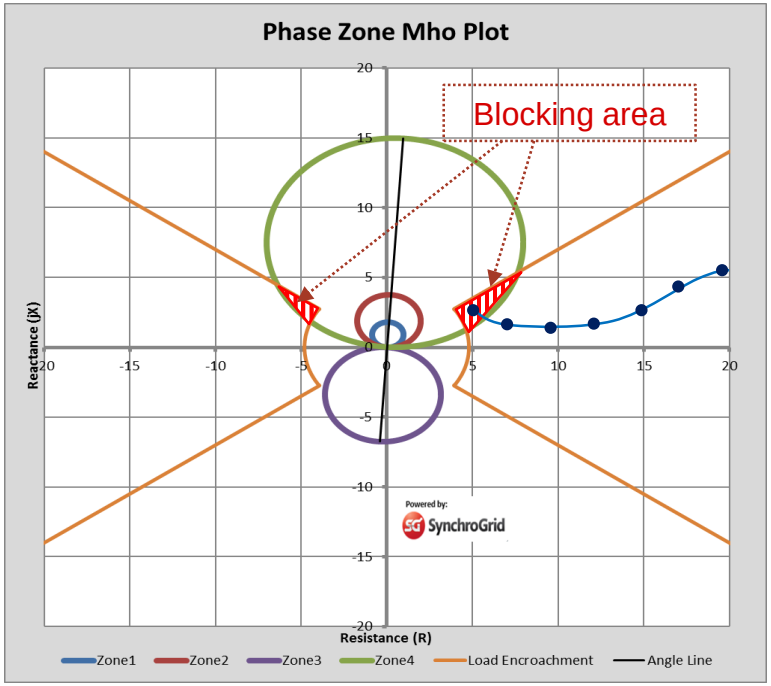
Necessity of Blocking Trip

- Blackout in the Northeast in 2003

- Main two reasons which cause mis-trip in distance relay
  - Over load
  - Power swing

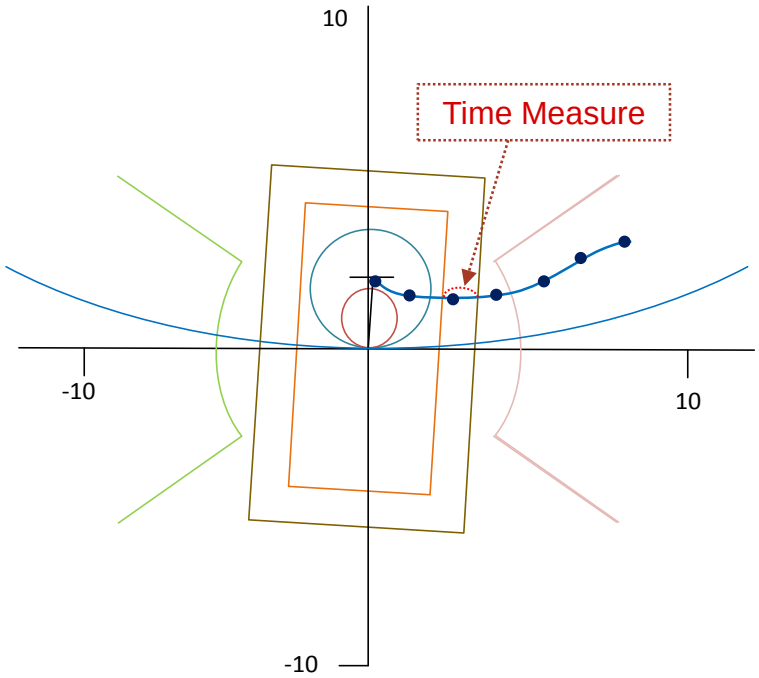
How to Block Over Load
- Load Encroachment Setting

- Load Encroachment is used in order to block zone 3
- Setting Elements
  - Magnitude for forward and reverse
  - Angle for forward positive / forward negative / reverse positive / reverse negative



How to Block Power Swing - Out-of-Step Setting

- Out-of-step logic is used in order to block power swing
- Usually set out of zone 2
- Setting Elements
  - Block zone outer top blinder / outer right blinder / inner top blinder / inner right blinder
  - Block time delay



Setting Philosophy for Loadability (NERC PRC-023-3 R1.)

- **R1.** Each Transmission Owner, Generator Owner, and Distribution Provider shall use any one of the following criteria (Requirement R1, criteria 1 through 13) for any specific circuit terminal to prevent its phase protective relay settings from limiting transmission system loadability while maintaining reliable protection of the BES for all fault conditions. Each Transmission Owner, Generator Owner, and Distribution Provider shall evaluate relay loadability at 0.85 per unit voltage and a power factor angle of 30 degrees.
- Criteria: **R1.1** Set transmission line relays so they do not operate at or below 150% of the highest seasonal Facility Rating of a circuit, for the available defined loading duration nearest 4 hours (expressed in amperes).

Setting Philosophy for Out-of-step (NERC PRC-023-3 R2.)

- **R2** Each Transmission Owner, Generator Owner, and Distribution Provider shall set its out-of-step blocking elements to allow tripping of phase protective relays for faults that occur during the loading conditions used to verify transmission line relay loadability per Requirement R1.

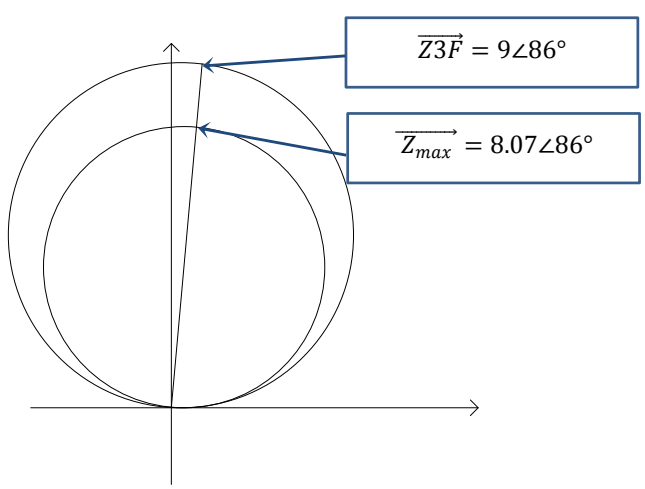
Loadability Calculation Verification

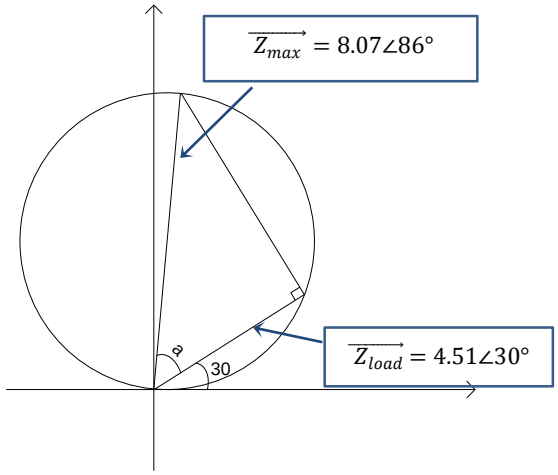
- $Z_{Load\ Encroachment} = \frac{85\% \times (V_{LL})}{\sqrt{3} \times 150\% \times I_{Limit}} \times \frac{CTR}{PTR}\ (by\ Criteria\ 1)$

  (Where: $I_{Limit} = Maximum\ Line\ Rating$)

- $\left|\overrightarrow{Z_{max}}\right| = \frac{85\% \times V_{LL}}{\sqrt{3} \times 150\% \times I_{limit\ of\ conductor} \times cos\ a} \times \frac{CTR}{PTR}$

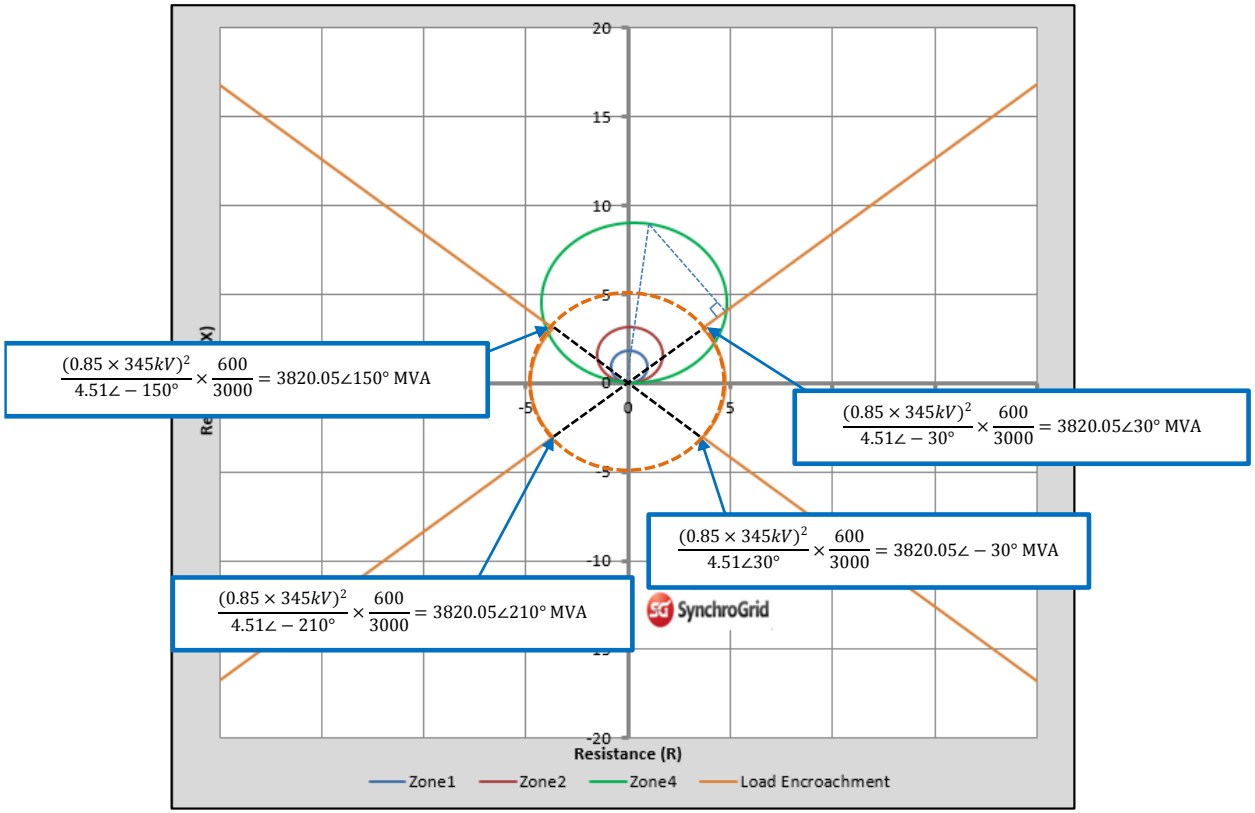
- $\left|\overrightarrow{Z_{load}}\right| = \left|\overrightarrow{Z_{max}}\right| \times cos\ a$



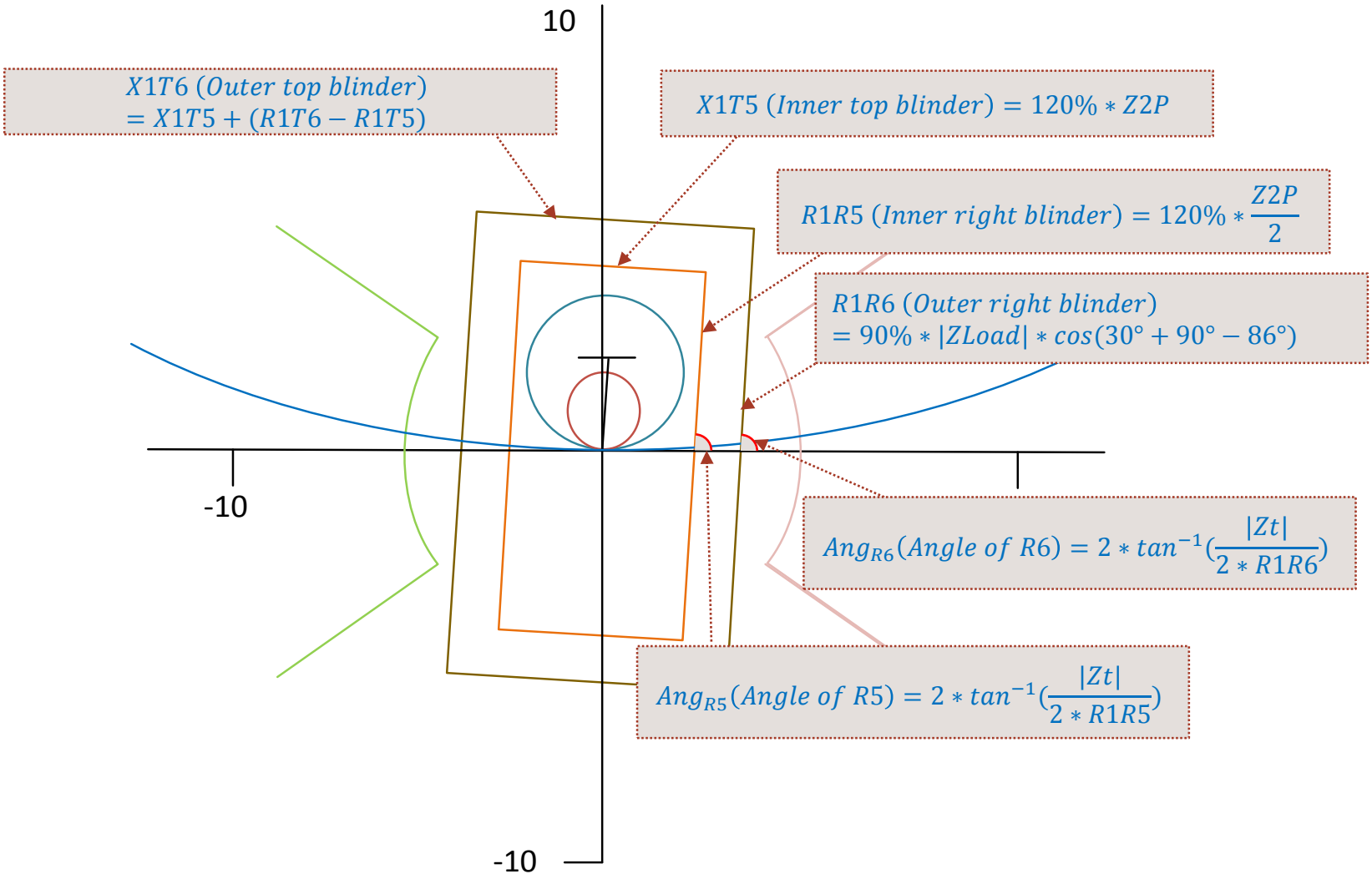


Loadability Calculation Verification

- MVA conversion: $\frac{(0.85 \times V_{LL})^2}{(Z_{Load\ Encroachment})^*} \times \frac{CTR}{PTR}$ $(*: conjugate)$



Out-of-step Calculation Verification

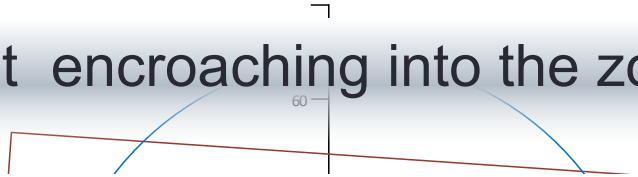


Out-of-step Calculation Verification

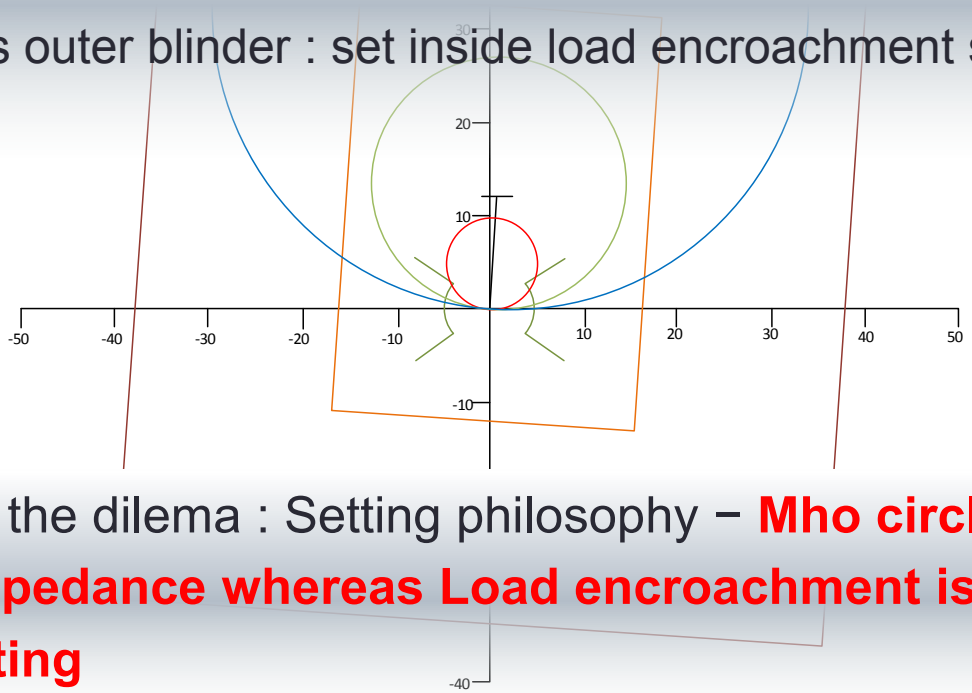
- $R1R5\ (Inner\ right\ blinder) = 120\% * \frac{Z2P}{2}$
- $R1R6\ (Outer\ right\ blinder) = 90\% * |ZLoad| * cos(35° + 90° - 86°)$
- $X1T5\ (Inner\ top\ blinder) = 120\% * Z2P$
- $X1T6\ (Outer\ top\ blinder) = X1T5 + (R1T6 - R1T5)$
- $Zt\ (Transfer\ impedance, secondary, positive\ sequence) = ZSrc1 + ZL1 + ZSrc2$
- $Ang_{R5}(Angle\ of\ R5) = 2 * tan^{-1}(\frac{|Zt|}{2*R1R5})$
- $Ang_{R6}(Angle\ of\ R6) = 2 * tan^{-1}(\frac{|Zt|}{2*R1R6})$
- $OSBD\ (OOS\ block\ time\ delay) = \frac{(Ang_{R5} - Ang_{R6}) * F_{nom}}{F_{slip} * 360\ °/\text{cycles}}$

Challenge of Very Long Line

- The loadability limit encroaching into the zone 1 mho circle.



- Dilemma
  - Out−of−step's inner blinder : set out of zone 2 circle
  - Out-of-step's outer blinder : set inside load encroachment setting



- The reason of the dilema : Setting philosophy − **Mho circle is based on conductor impedance whereas Load encroachment is based on conductor rating**

Solution for Very Long Line Case

- It is impossible to place the region of OOS between distance element and loadability.
- The best choice
  - Keep the priority requirement : Load Encroachment (R1)
  - Adjust the less important setting so that it does not follow the setting philosophy but does not violate NERC standard : Inner blinder is set right but outer blinder is larger than loadability
  - Use another type of relay to ensure that the relay trips correctly : Line Differential Relay
  - Why Diff. Relay is the best choice? The differential scheme is unaffected by external effects such as faults, load and power swing.

Example for Very Long Line Case

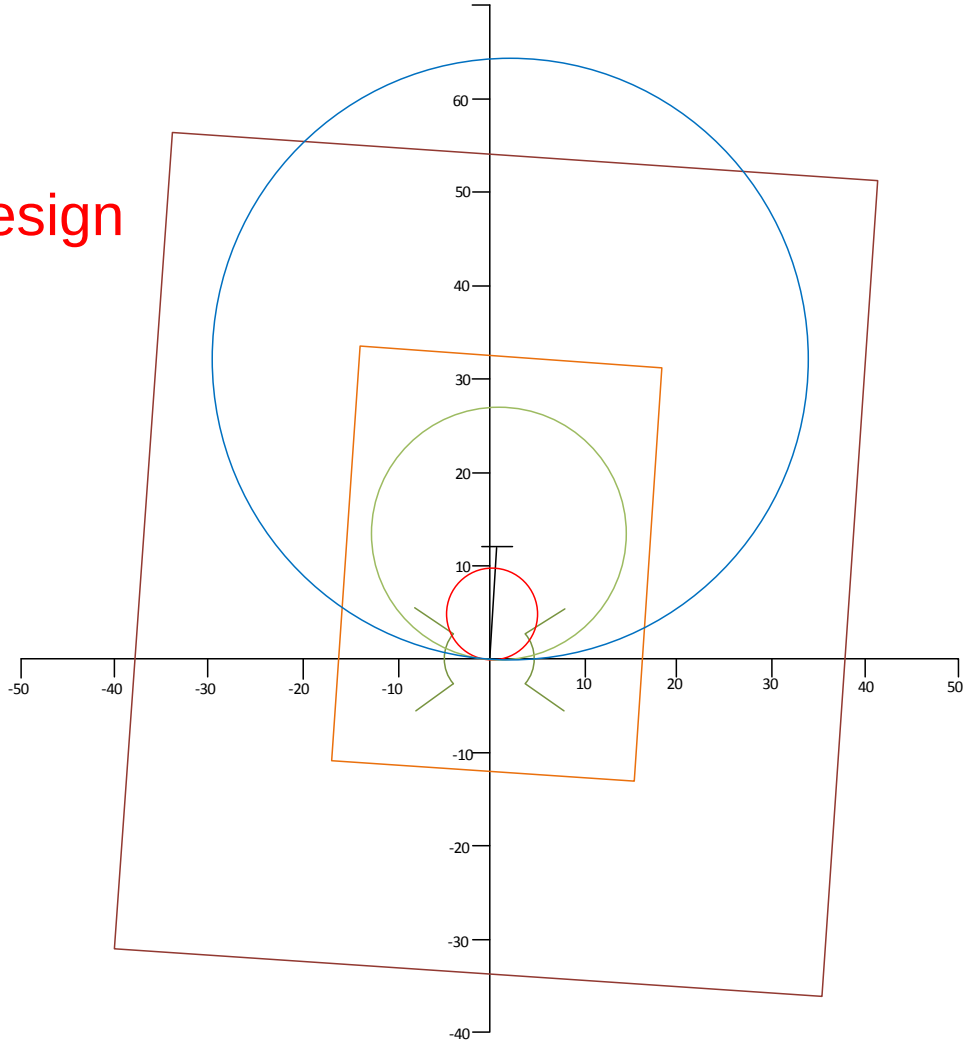
- System information
  - ZL1 (Protected line impedance, secondary, positive sequence): 10.81Ω∠ 86°
  - Z1MAG (Magnitude of protected line, secondary):10.81 Ω
  - Z1ANG (Angle of protected line, secondary): 86°
  - Z1P (Zone 1 pickup, secondary): 8.65Ω
  - Z2P (Zone 2 pickup, secondary): 24.33Ω
  - ZLoad (Load impedance, secondary): 4.78Ω∠35°
  - PTR (PT ratio): 3000
  - CTR (CT ratio): 600
  - ZSrc1 (Local source impedance, secondary, positive sequence): 2.65Ω∠86°
  - ZSrc2 (Remote source impedance, secondary, positive sequence): 1.85Ω∠86°

Example for Very Long Line Case

- Calculation of OOS elements
  - $Delay\ 1\ Pickup\ (PSBD, OOS\ block\ time\ delay)\colon = 1.0\ Cycles$
  - $Zt\ (Transfer\ impedance, secondary, positive\ sequence) = ZSrc1 + ZL1 + \mathrm{ZSrc2} = 2.65\Omega\angle 86° + 10.81\Omega\angle\ 86° + 1.85\Omega\angle 86° = 15.31\Omega\angle 86°$
  - $Inner\ Rgt\ Bld\ \ (INBS, Inner\ right\ blinder) = 120\% * \frac{Z2P}{2} = 14.6\ \Omega$
  - $Ang_{in}(Angle\ of\ Inner\ Blinder) = 2 * tan^{-1}(\frac{|Zt|}{2*INBS}) = 2 * tan^{-1}\left(\frac{15.31}{2*14.58}\right) = 55.4°$
  - $Ang_{out}(Angle\ of\ Outer\ Blinder) = Ang_{in} - PSBD * \frac{F_{slip}*360}{F_{nom}} = 55.4 - 1 * \frac{5*360}{60} = 25.4°$
  - $Outer\ Rgt\ Bld\ \ (OTBS, Outer\ right\ blinder) = \frac{|Zt|}{2*\tan(Ang_{out}/2)} = 34.0\ \Omega$
  - $Fwd\ Reach\ (XINBS, Inner\ top\ blinder) = 120\% * Z2P = 29.2\ \Omega$
  - $Quad\ Fwd\ Out\ (XOTBS, Outer\ top\ blinder) = X1NBS + (OTBS - INBS) = 29.2 + 34.0 - 14.6 = 48.6\ \Omega$
  - $Rev\ Reach\ (XINBS\_R, Inner\ Bottom\ blinder) = ZL1 = 10.81\ \Omega$
  - $Quad\ Rev\ Out\ (XOTBS\_R, Outer\ Bottom\ blinder) = INBS\_R + (OTBS - INBS) = 30.21\ \Omega$

Example for Very Long Line Case

- Add differential relay in relay design



References

- [1] System Protection and Control Task Force of the North American Electric Reliability Council, “Increase Loadability by Enabling Load Encroachment Functions of Digital Relays,” December 2005.

- [2] Schweitzer Engineering Laboratories, 421 Instructional Manual.

- [3] “Guide for Application of Digital 2 Line Current Differential Relays 3 Using Digital communication.” IEEE Power Engineering Society Power System Relay Committee Special Report, New York, NY; 2015.

- [4] “Power Swing and Out-of-Step Considerations on transmission” IEEE Power Engineering Society Power System Relay Committee Special Report, New York, NY; 2005.

THANK YOU

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