Do we have to reduce under-reaching distance relay reach solely based on System Impedance Ratio(SIR)?

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SIR- System Impedance Ratio

- Source to Line Impedance ratio, SIR is defined as

$$\text{SIR} = \frac{Z_S}{Z_L};$$

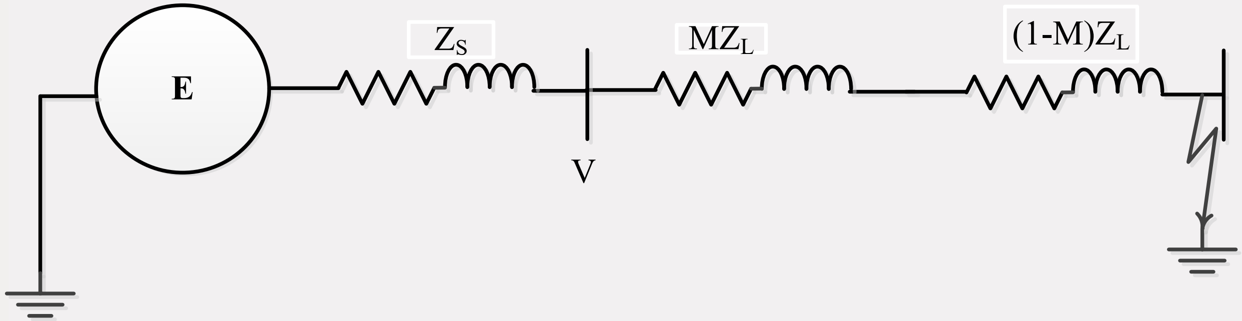
Where

Z_S = System source impedance behind the relay

Z_L = Line impedance

- Also known as System Impedance Ratio

Voltage Available to the Relay for Line End Fault



- Current through the relay terminal: $I_R = \frac{E}{(ZS+ZL)}$
- Voltage available to the relay for a remote end fault, $V = \frac{E}{(ZS+ZL)} Z_L = \frac{E}{(SIR+1)}$

Relay voltage Dependence on SIR

SIR	1	5	10	30	40	60
V_{PU}	0.5	0.166	0.09	0.032	0.024	0.016
V@ $69V_{NOM}$	34.5V	11.45V	6.21V	2.2V	1.65V	1.13V
V@ $115V_{NOM}$	57.5V	19V	1035V	3.68V	2.76V	1.88V

Table 1: Voltage at the relay for remote end fault

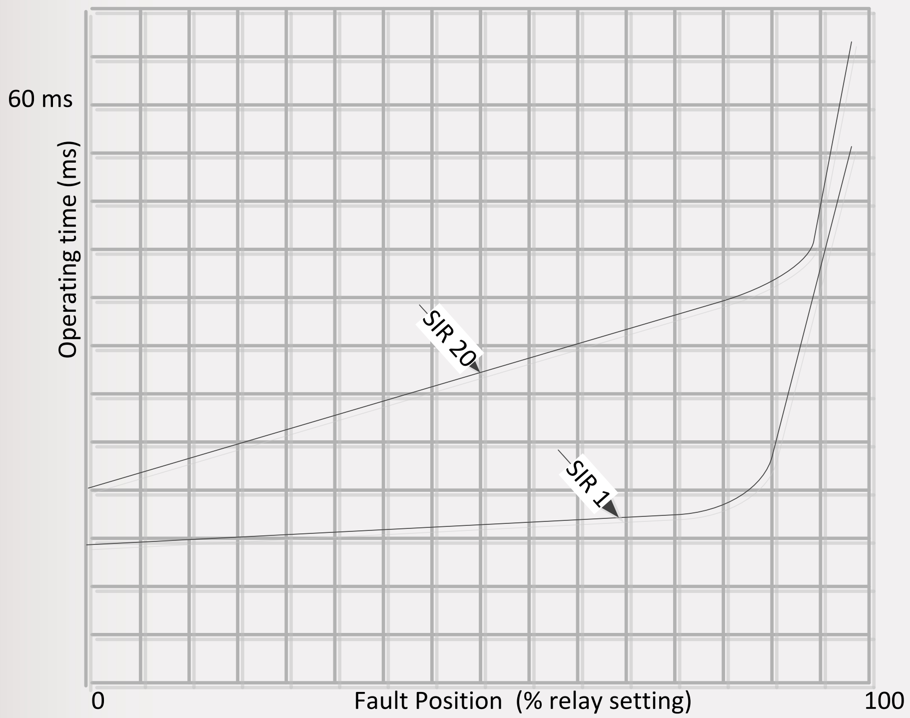
Relay Performance

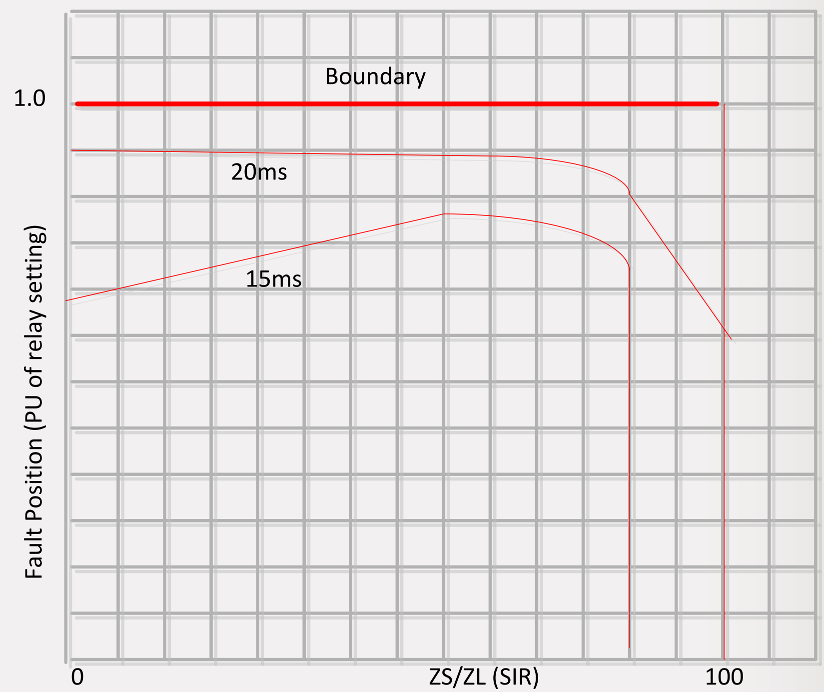
- Depends on the voltage sensitivity
- Current Sensitivity
- Impedance settings sensitivity
- Relay Design

Performance of Electro-Mechanical and Static Relays

- Protection & Automation and Application Guide (PAAG) from GE (formerly Network Automation and Protection Guide -NPAG from Alstom, GEC measurements) Chapter 11 shows errors seen by relays due to measurement inaccuracies due to high SIR .
- Error due to low voltages leads to ~5% over reach of impedance elements.
- Increase in operating times.

Legacy Relays –Operating times



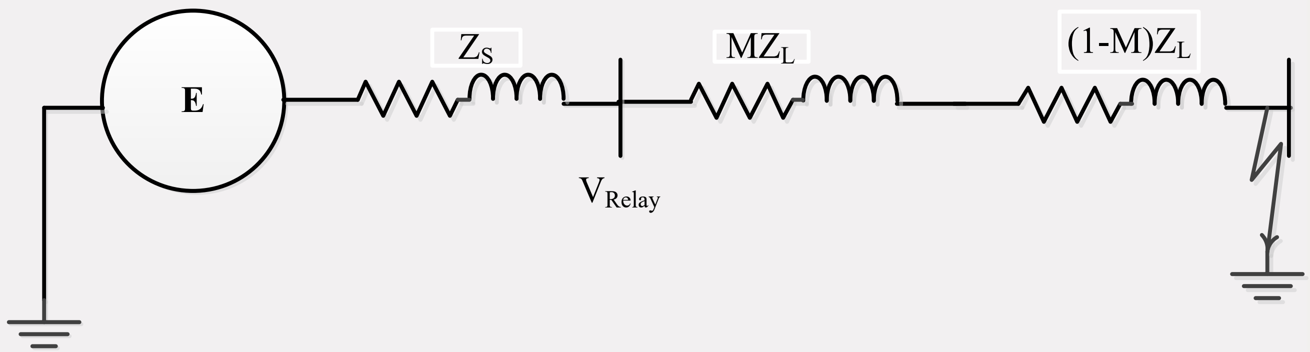


Relay Measurement Accuracy –A/D

Full Scale Range	12 bit A/D	16 bit A/D
150 V	LSB=150/2^{11}=73 mV	4.5 mV
250 V	112mV	7.7 mV
300 V	146 mV	9.16 mV

Use of Lower full scale range improves sensitivity
Compare it with Voltage at the relay for various SIRs

Voltage calculations for Three-Phase faults



- $SIR = \frac{Z_S}{Z_L}$; Z_S and Z_L are positive sequence source and line impedances
- Remote end: $V_{ZL} = \frac{E}{(Zs+ZL)} Z_L = \frac{E}{(SIR+1)}$
- At zone 1 reach location:
- $V_{Zone1} = \frac{E}{(Zs+MZL)} MZ_L = \frac{E}{(\frac{SIR}{M}+1)} = \frac{M*E}{(SIR+M)}$

Voltage Discrimination Approach

- Voltage Difference as seen by the relay between line end fault and at zone1 reach, ΔV is given by
- $\Delta V = \frac{E}{(SIR+1)} - \frac{M*E}{(SIR+M)} = \frac{E*SIR*(1-M)}{(SIR+1)*(SIR+M)}$
- The reason to calculate the voltage discrimination (ΔV) is to determine whether the relay zone 1 will restrain for a remote end fault.
- Pull back the reach if $\Delta V < 1.0$ V

ΔV in an Interconnected System

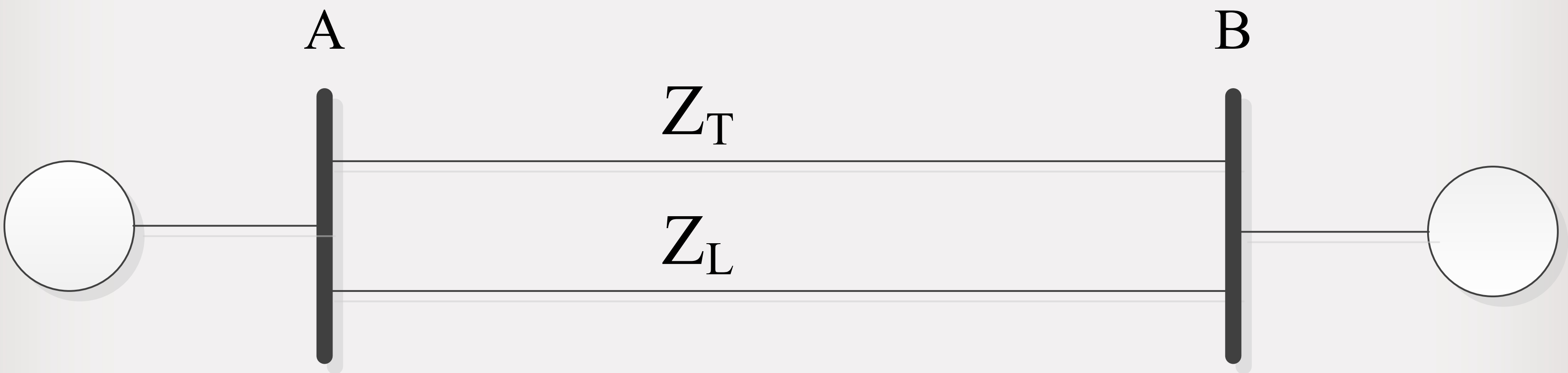
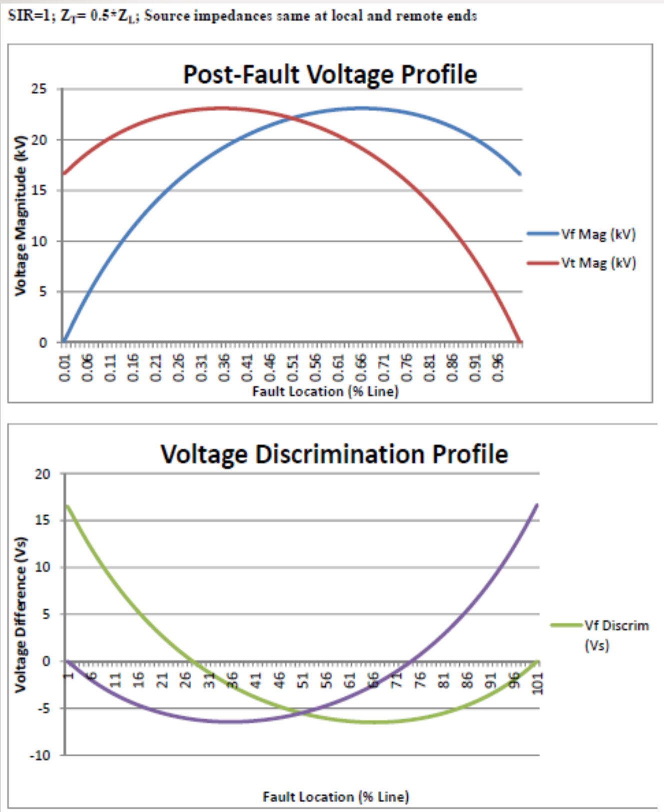
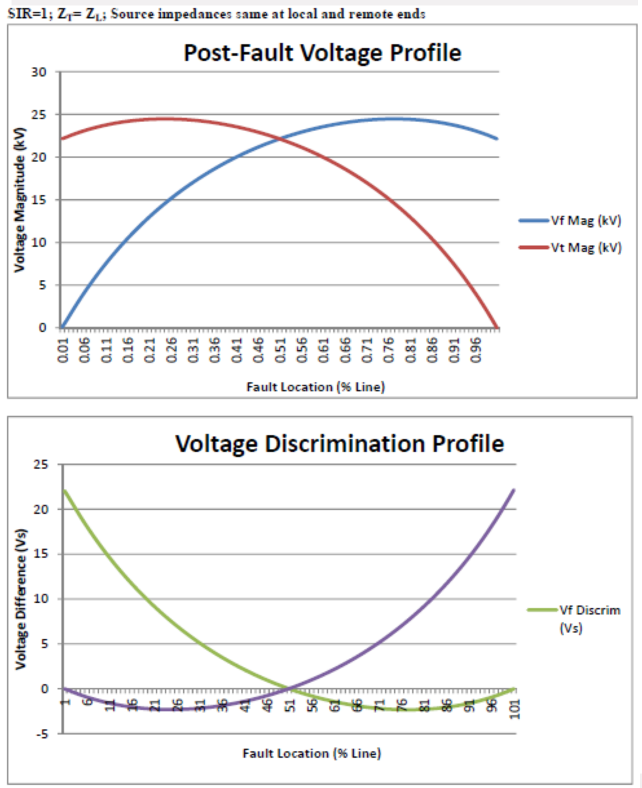


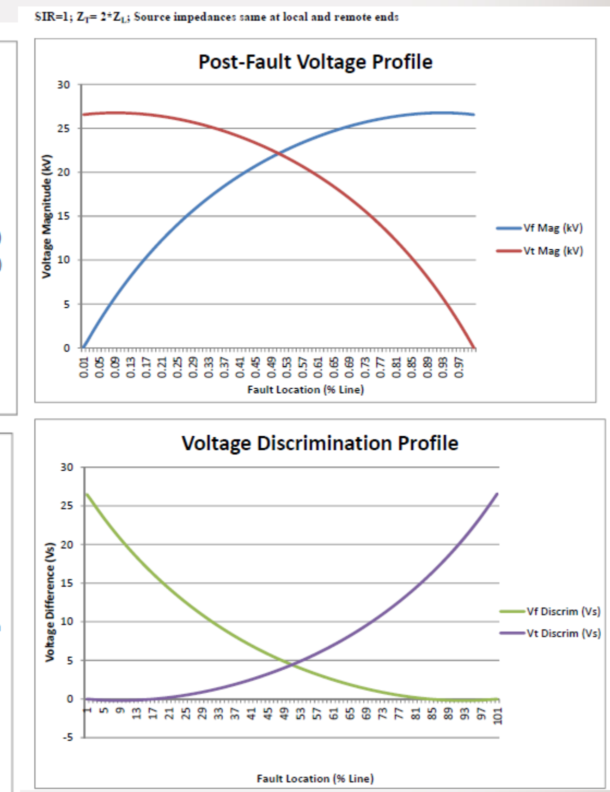
Figure 3: Two bus equivalent of the interconnected system

- Z_L: Transmission line under study
- ZT :Transfer impedance after system reduction

Sliding Faults -Variation of Relay Voltage and ΔV with Z_T and Source impedance







$Z_T = 0.5*Z_L$ $\quad$ $Z_T = Z_L$ $\quad$ $Z_T = 2*Z_L$

For $Z_T = 2*Z_L$, The discrimination voltage is less than 1V for faults at less than 70% even in a very strong system (SIR=1).

Voltage Discrimination

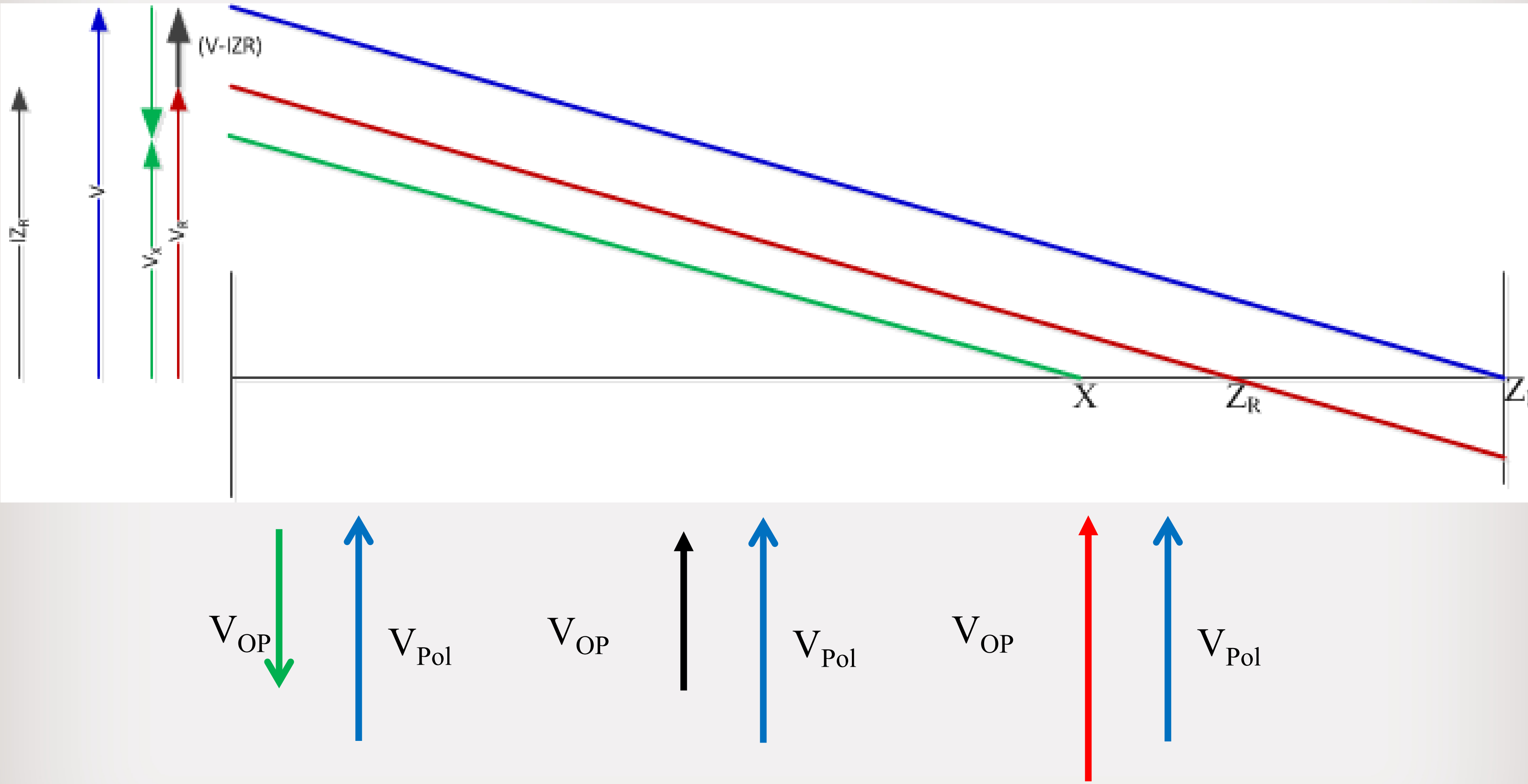
- Voltage discrimination varies with system Configuration and is not dependable.
- Value of 1V as the criterion for Zone 1 reach is questionable

Compensated Voltage ($V-IZ_R$)

- Distance Relay operating Principle
  - Checks Phase angle between $V_{op} = (V-IZ_R)$ and V_{ref}
  - V_{ref} –Fault Voltage or pre-fault Voltage (Memory)

- The compensated voltage term can be expressed in terms of SIR as $(V - IZ_R) = \frac{(Z_L - Z_R)}{Z_L} * \frac{E}{(SIR+1)}$
- This can also be expressed as $(V-IZ_R) = \frac{E*(1-M)}{(SIR+1)}$

$V_{OP} = (V-IZ_R)$



Internal Fault

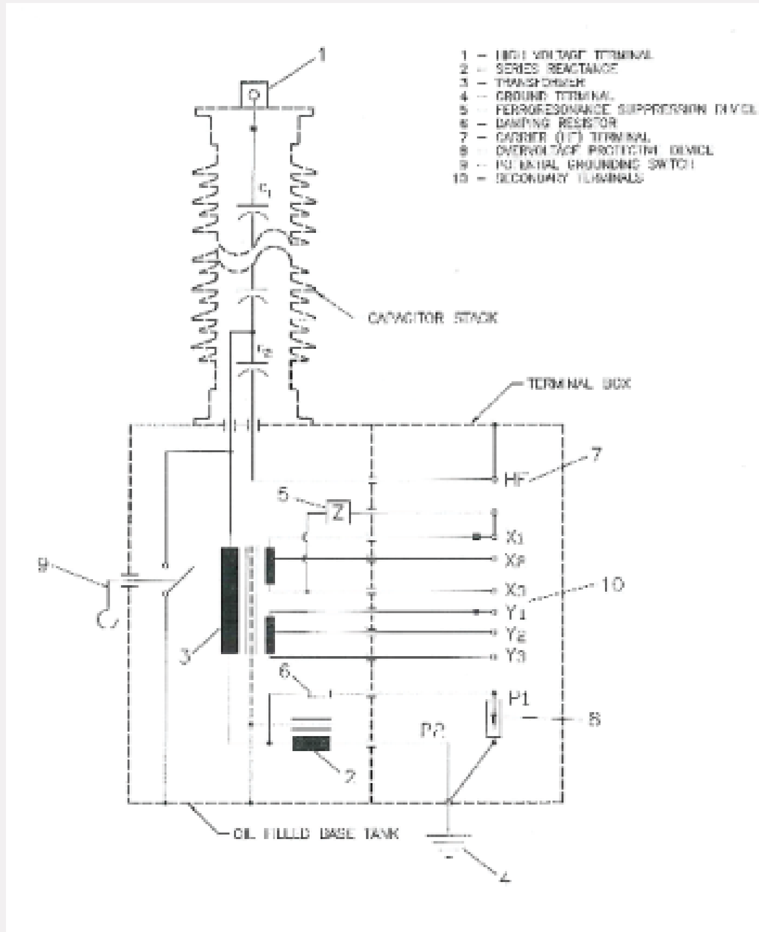
External fault

Reverse fault

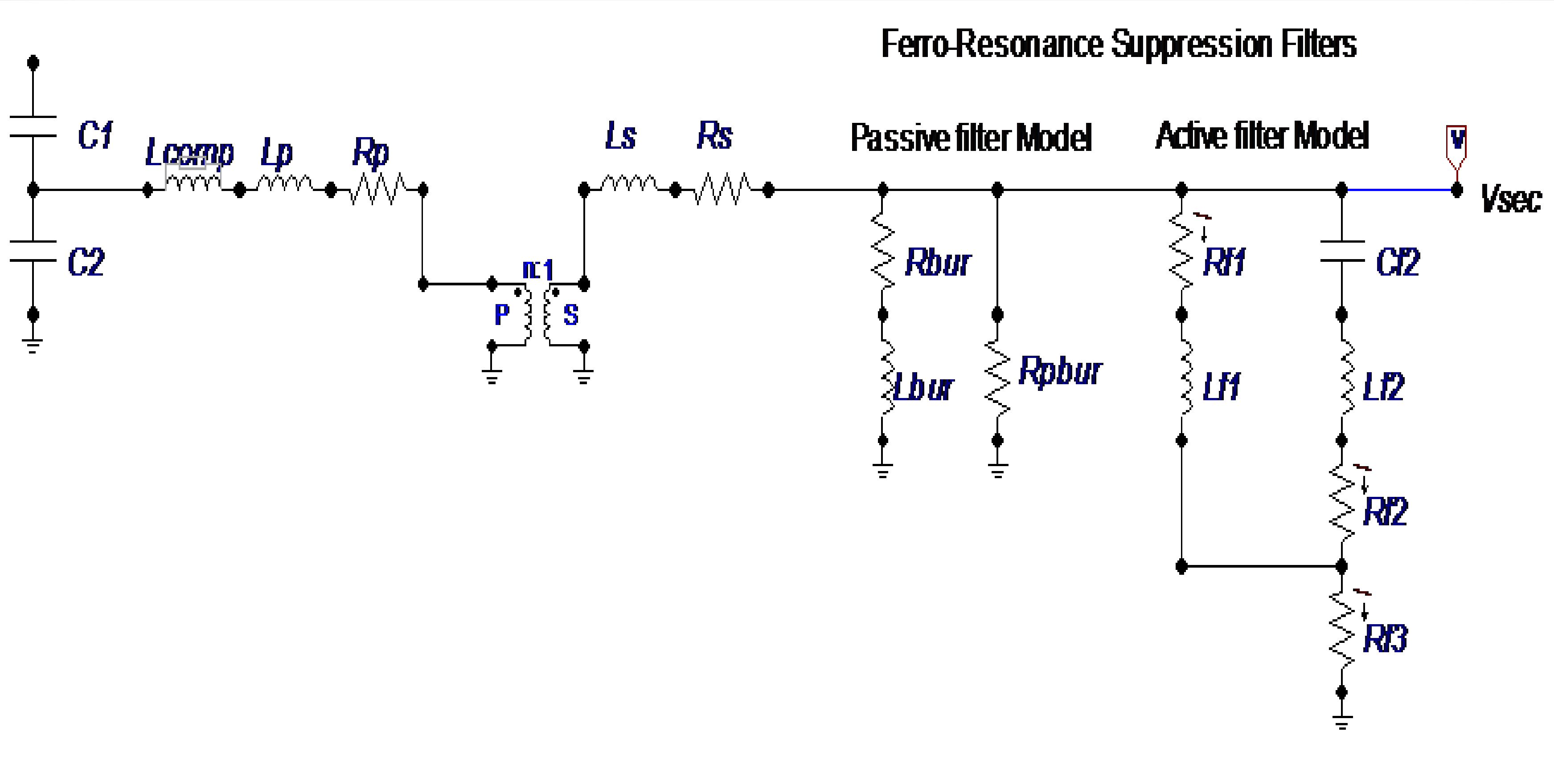
Operating Voltage in Distance Measurement

- V_{OP} = (V-IZ) Cannot be negative for external faults
- At the reach point, (V-IZ) =0
- Errors in I, Z and V contribute to overreach of distance element.
- Impedance Setting Error
- Current Measurement Error – DC offset or Ratio error due to burden and current magnitude
- Voltage Measurement Error

Voltage Instrument Transformer



CVT



Ferro-Resonance Suppression Filters
C1
C2
Lcomp
Lp
Rp
Ls
Rs
P
S
Passive filter Model
Active filter Model
Rbur
Lbur
Rpbur
Rf1
Lf1
Cf2
Lf2
Rf2
Rf3
V
Vsec

CVT Transient Response –Active and Passive Ferro-Resonance Suppression

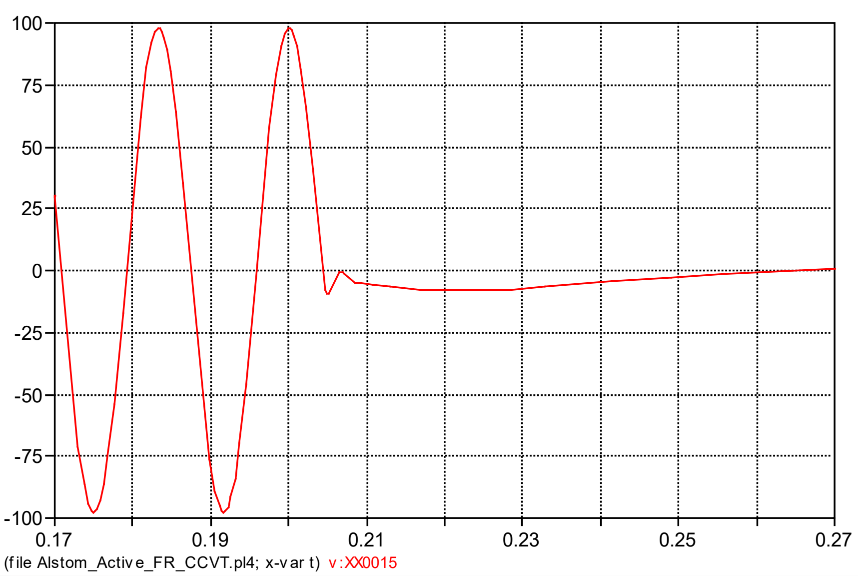


Figure 8: VT with active filter $-V_{SEC}$

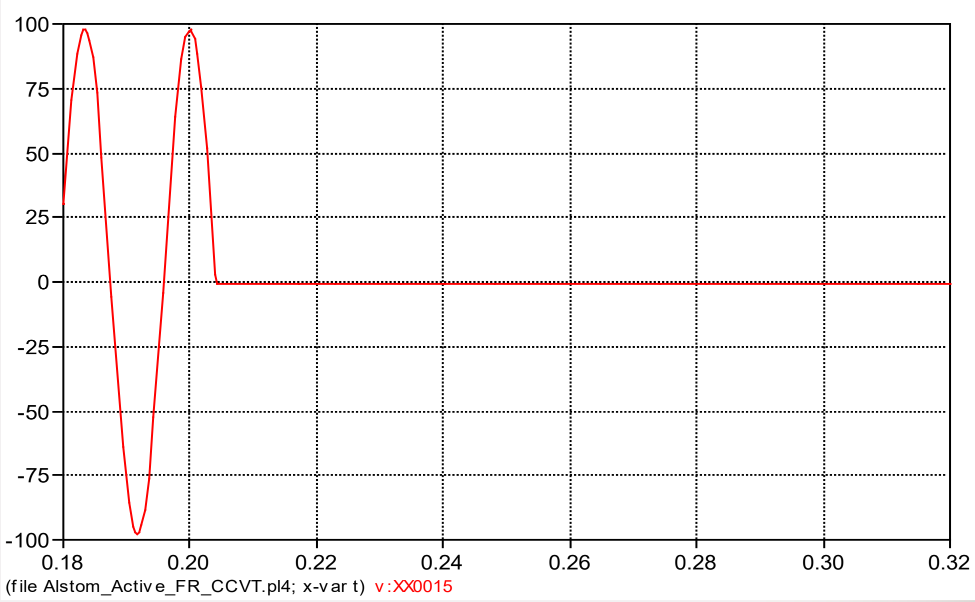
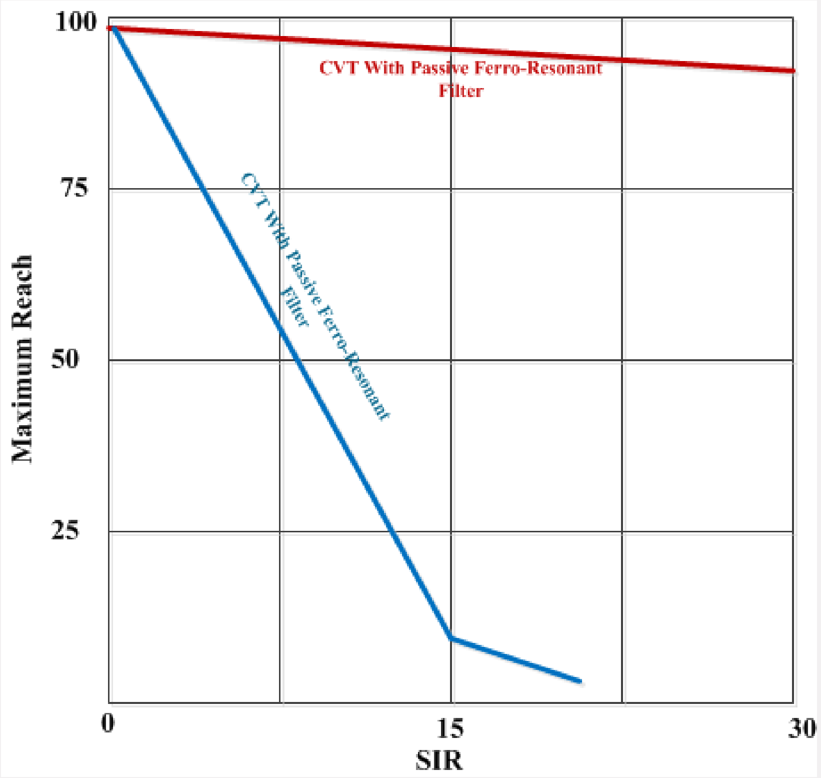


Figure 9: VT with Passove filter $-V_{SEC}$

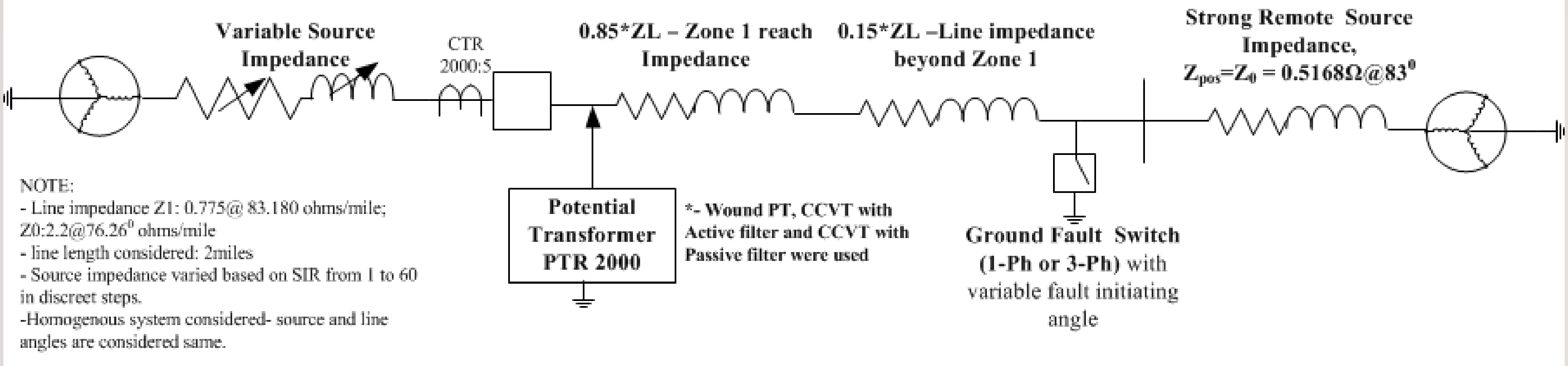
Relay Response to CVT Transients



Suggested Reduction in Zone reach ref [3]

- [3] Kasztenny, Bogdan; Sharples, Dave; Asaro, Vince and Pozzuoli, Marzio; "Distance Relays and Capacitive Voltage Transformers- Balancing Speed and Transient overreach", 53rd Annual conference for Protective Relay Engineers, April 2000. (Also Available as GER-3986)

Relay Testing – PSCAD Model



One Line model of the System simulated in PSCAD

- Number of Relays Tested: Five Relay types from Two Manufacturers
- Zone 1 set to 85% of the line.
- Fault location – remote bus (100% of the line)
- SIR varied from 1.0, 5.0, 10.0, 20.0, 30.0, 40 and 60.
- Fault inception angle changed from 0 to 180^0 in steps of 30^0.

Zone 1 Distance Element Response

With Wound PT and with CCVT with passive Ferro-Resonance suppression (Filter) circuit

- Zone 1 unit never operated for End zone faults for SIR up to 60.

With CCVT with active Ferro-Resonance suppression (Filter) circuit

- Relays with transient suppression settings did not operate.
  - All relays without and CVT transient suppression setting or with this setting disabled; Zone 1 over reached at SIR of 40 at certain fault inception angles.

Single line to ground Fault Tests

- Remote end source impedance set at ZS =0.5*ZL; Z_{0S} =Z_{1S}
- Relay response tested at SIR of 40
- Relay operations seen only with CVTs with active FR filter

Analysis in Progress

- All relay operation cases are in the process of retesting with reduced reach or adding zone 1 time delay
- Reviewing all test cases to verify

Conclusions

- Relay with PT inputs from CVTs with Passive FR filters did not show any need for reduction in the reach for SIRs up to 60
- Tests in progress to determine reach reduction for voltage inputs from CVTs with Active FR filter
- Ground Distance reach still needs to be checked for mutual coupling
- Few experts have expressed concerns with GPR and other noise inputs impact on reach settings (???)

Questions?