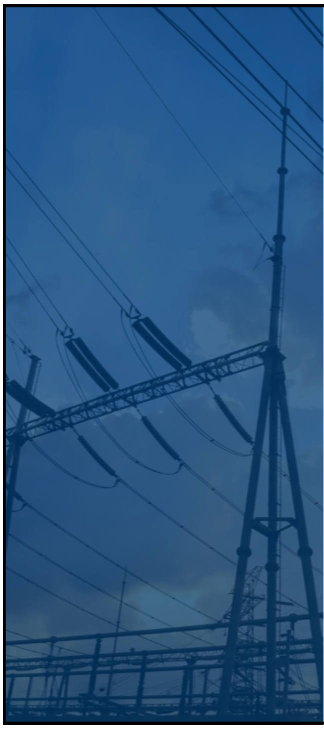

Impedance-Based Directional Elements – Why Have a Threshold Setting?

Ryan McDaniel and Michael Thompson
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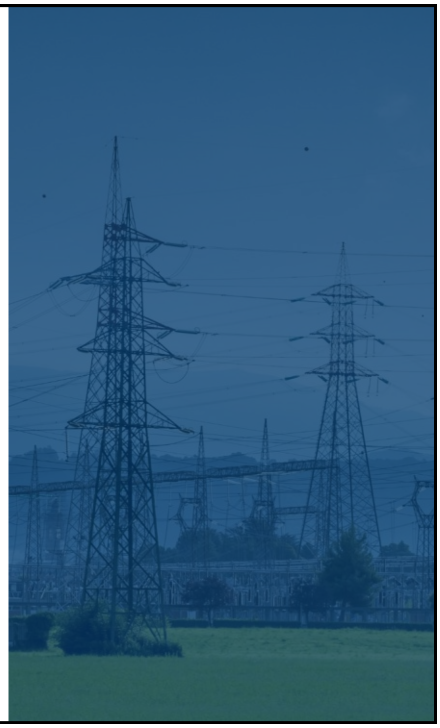
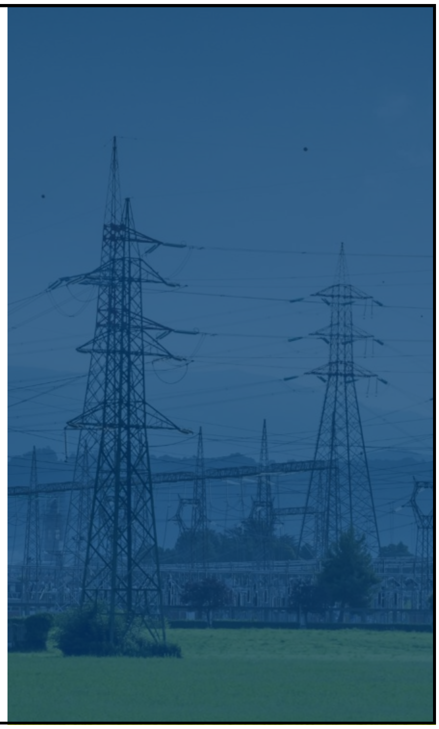
Overview

- Directionality fundamentals
- Torque versus impedance directional elements
- Setting impedance directional elements
  - Automatic schemes
  - Manual schemes
- Potential transformer error analysis



Overview

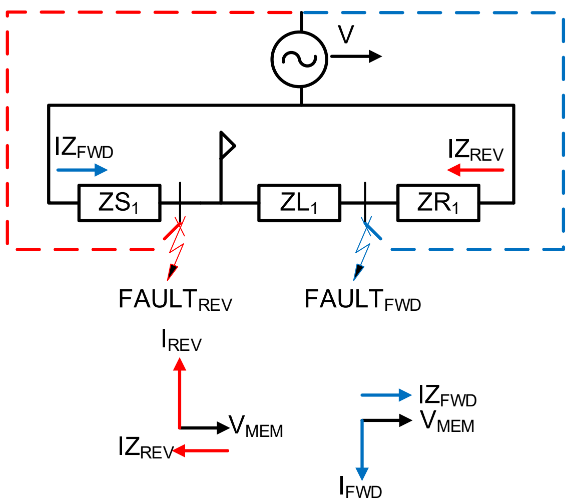
- Security and dependability evaluation of setting schemes
- Directional element overcurrent supervision



Positive-sequence directionality

Direction for balanced faults

- Z = 1 ∠ MTA
- IZ = $\vec{I}$ shifted + MTA°
- Relationship for metallic faults
  - Forward: V and IZ in phase
  - Reverse: V and IZ out of phase



Use cosine operator to determine direction

Balanced faults

- COS (∠ V – ∠ IZ) > 0 forward
  < 0 reverse
  = 0 no direction

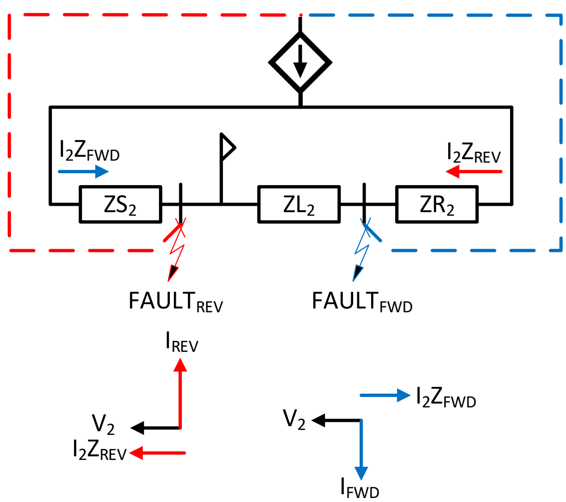
- R_f will affect COS (∠ V – ∠ IZ)

Use cosine operator to determine direction

Unbalanced faults

- COS (∠ $3V_2$ – ∠ $3I_2Z$) > 0 reverse
  < 0 forward
  = 0 no direction

- R_f will NOT affect COS (∠ $3V_2$ – ∠ $3I_2Z$)



$$\frac{3V_2}{3I_2} = -ZS_2 \text{ Forward} \qquad \frac{3V_2}{3I_2} = ZR_2 + ZL_2 \text{ Reverse}$$

Torque and impedance
Unbalanced faults

$|3V_2| \cdot |3I_2| \cdot \text{COS}(\angle 3V_2 - \angle 3I_2) < -|VA_{MIN}|$ Forward

$|3V_2| \cdot |3I_2| \cdot \text{COS}(\angle 3V_2 - \angle 3I_2) > |VA_{MIN}|$ Reverse

Defined by relay manufacturer

Divide by $|3I_2|^2$

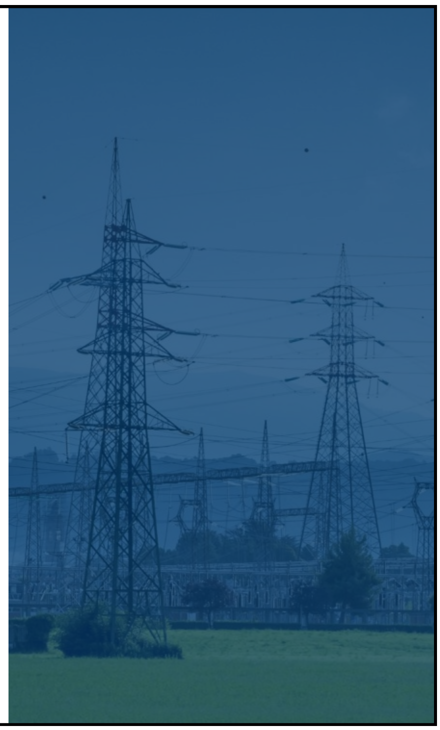
$$\frac{|3V_2| \cdot |3I_2| \cdot \text{COS}(\angle 3V_2 - \angle 3I_2)}{|3I_2|^2} < -|Z2F| \text{ Forward}$$

$$\frac{|3V_2| \cdot |3I_2| \cdot \text{COS}(\angle 3V_2 - \angle 3I_2)}{|3I_2|^2} > |Z2R| \text{ Reverse}$$

Defined by you!

Setting thresholds
Common automatic schemes

- AUTO
  - Z2F and Z2R are positive
  - Dependability bias (Zero 3V2 = FWD)
  - Need to know ZL
- AUTO2
  - Z2F is negative and Z2R is positive
  - No intentional bias (Zero 3V2 = 🚫)
  - Need to know ZS, ZL, and ZR



When to use AUTO

- System is strong (ZS_2 is small)
- High sensitivity is required
- Dependability bias is acceptable
- $ZL_2 > 0.6\ \Omega$

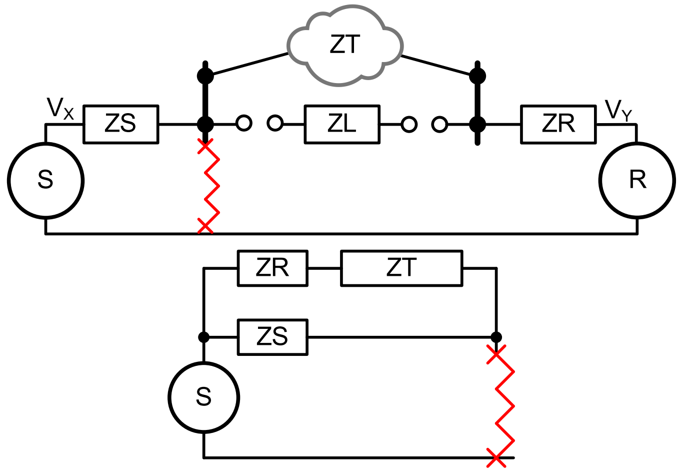
When to use AUTO2

- AUTO2 thresholds
  - $Z2F = -0.3\ \Omega$
  - $Z2R = 0.3\ \Omega$
- $|ZS_{2MIN}| > 0.5\ \Omega$
- $|ZL_2 + ZR_{2MIN}| > 0.5\ \Omega$
- More balanced approach to dependability / security is desired
- Closely mimics 32TQ (not biased forward or reverse), but generally, still more sensitive

Requires fault study

How to get ZS_{2MIN}

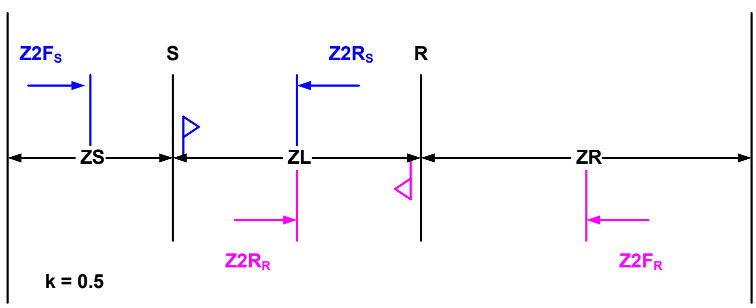
- Obtain Thevenin equivalent
  - Take line out of service
  - Place fault on the bus
- Or calculate ZS_2
  - Place close-in SLG fault with remote end open
  - Divide $V_2 / I_2 = ZS_2$
- Place $ZR_2 + ZT_2$ in parallel with ZS_2
  - Reduces apparent ZS_2



Manual threshold settings

k•ZS_2 scheme

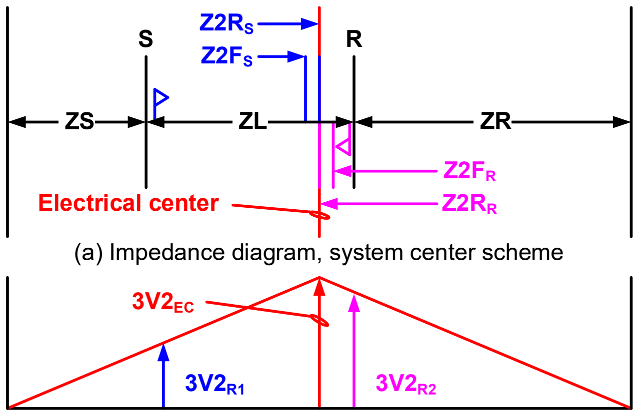
- Setting guidelines
  - $Z2F = -k \cdot ZS_2$
  - $Z2R = k \cdot ZL_2$
- For weaker systems:
  - Adds security
  - Doesn't sacrifice dependability



Manual threshold settings

System center scheme

- Set thresholds near electrical center
- Calculate 50QF to tolerate an assumed 3V2 error
- Balance between security and dependability



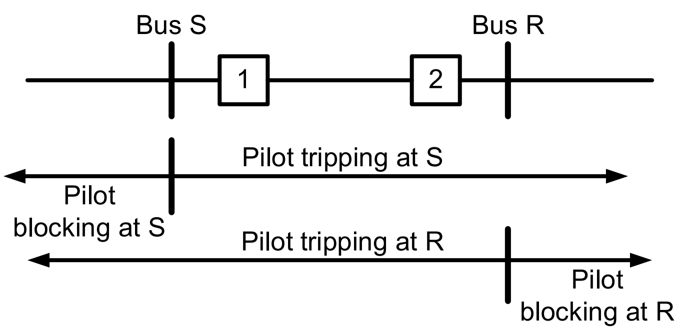
(a) Impedance diagram, system center scheme

(b) 3V2 Voltage profile

Transmission protection

DCB and POTT rely on direction for external fault security

- If local terminal declares forward, remote terminal must declare reverse
- If reverse is not declared:
  - DCB will not send block
  - POTT will echo permission
  - Local terminal will trip

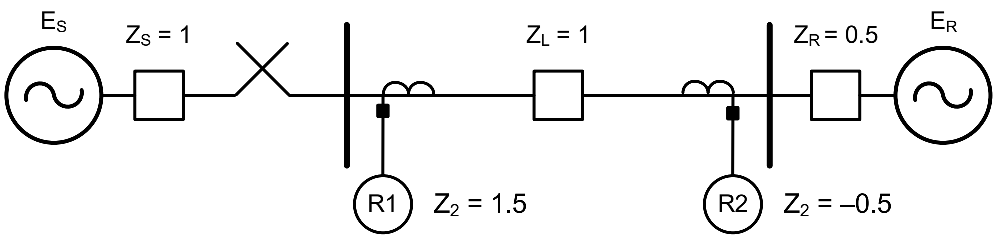


Pole open conditions

Security challenge

Single- and double-pole open conditions can challenge transmission line security with low $3V_2$ signal

Quantity	R1	R2
$\lvert 3I_2 \rvert$	0.5	0.5
$\lvert 3V_2 \rvert$	0.75	0.25



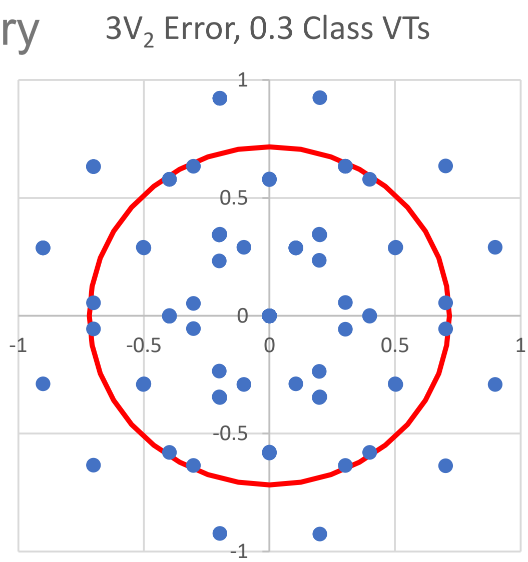
$3V_2$ error

VT error and system asymmetry

- Small $3V_2$ signal is susceptible to standing errors
- Small $3V_2$ is developed for external pole open conditions with low load
- Apparent Z_2 error is large for small $3I_2$

$$a)\ Z2_{Reverse} = ZR_2 + ZL_2 \pm \frac{3V_{2(ERROR)}}{3I_2}$$

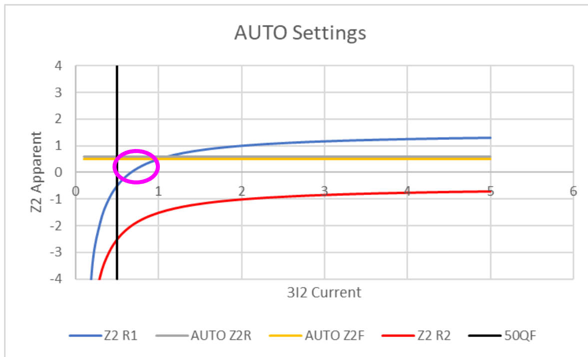
$$b)\ Z2_{Forward} = -ZS_2 \pm \frac{3V_{2(ERROR)}}{3I_2}$$

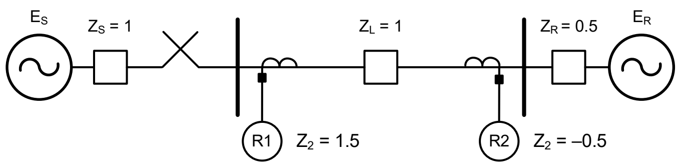


AUTO settings with pole open

1 V $3V_2$ error biasing R1 and R2 forward

- AUTO, Z2F threshold = ½ ZL
- R2 declares forward
- R1 does not declare reverse for $3I_2$ values below 1.12 A
- Set R2 50QFP above 1.12 A





Raising 50QF provides security with VT error

- Assume a reasonable $3V_2$ error
- Set local 50QF based on remote forward biased $3V_2$ error and remote Z2R setting
- Only pick up local forward 32ZQ for cases where remote reverse 32ZQ can assert for external faults

$$50QF_{Local} = \frac{3V_{2(ERROR)}}{ZS_2 + ZL_2 - Z2R_{\text{Remote}}}$$

Raising Z2F provides sensitivity with VT error

- With 50QF securely set, raising Z2F threshold can increase sensitivity with reverse biased $3V_2$ error
- However, Z2F < Z2R by rule

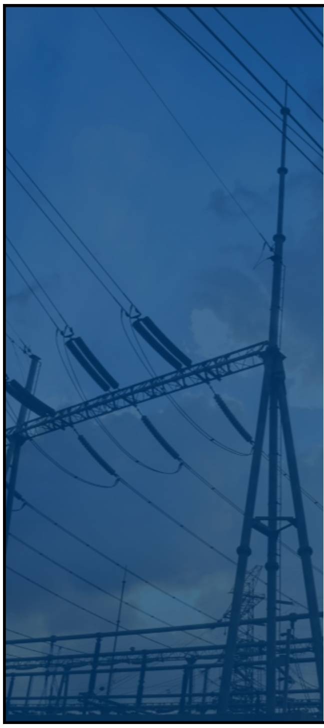
$$3I_2 \geq \frac{3V_{2(ERROR)}}{ZS_2 + Z2F_{(S)}}$$

Conclusion

- Automatic threshold settings offer convenience
  - Perform well under assumed system conditions
  - Can have security or dependability concerns when applied outside of assumed system conditions
  - Security concerns can be addressed by overcurrent supervision settings (50QF)
  - Paper covers when ***NOT*** to use automatic schemes
- Manual threshold settings can offer optimum performance
  - Settings are tailored to system being protected
  - Require some more work

Conclusion

- As the system shrinks, all schemes can have security concerns with $3V_2$ errors and very sensitive 50QF settings
- Threshold settings and overcurrent supervision allow users to balance security and sensitivity for 32 applications
- Same general guidelines also apply to a 32ZG element



Questions?