Improving Ground Fault Sensitivity for Transmission Lines Near Inverter-Based Resources

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Detecting ground fault directionality

Impedance-based directional elements

Negative-sequence voltage-polarized element (32Q)

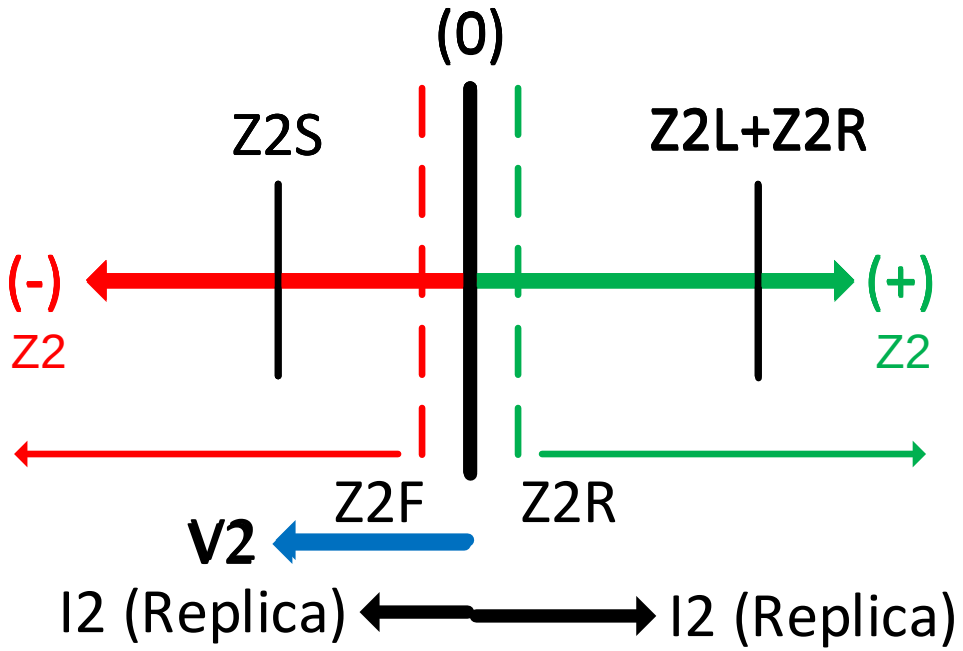
Zero-sequence voltage-polarized element (32V)

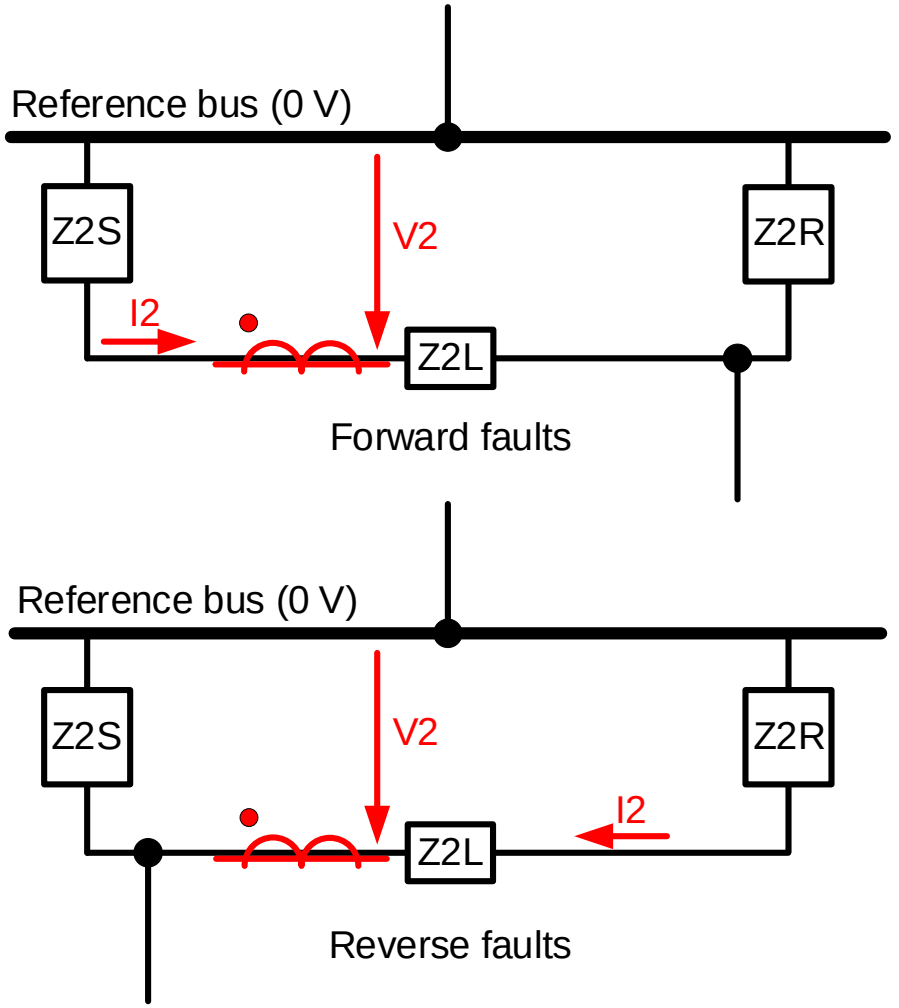
Phase comparison-based directional elements

Zero-sequence current-polarized element (32I)

Negative-sequence impedance element (32Q)

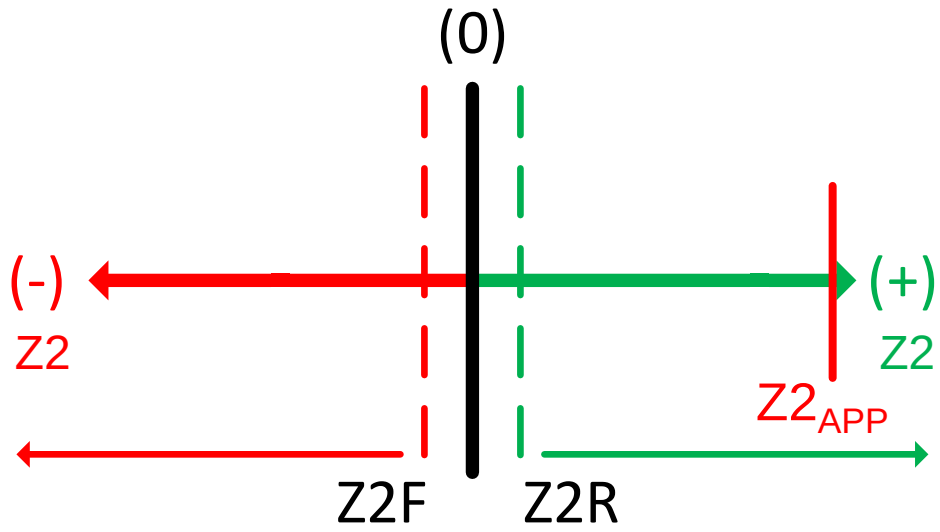
Uses V2 (polarizing quantity) and I2 (operating quantity)

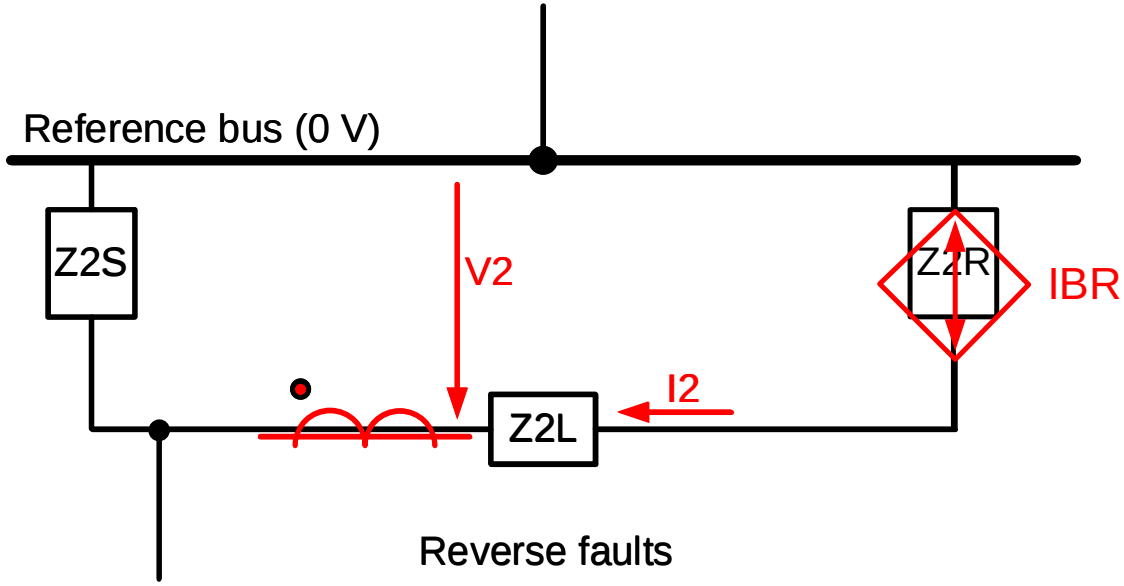




Negative-sequence impedance element (32Q)

Security challenge near IBRs

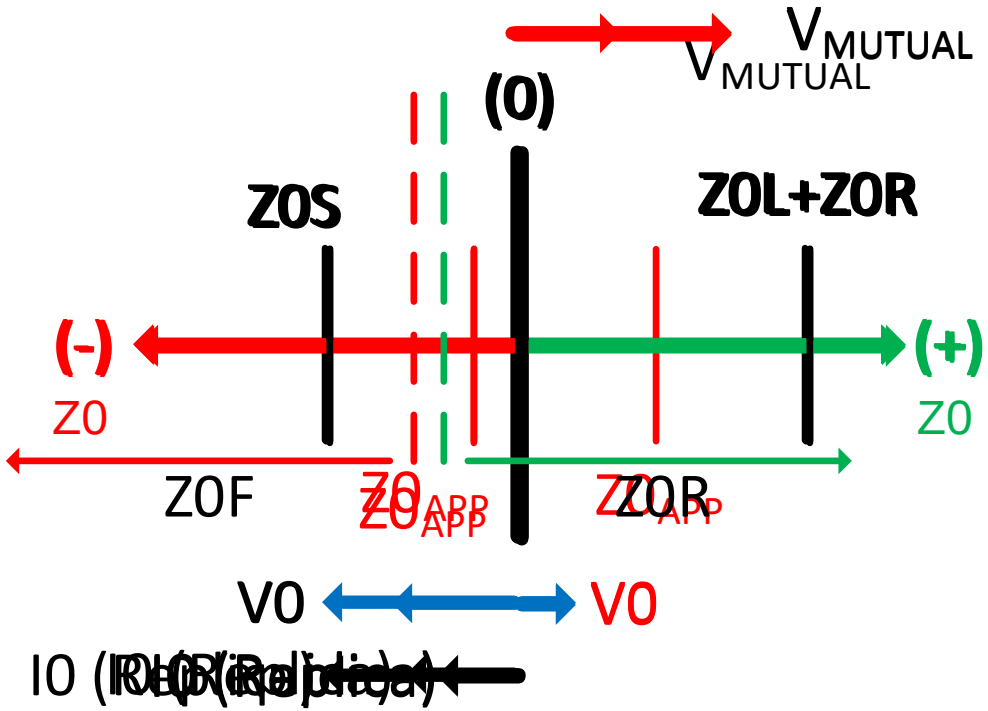


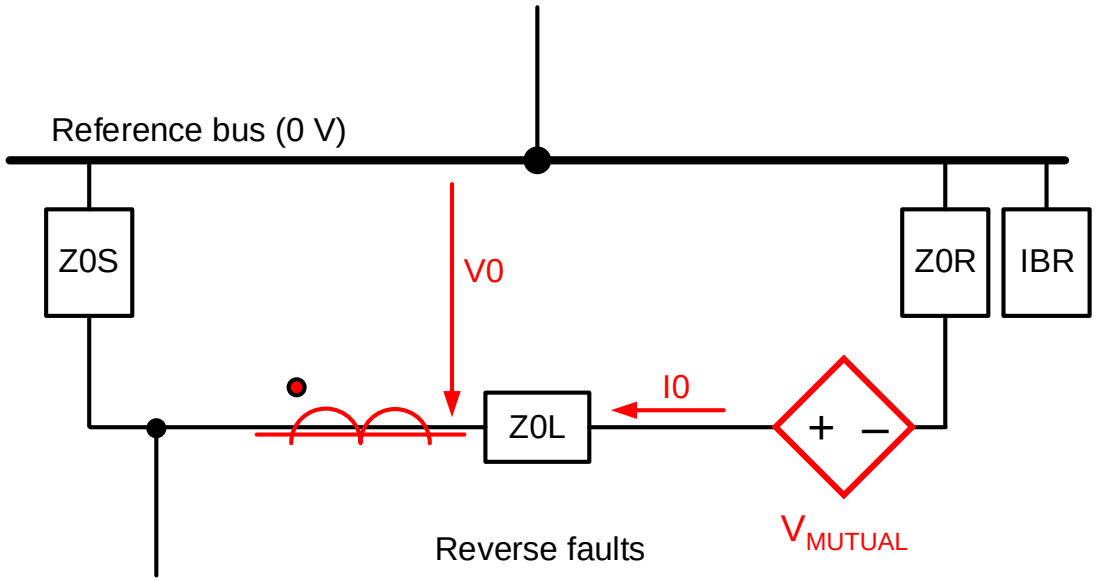


Raise 32Q O/C thresholds

Zero-sequence impedance element (32V)

Uses V0 (polarizing quantity) and I0 (operating quantity)





Mutual coupling can challenge 32V security

Evaluating strength and weakness of ground directional elements

32Q

- Immune to mutual coupling
- Security concern for IBR-fed faults

32V

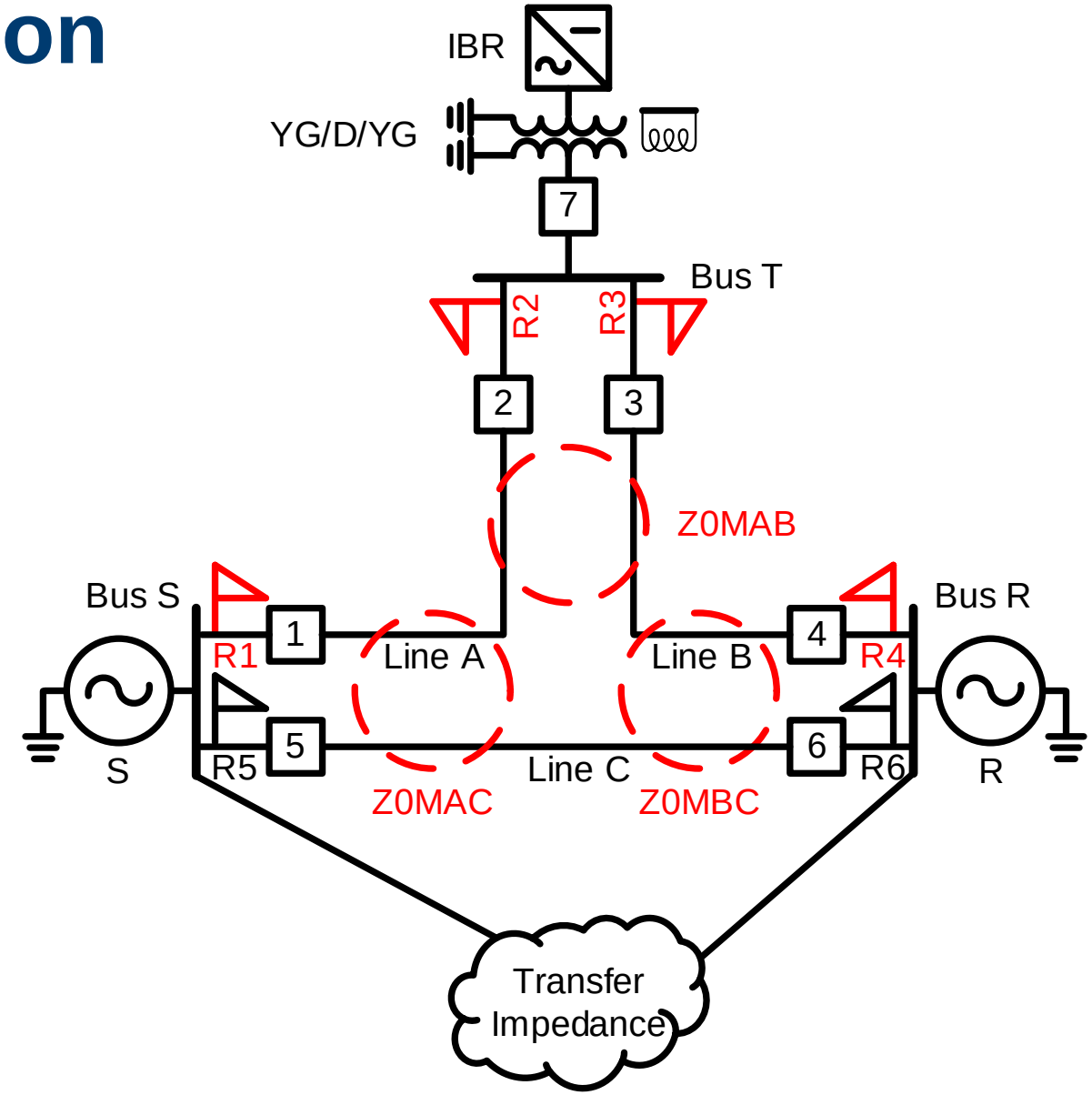
- Performs well for IBR-fed faults
- Security concern for mutual coupling

32Q security concerns are mitigated by desensitizing element

32V security concerns can be mitigated without desensitization

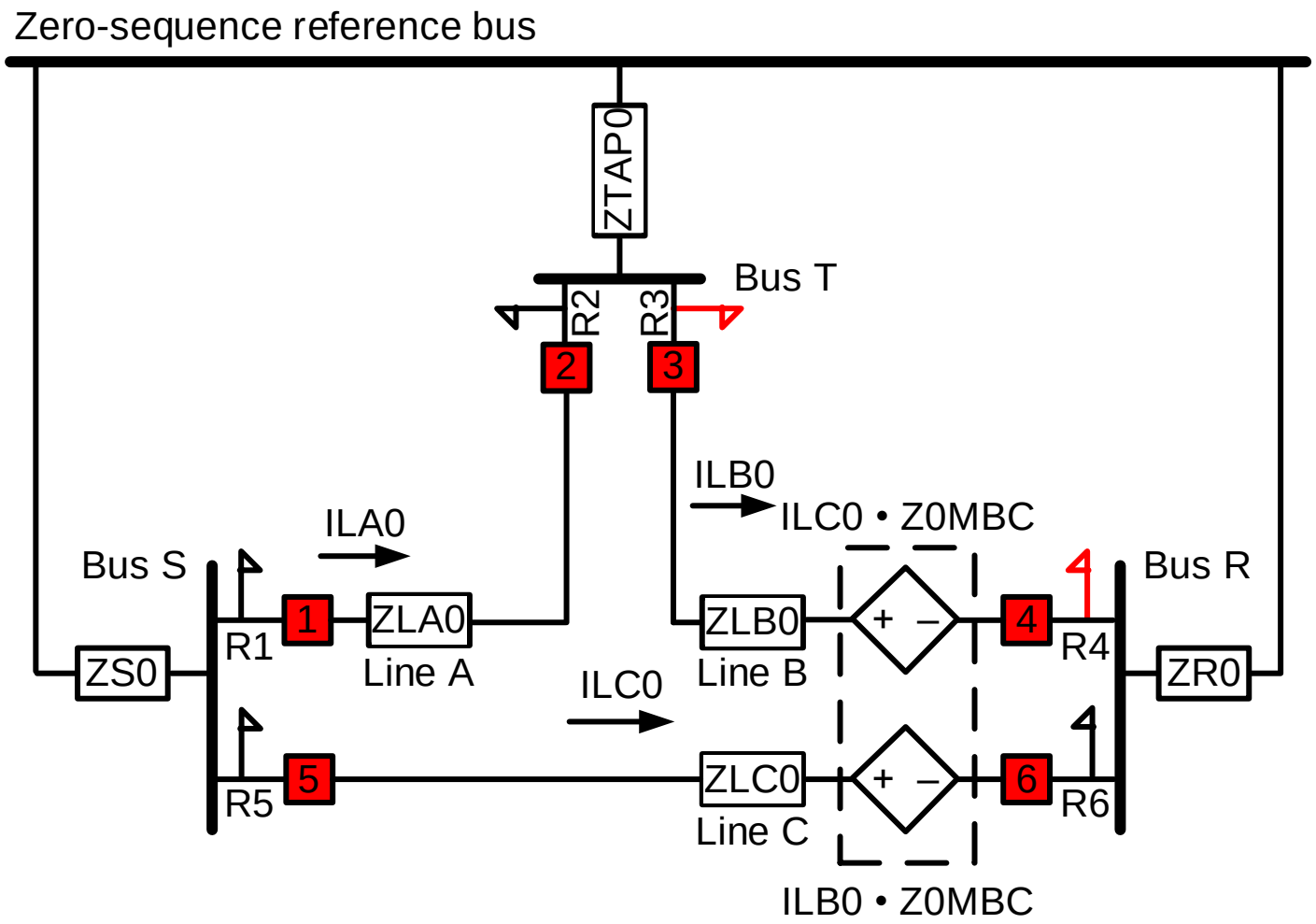
Consider an IBR installation on a double circuit

- Tapped into existing transmission line
- Switching station (Bus T) could be near / away from tap point
- 32V application requires additional considerations when mutual coupling is present



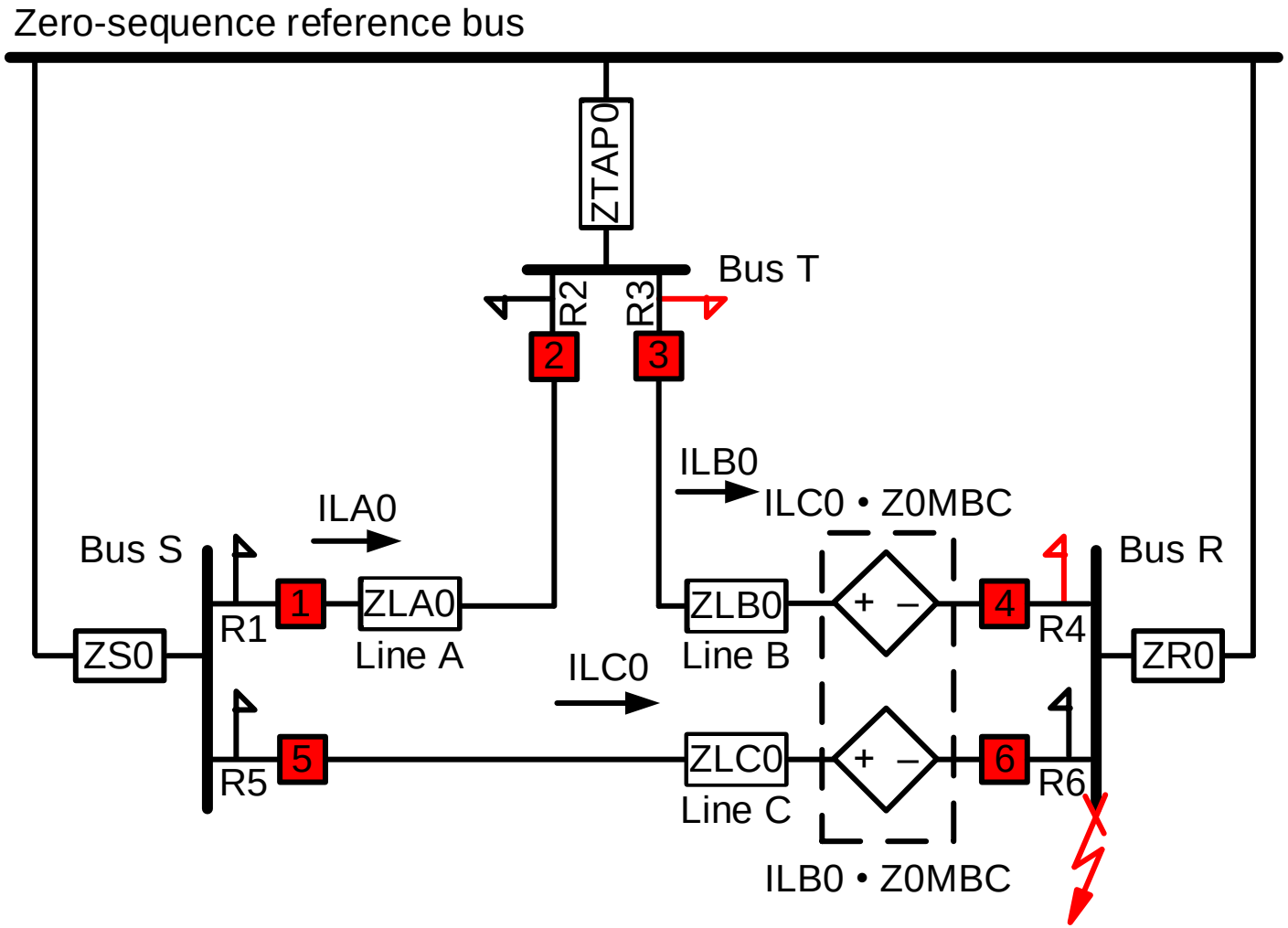
Security evaluation of 32V for Line B relays

Mutual coupling present between Line B and Line C



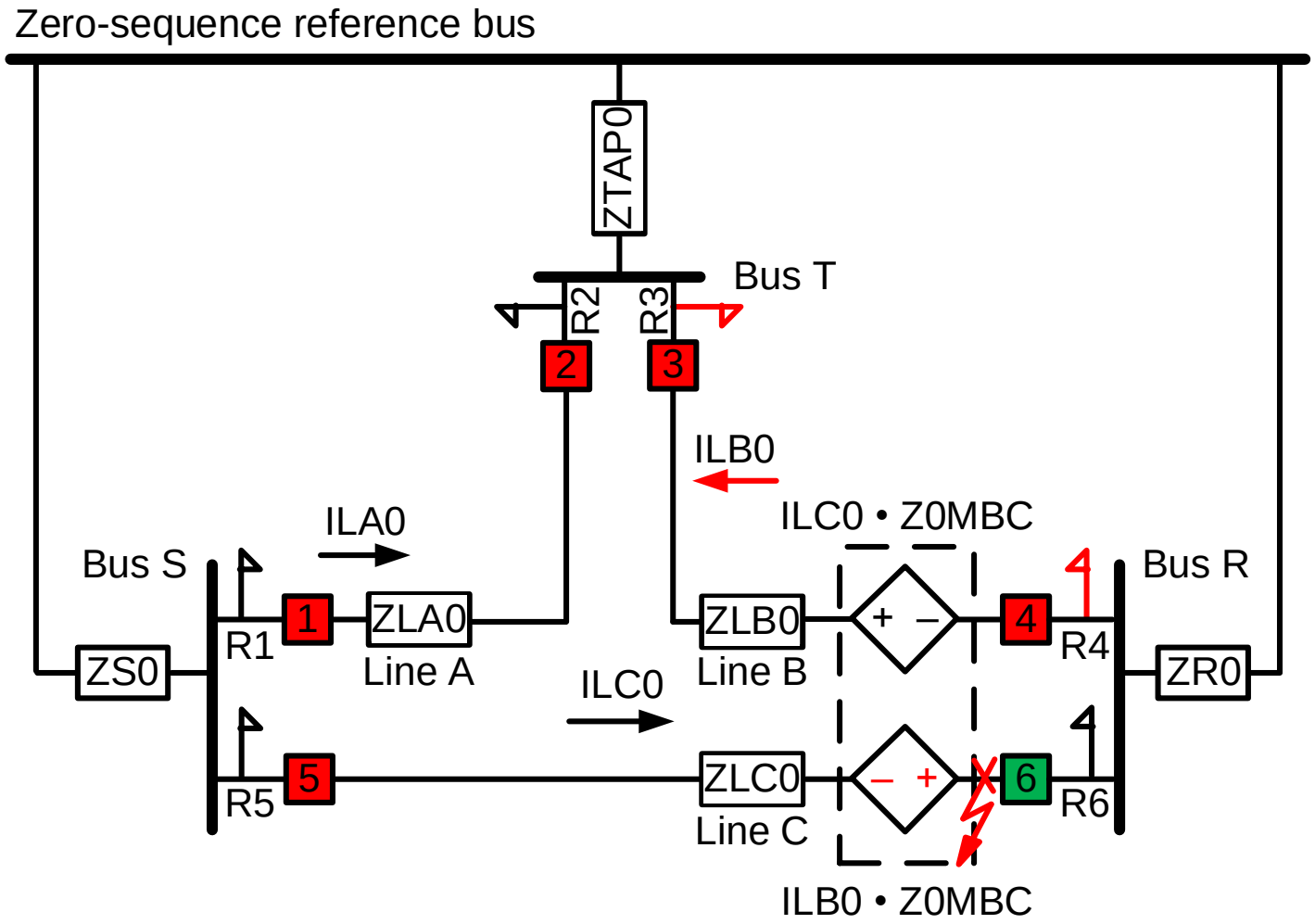
32V is secure in configuration 1

- V_{MUTUAL} is a voltage drop
- R4 will see an increased $Z0_{APP}$



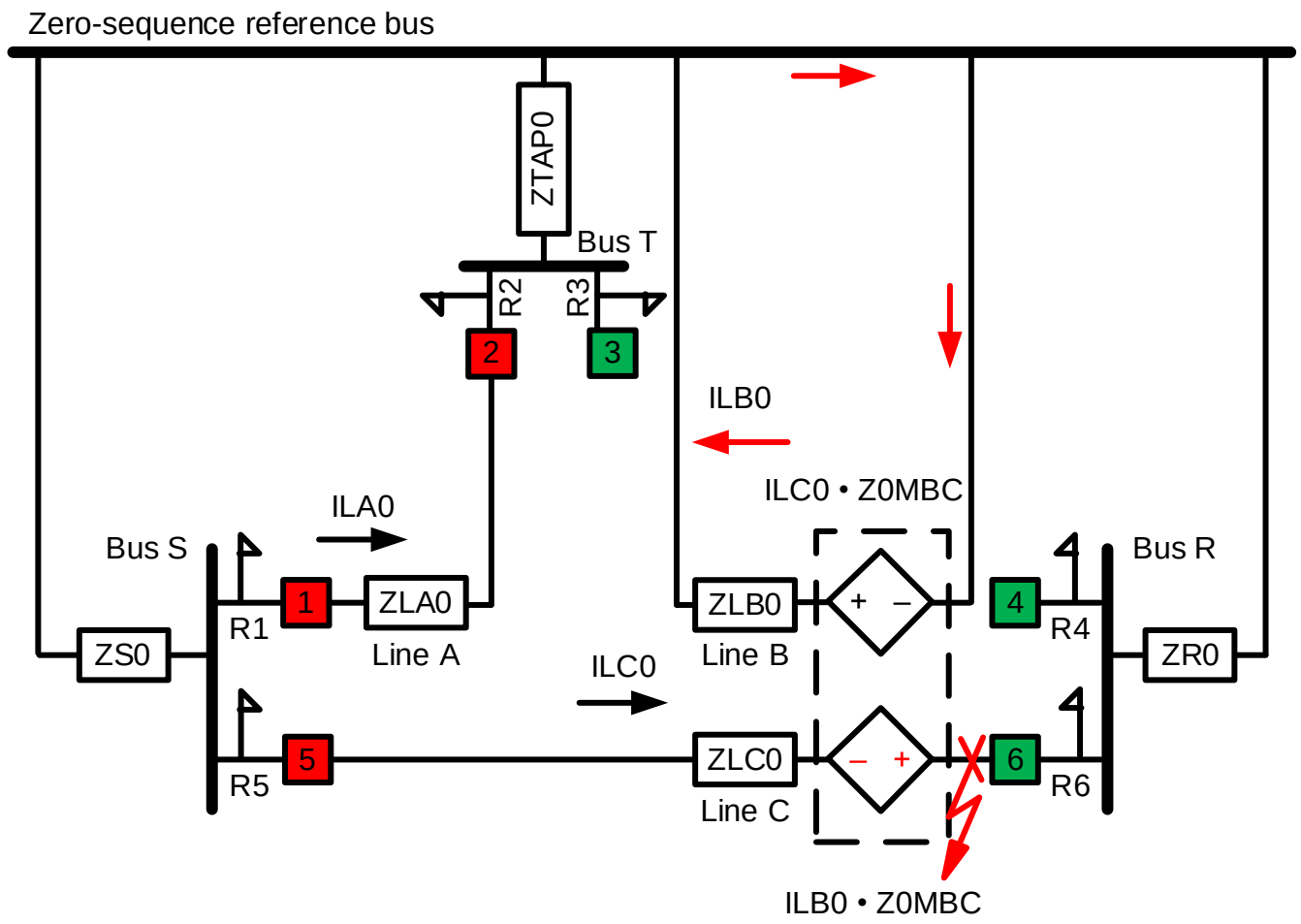
32V is secure in configuration 2a

- N-1 contingency
- V_{MUTUAL} is a voltage rise
- R3 will see a reduced $Z0_{APP}$



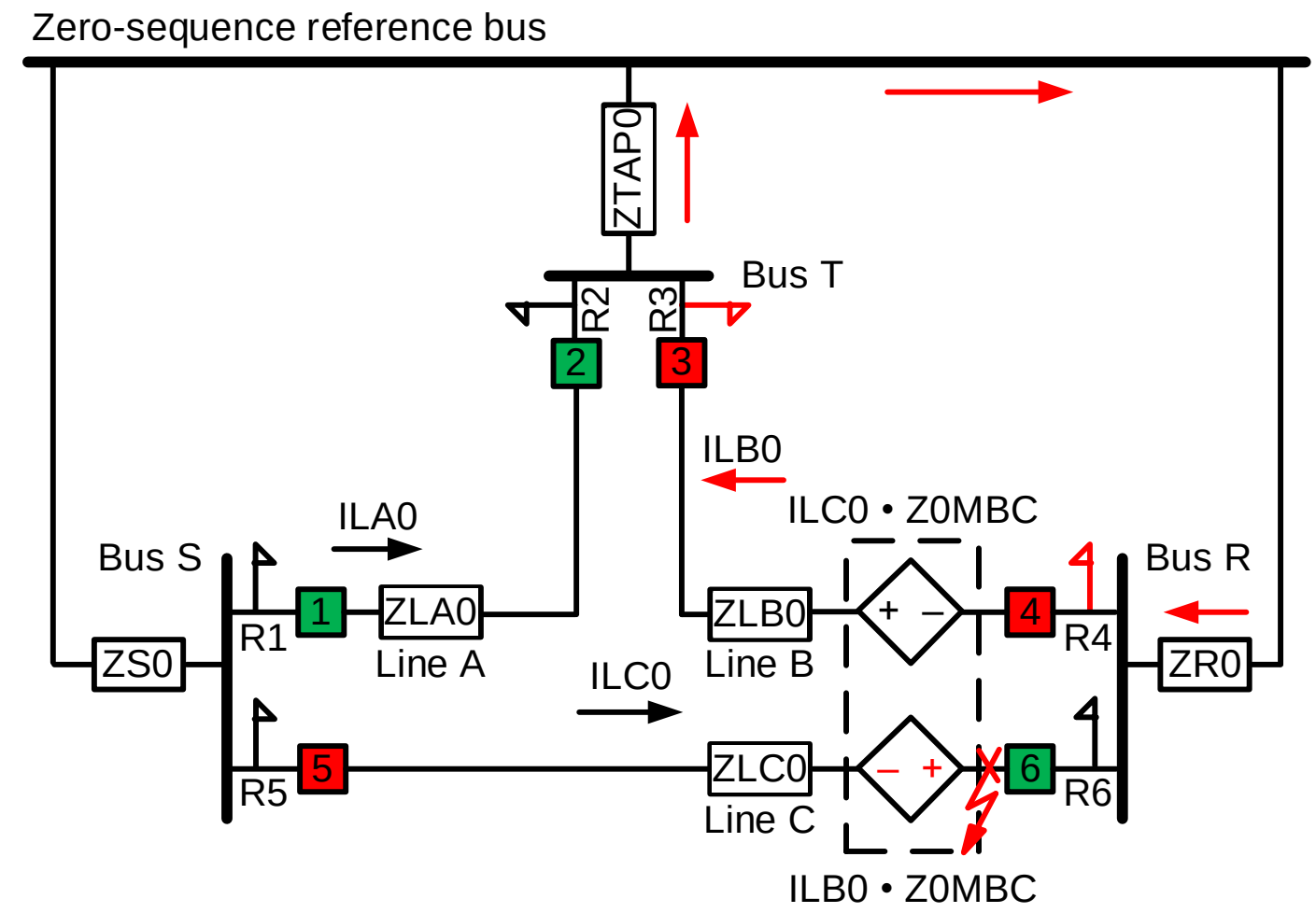
32V is not active in configuration 2b

- V_{MUTUAL} is a voltage rise
- ILB0 • ZLB0 is a voltage drop



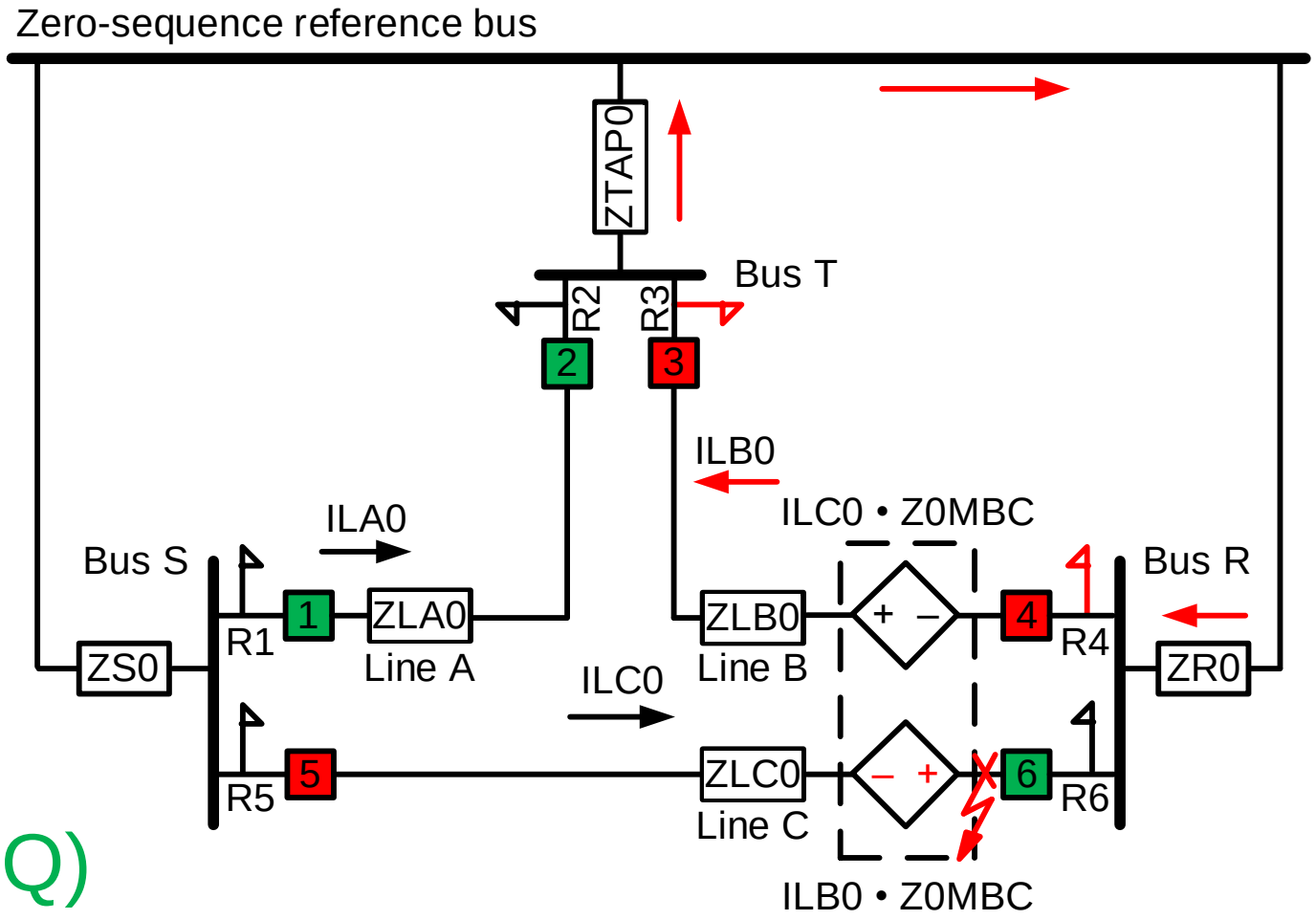
32V is not secure in configuration 2c

- Credible N-2 contingency
- V_{MUTUAL} voltage rise > ILB0 • (ZR0 + ZLB0) voltage drop
- R3 measures (+) V0 and (–) I0
- R4 measures (–) V0 and (+) I0



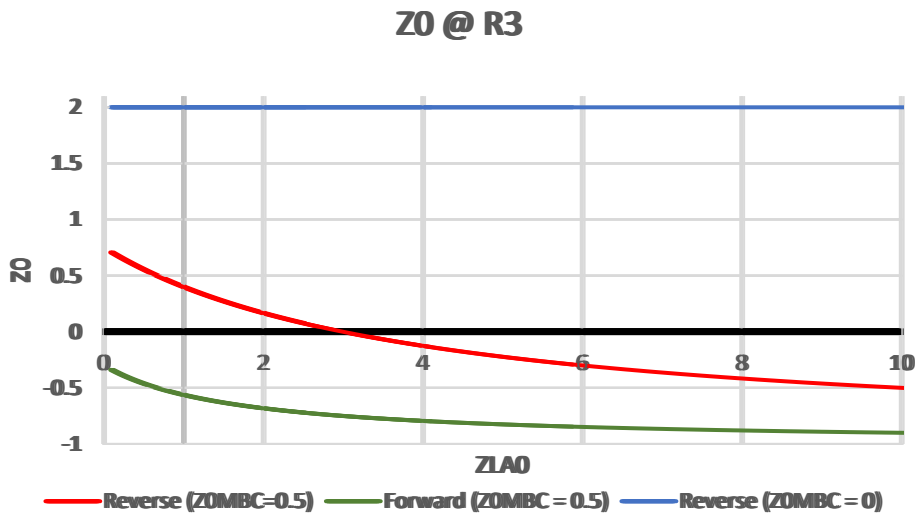
Improve security in Configuration 2c

No 3I2 current on Line B

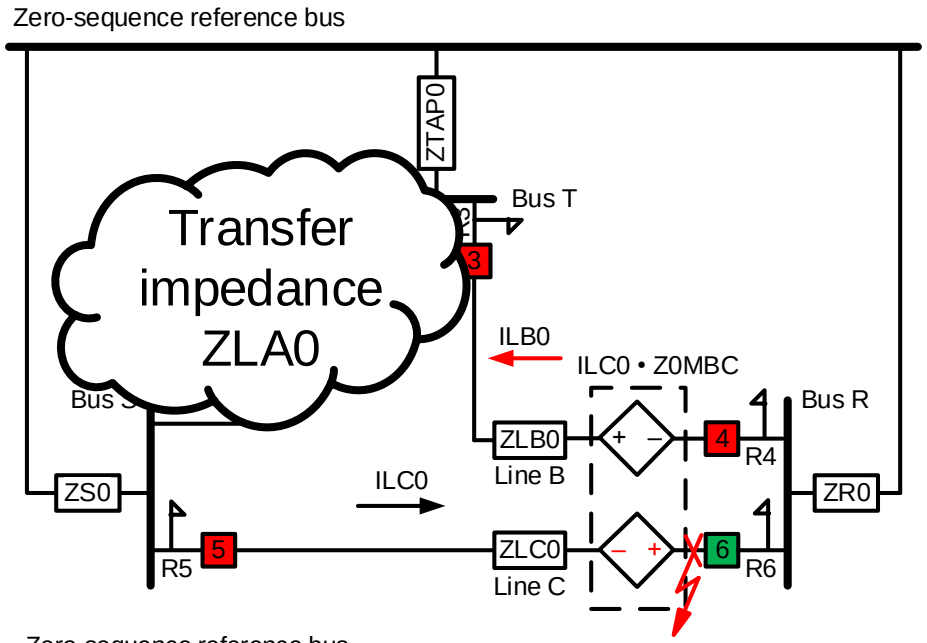


TRCOMM = (67G2) AND 50Q)

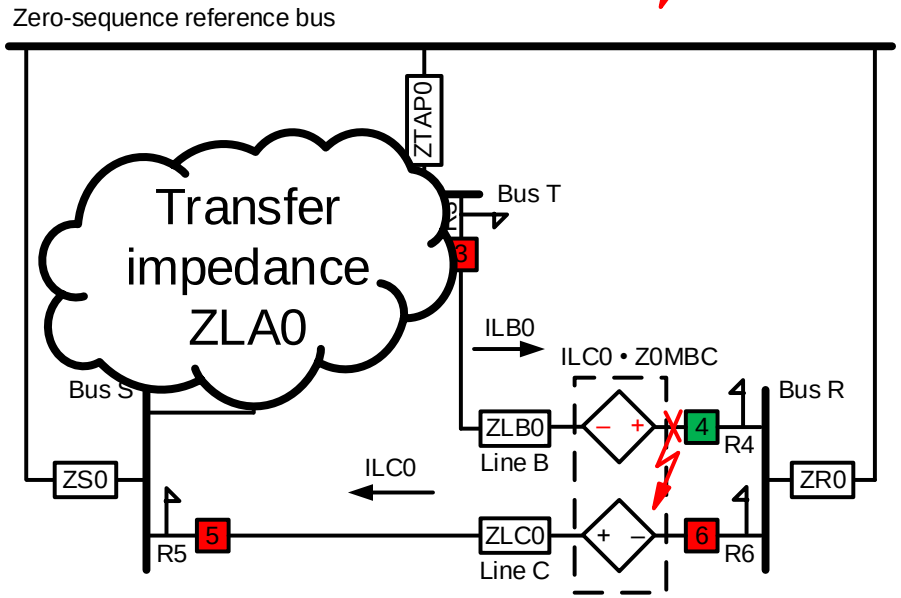
Mutual coupling shrinks apparent Z0 between forward and reverse faults



Values in per unit



Reverse



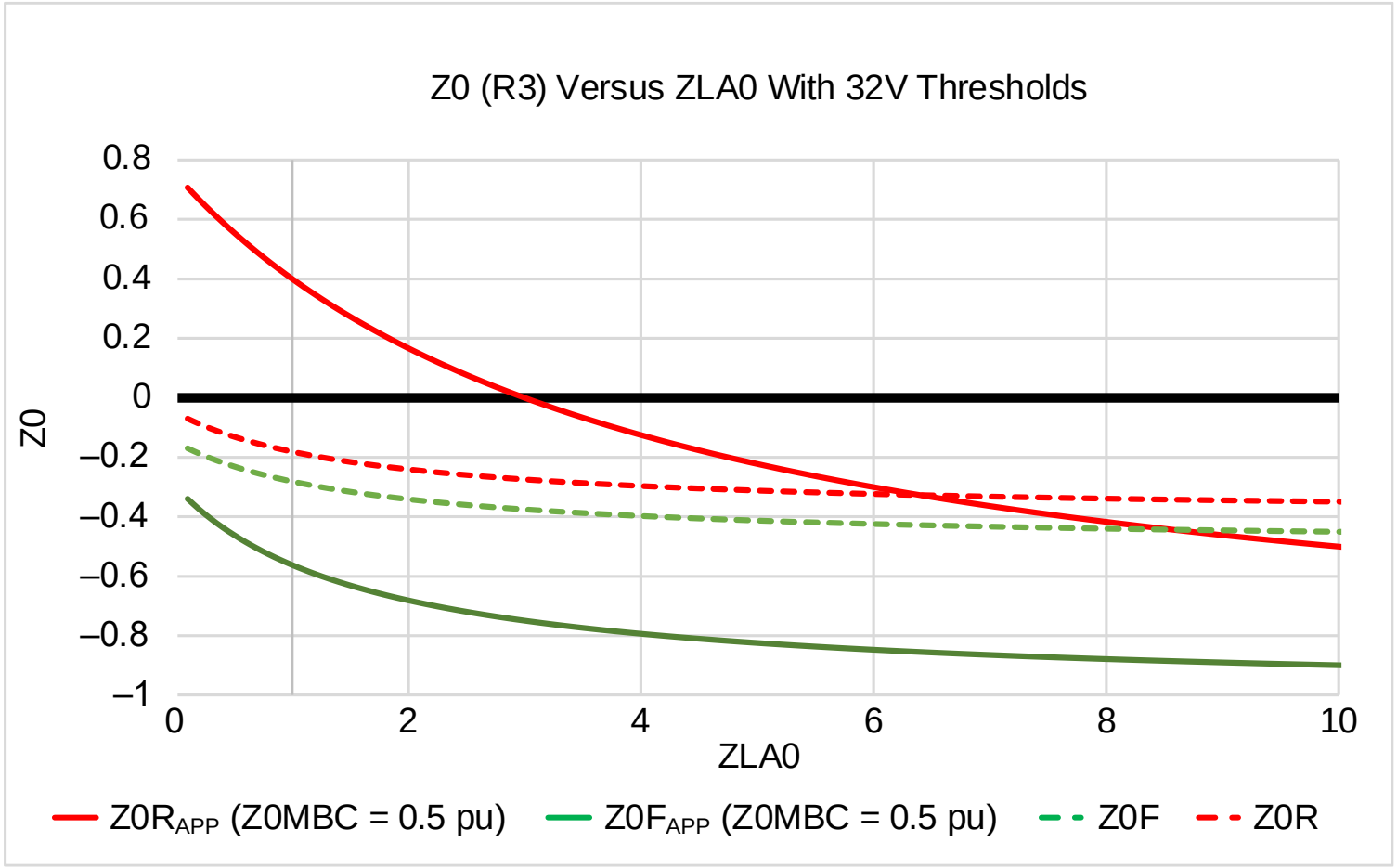
Forward

Improve 32V security with impedance thresholds

$$Z0F = -0.5 \bullet Z0F_{APP}$$

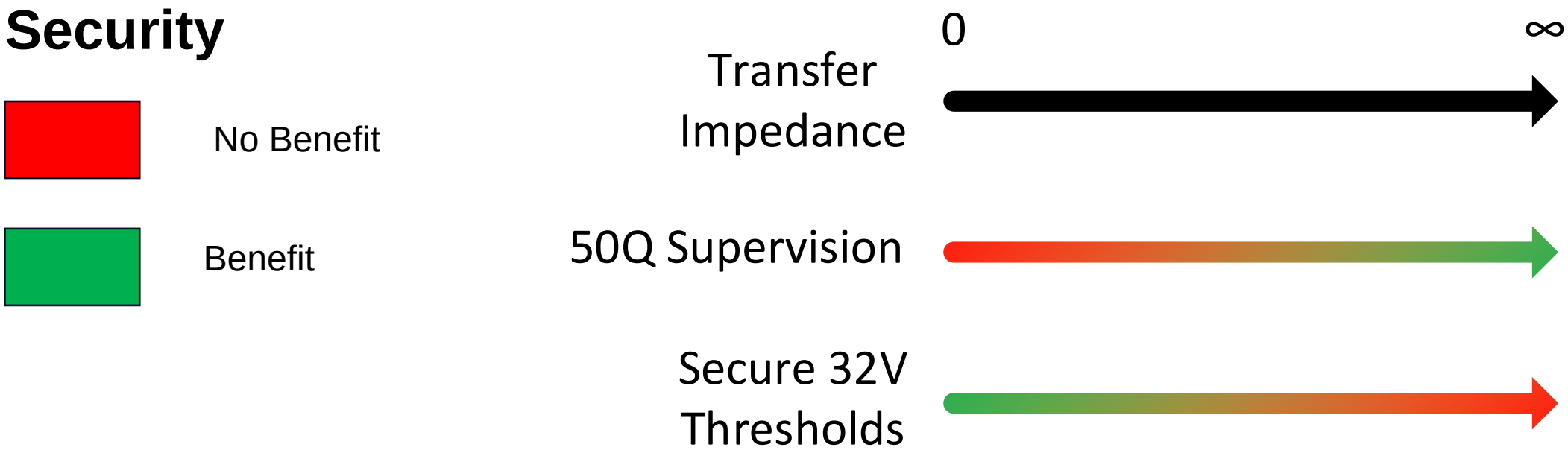
$$Z0R = Z0F + 0.1$$

$Z0F_{APP}$ is apparent zero-sequence source impedance



Values in per unit

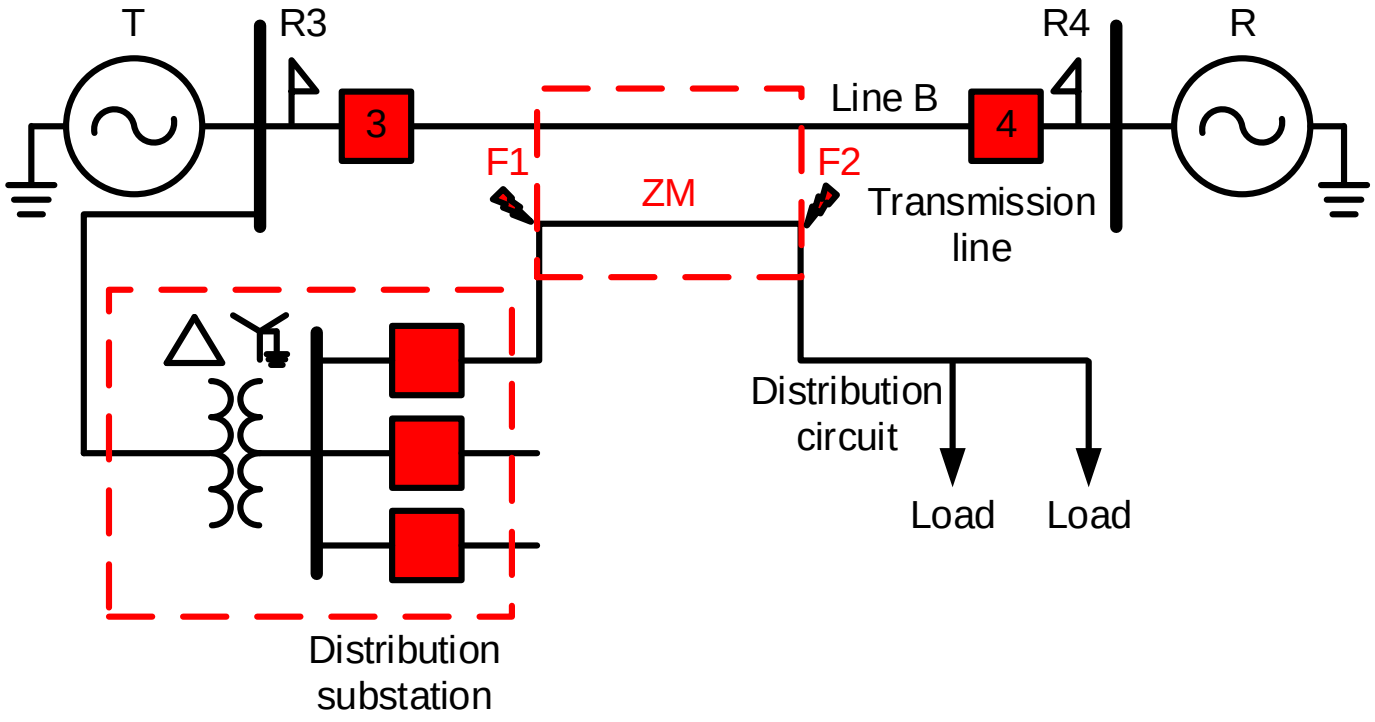
Improving 67G security without sacrificing sensitivity



Another challenge to 32V security

Mutual coupling between different voltage levels

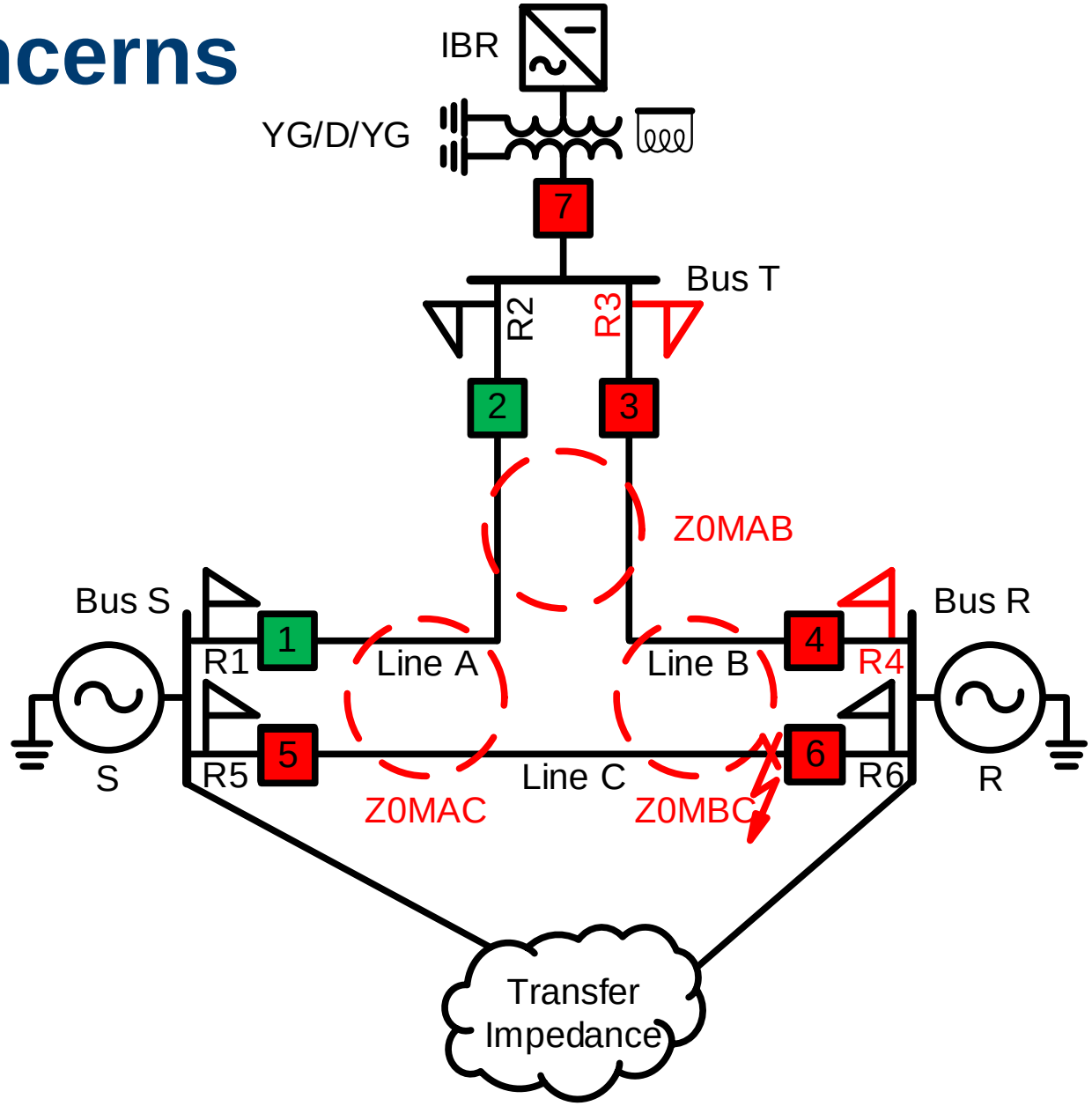
- Electrical **isolation** in zero-sequence network
- Electrical **connection** in negative-sequence network
- 32V threshold cannot be set secure
- Time-delayed sensitively set 67G
- Raise 67G pickup if necessary



Prevent 32V security concerns with smart reclosing

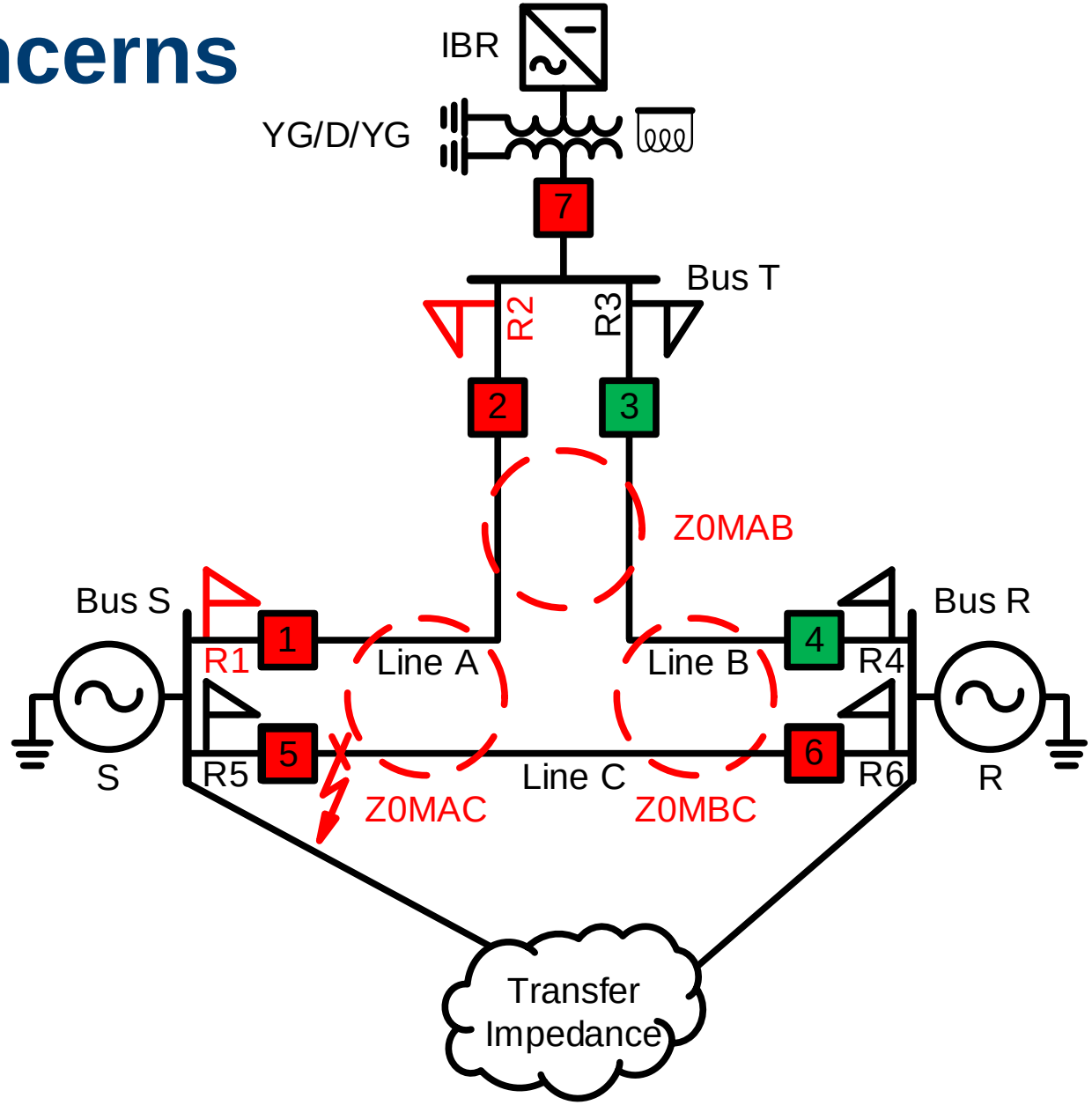
- Line A out of service
- Fault on Line C
- Reclose from Breaker 5?
- Reclose from Breaker 6?

Reclose from Breaker 6



Prevent 32V security concerns with smart reclosing

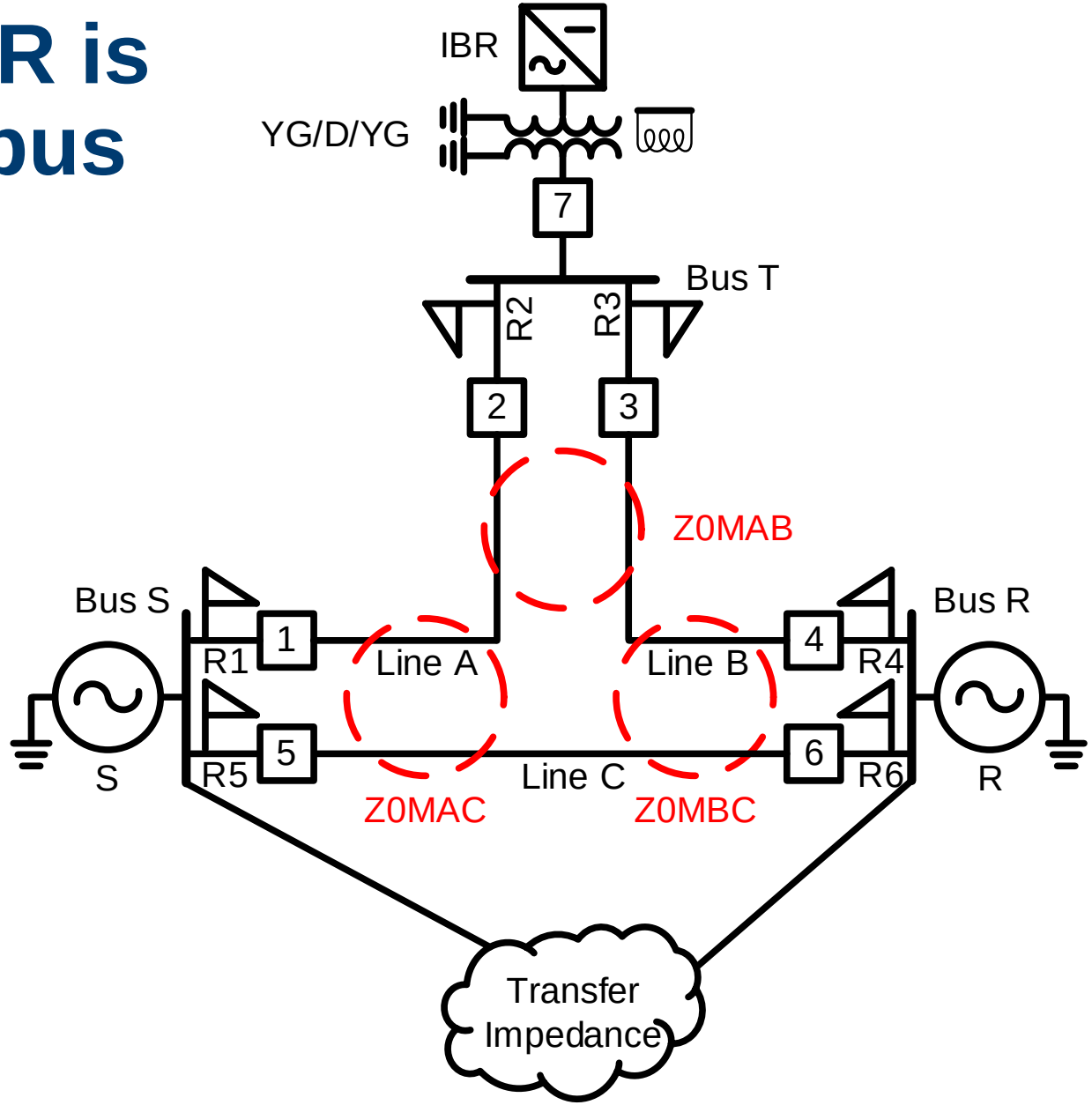
- Line B out of service
- Fault on Line C
- Reclose from Breaker 6?
- Reclose from Breaker 5?



Reclose from Breaker 5

Reclosing solutions if IBR is tapped near an existing bus

- If Z0MBC > Z0MAC, reclose from Breaker 6
- If Z0MBC < Z0MAC, reclose from Breaker 5
- If reclosing changes are not possible, consider a time-delayed sensitively set 67G



Conclusions

- 67Q provides good fault resistance coverage from grid terminal for N-1 contingencies
- 32V improves ground fault resistance coverage over 32Q near IBRs for all system contingencies
- Mutual coupling can cause 32V security concerns for credible N-2 contingencies

32V security improvements

- Supervise 67G with a low-set 50Q
- Manually set impedance-based directional thresholds biased towards security
- Reclose from terminals that maintain a strong electrical connection between mutually coupled lines
- Identify mutually coupled lines that are electrically isolated from each other in zero-sequence network and evaluate minimum allowable sensitivity or the use of 67G short time delays