Revisiting Open-Phase Detection for Fuse-Protected Power Transformers

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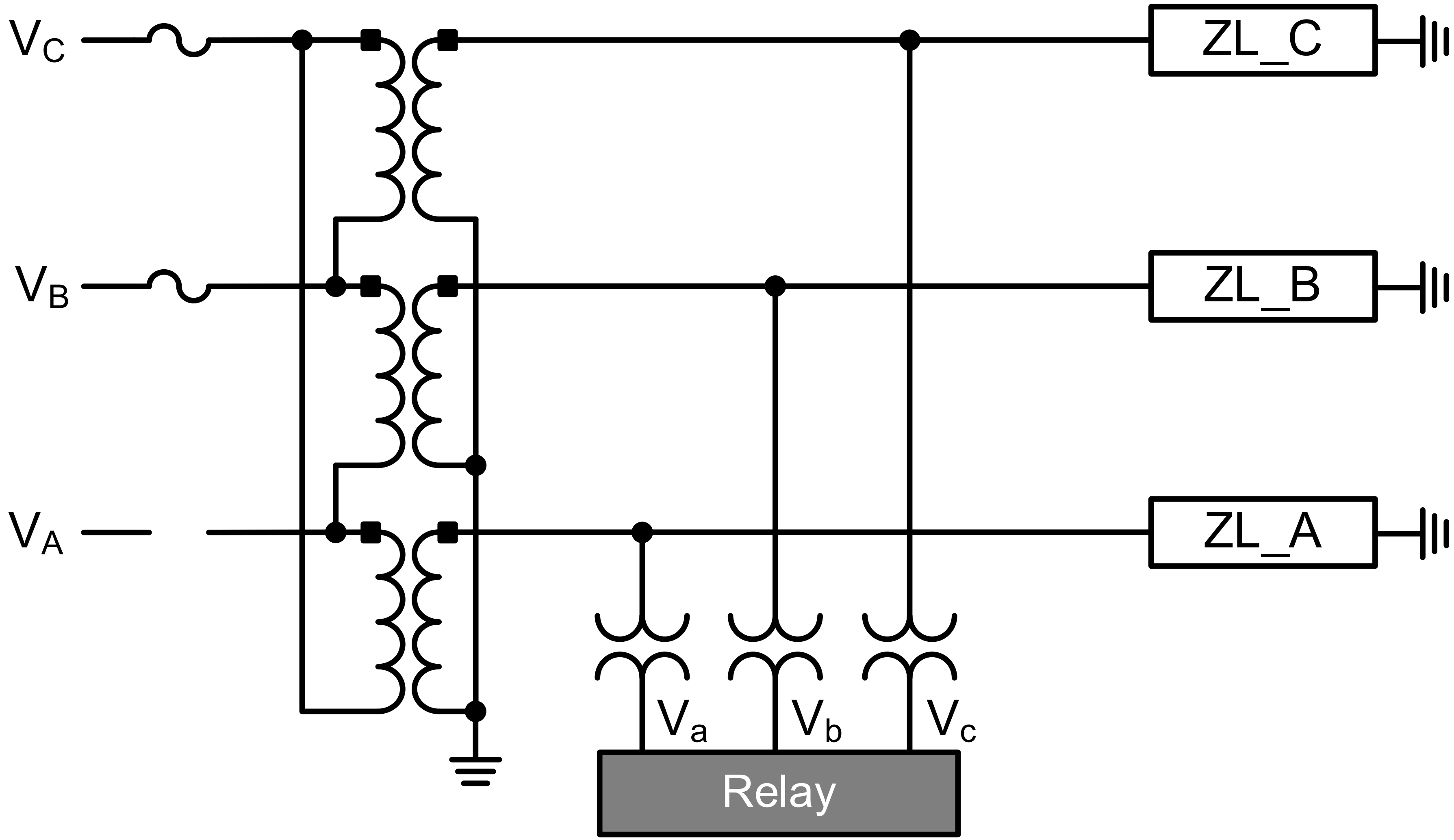
What is a transformer high-side open phase?



Causes of transformer high-side open phase

- Protection miscoordination
- Fuse weakening
- Switching device failure
- Broken conductor
- Transformer or bus faults

Open phases cause…

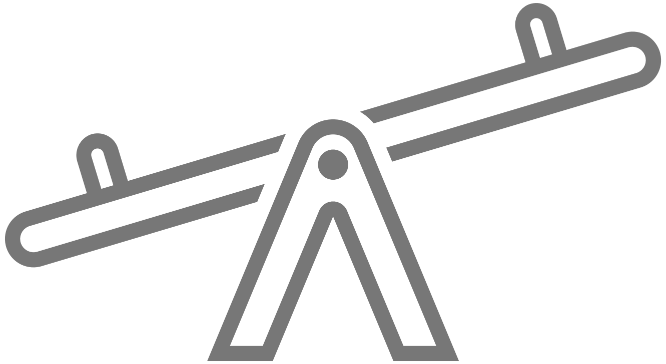
Increased
motor heating

Elevated
wildfire risk

Poor power quality

Must dependably detect open phases concurrent with…

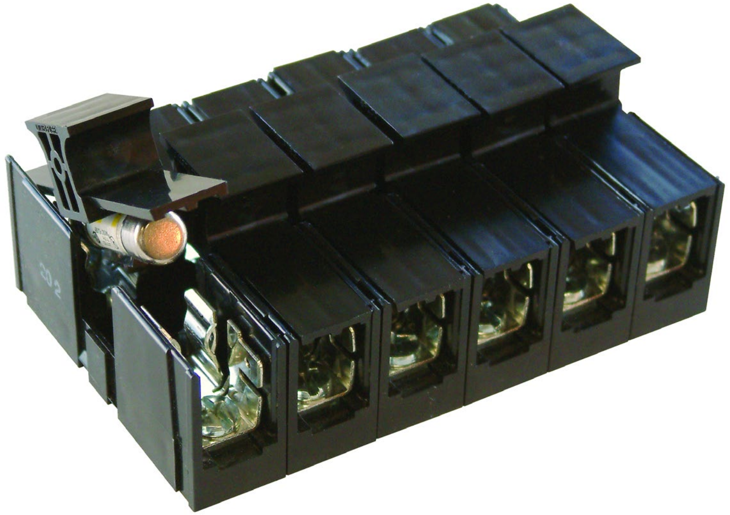
Balanced load impedance



Imbalanced load impedance

Permanent faults

And must remain secure during…

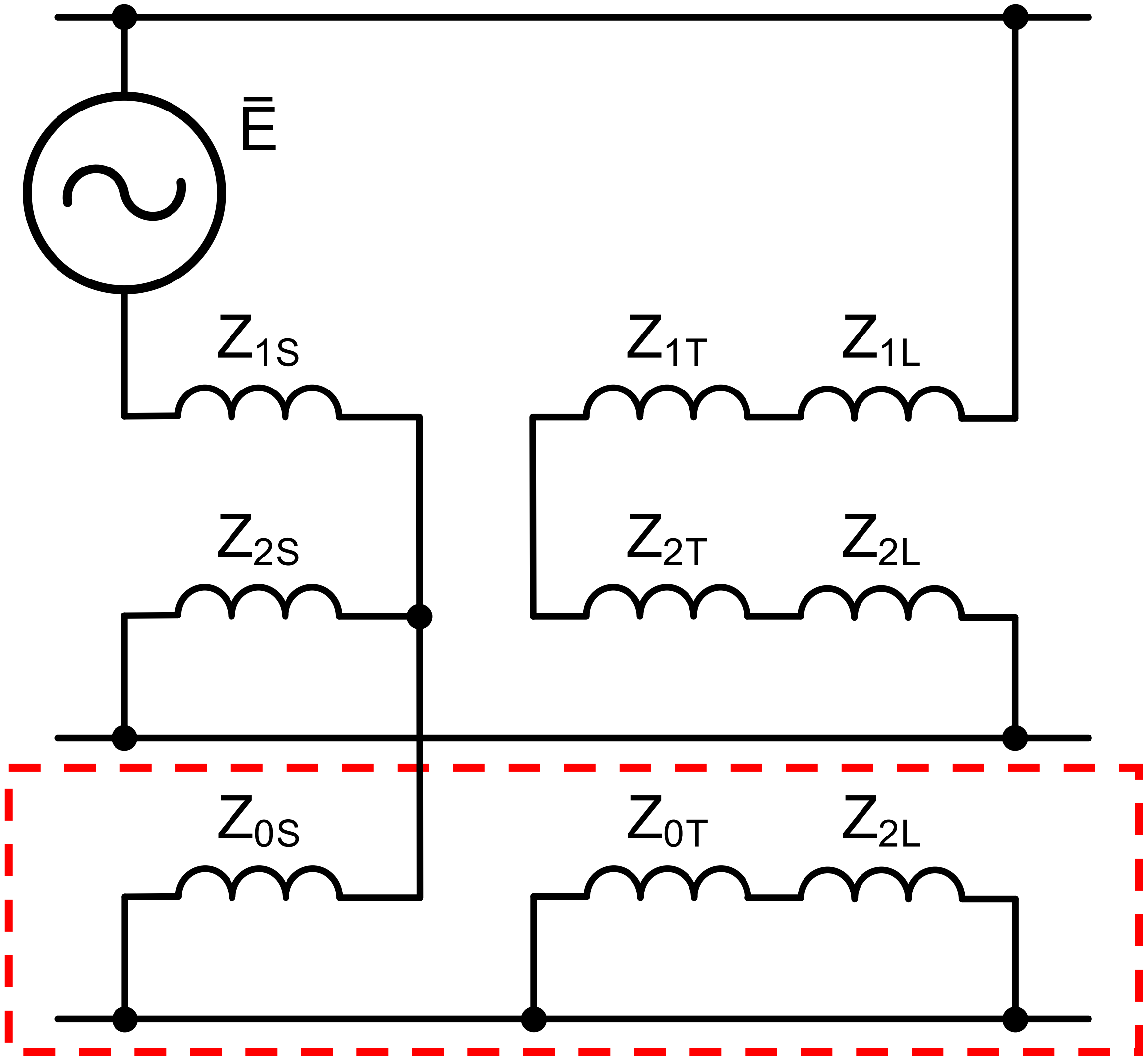


Loss of PT fuse

Load imbalances in healthy system

Temporary faults

High-side open-phase sequence network



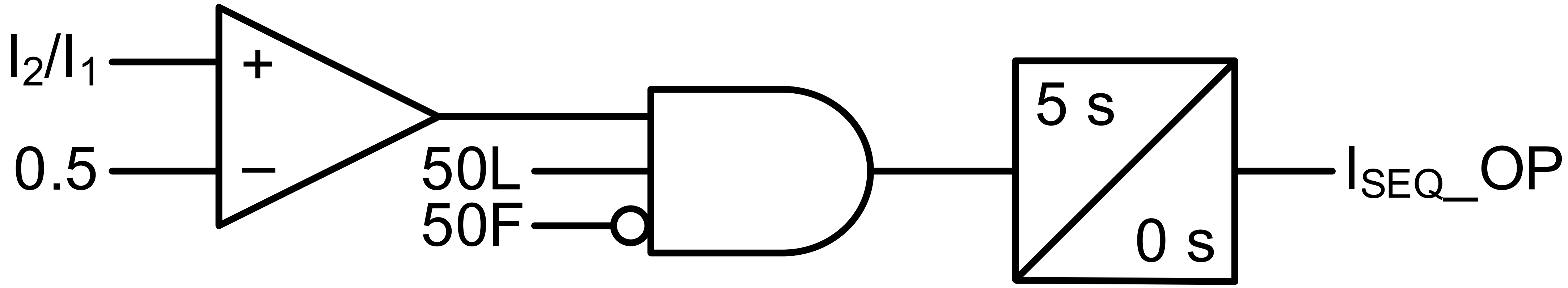
Detecting open phase by comparing negative-to positive-sequence current

Advantages

- Is inherently secure during LOP
- Can dependably detect open phases up- and downstream

Disadvantages

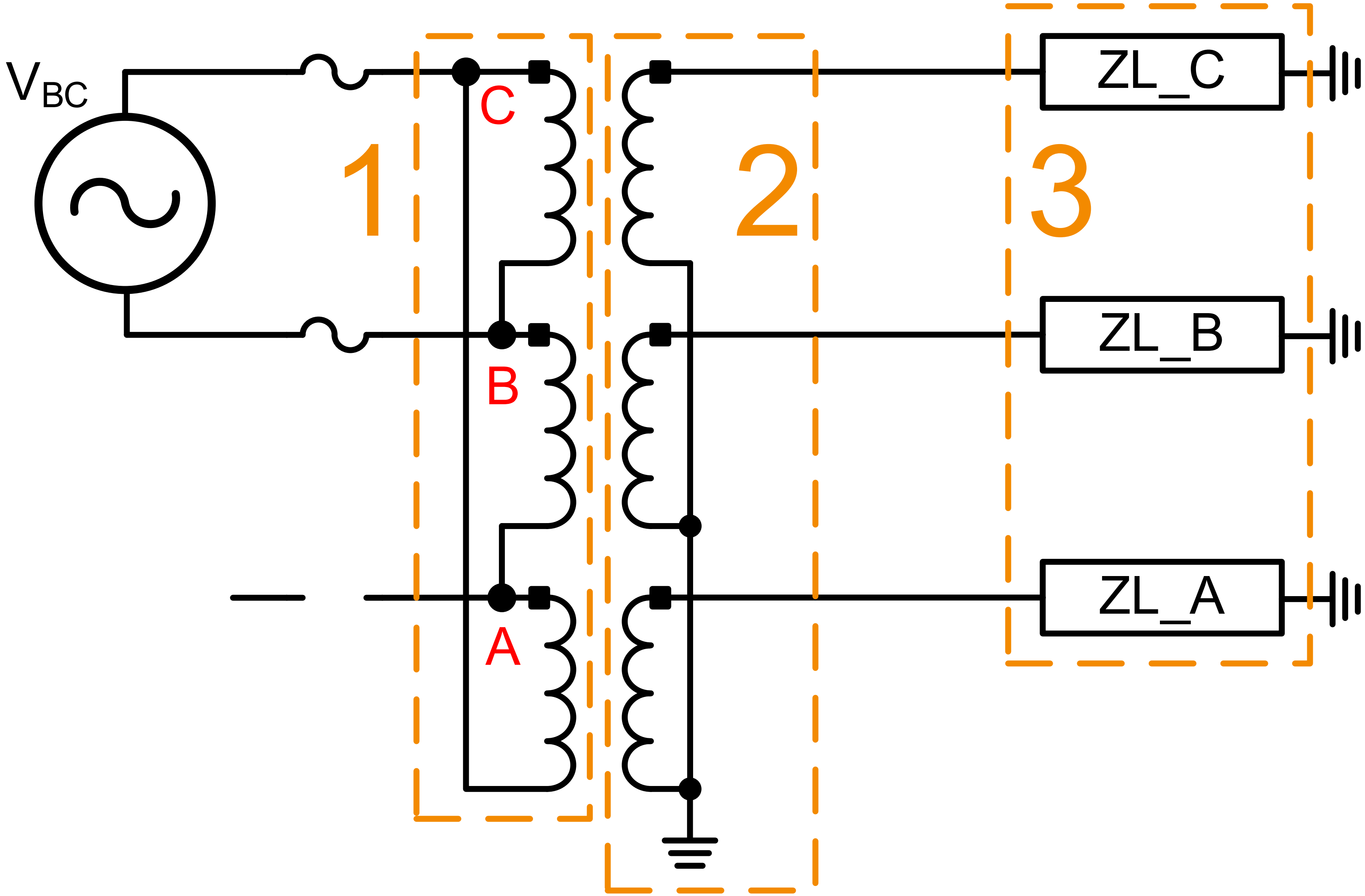
- Is blocked during light load
- Is sensitive to single-pole reclosing operation



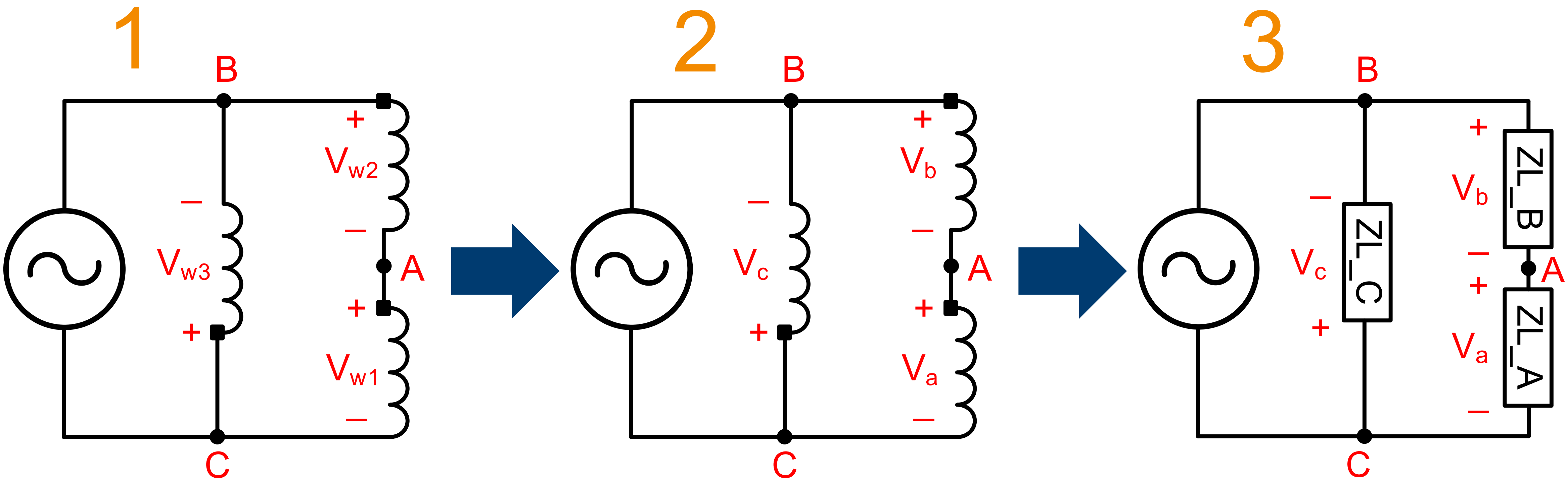
Detecting open phases with voltage is ideal in distribution systems

- Is not sensitive to load imbalance on healthy system
  - Single-pole reclosing
  - Load fluctuations
- Must distinguish LOP event from primary system open-phase event

Creating simplified circuits



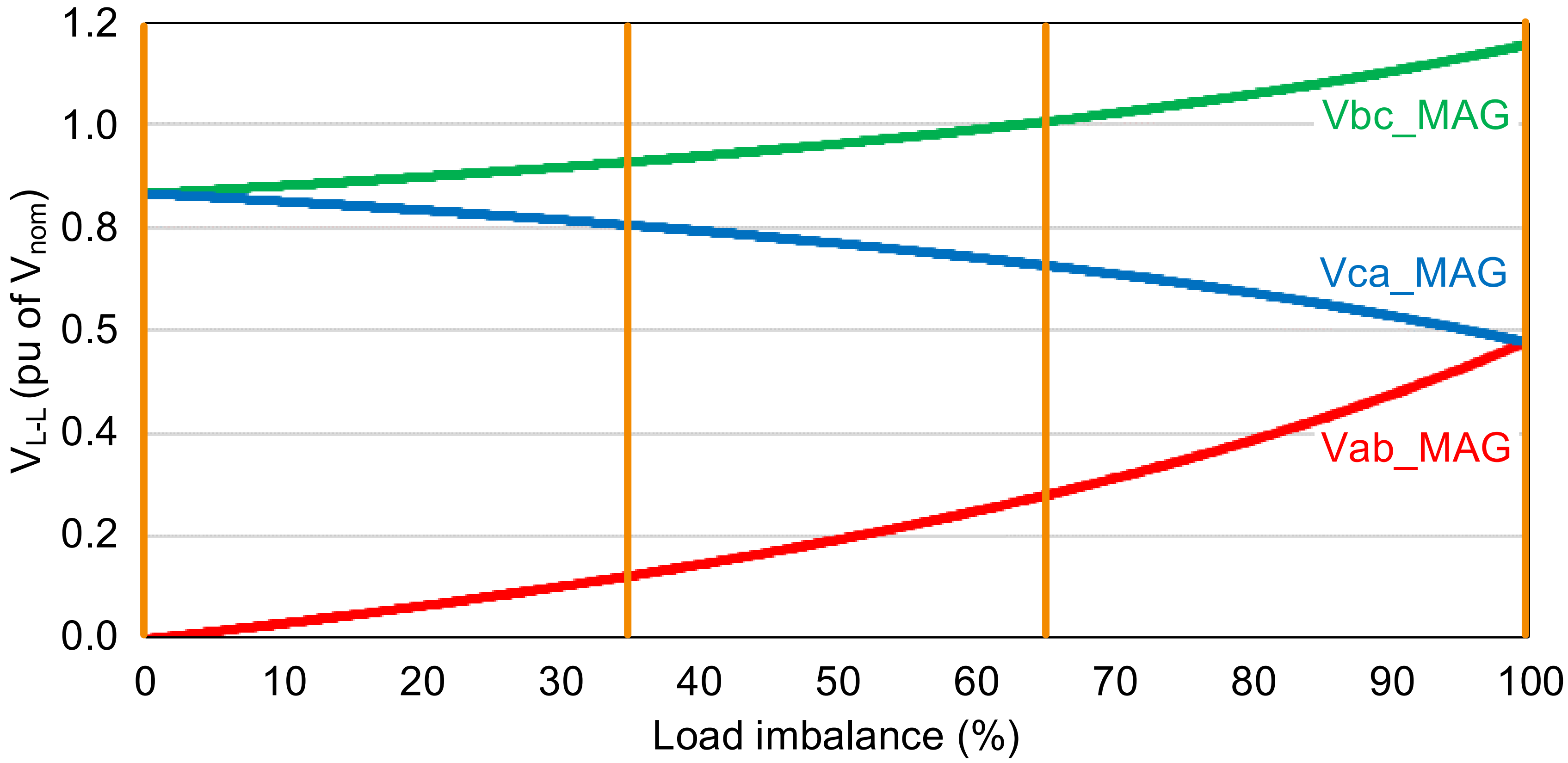
Reveals voltage divider circuit between impacted low-side phases

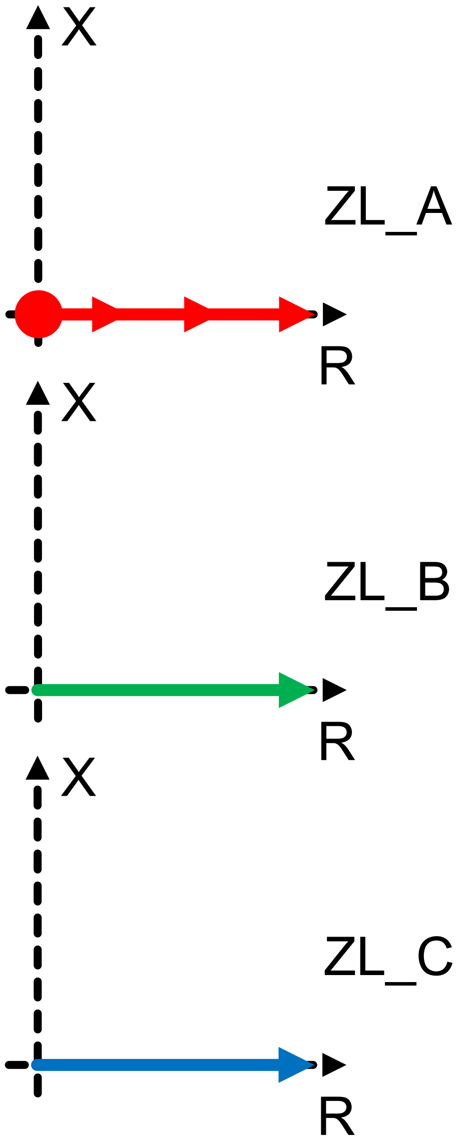


$$V_b = \frac{-V_c \cdot ZL\_B}{ZL\_A + ZL\_B}$$

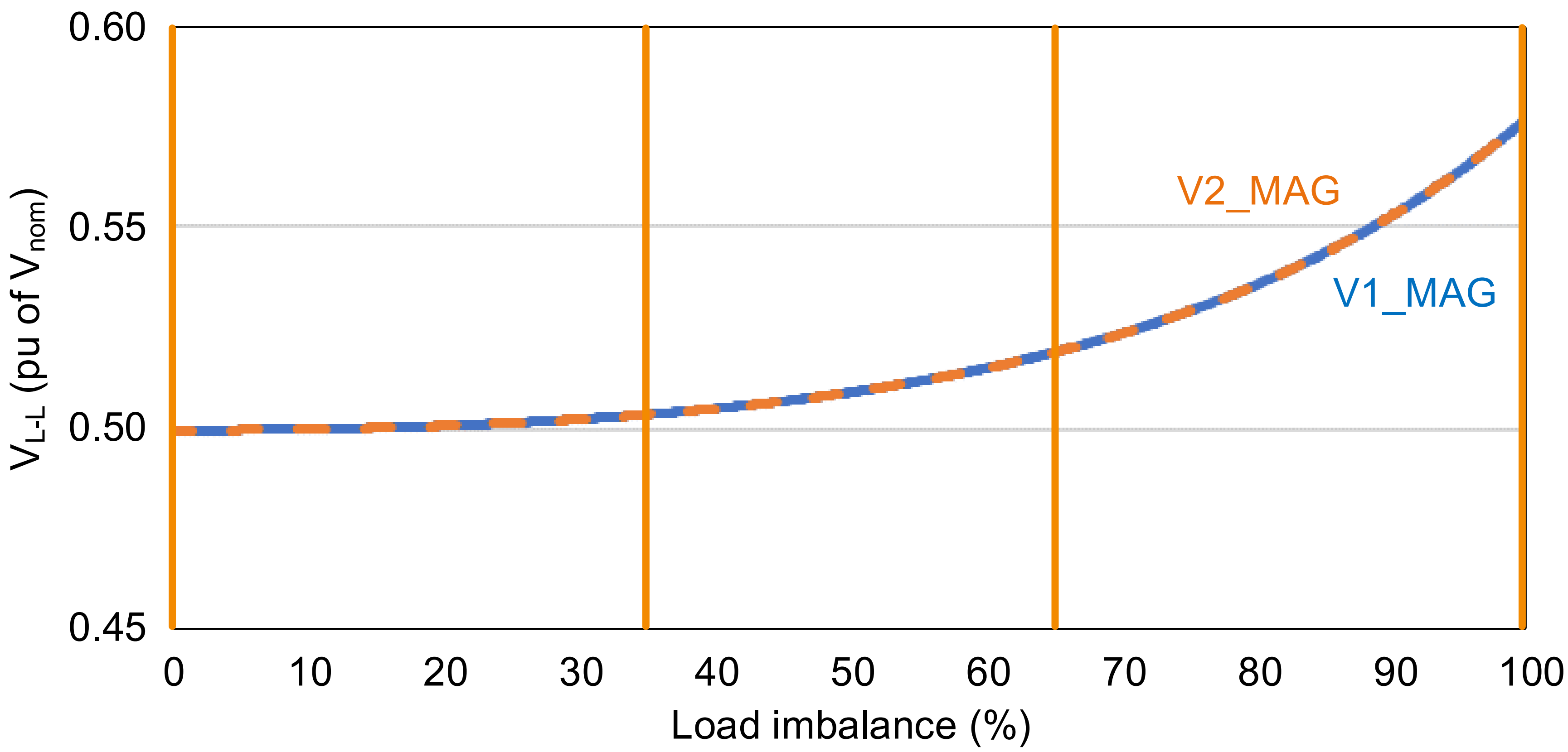
$$V_a = -(V_b + V_c)$$

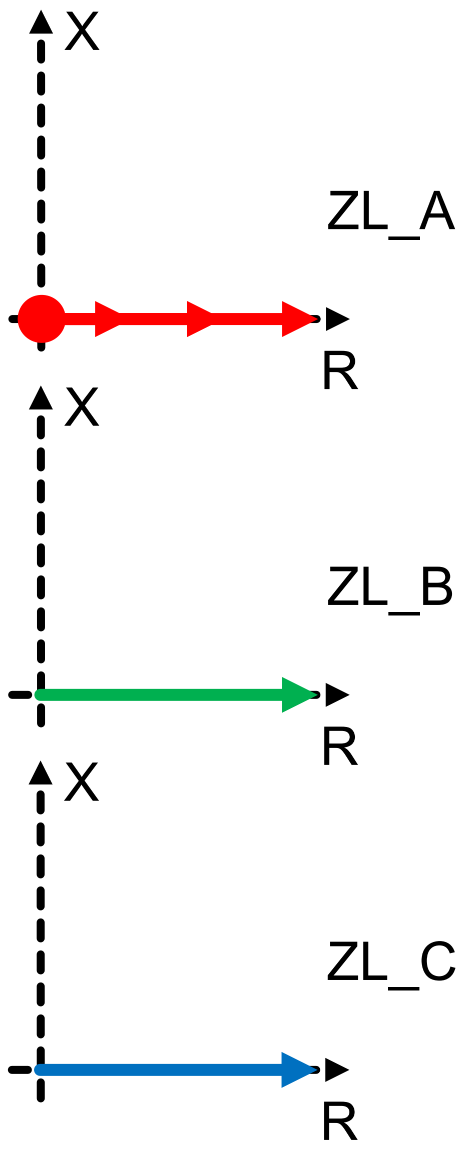
Load magnitude imbalance has large impact on $V_{L\text{-}L}$ magnitude



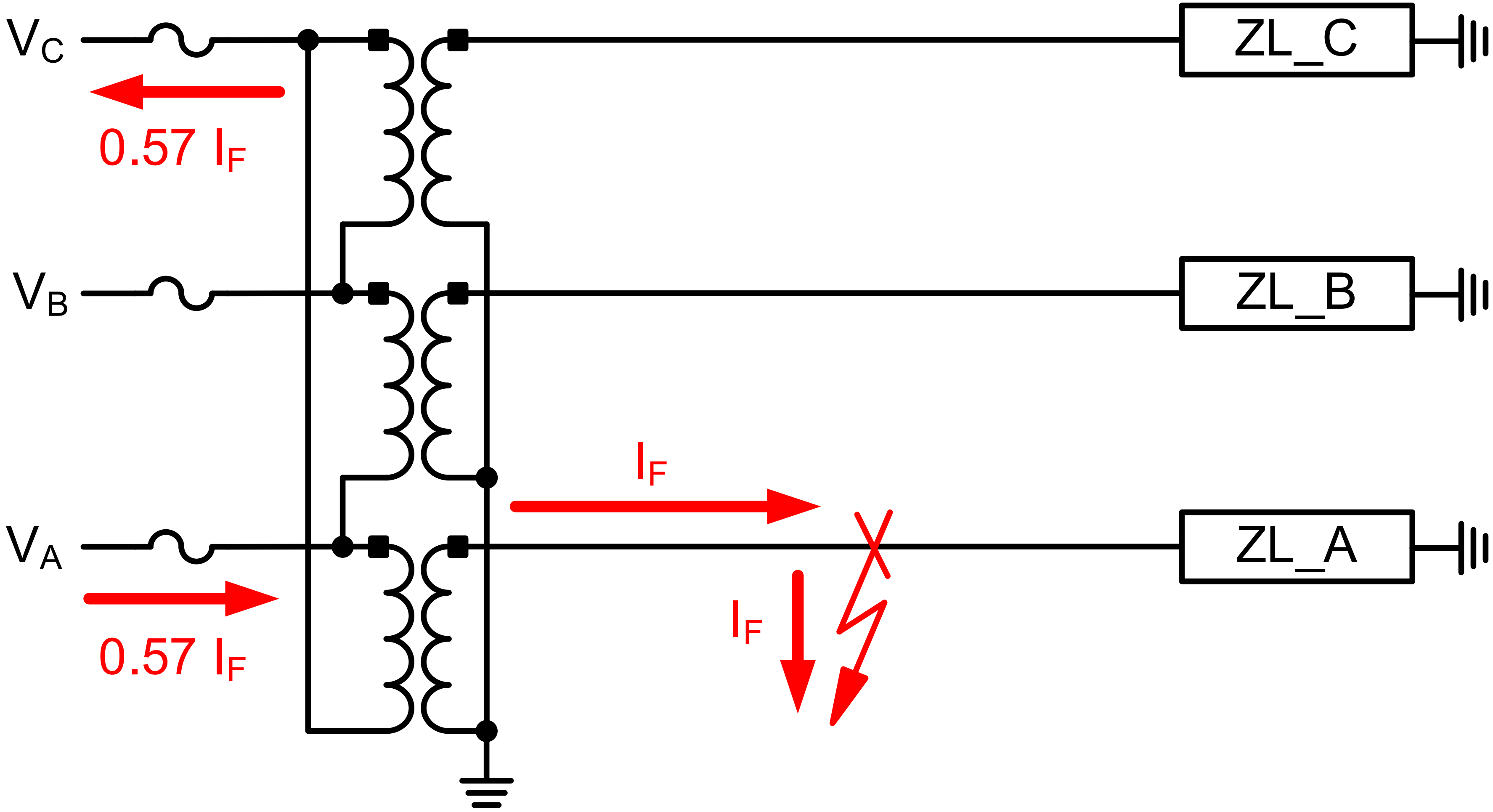


Load magnitude imbalance has small impact on V_{SEQ} magnitude

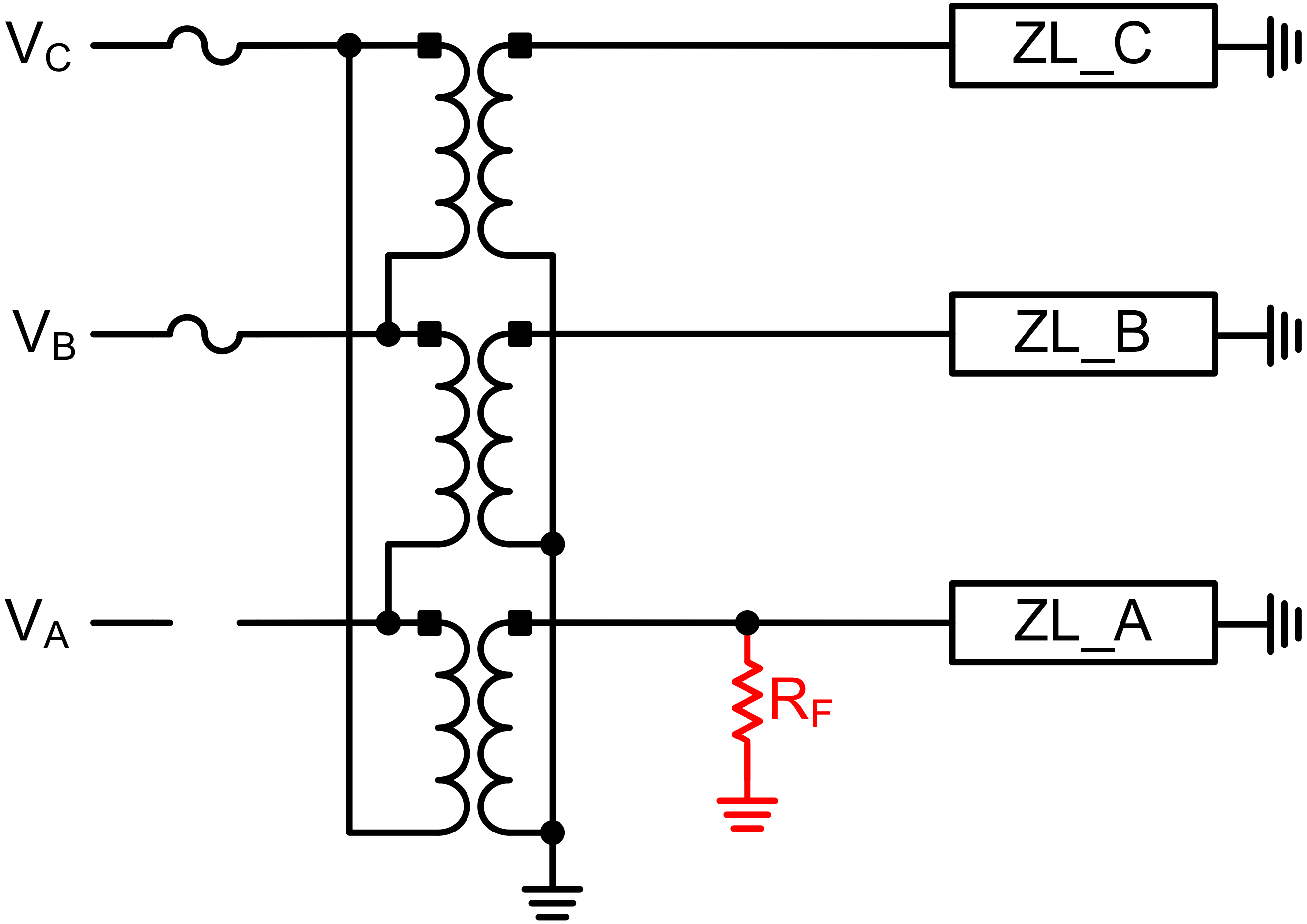


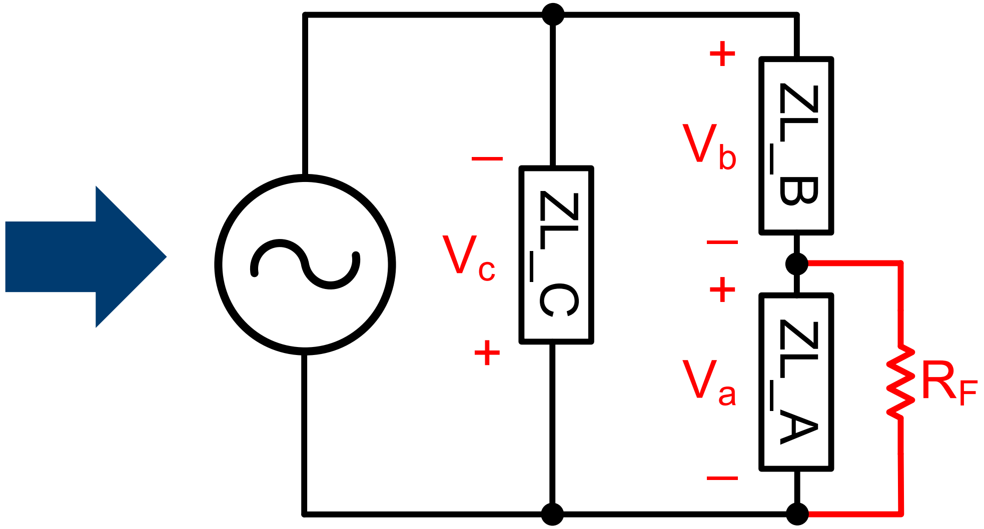


Low-side faults often result in single-fuse operation



Concurrent L-G faults create single-phase voltage divider circuit

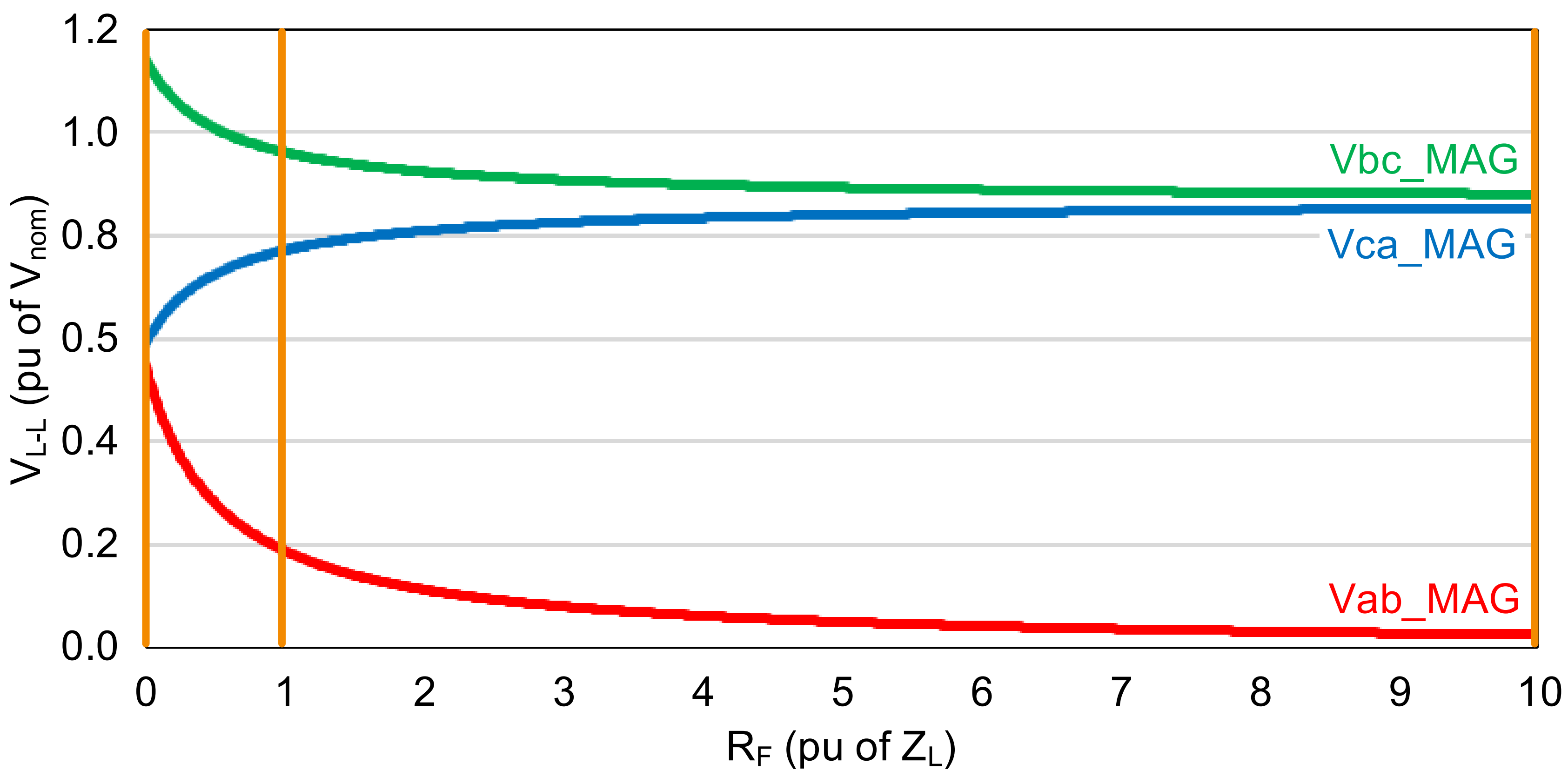


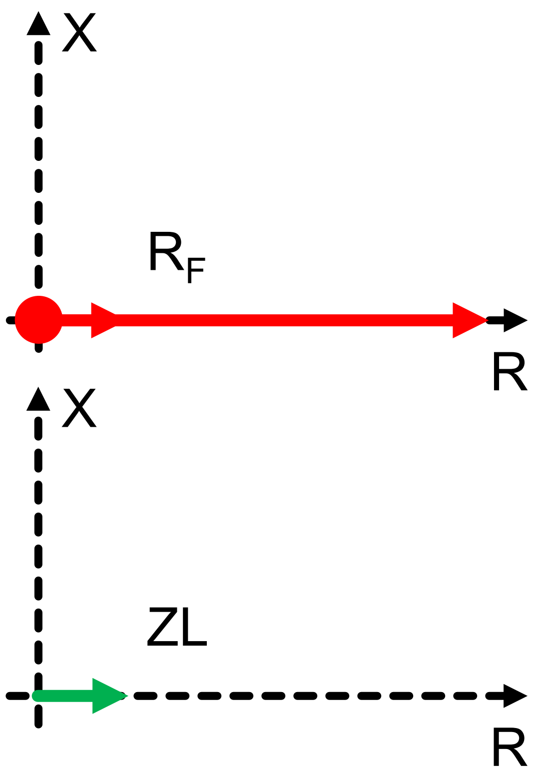


$$V_b = \frac{-V_C \cdot ZL\_B}{\frac{ZL\_A \cdot R_F}{ZL\_A + R_F} + ZL\_B}$$

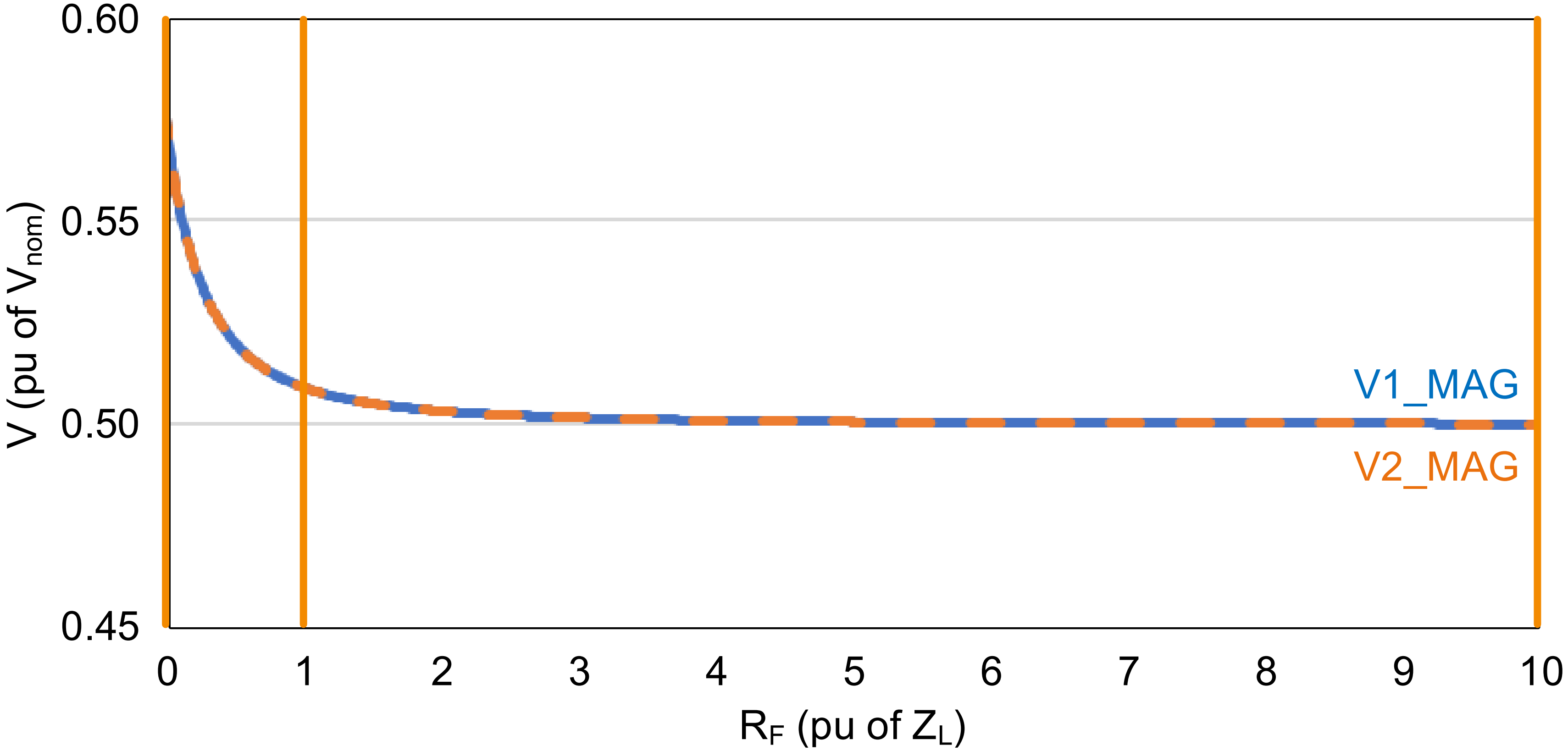
$$V_a = -(V_b + V_c)$$

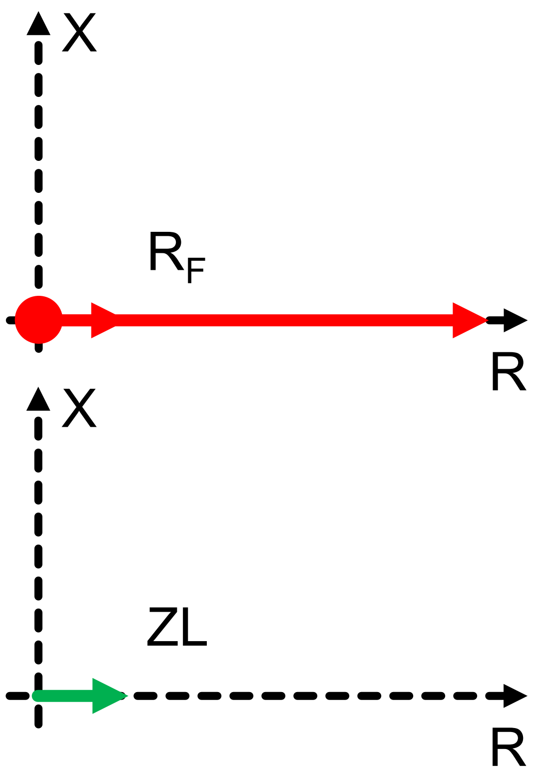
Fault resistance has large impact on $V_{L\text{-}L}$ magnitude





Fault resistance has small impact on V_{SEQ} magnitude

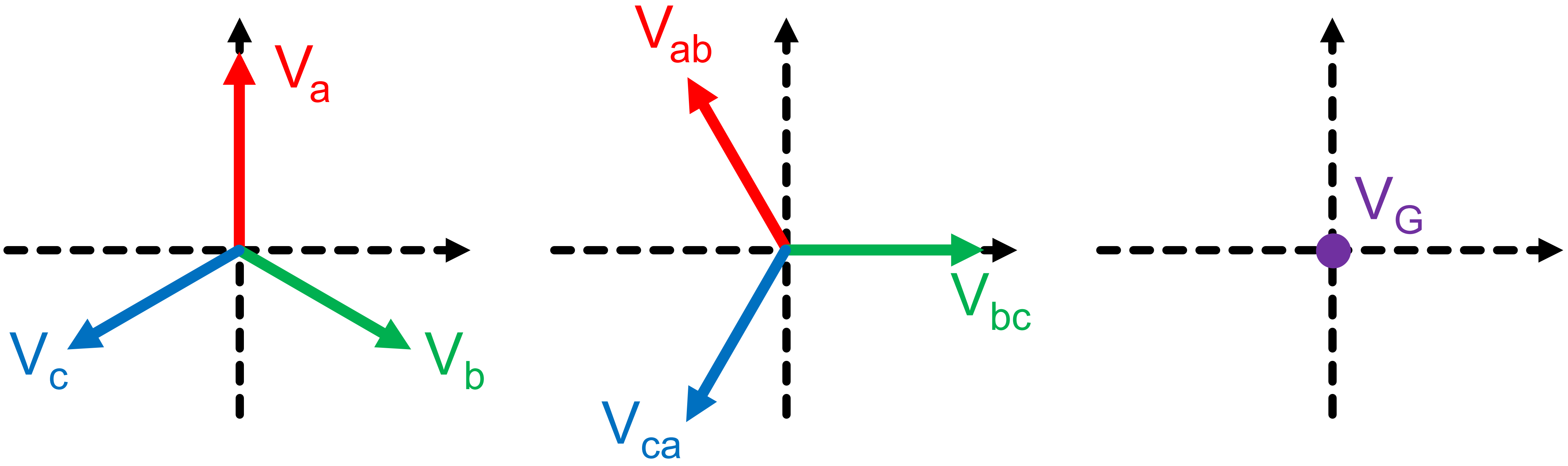




L-L faults cause open phase

- Low-side L-L faults cause a single-fuse operation on transformer high side
- Similar results are produced as imbalance load and L-G fault concurrent conditions
- If fuse weakening causes wrong fuse to operate, high phase voltages result

Securing voltage schemes during LOP

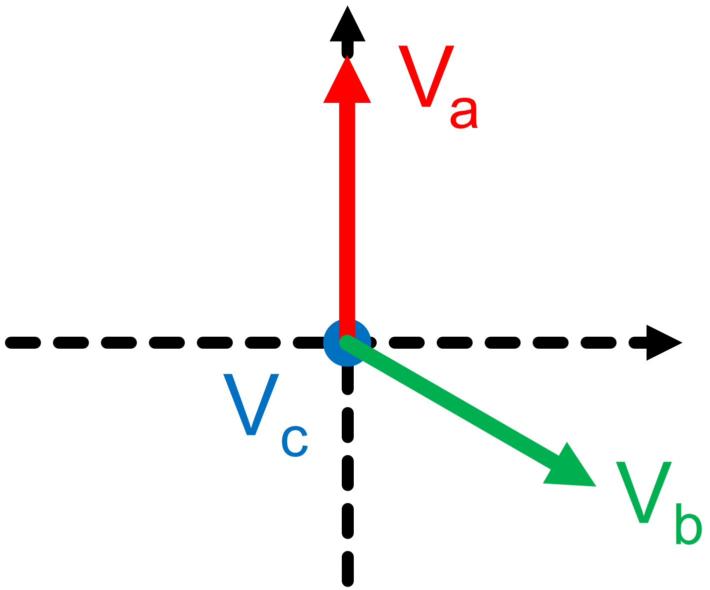


L-G voltage

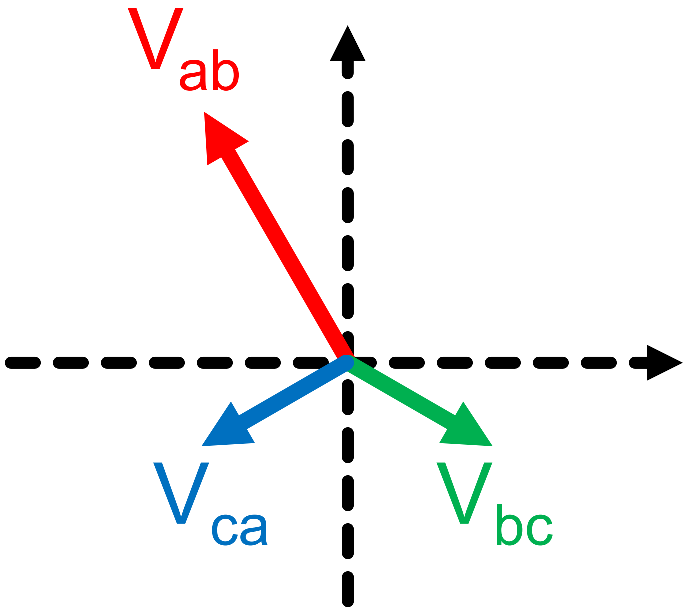
L-L voltage

Ground voltage

Voltage profiles during loss of single PT fuse



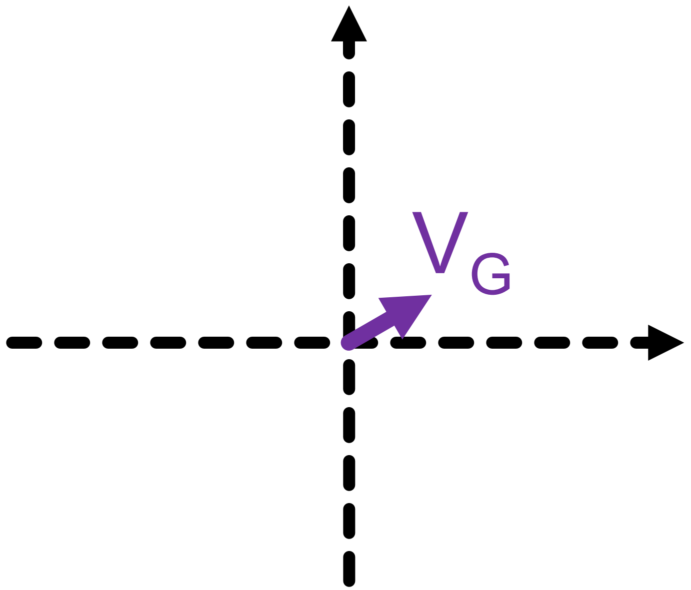
L-G voltage



V_{ab} = 1 pu

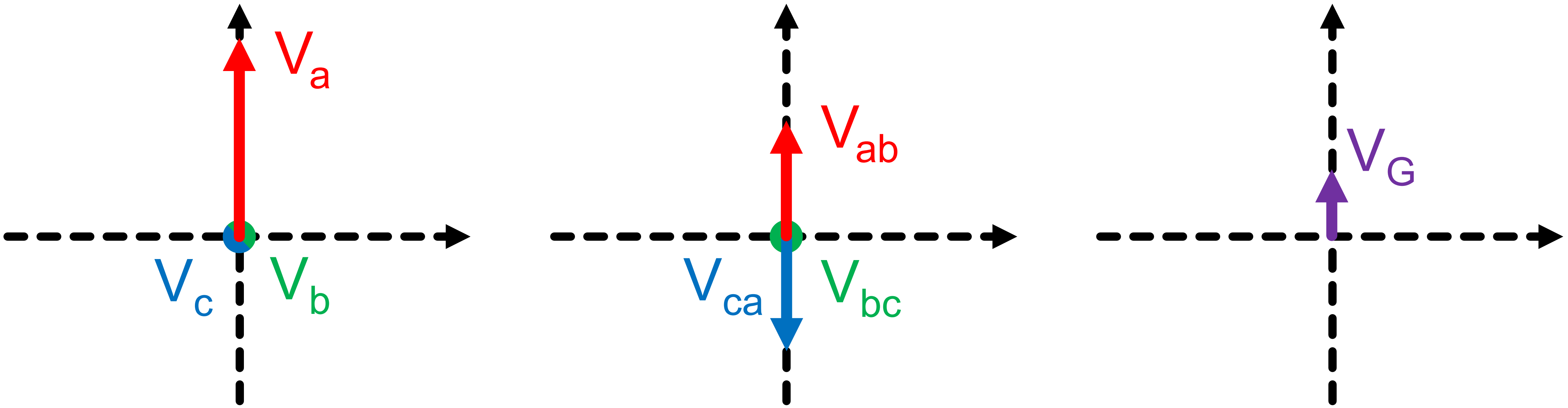
V_{bc} = 0.57 pu

V_{ca} = 0.57 pu



V_G = 0.33 pu

Voltage profiles during loss of two PT fuses



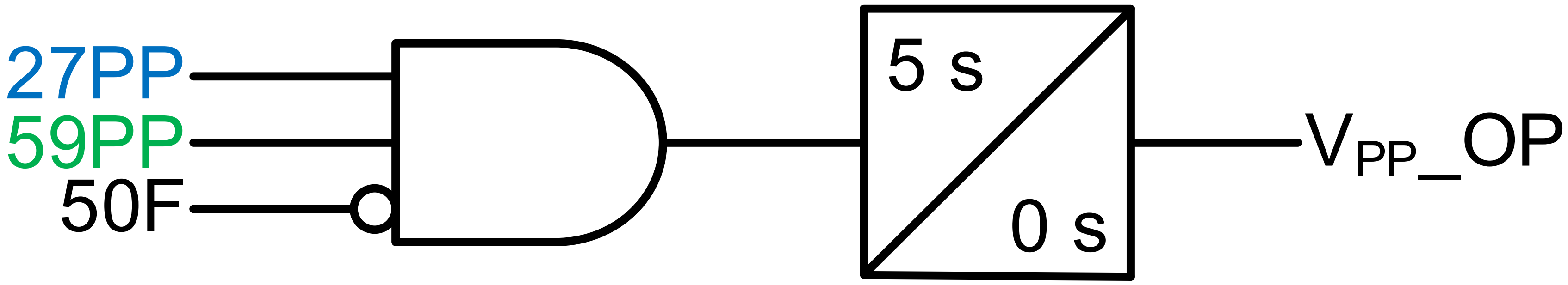
L-G voltage

$V_{ab} = 0.57$ pu
$V_{bc} = 0$ pu
$V_{ca} = 0.57$ pu

$V_G = 0.33$ pu

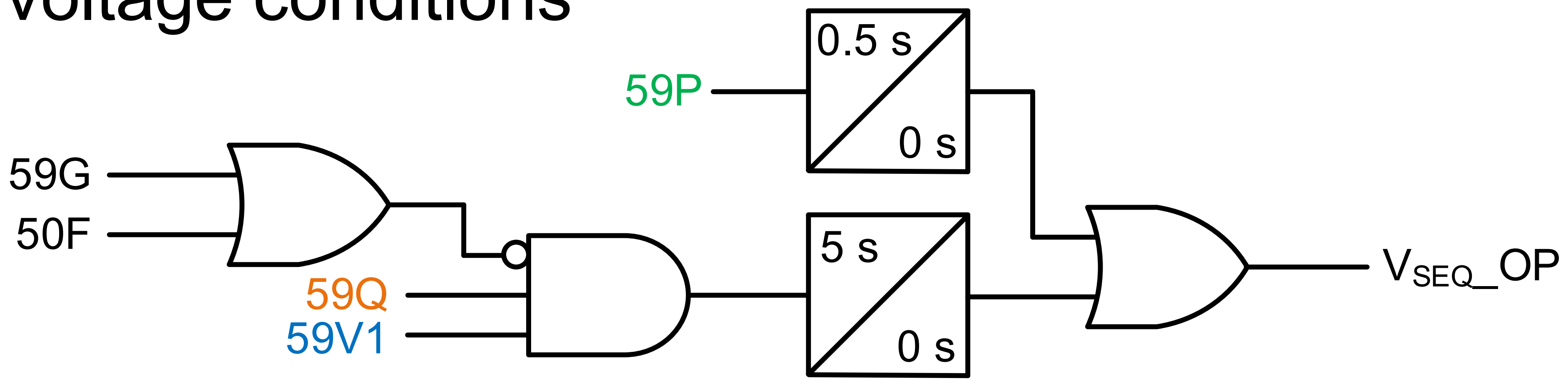
Detecting high-side open phase using L-L voltages

- Set **59PP** to 0.7 pu and **27PP** to 0.4 pu to secure for LOP events
- Dependable when load impedance is balanced
- Loses dependability during load impedance imbalance or concurrent fault conditions



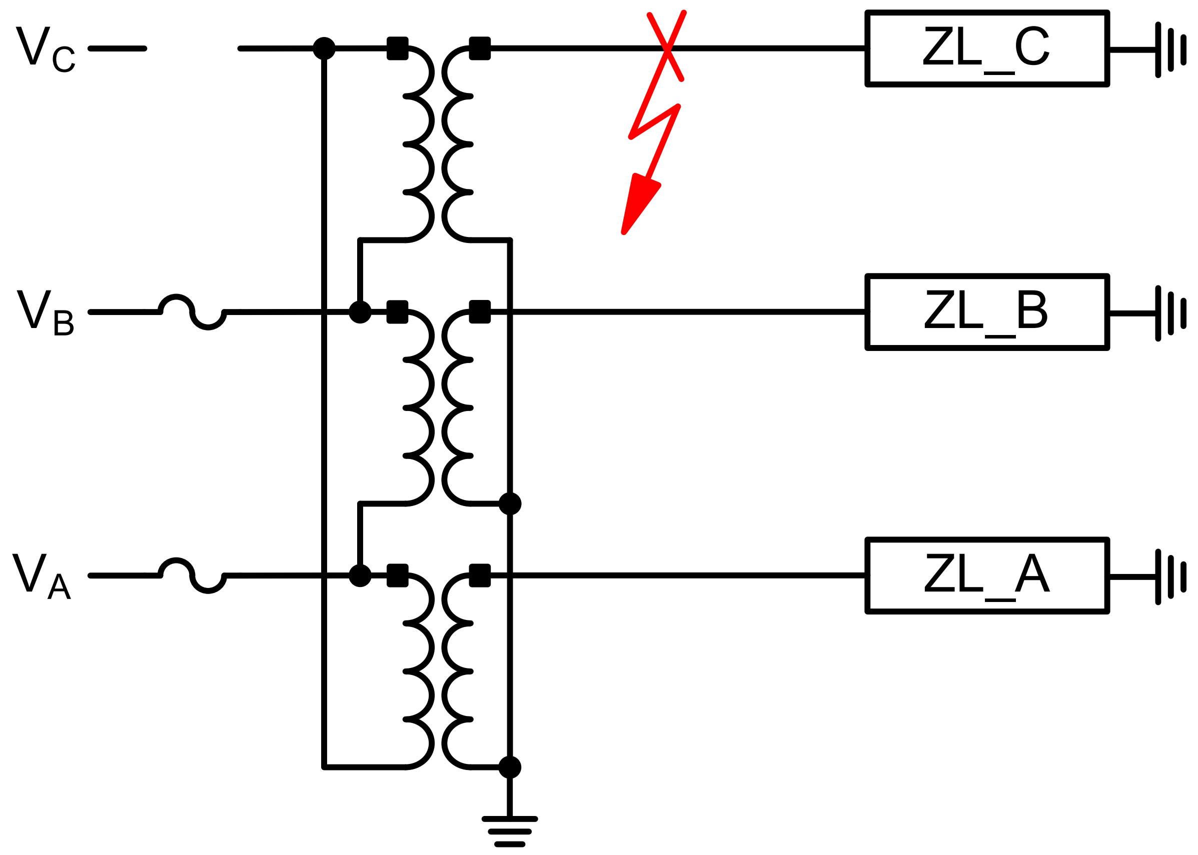
Sequence voltage methods provide dependability gain

- Set **59G** to 0.2 pu to remain secure during LOP events
- Set **59Q** and **59V1** to 0.15 pu for dependability during significant load imbalance
- Apply **59P** for fast operation during phase overvoltage conditions

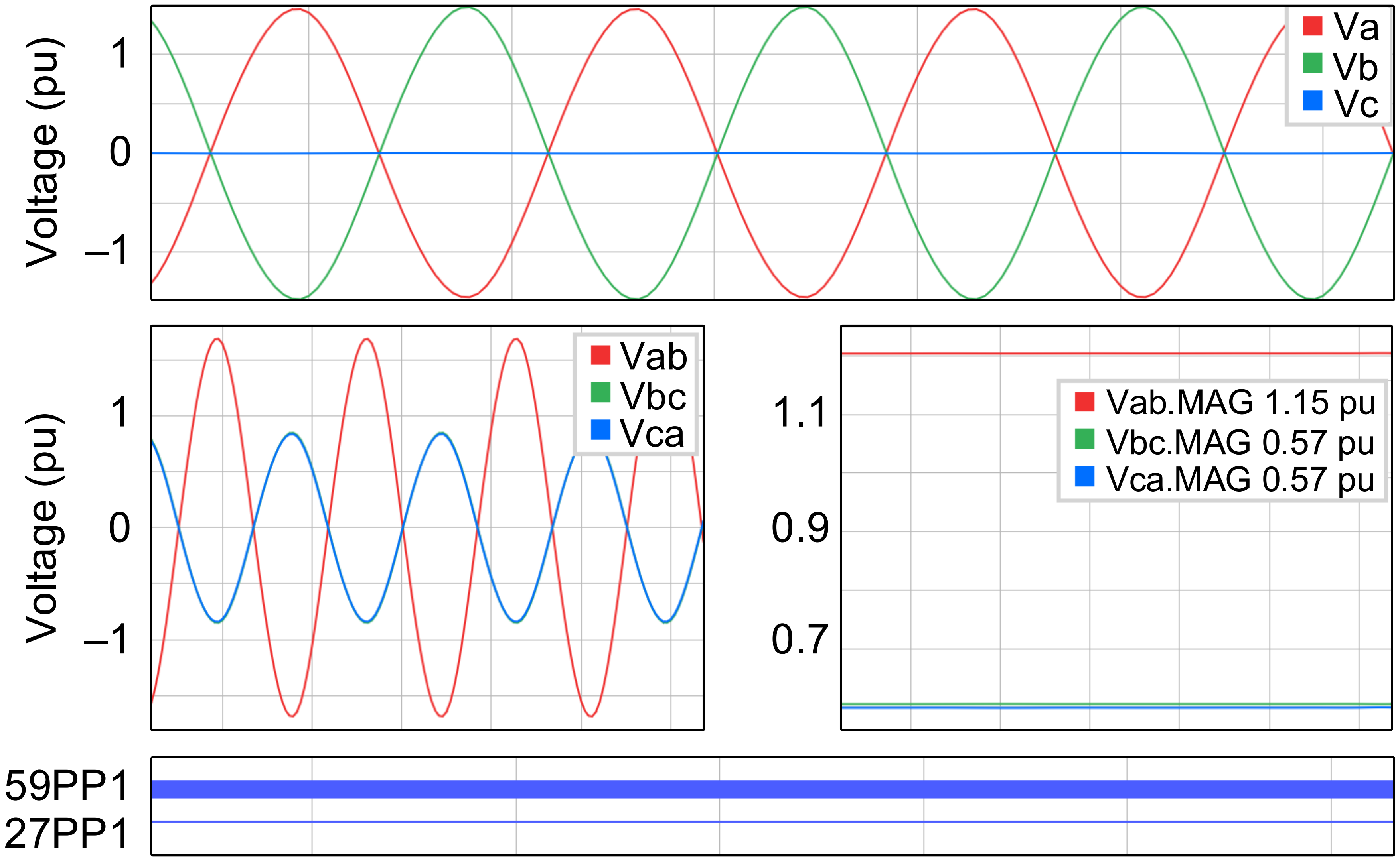


Real-world open-phase event

Low-side bushing failure results in C-phase fault



L-L detection techniques failed to operate



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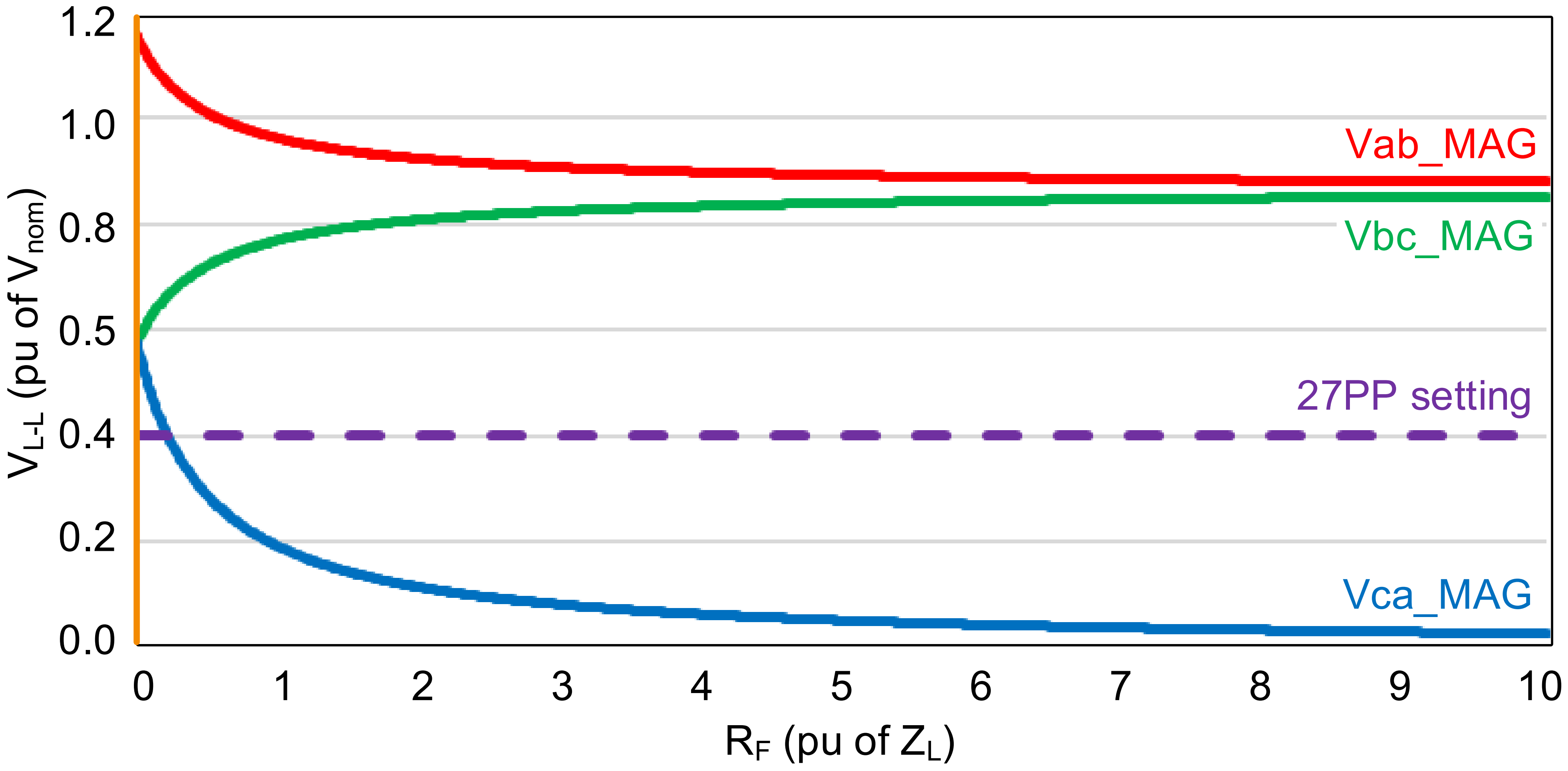
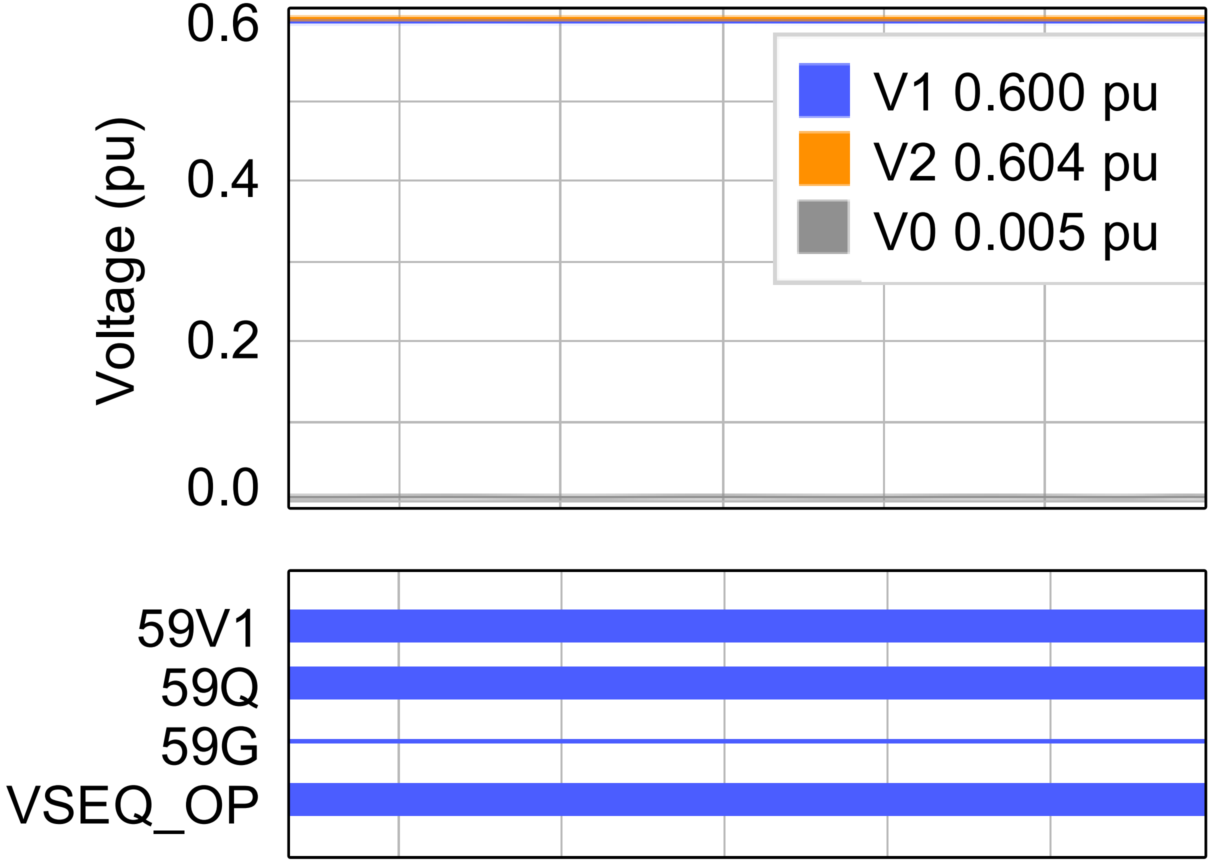
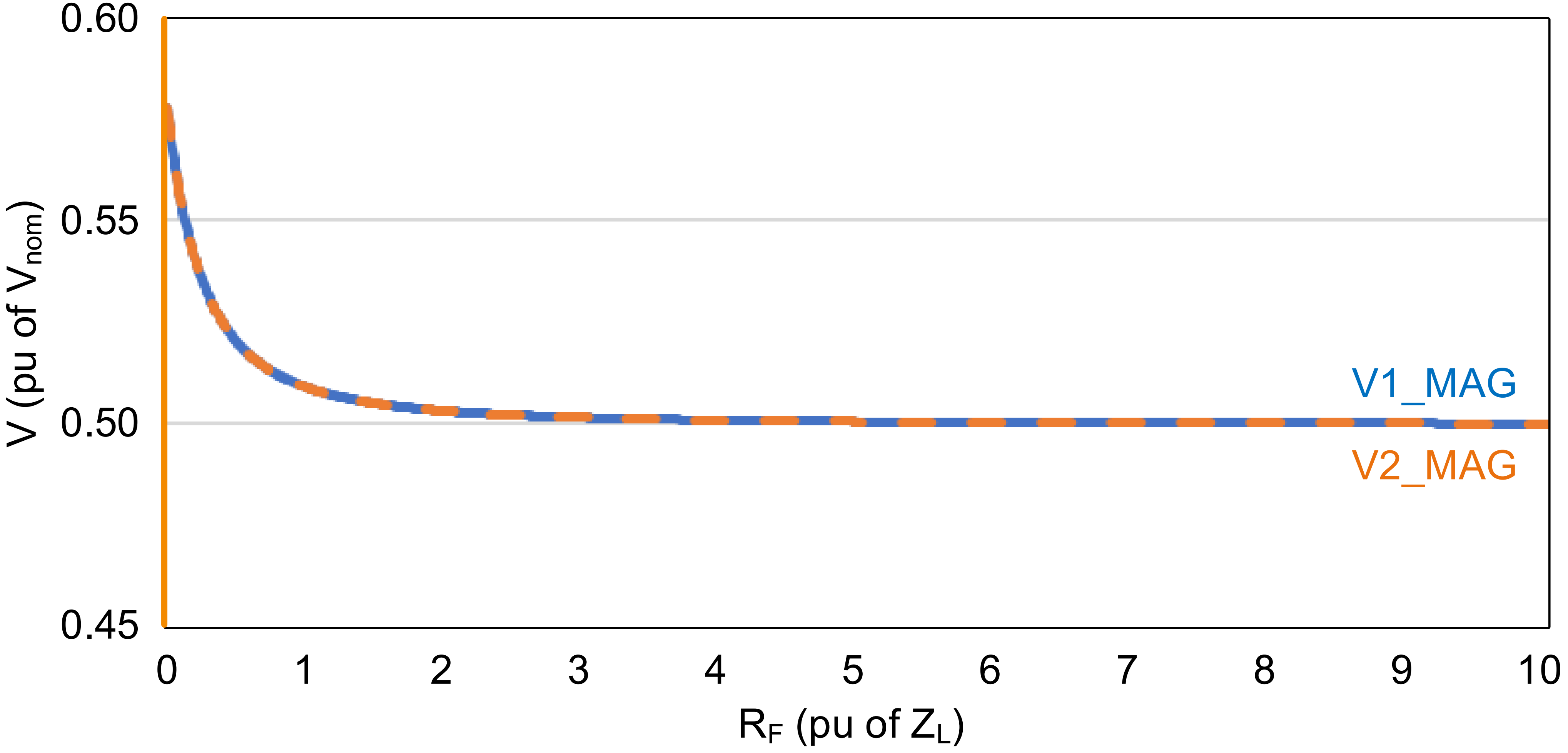


Sequence voltage method operates successfully



Sequence voltage method operates successfully



Conclusion

- Current method is only dependable with enough load current – poor security in single-pole reclosing applications
- Voltages during open-phase change depending on concurrent conditions
- $V_{L\text{-}L}$ method loses dependability during concurrent imbalances
- V_{SEQ} method remains dependable without security compromises

Questions?