Locating Complex Double-Line-to-Ground Faults: Theory and Field Case Study

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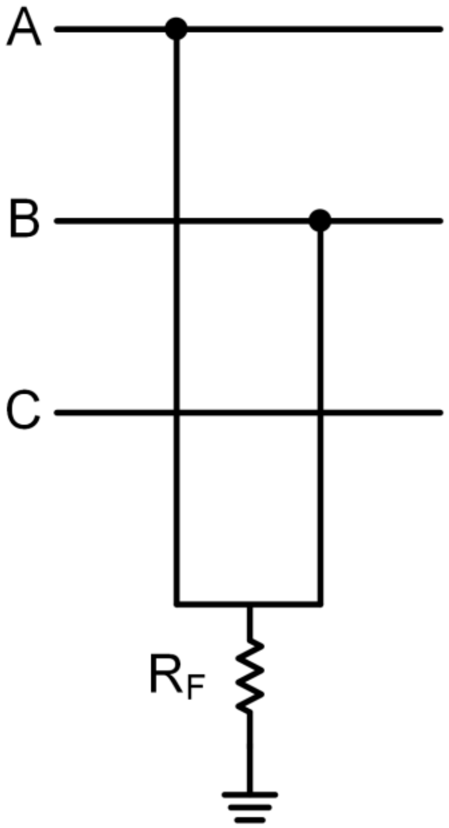
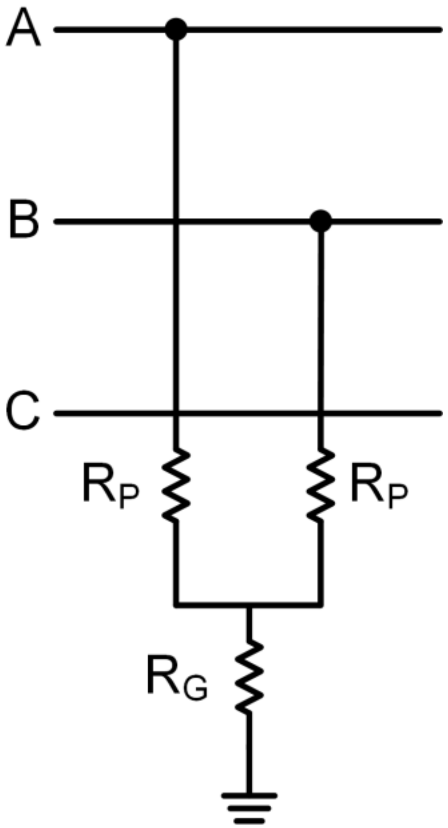
ABG fault representations

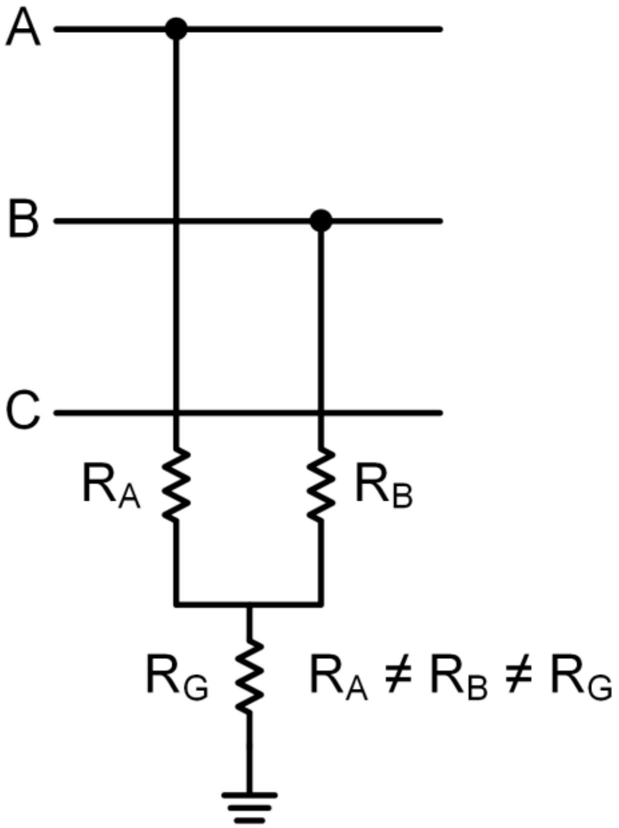
Polarizing quantities work for some but not all



I_{POL} = anything

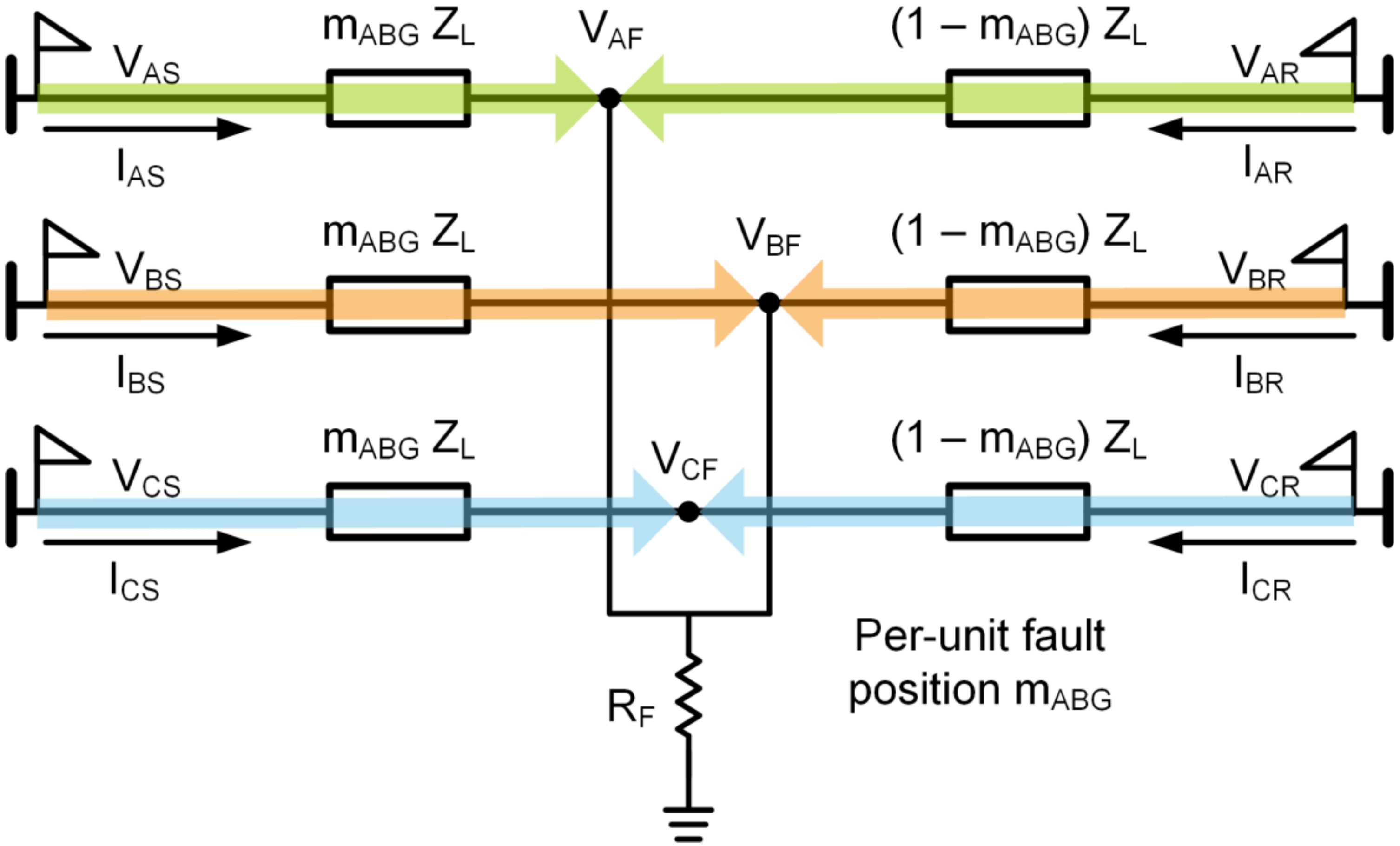


$I_{POL} = I_{AB\_FAULT}$



No polarizing quantity works;
sequence networks are coupled

Use event report data to check fault location results

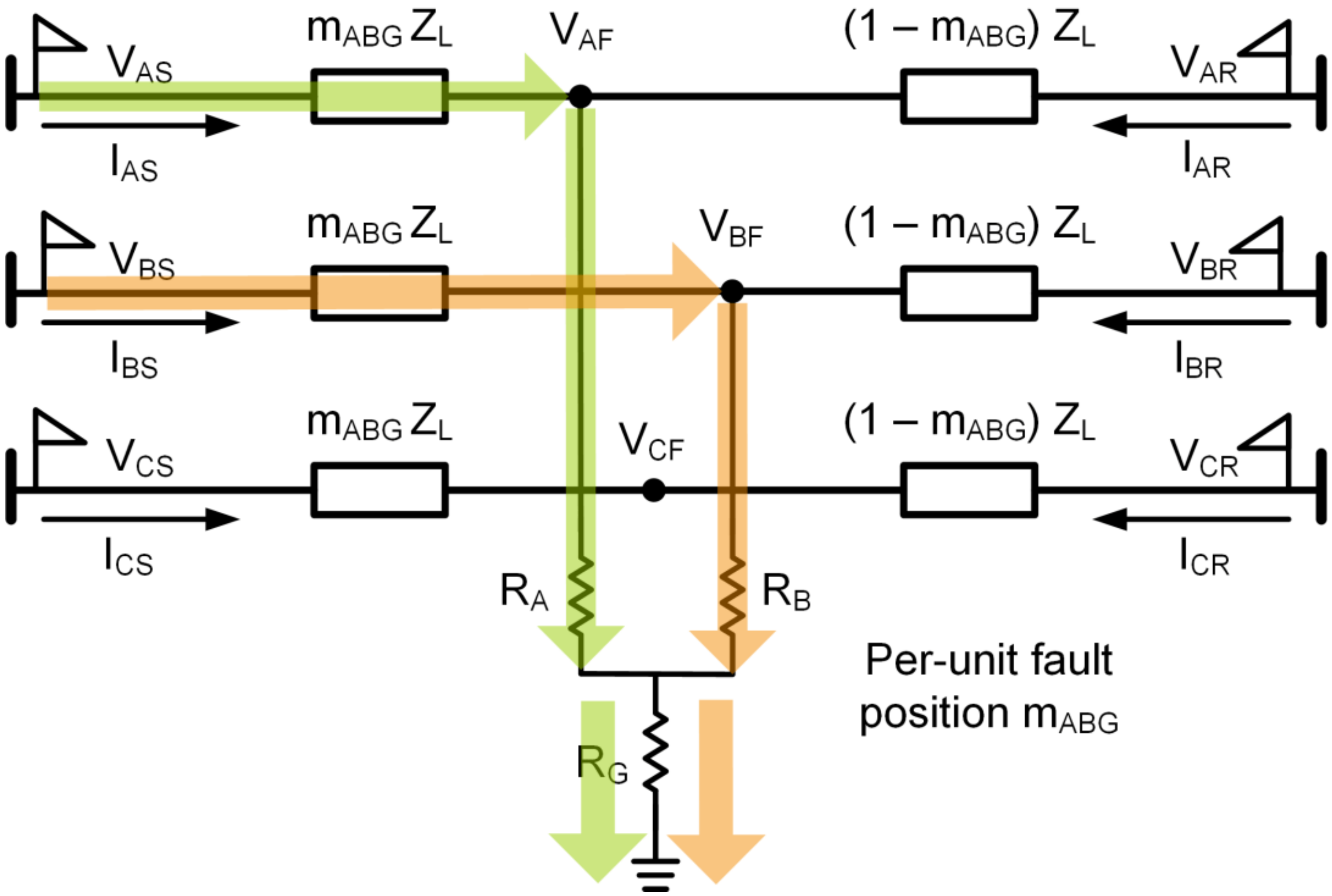


- Calculate fault voltages from S and R buses, check to see if they match (quality checks)
- Evaluate other fault topologies if fault voltage calculations do not match

m_{ABG} value comes from traditional fault locator

Alternate ABG T1, generalized ABG fault

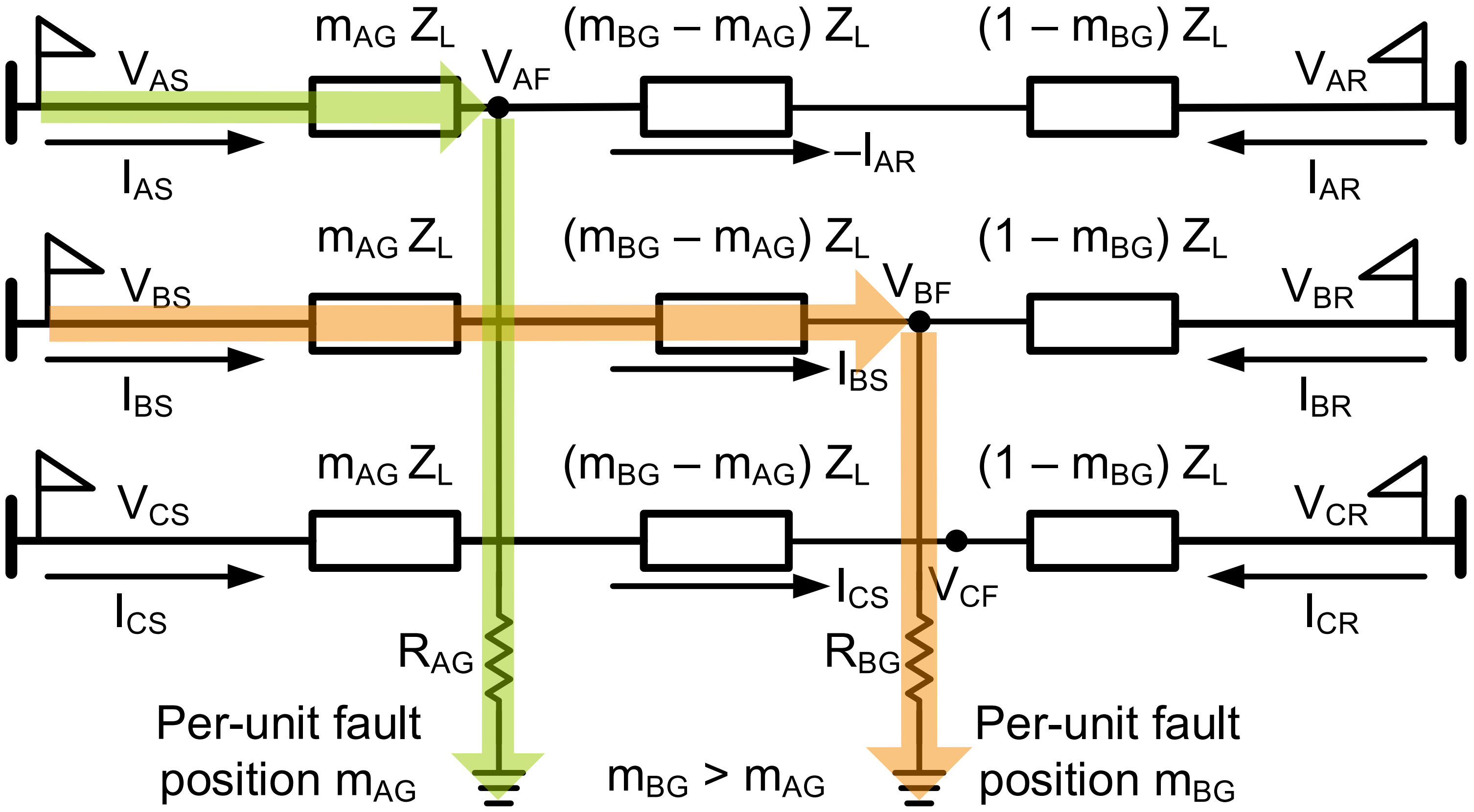
Unknowns – mABG, RA, RB, RG



- Write two complex-valued Kirchoff's Voltage Law (KVL) equations
- Split into four real-valued equations to solve for four unknowns
- Incorporate fault resistance into the solution to permit analysis of radial and nonradial lines

Alternate ABG T2, simultaneous AG, BG faults

Unknowns – mAG, mBG, RAG, RBG



- Write two complex-valued Kirchoff's Voltage Law (KVL) equations
- Split into four real-valued equations to solve for the four unknowns

Solve with unsynchronized data

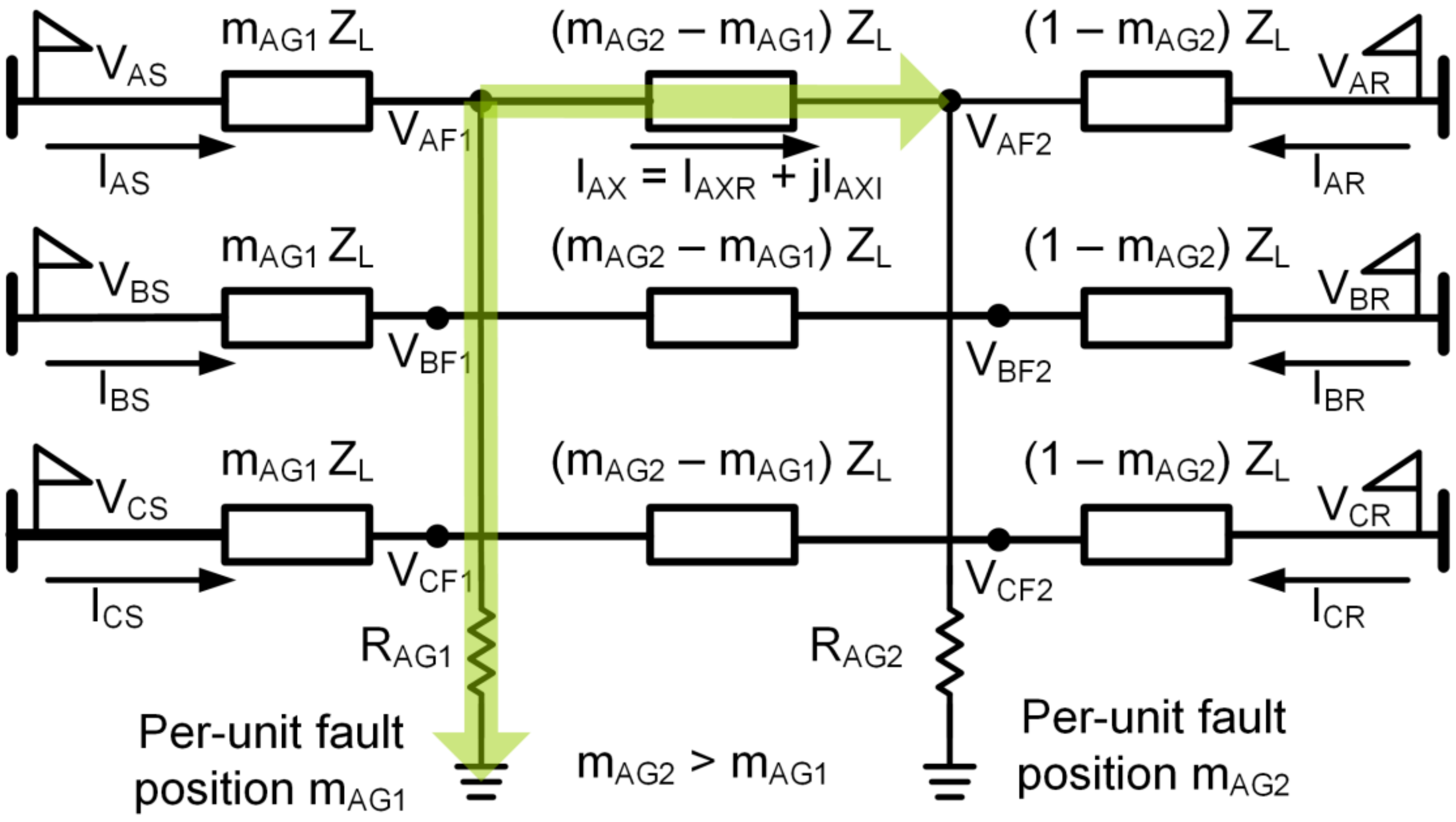
Equations are nonlinear

- Create (V_{AR}', V_{BR}', V_{CR}', I_{AR}', I_{BR}', I_{CR}') by referencing R-terminal signals to V_{AR}
- Add another unknown variable θ to align R-terminal signals with S-terminal signals

$$V_{AR} = V_{AR}' e^{j\theta} \qquad I_{AR} = I_{AR}' e^{j\theta}$$
$$V_{BR} = V_{BR}' e^{j\theta} \qquad I_{BR} = I_{BR}' e^{j\theta}$$
$$V_{CR} = V_{CR}' e^{j\theta} \qquad I_{CR} = I_{CR}' e^{j\theta}$$

- Incorporate the complex exponential, which makes fault location equations nonlinear
- Solve using Newton-Raphson iteration or similar methods

Multiple faults on same phase result in nonlinear equations, even with synchronized data

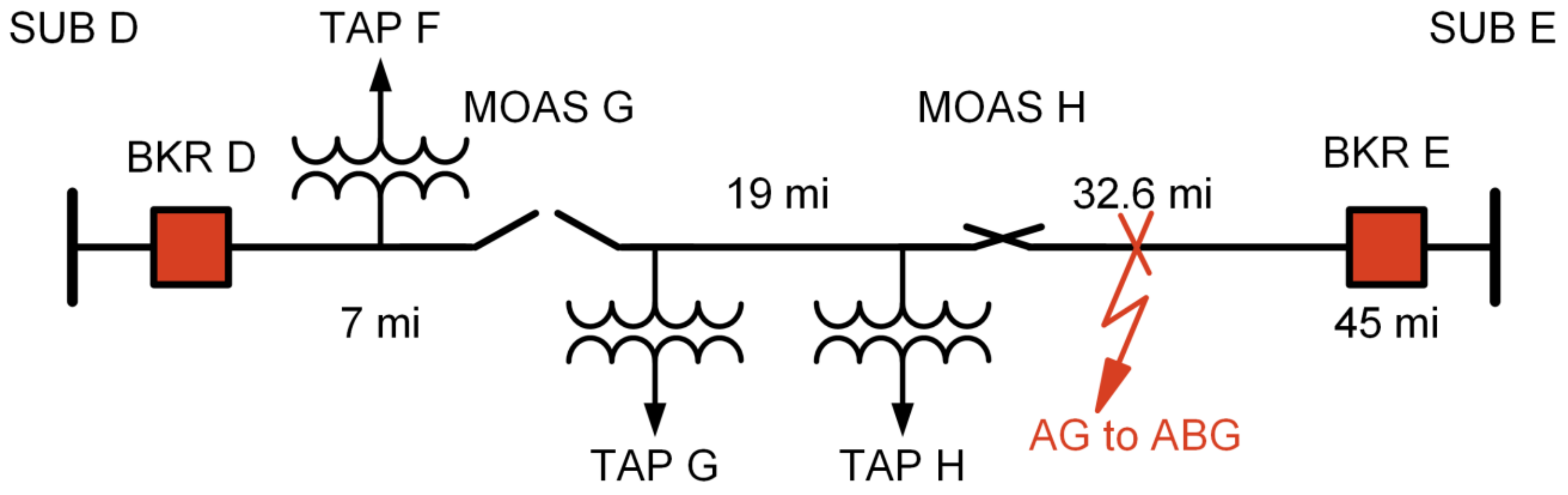


Six unknowns for two AG faults: m_{AG1}, R_{AG1}, m_{AG2}, R_{AG2}, I_{AXR}, I_{AXI}

Voltage drop equations have unknowns multiplied together

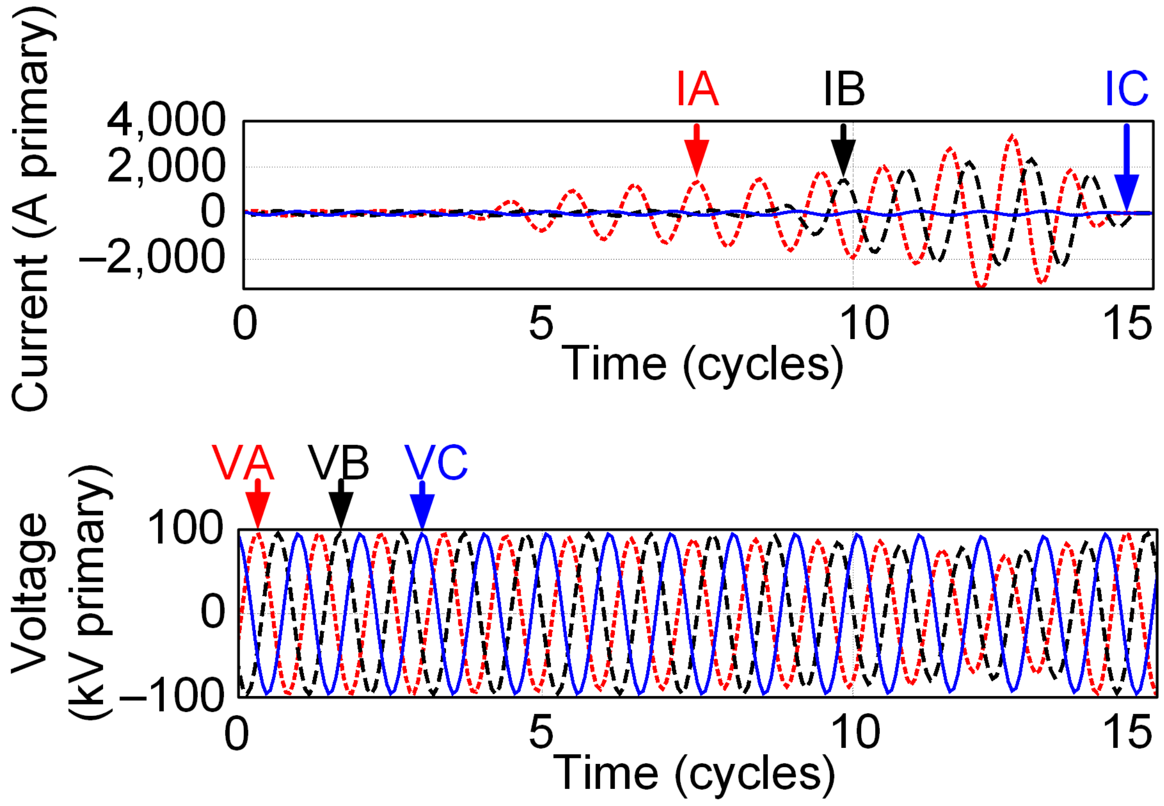
Field case – fault on Avista Utilities 115 kV transmission network

- Tree fell onto a 115 kV transmission line during a windstorm on January 13, 2021
- MOASs made the line radial as seen from Substation E



Fault evolves from AG to ABG

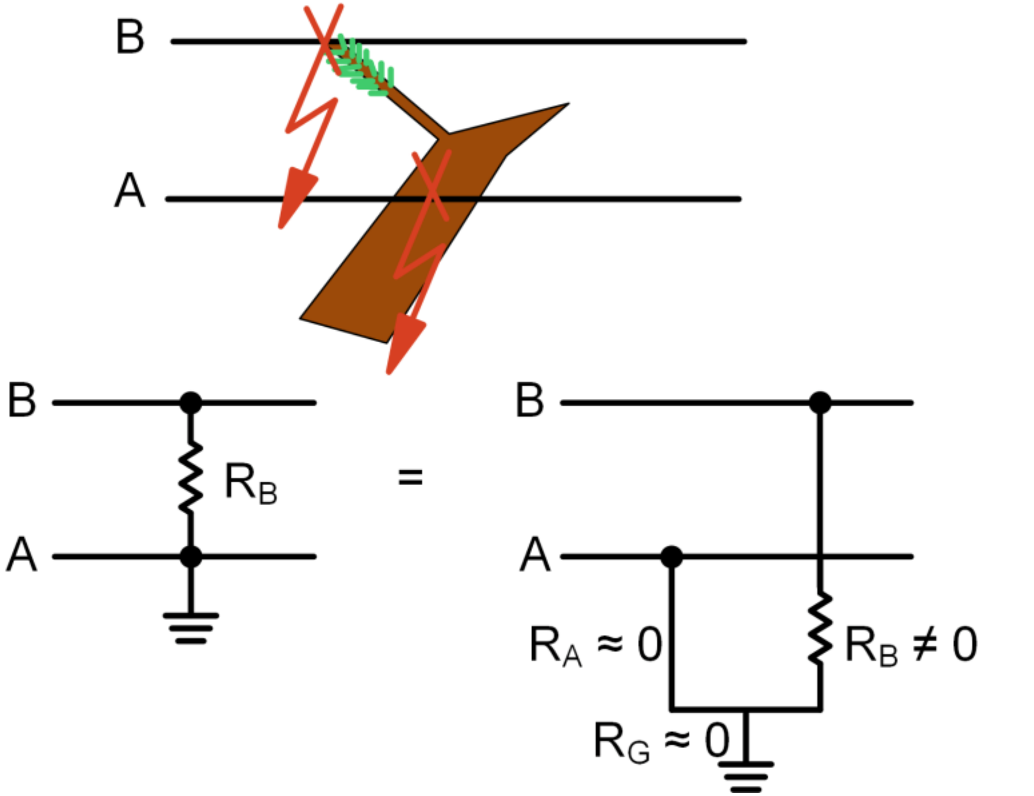
Oscillogram prior to first trip



Sequence of events

1. Falling tree touches A-phase, outer conductor, initiating AG fault
2. Five cycles later, tree contacts B-phase, causing fault to evolve to ABG
3. Circuit breaker opens after receiving trip signal from protective relay
4. Four seconds later, breaker recloses and ABG fault is still present; A and B conductors are on the ground
5. Breaker opens again and locks out
6. Field crew reports fault location as 0.28 pu from Substation E

Falling tree causes nonstandard ABG fault

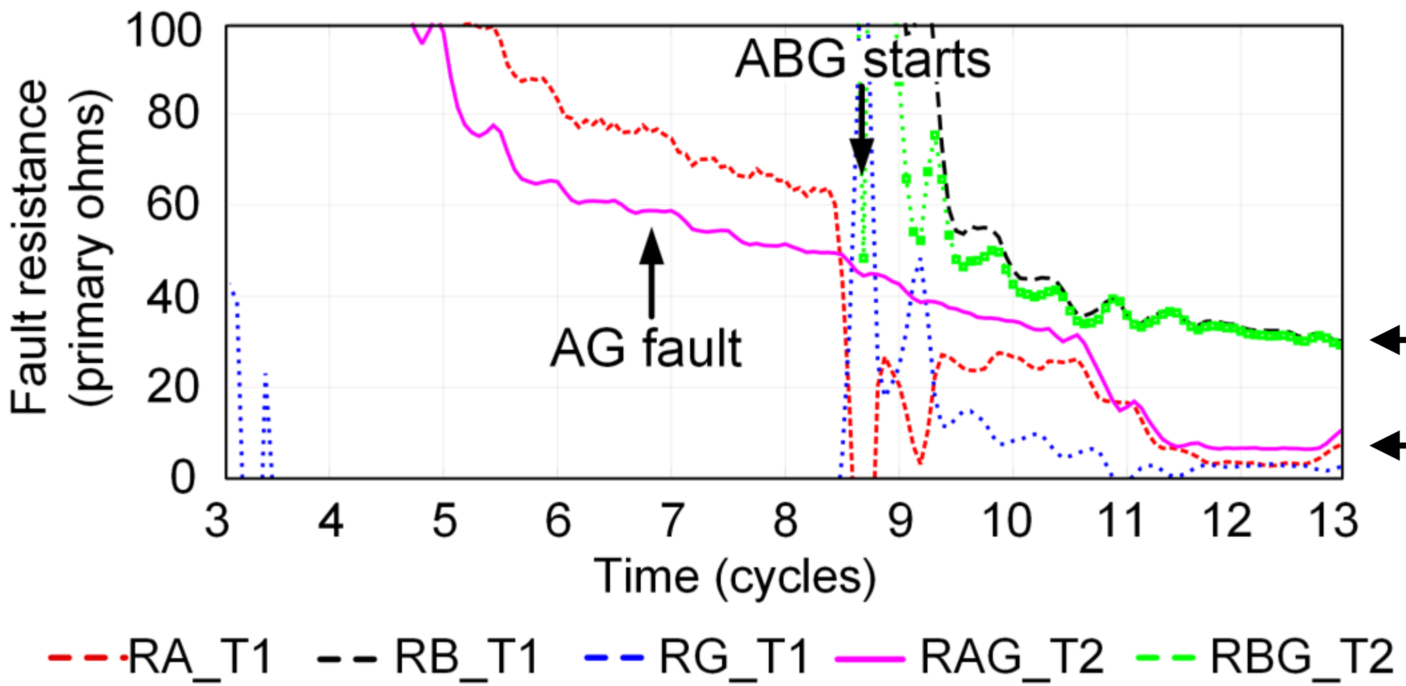


AG and BG in same location; special case of T2

ABG with $R_B >> R_A$ and R_G special case of T1

- Relatively high resistance from A-phase to B-phase (small branch with needles)
- Relatively low resistance from A-phase to ground (thick, bare tree trunk)
- This fault represents convergence of T1 and T2

Resistance calculations show convergence of T1 and T2



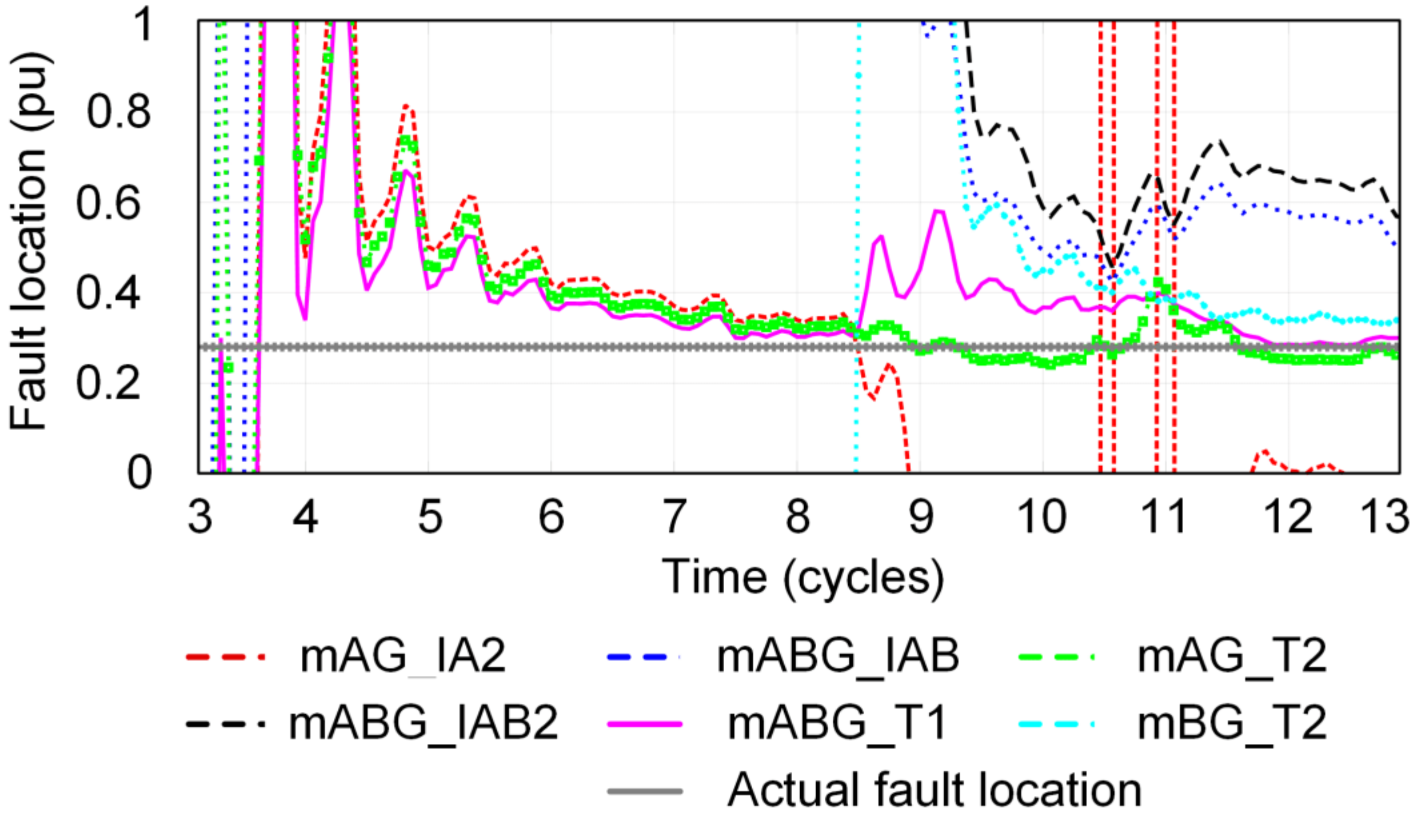
Relatively large B-phase resistances calculated for T1 and T2

Relatively small A-phase and ground resistances calculated for T1 and T2

T1 and T2 calculations locate fault correctly

Standard methods yield larger values

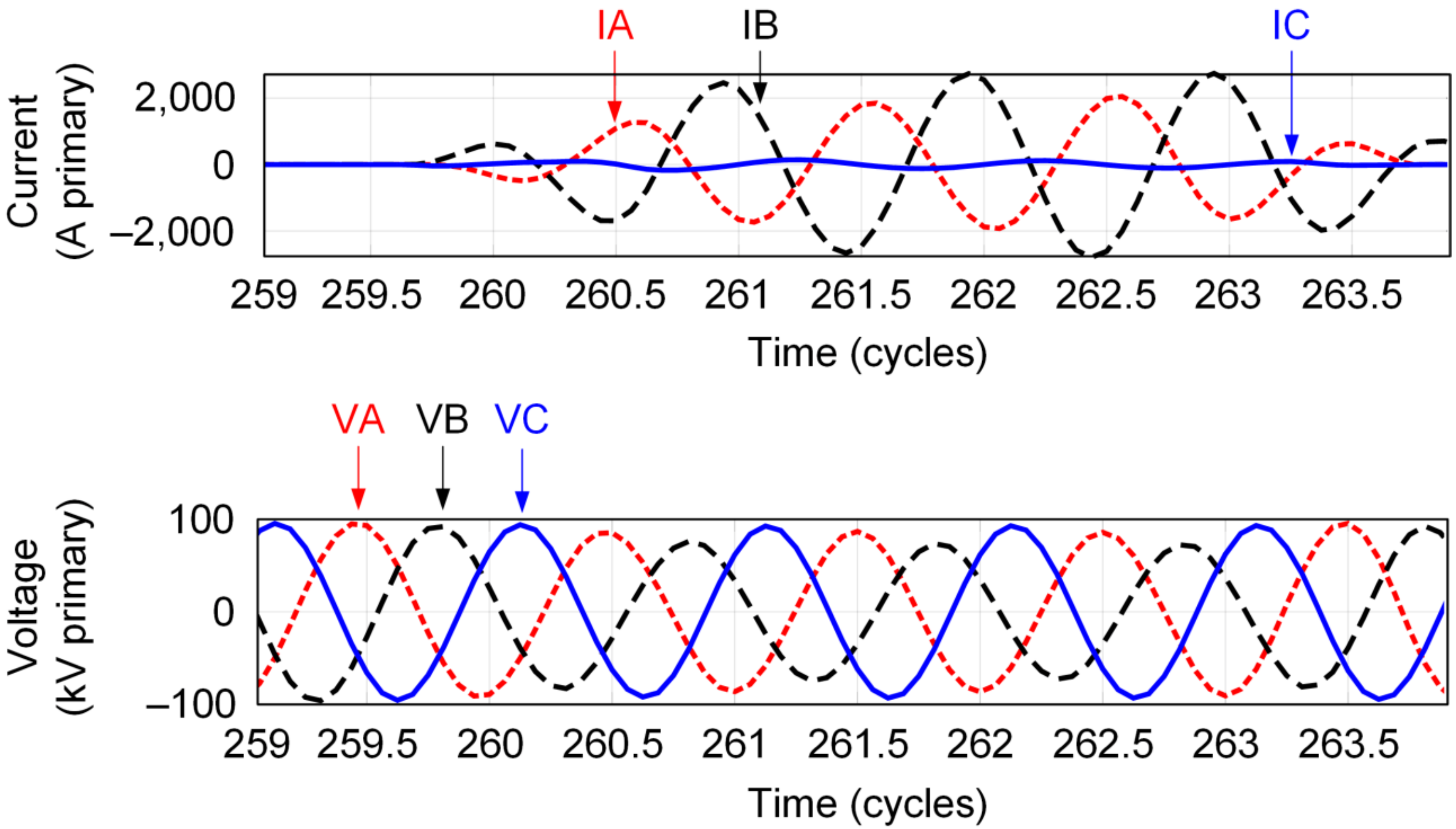
Actual fault location = 0.28 pu



Traditional I_{AB} and I_{AB2} polarized fault location results

T1 and T2 fault location results and actual fault location

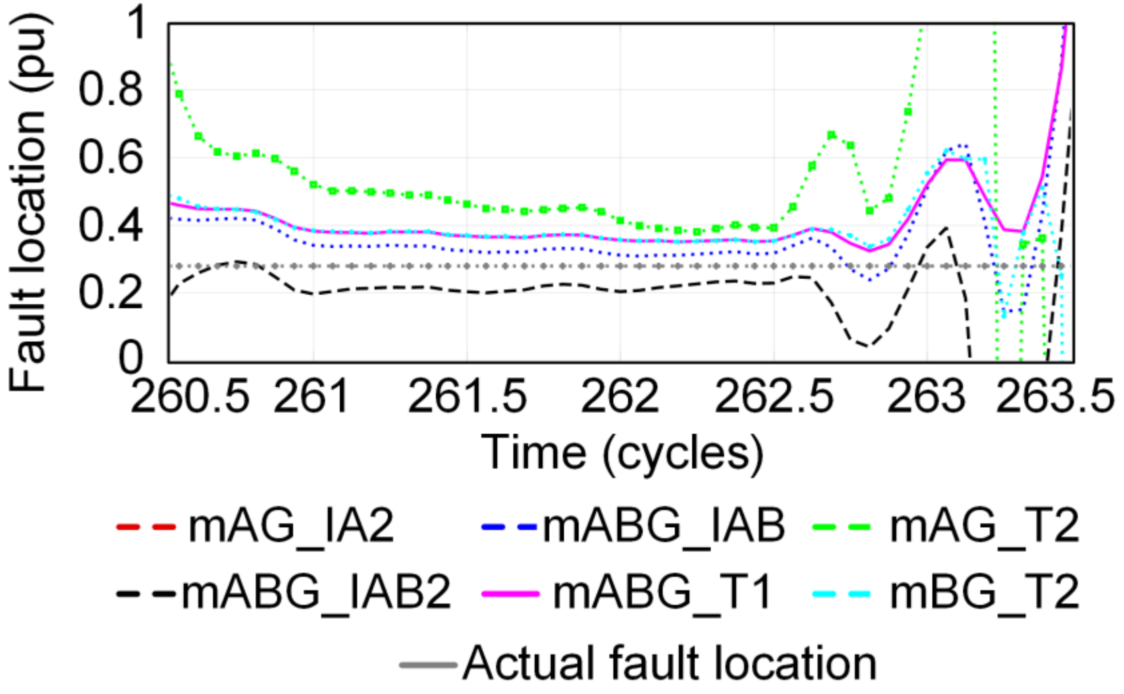
Currents and voltages for ABG fault after reclosing



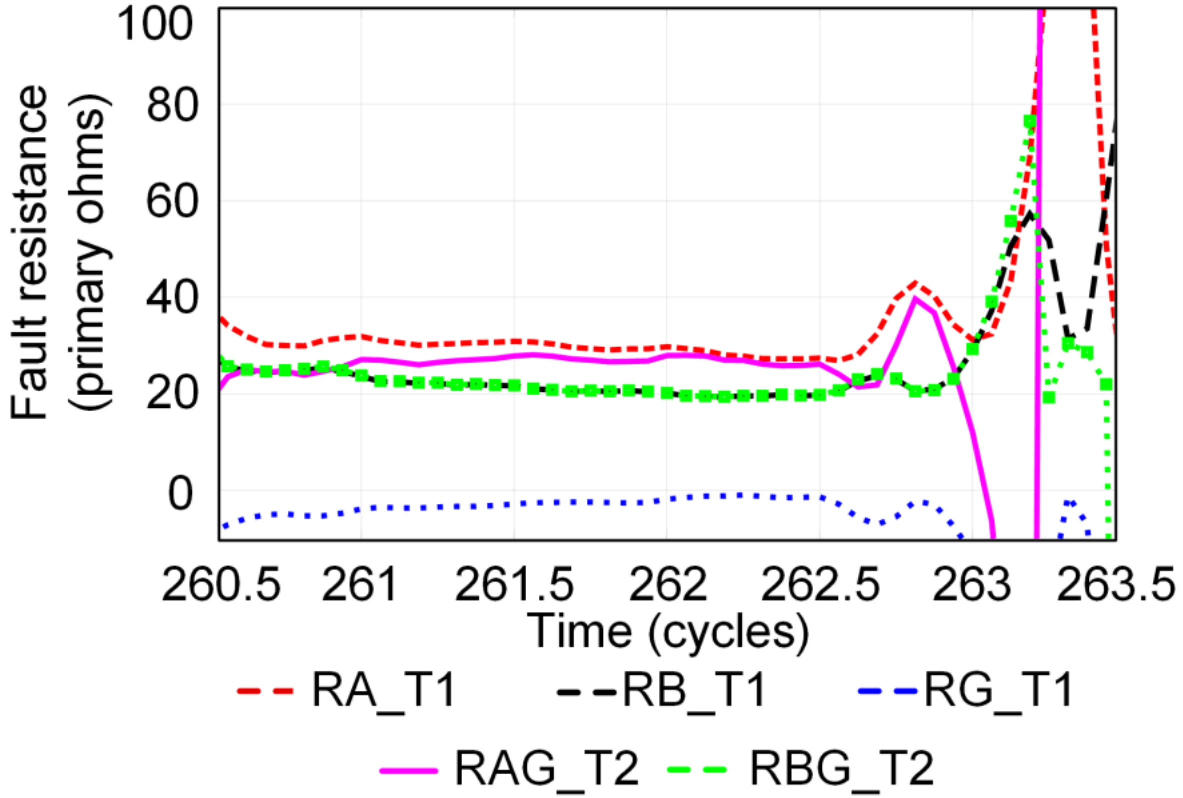
Traditional fault locators better after reclosing

When A-phase and B-phase resistances match

A-phase and B-phase conductors on the ground after reclosing



Standard polarizing quantities work better in this case; results closer to T1 and T2 values



Calculated RA and RB values are much more similar than before

Conclusion

- Phase-domain (A, B, C) analysis can be applied for nonstandard DLG topologies; these methods naturally incorporate fault resistance into the solution
- Synchronized data from event reports at both line ends allow for linear algebra solutions
- Iterative solutions are required when data are unsynchronized or when the same phase is faulted at multiple locations
- Quality checks can be performed to determine which candidate topology is most likely correct
- Real-world faults can have nonstandard topologies, as shown by Avista event

Questions?