NorthWestern Energy
Broken Conductor Philosophy

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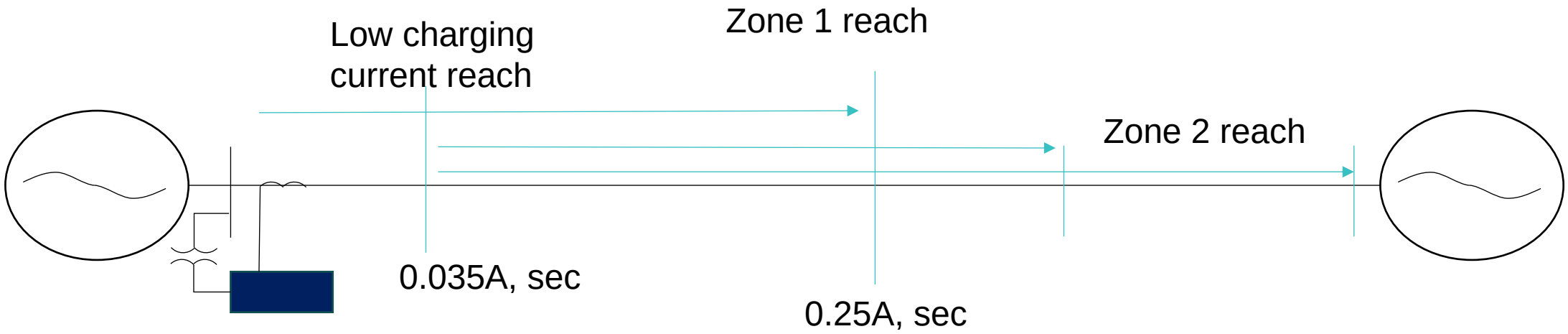
NWE Evaluation of Lines

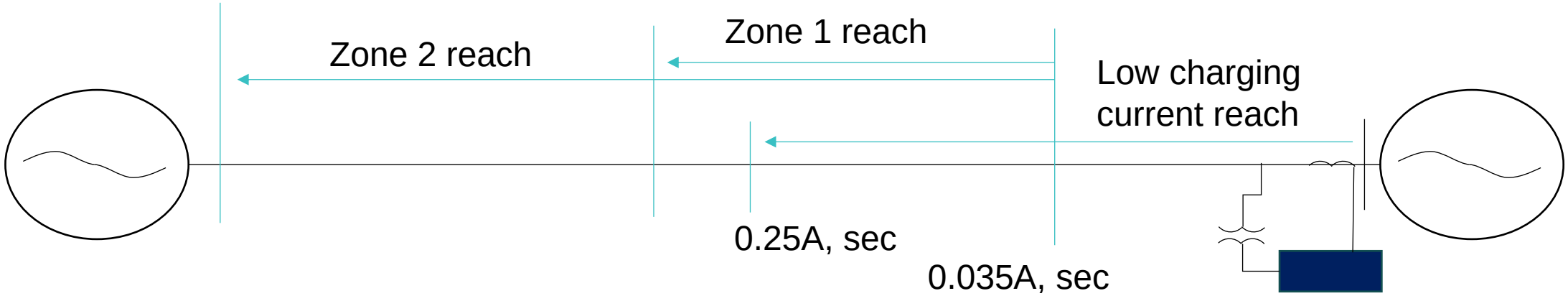
- Total line charging current
  - 0.07 A,sec
- CTR, TRF, FAC-008, 881
- Saturation
- Communication assisted relaying
- No taps*
- Historical loading
  - Higher loading, higher security, higher predicted availability of BCD element

Broken Conductor Reach



*Assumes 5A nominal relays, and
a BCCIM > 0.25A,sec

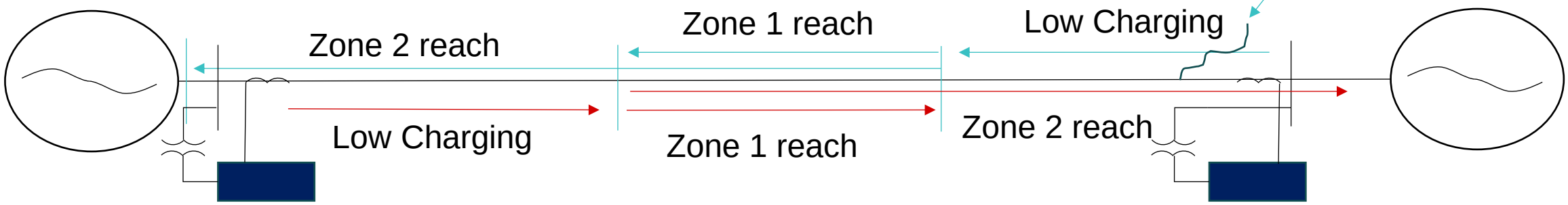
Broken Conductor Reach



*Assumes 5A nominal relays, and
a BCCIM > 0.25A,sec

Considerations for No Comm Assisted Relaying

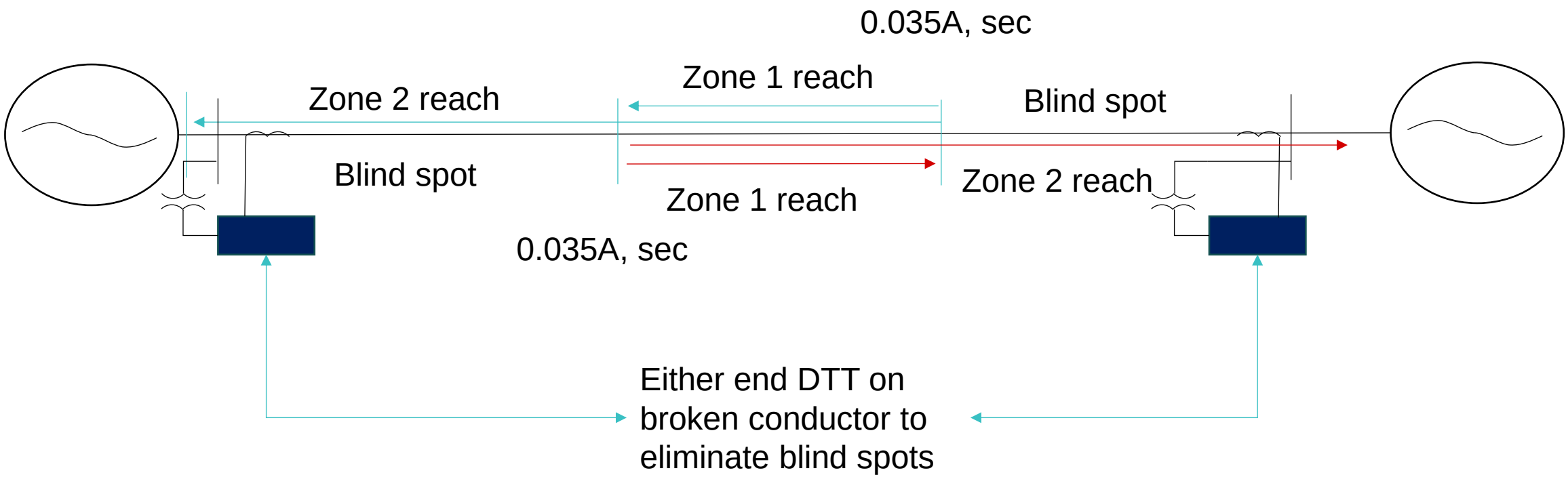
Be aware that BCD logic does not appear to work for staggered end clearing



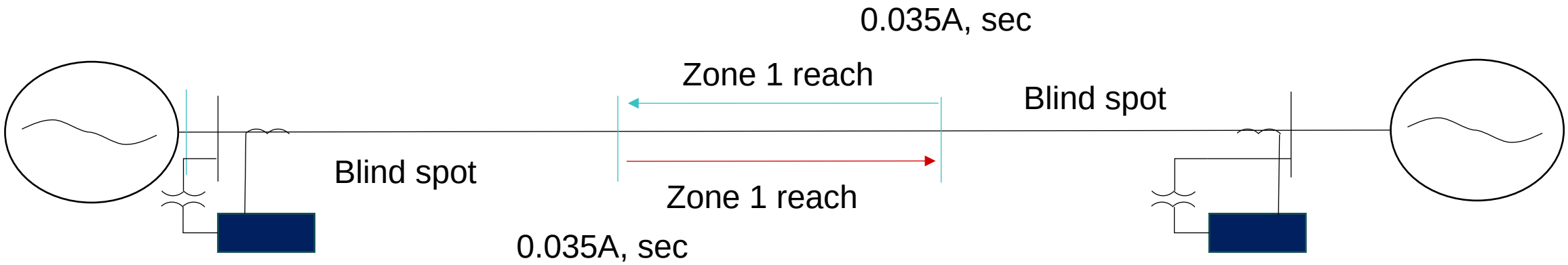
<u>Understanding of BCD logic is that it is for a single phase conductor breaking.</u> If one end trips instantaneously, and the other end sees the broken conductor in a delayed zone, the delayed end will not be expected to trip because the instantaneous trip end creates a ‘3-phase’ apparent broken conductor and the logic blocks the element for that.

Current NWE Implementation for comm assisted relaying schemes

*Low charging current turned off for time being, improved low charging current implemented on one lightly loaded line, is set to trip, evaluating performance



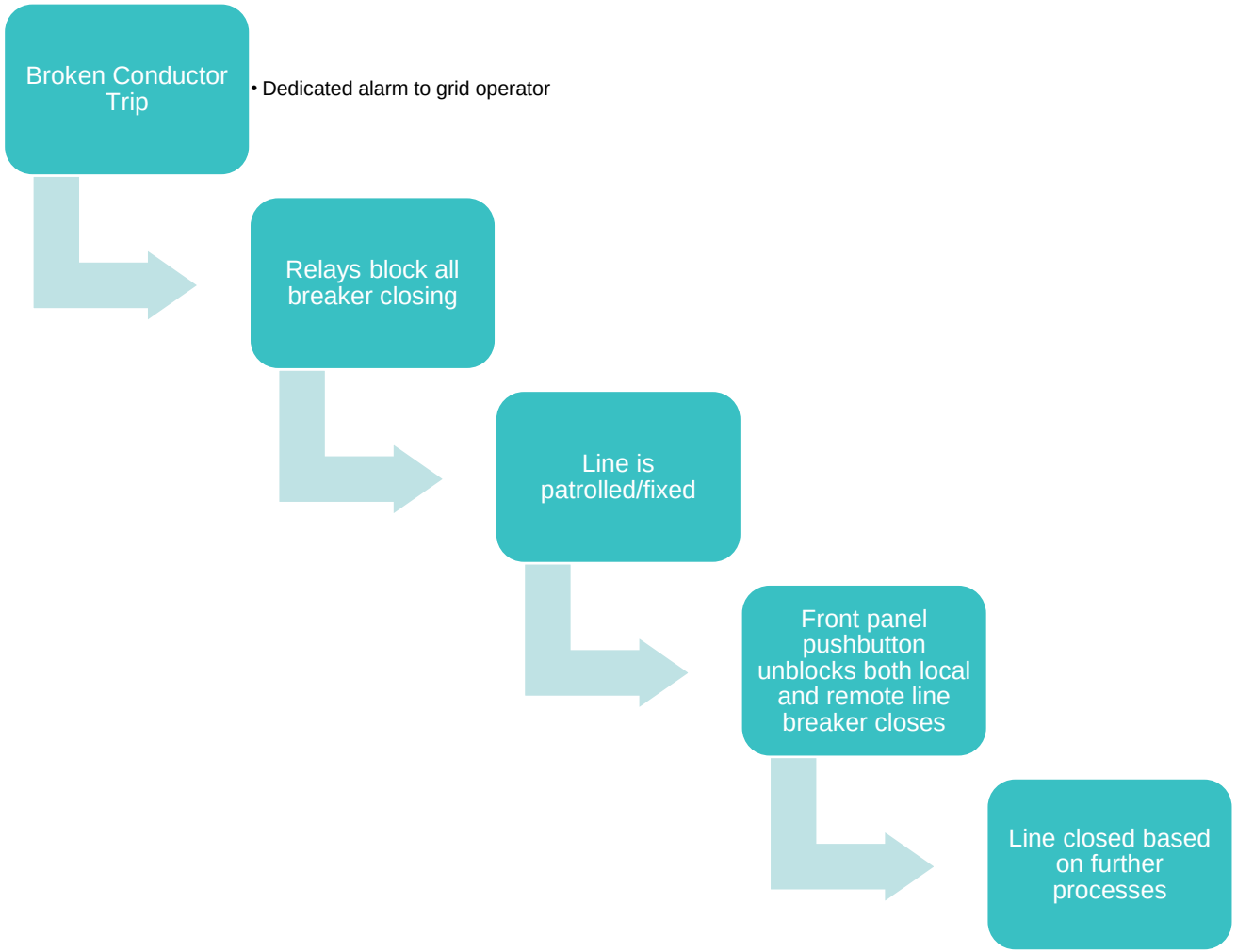
Current NWE Implementation for no comm assisted relaying or loss of comm



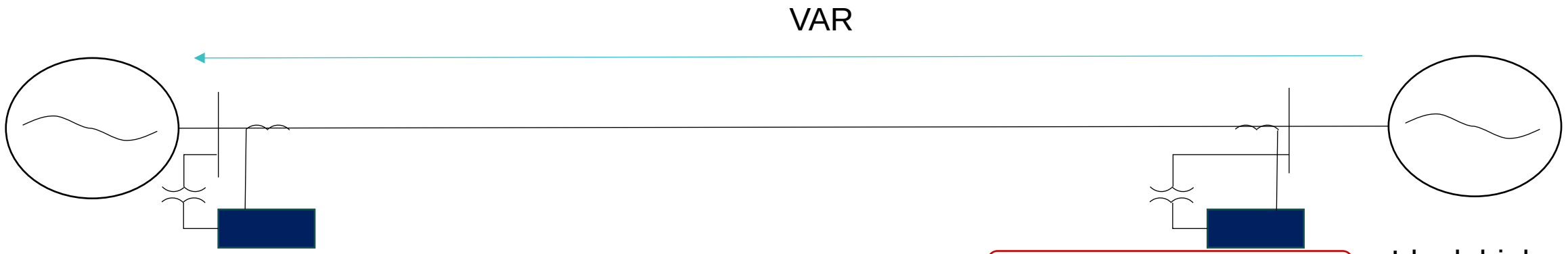
Match Zone 1 reach to start of remote end Zone 1 reach

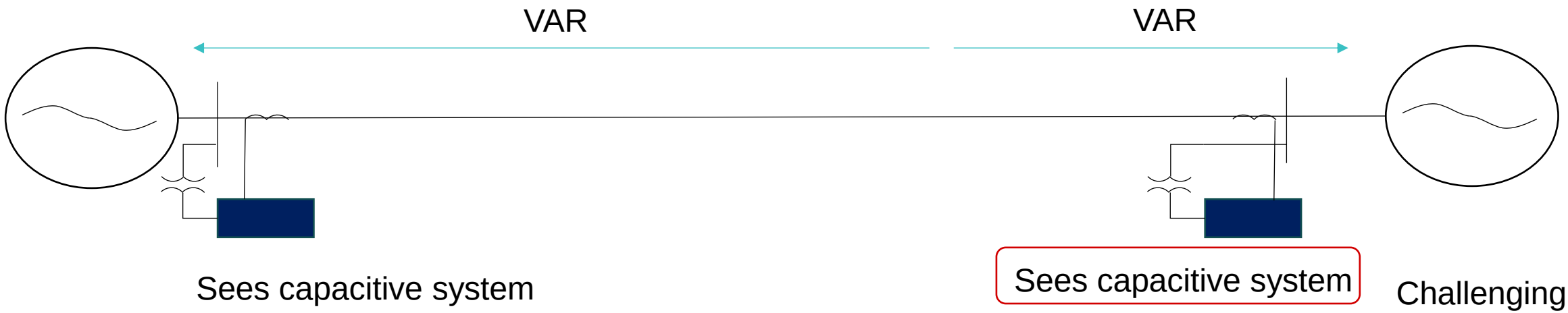
*Based on updated low charging current logic being evaluated, expectation is to update this application to have low charging current delayed to match remote end Zone 2 delay

Process following trip (All hands on deck)



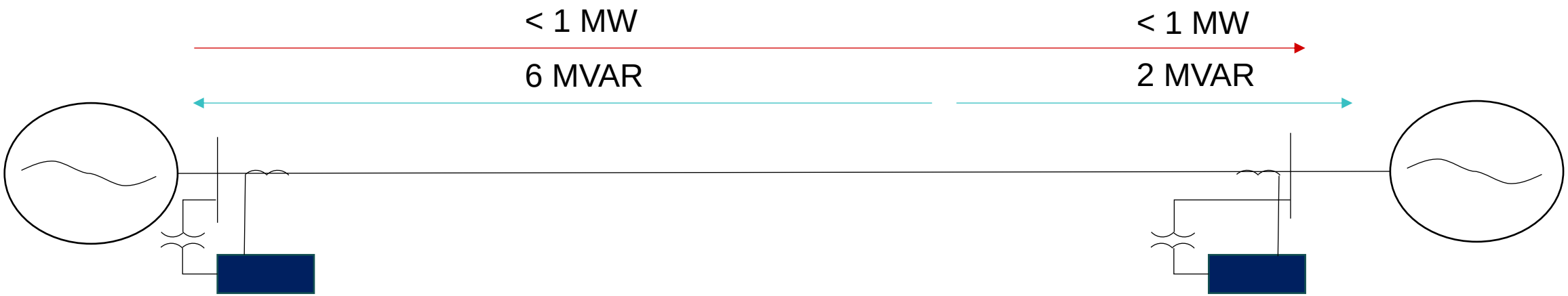
NWE Observed VAR Flows





Real Line Loading Example 1

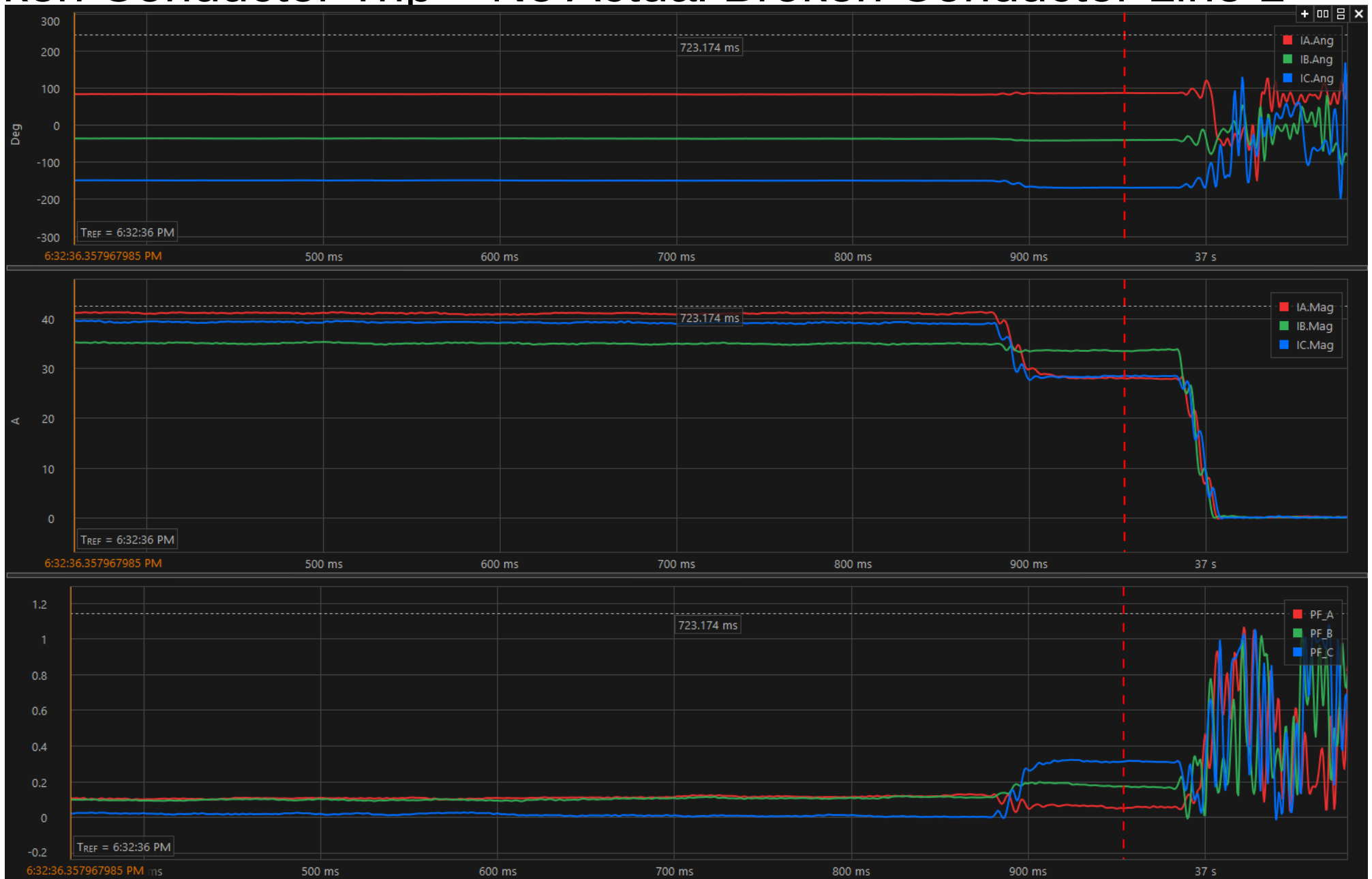
8 MVAR equivalent line from charging current test



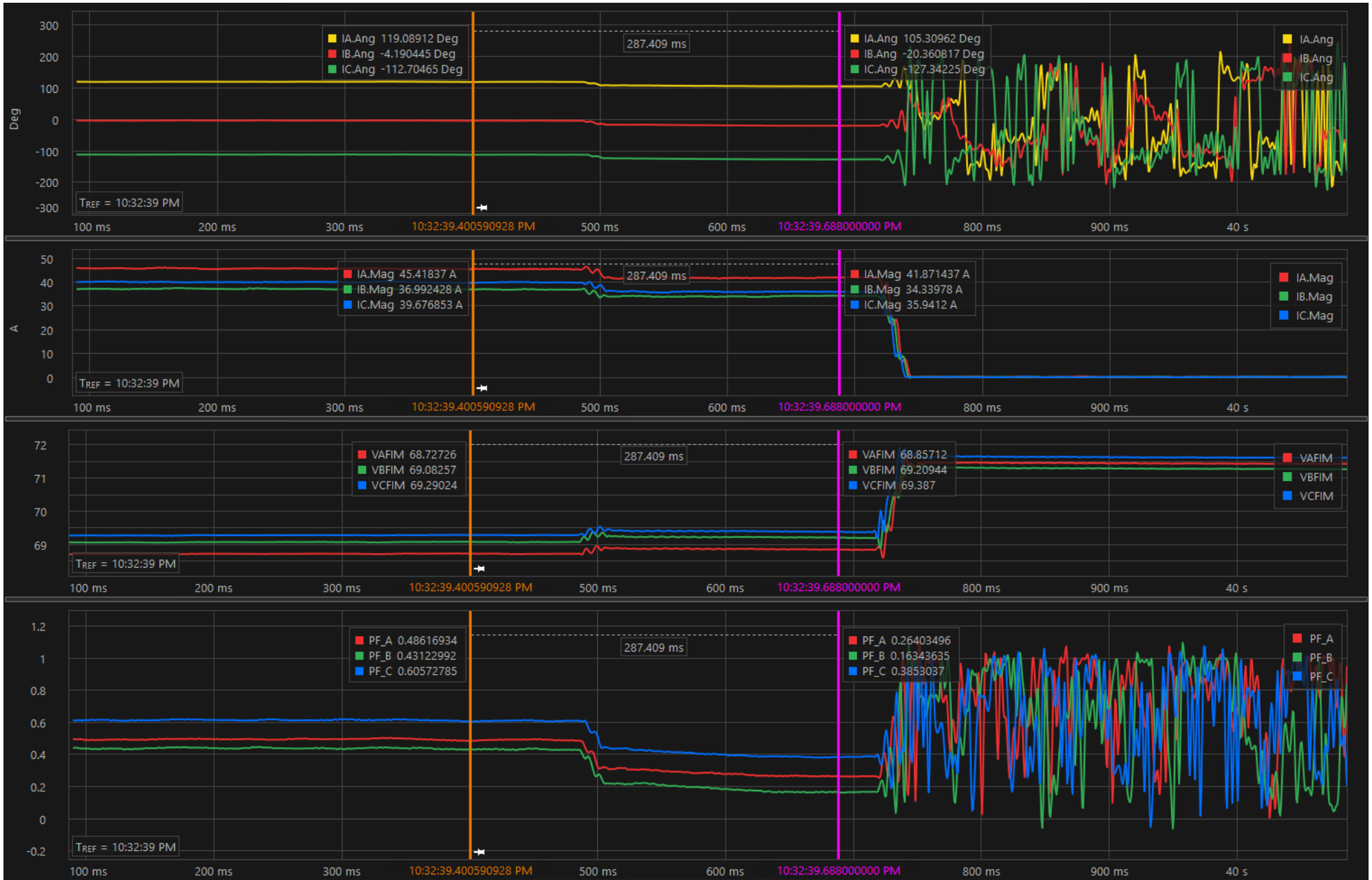
Sees IA, IB, IC unbalances fluctuating phases between Zone 1 and Zone 2, each phase independently

Sees IA, IB, IC bouncing within Low Charging Current then Zone 1 Magnitude persistently, each phase independently

Broken Conductor Trip – No Actual Broken Conductor Line 1

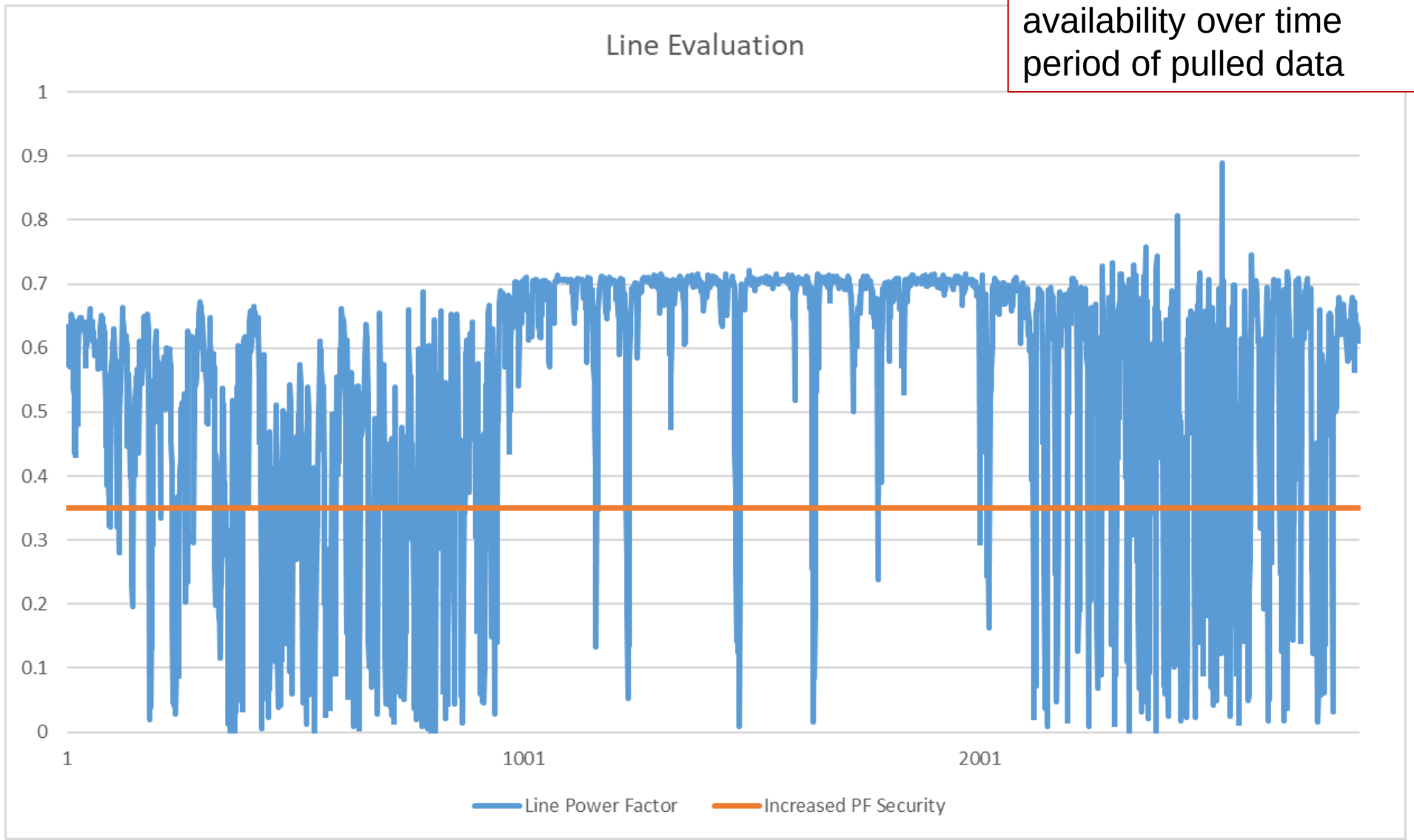


Next Day Broken Conductor Trip – No Actual Broken Conductor Line 1



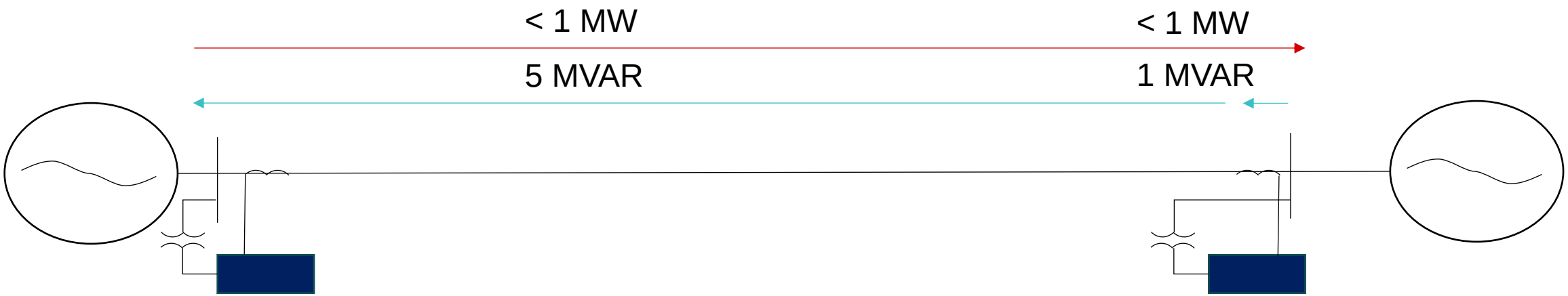
Line 1 Increased Security and Predicted Availability

Predicted 80% availability over time period of pulled data



Real Line Loading Example 2

4 MVAR equivalent line from charging current test



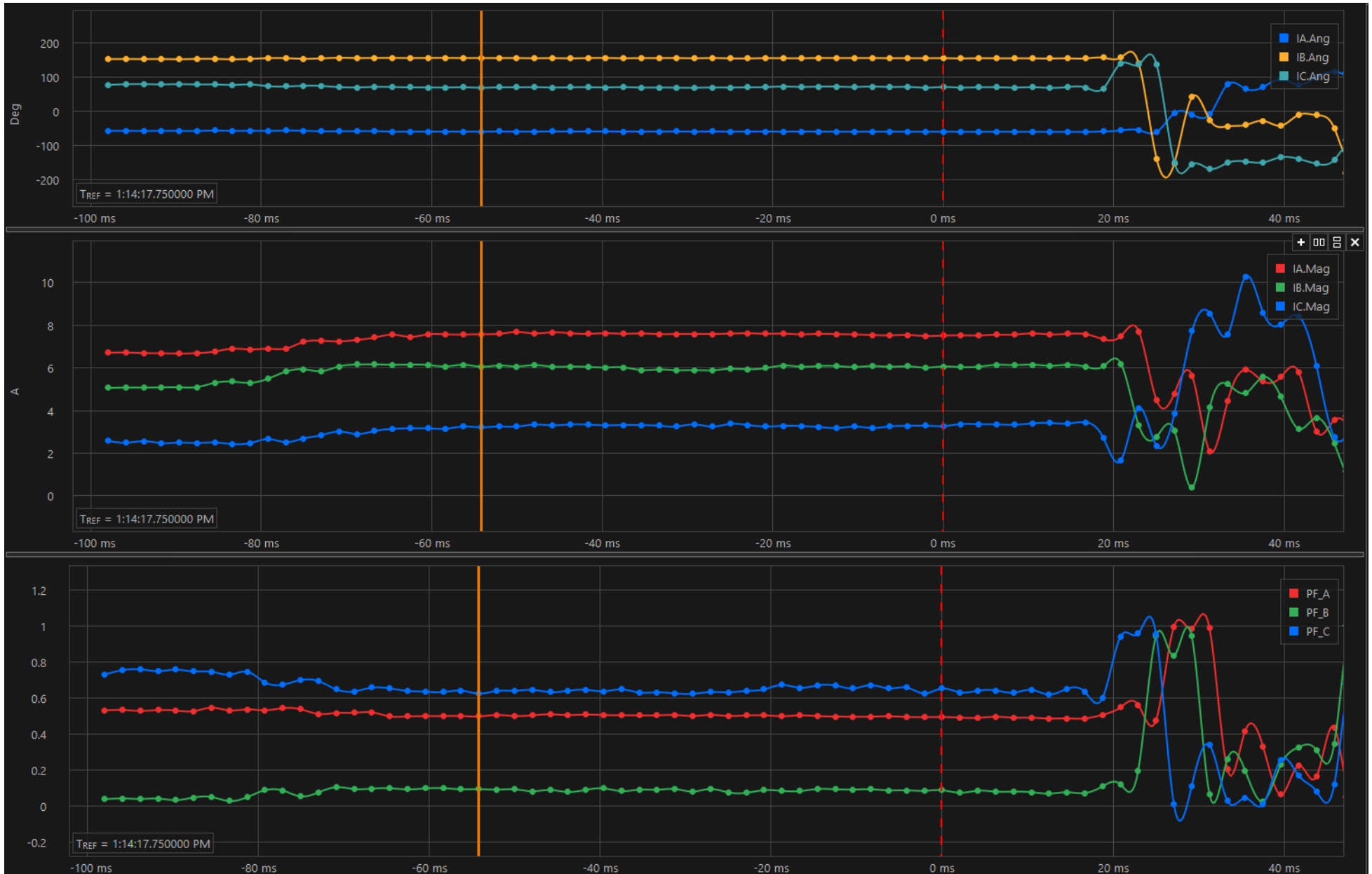
Sees IA, IB, IC bouncing into the Zone 2 Magnitude frequently

Sees IA, IB, IC bouncing within Low Charging Current Magnitude persistently

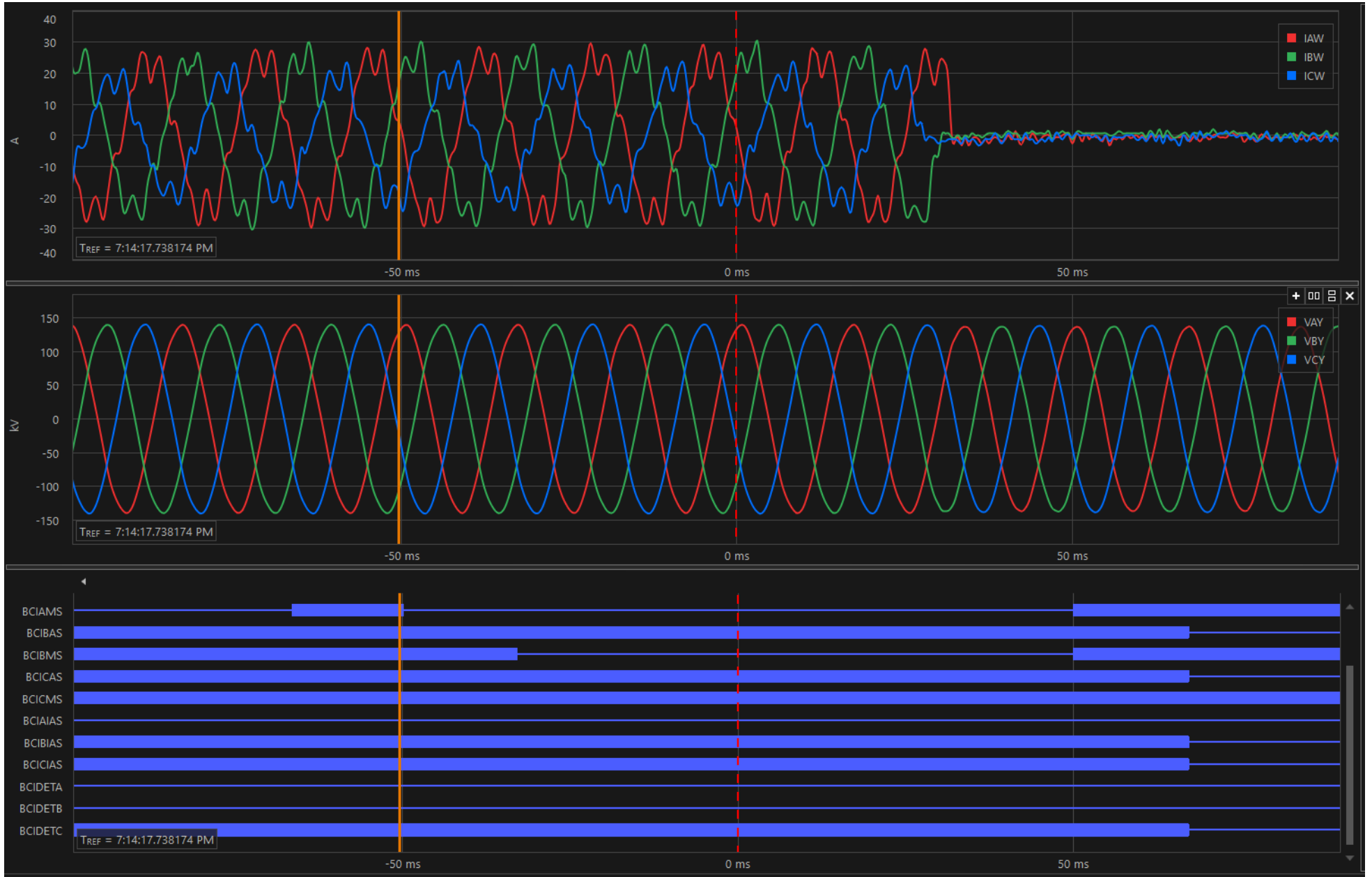
Broken Conductor Trip – No Actual Broken Conductor Line 2

Broken Conductor Trip – No Actual Broken Conductor Line 2

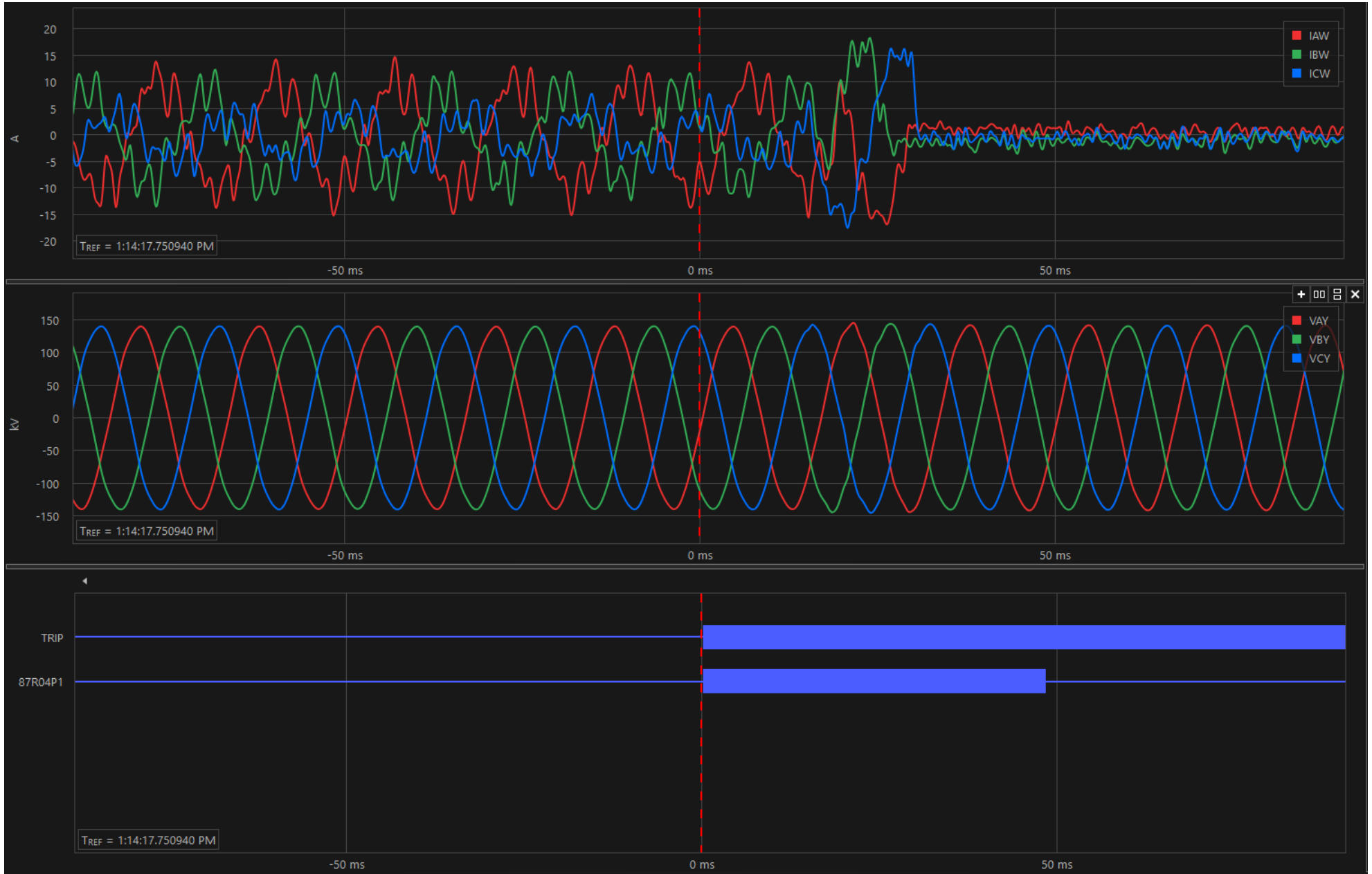
Broken Conductor Trip – No Actual Broken Conductor Line 2 – Remote DTT



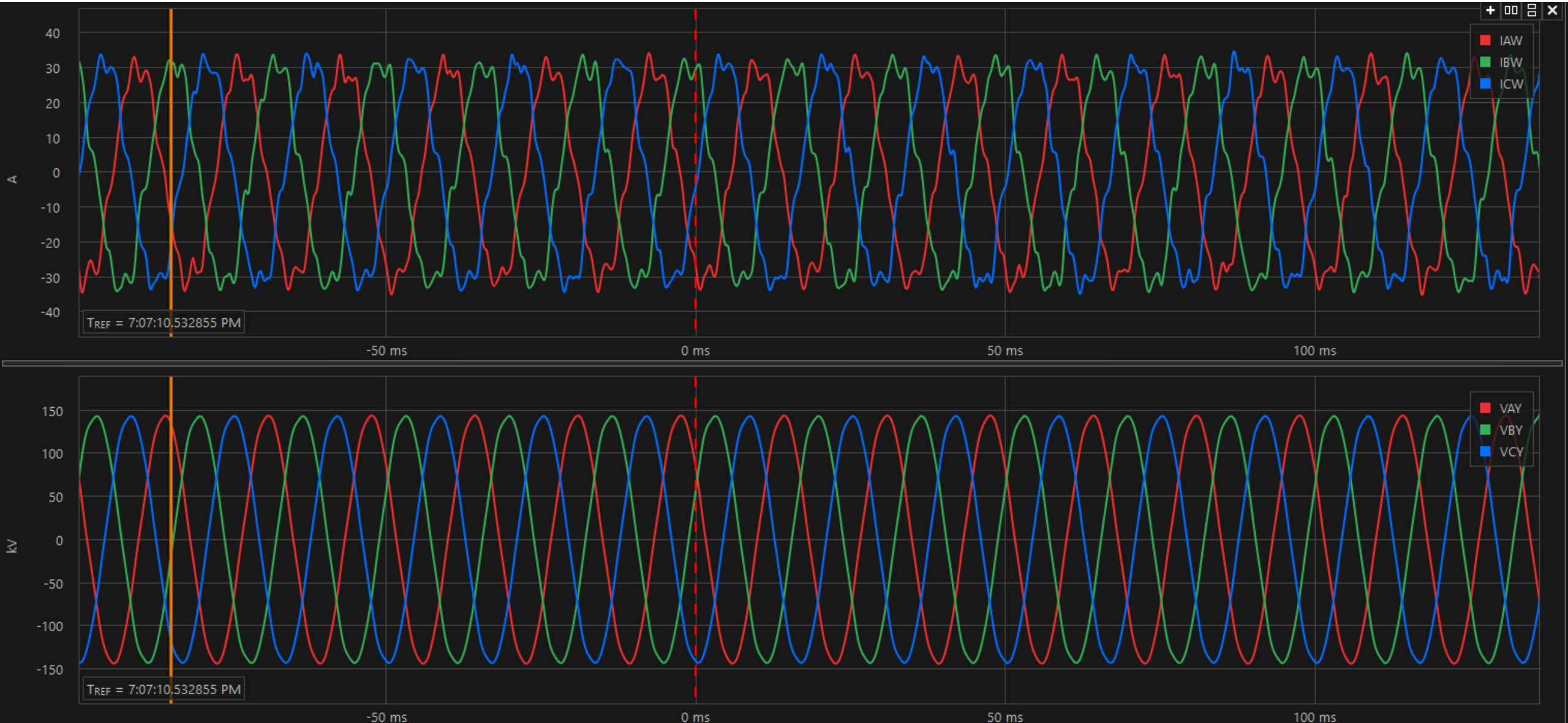
Broken Conductor Trip – No Actual Broken Conductor Line 2



Broken Conductor Trip – No Actual Broken Conductor Line 2

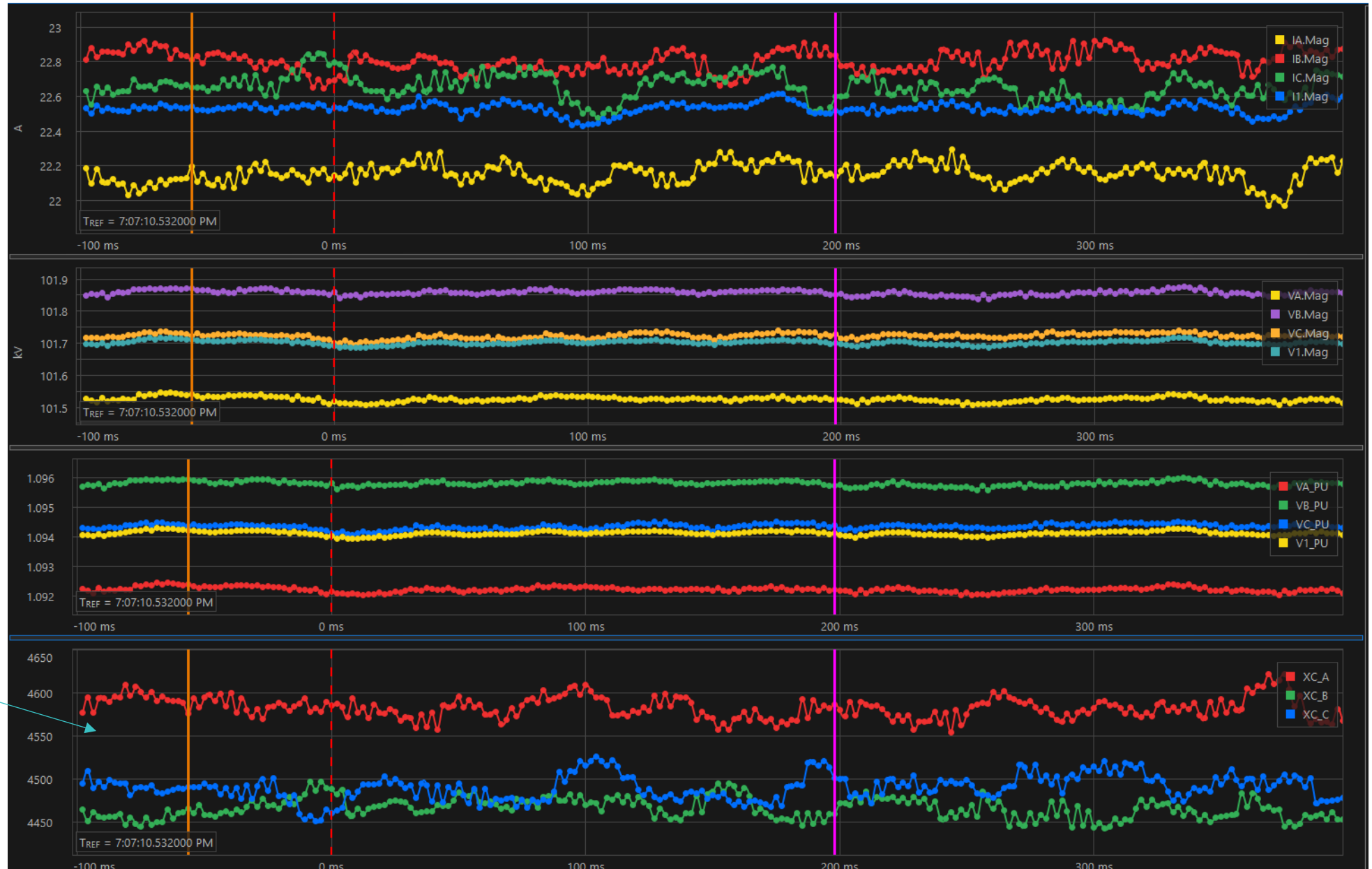


Harmonic Comparison to Line Charging Current Example



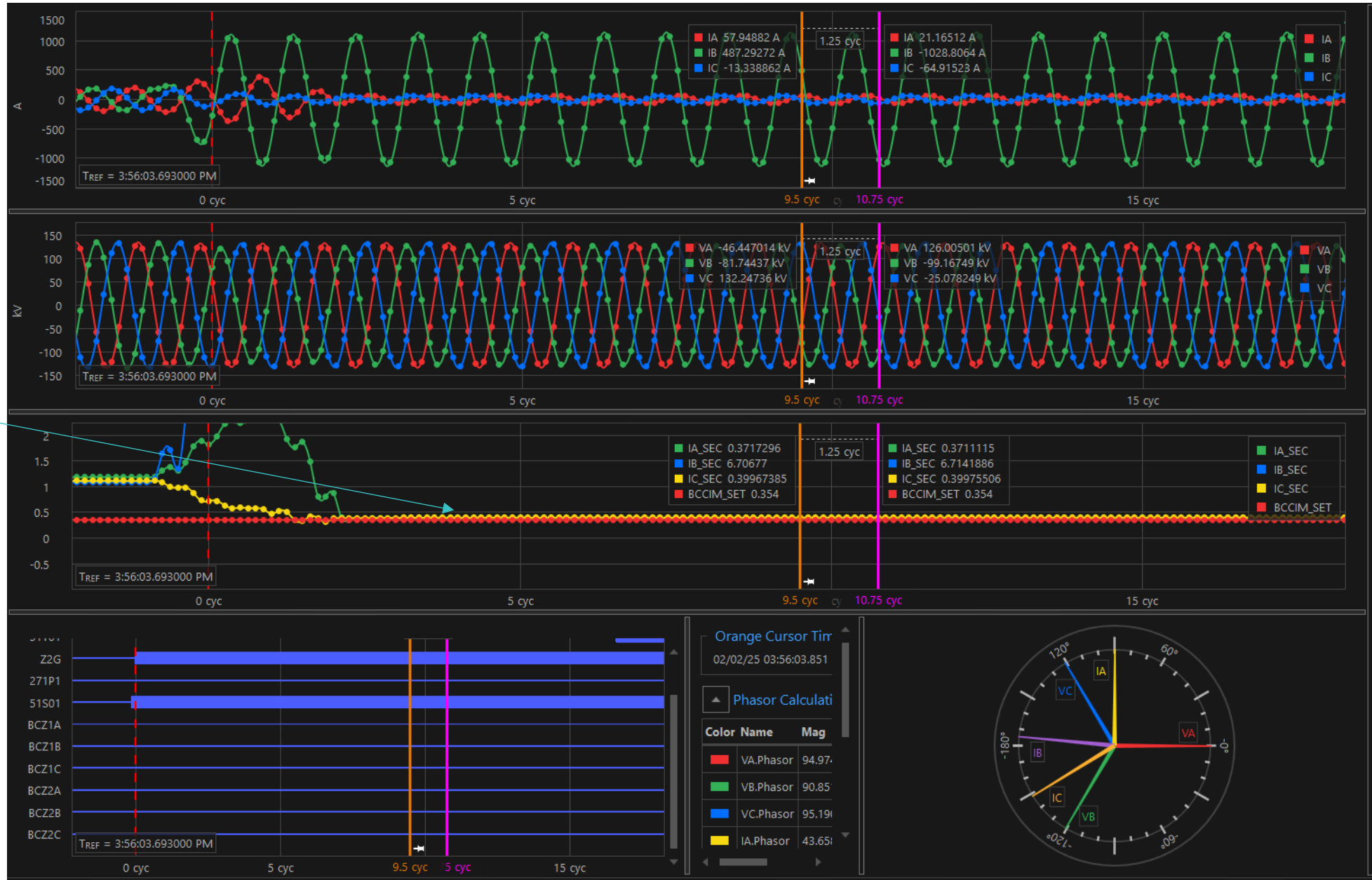
Verifying CT Accuracy, Expected Imbalance, and Calculating BCCIM?

Modeling tool for unbalanced phase capacitances?

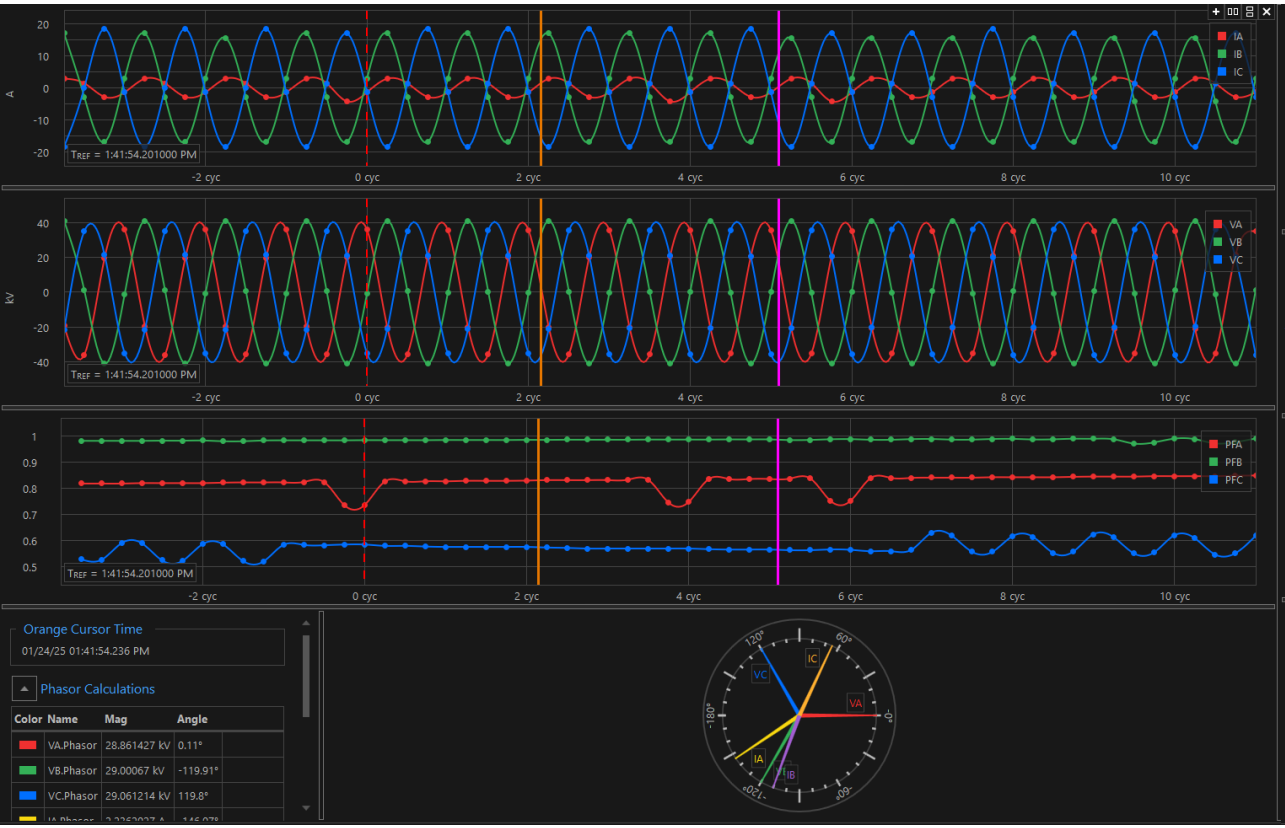


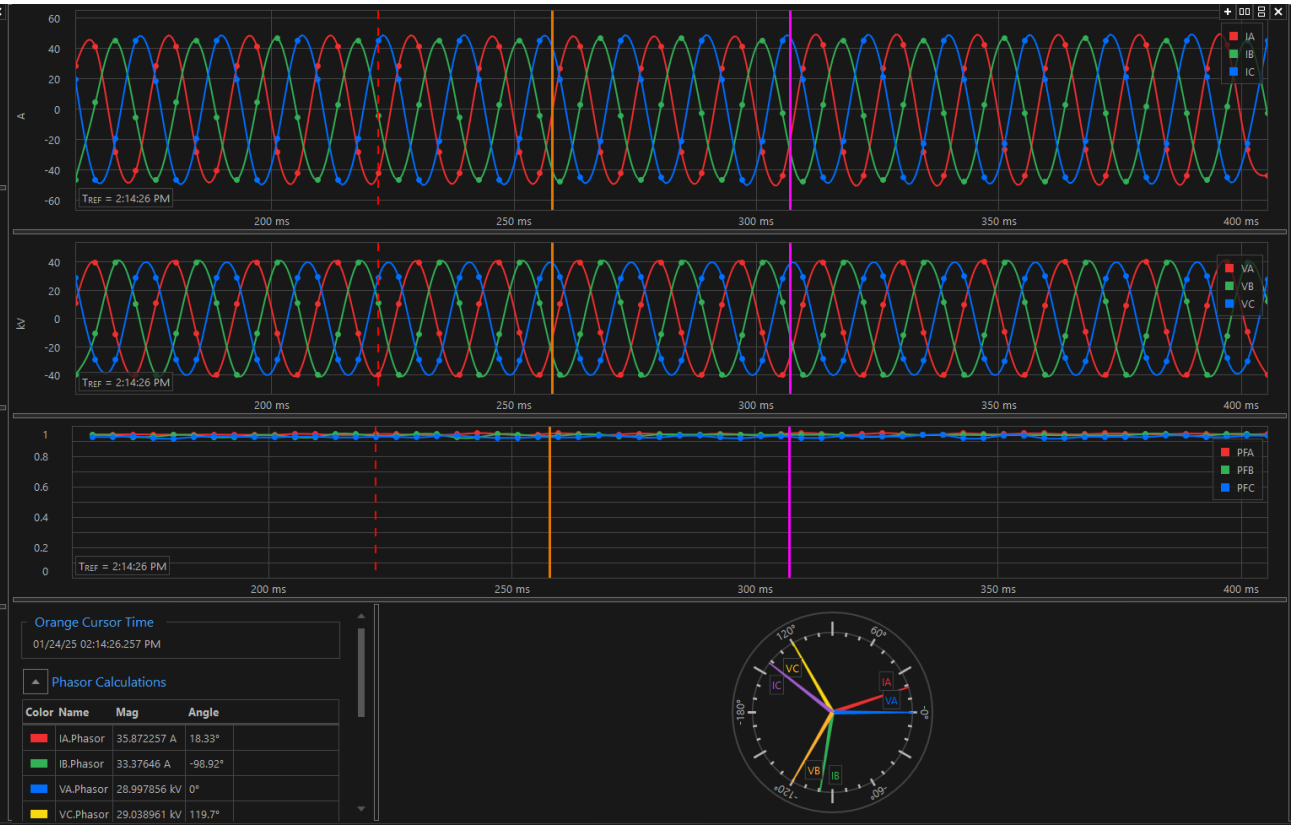
Typical Fault, Secure Under Staggered Breaker Operation

Modeling tool for coupling impact?

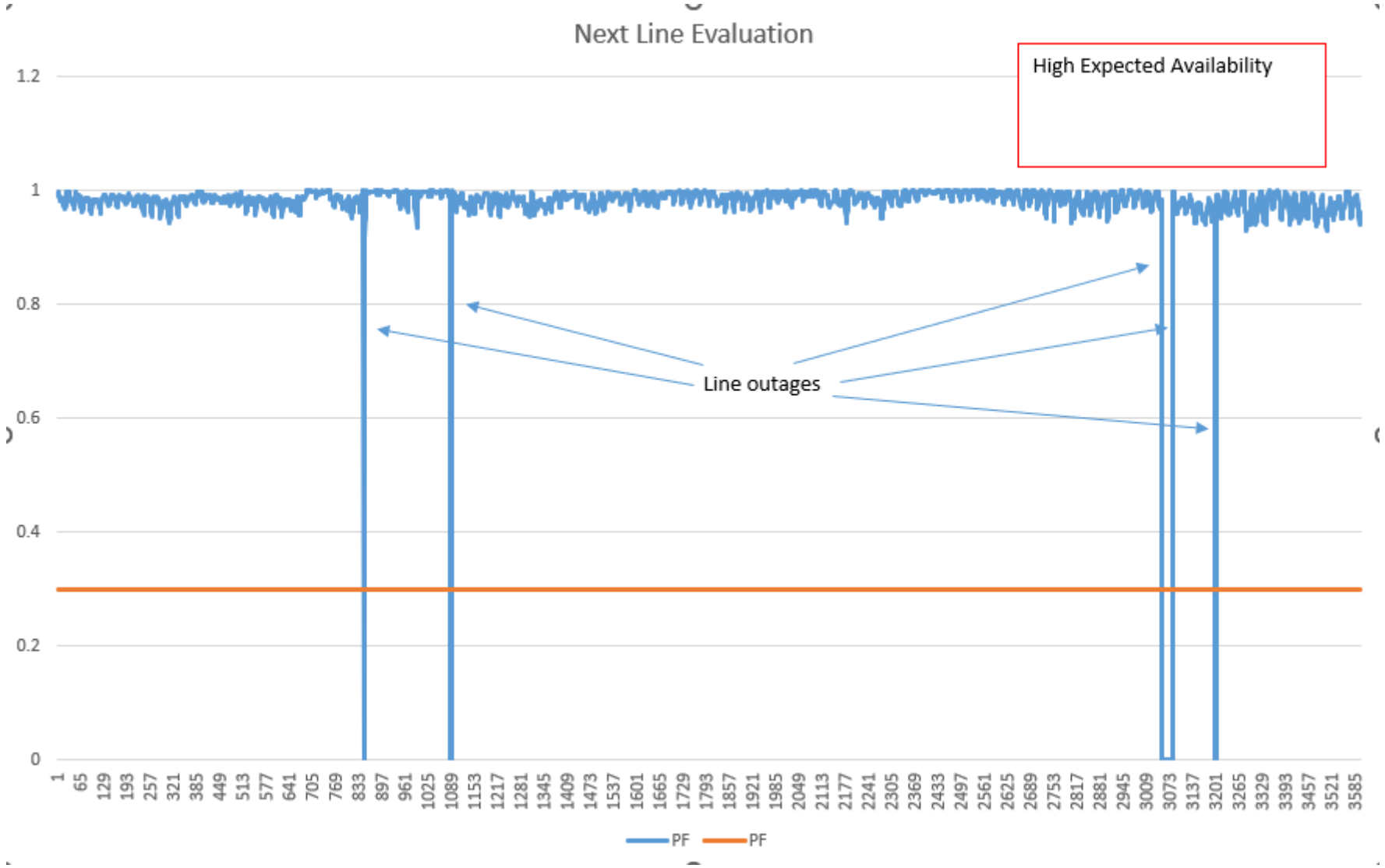


Bad Air Break Switch Seating and Load Flow Impact of Series Fault



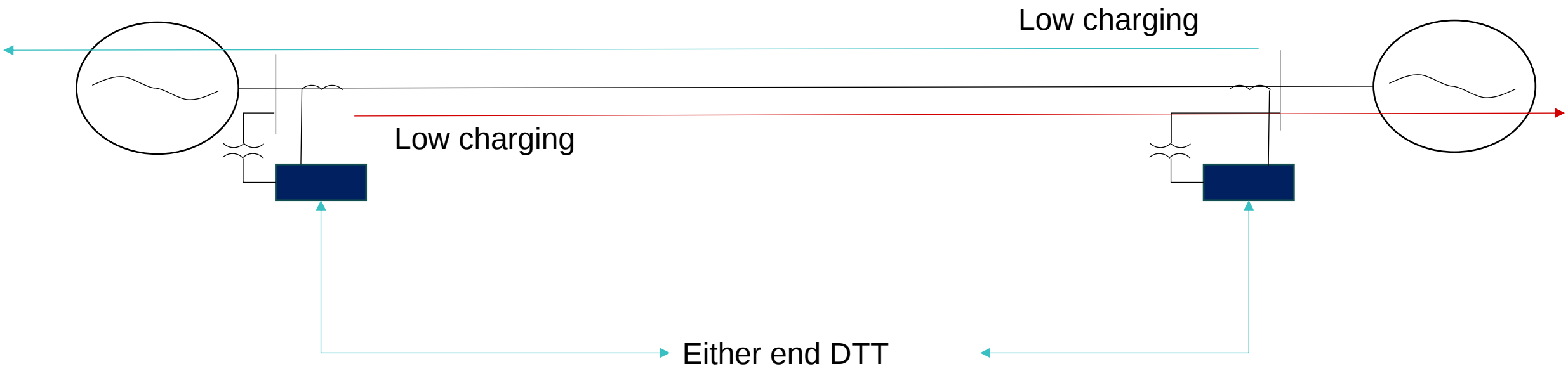


Expected Availability of Next Line to have BCD Trip Implemented



Next Evolution

On lines without sufficient charging current to set a zone 1, low charging current logic used, delayed 10 to 20 cycles.



Next Evolution