SMUD 230kV Broken Conductor Event and 411L Response

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Salt Lake City, UT

Powering forward. Together.

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Agenda

- Failed compression sleeve on a 22-mile long 230kV transmission line in 2015.
- Event data and test file development.
- Playback of COMTRADE event into a 411L with broken conductor detection (BCD) at SEL lab in Pullman, WA.
- Proposed 411L Settings for SMUDs system.

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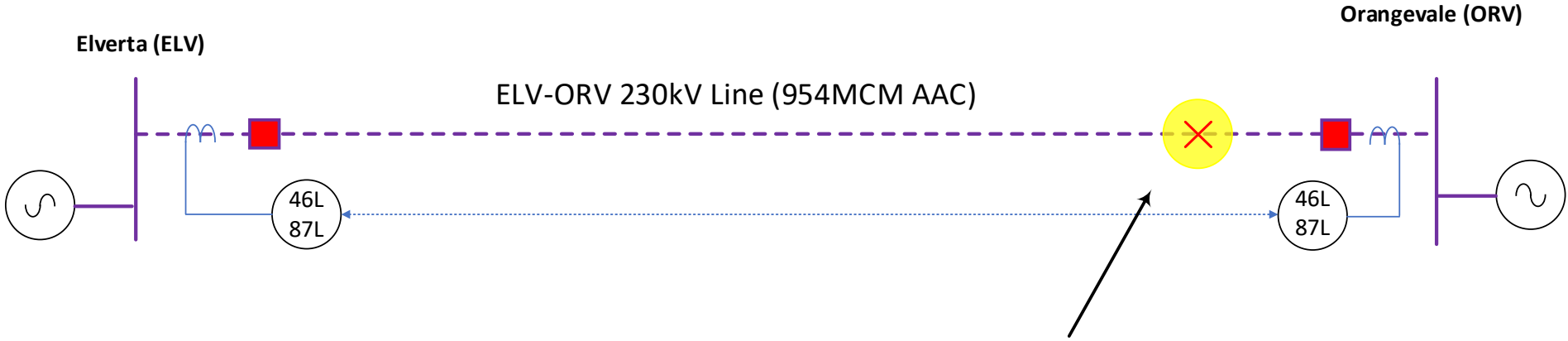
C-phase compression sleeve fails on the morning of December 17, 2015. The 230kV line correctly trips on negative sequence 87L when broken conductor hits ground, clearing the fault.



Calculated break distances:
12,241' (ORV to tower 317 + 415' (to sleeve)' = 12,656' = 2.397 miles from ORV.
101,111' (ELV to tower 316 + 600' (to sleeve)' = 101,711' = 19.263 miles from ELV.

19.263/21.66 = 88.9% the total length from ELV.

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Protective Relay Response

- C-phase conductor of the Elverta – Orangevale 230kV transmission line was the bottom phase of a vertical double circuit tower configuration.
- The 4,400A first fault was fed only from Elverta; the Orangevale conductor had not yet contacted either the tower or ground.
- Dual 87L differential 311L & Areva P543 relays (direct fiber comms) both tripped (and cross-tripped) on the differential developed by the Elverta-feed.
- 30 cycles later, the Orangevale terminal attempted a reclose, which resulted in a 9,000A Orangevale-feed only C-phase to ground fault and locked out.

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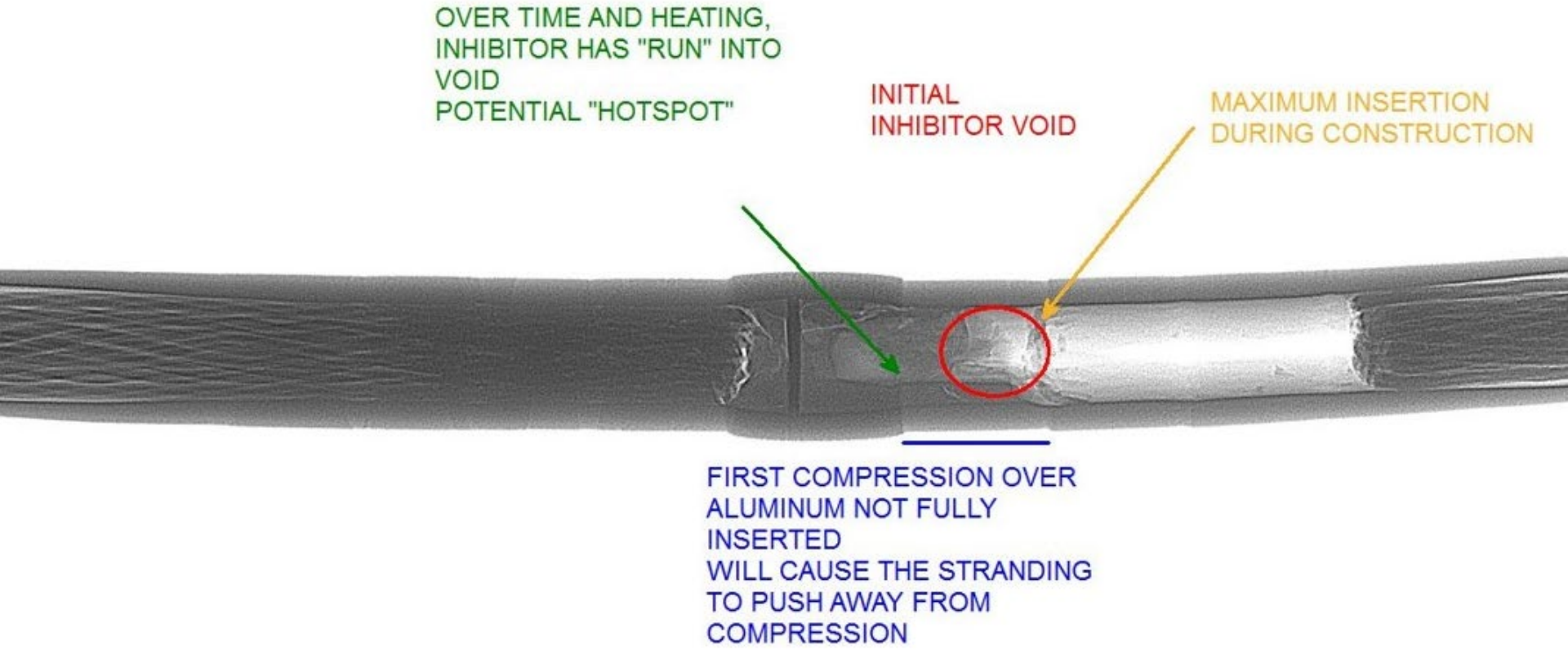
Failed Compression Sleeve.



The splice failed due to two reasons; insufficient compressive force applied, along with insufficient cable insertion.

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BCD Detection in SMUD Relays

- Broken Conductor Detection was “unheard of” in 2015:
  - Areva P543 relays have had broken conductor detection since 2000, using an $|I_2/I_1|$ ratio detection method; however, SMUD never employed this.
  - Low load conditions develop + seq load current approaching charging current, where $|I_2/I_1|$ would drop quite low.
  - Considering the delay required, not likely the relay would reliability detect a broken conductor before Newton.
  - Possible uses would be for bus section breaks, LTC tap failures, single phase fuse operation…all of which are not applicable to SMUDs transmission.

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Areva P543 Broken Conductor Detection Settings

1.3.9 Broken conductor

Menu Text	Default Setting	Setting Range		Step Size
		Min.	Max.	
Broken Conductor	Disabled	Enabled/Disabled		N/A
Enables or disables the broken conductor function.				
I2/I1	0.2	0.2	1	0.01
Setting to determine the pick- up level of the negative to positive sequence current ratio.				
I2/I1 Time Delay	60s	0s	100s	1s
Setting for the function operating time delay.				

COMTRADE Test File Development

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Retrieved Event Records

- At the time of the event, there was no driver (no reason) to extract the COMTRADE event from either the 311L or P543.
  - 311L .cev file was the only event extracted.
- However, the Elverta DFR captured the charging current and shunt fault oscillography.
- The actual break in the conductor was never retrievable, based on the relay and DFR triggering settings at the time.
- SER data did not provide any additional information.
- Nonetheless, SEL stitched together the data from the 311L .CEV and DFR COMTRADE event records and re-created a COMTRADE for the event seen from Elverta.

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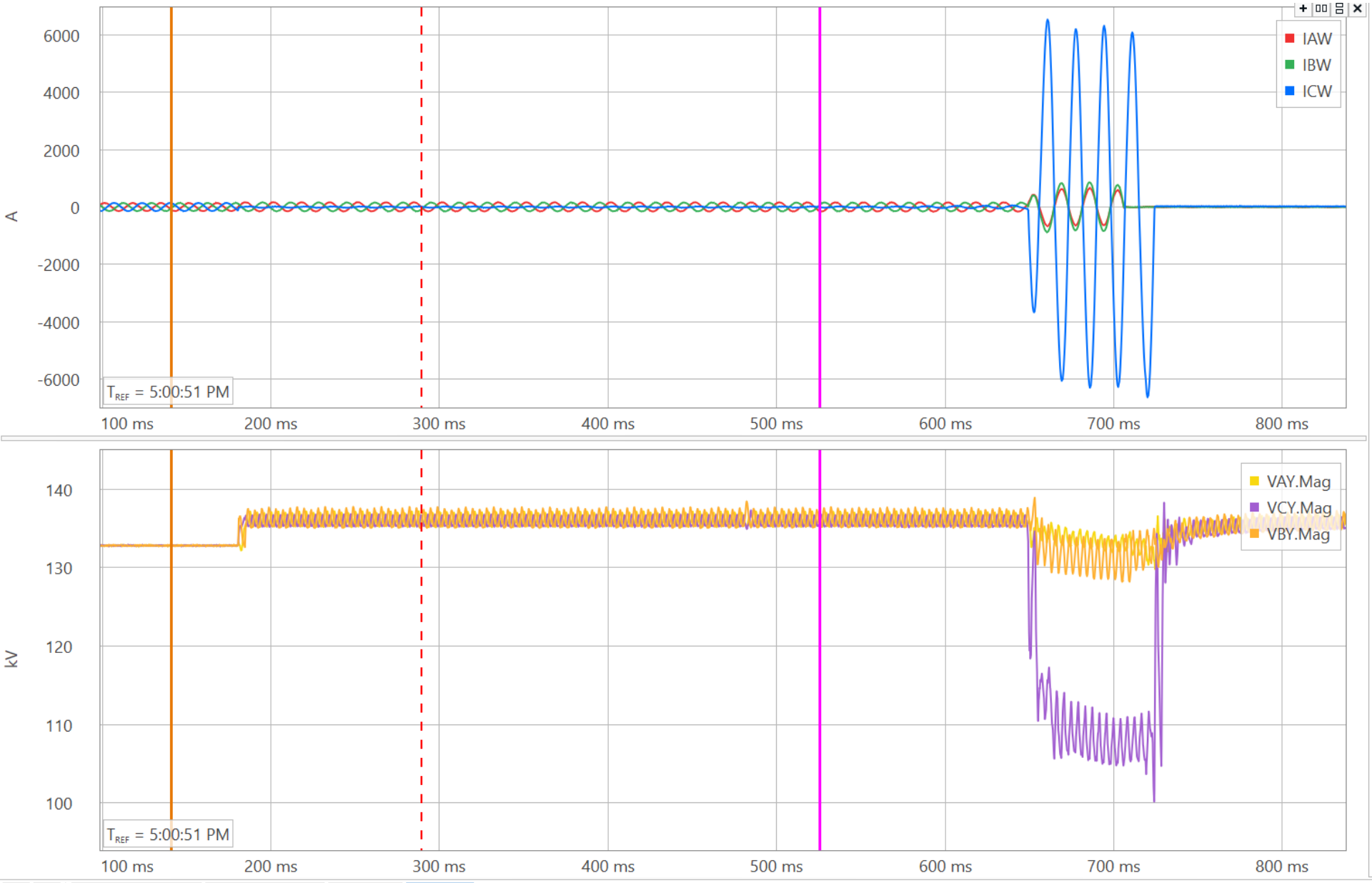
<Public>


6000
4000
2000
0
-2000
-4000
-6000
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IAW
IBW
ICW
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100 ms
200 ms
300 ms
400 ms
500 ms
600 ms
700 ms
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140
130
120
110
100
kV
VAY.Mag
VCY.Mag
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100 ms
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600 ms
700 ms
800 ms

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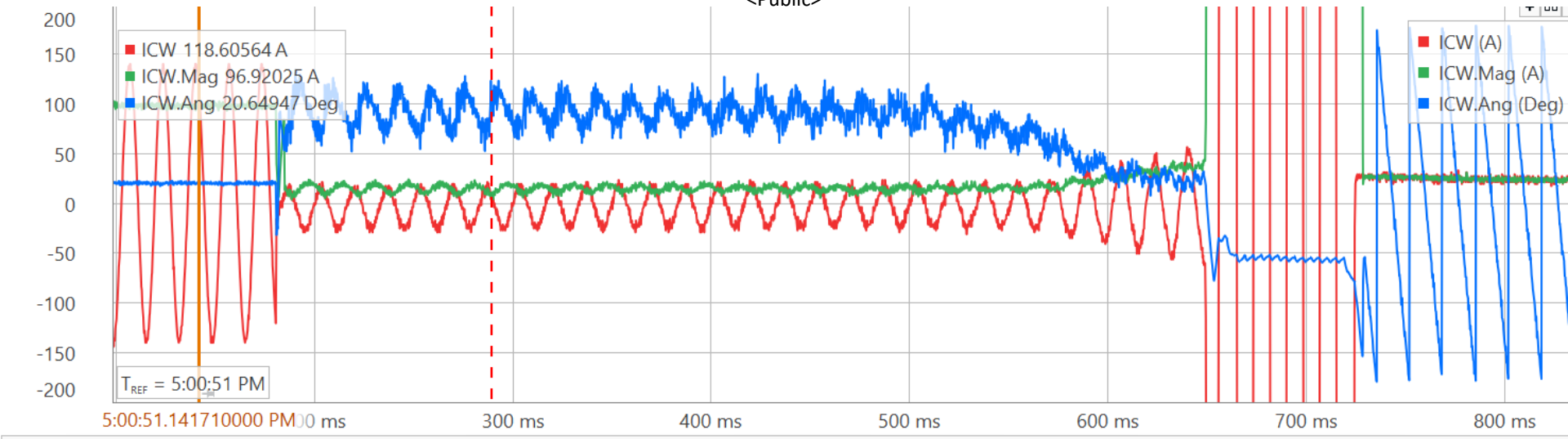

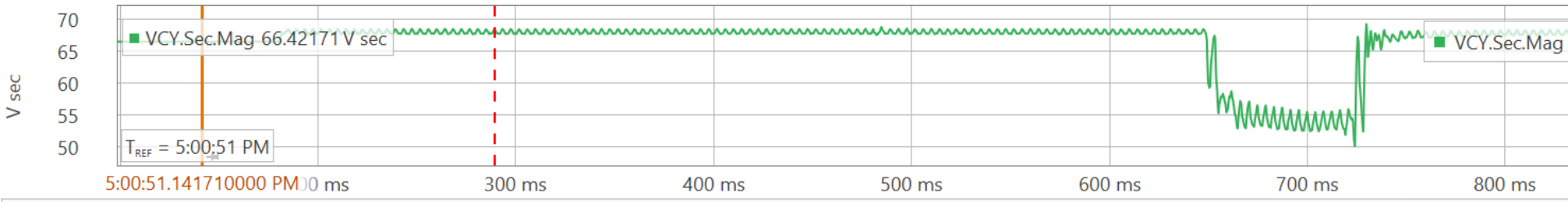

Orange Cursor Time

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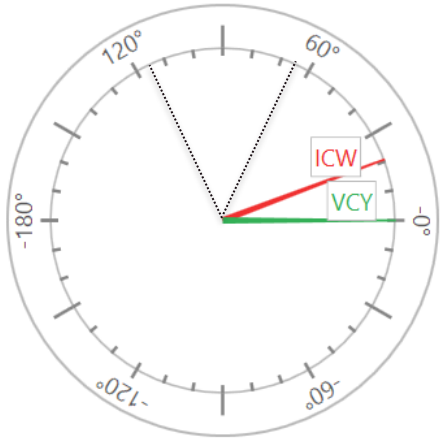
Phasor Calculations

Color	Name	Mag	Angle
	ICW.Phasor	96.92025 A	20.65°
	VCY.Phasor	132.84341 kV	0°

Chart Options

Cursor Selection

For the incremental ∠ check, pre-break ∠ must be <60° or <115°.



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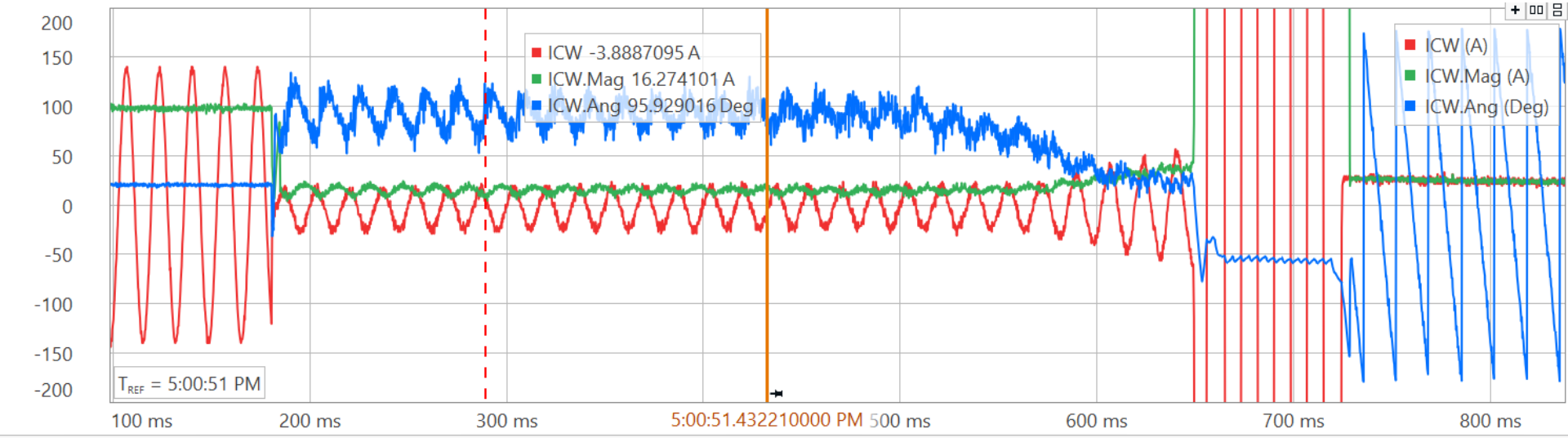

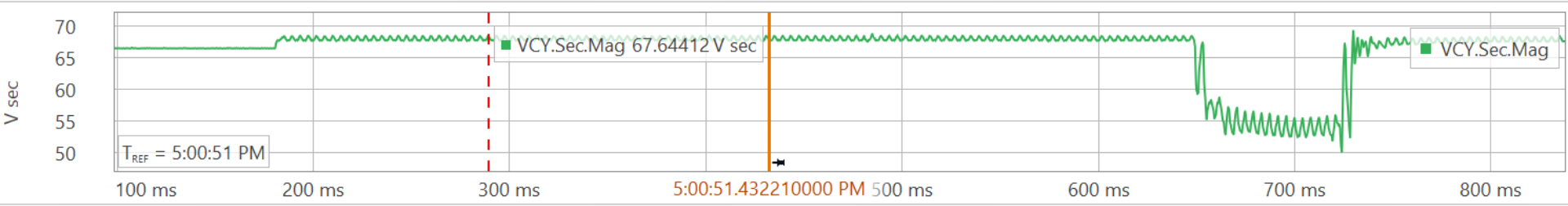

Orange Cursor Time

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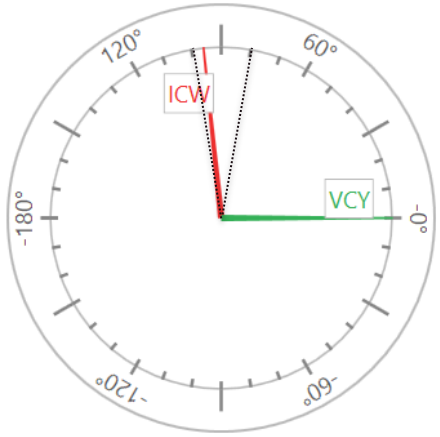
Phasor Calculations

Color	Name	Mag	Angle
	ICW.Phasor	16.274101 A	95.93°
	VCY.Phasor	135.28824 kV	0°

Chart Options

Cursor Selection

For the incremental ∠ check, post-break ∠ must be between 80° and 100°.



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BCD Trip Logic Requirements

- Phase Current Magnitude Check
  - After conductor breaks
- Phase Current Angle Check
- Phase Current Incremental Angle Check
  - Comparison of angles pre-break and post-break
- Distance Check

SEL 411L Broken Conductor Logic
(C-Phase Shown)

VCFIM
Cϕ Filtered Instantaneous Voltage Mag
(During BC, measured at 67.6 Volts)

LOP
67.5 V EBCD = Y
VCFIM > 70% of $VNOM_{L-N}$
Unbalance Fault Detected
→ BCENC *Cϕ BC Enabled*

$$\frac{\textbf{.067 A}}{1000}\ LICFIM \times \frac{\textbf{66.4 V}}{\textbf{67.5 V}}\ VNOM_{L-N}/VCFIM < 1.5 \times \textbf{BCCIM}\ \textbf{.0759 A}$$

→ BCICMS *Cϕ Current Mag Supv*

BCIVCAP
Cϕ Voltage and Current ∠ Difference 300mS before Present Processing Interval (pre-fault)
20°

BCIVCA
Cϕ Voltage and Current ∠ Difference at Present Processing Interval
90°
115° < BCIVCAP < 65°
80° < BCIVCA < 100°
LICFIM > 0.035 A (sec) **.067 A**
→ BCICAS *Cϕ Current ∠ Supv*

LICFIM
Cϕ Filtered Instantaneous Current Mag
(During BC, measured at .0667 Amps)

BCICIAS *Cϕ Incremental ∠ Supv*

0.86 pu

$$LICFIM \times \frac{1}{\textbf{BCCIM}}\ \textbf{.0759 A} \times \frac{\textbf{66.4 V}}{VNOM_{L-N}/VCFIM}\ \textbf{67.5 V} < \textbf{BCZ1R}\ \textbf{0.9 pu}$$

BCZ1C Cϕ Broken Conductor in Zone I

$$LICFIM \times \frac{1}{\textbf{BCCIM}}\ \textbf{.0759 A} \times \frac{\textbf{66.4 V}}{VNOM_{L-N}/VCFIM}\ \textbf{67.5 V} < \textbf{BCZ2R}\ \textbf{1.2 pu}$$

BCZ2C Cϕ Broken Conductor in Zone II

0.86 pu

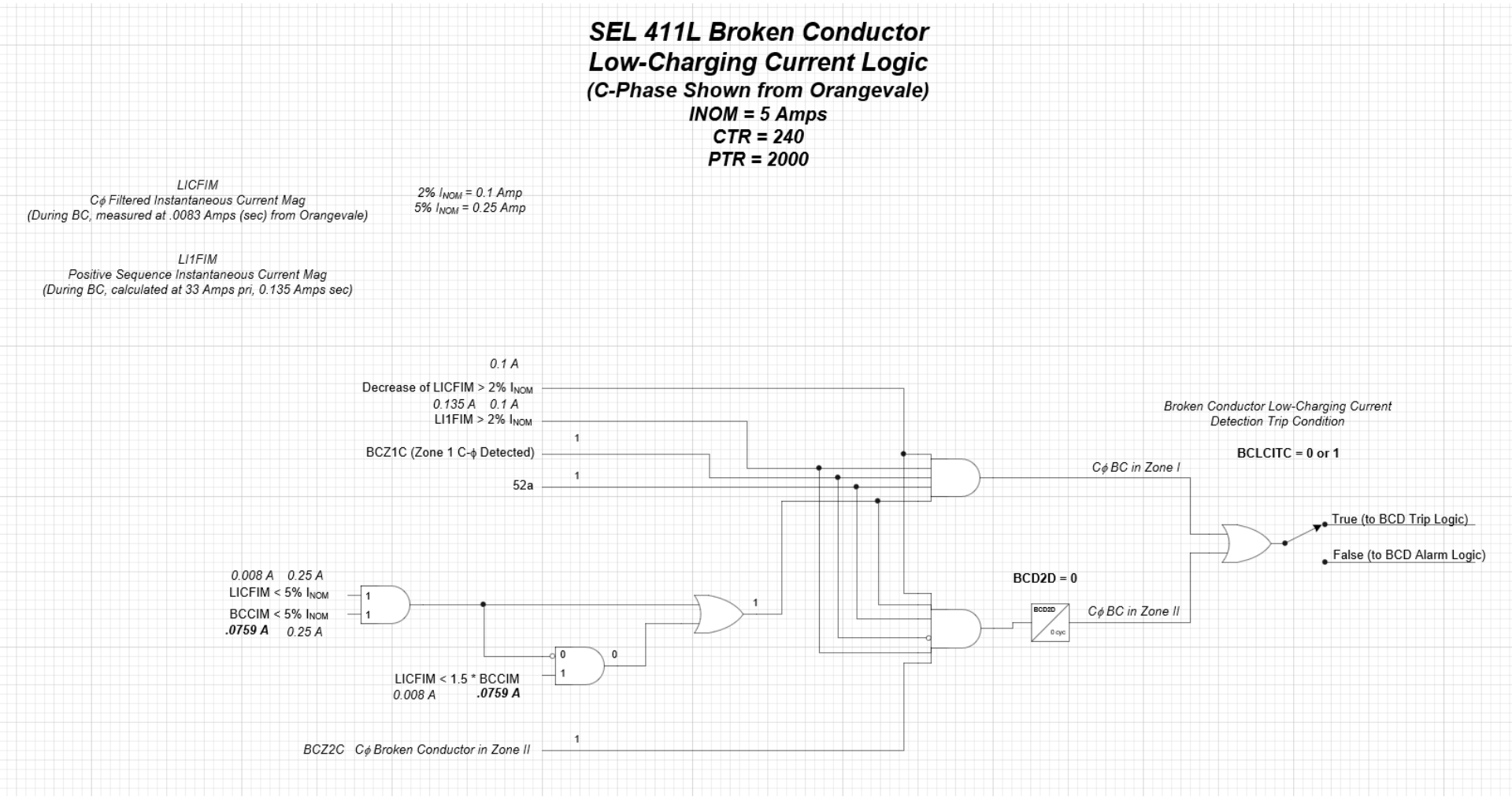
BCD2D = 0

Low-Charging Current Logic

BCIAMS
BCIAAS
BCIBMS
BCIBAS
→ BCIDETA
→ BCIDETB
→ No other phase has a detected break

BCDTC *Torque Control (set to BCZIC)*
→ BCDETC → TR → OUT101

Low Charging Current Logic



Testing the BCD Logic

- Don’t yet know how to create a BCD COMTRADE test file in OneLiner:
  - Can create a series fault:
    - Set load current to mimic charging current with a pf = 0;
    - Drops out the moment the series fault is applied.
  - Test Universe/Relay SimTest may be able to create the files.
  - May be able to scale the ELV-ORV COMTRADE as all lines are relatively similar.

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411L Proposed Settings for BCD

- Use both zone I and zone II without any delay:
  - No planned terminal is in-and-out; zone II overreaching is not an issue.
  - As both terminal relays trip independently, set DTT to trip the remote end for BCD trip determination
    - Uses 87L communication bits (e.g., 87T1P1/87R01P1)
- Do not use low-charging current logic:
  - Insecure method of close-in broken conductor detection;
  - DTT allows for zone II cross-tripping
- Send reclosing block signal to 79BF recloser

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Trip Logic

TR Trip Equation (SELogic)

BCDETA OR BCDETB OR BCDETC OR 87R01P1 OR 87R02P1 ...

Broken Conductor Detection

BCLL Line Length for Broken Conductor Detection

21.66 Range = 0.10 to 999.00

BCB1 Broken Conductor Detection Positive-Sequence Line Susceptance (mS,sec or FM - Field Measurements)

FM Range = 1.443 to 250.000, FM

BCCIM Broken Conductor Detection Average Phase Charging Current Magnitude Corresponding to Line Length (A,sec)

0.0759 Range = 0.0500 to 43.3000

BCZ1R Broken Conductor Detection Zone 1 Reach (p.u.)

0.90 Range = 0.10 to 1.50, OFF

BCZ2R Broken Conductor Detection Zone 2 Reach (p.u.)

1.20 Range = 0.10 to 1.50, OFF

BCZ2D Broken Conductor Detection Zone 2 Pickup Delay (cyc)

0 Range = 0 to 600, OFF

BCDTC Broken Conductor Detection Torque Control (SELogic)

1 ...

BCLCITC Broken Conductor Detection with Low Charging Current Trip Condition (SELogic)

0 ...

BCALRTC Broken Conductor Detection Alarm Torque Control (SELogic)

0 ...

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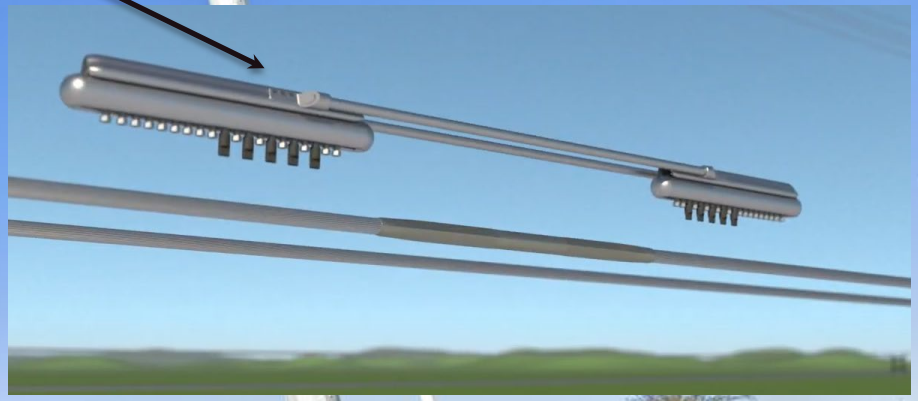
Compression sleeves have been reinforced with ClampStar bracing



Questions?

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