American Electric Power's Experience with Protection System Misoperations and Improvements

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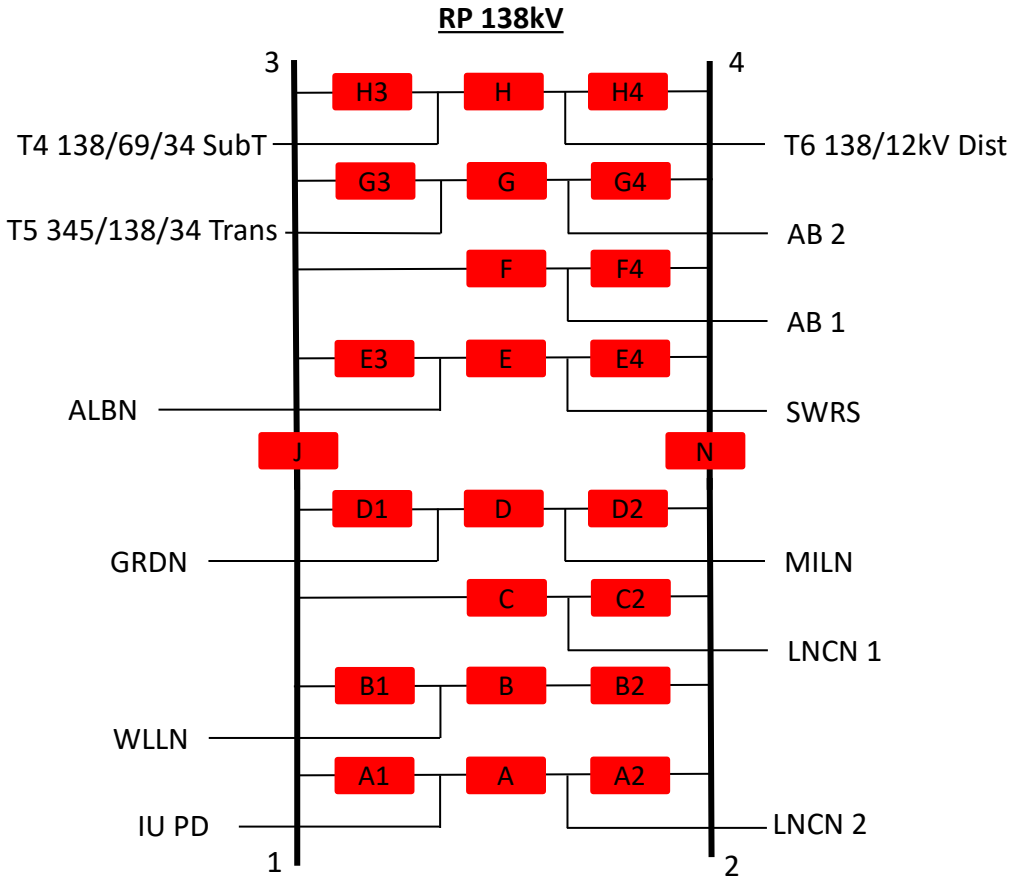
AEP Misop Event of 1/26/2022

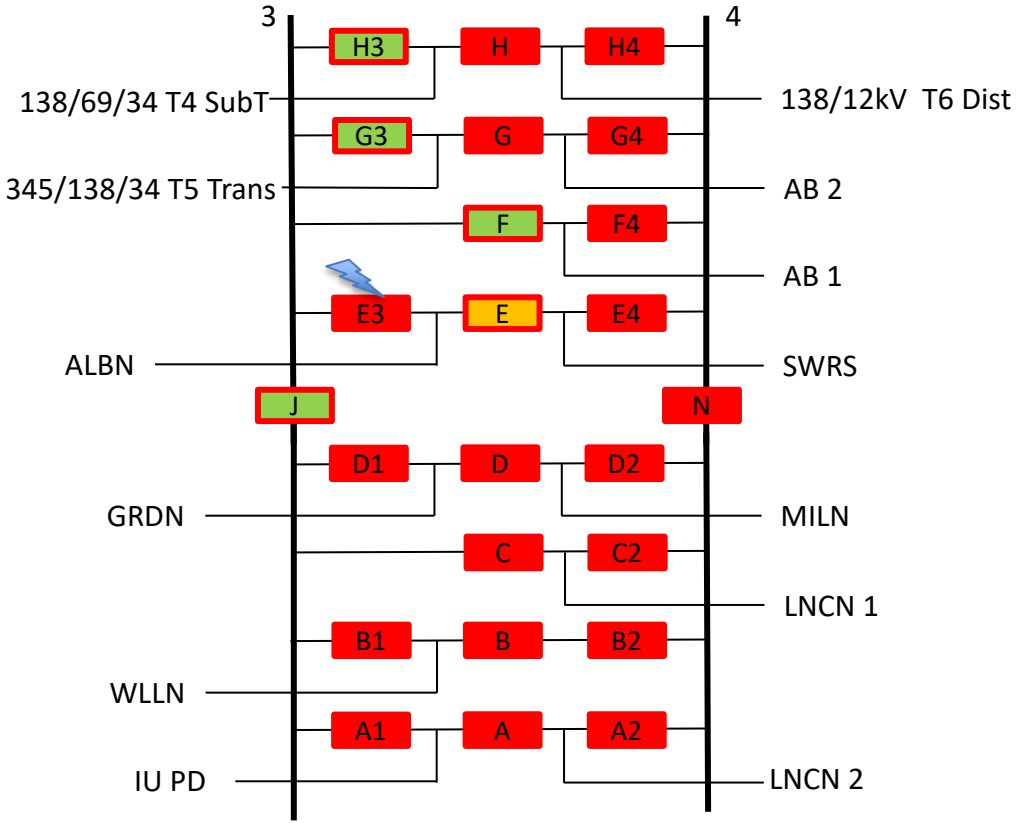
- 138kV CB – E3 Internal Fault
  - Multiple stages to this event, but there was only a single permanent fault. CG fault inside CB-E3.
  - During Stage 2 of the event, 2 – 138kV Circuits and 345/138/34.5 kV T5 lowside lead differential misoperate.

Pre-fault Configuration



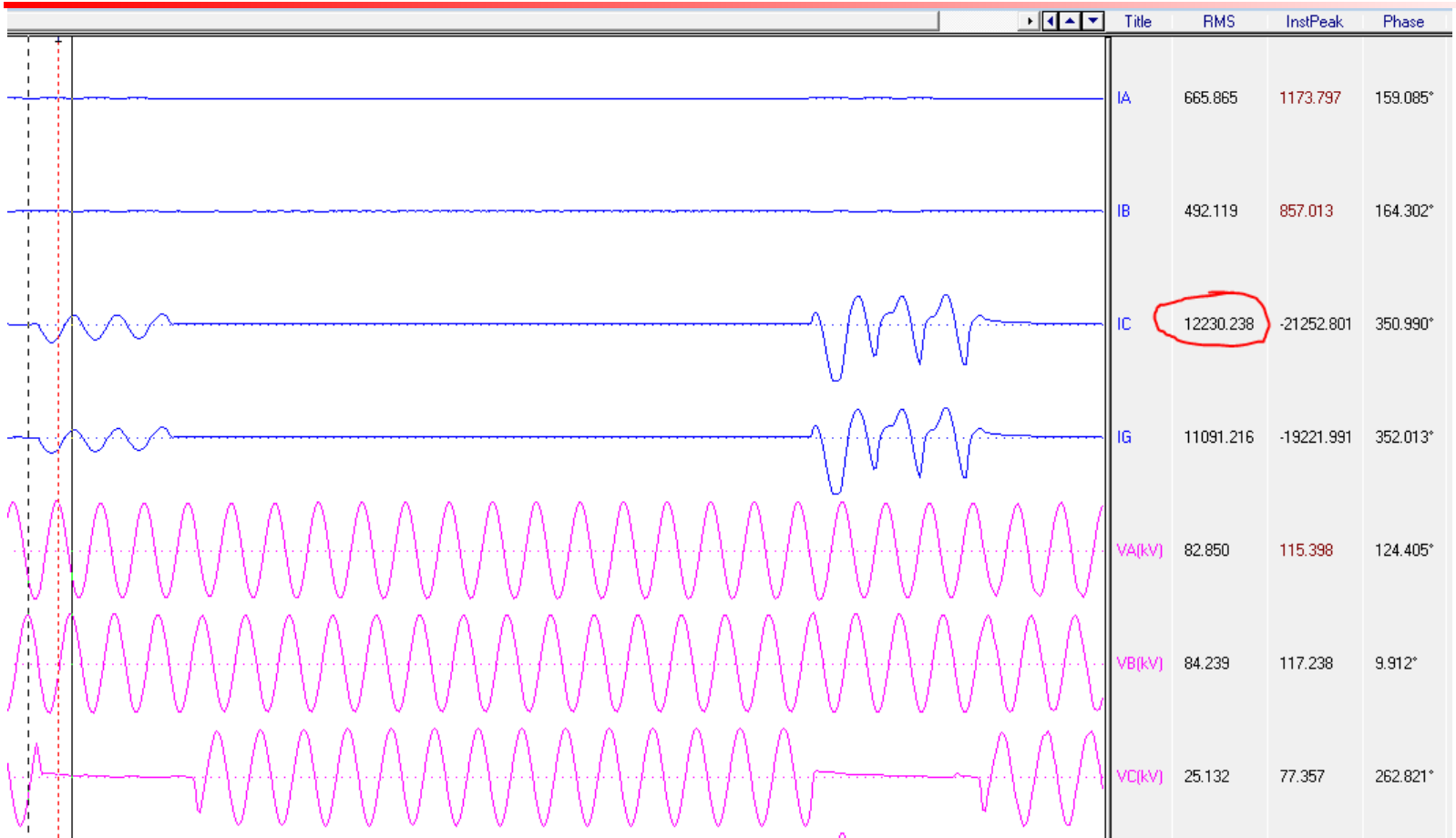
- 138kV RP Station
- System Normal
- CB-E3 is the fault location
- 5 – 345kV circuits on highside of T5
- 10 – 138kV circuits
- 4 – 138kV Bus zones
- Transformers
  - Trans = Transmission Auto
  - Dist = Distrubution 2-Winding
  - SubT = Sub-Tranmission Auto

Fault Stage 1 – Initial Operation



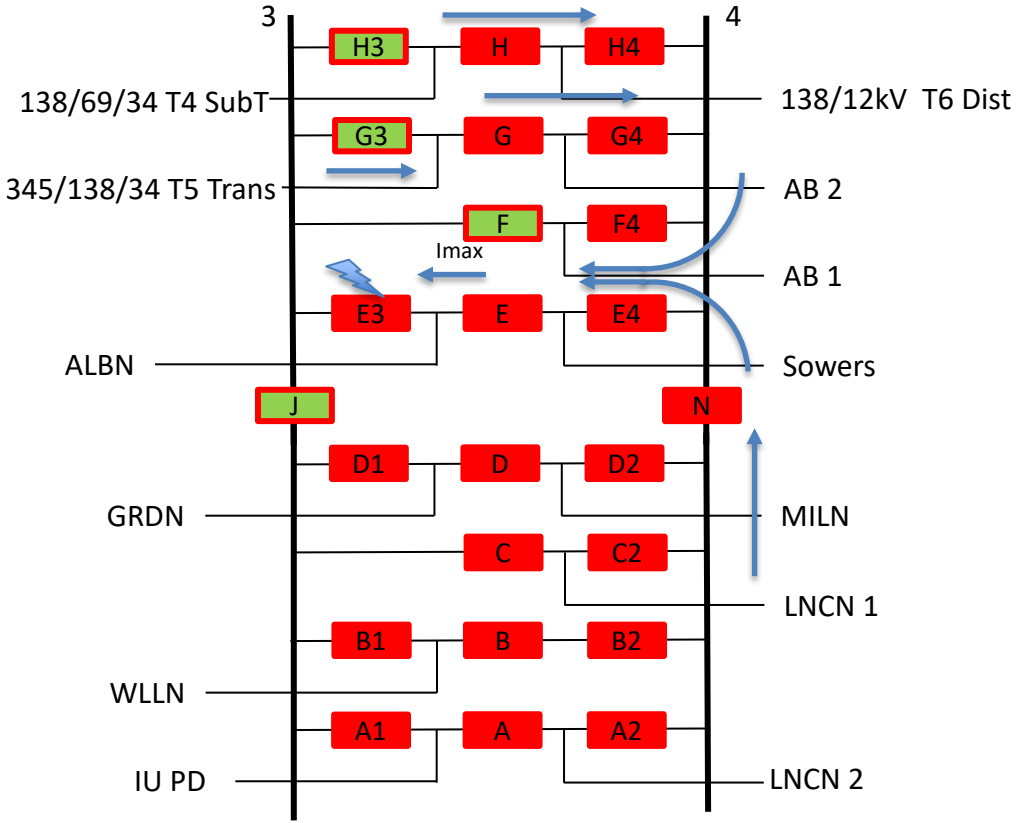
- Internal CB-E3 fault
  - Fault is located between ALBN Line zone and 138kV Bus #3.
  - Both zones operate correctly, with CB's H3, G3, F, and J tripping and locking out from the 87 Bus protection.
  - CB-E trips from line protection zone 1 and is set to reclose highspeed ~18 cycles after initial trip.
  - CB-E sees ~12 kA fault current

Fault Stage 1 – Initial Operation CB-E (SEL-351S 79/551E)



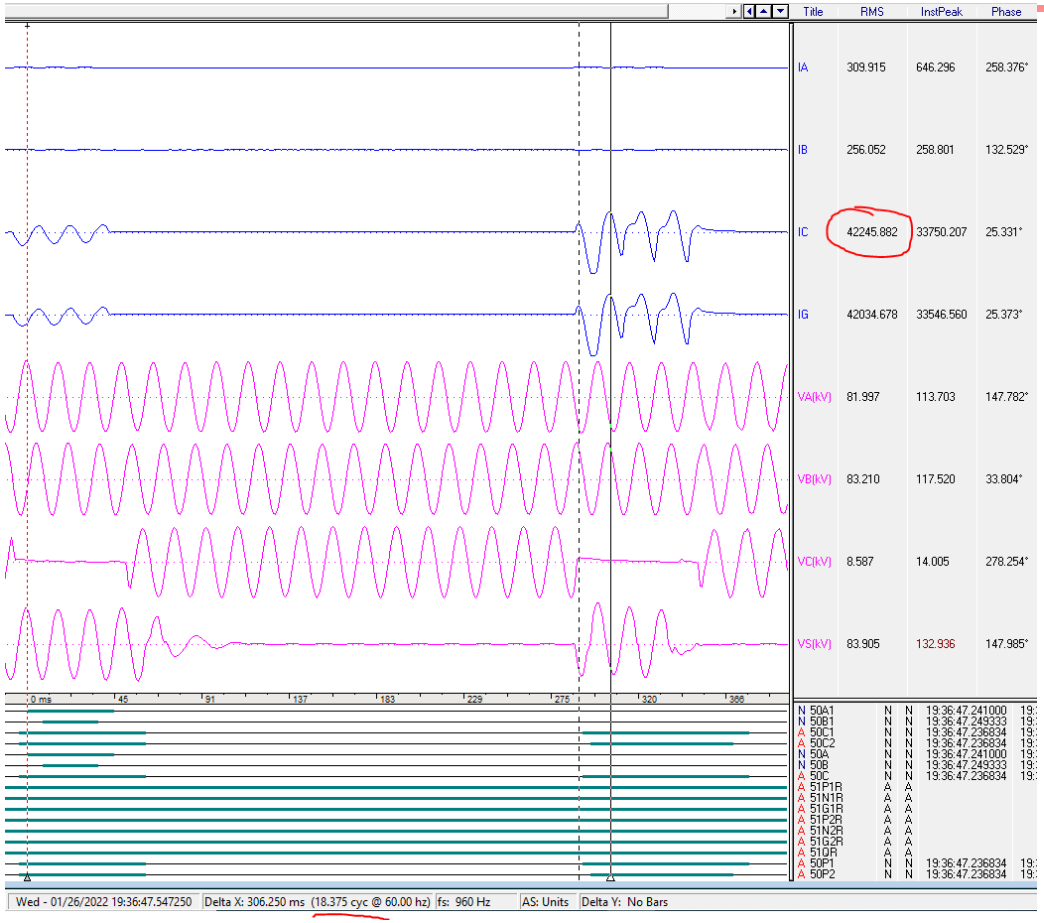
Title	RMS	InstPeak	Phase
IA	665.865	1173.797	159.085°
IB	492.119	857.013	164.302°
IC	12230.238	-21252.801	350.990°
IG	11091.216	-19221.991	352.013°
VA(kV)	82.850	115.398	124.405°
VB(kV)	84.239	117.238	9.912°
VC(kV)	25.132	77.357	262.821°

Fault Stage 2- CB-E Reclose



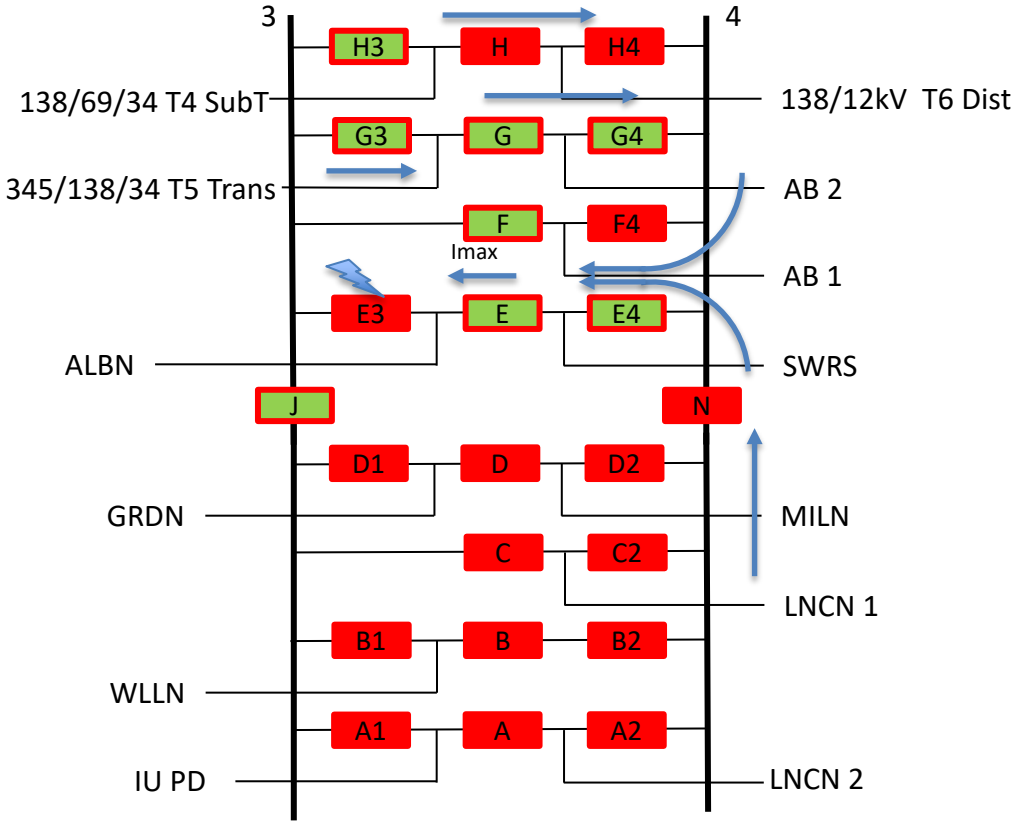
- CG fault is permanent
  - CB-E recloses back into the permanent fault.
  - Imax = 42 kA with a large contribution from T5
- Notice the new path of fault current due to 138kV Bus #3 being locked out.

Fault Stage 2 – CB-E Reclose (SEL-351S 79/551E)



- ~18cyc between cursors verifying CB-E HS reclose time.
- IC RMS magnitude much larger then Stage 1.

Fault Stage 2- CB-E Reclose & Misoperation

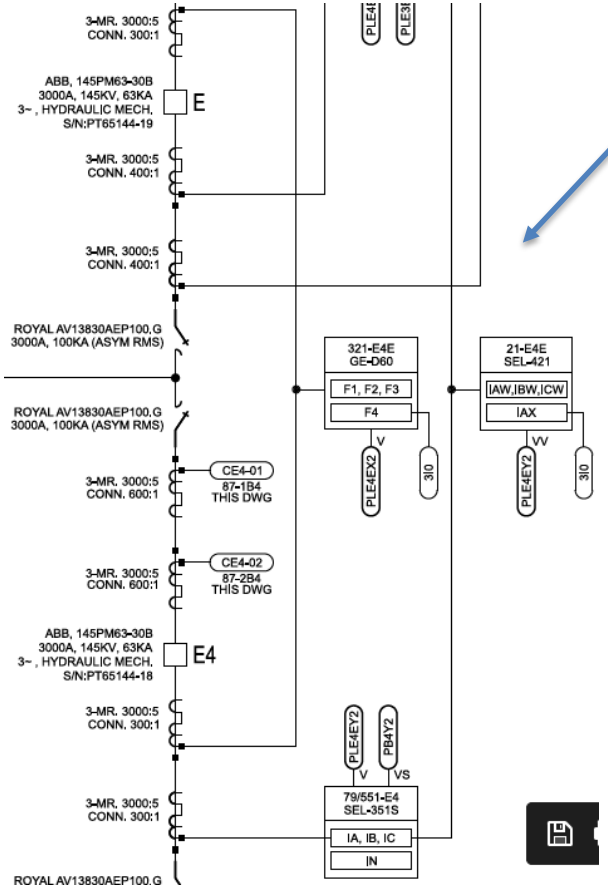


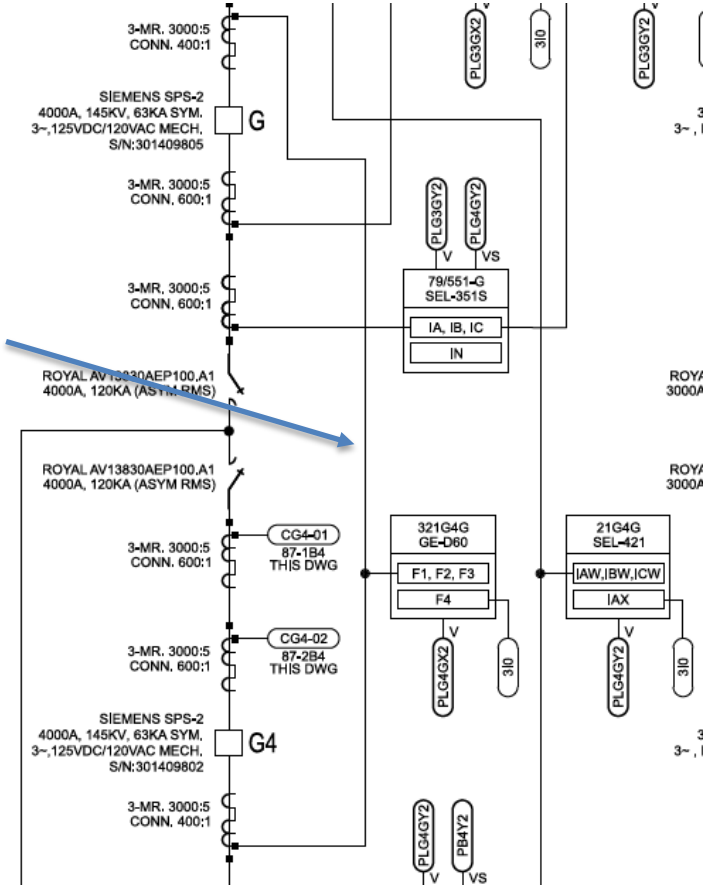
- CG fault is permanent (same phase as slide 6).
  - CB-E recloses back into the permanent fault.
  - Imax = 42 kA with a large contribution from T5
- CB's E, E4, G, and G4 misoperate operate for a close-in 1LG fault.
- T5 trips and locks out due to lowside lead differential L90 misoperation.

Misoperated 138kV Line Protection

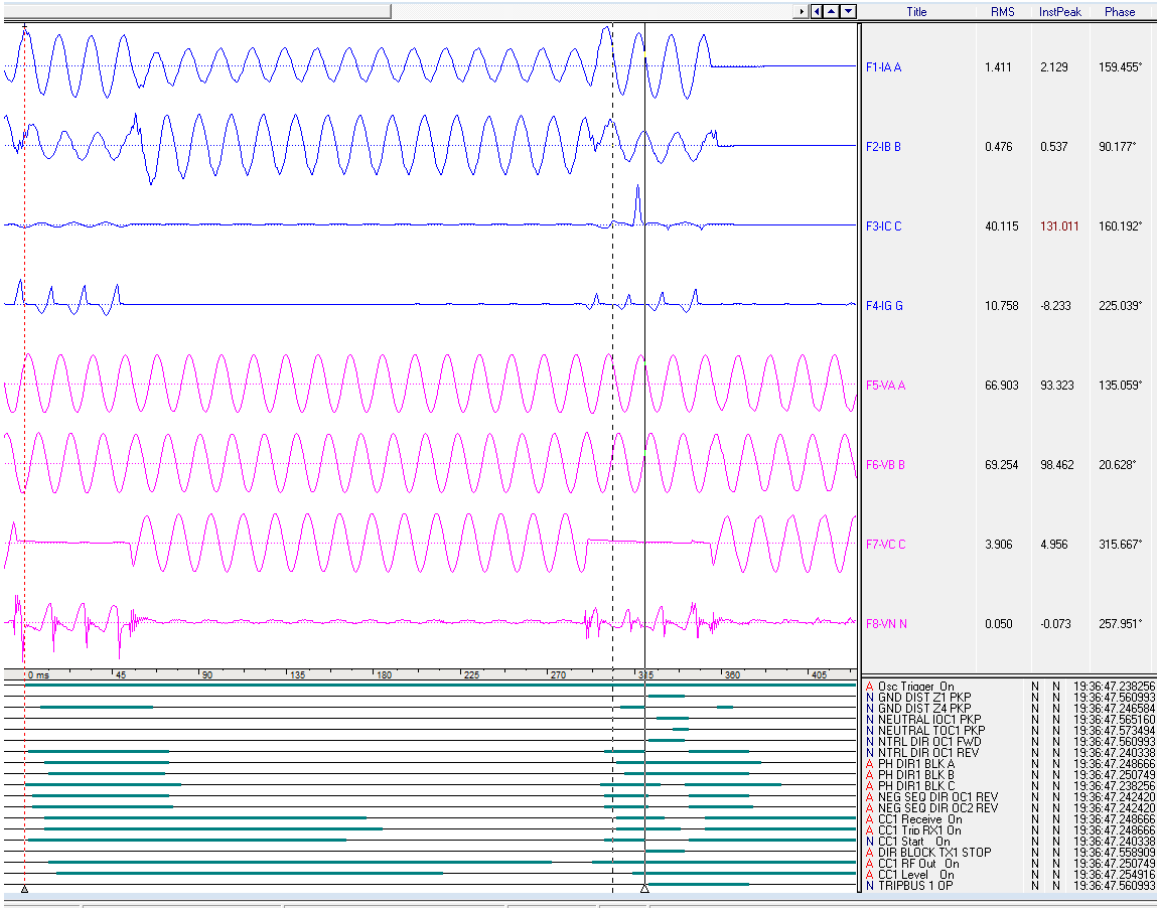
SWRS Line
321-E4E DCB
21-E4E SD

AB 2 Line
321-E4E DCB
21-E4E SD





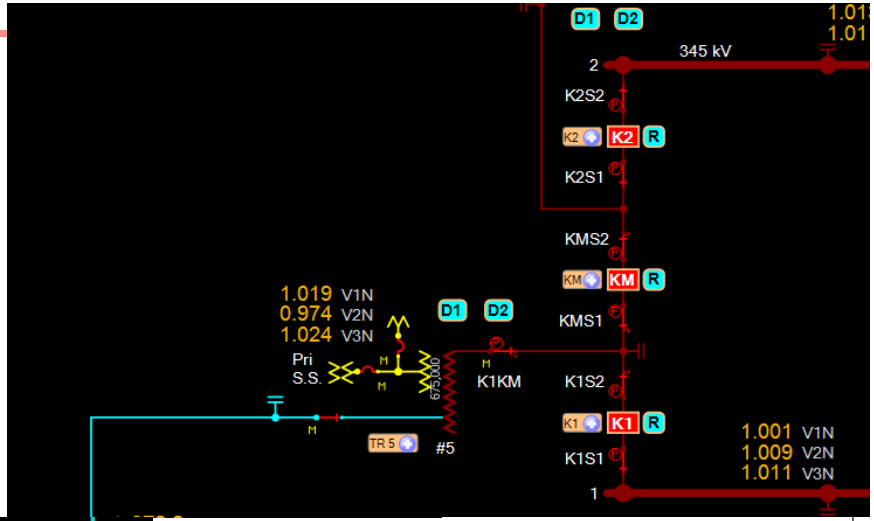
Misoperated 138kV Line Protection (GE-D60 321-E4E)

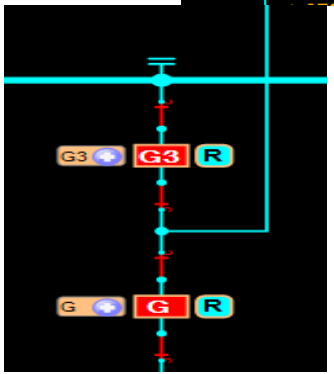


- 40 * 300 = 12kA

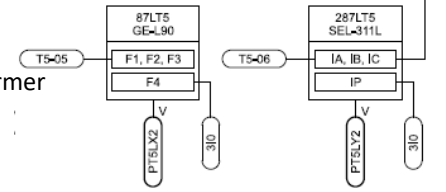
RP T5 Layout

345 Yard-to-138 yard distance is approximately 0.26 miles (~1,400ft.).

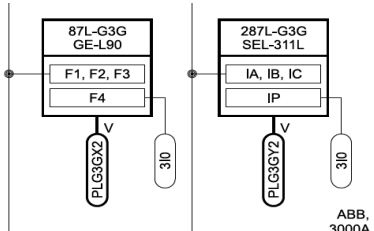




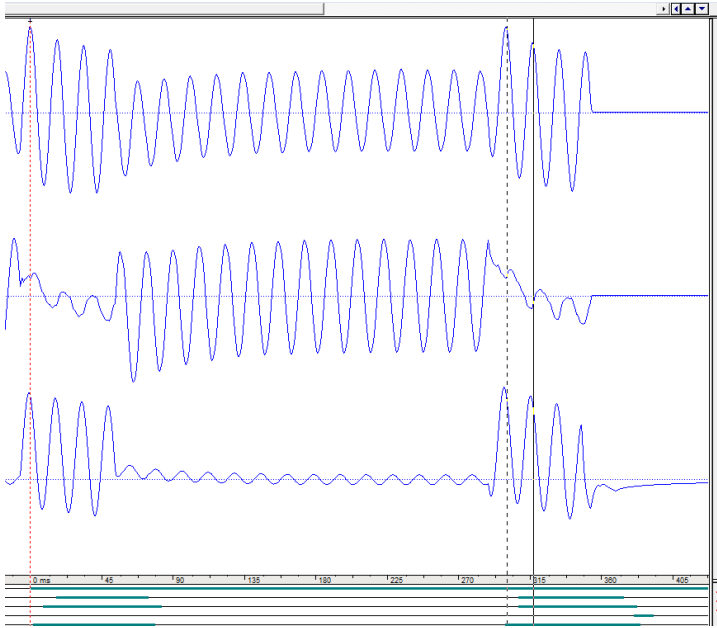
138kV Lowside Transformer Connected Relays →



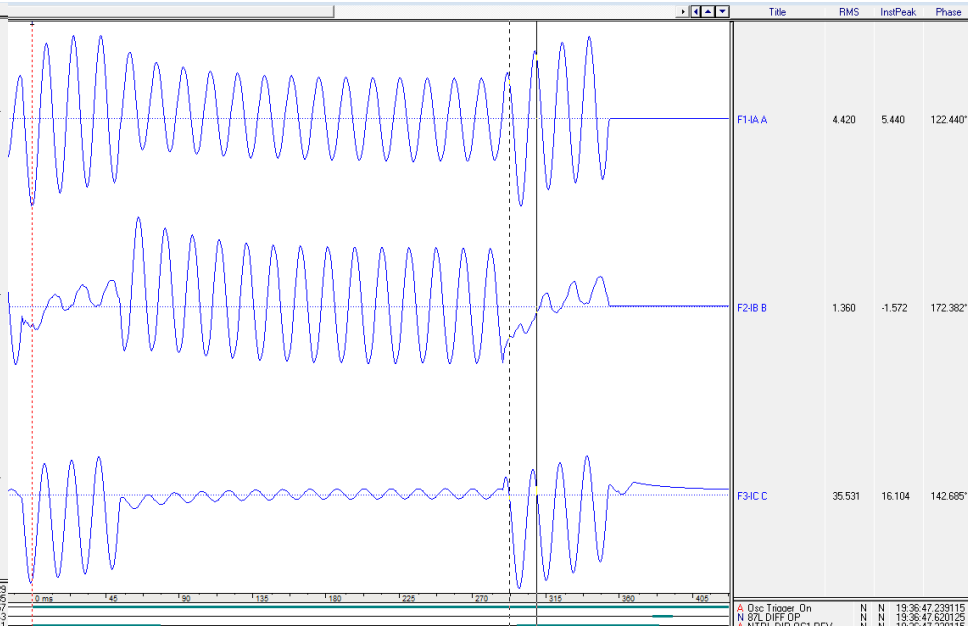
138kV CB's G3G Connected Relays →



RP T5 Lowside Lead Differential



L90 – 87T5 (Lowside T5 CT)



L90 – 87L-G3G (138kV Yard BCTs)

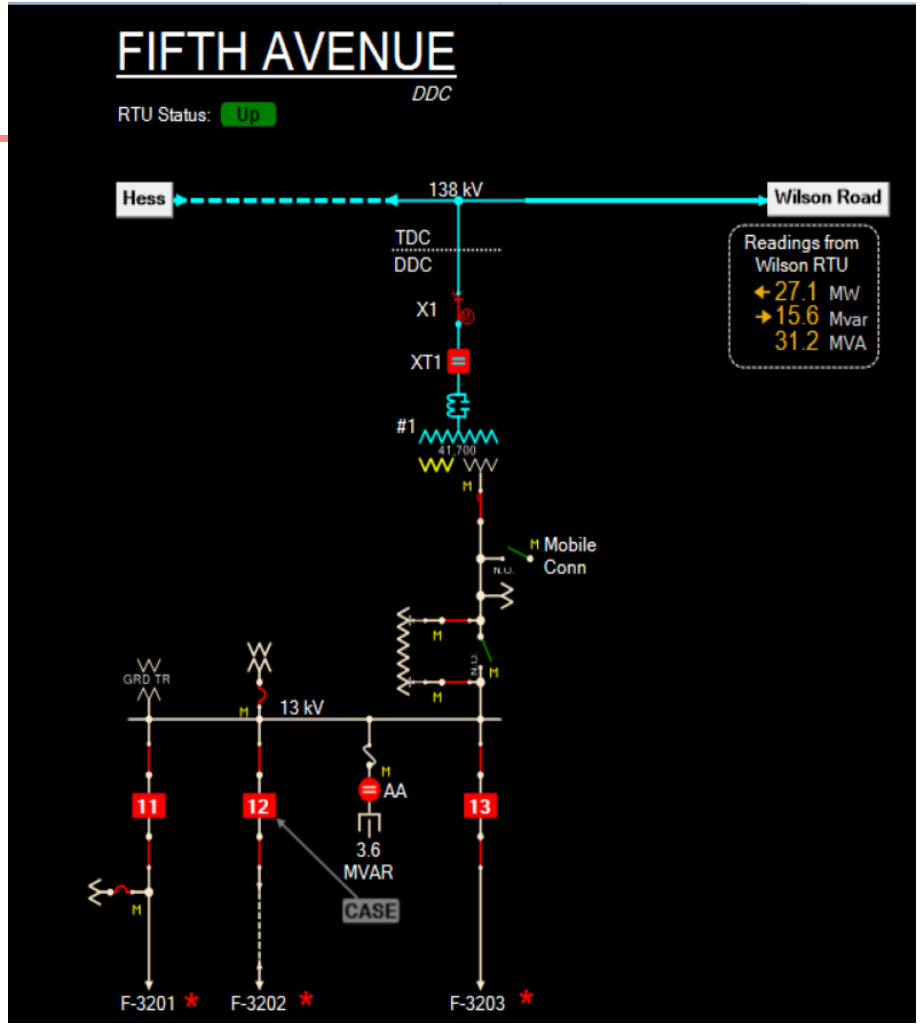
Corrective Action Plans

- 138kV line Misoperations
  - CB-E high speed reclosing will be evaluated with AEP Operations group and the CT connected ratio will be evaluated and connected at the highest ratio possible to help minimize any future CT saturation.
- 345/138/34.5kV T5 lowside lead differential Misoperation
  - L90 relay settings will be evaluated (break point, differential slopes, and differential pickup) to better handle any future CT saturation that may occur. The connected CTs are already at full tap (600/1) so the CT ratios cannot be raised any higher.

Minimize risk of CT Saturation

- Use highest CTR (accounting for sensitivity) for line protection.
- Use separate current inputs into the relays to monitor breaker currents as opposed to external summation if possible.
- Substations are unique (X/R, CT cable lengths etc.) however using high CTR connections at high fault current stations is best practice to avoid high thru-current CT saturation.
- Fault currents have increased at this station ~30% over the past 7 years and one of these lines had not been re-evaluated since 2015 when it was originally chosen at 400/1 instead of the max 600/1 CT ratio

AEP Fifth Avenue Mobile Misop



Background

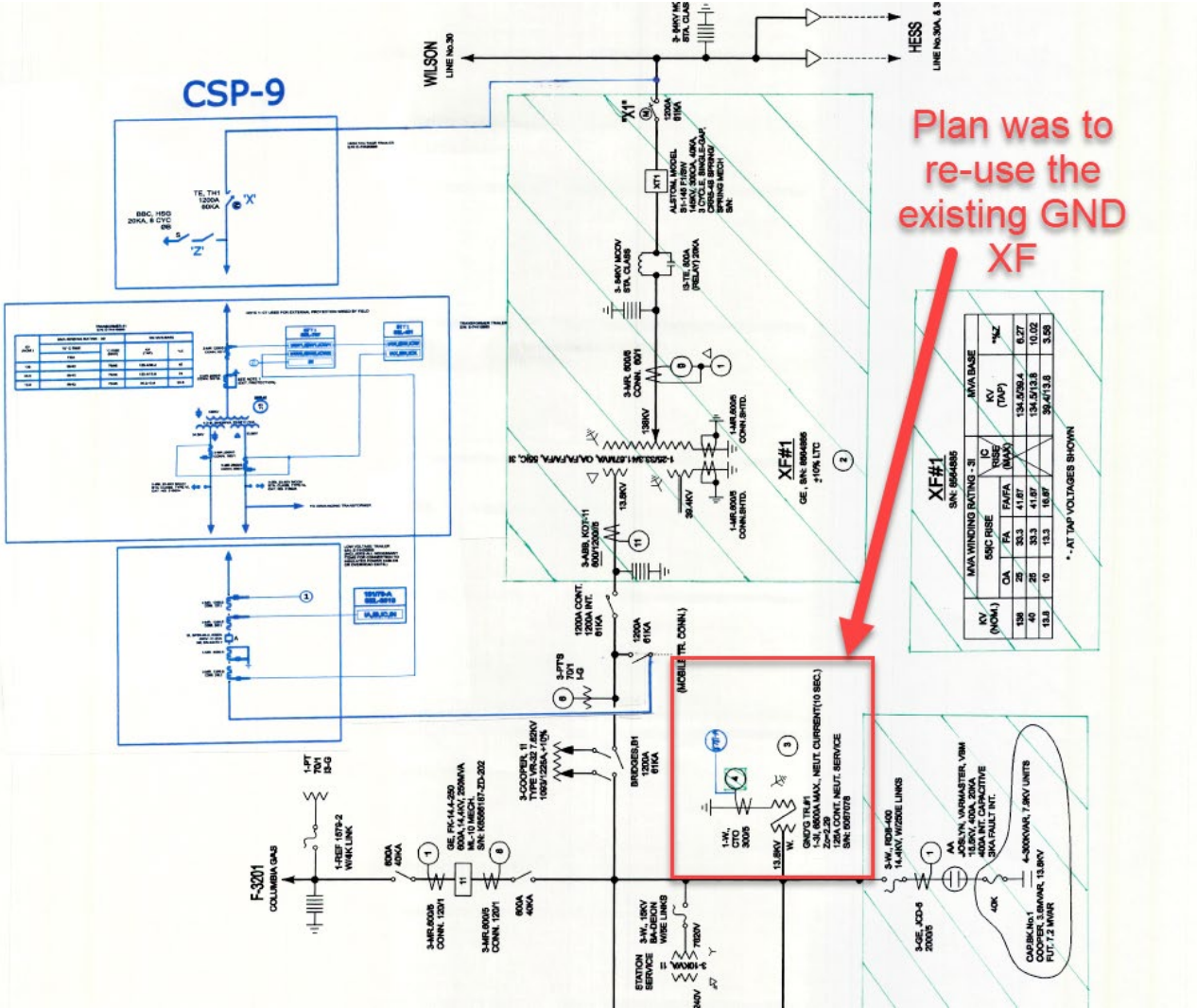
- TFS needed to do XF maintenance, so a mobile unit was required
- Not your typical distribution XF (it is a wye-grounded high side / delta low side)
- Since delta low side, a grounding XF is required
- To keep things in phase with the existing XF, mobile CSP-9 was selected since it is an auto XF with the same vectors
- Mobile CSP-9 is very modern and is outfitted with all new IED relays

What Happened?

- Mobile had been commissioned and was in service for a few days, but then tripped out via its SEL-787 XF diff for a 1LG feeder fault (out of zone fault)
- During commissioning, no differential current was present on the SEL-787 while doing final load checks

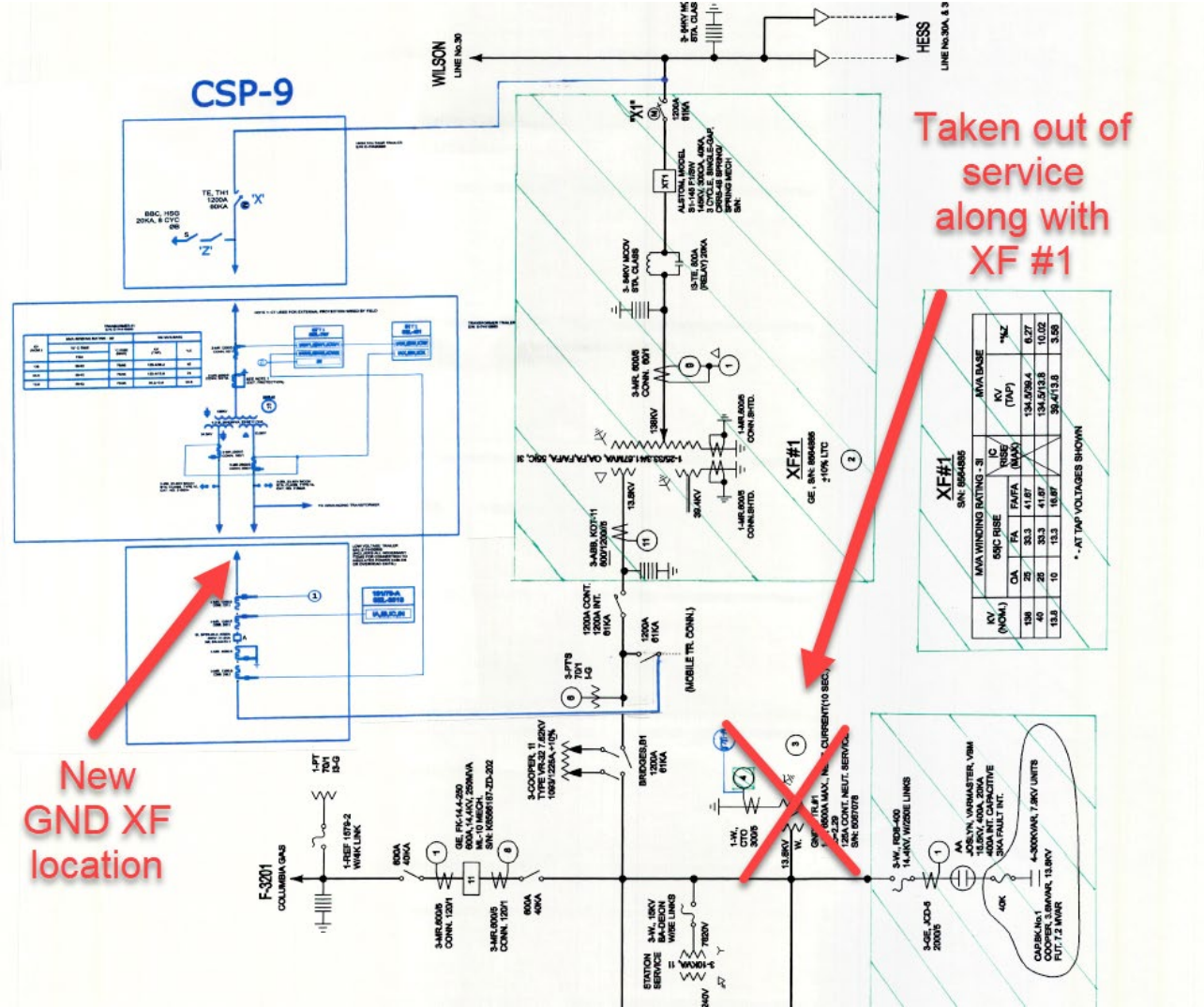
Result of the Trip

- The two non-faulted feeder circuits were tripped and locked out along with the feeder that actually had the fault on it
- Since mobile CSP-9 didn’t include a high side interrupting device (only ground switch/MOAB) the remote 138kV terminals were also tripped


CSP-9
WILSON
HESS
Plan was to re-use the existing GND XF
XF#1
XF#1
F-3201
COLUMBIA GAS
(MOBILE TR. CONN.)
STATION SERVICE
CAP.BK.No.1
COOPER, 5.8MVAR, 13.8KV
FUT. 7.2 MVAR

What Happened?

- During the mobile installation, the plan changed
- Existing GND XF was no longer used (taken out for maintenance along with the main XF) and the GND XF that rides along with CSP-9 was used
- The position of where the GND XF was connected had been modified (bus before, but now between XF and LS CB)


CSP-9
Taken out of service along with XF #1
New GND XF location
WILSON
HESS
XF#1
F-3201

SEL787 Trip & Fix

- The SEL-787 XF differential was set based on the original plan with the GND XF outside of the XF differential zone.
- Since the low side winding was delta, the SEL-787 relay doesn't filter out zero sequence current in its low side CT because no zero-sequence current can flow through a delta.
- The fix was very simple: Change the W2CTC setting from 0 to 12.
- This still maintains the same angle compensation, but the 12 setting also filters out the zero-sequence current.

The WxCTC settings are used to match the phase shifting of the current signals and to remove zero sequence. WxCTC = 0 or 12 provides zero phase shift. If WxCTC = 12 is used than this selection removes the zero sequence. Each increment of WxCTC represents a 30 degree phase shift. For ABC phase rotation each increment in phase shift is in the counter clockwise direction. Reference the SEL787 instruction manual for more details.

Lessons Learned

- Whenever a plan changes, all involved groups should reconvene to discuss the effects of the change. A change may seem small to one group but may be a big change to another group.
- Team members should use extra caution and be on alert when working with unique configurations and designs (transformer was not typical delta high side / wye-grounded low side).
- The placement of grounding transformers is very important since they act as a zero-sequence current sources. The protection zone that the grounding transformer is connected within should be examined with extra care to ensure that the grounding transformer is accommodated for properly.

Quiz

- Why didn’t the XF differential load check test catch these bad XF differential compensation settings during commissioning?

Questions?