A Voltage-Controlled Overcurrent based Adaptive Protection Scheme for Microgrids

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Background on DOE PV-MOD Project

Develop vendor-independent adaptive protection (AP) designs

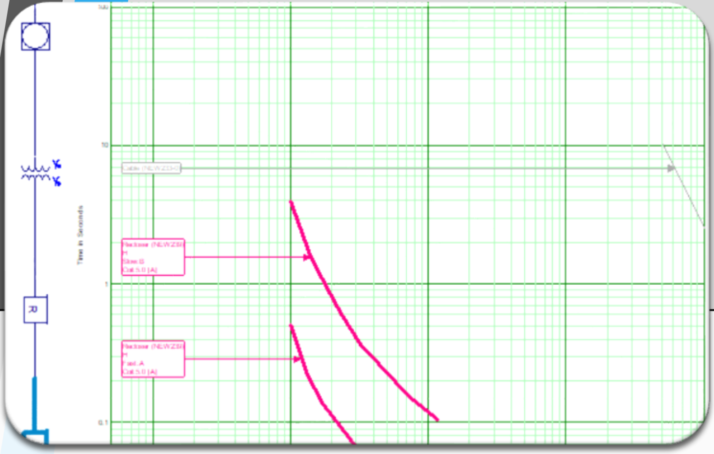
Demonstrate advanced application of the new models for automated assessment and design of adaptive distribution protection schemes

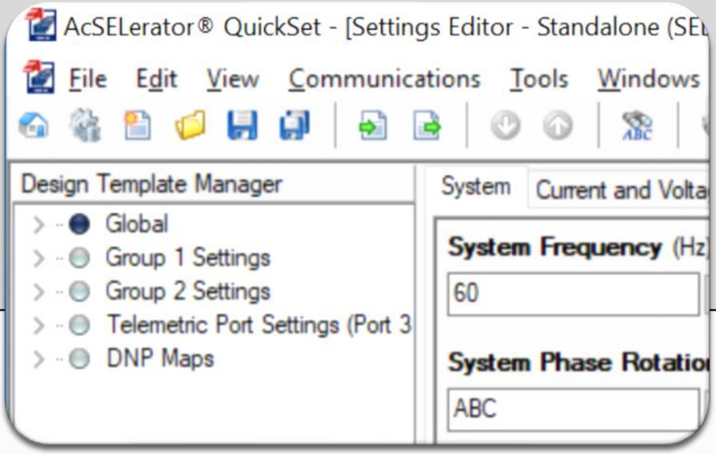
Demonstrate correct operation using simulations and lab-tests of site- and hardware-specific implementations

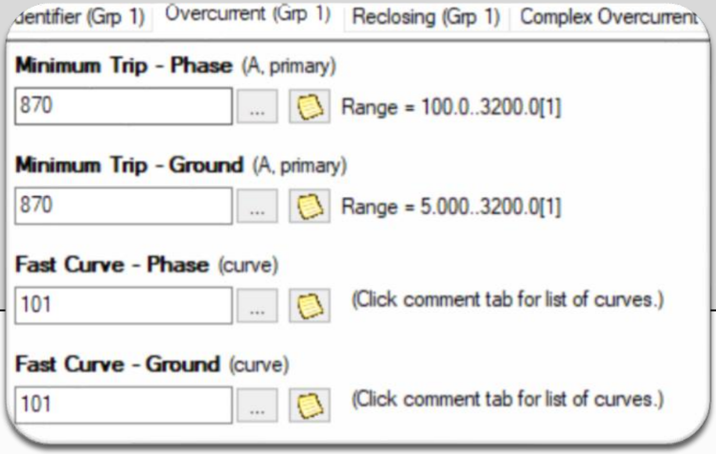
Deploy and test protection schemes on various types of networks

Adaptive Protection

Broad definition: Anything that changes how protection responds to faults







Block or release protection functions

Change settings group

Update relay settings

Triggers can be commands, time or measurements

Microgrid Protection Challenges

- Sensitivity and Safety
  - Low fault currents
    - Will overcurrent devices operate?
      - Set for grid connected operation
  - Slow tripping = Higher arc-flash levels
  - Is the microgrid effectively grounded?
  - Coordinate with IBR undervoltage protection

- Reliability
  - Is coordination possible with series protection devices?

Other Protection Considerations

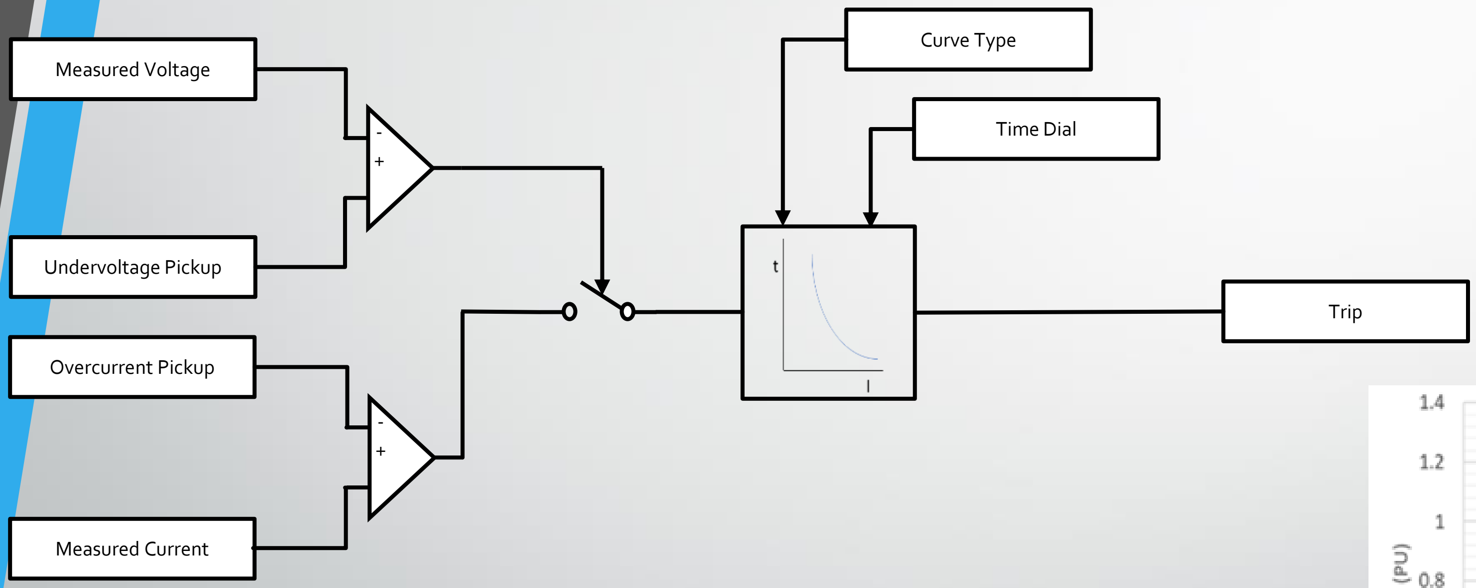
- If infrequently operated in islanded mode, reduced protection sensitivity may be an acceptable alternative to expensive protection upgrades
- Recloser fast curves may provide fast protection without major changes
- Undervoltage elements offer a simple method to clear faults
- Need to consider the impact of grounding transformer failure, if used, on protection scheme operation
- Need to understand the impact of synchronous condenser failure, if used, on protection scheme operation

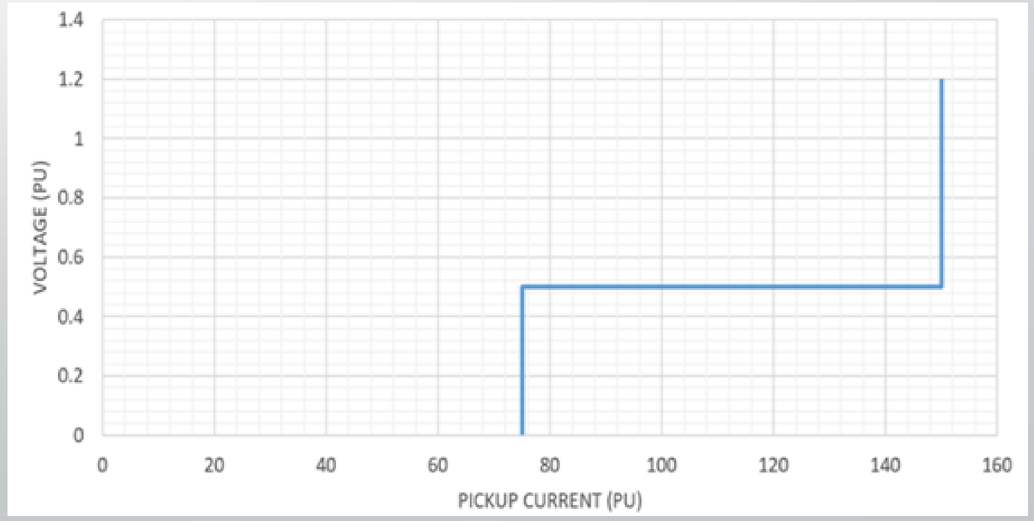
Microgrid Adaptive Protection Overview

- Centralized or decentralized design
- Easy to deploy
- Supplements existing protection design and logic
  - Trips for all credible faults within the microgrid
  - Does not trip incorrectly during soft or hard black starts
  - Does not trip during transformer inrush
  - Does not trip during block loading, motor-starting, or cold-load pickup

Voltage Controlled Overcurrent logic

- Requires 1 phase separated voltage stage and 1 phase separated current stage
- Can be easily implemented in many modern IEDs





Microgrid Adaptive Protection Overview

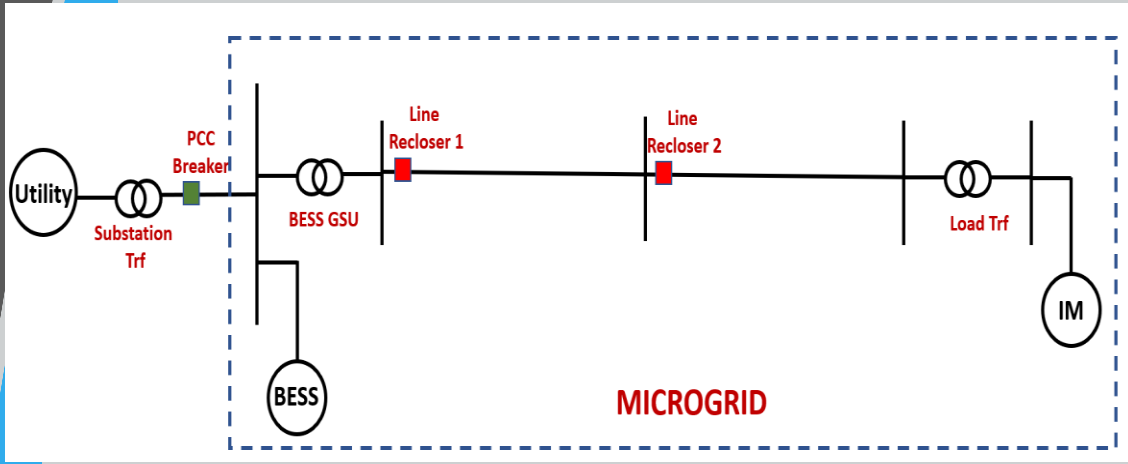
	Centralized Microgrid Adaptive Protection	De-centralized Microgrid Adaptive Protection
Islanded Mode	Voltage-Controlled Overcurrent 50/51C Example settings: • Undervoltage pickup 0.8pu • Inverse overcurrent pickup equal to 50% of the current in islanded mode	

Grid-Connected Mode	Conventional inverse time overcurrent	• Enable inverse time overcurrent used if the measured current exceeds a set threshold
		• Enable voltage-controlled overcurrent for large voltage sags and the current does not exceed a set threshold
		    ○ Threshold current = 120% of the maximum short circuit current in island-mode.
		    ○ If current is in excess of this value, then the microgrid must be grid-connected, so the voltage-controlled overcurrent element will be blocked.

Laboratory Tests

Scenarios Simulated

- Islanded Mode Faults
- Soft Start Faults
- Hard Start Faults
- Motor Start – Various Sizes
- Transformer Energization – Various Sizes

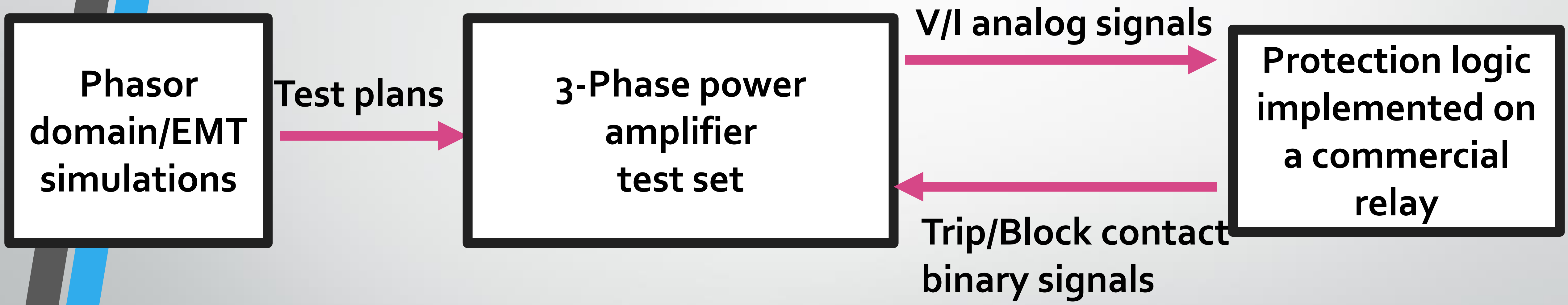


Equipment	Nameplate Specifications
BESS	3MVA, 400V, 0.95 pf
BESS GSU	3.75MVA, 12.47/0.4kV Dyno %Z = 7, X/R = 20
Overall Feeder section	Length=4 mi, R1 = 0.016 ohm/mi, X1 = 0.16 ohm/mi, R0 = 0.048 ohm/mi, X0 = 0.48 ohm/mi
Load Transformers	0.5MVA – 3 MVA in size, 12.47/0.4kV Dyno, %Z = 7, X/R = 20
Induction Motor	0.25-2.5 MW 0.4kV 0.82 pf

Microgrid Adaptive Protection Test Cases

- ABC, BC, BCG, AG, and AG with Rf = 10 Ohms Faults Simulated
  - Hard Start
  - Soft Start
  - Islanded Operation
- Motor Starting Condition
  - 500-2500kW induction motors, in steps of 500kW
- Transformer Energization
  - 500-2500kVA transformers, in steps of 1000kVA

Block Diagram for Test Bench Setup



Test Plan Document Example

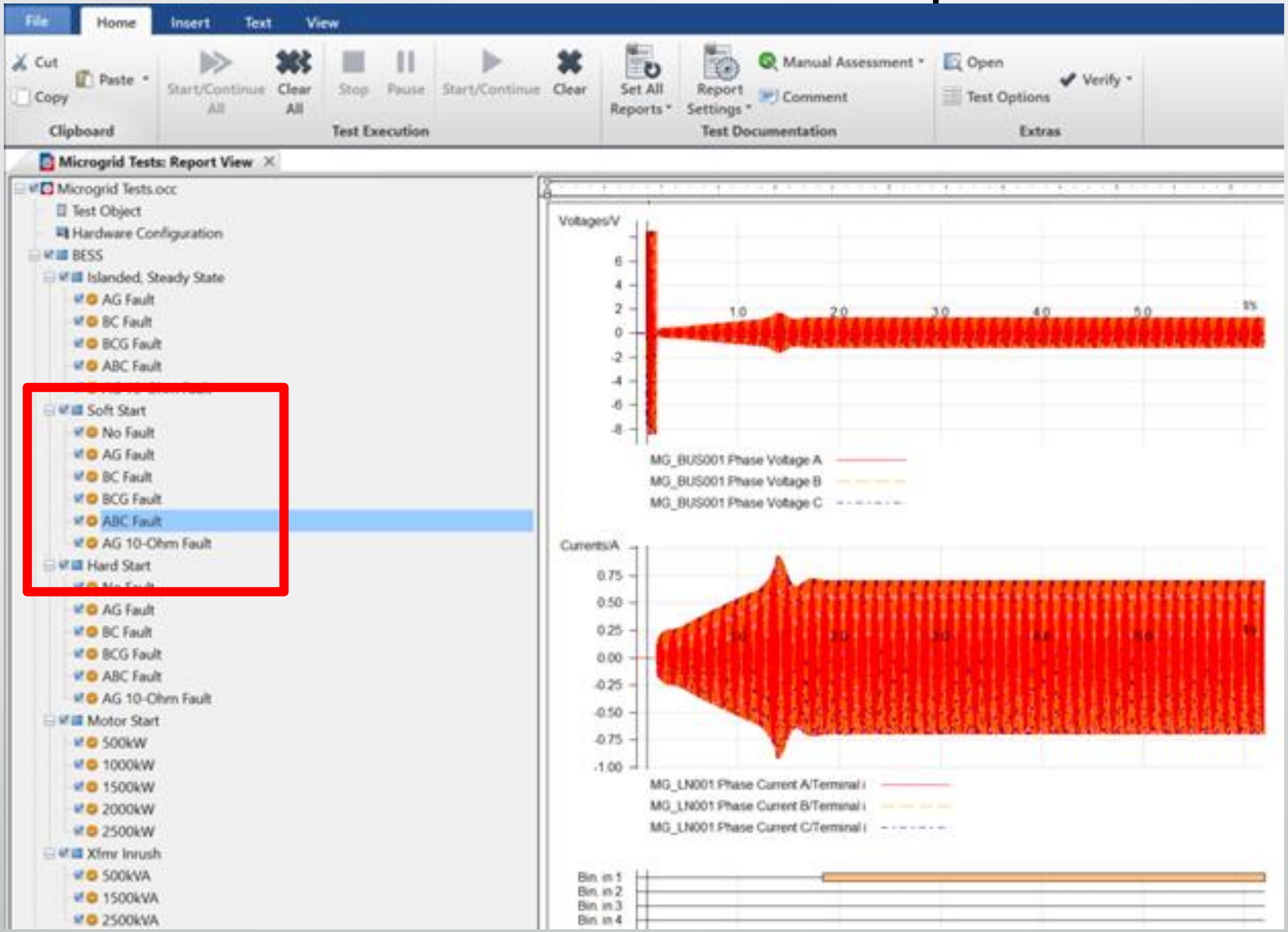
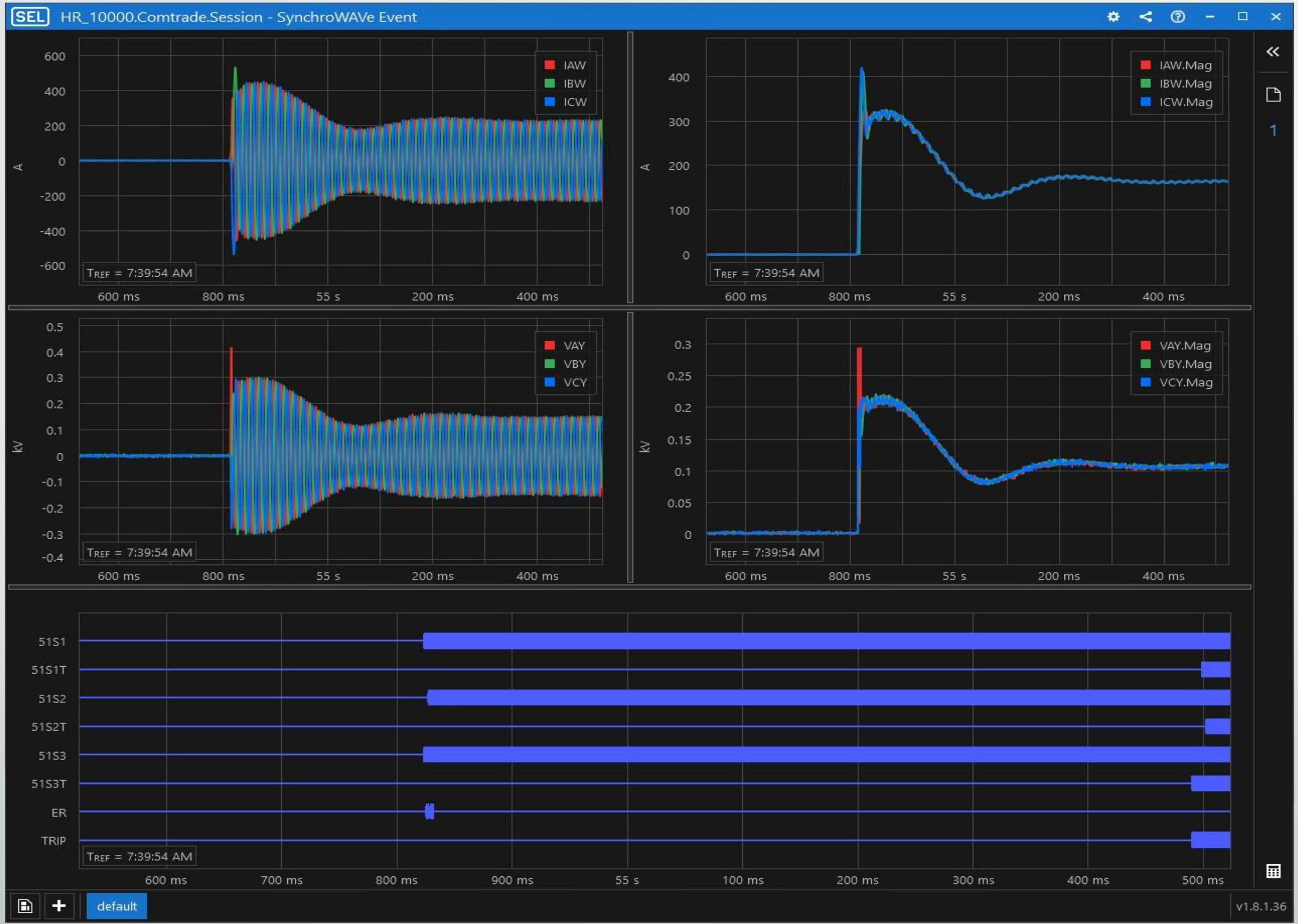


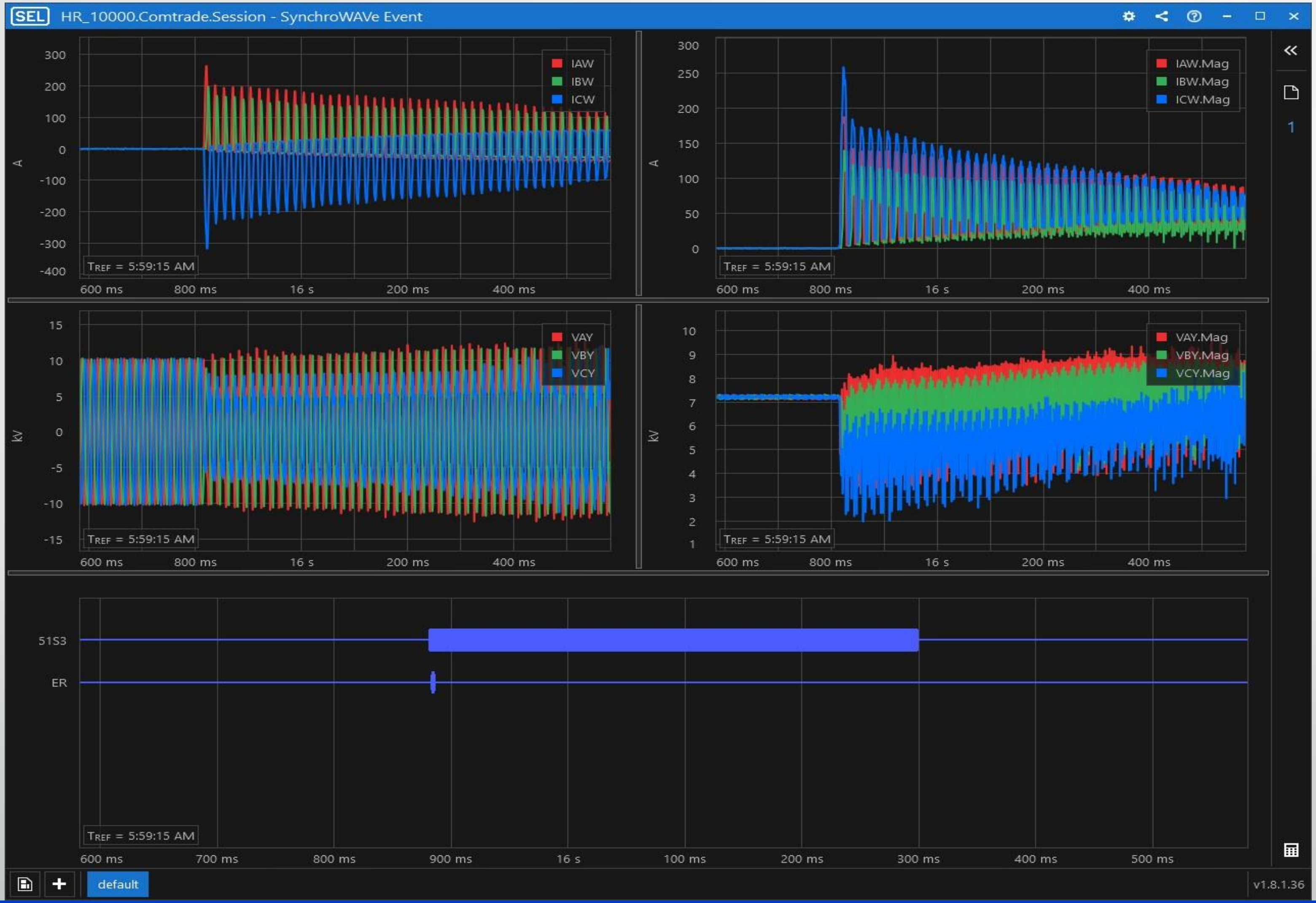
Fig: Snippet of a sample test plan document

Hard Start – ABC Fault



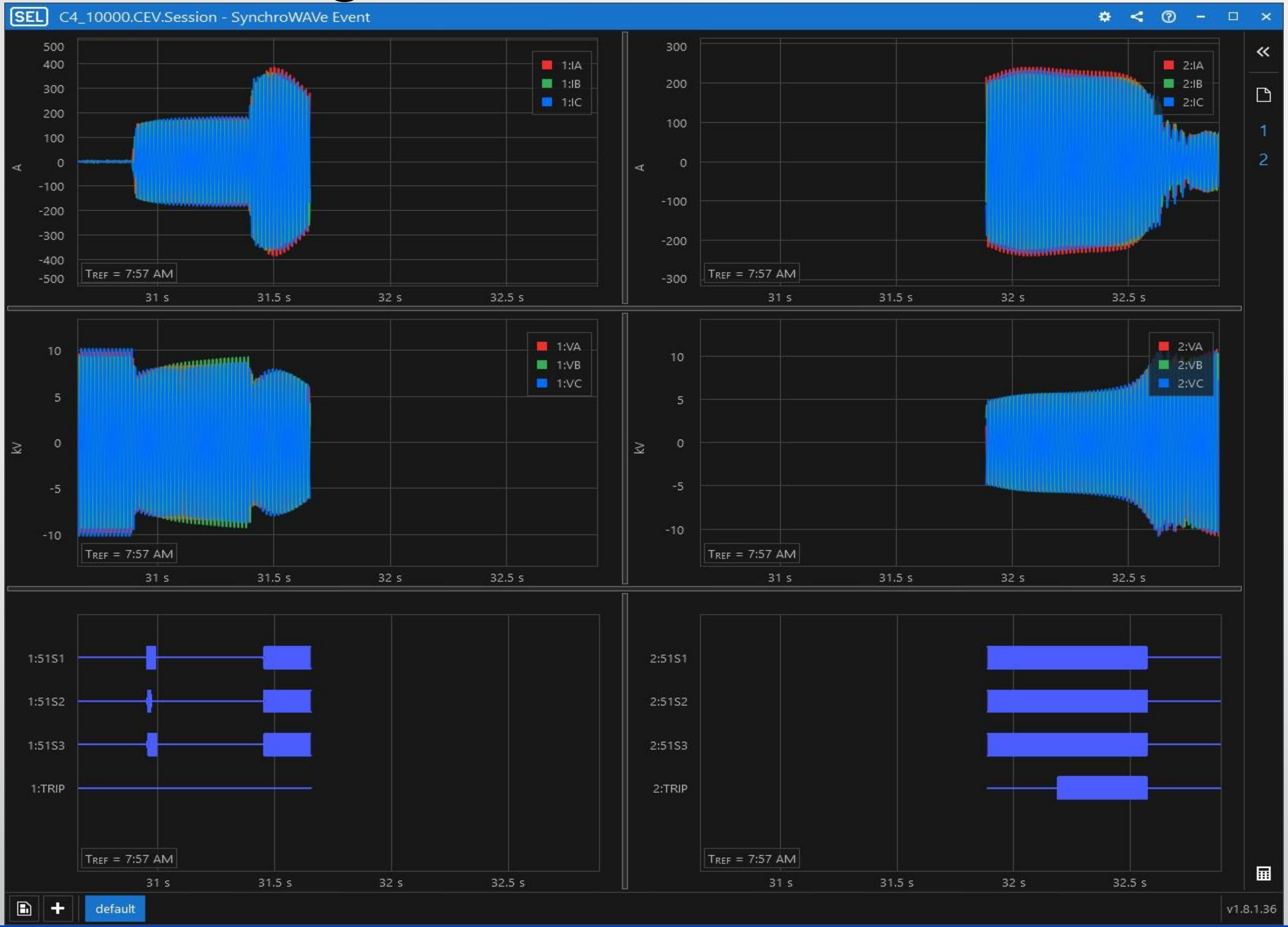
Successful Trip

1500kVA Transformer Energization



Successful No Trip

2500kW Motor Start

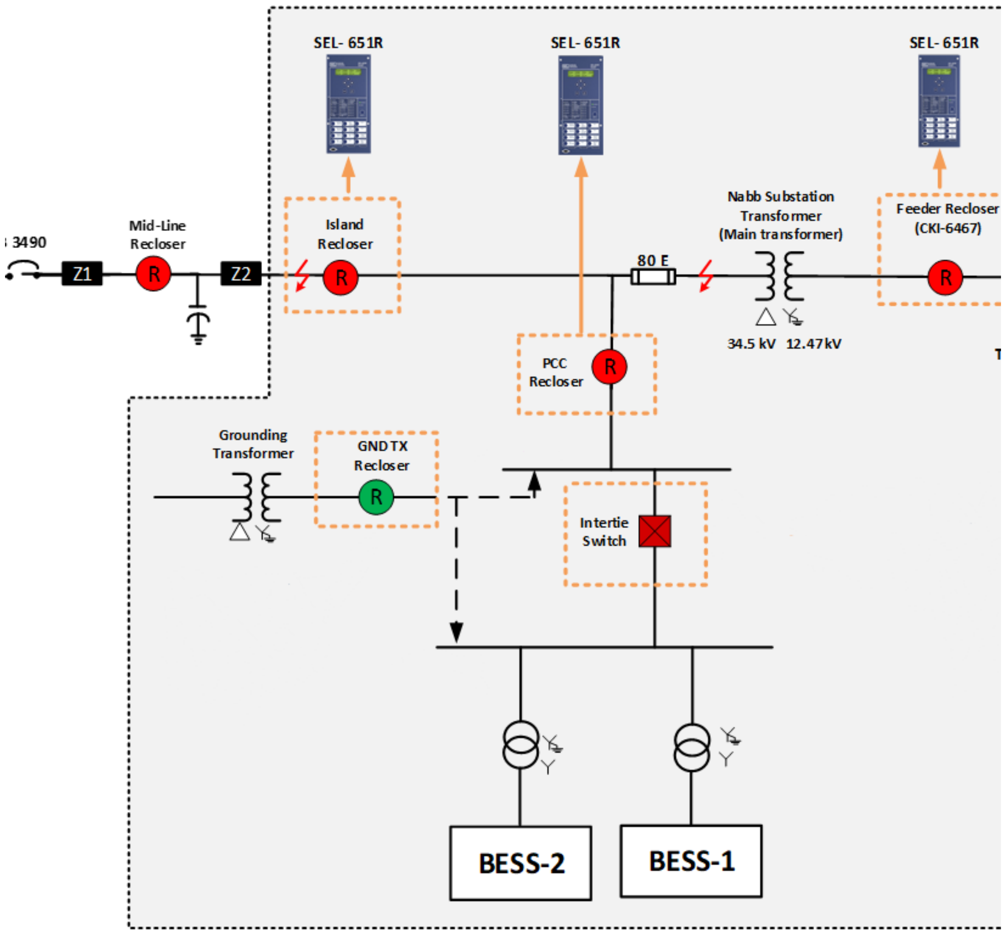


Element Misoperation

HIL Testing

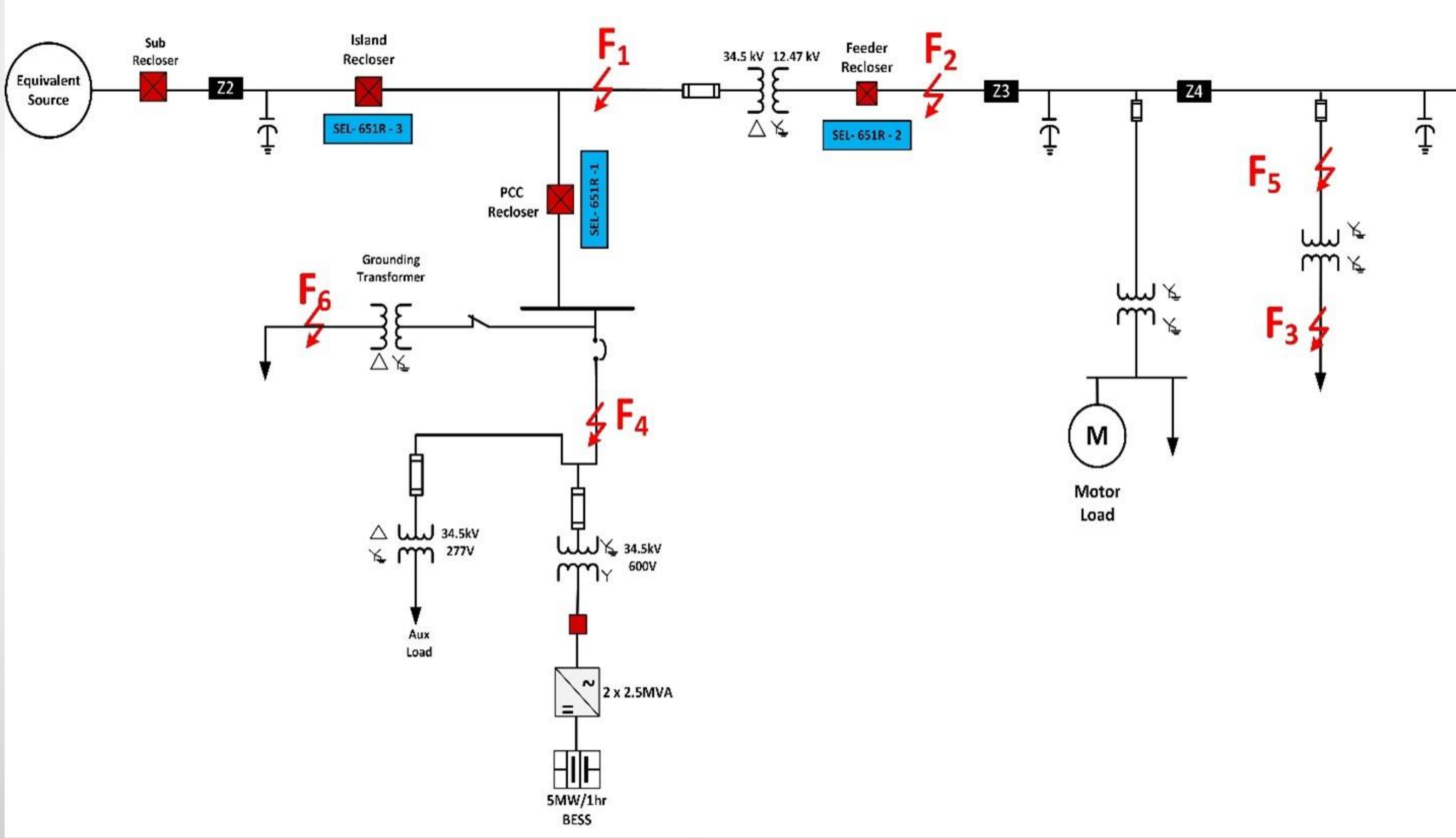
- Recloser Controllers
  - Islanding recloser, SEL-651R
  - PCC recloser, SEL-651R
  - Feeder recloser, SEL-651R

- Over 96 test cases
  - Faults (phase and ground)
  - Black start
  - Transformer energization
  - BESS state changes
  - BESS trip



HIL Test fault locations

Faults	Description
F_1	Faults at the high side of the step-up transformer
F_2	Close fault downstream of feeder recloser
F_3	Far fault downstream of the feeder recloser (customer side)
F_4	Fault at the PCC (high side of the BESS transformer)
F_5	Far fault downstream of the feeder recloser (utility side)
F_6	Fault on the low side of the grounding transformer



HIL Test Results

- The detects detects majority of faults.
- 5 faults at F3 remained undetected.
  - ✓ The fault currents are very low to be sensed by 51 elements.
  - ✓ The faults do not cause adequate under-voltage condition to allow voltage-based protection to operate.
  - ✓ Only solid SLG faults at F3 can be detected (they do generate large ground currents which activate the unsupervised 50G element).
- Faults at F6 remained undetected.

Case No	ISL Rec.	PCC Rec.	FDR Rec.	Tripping Element 1	Tripping Element 2	Tripping Time 1 (s)	Tripping Time 2 (s)	Pass/Fail
Case1073		1		50		0.8425		Pass
Case 1074		1		50		0.8462		Pass
Case 1075		1		50		0.8443		Pass
Case 1076			1	50G		0.5756		Pass
Case 1077			1	50		0.6507		Pass
Case 1078			1	50		0.6151		Pass
Case 1079			1	50G		0.5924		Pass
Case 1080								Fail (No Trip)
Case 1081								Fail (No Trip)
Case 1082		1		27		2.51		Pass
Case 1083		1		27		2.68		Pass
Case 1084		1		27		2.51		Pass
Case 1085			1	50G		0.58		Pass
Case 1086			1	50		0.6216		Pass
Case 1087			1	50		0.6146		Pass
Case 1088								Fail (No Trip)
Case 1089		1		27		2.511		Pass
Case 1090		1		27		2.518		Pass
Case 1091		1		50		0.8459		Pass
Case 1092		1		50		0.8427		Pass
Case 1093		1		50		0.8439		Pass
Case 1094		2	1	50G	27	0.5753	2.278	Pass
Case 1095			1	50		0.6166		Pass
Case 1096			1	50		0.6197		Pass
Case 1097								Fail (No Trip)
Case 1098								Fail (No Trip)
Case 1099								Fail (No Trip)
Case 1100		1		27		2.511		Pass
Case 1101		1		27		2.695		Pass
Case 1102		1		27		2.511		Pass
Case 1103			1	50		0.5773		Pass
Case 1104			1	50		0.6179		Pass
Case 1105			1	50		0.6178		Pass
Case 1106								Fail (No Trip)
Case 1107								Fail (No Trip)
Case 1108								Fail (No Trip)

HIL Testing Conclusions

- EMT studies and HIL testing were done to thoroughly examine the proposed scheme
  - Three recloser controllers were used for HIL testing
- Results show that the scheme can appropriately detect and isolate majority of faults
  - High-impedance fault and secondary faults (downstream the service or grounding transformer) are not detected reliably
- Results indicate that the proposed APS does not trip falsely during the transients or contingencies scenarios such as black start, motor starts up, and transformer energization

Thank You

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Questions?