RTDS in the Dominion Energy Blackstart Study

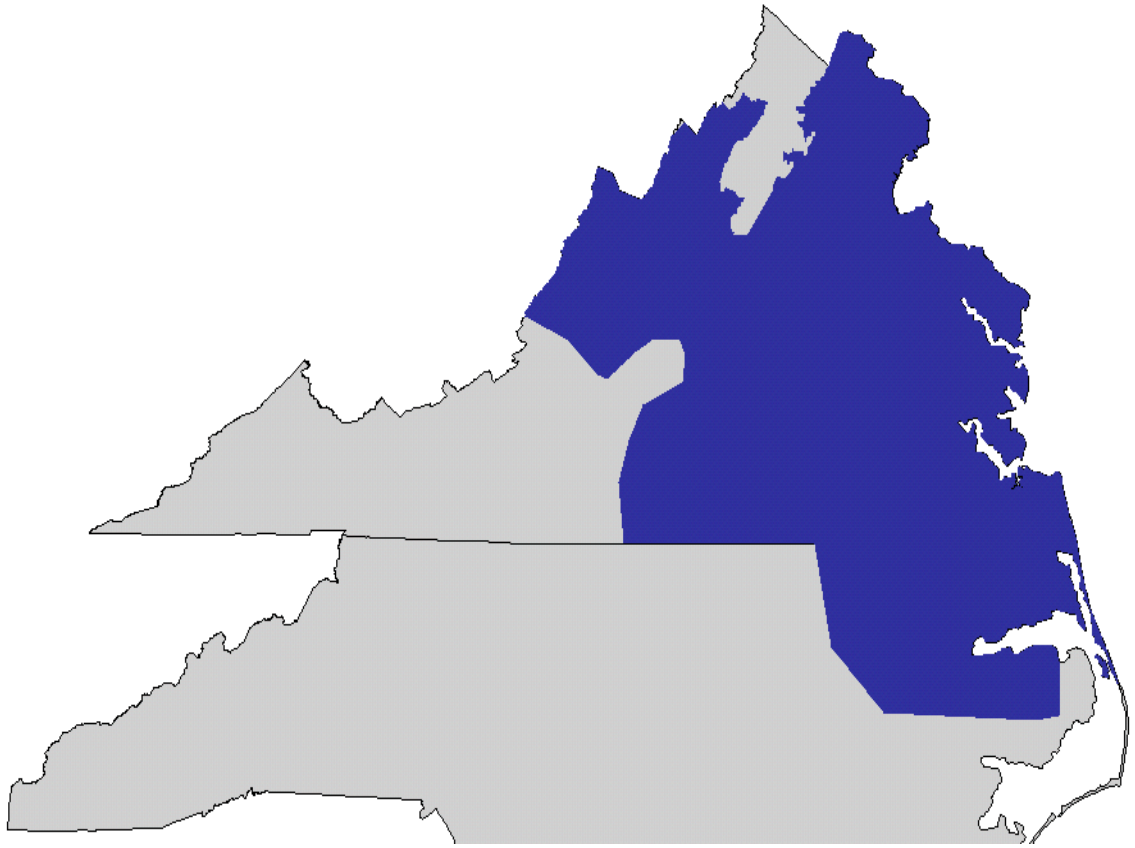
Dr. Ren Liu

Dominion Energy

Dominion Energy Virginia/NC

- Electric Transmission
  - 6,600 miles of transmission lines in Virginia, North Carolina and West Virginia

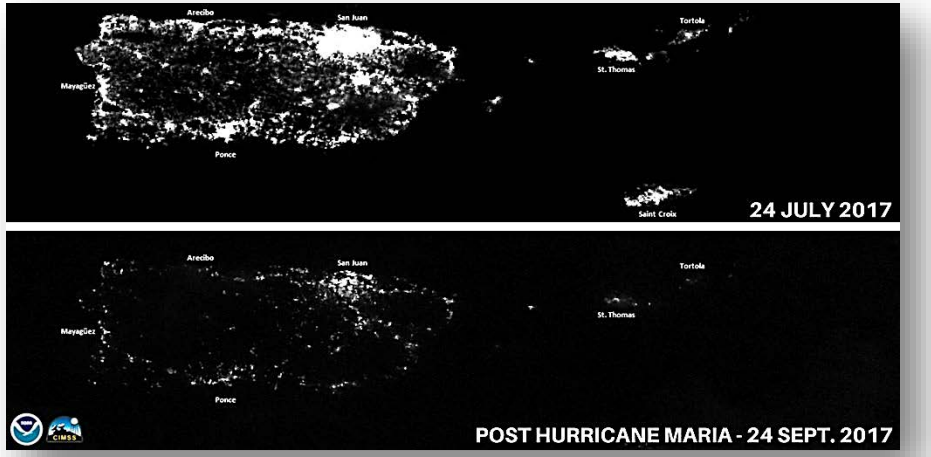
- Electric Distribution
  - 57,600 miles of distribution lines in Virginia and North Carolina
  - Serves 2.6 million customers



Dominion Energy®

About Blackstart

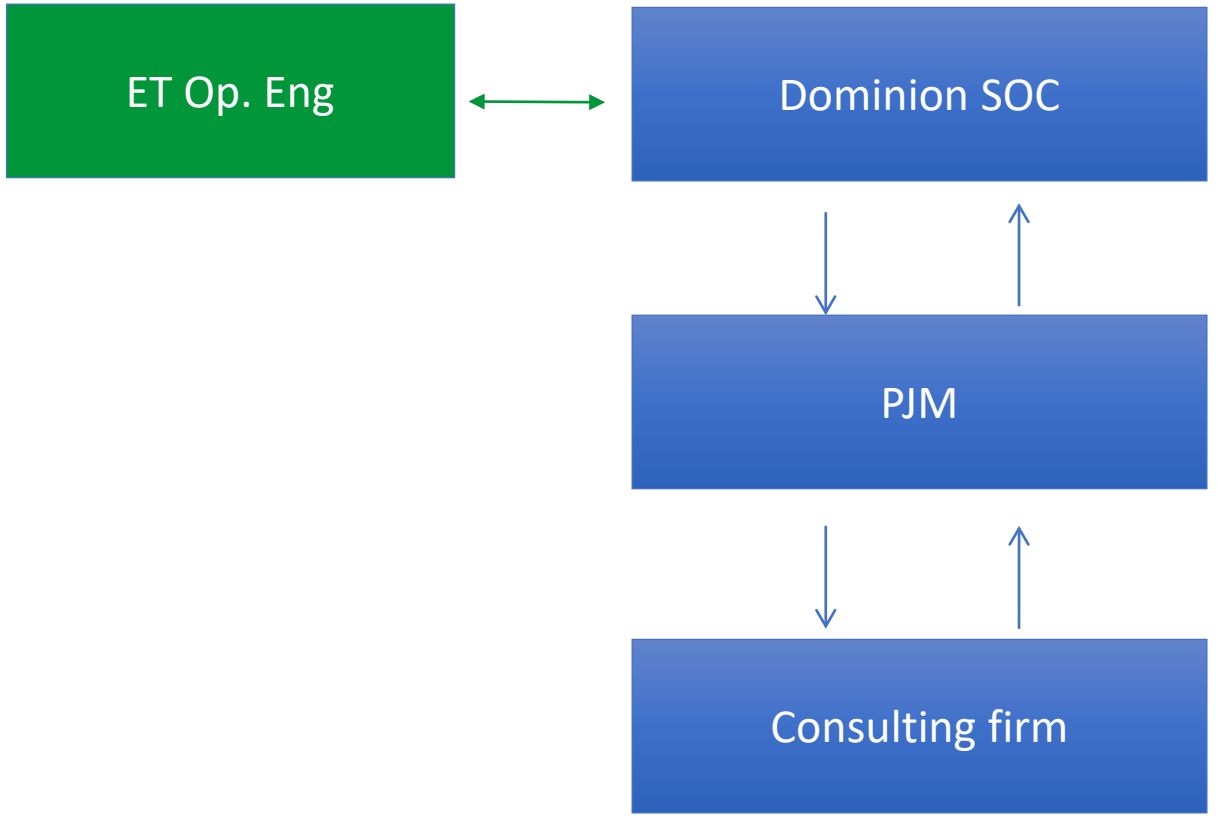
- Energizing the grid from total blackout
- Has never happened in mainland USA
- Need to be prepared



Hurricane Maria

System Restoration Plan (SRP) study

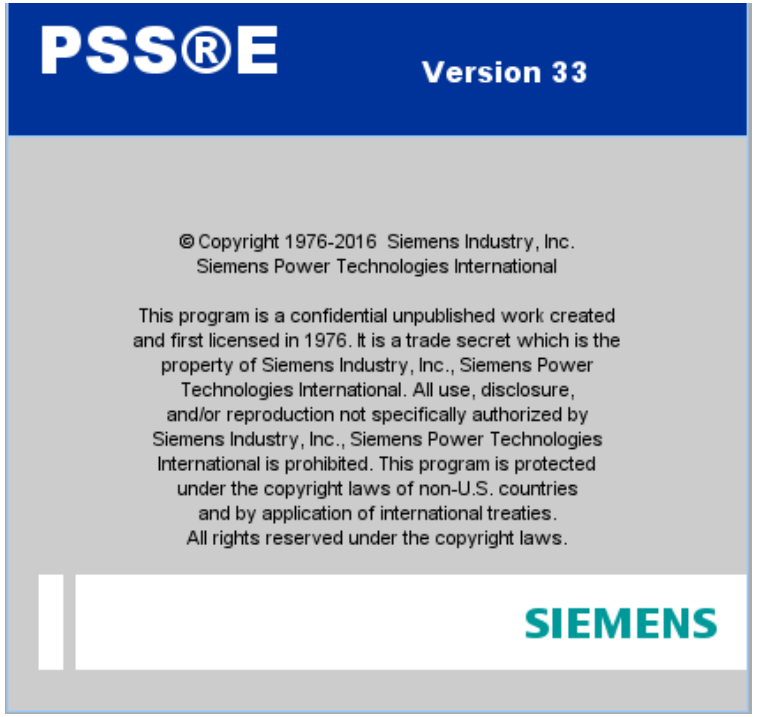
- Began in 2013, on-going today
- Lead: ET Operations Engineering
- Internal Collaboration:
  - ET System Protection Engineering
  - ET SOC
  - ET Planning
  - Dominion Generation
  - Dominion Distribution



Major tasks

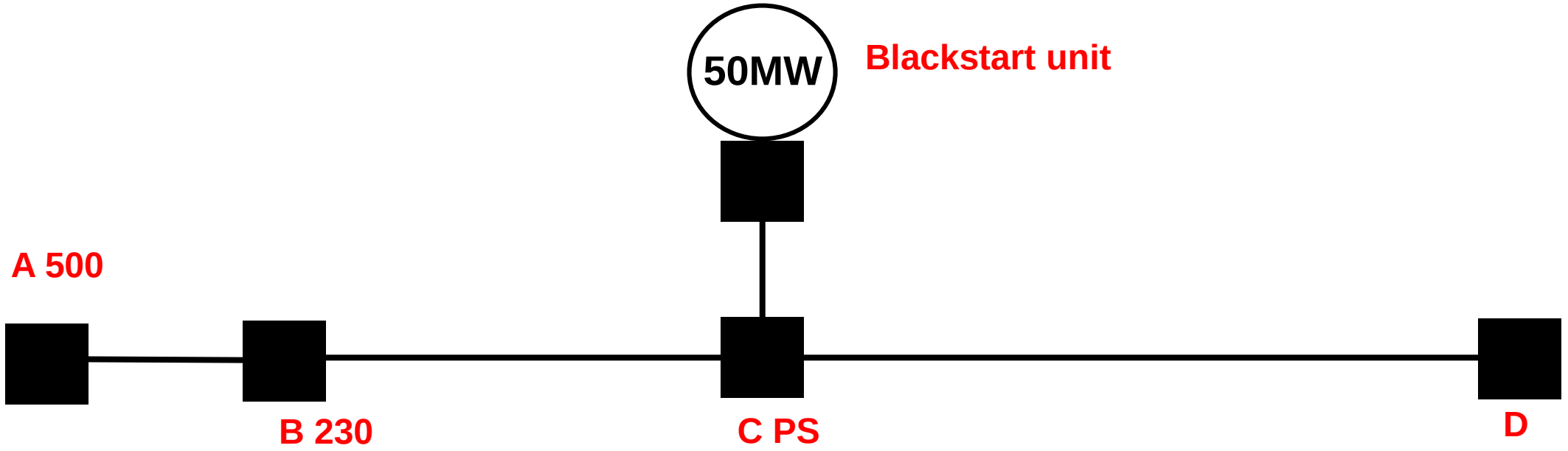
- Study the feasibility of the paths (Load flow study)
- Study blackstart path dynamic behaviors
- Validate existing protection schemes
- Real-time decision support tool

Load Flow Studies

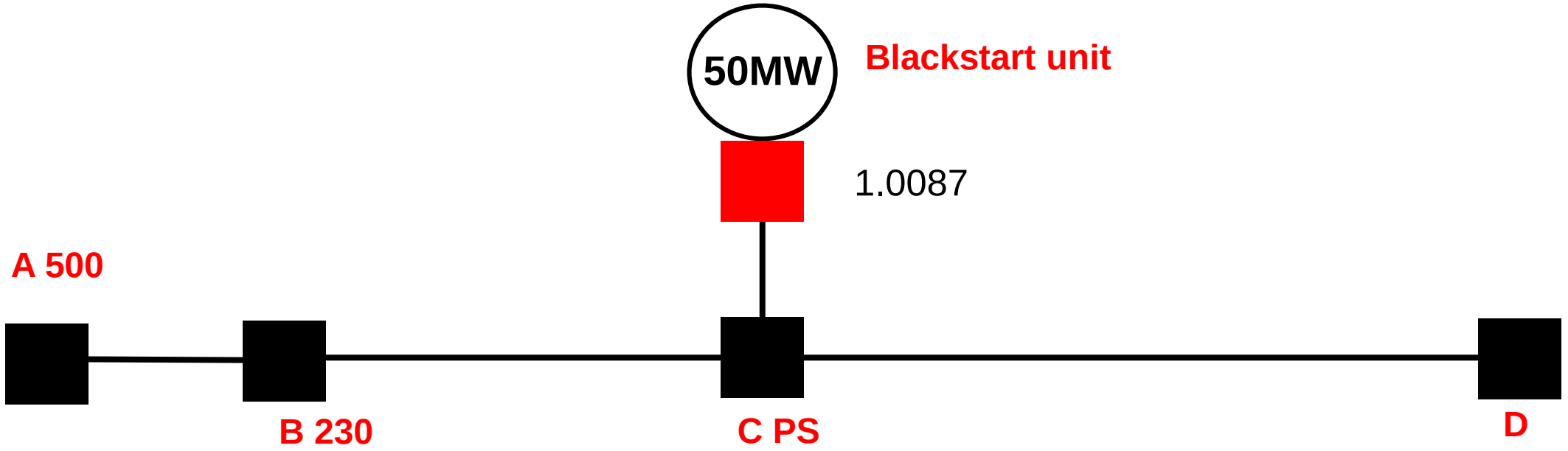


- Voltage
- Generation output (MW, Mvar)

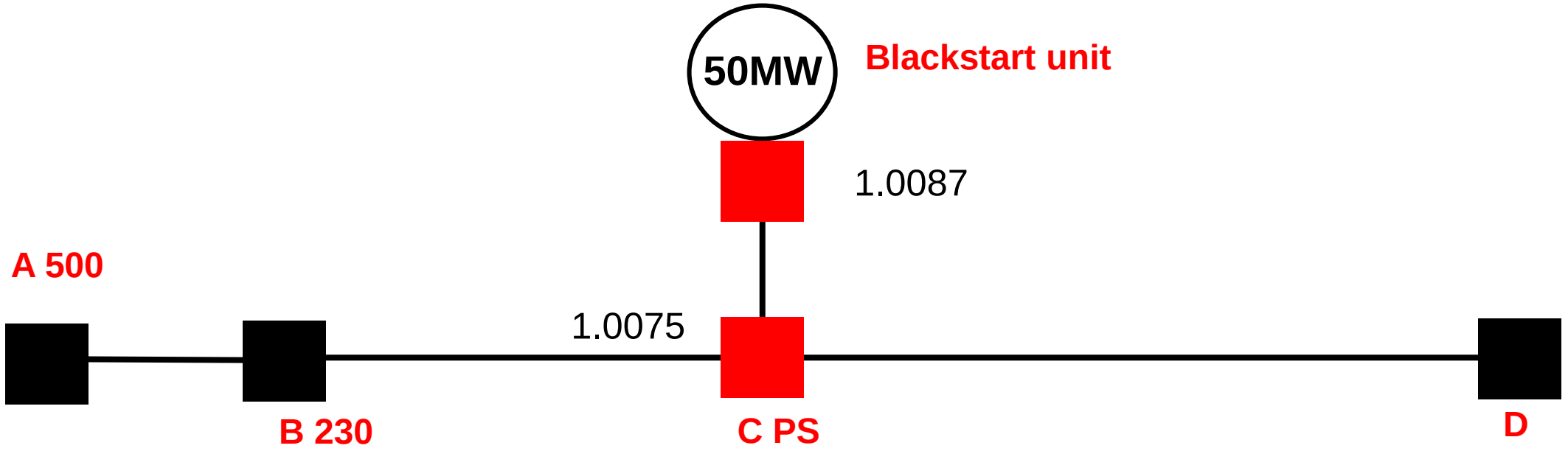
PSS/E study example



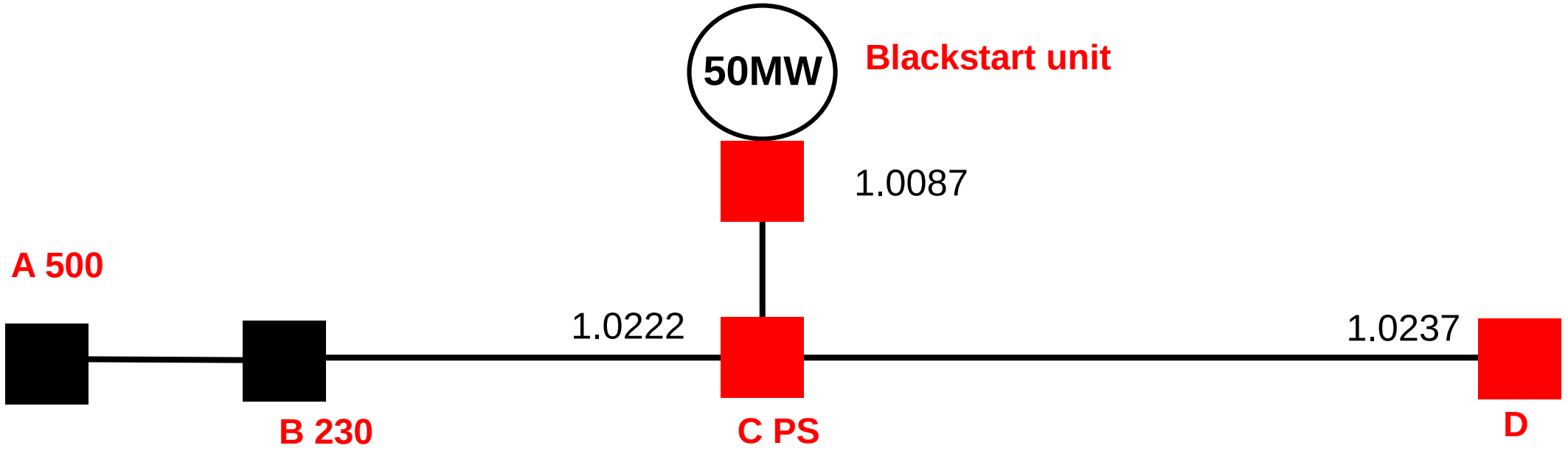
PSS/E study example



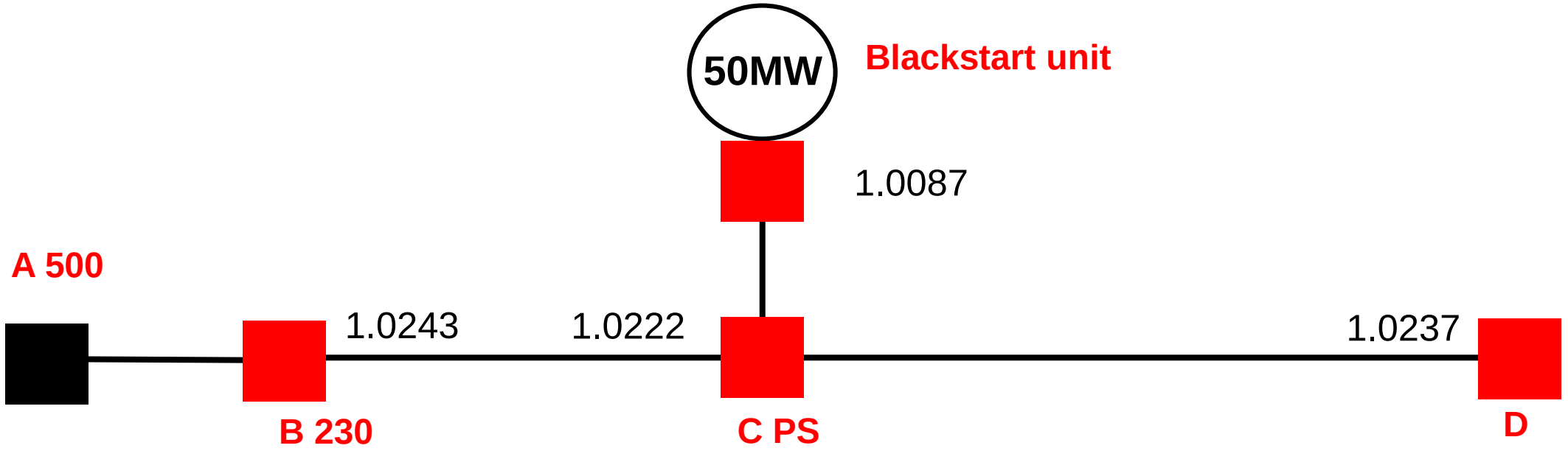
PSS/E study example



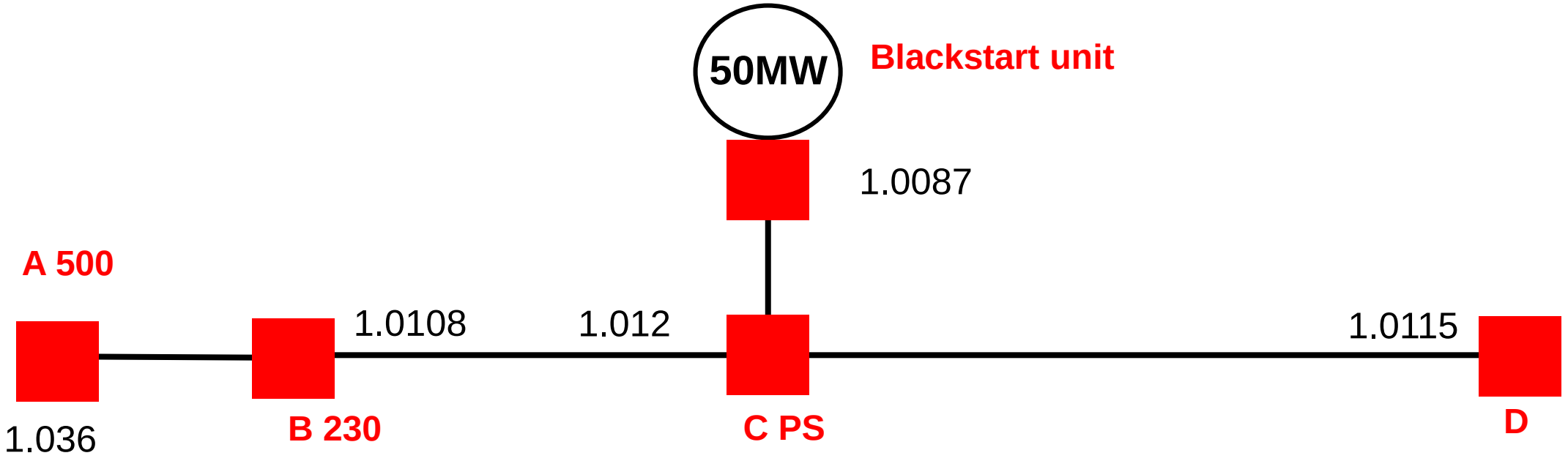
PSS/E study example



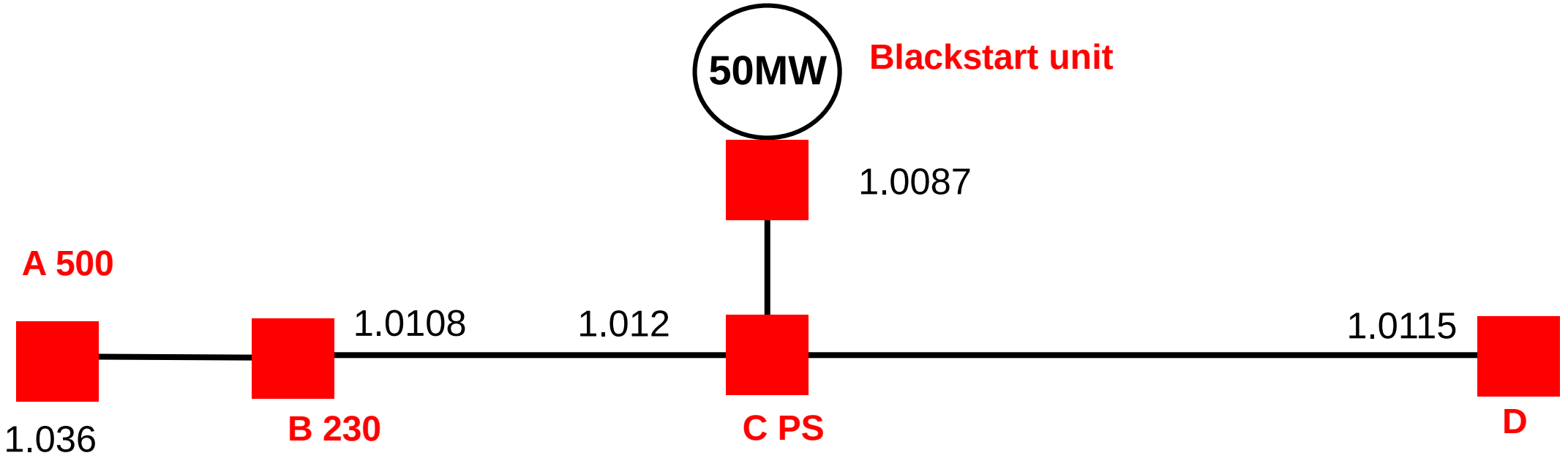
PSS/E study example



PSS/E study example



PSS/E study example



- All voltages are maintained within 1±0.05 p.u. for energized system nodes
- More loads can be picked up when more black out area is energized

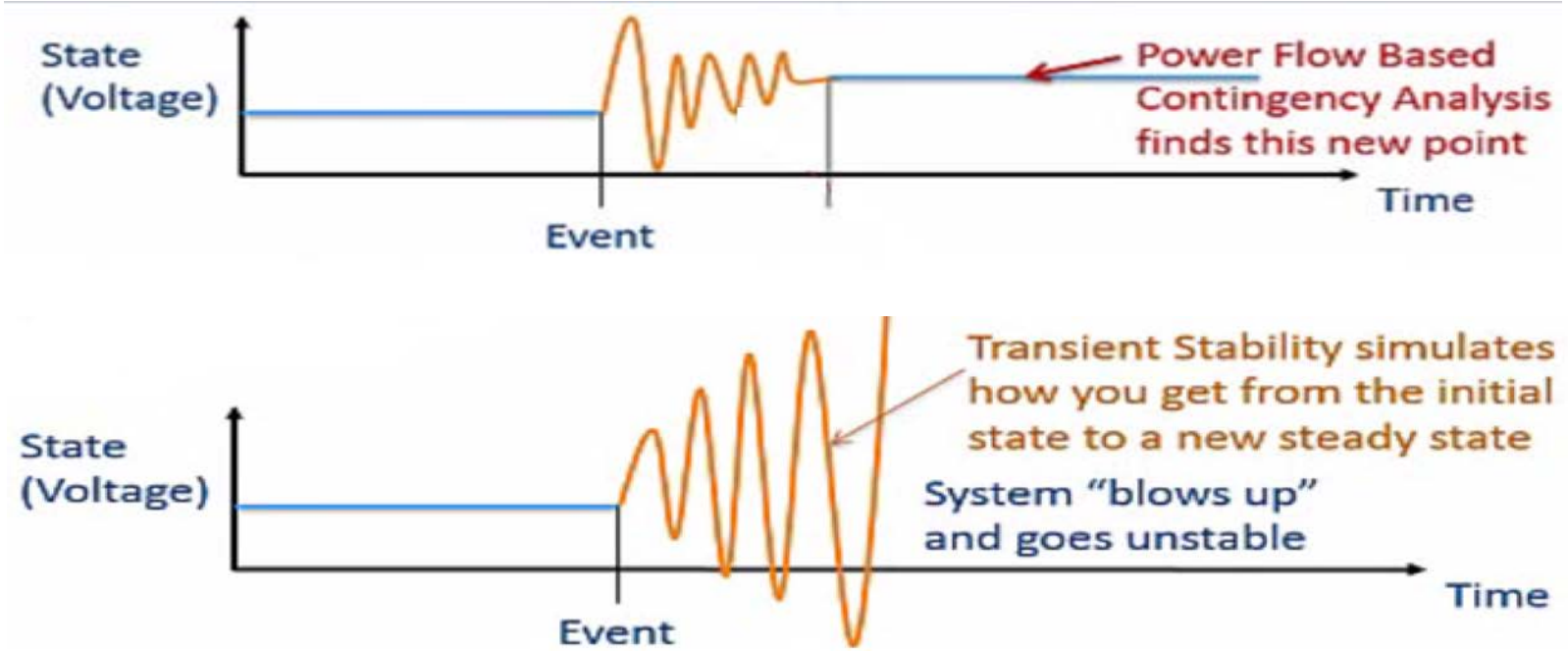
Bus status for restoration path A

Bus	Base (kV)	Step 1-2		Step 3-4		Step 5-7	
		Voltage (p.u.)	Angle (deg)	Voltage (p.u.)	Angle (deg)	Voltage (p.u.)	Angle (deg)
1	13.8	1.0087	-51.29	1.0087	-51.29	1.0087	-51.29
2	230	1.0087	-53.53	1.0087	-54.01	1.0087	-54.28
3	230	1.0082	-53.81	1.0082	-54.29	1.0082	-54.56
4	230	1.0075	-53.95	1.0075	-54.43	1.0075	-54.7
5	500	1.0327	-53.95	1.0327	-54.43	1.0327	-54.7
6	230	1.0087	-53.53	1.0086	-54.05	1.0087	-54.32
7	230	1.0087	-53.53	1.0085	-54.07	1.0087	-54.35
8	13.8	1.0047	-53.48	1.0126	-50.67	1.0025	-50.89
9	230	-	-	1.0083	-54.13	1.0087	-54.42
10	230	-	-	1.0071	-54.4	1.0086	-54.73
11	115	-	-	1.0016	-54.19	1.0018	-54.47
12	230	-	-	1.007	-54.43	1.0086	-54.76
13	230	-	-	1.0075	-54.43	1.0105	-54.81
14	230	-	-	-	-	1.0111	-54.84
15	230	-	-	-	-	1.0116	-54.89
16	115	-	-	-	-	1.0048	-54.94
17	230	-	-	-	-	1.0116	-54.89

Machine status for restoration path A

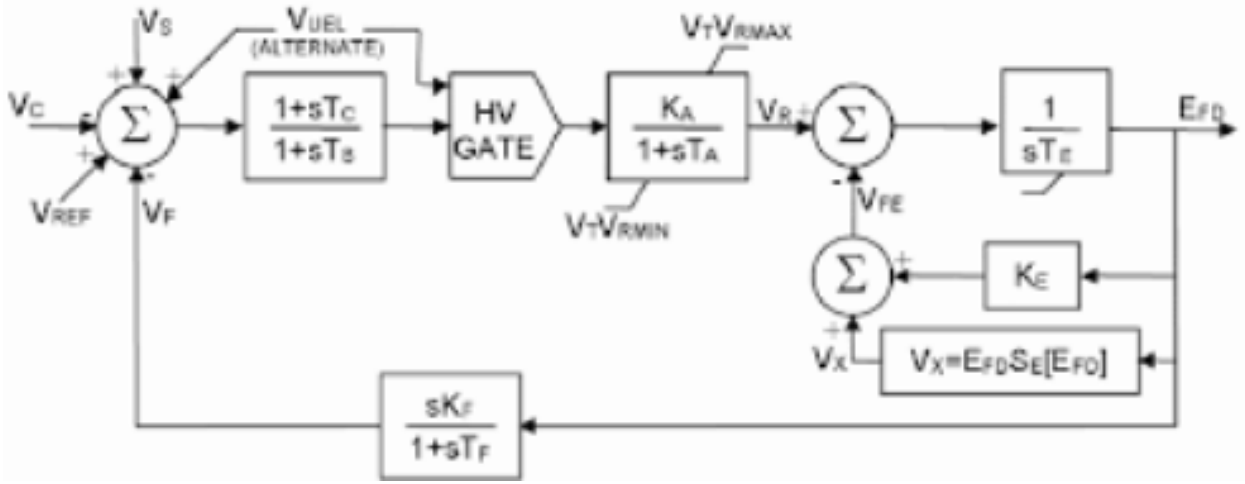
Machine	Base (kV)	PMax (MW)	Step 1-2		Step 3-4		Step 5-7		Power Reserve (MW)
			PGen (MW)	QGen (MVAR)	PGen (MW)	QGen (MVAR)	PGen (MW)	QGen (MVAR)	
1	13.8	72	33.214	-0.2089	40.342	-0.0849	44.369	0.011509	27.631
2	13.8	72	0.6	-3.3915	50	3.4845	50	-5.04305	22

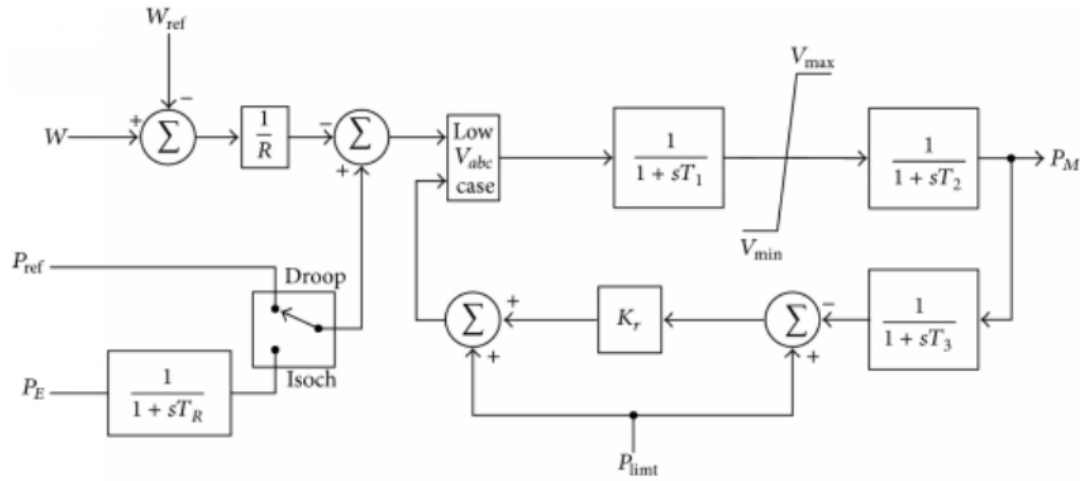
Load flow study vs dynamic study



Dynamic study for Blackstart

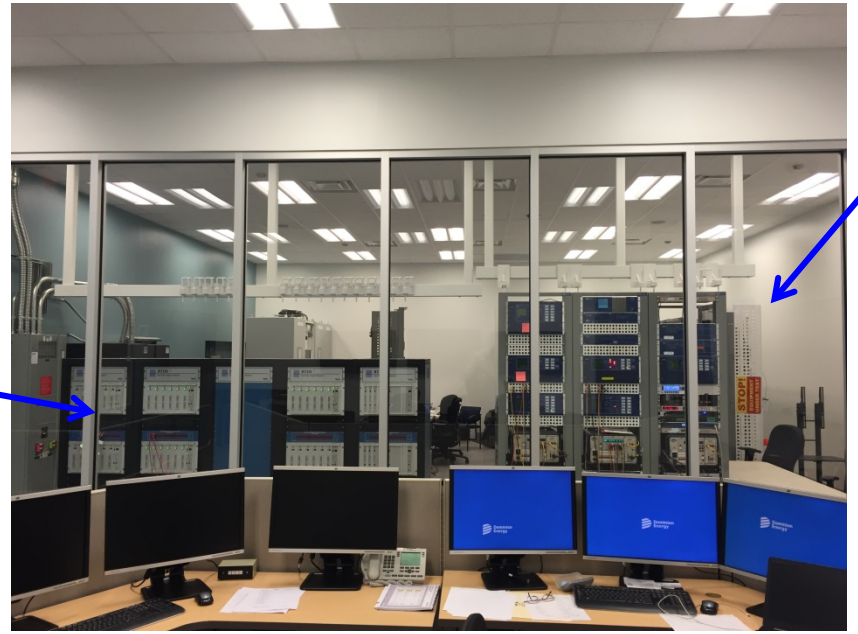
- Transient response
- Generator control
  - Voltage control
  - Frequency control
- Island synchronization
- Protection validation





RTDS Lab in Dominion Energy

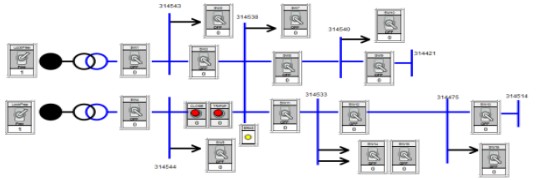
RTDS



Hardware under test:
Relay, GPS clock,
Substation computer,
FACTS controller

- Multiple analog I/O and digital I/O
- Advanced Studies: Root cause analysis, FACTS, Harmonics, Blackstart, Protection, Inverter testing, etc

Dynamic study of Blackstart in RTDS



Dynamic analysis

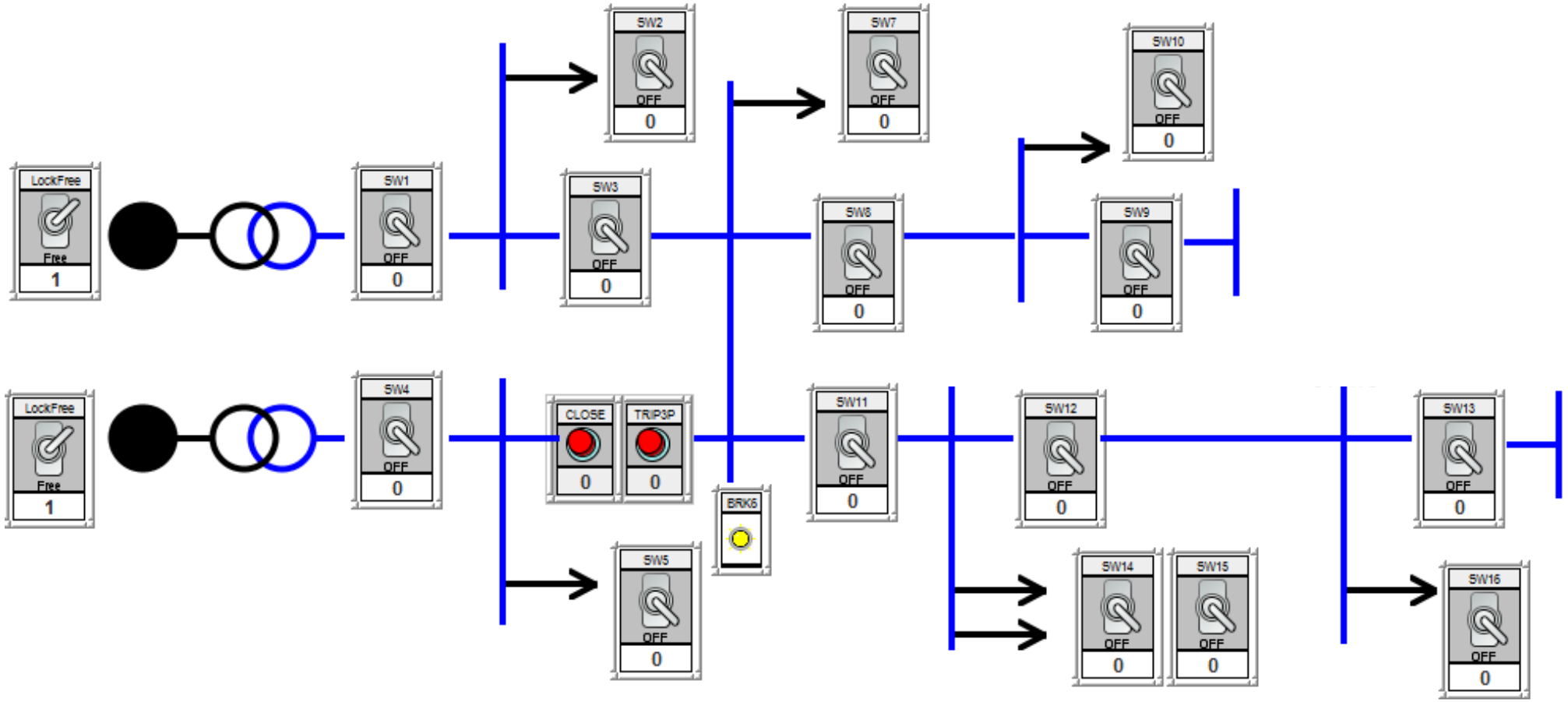
Synchronization of islands

Protection validation

Dynamic analysis of Blackstart

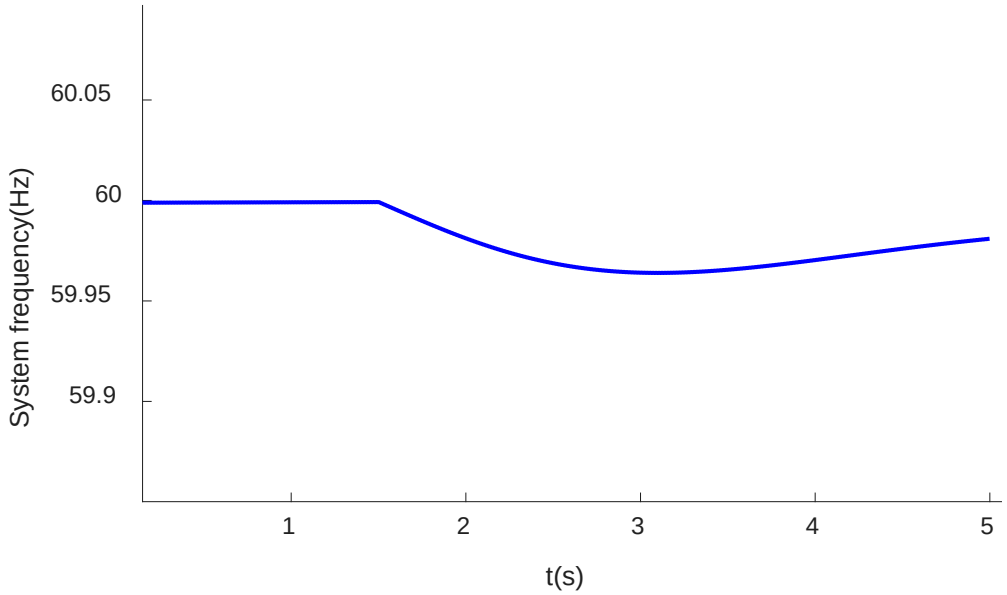
- All the cranking paths are built in RTDS
- Dynamic response of each step is simulated
- Lots of efforts
  - Network reduction
  - Model validation (on-going process)

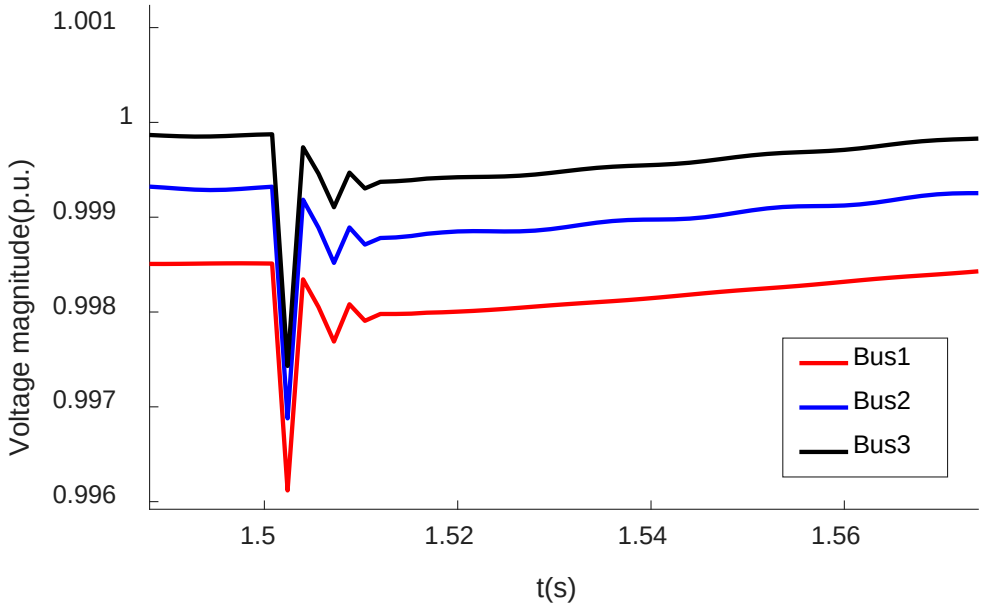
RSCAD model of a particular path



Dynamic simulation in RTDS

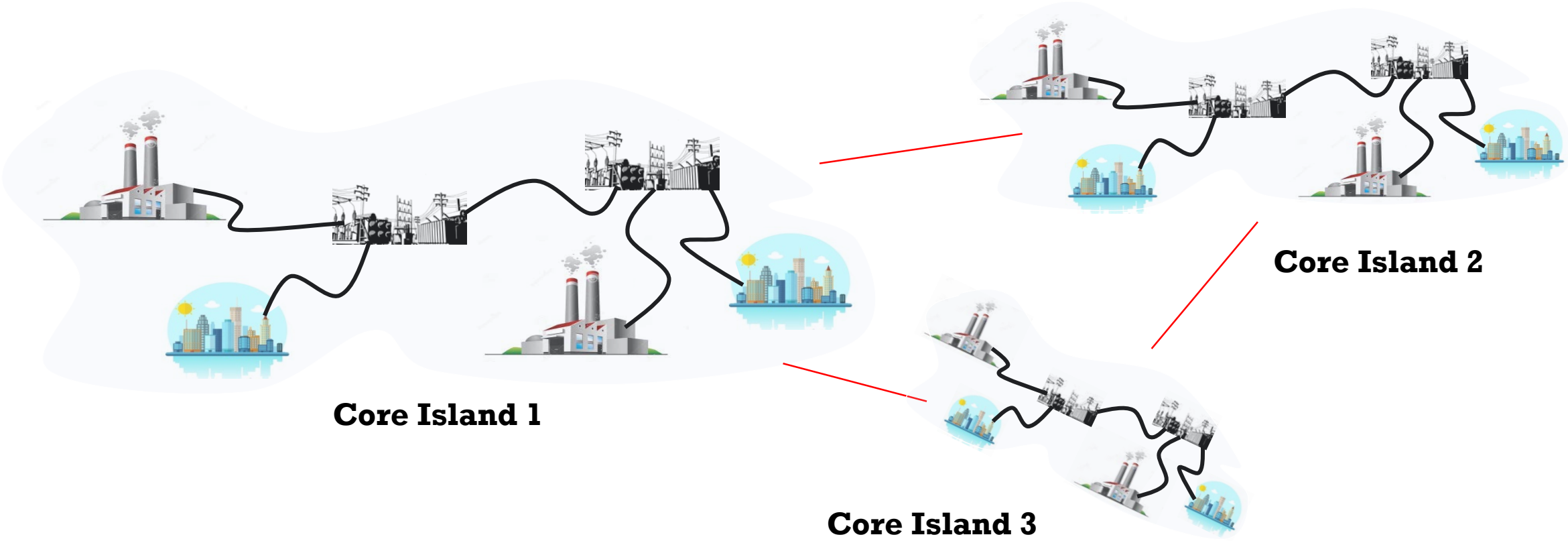
- Dynamic responses are captured after each switching step
- The frequency and voltages should remain within the acceptable limits



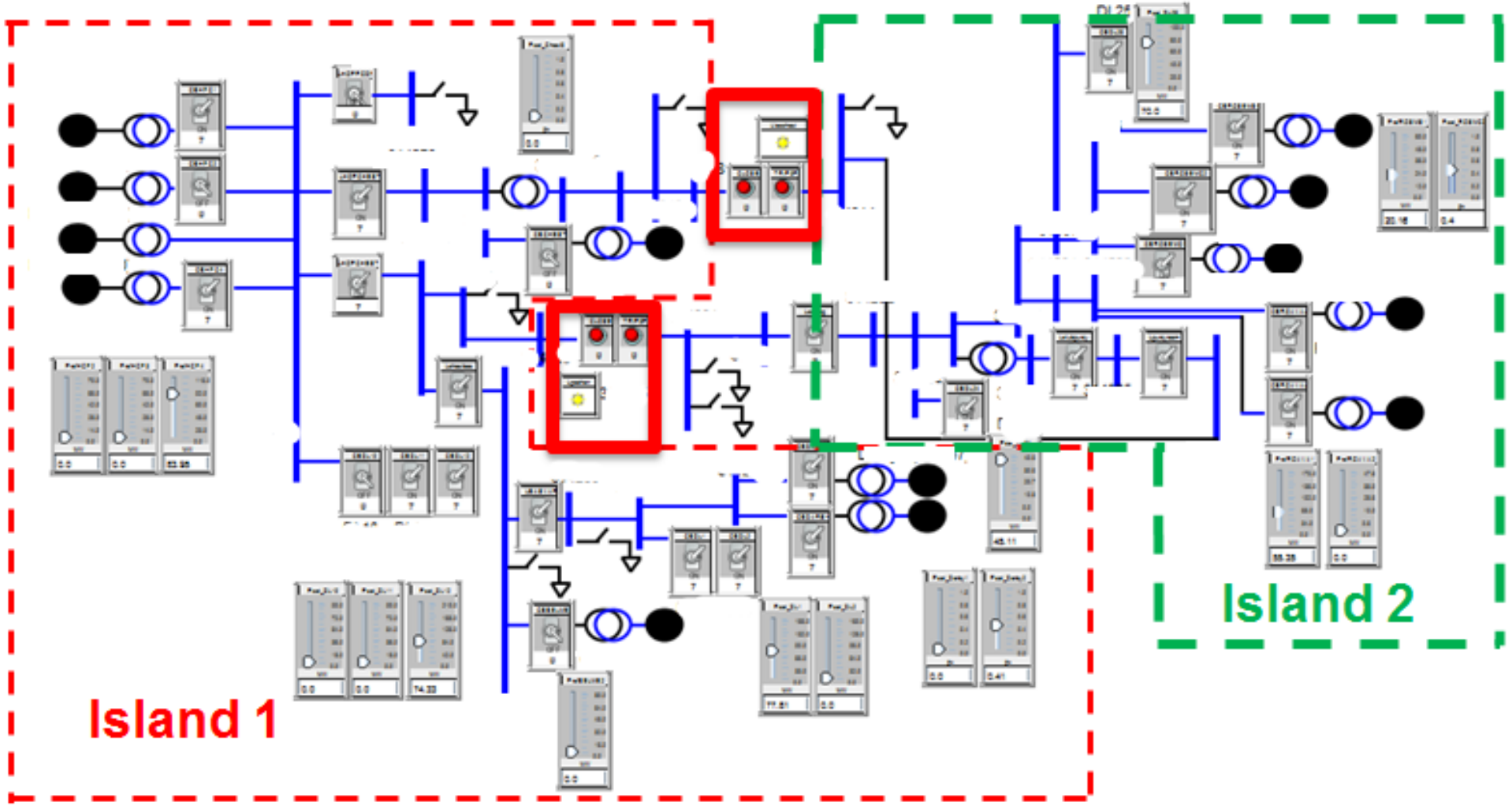


- Frequency and voltage response after a switching step

Islands synchronization



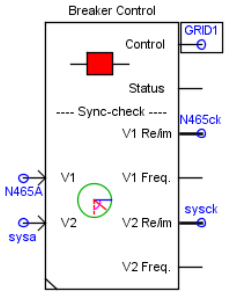
Islands synchronization Example



Islands synchronization Simulation Results

Thresholds:

- 5 degrees
- 0.1 Hz
- 5% voltage mag diff

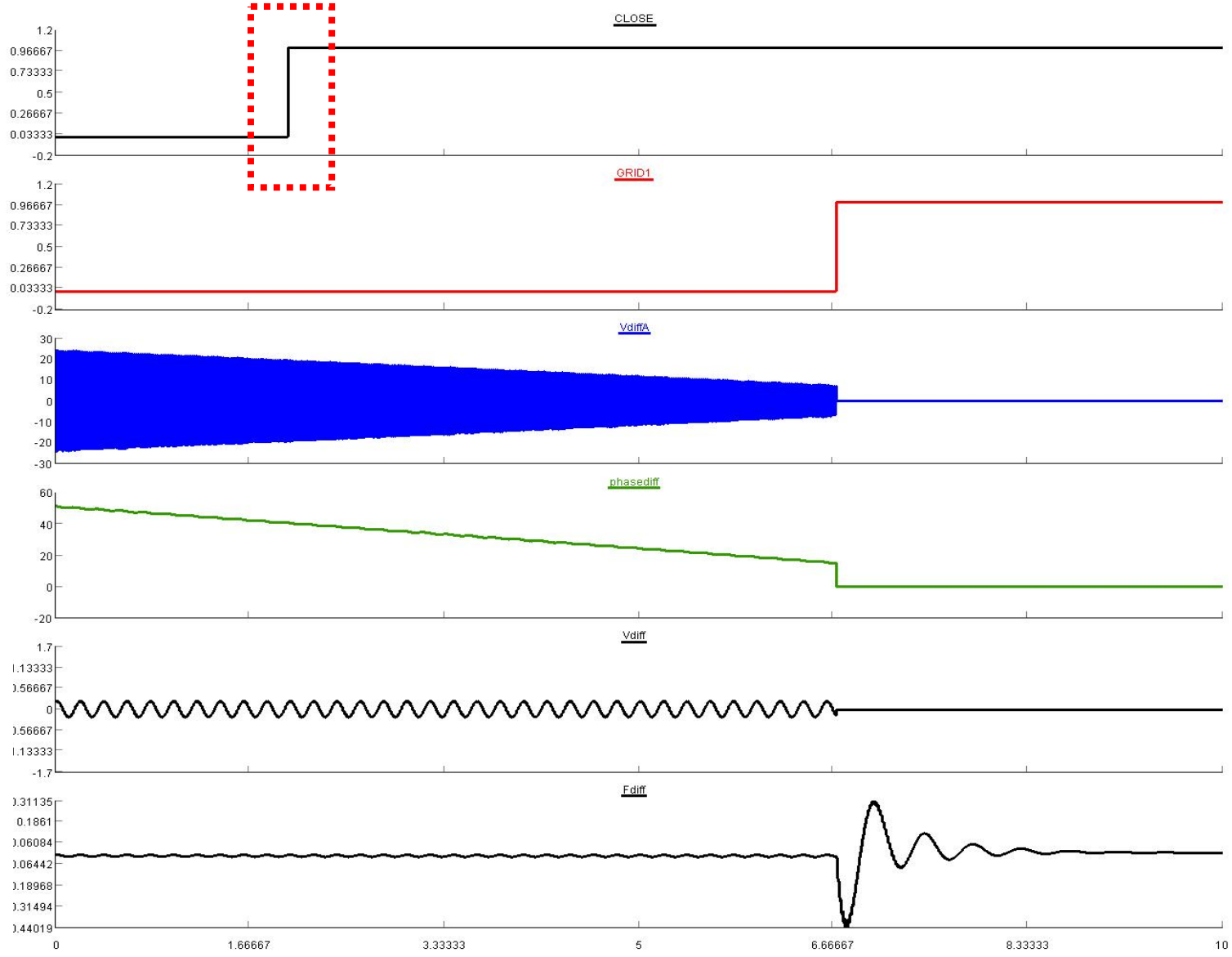


_rtds_BreakerControl.def

CONFIGURATION | Breaker Status | 25 Synchro Check Element | VT Parameters

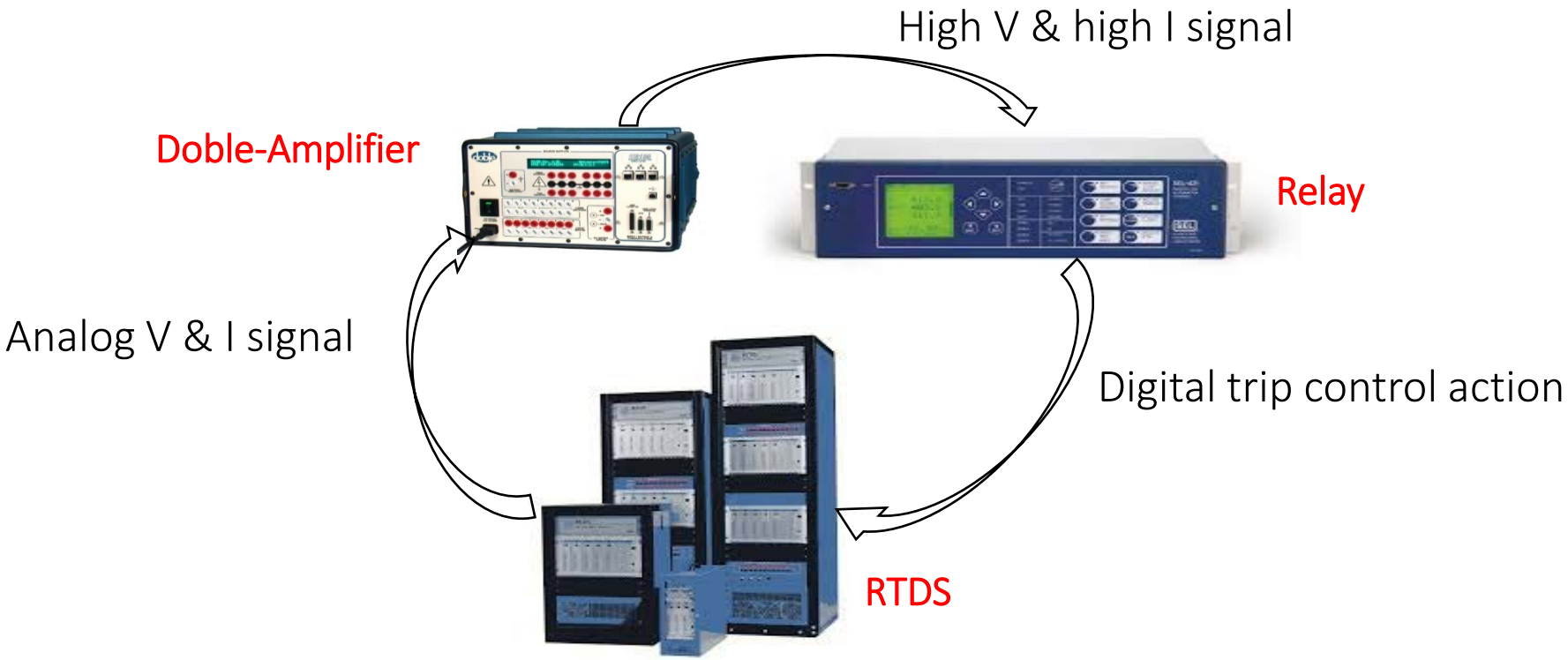
Name	Description	Value	Unit	Min	Max
StrValAdiff	Maximum Angle Difference	15	degrees	0.0	100.00
StrValFdiff	Maximum Slip Frequency (pickup)	0.2	Hz	0.0	3.0
StrvalVdiff	Maximum Voltage Difference	5.0	%	0.0	20.00
FgenH	V1 Frequency > V2 Frequency	NO		0	1
VgenH	V1 Voltage > V2 Voltage	NO		0	1
StrVal27S1	Minimum V1 Voltage	0.5	volts	0.5	200.0
StrVal27S2	Minimum V2 Voltage	0.5	volts	0.5	200.0
DeadBus	Enable Dead Bus (V2) Check	YES		0	1

Update | Cancel | Cancel All



Protection validation: Hardware-in-the-loop

- Relay should operate correctly during the restoration
- Much different condition during blackstart

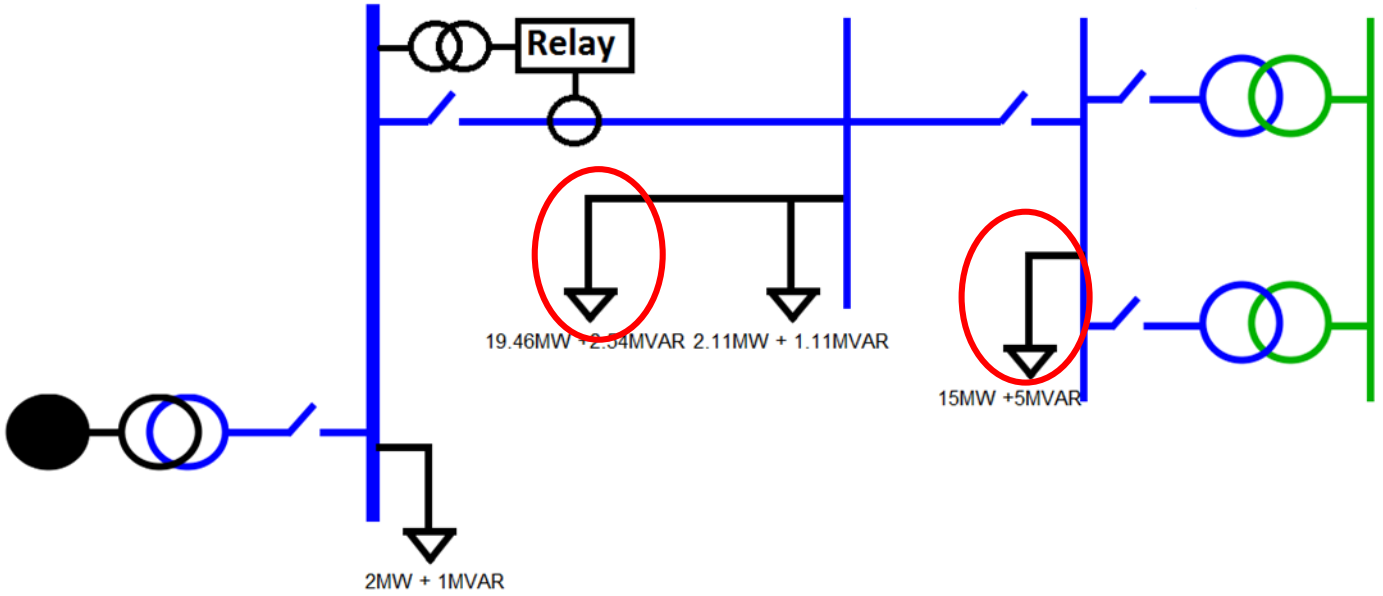


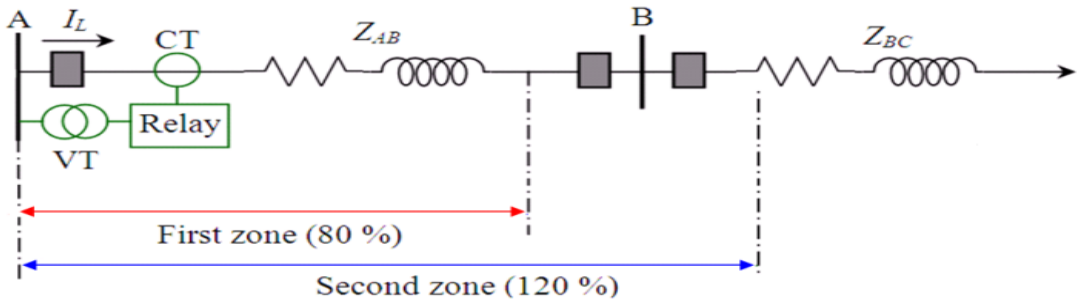
Hardware-in-the-Loop Relay Testing

- Possible Problems:
  - The fault current may be less than the relay pick up current.
  - Time inverse overcurrent functions may respond slower than normal.
  - The relay may misoperate when the fault happens during the blackstart switching transient.
- Following conditions are tested:
  - Normal blackstart switching operation should not trigger protection relays
  - Relays should operate correctly towards faults during blackstart steady state operation
  - Relays should operate correctly towards faults during blackstart switching operation

Dominion Energy®

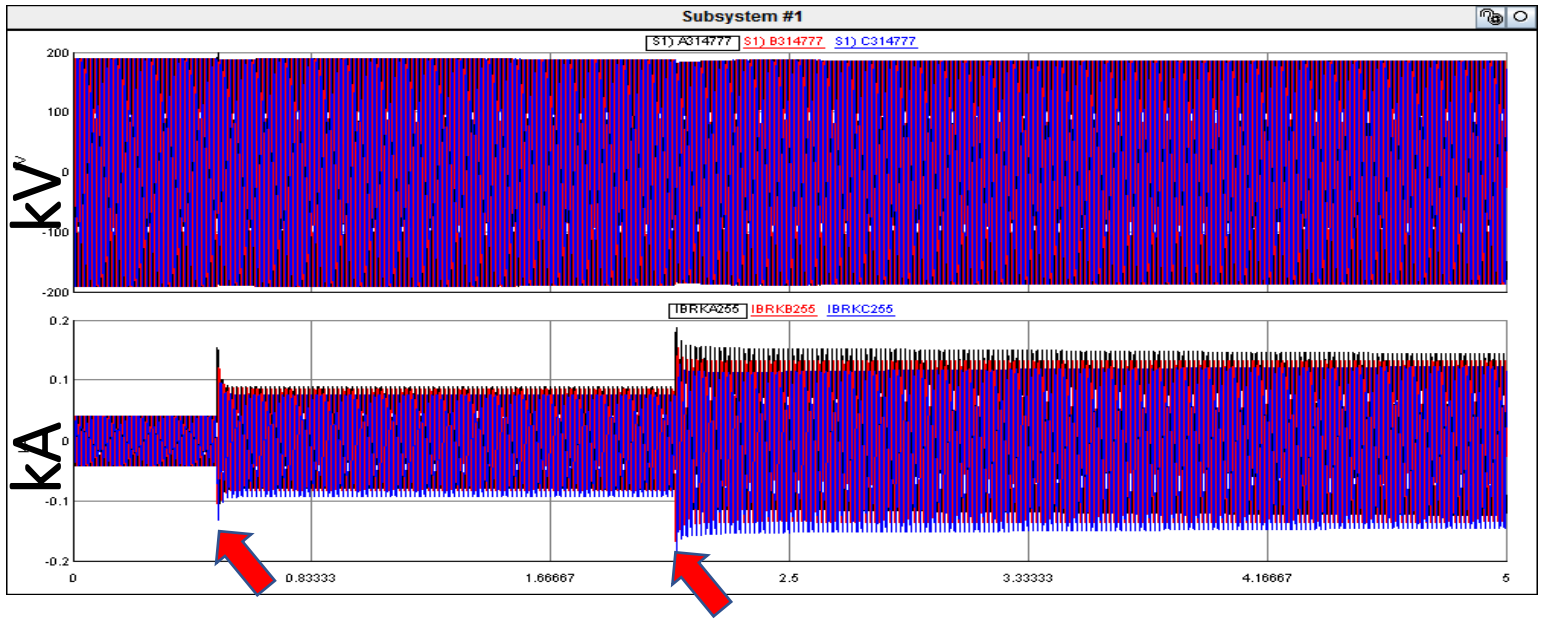
No-fault during Blackstart switching event



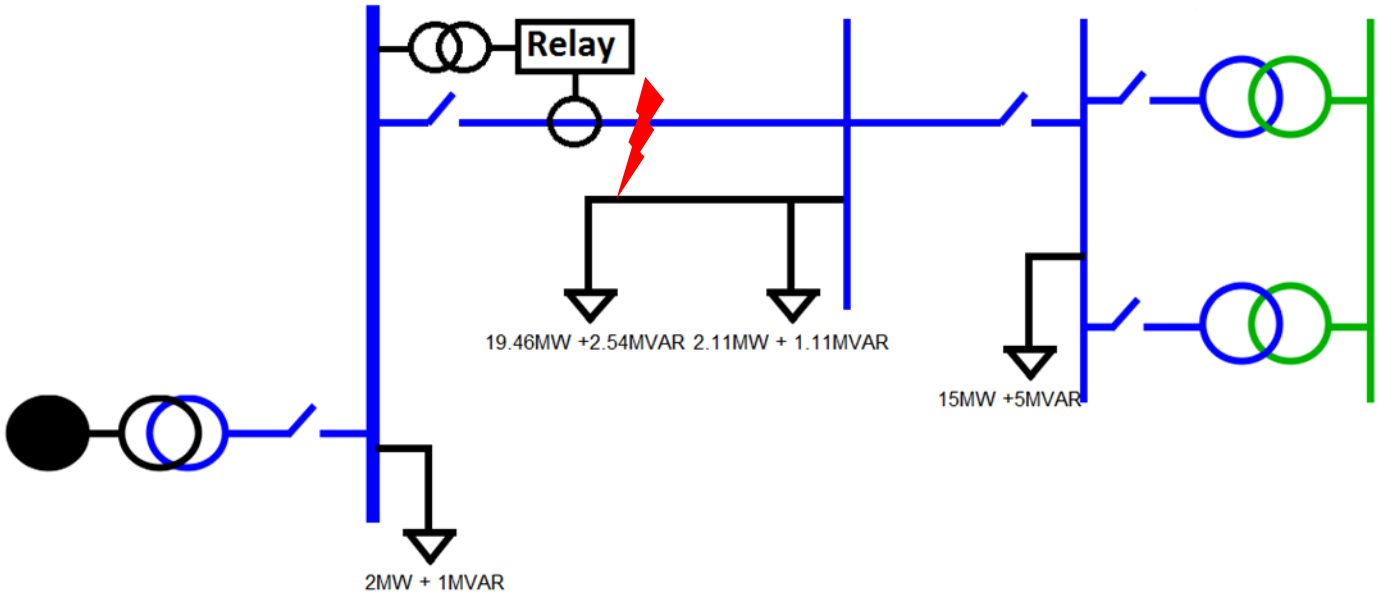


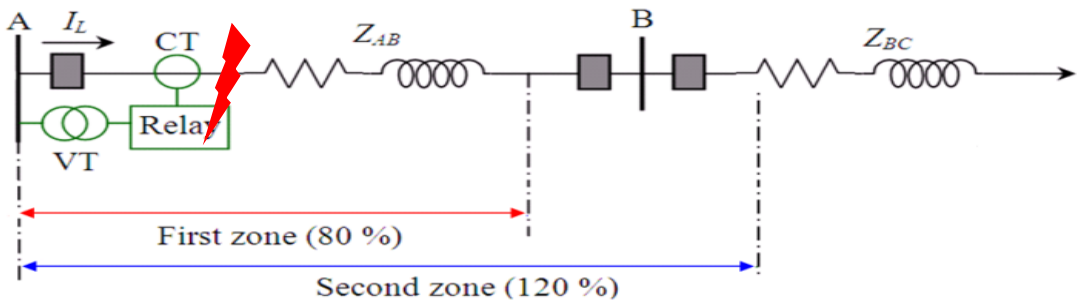
Relay: SEL-421 Line Distance Protection

- Blackstart switching event did not trigger Relay Function.
- Relay operated properly.



Zone 1-Single Phase to Ground Fault during blackstart steady state

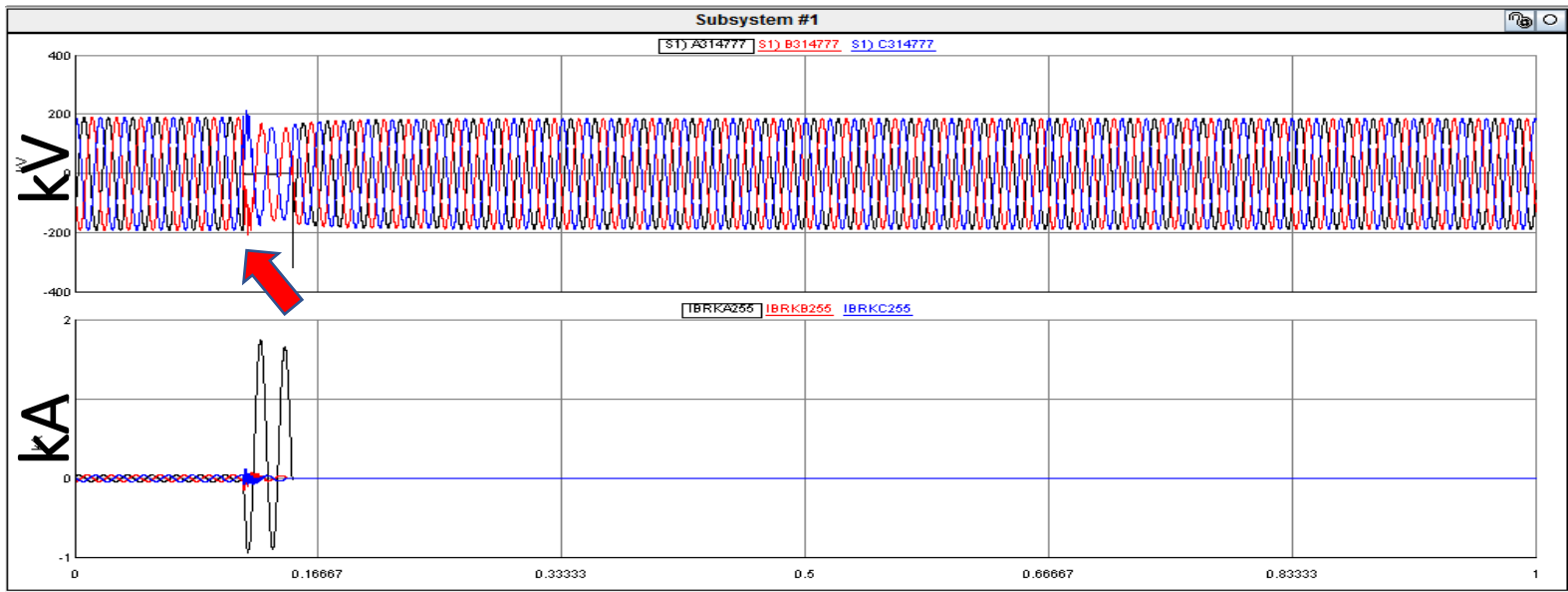




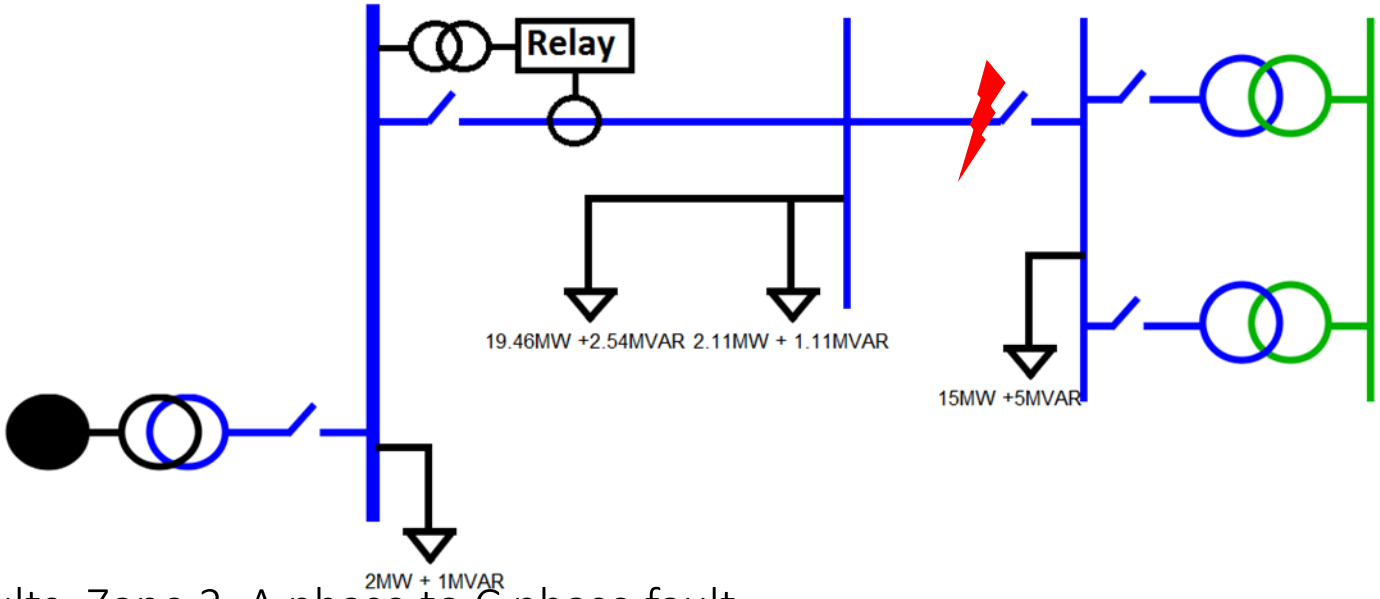
Faults: Zone 1, A phase to ground fault

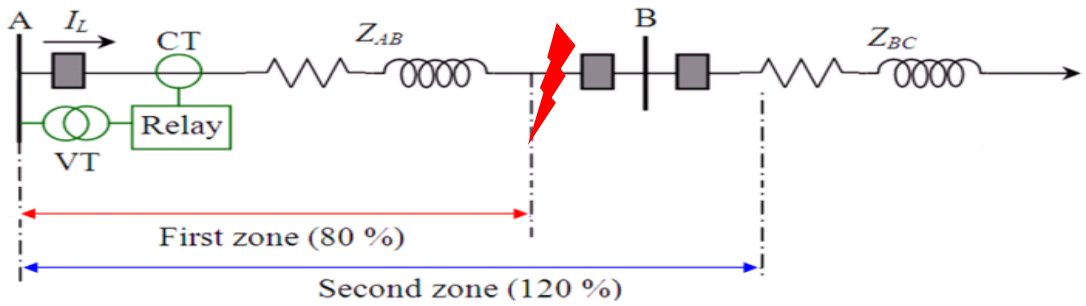
Results:

- Relay takes two cycles to trip the circuit breaker
- Relay front panel shows:
  - TRIP
  - INST
  - ZONE1
  - PHASE A
  - GROUND
- Relay operated properly.



Zone 2-Phase to Phase Fault during blackstart steady state

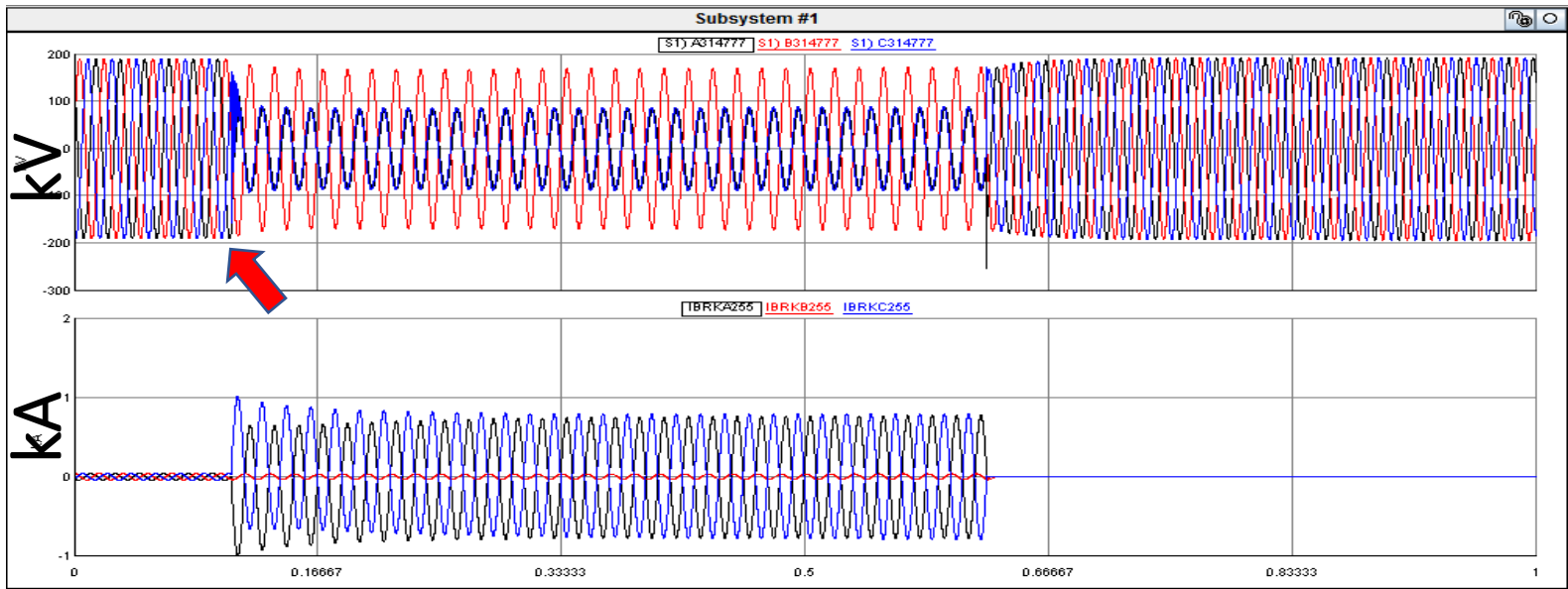




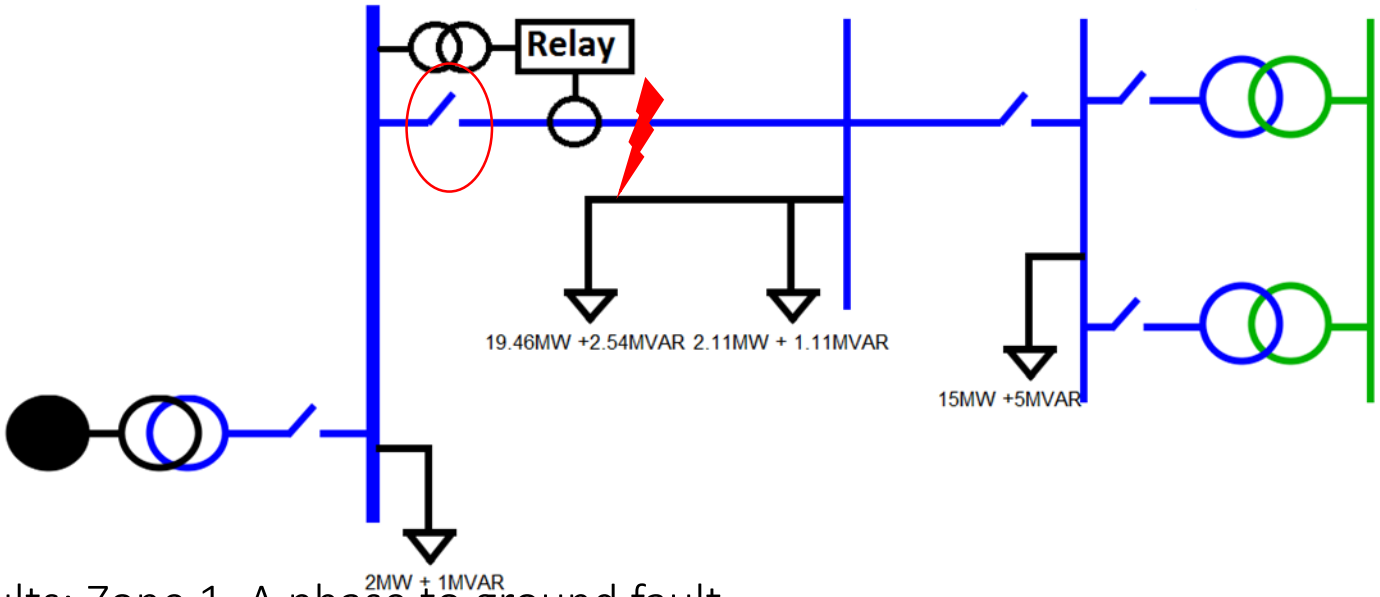
Faults: Zone 2, A phase to C phase fault

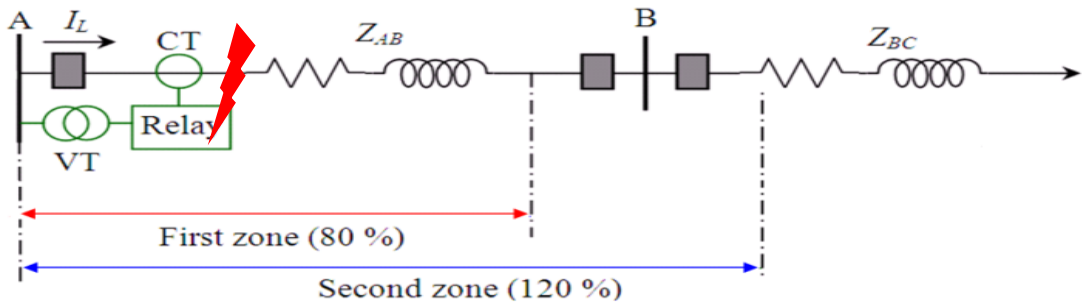
Results:

- Time-delayed backup Relay function waits for half second, then trips the circuit breaker
- Relay front panel shows:
  - TRIP
  - TIME
  - ZONE2
  - PHASE A
  - PHASE C
- Relay operated properly.



Zone 1-Single Phase to Ground Fault during blackstart switching operation



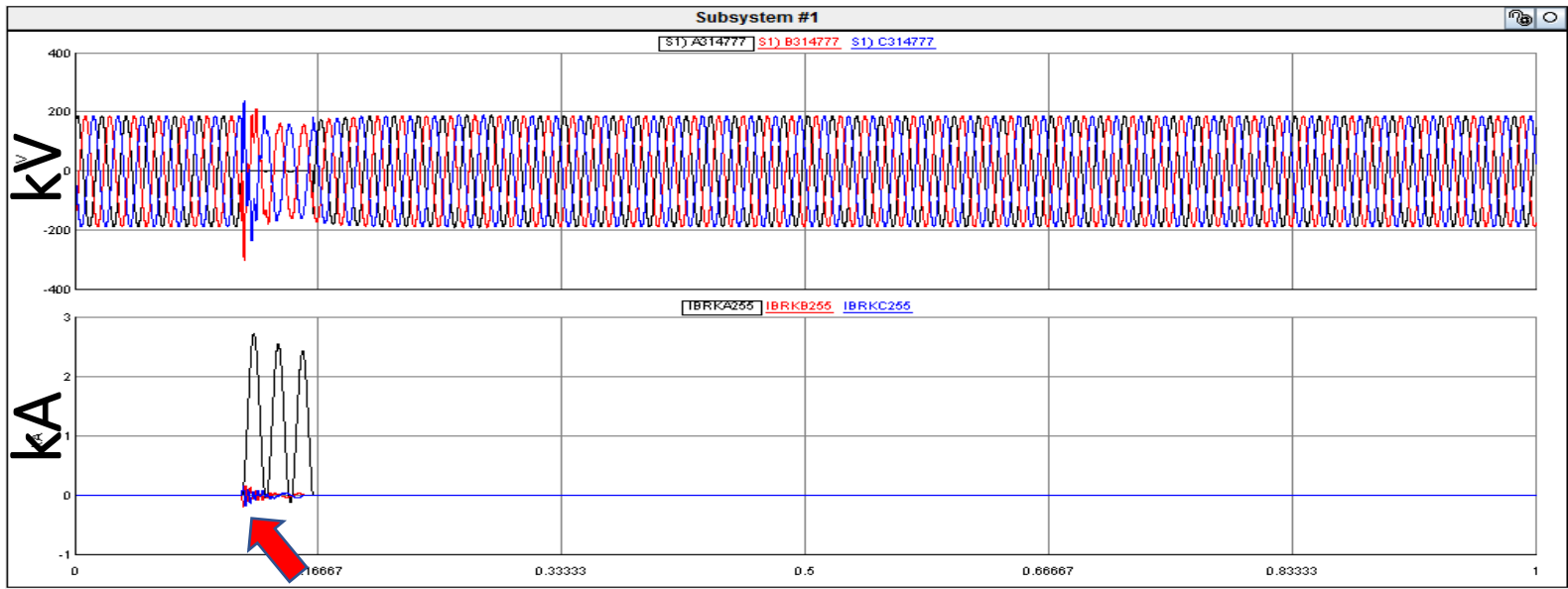


Faults: Zone 1, A phase to ground fault

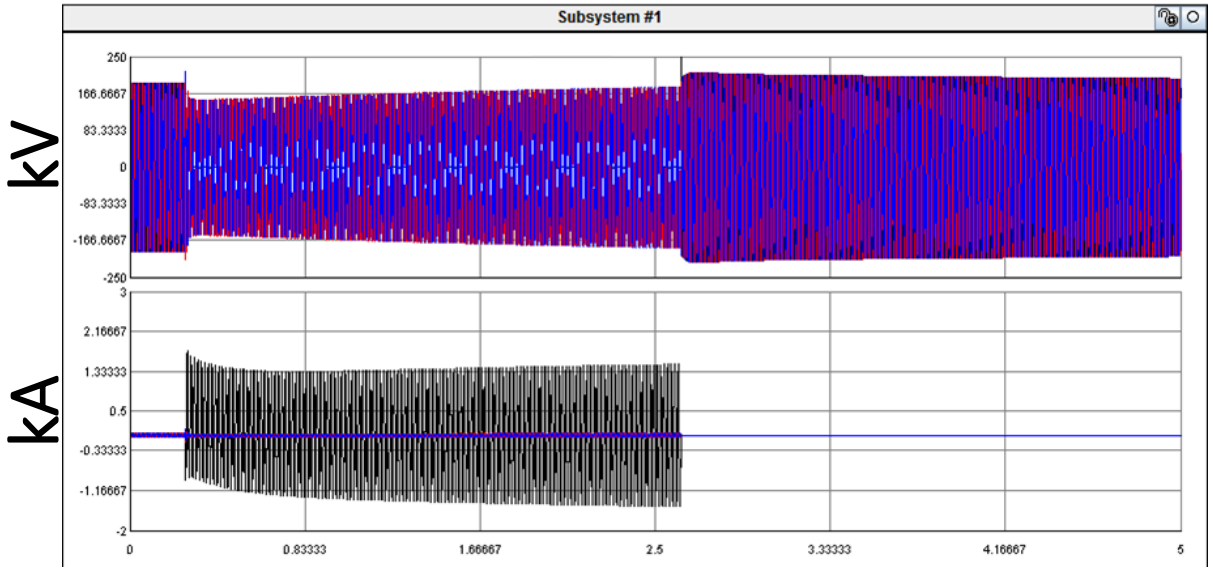
Time: Fault happens when energize Transmission Line

Results:

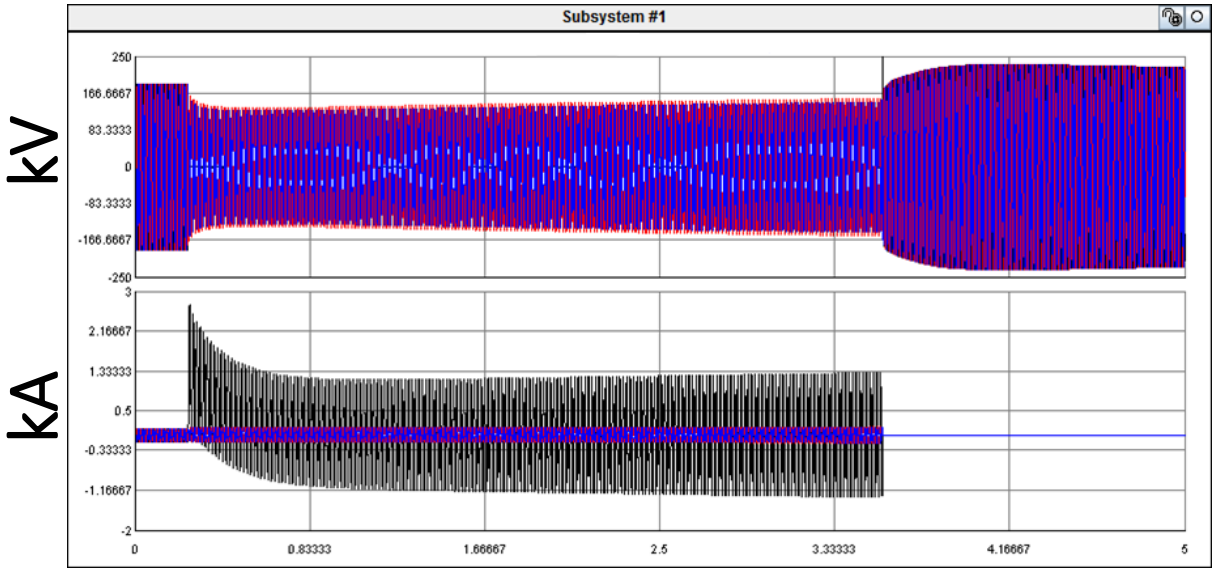
- Relay takes three cycles to send trip to the circuit breaker
- Relay front panel shows:
  - TRIP
  - INST
  - ZONE1
  - PHASE A
  - GROUND
- Relay operation is delayed by switching.



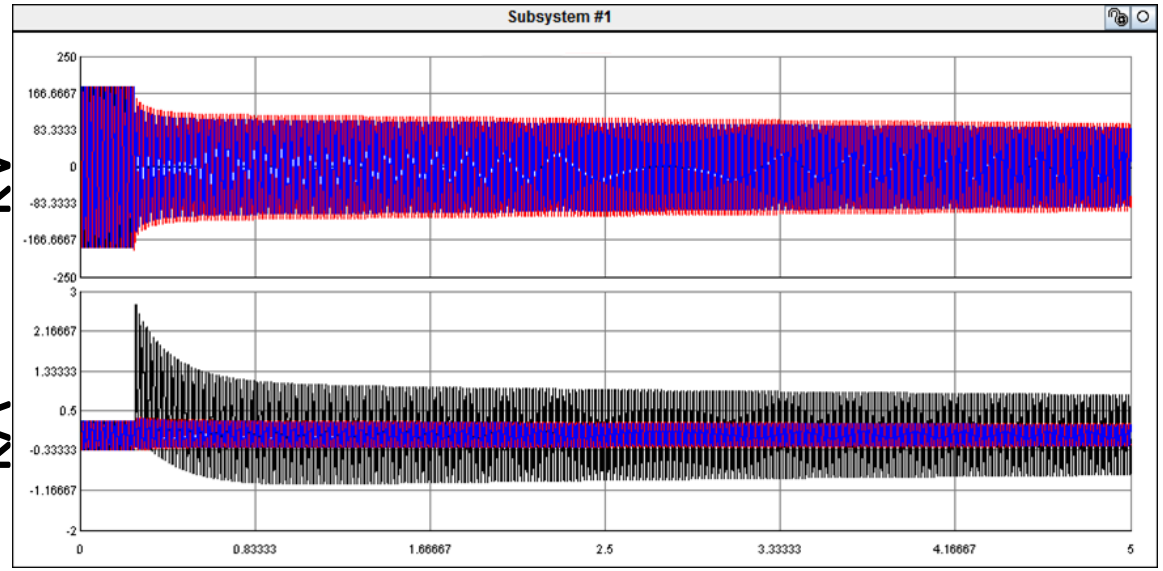
Time-Inverse Overcurrent Backup Protection Scheme Test



Small Load (5MW) Relay trip at 2.3s



Large Load (40MW) Relay trip at 3.3s



Larger Load (80MW) Relay didn't trip

Faults: A phase to ground unbalanced fault

Relay:

- Time-inverse overcurrent backup protection scheme
- Primary line distance protection is disabled.

Results:

- Overcurrent backup protection scheme is delayed and did NOT operate.

Dominion Energy®

Real-time decision support

RTDS

Path 2

Path 3

Path 4

Path 4

Power Grid

Path 1

Path 4

SOC

Conclusion

- In the future, RTDS will be used extensively in Dominion blackstart studies, such as:
  - Improve generator and load modeling (PMU, DFR)
  - Validate more complicated protection schemes
  - Automate the process for different paths in SRP
  - Refine the communication procedure/method with SOC
  - Real-time decision support

- RTDS will play much more important role in blackstart

Questions?

If you have additional questions, please contact me at:
Dr. Ren Liu ren.liu@dominionenergy.com