QUANTA TECHNOLOGY

PROTECTION TESTING OF UTILITY MICROGRIDS EMBEDDING GRID-FORMING INVERTERS

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2023 North American RTDS TECHNOLOGIES INC. APPLICATIONS & TECHNOLOGY CONFERENCE

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AGENDA

- ❑ Introduction
- ❑ System Model in RSCAD
- ❑ RTDS Setup
- ❑ Test scenarios & results
- ❑ Conclusion

INTRODUCTION

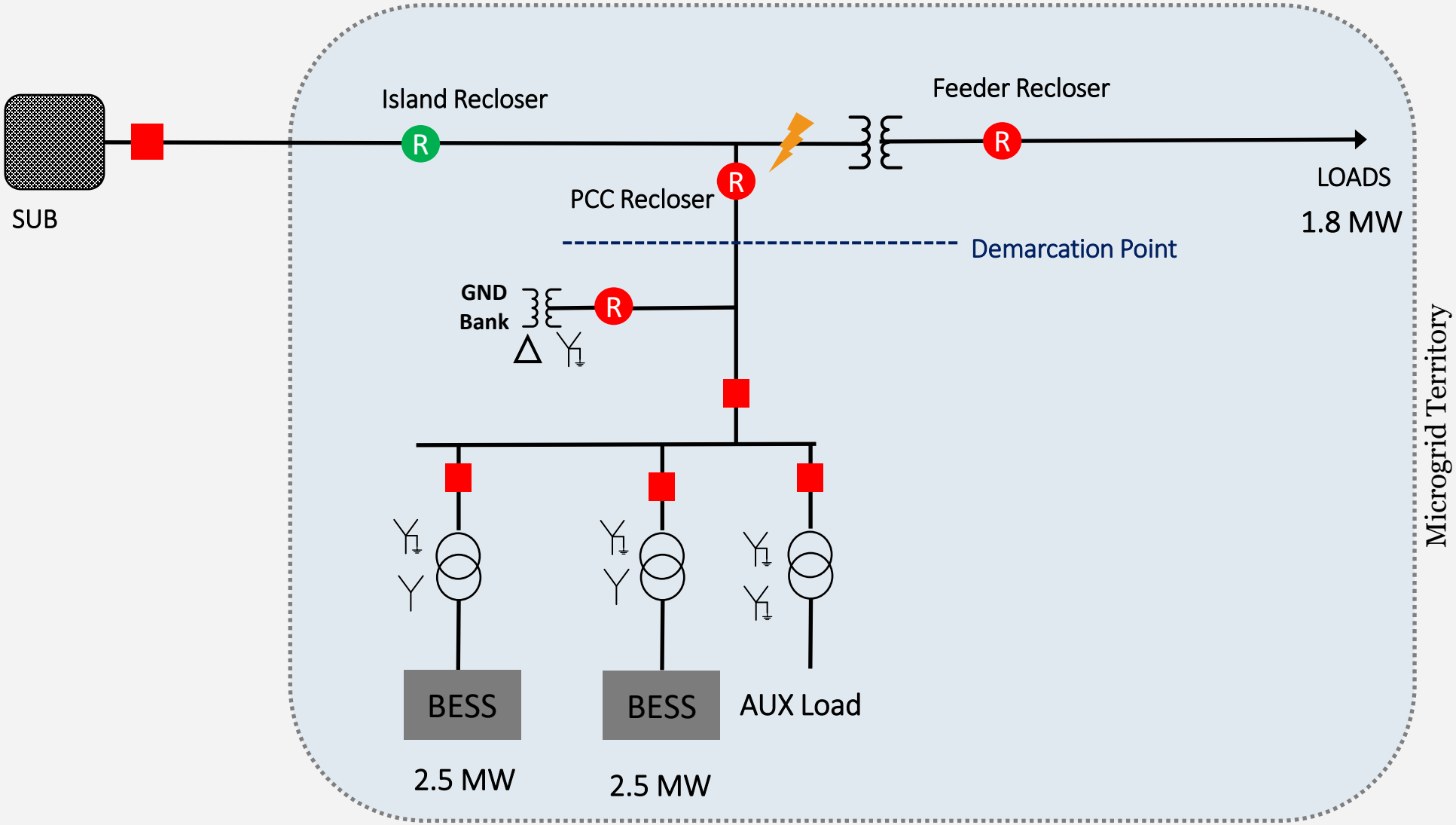
- Advances in control of IBRs enable deployment of microgrids for improved electric power system reliability and resiliency.
- Microgrids pose significant operational challenges to distribution systems due to various operating modes, fault current characteristics, nontraditional energy resource response, and advanced automation schemes.
- Reliable protection scheme design for microgrids in both **grid-connected** and **island modes** is challenging, requiring special studies and testing for sensitive and selective overcurrent, voltage, and frequency protection.

QUANTA TECHNOLOGY

INTRODUCTION

- Non-conventional fault behavior of **grid-forming inverters** as a dominant source of energy in the island mode highlights the importance of protection system design for microgrids.
- The presentation focuses on **pre-deployment testing of protection systems** for utility microgrids embedding grid-forming Inverters.
- **The microgrid system is simulated in a Real-Time Digital Simulator (RTDS) and interfaced with protective relays for microgrid protection.**
- The effectiveness of the proposed protection system is evaluated through comprehensive **Controller Hardware-in-the Loop (CHIL) testing,** considering microgrid control system interaction during various operating conditions and faults.

MG SIMPLIFIED SLD (ISLANDING MODE)



RSCAD MODEL VALIDATION

- ❑ **Model validation performed**
  - **Through the comparison between PSCAD model and RSCAD model results**
  - **Through load flow and short-circuit analysis in both Islanding and grid-connected mode**
- ❑ **Inverter model in PSCAD is provided by inverter manufacture**

Short Circuit Validation (Islanding Mode)

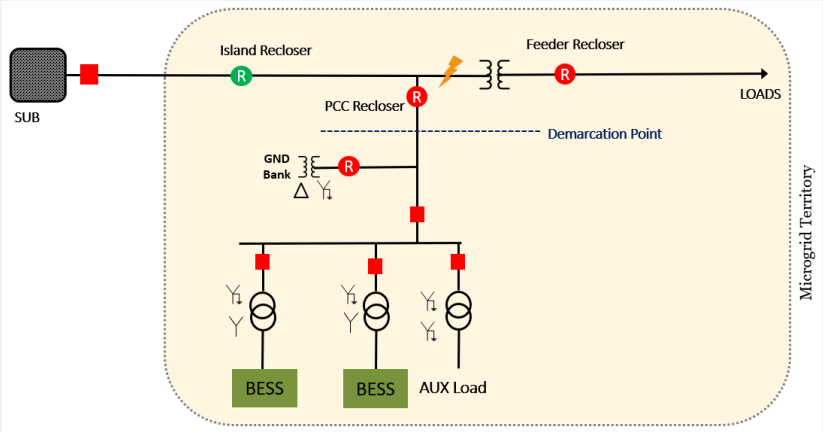
Node	PSCAD		RSCAD		Error (%)	
	LLLG Fault (A)	SLG Fault (A)	LLLG Fault (A)	SLG Fault (A)	LLLG Fault	SLG Fault
PCC Recloser	102.00	153.00	101.00	153.00	0.98	0.00
Feeder HEAD	288.00	435.00	288.00	450.00	0.00	-3.45
Feeder End	275.00	380.00	275.00	377.50	0.00	0.66

Load Flow Validation (Islanding Mode)

Node	PSCAD			RSCAD			Error (%)		
	P(kW)	Q(kVAr)	V (V)	P(kW)	Q(kVAr)	V (V)	P	Q	V
PCC Recloser	1826.00	-189.00	20.66	1850.00	-178.00	20.60	-1.31	5.82	0.31
BESS1_HV	900.00	84.00	20.65	908.00	79.00	20.64	-0.89	5.95	0.05
Feeder HEAD	1804.00	-335.00	7.29	1870.00	-346.80	7.28	-3.66	-3.52	0.09
Feeder End	0.00	0.00	7.15	0.00	0.00	7.17	0.00	0.00	-0.23

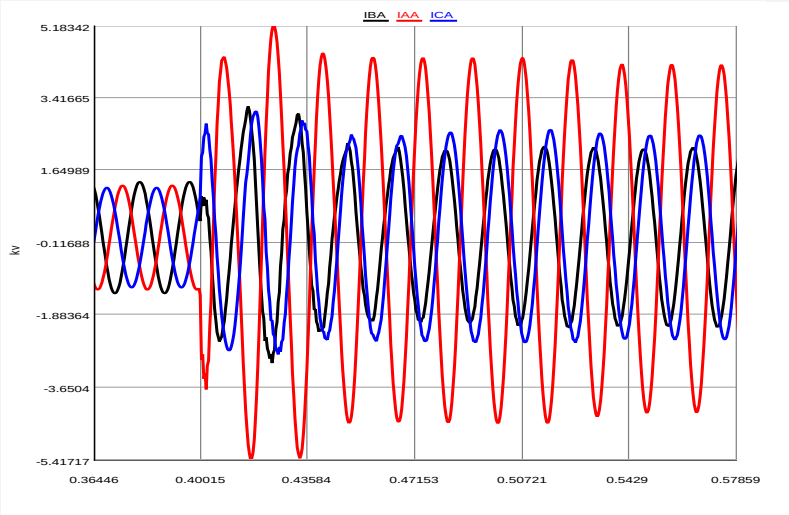
INVERTER MODEL VALIDATION (SLG FAULT AT PCC)

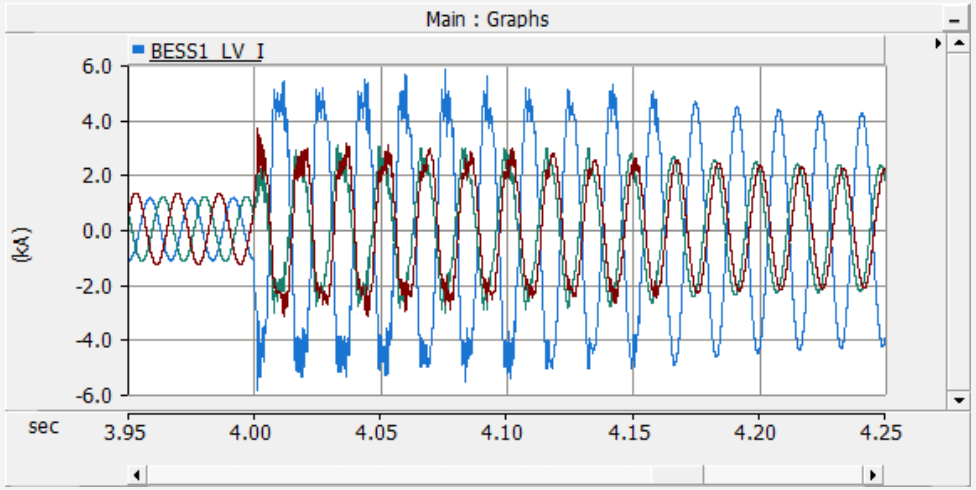
RSCAD



PSCAD

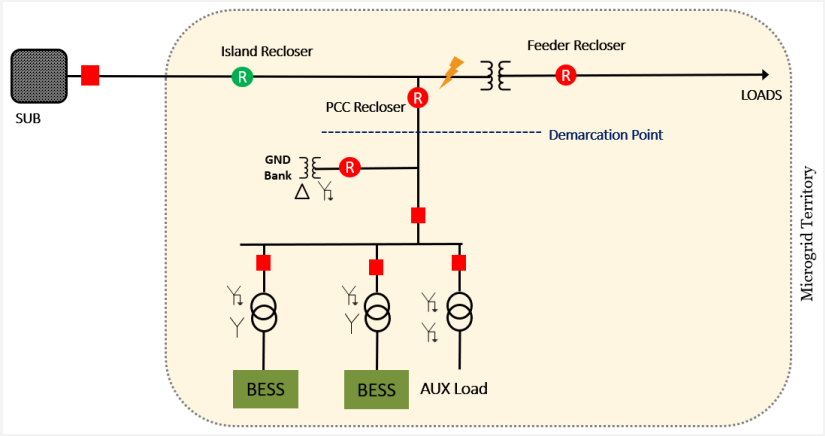
BESS-1 Current during Fault Initiation





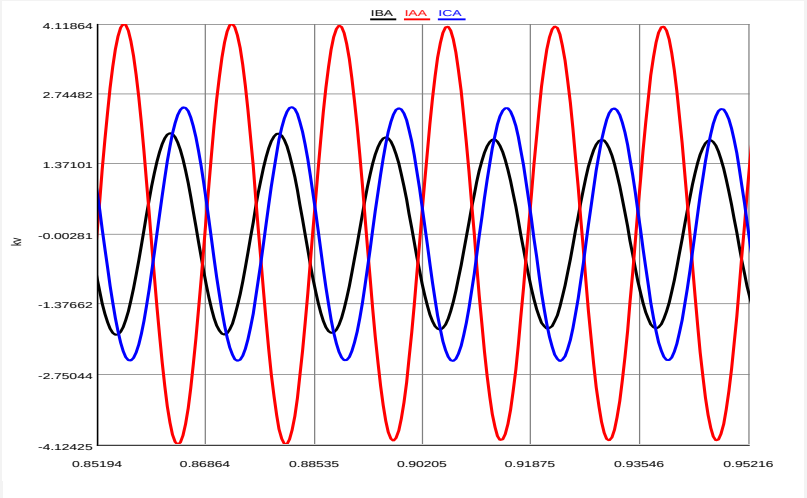
INVERTER MODEL VALIDATION (SLG FAULT AT PCC)

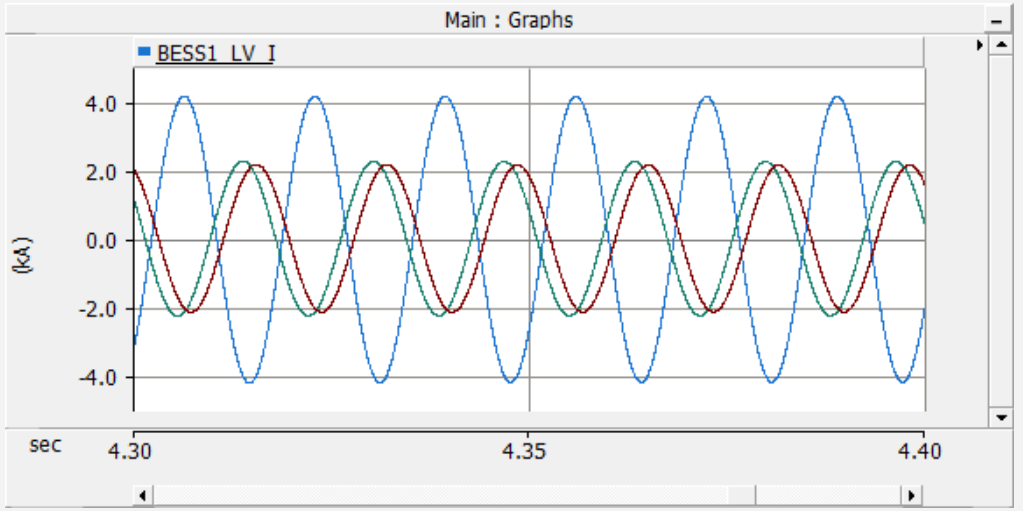
RSCAD



PSCAD

BESS-1 Current after Fault (steady state)

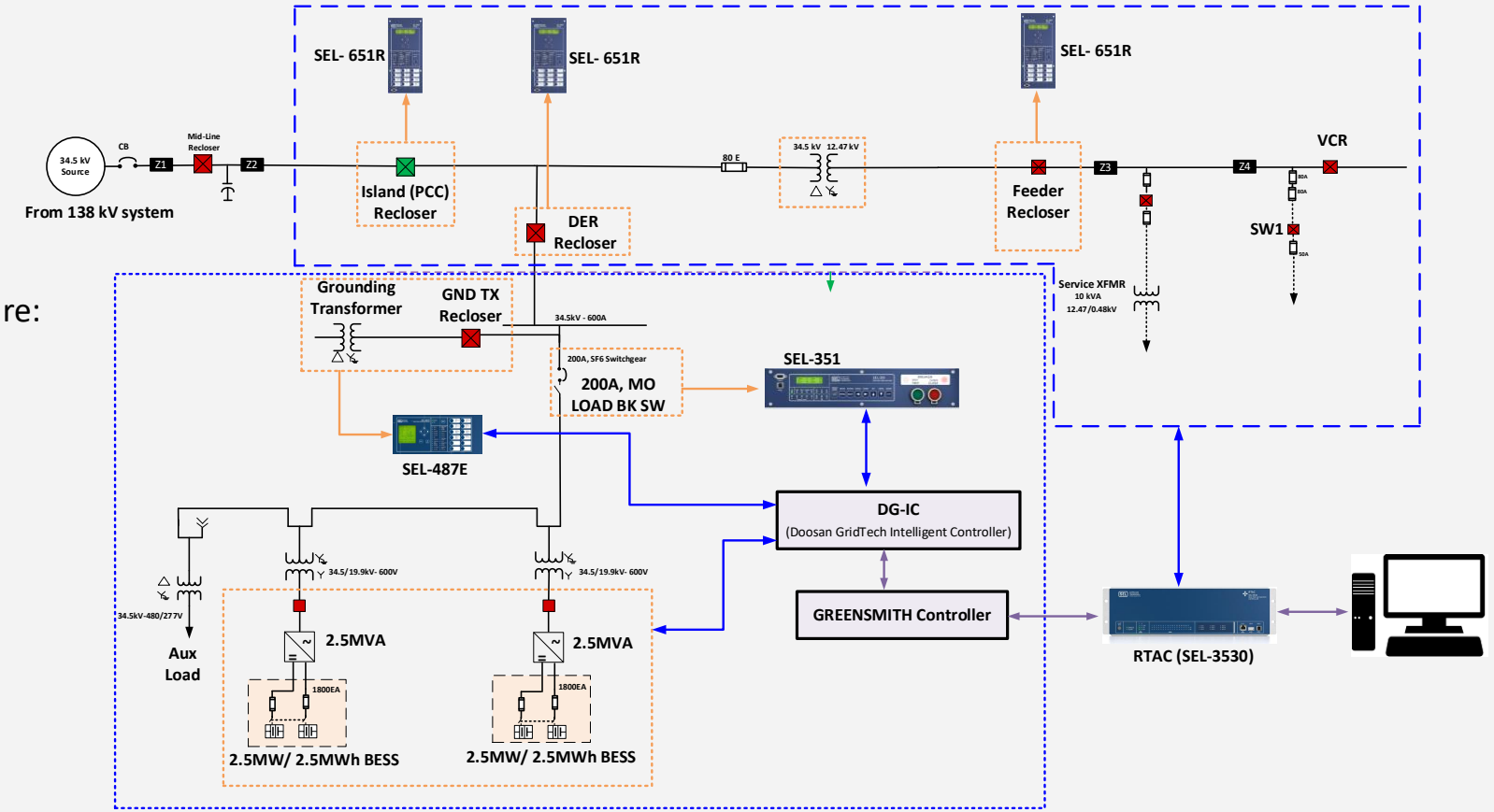




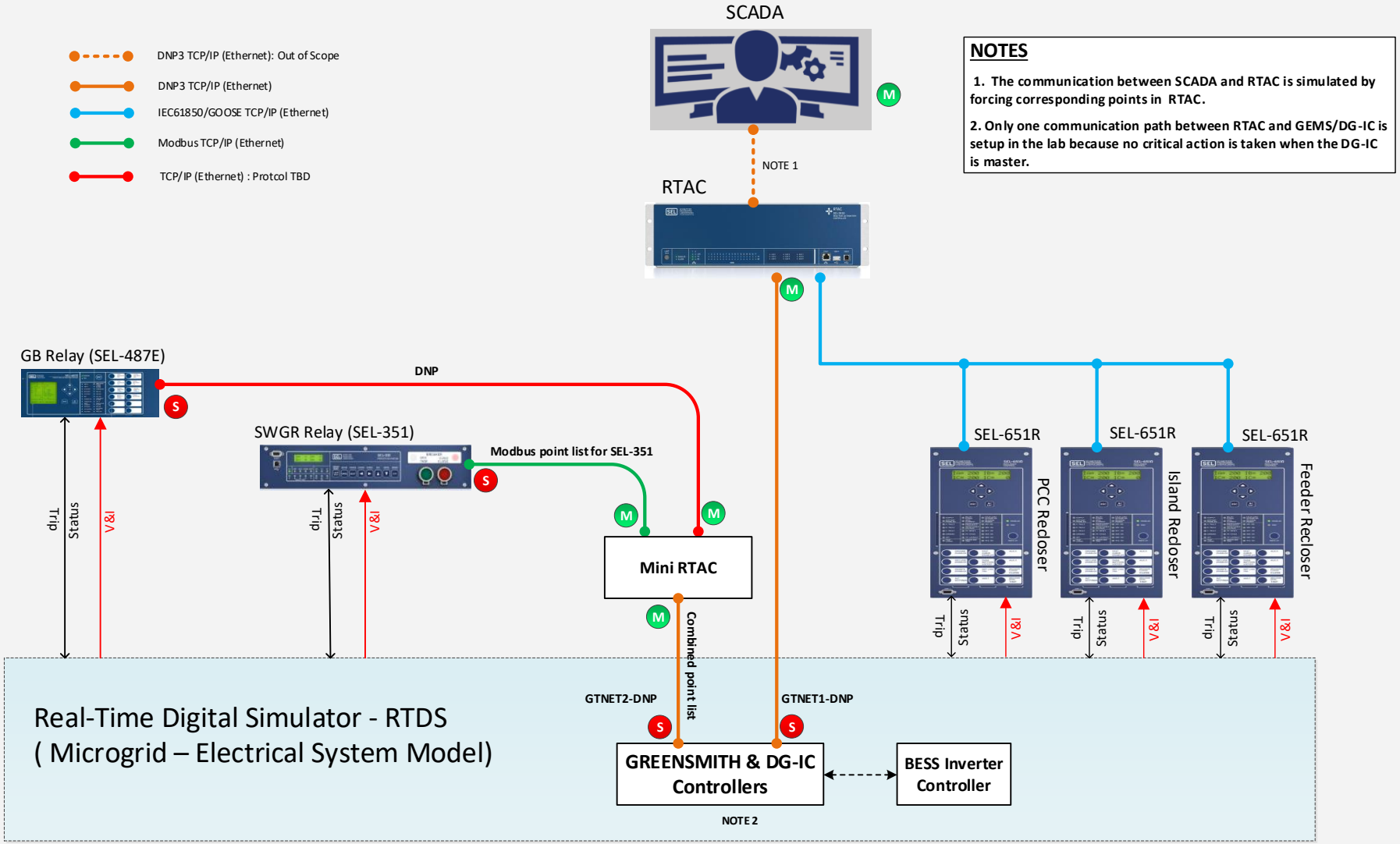
RTDS CONTROLLER HARDWARE IN LOOP (CHIL) SETUP

The major equipment included in this CHIL test setup are:

1. Relays
a) Islanding recloser controller, SEL-651R
b) PCC recloser controller, SEL-651R
c) Feeder recloser controller, SEL-651R
d) Intertie relay, SEL-351
e) Grounding transformer relay, SEL-487E
f) Real Time Automation controller (RTAC)



RTDS TEST SETUP ARRANGEMENT

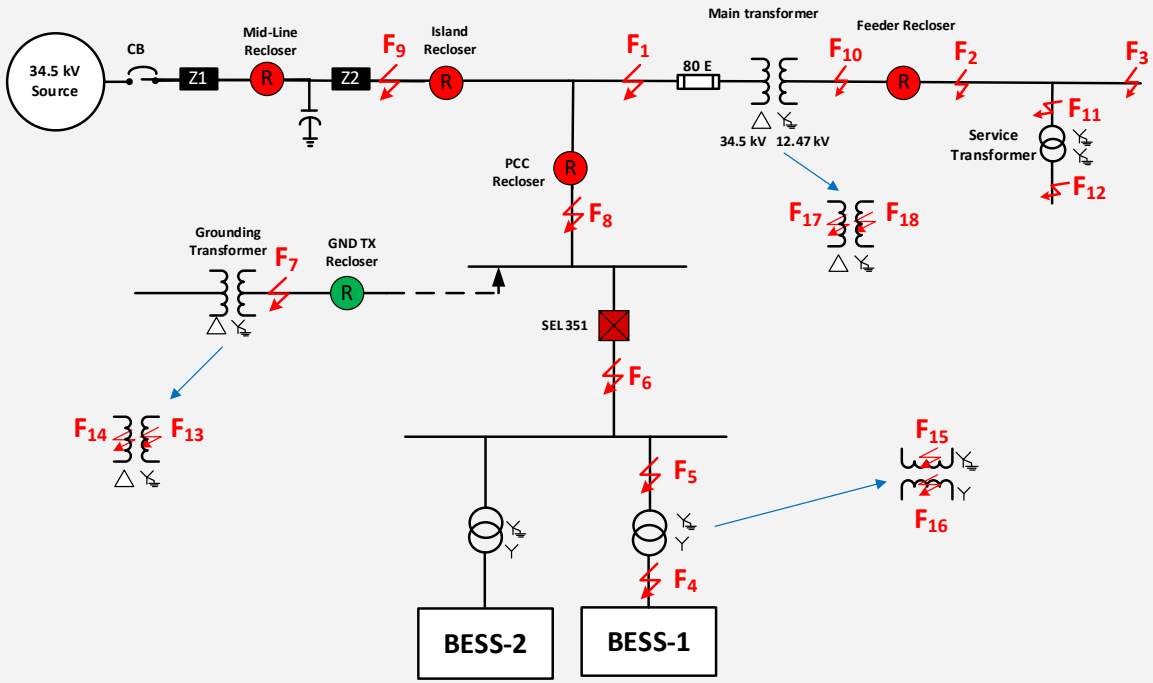


NOTES

1. The communication between SCADA and RTAC is simulated by forcing corresponding points in RTAC.
2. Only one communication path between RTAC and GEMS/DG-IC is setup in the lab because no critical action is taken when the DG-IC is master.

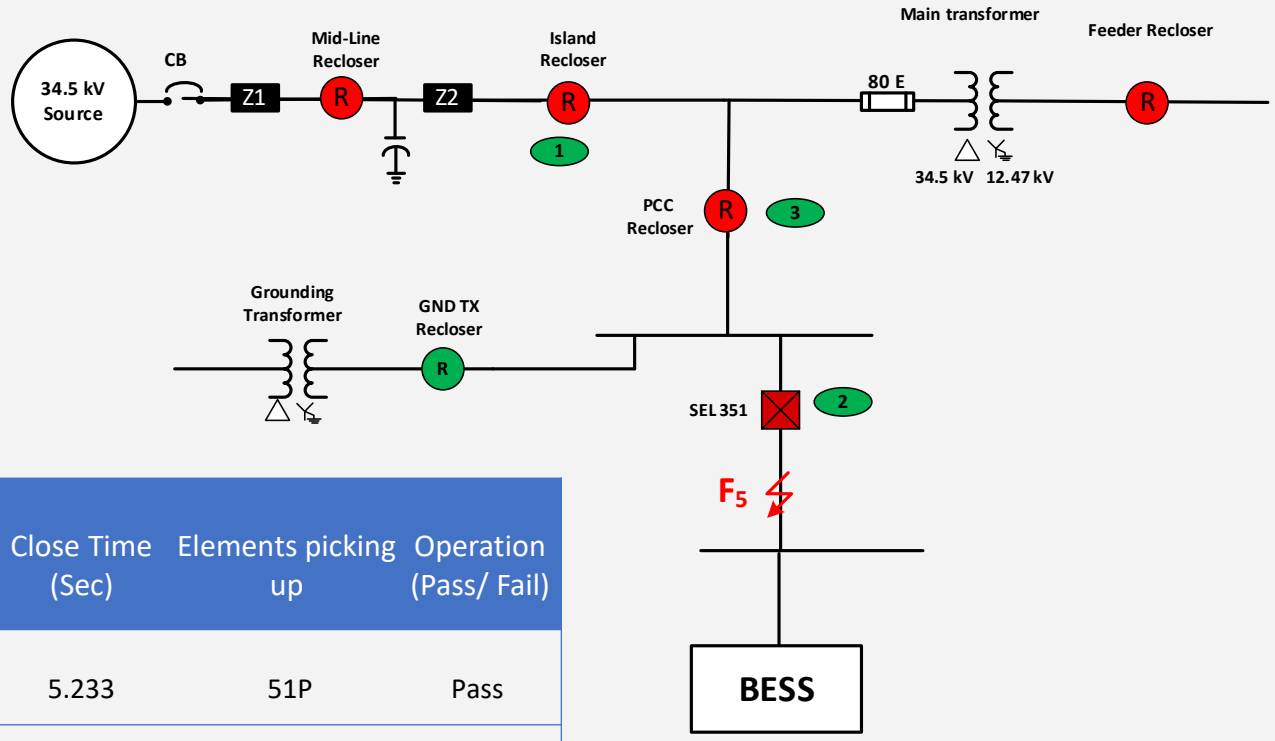
TEST SCENARIOS

1. **Operation condition:** Islanded mode & Grid-connected mode
2. **Loading condition:** Peak loads & Valley Load
3. **Fault Studies:** LLLG , LL, SLG
4. **Abnormal Cases:** Motor-starting , Transformer energization, Voltage transients (Load Rejection Overvoltage – LROV), Capacitor switching
5. **Functional and Communication Tests:** Black start and Load restoration, Grid reconnection, Loss of communication, BESS contingency (1 BESS out of service)



TEST RESULTS

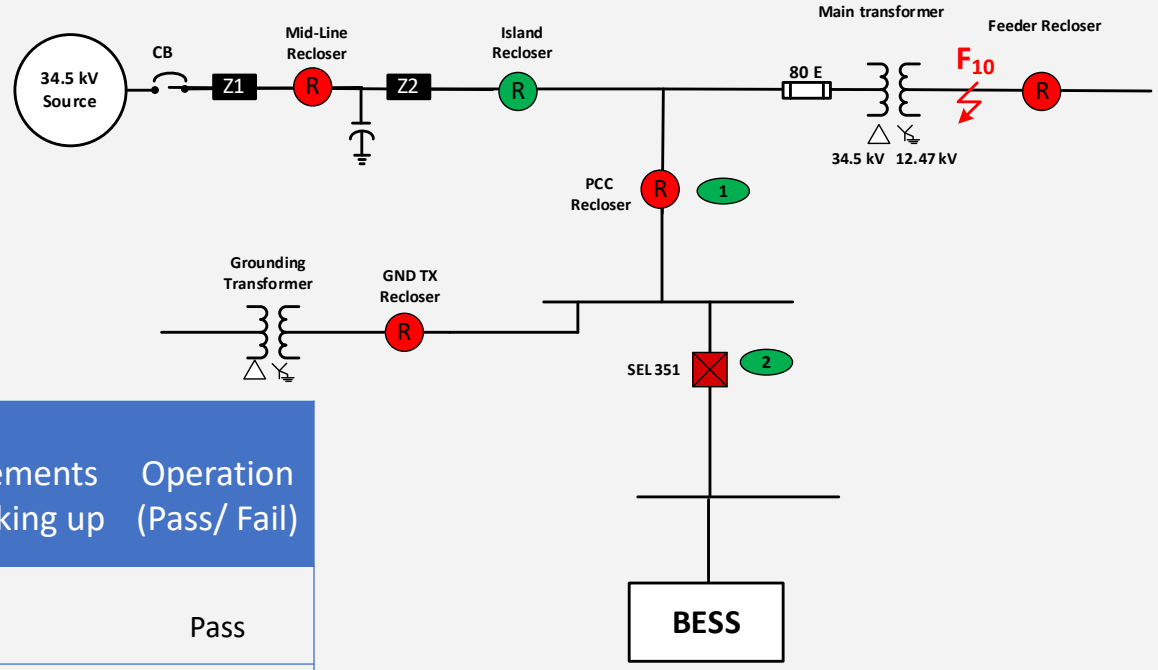
F5 – 3LG – Grid Connected Mode



No	Fault Location/ Case	Fault Type	Fault Duration	Islanded/Grid -Connected	Loading	Relays	Trip time (sec)	Close Time (Sec)	Elements picking up	Operation (Pass/ Fail)
1	**F5**	**3LG**	**Permanent**	**Grid-Connected**	**Peak**	**Island Recloser (SEL-651R)**	0.03745	5.233	51P	Pass
						Feeder Recloser (SEL-651R)			-	-
						PCC recloser (SEL-651R)	0.5199		27	Pass
						Intertie Switch (SEL-351)	0.1772		27	Pass
						Inverter	2.502		27	Pass
						Fuse	-		-	-

TEST RESULTS

F10 – 3LG – Islanded Mode



No	Fault Location/ Case	Fault Type	Fault Duration	Islanded/Grid-Connected	Loading	Relays	Trip time (sec)	Elements picking up	Operation (Pass/ Fail)
1	**F10**	**3LG**	**Permanent**	**Islanded**	**Peak**	**Feeder Recloser (SEL-651R)**	-		Pass
						PCC recloser (SEL-651R)	0.05465	50P	Pass
						Intertie Switch (SEL-351)	2.12	27	Pass
						Inverter	0.08255	59	Pass
						Fuse	-	-	-
						GB Relay (SEL-487E)	-	-	-

TEST RESULTS

Black Start

RTAC Black Start Sequence

Step	Description	System State
1	System is islanded	Island Mode
2	Grid voltage returns	Island Mode
3	RTAC waits for 5 minutes for grid voltage to stay healthy	Island Mode
4	After 5 minutes, RTAC opens PCC and Feeder reclosers	Open Critical Points
5	RTAC requests Greensmith to disable islanding	Remove Island Signal
6	RTAC changes PCC and Feeder groups back to normal	Change Groups to Normal
7	RTAC closes Island and Feeder reclosers	Close Critical Points
8	System is in normal condition	System Normal
9	RTAC waits 3 minutes to close PCC (delayed restore)	System Normal

RTAC Black Start SOE

Tag Name	Message	Time
gv_System_Enabled	Asserted	5:32:06 PM
Tags.IID_3P59Y.stVal	Grid Lost	5:32:18 PM
Tags.OpenIID.stVal	Asserted	5:33:28 PM
Tags.OpenPCC.stVal	Asserted	5:33:28 PM
Tags.OpenSW1.stVal	Asserted	5:33:28 PM
Tags.SW1_52A3P.stVal	Open	5:33:28 PM
Tags.IID_52A3P.stVal	Open	5:33:28 PM
Tags.OpenIID.stVal	Deasserted	5:33:29 PM
Tags.OpenPCC.stVal	Deasserted	5:33:29 PM
Tags.OpenSW1.stVal	Deasserted	5:33:29 PM
Tags.PCCIslandSettings.stVal	Asserted	5:33:29 PM
Tags.PCC_Setting_Group_1.stVal	Deasserted	5:33:29 PM
Tags.PCC_Setting_Group_2.stVal	Asserted	5:33:29 PM
Tags.PCCIslandSettings.stVal	Deasserted	5:33:29 PM
Greensmith_DNP.ISLAND_PERMISSVIE.operLatchOn.ctlVal	Asserted	5:33:29 PM
Greensmith_DNP.ISLAND_PERMISSVIE.operLatchOn.ctlVal	Deasserted	5:33:55 PM
Greensmith_DNP.ISLAND_ENABLED.stVal	System Islanded	5:33:55 PM
Tags.ClosePCC.stVal	Asserted	5:33:55 PM
Tags.PCC_52A3P.stVal	Closed	5:33:55 PM
Tags.ClosePCC.stVal	Deasserted	5:33:55 PM
Tags.SW1IslandSettings.stVal	Asserted	5:33:56 PM
Tags.SW1_Setting_Group_4.stVal	Deasserted	5:33:57 PM
Tags.SW1_Setting_Group_6.stVal	Asserted	5:33:57 PM
Tags.SW1IslandSettings.stVal	Deasserted	5:34:05 PM
Tags.CloseSW1.stVal	Asserted	5:34:06 PM
Tags.SW1_52A3P.stVal	Closed	5:34:06 PM

TEST RESULTS

Grid Reconnection

RTAC Reconnection Sequence

Step	Description	System State
1	System is islanded	Island Mode
2	Grid voltage returns	Island Mode
3	RTAC waits for 5 minutes for grid voltage to stay healthy	Island Mode
4	After 5 minutes, RTAC opens PCC and Feeder reclosers	Open Critical Points
5	RTAC requests Greensmith to disable islanding	Remove Island Signal
6	RTAC changes PCC and Feeder groups back to normal	Change Groups to Normal
7	RTAC closes Island and Feeder reclosers	Close Critical Points
8	System is in normal condition	System Normal
9	RTAC waits 3 minutes to close PCC (delayed restore)	System Normal

RTAC Reconnection SOE

Tag Name	Message	Time
Tags.IID_3P59Y.stVal	Grid OK	5:34:37 PM
Tags.OpenPCC.stVal	Asserted	5:35:38 PM
Tags.OpenSW1.stVal	Asserted	5:35:38 PM
Tags.PCC_52A3P.stVal	Open	5:35:38 PM
Tags.SW1_52A3P.stVal	Open	5:35:38 PM
Tags.OpenPCC.stVal	Deasserted	5:35:38 PM
Tags.OpenSW1.stVal	Deasserted	5:35:38 PM
Tags.CloseSW1.stVal	Deasserted	5:35:38 PM
Tags.SW1NormalSettings.stVal	Asserted	5:35:38 PM
Tags.SW1_Setting_Group_4.stVal	Asserted	5:35:40 PM
Tags.SW1_Setting_Group_6.stVal	Deasserted	5:35:40 PM
Greensmith_DNP.ISLAND_ENABLED.stVal	Deasserted	5:35:59 PM
Tags.PCCNormalSettings.stVal	Asserted	5:36:01 PM
Tags.PCC_Setting_Group_1.stVal	Asserted	5:36:02 PM
Tags.PCC_Setting_Group_2.stVal	Deasserted	5:36:02 PM
Tags.PCCNormalSettings.stVal	Deasserted	5:36:02 PM
Tags.CloseIID.stVal	Asserted	5:36:02 PM
Tags.IID_52A3P.stVal	Closed	5:36:02 PM
Tags.CloseIID.stVal	Deasserted	5:36:02 PM
Tags.SW1NormalSettings.stVal	Deasserted	5:36:02 PM
Tags.CloseSW1.stVal	Asserted	5:36:02 PM
Tags.SW1_52A3P.stVal	Closed	5:36:03 PM
Tags.CloseSW1.stVal	Deasserted	5:36:03 PM
Tags.ClosePCC.stVal	Asserted	5:39:03 PM
Tags.PCC_52A3P.stVal	Closed	5:39:03 PM
Tags.ClosePCC.stVal	Deasserted	5:39:03 PM

CONCLUSION

- Most of the utilities require comprehensive testing of microgrid protection and control (P&C) systems before commissioning. This is because:
  - Grid-forming inverter technology is new and their fault response is not fully known.
  - Special (non-standard) protection schemes and setting values may be needed for Islanding operation.
- RTDS provides a proper platform to test Microgrid P&C systems before field deployments.
- The conducted studies resulted in a better understanding of the relays performance, especially protection coordination and protection settings troubleshooting.
- Based on the results of the CHIL testing, some of the originally designed protection schemes and settings were modified for grid-connected and islanded modes. Some of the original MG site controller settings were also modified.
- Generally, generic inverter models are used and their control parameters are tuned to verify vendor EMT models; however, detailed vendor control shall be included in the GFM RSCAD model:
  - Digital-twin model of inverter by having the inverter controller as hardware is proposed to resolve this issue