Distribution Automation Case Study using RTDS

For
Intended Recipient(s) Only

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1. Introduction

RTDS was used for testing real IEDs in a closed loop simulation setup for a Distribution Automation project. The test setup consisted of physical IED's controlling one Feeder Tie Breaker, two Reclosers, one Voltage Regulator, three Cap Banks, two Switched Loads, and two DERs. This report discusses the RSCAD/RTDS model development aspect of the project. HIL testing results which demonstrated successful implementation of all use cases is not included in this report.

2. Assumptions, Estimates, Limitations

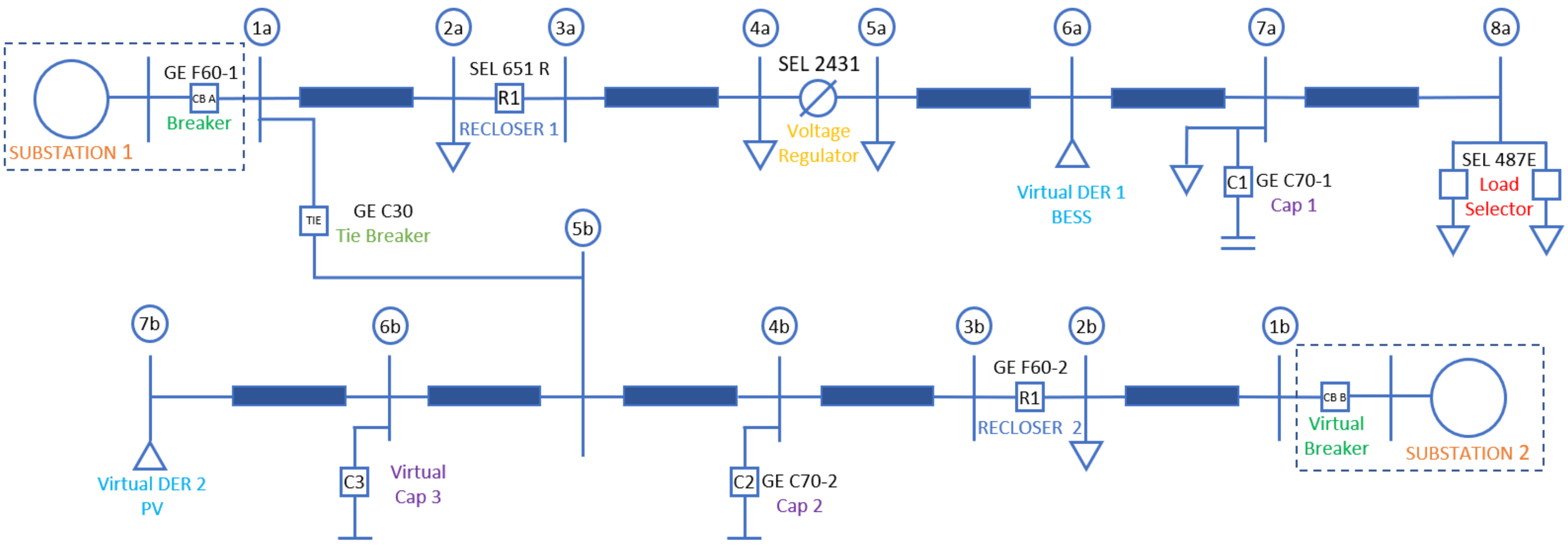
- The RSCAD case was developed in Distribution mode of RTDS which models the components with less details compared to normal mode. For testing objective of this project, accuracy of the distribution mode is adequate.
- The simulation case represents a typical utility distribution feeder. Loads have been aggregated to make the circuit simpler yet detailed enough to demonstrate all use cases.
- All distribution line sections have been modelled using PI model since the length of the lines are small and the accuracy of the PI model is sufficient for the objective of this study.
- Charging capacitance of the line sections is either ignored or estimated as this data was not available.
- The substation transformer and the high side grid is modeled with a Thevenin equivalent source so that the fault level on the low side substation bus is proper.

3. Methodology

1. The RSCAD model of circuit 1 and 2 was developed based on the distribution data extracted from distribution database.
2. Feeder sections are equivalenced judiciously by retaining only the buses that have loads, capacitor banks, reclosers, tie-breaker, regulators, etc., that are needed to exercise the use case scenarios.
3. The RSCAD model is validated against the load flow and short circuit data. The main purpose of this process is to validate the extracted data and the equivalencing process. Because of the equivalencing described above, certain mismatch is to be expected.
4. The RSCAD GTAO, GTAI, GTDO and GTDI components were added to the model for communication with IEDs through wired signal connection either directly at low-level interface or via Voltage/Current amplifiers.
5. GTNET card with required protocols such as DNP3 and MODBUS are added to the model to represent protocol-based interface with the IEDs and controllers.
6. Three virtual controllers (one each for breaker, capacitor and DER) were added to the simulation to communicate with rest of the physical devices/controllers through DNP and MODBUS communication protocol (GTNETx2). The purpose of this is to demonstrate RTDS capability to provide a virtual means to expand the number of communication test points beyond the available physical devices to exercise the central controller such as DMS/ADMS, HMI, etc.

Detailed description of the case is discussed under the RSCAD model development section.

4. RSCAD Model



DEVICES:

- Two feeder sources (Left and Right)
- One Feeder Tie Breaker
- Two Reclosers
- One Voltage Regulator
- Three Cap Bank Controller
- Two switched loads
- Two DERs
- Two substation breakers and protection

Figure 1: Equivalenced Single Line Diagram of Multi-Source Distribution Feeder

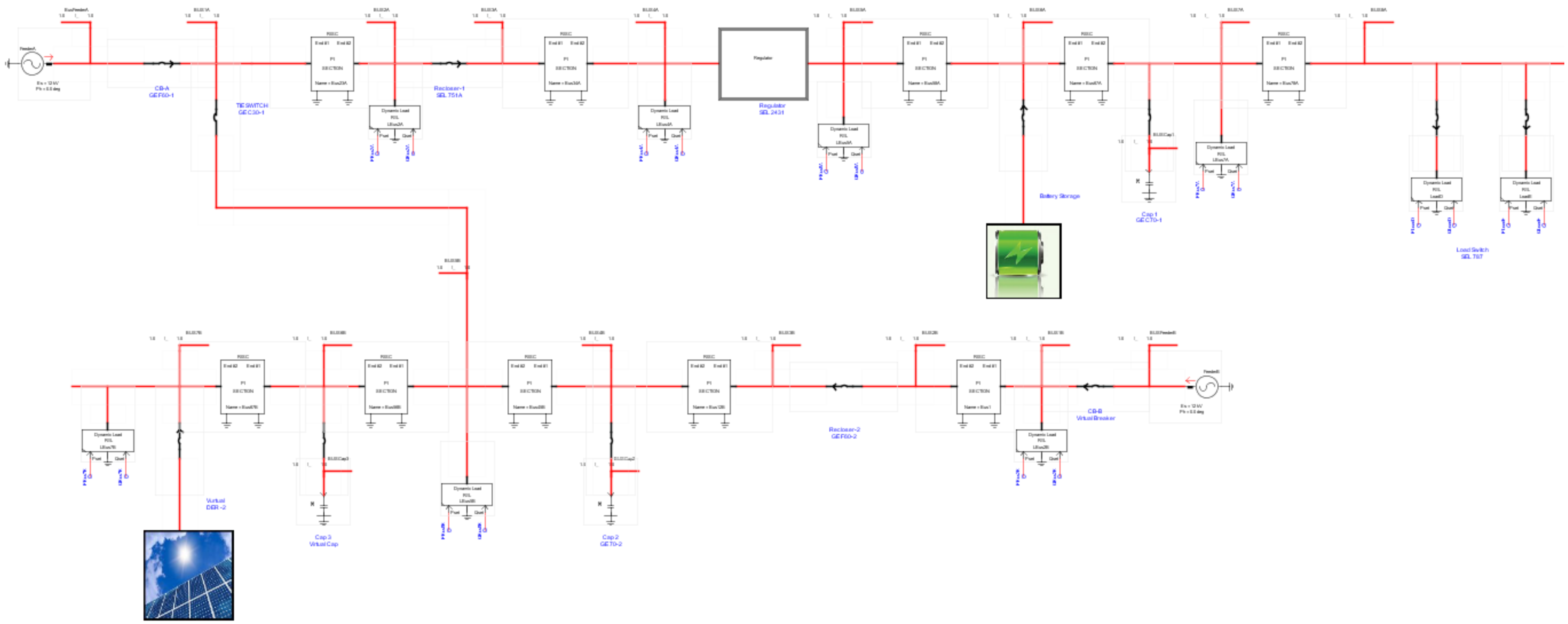


Figure 2: RSCAD Implementation of Multi-Source Distribution Feeder Automation

IED	Circuit	Node (as per SLD)	RSCAD Bus Number
CB-A (GE F60-1)	1	Bus Feeder A & 1	Bus Feeder A & 1A
CB-B (Virtual Breaker)	2	Bus Feeder B & 1B	Bus Feeder B & 1B
Tie (GE C30)	1	1A	1A
	2	5B	5B
Battery Storage (PHIL)	1	6A	6A
Recloser 1 (SEL 651R)	1	2A & 3A	2A & 3A
Cap-1 (GE C70-1)	1	7A	7A
Voltage Regulator (SEL 2431)	1	4A & 5A	4A & 5A
Load Selector Switch (SEL 487E)	1	8A	8A
Recloser 2 (GE F60-2)	2	2B & 3B	2B & 3B
Cap-2 (GE C70-2)	2	4B	4B
Virtual Cap (Cap-3)	1	6B	6B
Virtual DER 2 (PV)	2	7B	7B

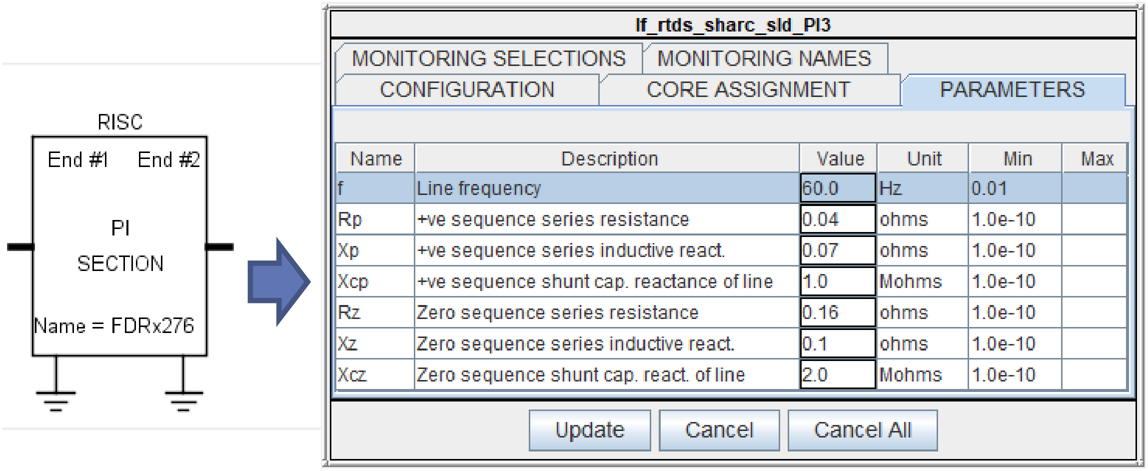
Table 1: Device Location

	Number of Channels				**Number of Cards**	
Device Name	**AO**	**AI**	**DO**	**DI**	**DNP3**	**MODBUS**
F60 - 1	6	0	2	2	0	0
GE C 30	0	0	2	2	0	0
SEL 651 R	6	0	1	2	0	0
GE C 70-1	6	0	2	2	0	0
GE C 70-2	6	0	2	2	0	0
SEL 487 E	9	0	1	4	0	0
F60 - 2	7	0	2	2	0	0
Battery Storage (inverter)	3	3	0	0	0	0
Virtual Breaker	0	0	0	0		0
Virtual Capacitor	0	0	0	0	1	0
Virtual DER -1	0	0	0	0	0	1
Total	**43**	**3**	**12**	**16**	**1**	**1**
# of Cards	**4**	**1**	**1**	**1**	**1**	**1**

Table 2: RTDS I/O Channel Usage

Line Model

All lines have been modelled using PI section line models with R, X, B data obtained from the distribution database.



Name	Description	Value	Unit	Min	Max
f	Line frequency	60.0	Hz	0.01	
Rp	+ve sequence series resistance	0.04	ohms	1.0e-10	
Xp	+ve sequence series inductive react.	0.07	ohms	1.0e-10	
Xcp	+ve sequence shunt cap. reactance of line	1.0	Mohms	1.0e-10	
Rz	Zero sequence series resistance	0.16	ohms	1.0e-10	
Xz	Zero sequence series inductive react.	0.1	ohms	1.0e-10	
Xcz	Zero sequence shunt cap. react. of line	2.0	Mohms	1.0e-10	

Figure 3: RSCAD Line Model

Load Model

All loads have been modelled using the RSCAD “Dynamic Load” model. These models are configured so that the P and Q values can be changed during the simulation using Runtime sliders. This functionality is very useful to emulate various system conditions as per the use cases. These operating sequences (load changes, switch operation, etc. with actual delays between operations) can be programed.

The circuit contains a load selector switch which has been modelled using two dynamic load models. These load models have been configured to change P and Q values of paths S and T during runtime using sliders to emulate various loading scenarios. The load selector is controlled by SEL 487E. The three-phase voltage at the feeder terminal and the three-phase current through each load circuit are sent to SEL 487E through RTDS GTAO channels while breaker commands for each load circuit S and T are fed back into RTDS using GTDI channels. Breaker status signals of S and T are sent to SEL 487 relay using GTDO channels.

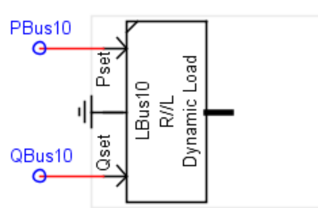


Figure 4: Dynamic load model in RSCAD

Capacitor Bank

Capacitor banks are modelled using RSCAD standard shunt capacitor model. Single phase shunt capacitor models are used to model unbalanced capacitor banks. All capacitor banks have been modelled as fixed capacitors. Capacitor bank (2) in circuit 1 and Capacitor bank (2) in circuit 2 are controlled via external IEDs (C70’s). The voltage and current at the capacitor bank terminal and the breaker status are sent to C70’s through GTAO channels and GTDO channels, respectively. The breaker trip and close commands are taken into RTDS using GTDI channels.

Capacitor bank 3 in circuit 2 is controlled by a virtual capacitor bank controller and is discussed separately.

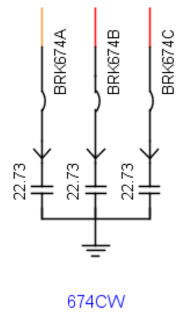


Figure 5: Capacitor bank model

DER

A physical DER setup was used as the distributed energy resource. The model to represent the inverter amplifier set up was added at node 6 of circuit 1 in the RSCAD case. The simulator interface for the power hardware-in loop (PHIL) operation was successfully tested by manually controlling the DER. The terminal voltages at the DER are sent to the amplifier through GTAO card channels and the currents are fed back into the RTDS simulation using GTAI card channels which are interfaced as a current injection source into the feeder model. During demonstration of various use cases, the inverter is controlled from the main Control Portal HMI using MODBUS communication.

Voltage Regulator (741G)

Three single phase voltage regulator models available in RSCAD master library were used to model the voltage regulator. The raise and lower commands to the regulator come from SEL 2431 relay via GTDI. Only phase 'A' voltage at either side of the regulator is sent to the relay using GTAO channels. Other two phases operate using information from Phase A.

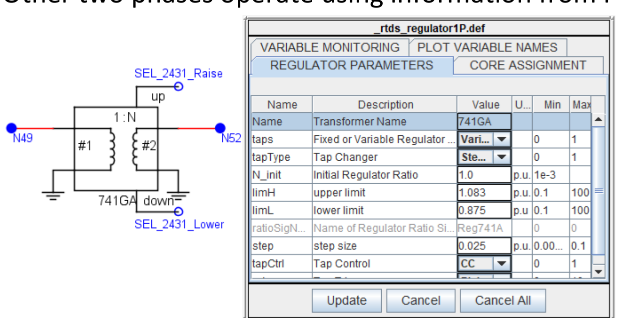


Figure 6: Voltage regulator for Phase A in RSCAD

Recloser

Two reclosers are modelled in the case are controlled by two physical IED's. In RSCAD case, reclosers are modelled as breakers. The voltages at the recloser terminal and the current through them are sent to the IEDs using GTAO cards. The recloser trip and close commands are fed back into RTDS using GTDI channels. The recloser statuses (52a and 52b commands) are sent to IEDs using GTDO channels.

Tie Switch

Tie switch between bus 1 in circuit 1 and bus 5 in circuit 2 is implemented using the RSCAD standard breaker model. The breaker trip and close commands for the tie switch are taken into RTDS using GTDI channels while the tie breaker statuses are sent to physical relay (C30) using GTDO channels.

Breaker Control

Implementation of the breaker control is shown below. Provision has been made to allow manual control in case the user needs to control the breakers without IEDs.

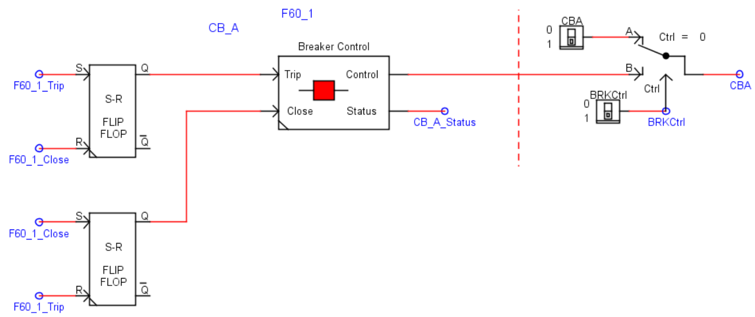


Figure 7: Breaker control

Virtual DER

A dynamic PQ source at bus 7 of circuit 2 has been added to simulate a virtual DERs. P, Q and V set points are provided to RSCAD through MODBUS communication from the control portal depending upon the DER control method. A dynamic PQ source is used to represent PQ control and PV control and are being switched depending upon the control method command coming from control portal. To achieve MODBUS communication, RTDS GTNETx2 cards with MODBUS protocol is used. Point map file for MODBUS communication was developed. A sample map is shown in the Appendix.

Virtual Capacitor

The capacitor 3 in circuit 2 is controlled by a virtual IED. Hence, there is no physical relay controlling this capacitor. The control command for the capacitor breaker arrives from both the traditional HMI and the control portal through DNP protocol. RTDS DNP can only support one master per protocol. Hence, two GTNET DNP protocols are used to allow control from either HMI and control portal. The logic has to accept control commands from either HMI or control portal is programed within the virtual IED setup in RSCAD.

Virtual Breaker

The main feeder breaker controller for circuit 2 is set up as a virtual breaker in RSCAD, i.e., there is no physical IED. Control commands are being sent from the HMI. DNP communication protocol is used to communicate between RTDS and the HMI.

The following sections discuss important aspects about different RTDS I/O cards used.

GTAO

All the above mentioned GTAO signals are first converted to CT/PT secondary quantities before connecting the signals to the GTAO components in RSCAD. Appropriate scaling values have been entered in the GTAO Component. Except for two IEDs, all other GTAO outputs are connected to IEDs at their low-level interface and proper scaling has been implemented by taking into account these low-level interface gains. These values are available in the respective relay manuals and whenever those are not available, manual adjustments have been made by comparing the values seen by the relay and RTDS runtime. Detailed information about CT/PT ratio, GTAO card channel numbers and GTAO scaling factors as used in the RSCAD case for each IED are listed in the Appendix.

GTAO card # which can be seen on the seven-segment display on the card and the fiber port # in the NovaCor chassis it is connected to, must be specified under the GTAO configuration page. The default measured quantities in RSCAD are in kV and kA and hence they have been converted to V and A by multiplying by 1,000 before multiplying by the CT/PT ratios.

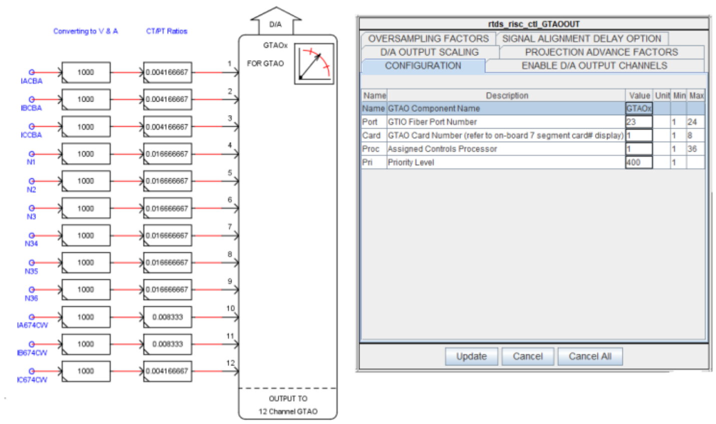


Figure 8: GTAO

GTDI

GTDI card channels are used to bring the relay trip and close commands into RTDS. The relay contacts are dry contacts but to operate GTDI channels, voltage in the range of 5-24V is required. This is achieved by vetting the signal using an external 24 V supply. The connection is as shown below.

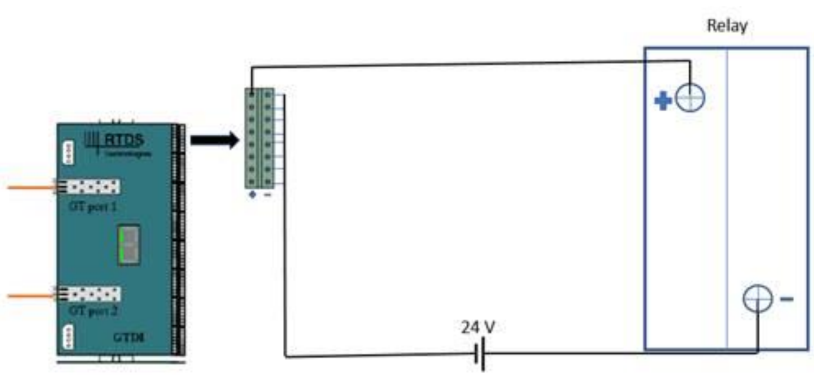


Figure 9: GTDI connection

Care must be taken to replace the SIP resistors of GTDI cards corresponding to the external voltage supply applied. The GTDI channel mapping with respect to each IED is shown in the appendix

GTDO

The breaker statuses (52a and 52b) are sent to IEDs using the GTDO channels. SEL devices require only the breaker status (52a) while GE devices require both 52a and 52b. The relays require a 24 V signal and hence, external voltage supply is used.

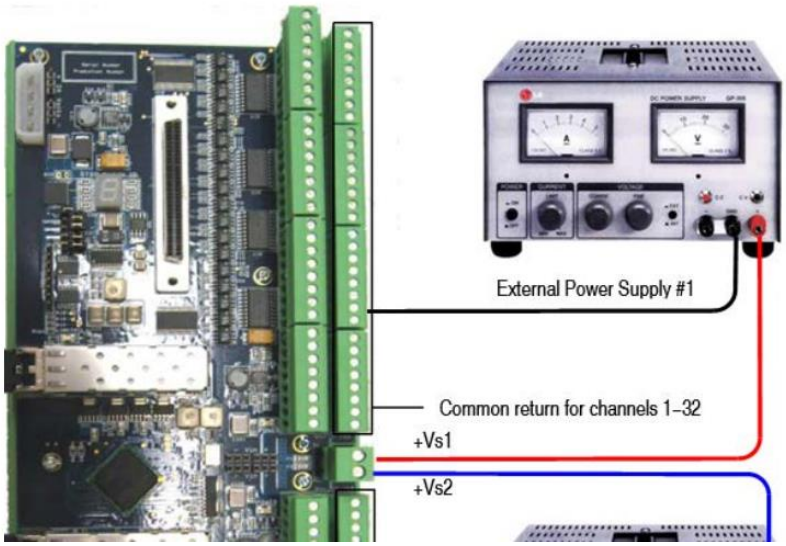


Figure 10: GTDO external power supply connection

SEL 651R is expecting a maximum of 8V signal and hence a 2 kΩ resistor is used in series with the corresponding GTDO channel. The GTDO channel mapping with respect to each IED is shown in the Appendix.

GTNETx2

The communication protocol capability of RTDS is implemented using the GTNETx2 cards. Virtual breaker and capacitor communicate via DNP protocol and Virtual DER communicates through MODBUS protocol. To facilitate the communication, 4 GTNET modules have been used in this case (3 DNP and 1 MODBUS).

DNP

The communication between the virtual breaker and the HMI, virtual cap and both HMI and control portal is achieved using the DNP protocol. In RTDS, DNP communication is achieved using the GTNETx2 cards. In the RSCAD DNP module, the DNP slave address, IP address of the master and port number has to be specified. A point mapping text file is used to map the DNP data point addresses to signal names assigned in RSCAD draft.

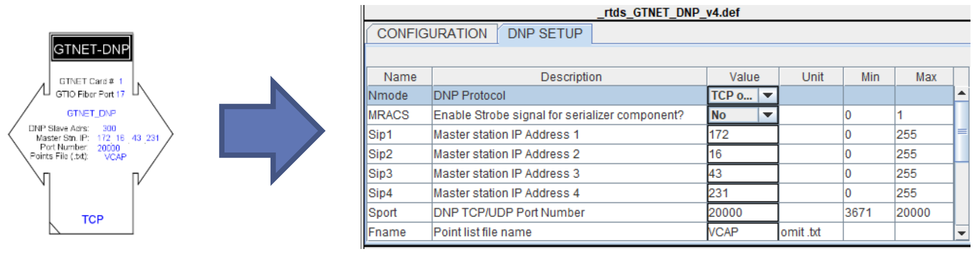


Figure 11: GTNET DNP representation

The control portal and HMI are expecting voltage and current values in Volts and Amperes while angles in degrees. The measured instantaneous quantities must be converted to Volts and Amperes. These values are also converted to obtain magnitude and angle (in degrees). The control logic is shown below.

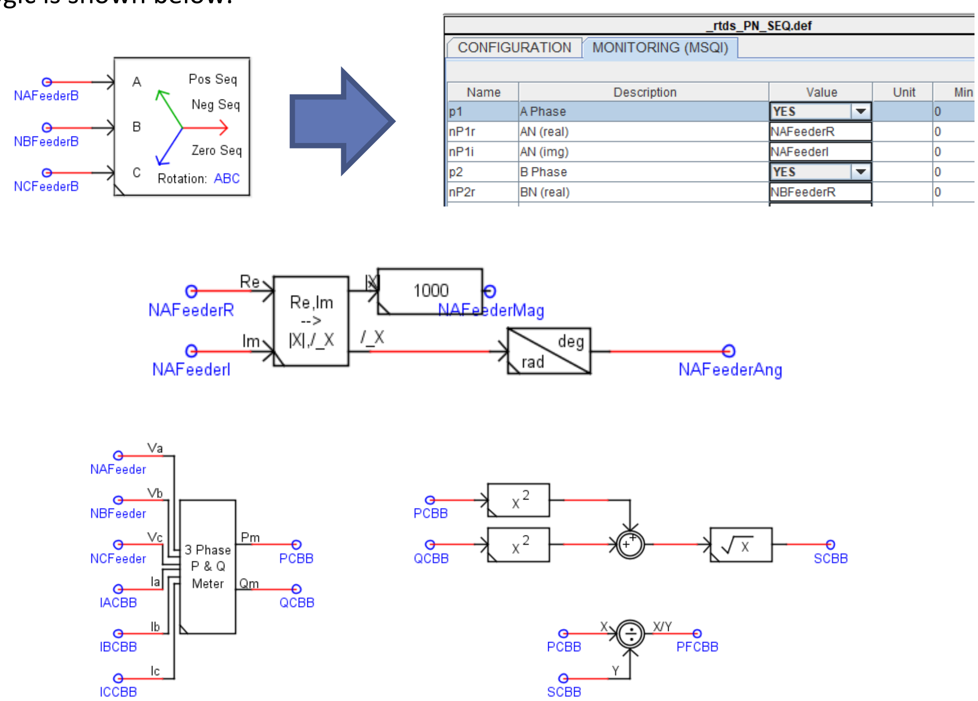


Figure 12: Calculation of signals for DNP point map file

MODBUS

The communication between the virtual DER and the control portal is achieved using the MODBUS communication portal. In the MODBUS module, the local port number must be specified if the mode is “TCP”. Points mapping text file is used to map the MODBUS data point addresses to signal names assigned in RSCAD draft.

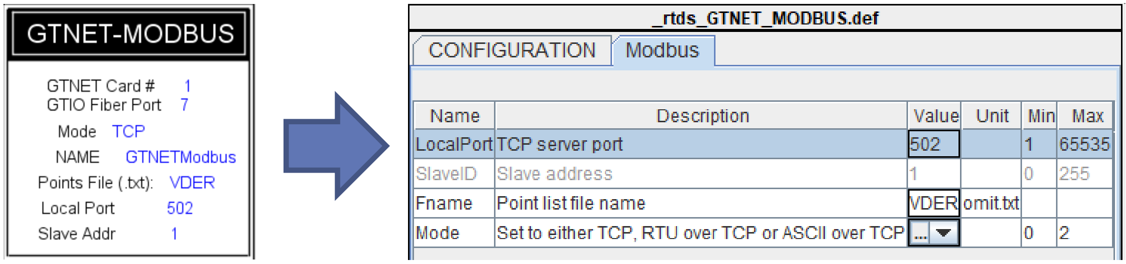


Figure 13: GTNET MODBUS

The following table summarizes the DNP and MODBUS settings.

DNP

Device Name	DNP Master IP	DNP slave	Port #	GTNET DNP IP
Virtual Cap - HMI	10.16.42.10	600	20000	10.16.43.206
Virtual Cap - Control Portal	10.16.43.231	300	20000	10.16.43.202
Virtual Breaker	10.16.42.10	400	20000	10.16.43.204

MODBUS

Device Name	Local Port #	GTNET MODBUS IP
Virtual DER	502	10.16.43.203

Table 3: DNP and MODBUS configurations

5. Model Validation

The developed case is validated against the distribution database load flow and short circuit data. Sample validation table is shown below.

				Distribution Program		RTDS					
From	Distribution Pro	RTDS	To	MW	MVAR	MW	MVAR	Difference		% Difference	
Bus 1			Bus 2	50.0	25.0	51.2	24.0	1.2	-1.0	2.4%	-4.0%
33.00	33.2	33.15	Bus 3	-10.0	5.0	-9.5	5.1	0.5	0.1	-5.0%	2.0%
kV	1.006060606	1.00454545	Bus 6	-20.0	-10.0	-20.7	-10.1	-0.7	-0.1	3.5%	1.0%
Deg	3.59	3.58	Bus 5	-20.0	-20.0	-21.0	-19.0	-1.0	1.0	5.0%	-5.0%
			Total	0.0	0.0	0.0	0.0	0.0	0.0		

Table 4: Load flow validation

	Distribution Program		RTDS		% Difference	% Difference
Bus #	3PH (kA)	SLG (kA)	3PH (A)	SLG (kA)	3PH	SLG
1	10030	7508	10105	7450	1%	1%

Table 5: Short Circuit Validation

6. Use Cases

Following are some use cases that can be demonstrated using the setup discuss above.

Case 1

When 3-phase VARS exceeds 3.4MVAR at CB-A, send R-GOOSE message from CB-A to close CAP-1 and OpenFMB command sent to move VR-1 to manual mode

- Pre-test conditions: CB-A closed, CB-B closed, TIE Open, RECLOSER-1 closed, RECLOSER-2 closed, CAP-1 Open, CAP-2 Open, SW-1 both positions closed, VR-1 in Auto Mode.
- Initial 3-phase VARs at CB-A =2.1 MVAR, nominal voltages of 7.2kV line to neutral on both feeders
- Change 3-phase VARS in RTDS model to 3.5 MVAR will result in CAP-1 closing and VR-1 moving to Manual Mode.

Case 2

When 3-phase VARS exceeds 3.4MVAR at CB-A, send R-GOOSE message from CB-A to close CAP-1 (and close CAP-2 if CB-B open + RECLOSER-2 open + TIE closed) and OpenFMB command sent to move VR-1 to manual mode

- Pre-test conditions: CB-A closed, CB-B closed, TIE Open, RECLOSER-1 closed, RECLOSER-2 closed, CAP-1 Open, CAP-2 Open, SW-1 both positions closed, VR-1 in Auto Mode.
- Initial 3-phase VARs at CB-A =2.1 MVAR, nominal voltages of 7.2kV line to neutral on both feeders
- Open CB-B by Control Portal, Control Portal opens RECLOSER-2, Control Portal closes TIE.
- Change 3-phase VARS in RTDS model to 3.5 MVAR will result in CAP-1 closing, CAP-2 closing and VR-1 moving to Manual Mode.

Case 3

When line-to-line voltage on CAP-1 is too high (over 1.03pu), CAP-1 refuses the close command from Control Portal (CP) and sends a message to the CB-A indicating refusal of the CAP-1 device to execute the requested CP close action

- Pre-test conditions: CB-A closed, CB-B closed, Tie Switch Open, RECLOSER-1 closed, RECLOSER-2 closed, CAP-1 Open, CAP-2 Open, SW-1 both positions closed, VR-1 in Auto Mode.
- Initial 3-phase VARs at CB-A =2.1 MVAR, nominal voltages of 7.2kV line to neutral on both feeders
- Change line-to-line voltage at CAP-1 to 1.10pu (13,717V for Vab, Vbc and Vca) in RTDS model will result in CAP-1 sending a OV block message when CP requests to close CAP-1.

Case 4

Able to monitor and control Virtual Capacitor (CAP-3) from Control Portal (CP) via DNP

- Pre-test conditions: CB-A closed, CB-B closed, TIE Open, RECLOSER-1 closed, RECLOSER-2 closed, CAP-1 Open, CAP-2 Open, SW-1 both positions closed, VR-1 in Auto Mode, 3-phase VARs at CB-A =2.1 MVAR, nominal voltages of 7.2kV line to neutral on both feeders

Case 5

Able to monitor and control Virtual DER-1 and Virtual DER-2 from Control Portal (CP) via Modbus

- Pre-test conditions: CB-A closed, CB-B closed, TIE Open, RECLOSER-1 closed, RECLOSER-2 closed, CAP-1 Open, CAP-2 Open, SW-1 both positions closed, VR-1 in Auto Mode, 3-phase VARs at CB-A =2.1 MVAR, nominal voltages of 7.2kV line to neutral on both feeders

7. Appendix

Virtual DER Point Map File

 # RDI: Discrete Inputs (from RTDS)

 # RIR: Input Registers (from RTDS)

 # WCO: Coils (From Master)

 # WHR: Holding Registers (From Master)
WHR: 3 start_cmd 0
WHR: 7 commn_cmd 2
WHR: 8 PCS_md_cmd 2
WHR: 9 P_set 0
WHR: 10 Q_set 0
WHR: 101 HL_clt_cmd 0

END

Virtual Capacitor Point Map File

 # BI: Binary Input Objects 1,2 in DNP Specification (Outputs from RTDS)
BI: 0 BRK1248_b0 BRK1248_T 0
BI: 1 BRK1248_b1 BRK1248_Status 0

 # BO: Binary Output Objects 10, 12 in DNP Specification (Inputs to RTDS)
BO: 0 BRK1248Ctrl_b00 BRK1248_Trip_HMI 0
BO: 1 BRK1248Ctrl_b10 BRK1248_Close_HMI 0

 # AI: Analog Input Objects 30,32 in DNP Specification (Outputs from RTDS)
AI: 0 NAVCapMag 1%
AI: 1 NAVCapAng 1%
AI: 2 NBVCapMag 1%
AI: 3 NBVCapAng 1%
AI: 4 NCVCapMag 1%
AI: 5 NCVCapAng 1%
AI: 6 IA1248CWMag 1%
AI: 7 IA1248CWAng 1%
AI: 8 IB1248CWMag 1%
AI: 9 IB1248CWAng 1%
AI: 10 IC1248CWMag 1%
AI: 11 IC1248CWAng 1%
AI: 12 In_Mag 1%
AI: 13 In_Ang 1%
AI: 14 P_VCap 1%
AI: 15 Q_VCap 1%
AI: 16 S_VCap 1%

AI: 17 PF_VCap 1%
AI: 18 Vx_Mag 1%
AI: 19 Vx_Ang 1%

 # AO: Analog Output Objects 40,41 in DNP Specification (Inputs to RTDS)

Virtual Breaker Point Map File

 # BI: Binary Input Objects 1,2 in DNP Specification (Outputs from RTDS)
BI: 0 BRKCBB_b1 BRKCBB_Status 0

 # BO: Binary Output Objects 10, 12 in DNP Specification (Inputs to RTDS)
BO: 0 BRKCBBCtrl_b0 BRKCBB_Trip 0
BO: 1 BRKCBBCtrl_b1 BRKCBB_Close 0

 # AI: Analog Input Objects 30,32 in DNP Specification (Outputs from RTDS)
AI: 0 NAFeederMag 1%
AI: 1 NAFeederAng 1%
AI: 2 NBFeederMag 1%
AI: 3 NBFeederAng 1%
AI: 4 NCFeederMag 1%
AI: 5 NCFeederAng 1%
AI: 6 IACBBMag 1%
AI: 7 IACBBAng 1%
AI: 8 IBCBBMag 1%
AI: 9 IBCBBAng 1%
AI: 10 ICCBBMag 1%
AI: 11 ICCBBAng 1%
AI: 12 InCBB_Mag 1%
AI: 13 InCBB_Ang 1%
AI: 14 PCBB 1%
AI: 15 QCBB 1%
AI: 16 SCBB 1%
AI: 17 PFCBB 1%

 # AO: Analog Output Objects 40,41 in DNP Specification (Inputs to RTDS)

GTAO Mapping & Scaling

IED Name	Card #	Channel #	Signal name	CT/PT Ratio	Scaling
F60-1	1	1	Ia	240	333.33
		2	Ib	240	333.33
		3	Ic	240	333.33
		4	Va	60	375
		5	Vb	60	375
		6	Vc	60	375
C70-1	1	7	Va	60	375
		8	Vb	60	375
		9	Vc	60	375

		10	Ia	120	333.33
		11	Ib	120	333.33
		12	Ic	120	333.33
C70-2	2	1	Va	60	375
		2	Vb	60	375
		3	Vc	60	375
		4	Ia	120	333.33
		5	Ib	120	333.33
		6	Ic	120	333.33
F60-2	2	7	Va	60	111.6505
		8	Vb	60	111.6505
		9	Vc	60	111.6505
		10	Vx	60	111.6505
	3	10	Ia	160	10.1
		11	Ib	160	10.1
		12	Ic	160	10.1
SEL651R	3	1	Ia	1000	61
		2	Ib	1000	61
		3	Ic	1000	61
		4	Va	60	505
		5	Vb	60	505
		6	Vc	60	505
SEL 2431	3	8	Va (primary)	60	192
		9	Va (secondary)	60	192
SEL 487E	4	1, 2, 3	IaS, IbS, IcS	120	400
		4, 5, 6	IaT, IbT, IcT	120	400
		7, 8, 9	VaZ, VbZ, VcZ	60	187.5

Table 6: GTAO mapping and scaling

GTDI Mapping

IED Name	GTDI Channel #	Signal
F60-1	1	Trip
	2	Close
C70-1	3	Trip
	4	Close
C30-1	5	Trip
	6	Close
C70-2	7	Trip
	8	Close
F60-2	9	Trip
	10	Close
SEL651	11	Trip
	12	Close
SEL2431	13	Lower
	14	Raise
SEL487	15	Trip-S
	16	Close-S
	17	Trip-T
	18	Close-T

Table 7: GTDI mapping

GTDO Mapping

IED Name	GTDO Channel #	Signal
F60-1	1	52b
	2	52a
C70-1	3	52b
	4	52a
C30-1	5	52b
	6	52a
C70-2	7	52b
	8	52a
F60-2	17	52b
	18	52a
SEL651	19	52a
SEL487	20	52a-S
	21	52a-T

Table 8: GTDO mapping

Typical Circuit Data

SectionId	FeederId	FromNodeId	ToNodeId	SectionPhases	Description	R1	X1	R0	X0	kW			kVar		
1	A	1	2	ABCN	FeederA	0.12	0.46	0.32	1.07	173	180	201	146	151	165
2	A	2	3	ABCN	x_2_3	0.02	0.09	0.05	0.21	16	15	19	13	13	15
3	A	3	4	ABCN	x_3_4	0.14	0.33	0.3	0.79	435	409	108	296	280	74
4	A	4	5	ABCN	x_4_5	0.04	0.04	0.06	0.11	44	45	45	-88	-87	-86
5	A	5	17	ABCN	x_5_17	0.03	0.02	0.17	0.08	0	0	0	0	0	0
6	A	17	18	ABCN	x_17_18	0.09	0.01	0.17	0.04	0	0	0	0	0	0
7	A	17	19	ABCN	x_17_19	0.02	0.01	0.11	0.06	121	126	124	76	79	78
8	A	5	6	ABCN	x_5_6	0.08	0.11	0.15	0.28	1	13	63	1	8	41
9	A	6	7	ABCN	x_6_7	0.17	0.17	0.3	0.43	258	192	300	174	128	198
10	A	7	9	ABCN	x_7_9	0.04	0.1	0.08	0.23	0	0	0	0	0	0
11	A	10	11	ABCN	x_10_11	0.06	0.22	0.14	0.54	11	16	25	14	19	26
12	A	11	12	ABCN	x_11_12	0.03	0.07	0.06	0.15	0	0	0	0	0	0
13	A	11	13	ABCN	x_11_13	0.07	0.17	0.15	0.4	53	19	65	40	16	49
14	A	13	14	ABCN	x_13_14	0.02	0.06	0.05	0.13	39	8	34	27	5	24
15	A	14	15	ABCN	x_14_15	0.12	0.28	0.26	0.69	73	195	189	56	143	141
16	A	15	20	ABCN	x_15_20	1.91	0.76	2.6	2.33	229	186	192	153	121	122
17	A	20	21	ABCN	x_20_21	0.33	0.09	0.95	0.44	149	62	128	102	44	88
18	A	15	16	ABCN	x_15_16	0.06	0.12	0.11	0.3	28	45	12	19	30	10
19	A	16	22	ABCN	x_16_22	0.55	0.21	0.74	0.64	34	14	47	22	9	31
20	A	22	23	ABCN	x_22_23	0.22	0.11	0.31	0.31	191	275	230	133	187	160

Table 9: Circuit Data