CIRP-5G project

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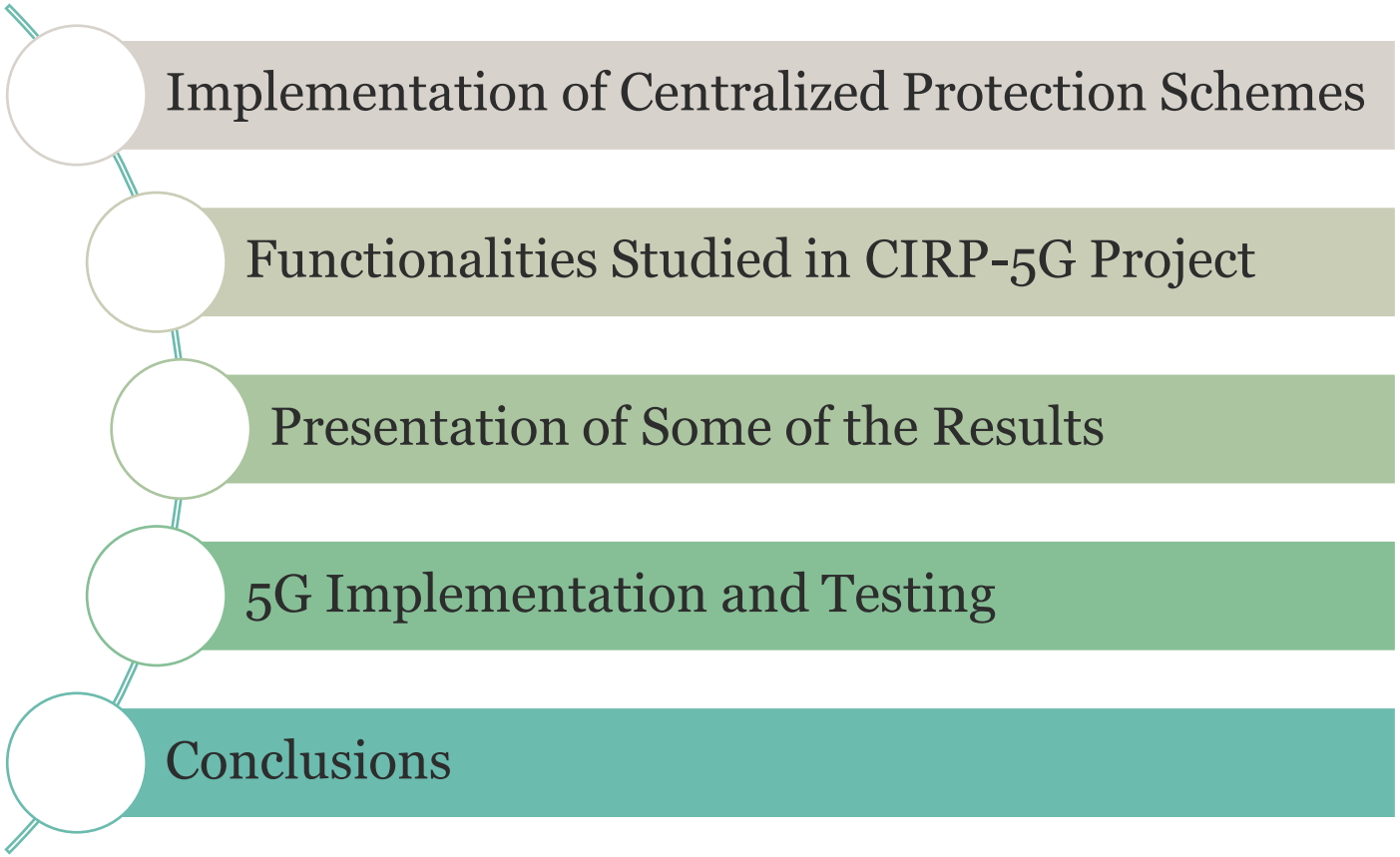
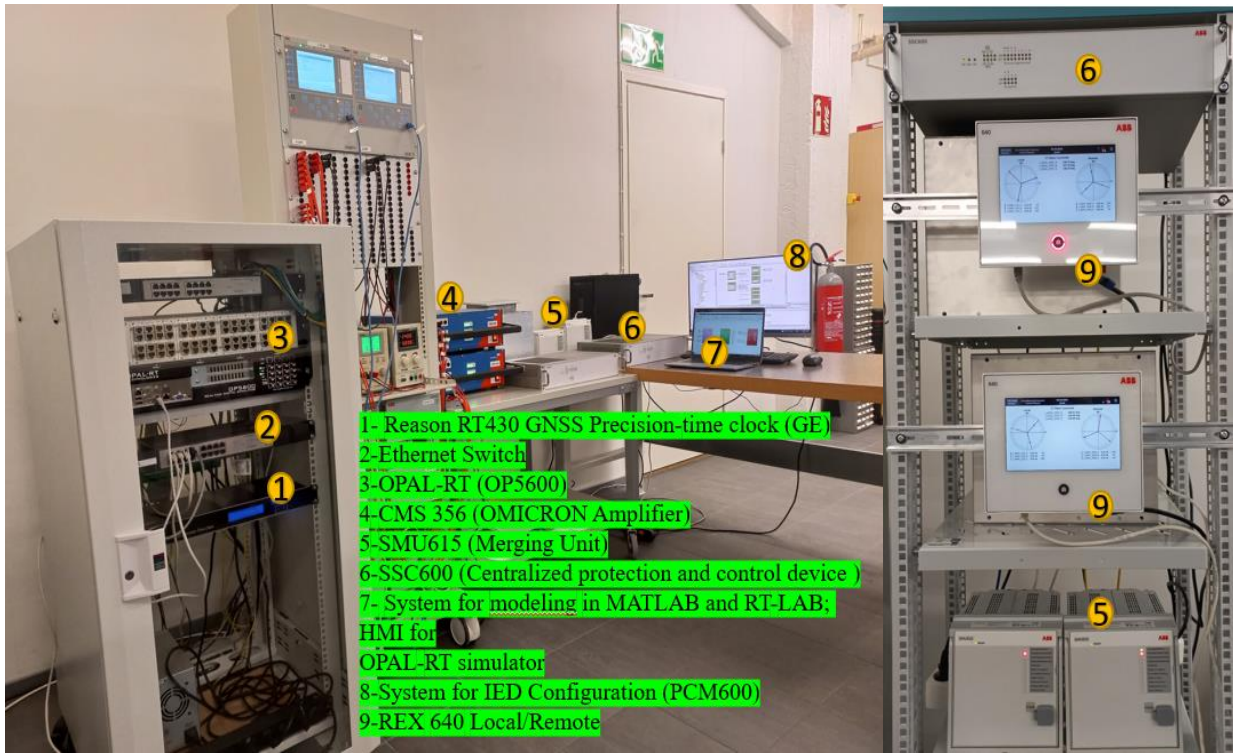
Contents


Implementation of Centralized Protection Schemes
Functionalities Studied in CIRP-5G Project
Presentation of Some of the Results
5G Implementation and Testing
Conclusions

Centralized Protection Scheme Setup



- CIRP-5G Project Setup to test IEC 61850-based centralized protection and control schemes *
- SSC600 ABB (centralized devices) and SMU615 (merging unit) as key enablers

** Real-time hardware-in-the-loop approach for adaptive centralized protection schemes using clustering algorithms. Expert Systems with Applications, 255, 124707. https://doi.org/10.1016/j.eswa.2024.124707*

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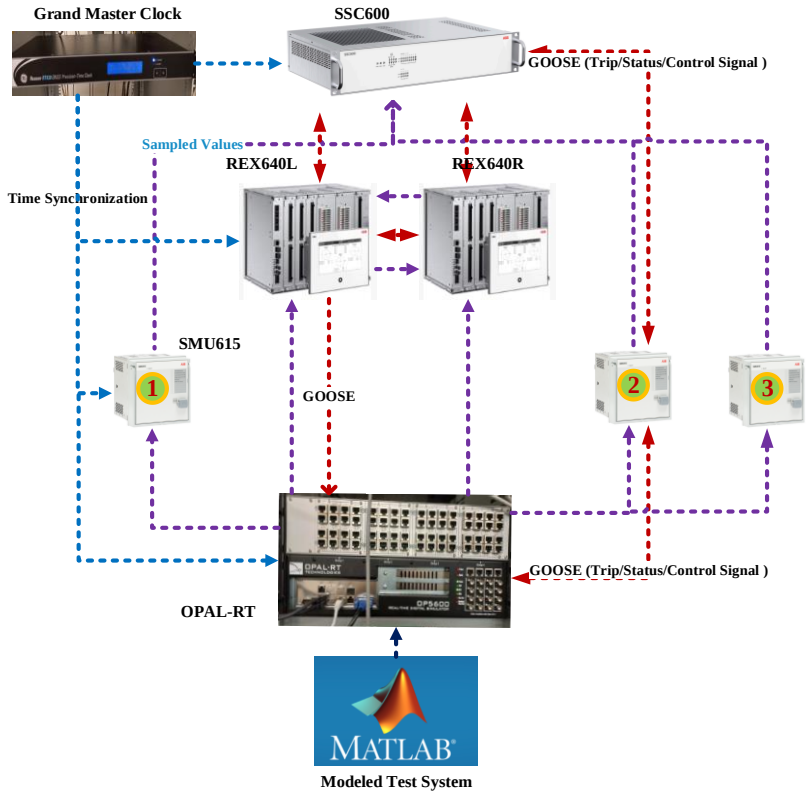
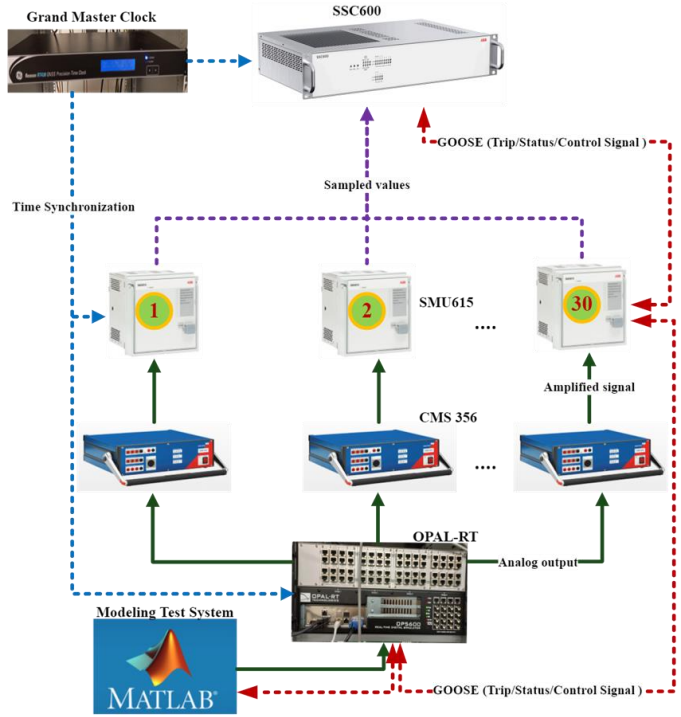
Communication diagram between HIL devices





- Sampled Values and GOOSE message communication between setup devices presented in previous slides*
- Accurate time synchronization (100 nse)

*Pashaei, M., Kauhaniemi, K., & Laaksonen, H. (2024, September 10). *Implementation of Adaptive Centralized Protection Scheme in Active Networks with a HIL Setup*. 7th International Conference on Smart Energy Systems and Technologies (SEST 2024), Turin, Italy. https://doi.org/10.1109/SEST61601.2024.10694251

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Configuration process in RT-LAB

```
Main priority set to 99
 Synchronization: External sync accuracy set to 100 nanoseconds
 Synchronization: PTP sync state set to 'Slave'
```

General / GOOSE (8-1) Publishers

#	SCL file	IED	GOOSE ID	Ethernet Adapter	Clock	AppID
1	... meysampa\Desktop\SMU61501.icd	TEMPLATE	SMU615MU0101CTRL/LLN0.gcbCBSTATUS	eth2	EXTERNAL	0x0006
2	... meysampa\Desktop\SMU61502.icd	TEMPLATE	SMU615MU0102CTRL/LLN0.gcbCBSTATUS	eth2	EXTERNAL	0x0007
3	... meysampa\Desktop\SMU61503.icd	TEMPLATE	SMU615MU0103CTRL/LLN0.gcbCBSTATUS	eth2	EXTERNAL	0x0008
4	... meysampa\Desktop\SMU61505.icd	TEMPLATE	SMU615MU0105CTRL/LLN0.gcbCBSTATUS	eth2	EXTERNAL	0x0009

General / GOOSE (8-1) Subscribers

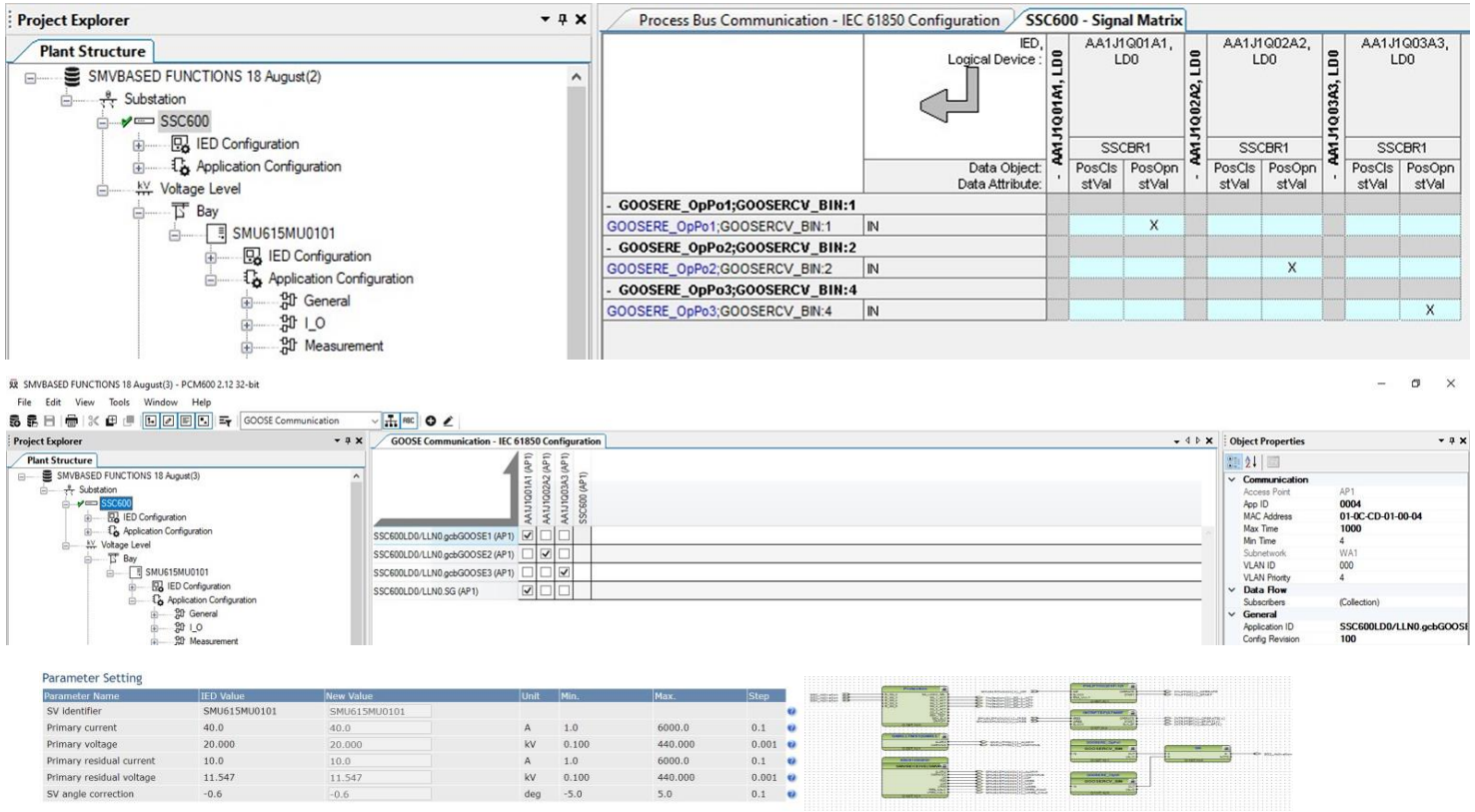
#	SCL file	IED	GOOSE ID	Ethernet Adapter	AppID	MAC address
1	... meysampa\Desktop\SSC600.icd	TEMPLATE	SSC600LD0/LLN0.gcbGOOSE1	eth2	0x0001	01-0C-CD-01-00-01
2	... meysampa\Desktop\SSC600.icd	TEMPLATE	SSC600LD0/LLN0.gcbGOOSE2	eth2	0x0002	01-0C-CD-01-00-02
3	... meysampa\Desktop\SSC600.icd	TEMPLATE	SSC600LD0/LLN0.gcbGOOSE3	eth2	0x0003	01-0C-CD-01-00-03
4	... meysampa\Desktop\REX640L.icd	TEMPLATE	REX640LLD0/LLN0.gcbPhsMeas	eth2	0x0010	01-0C-CD-01-00-10
5	... meysampa\Desktop\SSC600.icd	TEMPLATE	SSC600LD0/LLN0.gcbGOOSE4	eth2	0x0004	01-0C-CD-01-00-04
6	... meysampa\Desktop\SSC600.icd	TEMPLATE	SSC600LD0/LLN0.gcbSG	eth2	0x0005	01-0C-CD-01-00-05

General / Sampled Values (9-2LE) Publishers

#	LD Name	MAC address	Ethernet Adapter	VLAN ID	Nominal Frequency	Sampling Rate	Clock
1	SMU615MU0101	01-0C-CD-04-00-01	eth2	2	50 Hz	80 Samples Per Cycle	EXTERNAL
2	SMU615MU0102	01-0C-CD-04-00-02	eth2	2	50 Hz	80 Samples Per Cycle	EXTERNAL
3	SMU615MU0103	01-0C-CD-04-00-03	eth2	2	50 Hz	80 Samples Per Cycle	EXTERNAL
4	SMU615MU0104	01-0C-CD-04-00-04	eth2	2	50 Hz	80 Samples Per Cycle	EXTERNAL
5	SMU615MU0105	01-0C-CD-04-00-05	eth2	2	50 Hz	80 Samples Per Cycle	EXTERNAL

- Power system modeling in MATLAB
- GOOSE and process bus configuration in RTLAB and use of SCL file generated after IEDs configuration

Configuration process in PCM600



- Process bus and GOOSE configuration in PCM 600
- Application configuration and relay setting

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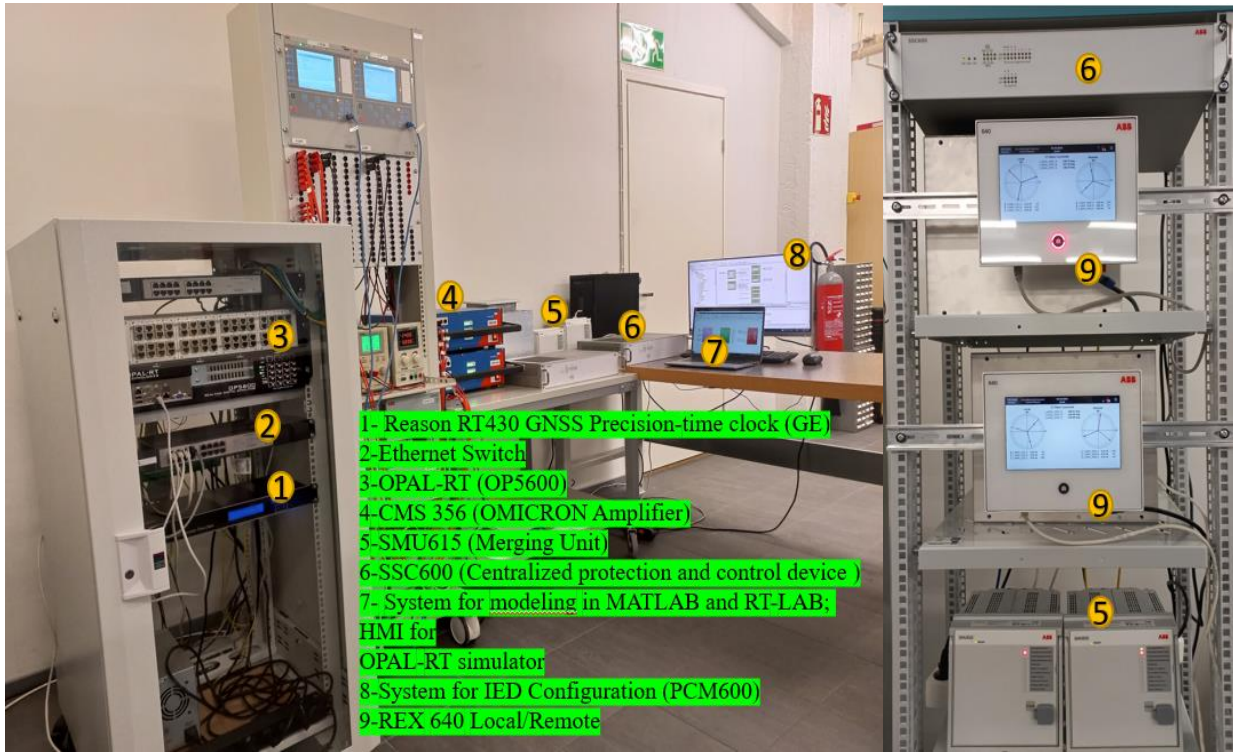
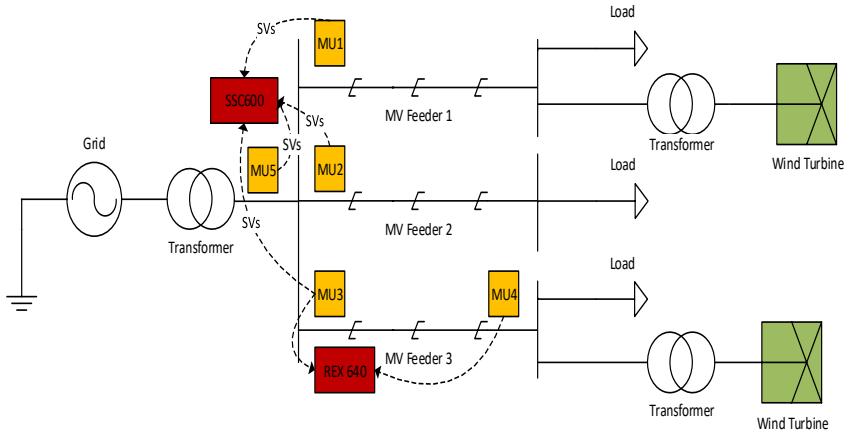
Adaptive SG-based protection results *





- Details in final report of the project and publications

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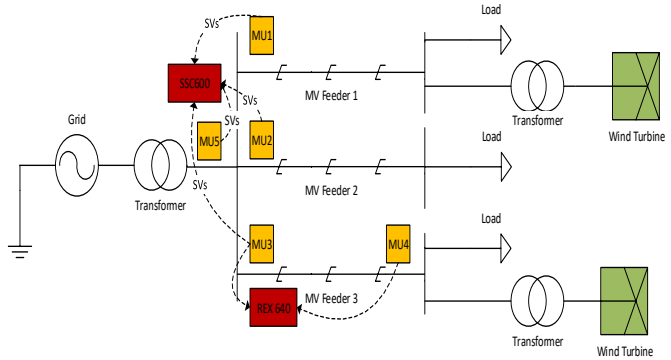
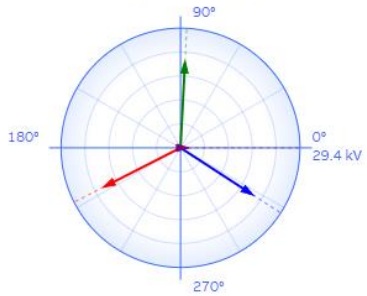
Normal operation of test system



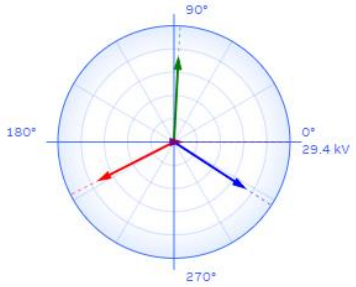
▼ Voltages

SMU615MU0101



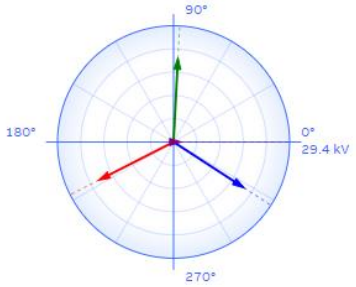
UL1:	20.76 kV	-153°
UL2:	20.76 kV	87°
UL3:	20.76 kV	-33°
Uo:	0 kV	0°

SMU615MU0102
VMMXU2



UL1:	20.76 kV	-153°
UL2:	20.75 kV	87°
UL3:	20.75 kV	-33°
Uo:	(0 kV	0°)

SMU615MU0103
VMMXU3

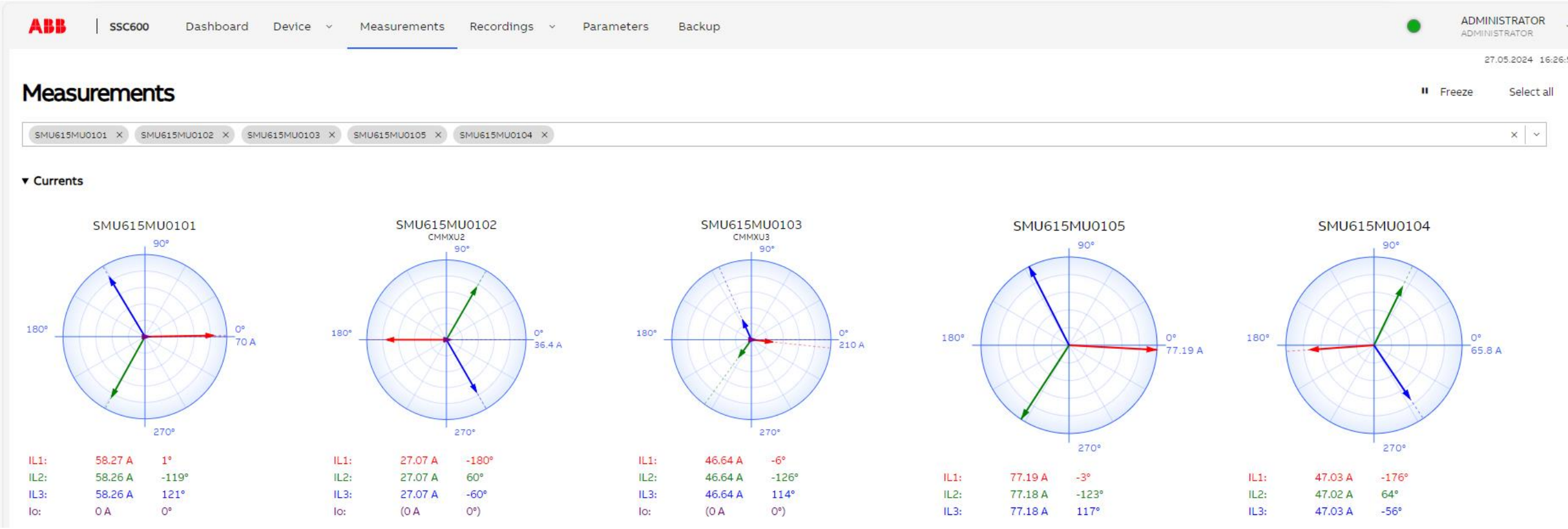


UL1:	20.76 kV	-153°
UL2:	20.75 kV	87°
UL3:	20.75 kV	-33°
Uo:	(0 kV	0°)

▸ Sequence: currents

▸ Sequence: voltages

Normal operation of test system



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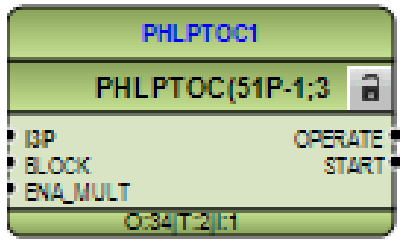
Current-based functions in SSC600

Three-phase non-directional overcurrent protection PHxPTOC (51P/50P)

- 3I> (Low, PHLPTOC)
- 3I>> (High, PHHPTOC)
- 3I>>> (Instantaneous, PHIPTOC)



PHLPTOC: 1

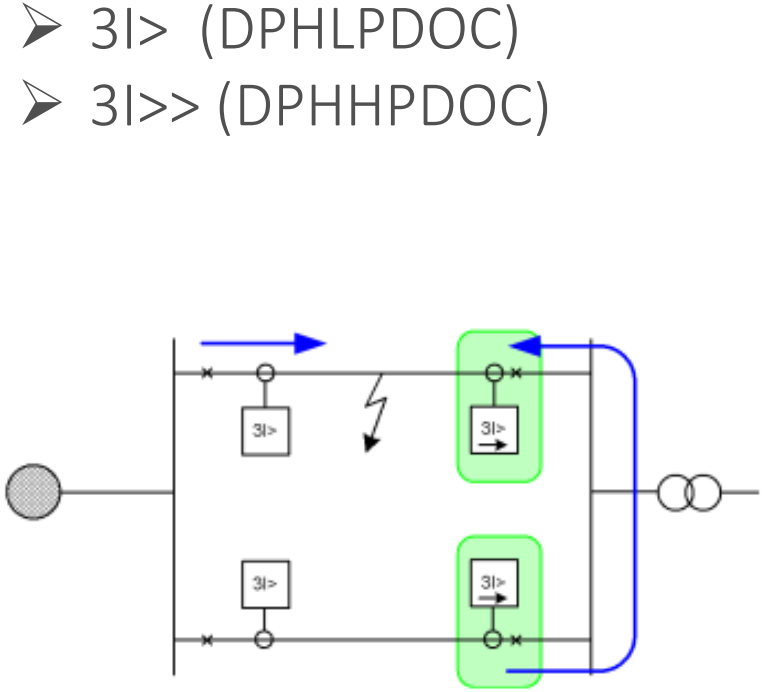
Write to device: 1 parameter | Disable Edit | Import | Export | Refresh

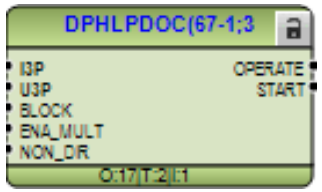
PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Settings					
Operation	off	on			
Measurement mode	DFT	DFT			
Num of start phases	3 out of 3	3 out of 3			
Reset delay time	40	40	ms	0	60000
Setting Group 1					
Operating curve type	IEC Def. Time	IEC Def. Time			
Start value	5.00	5.00	xIn	0.05	5.00
Start value Mult	1.0	1.0		0.8	10.0
Operate delay time	300	300	ms	40	300000

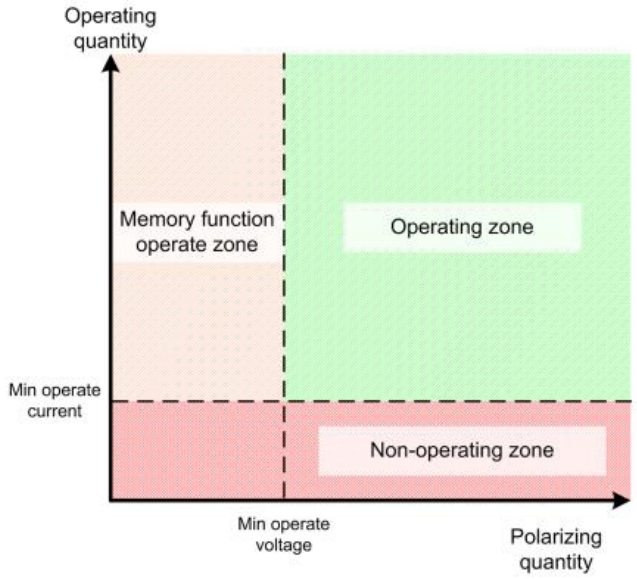
Current-based functions in SSC600

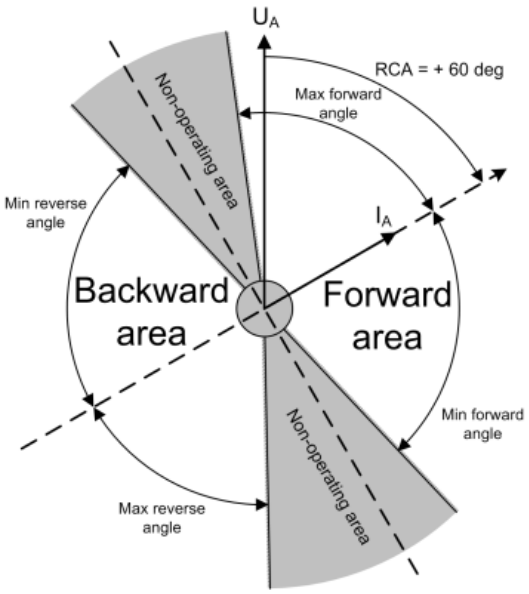
Three-phase directional overcurrent protection DPHxPDOC (67)

- 3I> (DPHLPDOC)
- 3I>> (DPHHPDOC)









https://new.abb.com/medium-voltage/digital-substations/protection-relays/multiapplication/ssc600

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Current-based functions in SSC600

DPHLPDOC: 1

Write to device: 1 parameter | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Settings					
Operation	off	on			
Measurement mode	DFT	DFT			
Num of start phases	3 out of 3	3 out of 3			
Minimum operate time	20	20	ms	20	60000
Reset delay time	40	40	ms	0	60000
Allow Non Dir	False	False			
Min operate current	1.00	1.00	xIn	0.01	1.00
Min operate voltage	0.10	0.10	xUn	0.01	1.00

Current-based functions in SSC600

Setting Group 1

Operating curve type	IEC Norm. inv.	IEC Norm. inv.				
Type of reset curve	Immediate	Immediate				
Time multiplier	0.025	0.025		0.025	15.000	
Start value	1.10	1.10	xIn	0.05	5.00	
Start value Mult	1.0	1.0		0.8	10.0	
Operate delay time	70	70	ms	40	200000	
Voltage Mem time	3000	3000	ms	0	3000	
Directional mode	Forward	Forward				
Characteristic angle	60	60	deg	-179	180	
Max forward angle	80	80	deg	0	90	
Max reverse angle	80	80	deg	0	90	
Min forward angle	80	80	deg	0	90	
Min reverse angle	80	80	deg	0	90	
Pol quantity	Self pol	Self pol				

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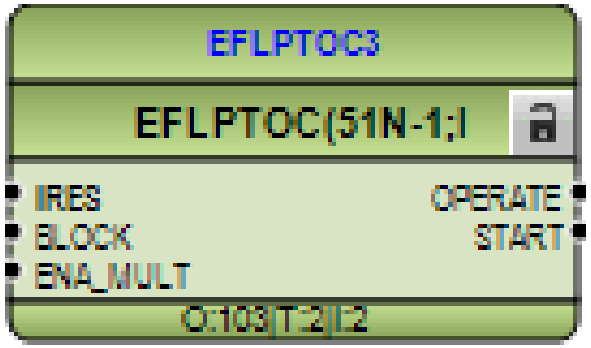
Current-based functions in SSC600

Non-directional earth-fault protection EFxPTOC (51N/50N)

- I0> (Low, EFLPTOC)
- I0 >> (High, EFHPTOC)
- I0 >>> (Instantaneous, EFIPTOC)



Four special connections of current transformers in relay protection applications | EEP (electrical-engineering-portal.com)

Current-based functions in SSC600

EFLPTOC: 1

Write to device: 3 parameters | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Settings					
Operation	off	on			
Measurement mode	DFT	DFT			
Reset delay time	20	20	ms	0	60000
Setting Group 1					
Start value	0.010	0.100	xIn	0.010	5.000
Start value Mult	1.0	1.0		0.8	10.0
Operating curve type	IEC Def. Time	IEC Def. Time			
Operate delay time	40	40	ms	40	200000

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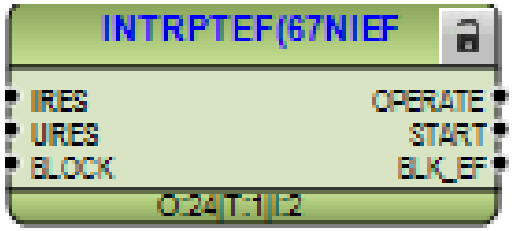
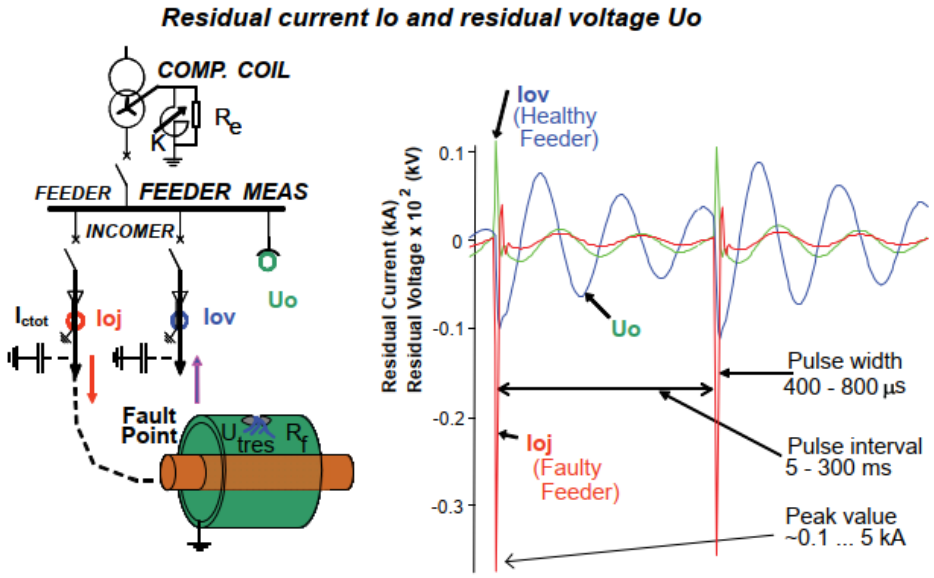
Current-based functions in SSC600

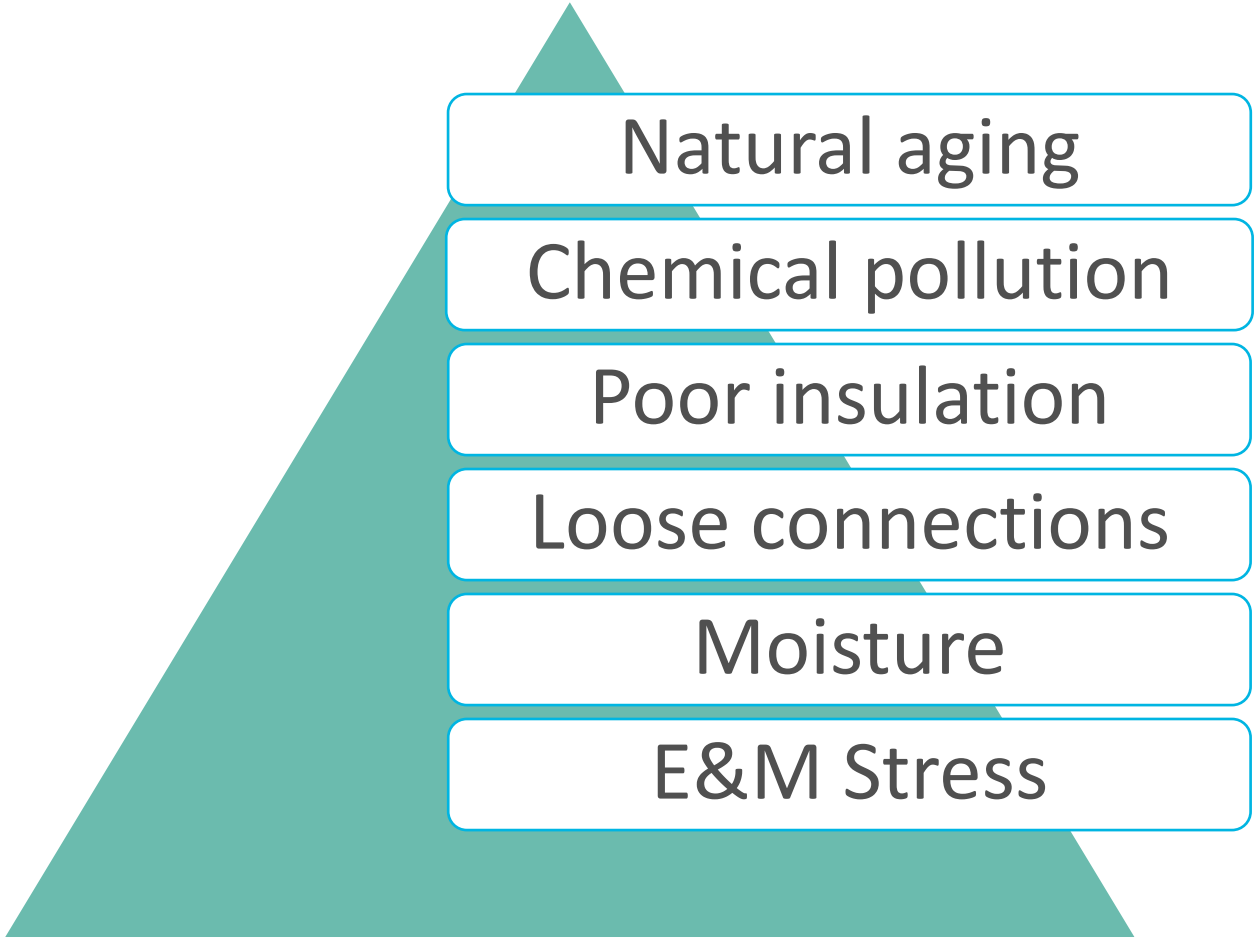
Intermittent earth-fault protection INTRPTEF (67NIEF)

- Io> -> IEF(INTRPTEF)



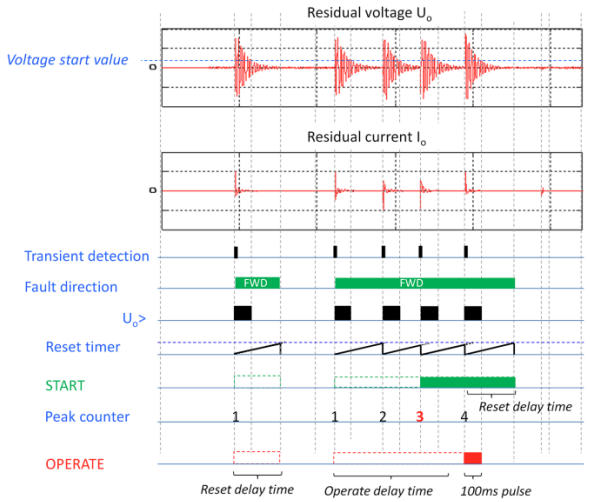


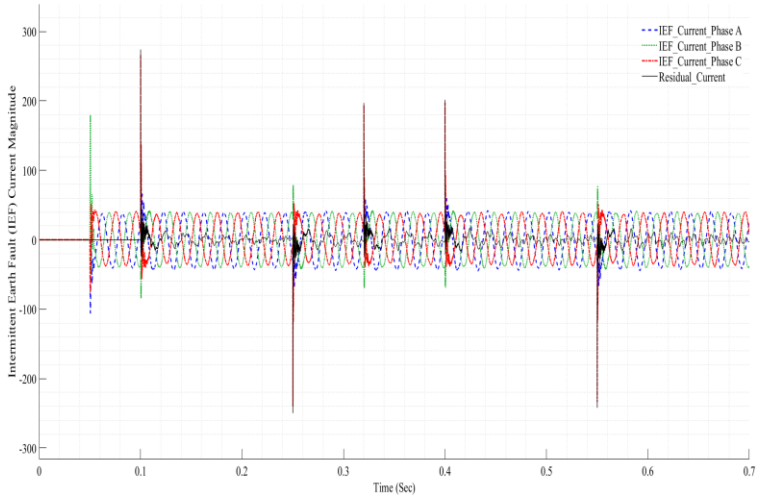
Reasons behind intermittent earth fault



M. Pashaei, M. Karimi, K. Kauhaniemi, A. Asadi, S. Pil Ramli and A. Pourdaryaei, "Intermittent earth fault detection in distribution network based on the voting classification technique," *27th International Conference on Electricity Distribution (CIRED 2023)*, Rome, Italy, 2023, pp. 3759-3763, doi: 10.1049/icp.2023.0726.

Intermittent earth fault detection



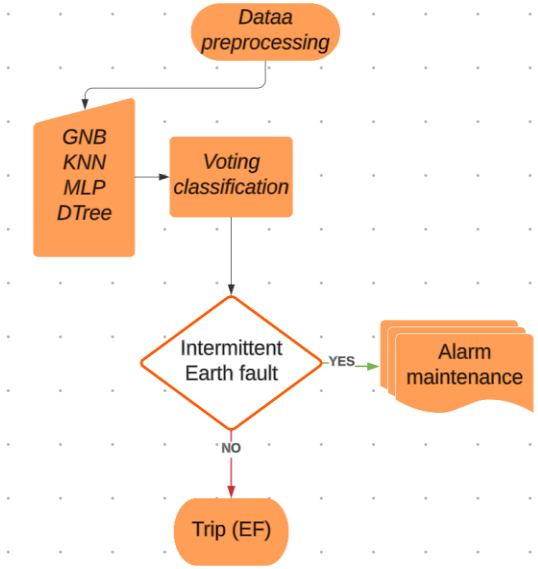


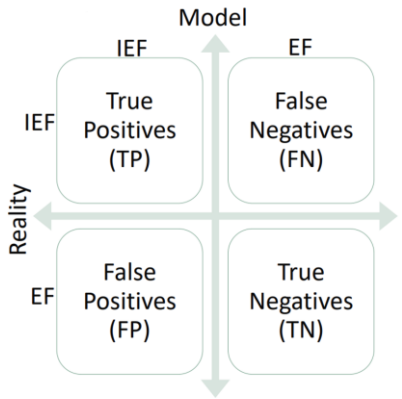

```
Product identifiers
-------------------------------------------------------------------------------
Type                    :    SSC600
Product version         :    1.0 FP3
-------------------------------------------------------------------------------
Fault record 905
Parameter name          IED value           Unit        Min         Max
-------------------------------------------------------------------------------
Fault number            905                             0           999999
Time and date           2023.09.08 19:12:40:856
Protection              INTRPTEF
Protection instance     1                               1           999999
Start duration          100.00              %           0.00        100.00
Operate time            0.449               s           0.000       1000000.000
Breaker clear time      (3.000)             s           0.000       3.000
Active group            1                               1           6
-------------------------------------------------------------------------------
Fault record 902
Parameter name          IED value           Unit        Min         Max
-------------------------------------------------------------------------------
Fault number            902                             0           999999
Time and date           2023.09.08 19:09:46:844
Protection              INTRPTEF
Protection instance     3                               1           999999
Start duration          77.00               %           0.00        100.00
Operate time            0.300               s           0.000       1000000.000
-------------------------------------------------------------------------------
Fault record 901
Parameter name          IED value           Unit        Min         Max
-------------------------------------------------------------------------------
Fault number            901                             0           999999
Time and date           2023.09.08 19:09:44:533
Protection              INTRPTEF
Protection instance     1                               1           999999
Start duration          99.99               %           0.00        100.00
Operate time            0.395               s           0.000       1000000.000
-------------------------------------------------------------------------------
```

Parameter Setting

Parameter Name	IED Value	New Value	Unit	Min.	Max.	Step
Operation	on	on				
Operation mode	Intermittent EF	Intermittent EF				
Directional mode	Forward	Forward				
Operate delay time	500	500	ms	40	1200000	10
Reset delay time	1000	1000	ms	40	60000	1
Peak counter limit	3	3		2	20	1
Voltage start value	0.20	0.20	xUn	0.05	0.50	0.01
Min operate current	0.20	0.20	xIn	0.01	1.00	0.01

ML-based intermittent earth fault detection

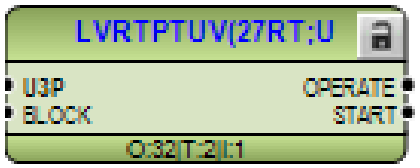


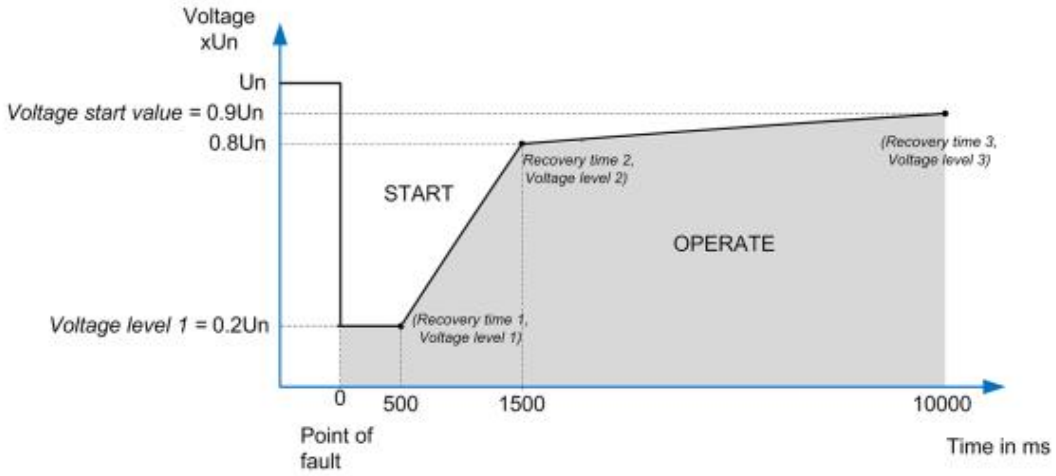


Method	Precision	Recall	F1	Accuracy
KNN	0.85	0.85	0.73	0.8
GNB	0.74	0.86	0.65	0.8
MLP	0.86	0.84	0.76	0.81
Dtree	0.84	0.83	0.74	0.79
Voting	0.87	0.86	0.78	0.82

- $Accuracy = \frac{TP + TN}{TP+TN+FP+FN}$
- $Precision = \frac{TP}{TP+FP}$
- $Recall = \frac{TP}{TP+FN}$
- $F1Score = 2 * \frac{Precision * Recall}{Precision + Recall}$

Voltage-based functions in SSC600





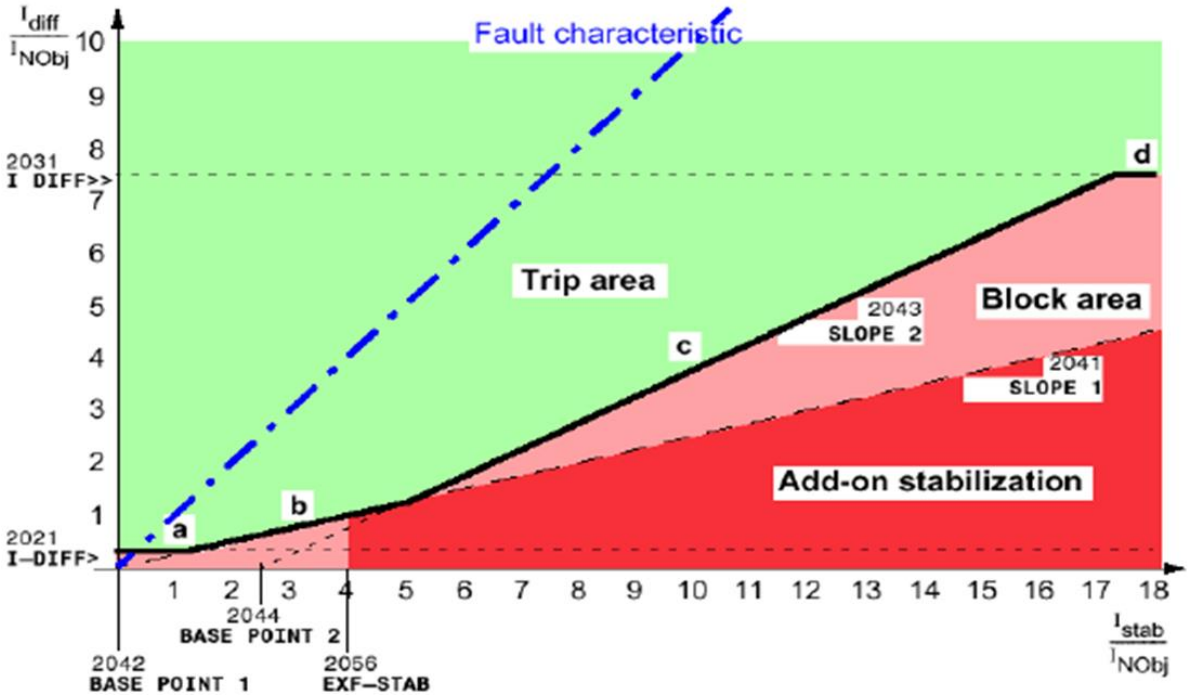
Voltage-based functions in SSC600

LVRTPTUV: 1

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Settings					
Operation	on	on			
Num of start phases	Exactly 3 of 3	Exactly 3 of 3			
Voltage selection	Lowest Ph-to-Ph	Lowest Ph-to-Ph			
Active coordinates	3	3		1	10
Voltage level 1	0.20	0.20	xUn	0.00	1.20
Voltage level 2	0.80	0.80	xUn	0.00	1.20
Voltage level 3	0.90	0.90	xUn	0.00	1.20
Voltage level 4	0.90	0.90	xUn	0.00	1.20
Voltage level 5	0.90	0.90	xUn	0.00	1.20
Voltage level 6	0.90	0.90	xUn	0.00	1.20
Voltage level 7	0.90	0.90	xUn	0.00	1.20
Voltage level 8	0.90	0.90	xUn	0.00	1.20
Voltage level 9	0.90	0.90	xUn	0.00	1.20
Voltage level 10	0.90	0.90	xUn	0.00	1.20
Recovery time 1	500	500	ms	0	300000
Recovery time 2	1000	1000	ms	0	300000
Recovery time 3	10000	10000	ms	0	300000

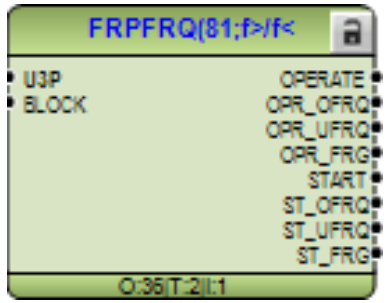
Differential protection in REX 640

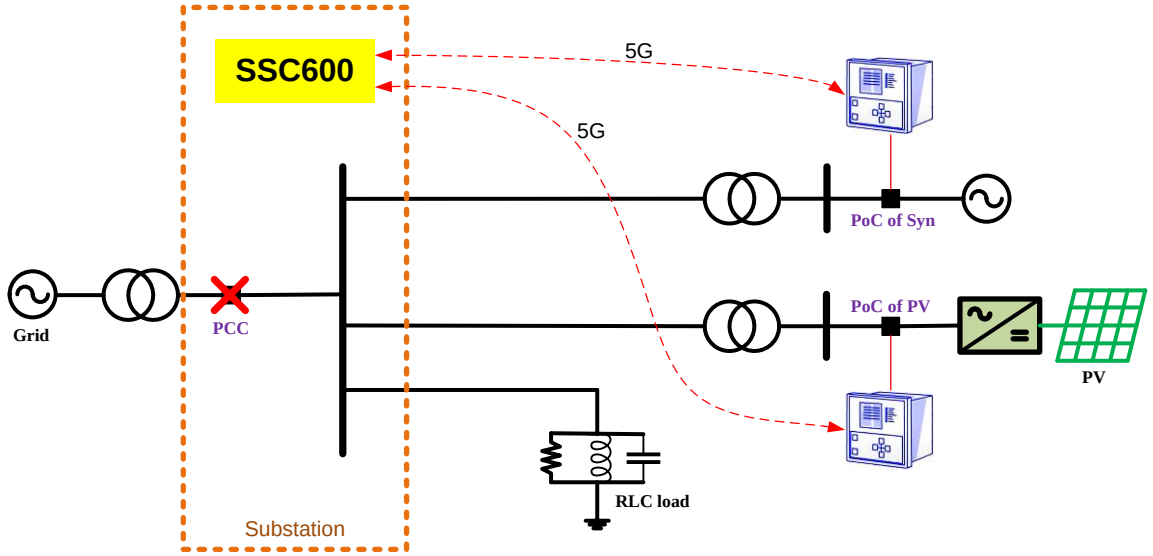


Frequency protection in SSC600

Frequency protection FRPFRQ (81)

- f>/f<,df/dt (FRPFRQ)





Frequency protection in SSC600

FRPFRQ: 1

Write to device: 1 parameter | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Settings					
Operation	off	on			
Reset delay Tm df/dt	130	130	ms	0	60000
Setting Group 1					
Start value df/dt	0.0200	0.0200	xFn /s	-0.2000	0.2000
Operate Tm df/dt	120	120	ms	120	200000
Operation mode	df/dt	df/dt			

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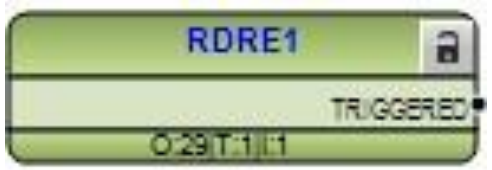
Disturbance recorder



General

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Periodic trig time	604800	604800	s	0	604800
Exclusion time	0	0	ms	0	1000000
Operation mode	Overwrite	Overwrite			
Pre-trg length	50	50	%	0	100
Record length	10	10	cycles	10	3000
Storage rate	80 samples / cycle	80 samples / cycle			
Stor. mode periodic	Waveform	Waveform			
Stor. mode manual	Waveform	Waveform			
Operation	on	on			
Append SMV streams	True	True			

https://search.abb.com/library/Download.aspx?DocumentID=9AKK107991A8236&DocumentPartId

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Relay settings and parameters

FLTRFRC: 1

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Configuration					
Operation	on	on			
Trig mode	From all faults	From all faults			
A measurement mode	DFT	DFT			

General

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Periodic trig time	604800	604800	s	0	604800
Exclusion time	0	0	ms	0	1000000
Operation mode	Overwrite	Overwrite			
Pre-trg length	50	50	%	0	100
Record length	10	10	cycles	10	3000
Storage rate	80 samples / cycle	80 samples / cycle			
Stor. mode periodic	Waveform	Waveform			
Stor. mode manual	Waveform	Waveform			
Operation	on	on			
Append SMV streams	True	True			

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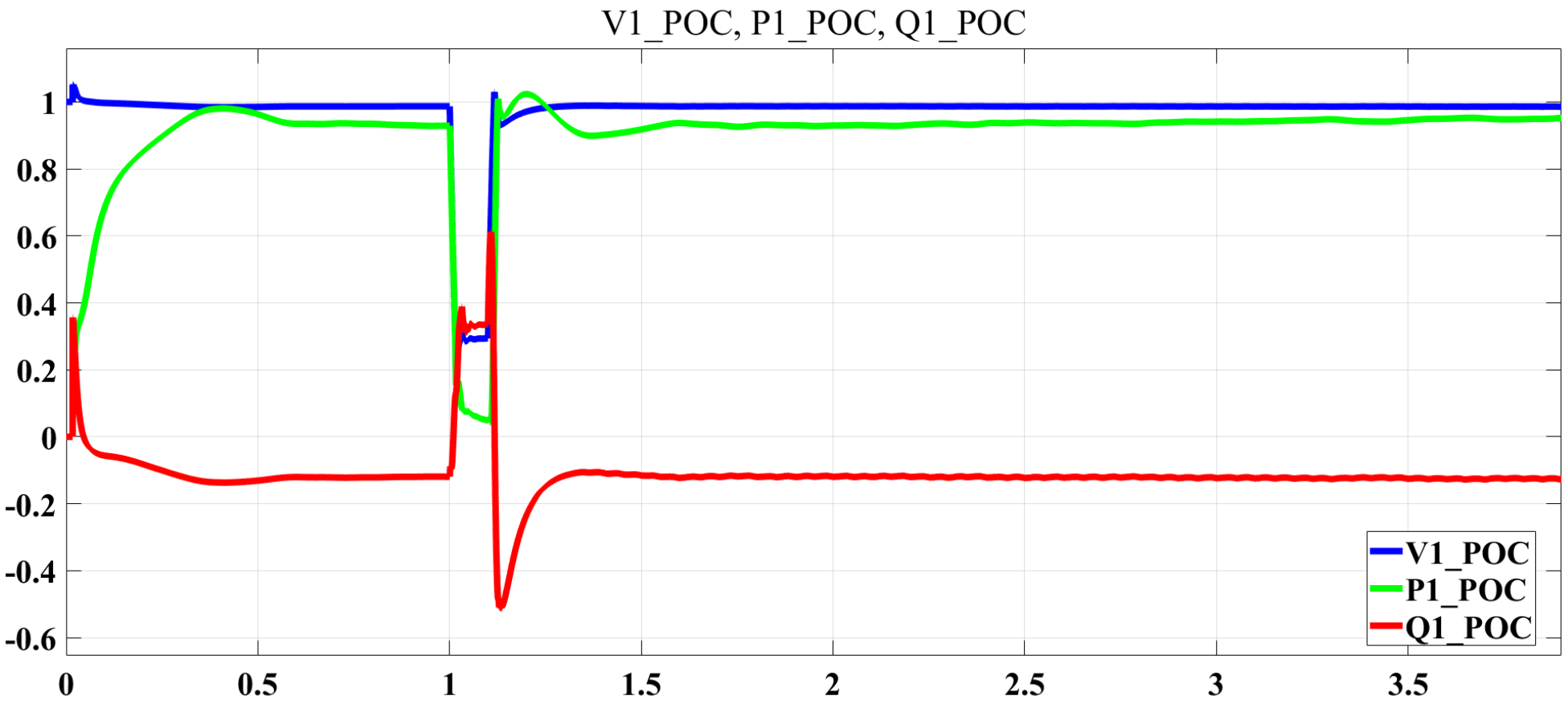
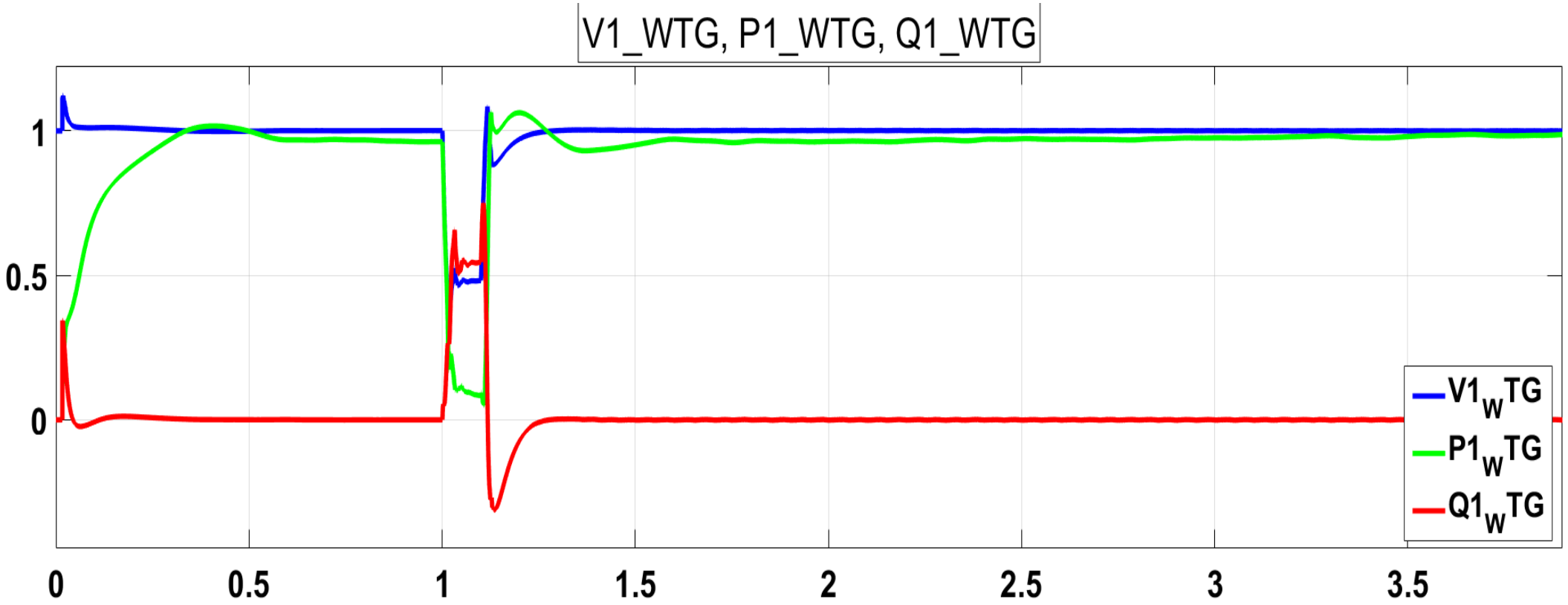
Low-voltage ride-through results



Low-voltage ride-through results



LVRT results: Case 1

```
-------------------------------------------------
Technical key          :    SSC600
IEC 61850 version      :    Edition 2
```

Date	Time	Source	Function	Description	Value
27.05.2024	09:14:24.459	SMU615MU0101	PROTECTION	Active group	
27.05.2024	09:14:24.458	Overcurrent	DPHLPDOC: 2	OPERATE	True
27.05.2024	09:14:24.432	FRT	LVRTPTUV: 1	OPERATE	True
27.05.2024	09:14:24.432	FRT	LVRTPTUV: 1	START	True
27.05.2024	09:14:24.418	Overcurrent	DPHLPDOC: 2	START	True

```
-------------------------------------------------
Technical key          :    SSC600
IEC 61850 version      :    Edition 2
```

Date	Time	Source	Function	Description	Value
27.05.2024	11:32:08.460	SMU615MU0101	PROTECTION	Active group	
27.05.2024	11:32:08.458	Overcurrent	DPHLPDOC: 2	OPERATE	True
27.05.2024	11:32:08.438	FRT	LVRTPTUV: 1	OPERATE	True
27.05.2024	11:32:08.437	SMU615MU0104	CMMXU: 5	HIGH_ALARM	True
27.05.2024	11:32:08.437	SMU615MU0103	VMMXU: 3	HIGH_WARN	False
27.05.2024	11:32:08.437	SMU615MU0102	VMMXU: 2	HIGH_WARN	False
27.05.2024	11:32:08.432	FRT	LVRTPTUV: 1	START	True
27.05.2024	11:32:08.418	Overcurrent	DPHLPDOC: 2	START	True

LVRT results: Case 1

Technical key : SSC600
IEC 61850 version : Edition 2

Fault record 25418

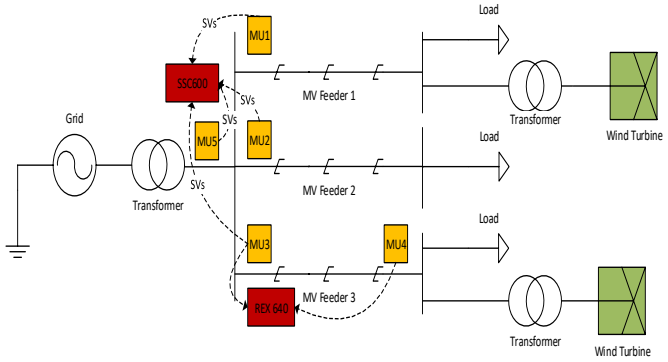
Parameter name	IED value	Unit	Min	Max
Application	FRT			
ProtectionFunction	LVRTPTUV: 1			
Fault number	25418		0	999999
Time and date	27.05.2024 09:14:24.418			
Start duration	100.00	%	0.00	100.00
Operate time	0.014	s	0.000	999999.999
Breaker clear time	(3.000)	s	0.000	3.000
Fault distance	(0.00)	pu	0.00	3000.00
Active group	1		1	6
Max current IL1	20.565	xIn	0.000	50.000
Max current IL2	18.652	xIn	0.000	50.000
Max current IL3	21.068	xIn	0.000	50.000
Voltage U12	0.192	xUn	0.000	4.000
Voltage U23	0.204	xUn	0.000	4.000
Voltage U31	0.202	xUn	0.000	4.000
Voltage Uo	0.000	xUn	0.000	4.000
Voltage Zro-Seq	0.000	xUn	0.000	4.000
Voltage Ps-Seq	0.115	xUn	0.000	4.000
Voltage Ng-Seq	0.007	xUn	0.000	4.000

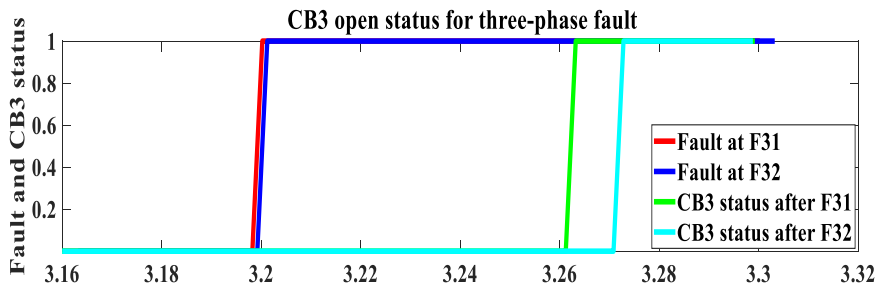
LVRT results: Case 2

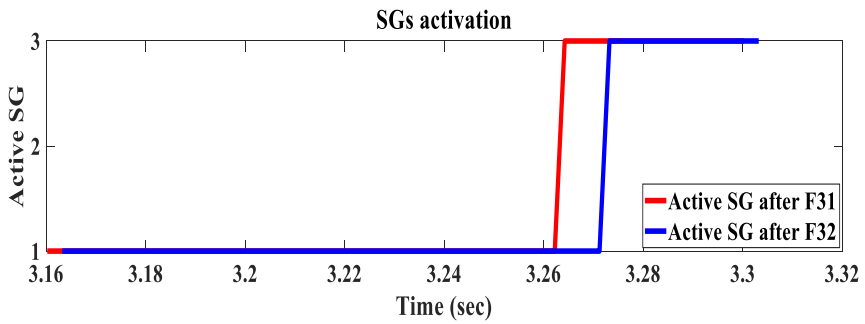
Technical key : SSC600
IEC 61850 version : Edition 2

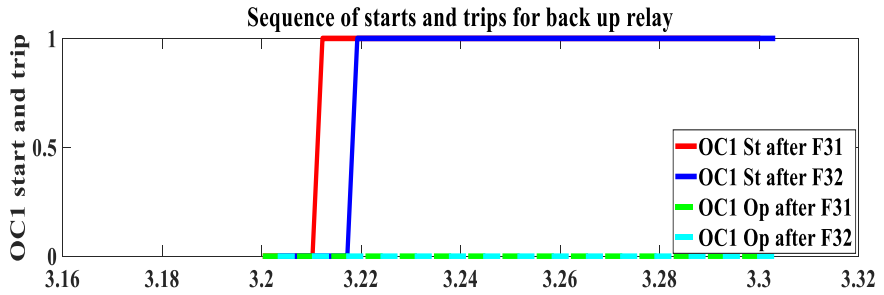
Date	Time	Source	Function	Description	Value
27.05.2024	09:30:04.462	SMU615MU0101	PROTECTION	Active group	
27.05.2024	09:30:04.460	Overcurrent	DPHLPDOC: 2	OPERATE	True
27.05.2024	09:30:04.449	SMU615MU0104	CMMXU: 5	HIGH_ALARM	True
27.05.2024	09:30:04.449	SMU615MU0101	CMMXU: 1	HIGH_WARN	True
27.05.2024	09:30:04.449	SMU615MU0101	CMMXU: 1	HIGH_ALARM	True
27.05.2024	09:30:04.434	FRT	LVRTPTUV: 1	START	True
27.05.2024	09:30:04.429	SMU615MU0104	CMMXU: 5	HIGH_WARN	True
27.05.2024	09:30:04.429	SMU615MU0103	VMMXU: 3	HIGH_WARN	False
27.05.2024	09:30:04.429	SMU615MU0103	VMMXU: 3	HIGH_ALARM	False
27.05.2024	09:30:04.429	SMU615MU0103	CMMXU: 3	HIGH_ALARM	True
27.05.2024	09:30:04.429	SMU615MU0102	VMMXU: 2	HIGH_WARN	False
27.05.2024	09:30:04.429	SMU615MU0102	VMMXU: 2	HIGH_ALARM	False
27.05.2024	09:30:04.429	SMU615MU0101	VMMXU: 1	HIGH_WARN	False
27.05.2024	09:30:04.429	SMU615MU0101	VMMXU: 1	HIGH_ALARM	False
27.05.2024	09:30:04.420	Overcurrent	DPHLPDOC: 2	START	True

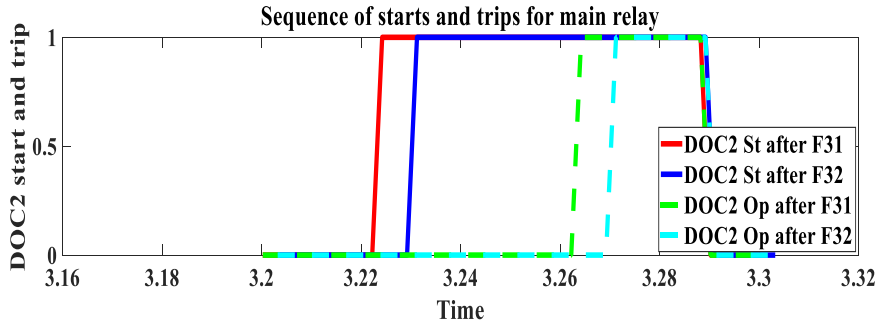
Three-phase fault at feeder3











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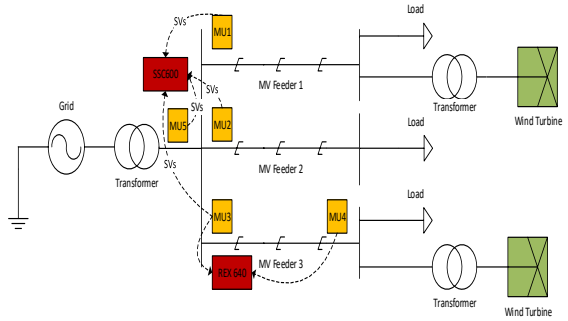
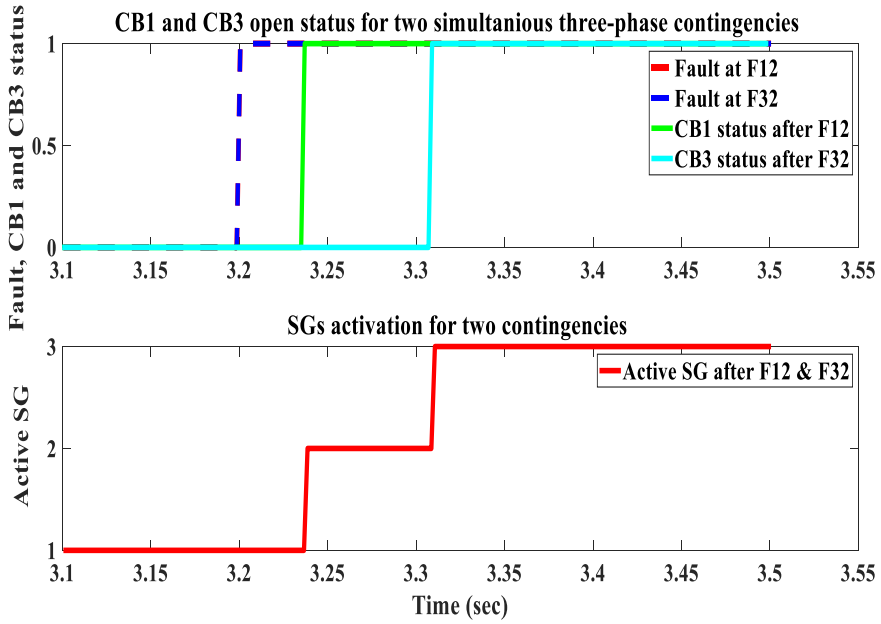
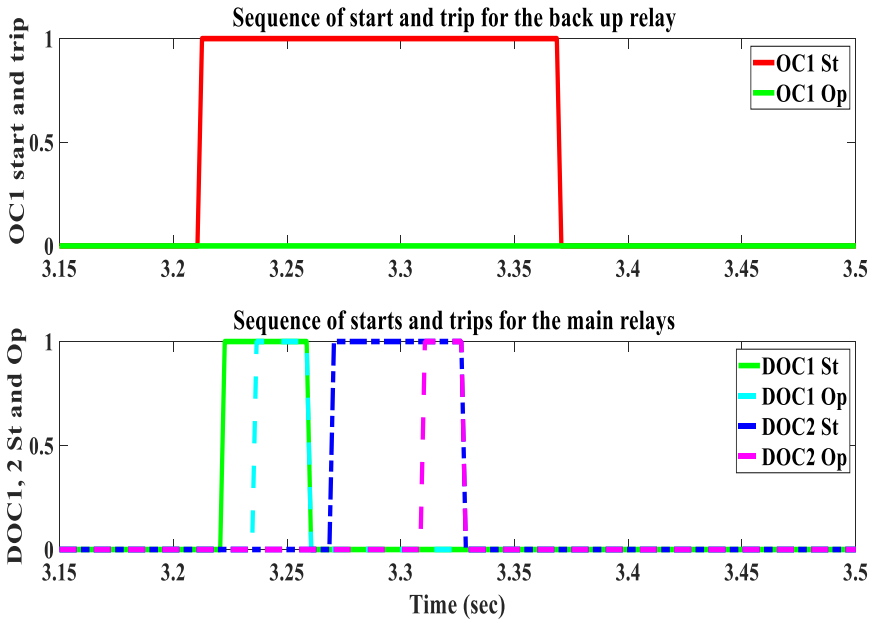
N-2 contingency analysis using HIL setup



GOOSE INPUT FOR ACTIVATING SGs					
Active SG	*BI_SG2*	*BI_SG3*	*BI_SG4*	*BI_SG5*	*BI_SG6*
1	False	False	False	False	False
2	True	False	False	False	False
3	any	True	False	False	False
4	any	any	True	False	False
5	any	any	any	True	False
6	any	any	any	any	True





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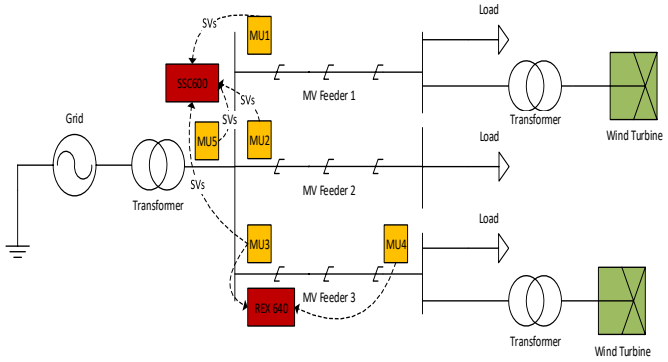

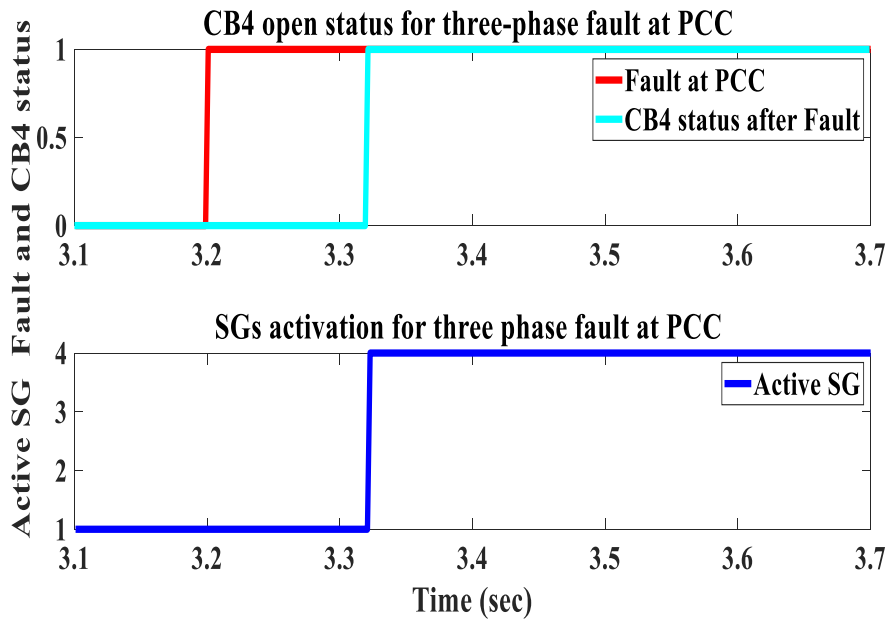

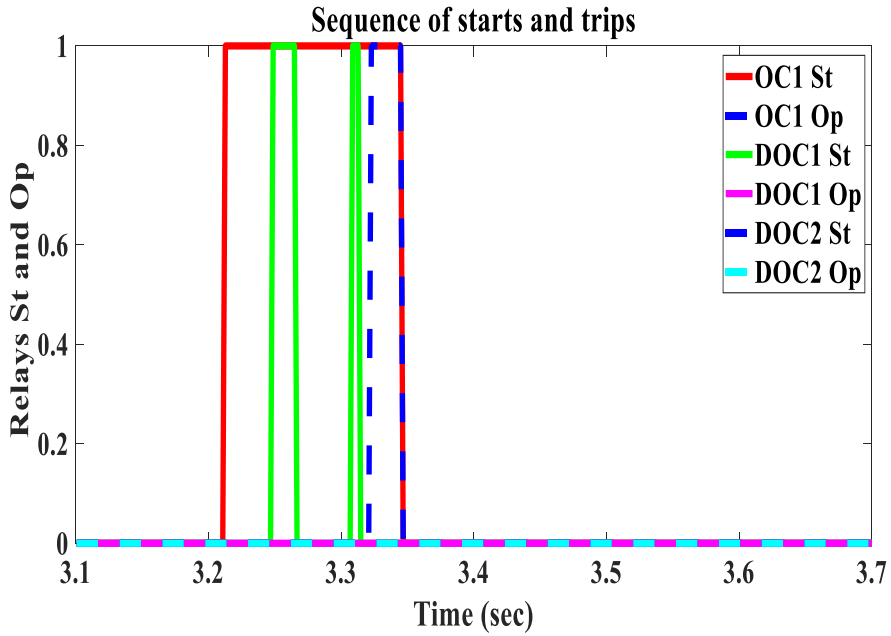

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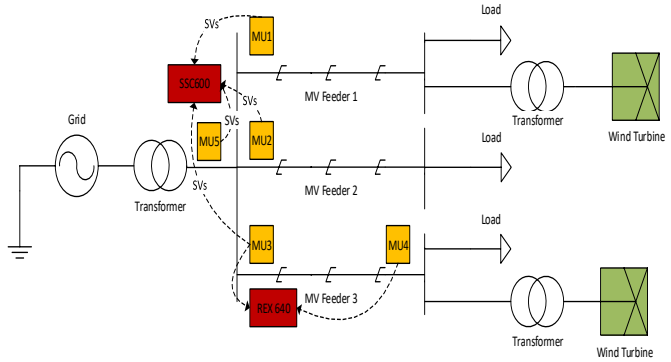
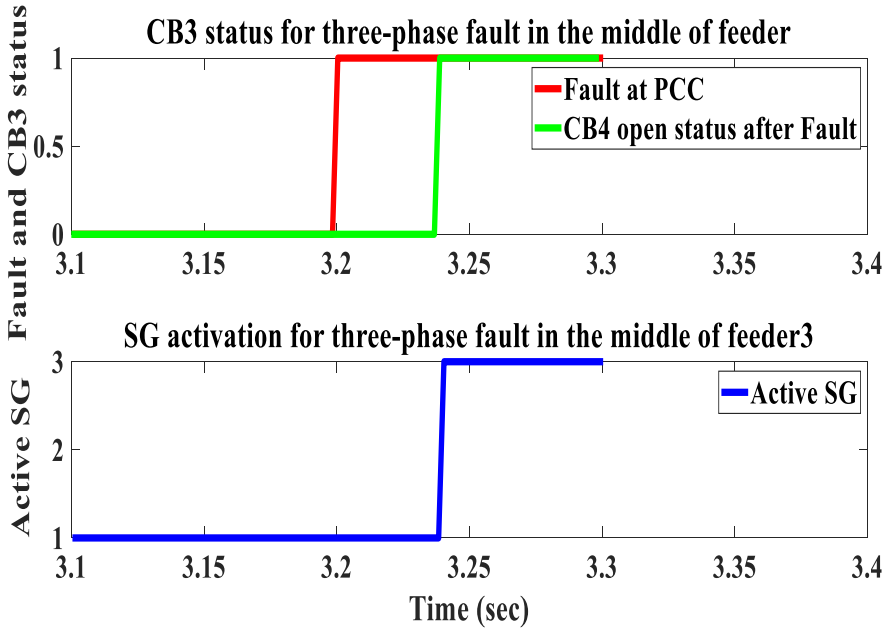
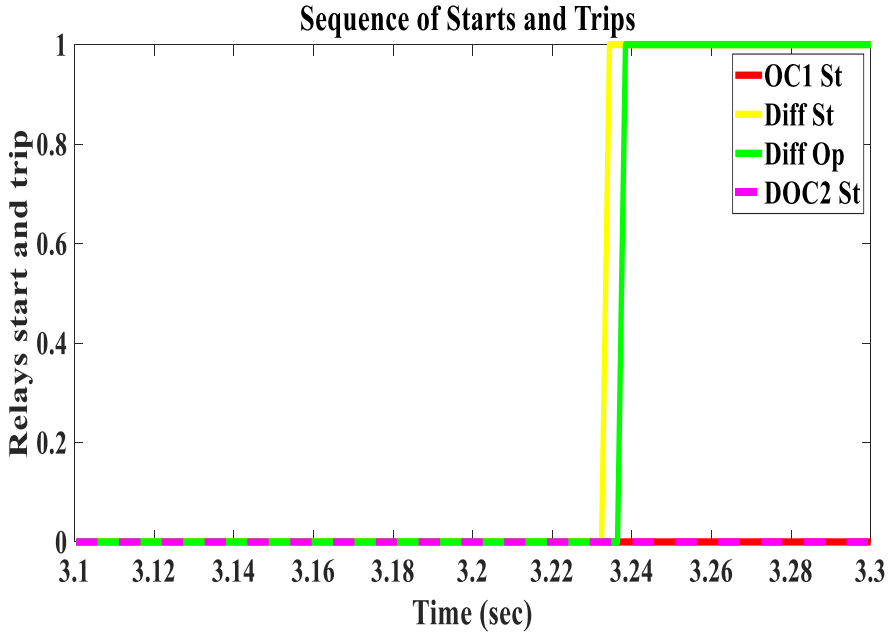
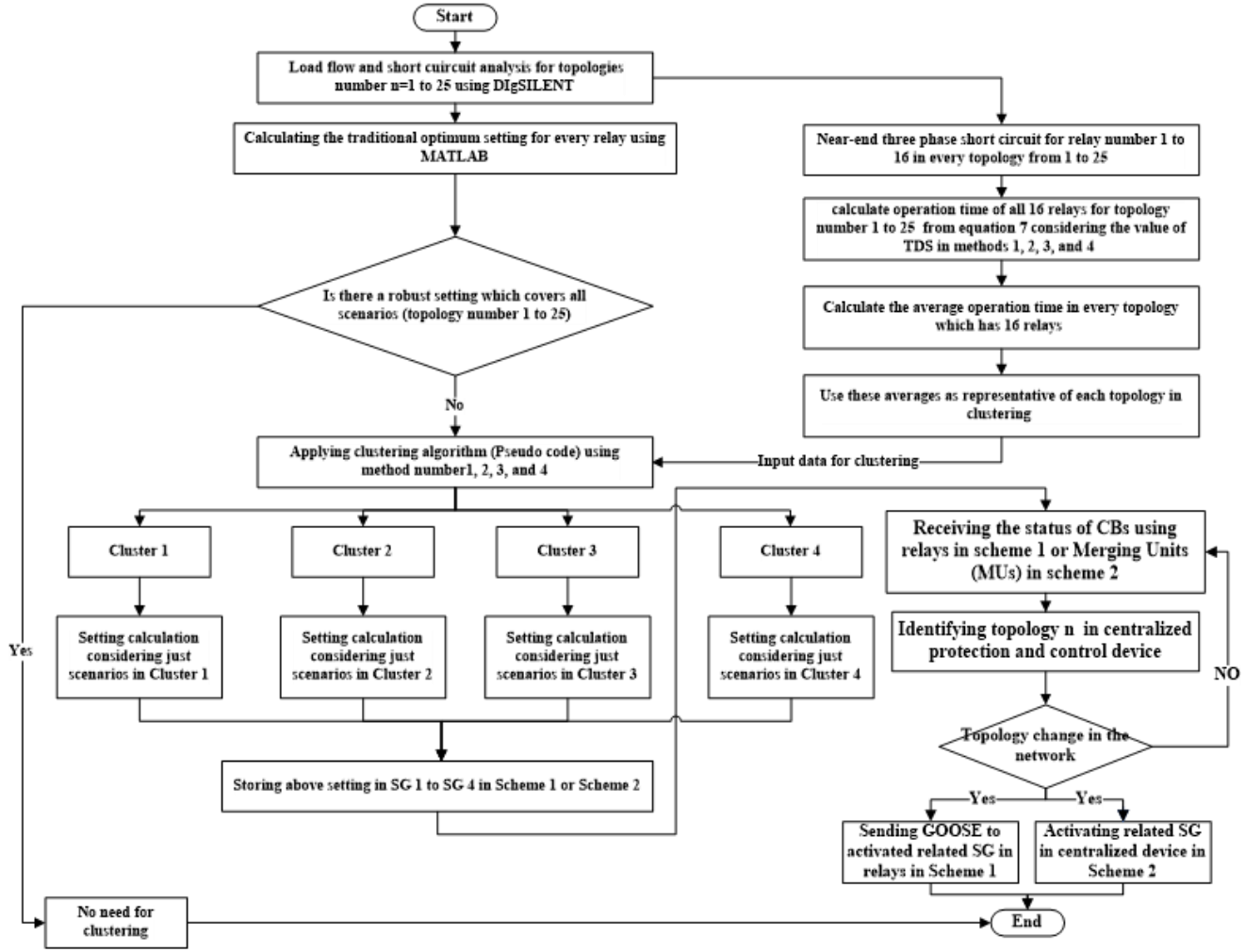
Differential protection as the main function

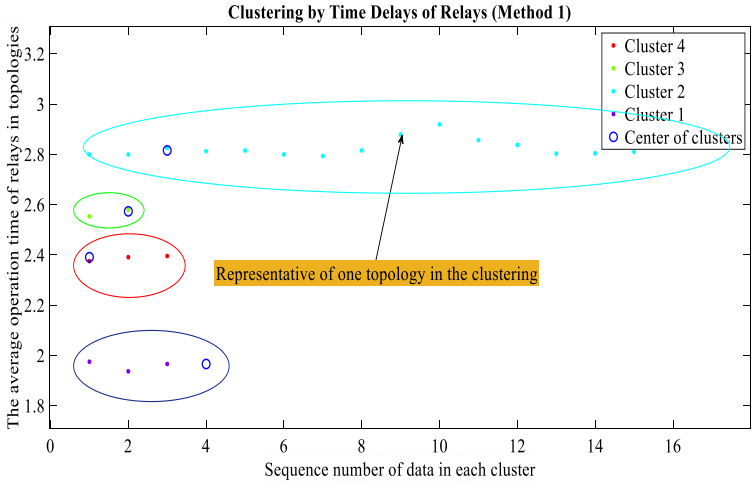


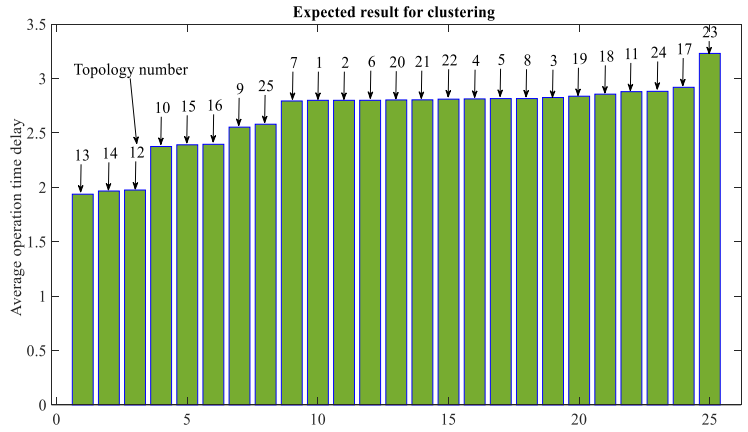




Adaptive SG-based protection results







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Relay settings and parameters

System

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Rated frequency	50Hz	50Hz			
Phase rotation	ABC	ABC			
Blocking mode	Freeze timer	Freeze timer			
Unit name	SSC600	SSC600			20
IDMT Sat point	50	50	I/I>	10	50
SV delay	100	100	%	10	5000

1.313 regardless of SmpCnt

Synchronization

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Synch source	IEEE 1588	IEEE 1588			
PTP domain ID	0	0		0	127
PTP profile	Power profile C37.238-2011	Power profile C37.238-2011			

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Relay settings and parameters

Outputs

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
SG_1_ACT	True	True			
SG_2_ACT	False	False			
SG_3_ACT	False	False			
SG_4_ACT	False	False			
SG_5_ACT	False	False			
SG_6_ACT	False	False			
SG_LOGIC_SEL	True	True			

Disturbance records

Write to device | Disable Edit | Import | Export | Refresh

PARAMETER NAME	IED VALUE	NEW VALUE	UNIT	MIN.	MAX.
Number of recordings	1	1		0	9999
Trig recording	Cancel	Cancel			
Rec. memory used	1	1	%	0	100
Rem. amount of rec.	9998	9998		0	9999
Time to trigger	603395	603395	s	0	604800

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5G Implementation and Testing

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Protection and Wireless Equipment

SMU615

REX640

How to communicate over 5G ?

RPi + 5G Hat

Basestation

SSC600

XR80 Sierra Router

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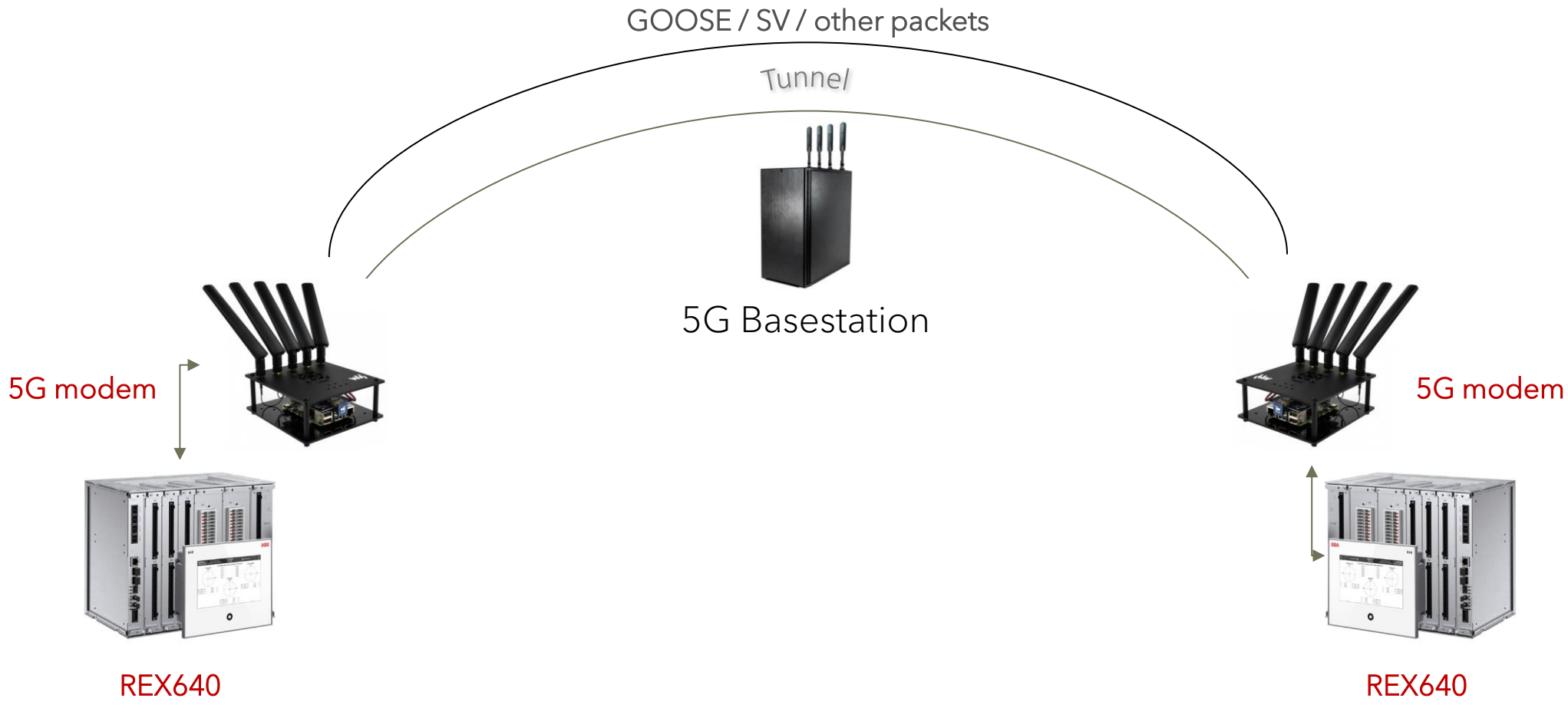
Possible Ways to Connect and Communicate

- Use Layer2 tunneling to transfer traffic between protection devices.
- Apply protocol stack change strategy.
- Use devices with native support for routable IEC61850

Use Case Line Differential Protection (layer 2 Tunnel)



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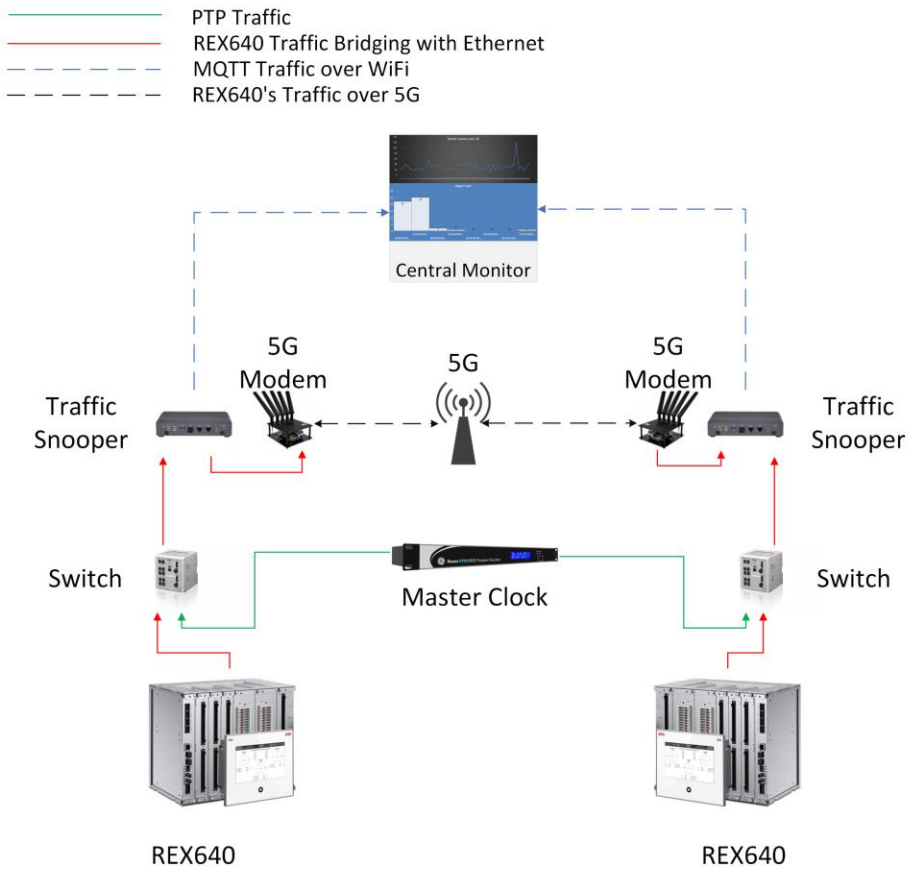
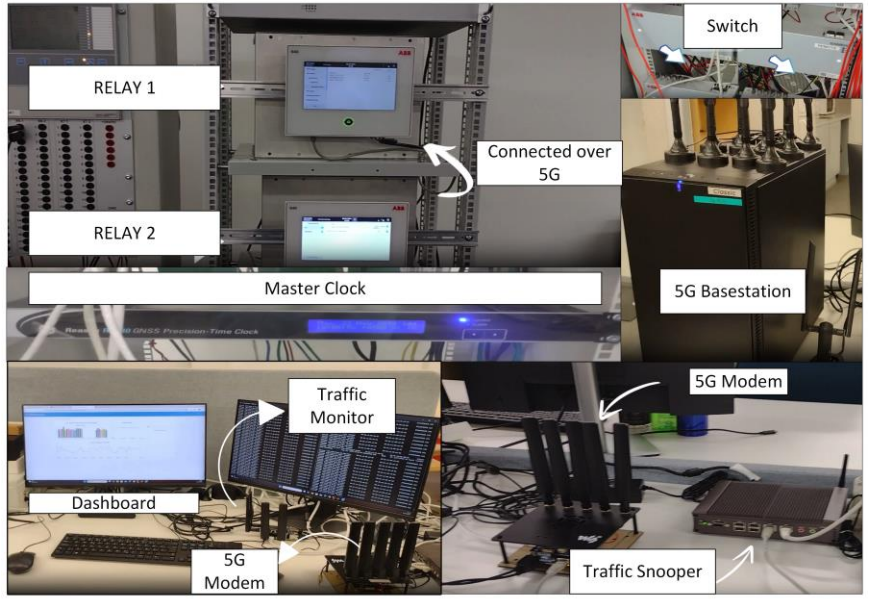
Monitoring Application for Line Differential Protection Applying 5G





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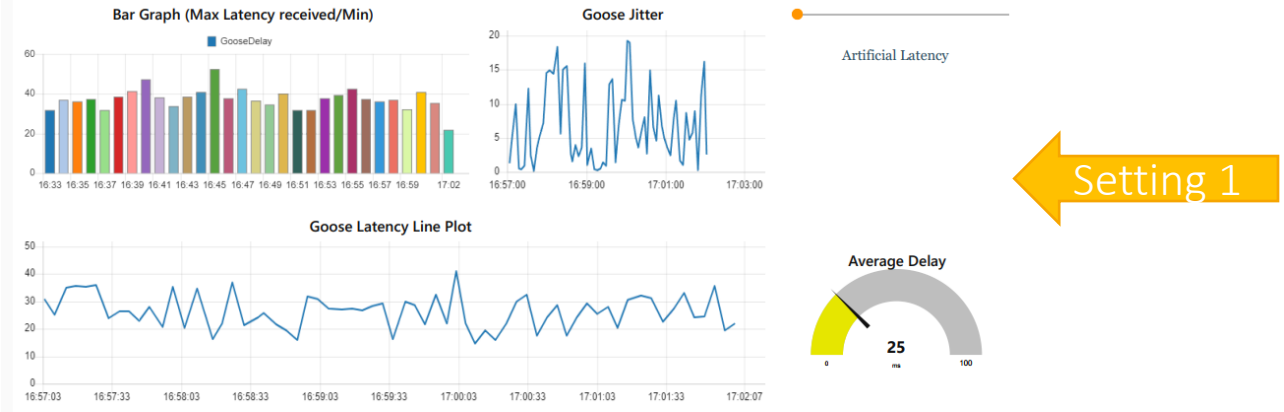
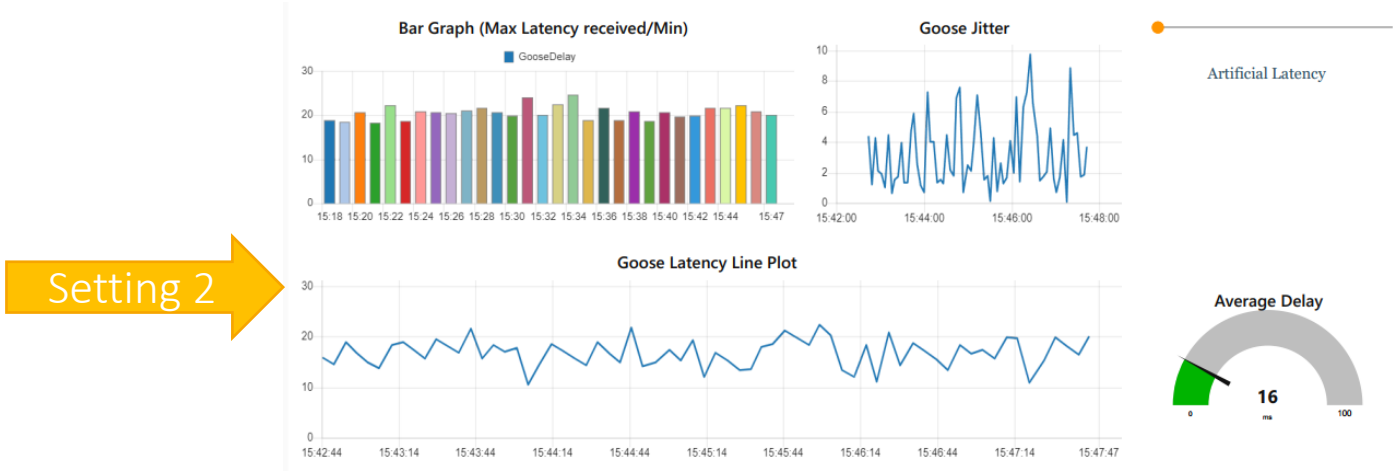
Monitoring Application for Line Differential Protection Applying 5G

TABLE I: 5G network configuration for different settings.

Settings	5G Standalone Setting 1	5G Standalone Setting 2
Bands	n77	n77
Frequency	3.900 – 3.950 GHz	3.900 – 3.950 GHz
Bandwidth	50 MHz	50 MHz
Subcarrier spacing (SCS)	30 kHz	30 kHz
Duplexing	TDD	TDD
MIMO Configuration	2x2	2x2
dl-UL-Transmsission Periodicity	5 ms	1 ms
SR-Period	10 ms	2 ms
rx_to_tx_latency	-	2 ms
DL slots allocated	7	1
UL slots allocated	2	0
DL symbols allocated	6	0
UL symbols allocated	4	12





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Monitoring Application for Line Differential Protection Applying 5G

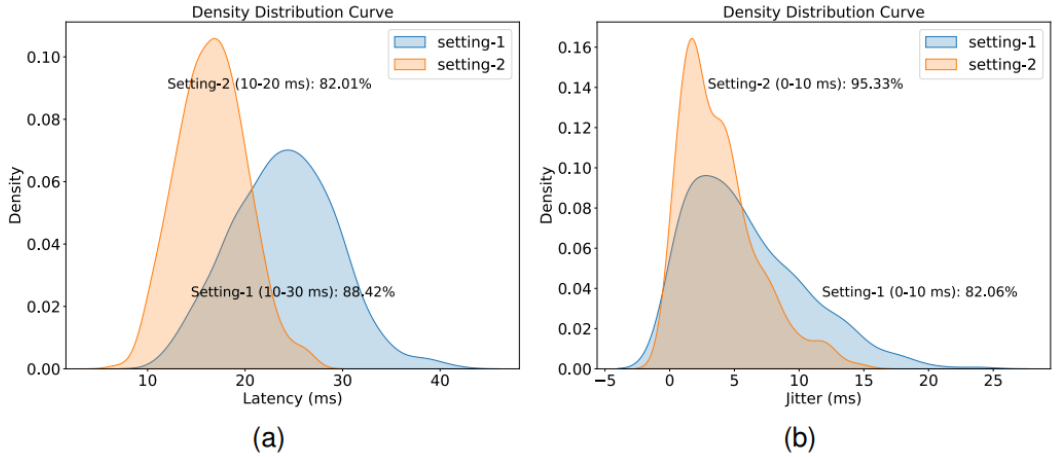

Fig. 12: Probability density curves for latencies and jitter a) Latency distribution for setting-1 and setting-2 b) Jitter distribution for setting-1 and setting-2

TABLE IV: Latency and Jitter Packets Distribution.

Majority Packets	Latency			Jitter	
	0-10 ms	10-20 ms	20-30 ms	0-5 ms	5-10 ms
SA Setting 1	0%	24.88%	63.55%	51.60%	30.47%
SA Setting 2	1.4%	82.01%	16.59%	72.66%	22.90%

Virtualized Intelligent Relaying of Smart Grid Over 5G

- The concept is implemented and tested in real-time by setting up three areas:
  - Power Grid Model in OPAL-RT
  - AI Algorithm Deployed on 5G Basestation
  - Private 5G physical communication network

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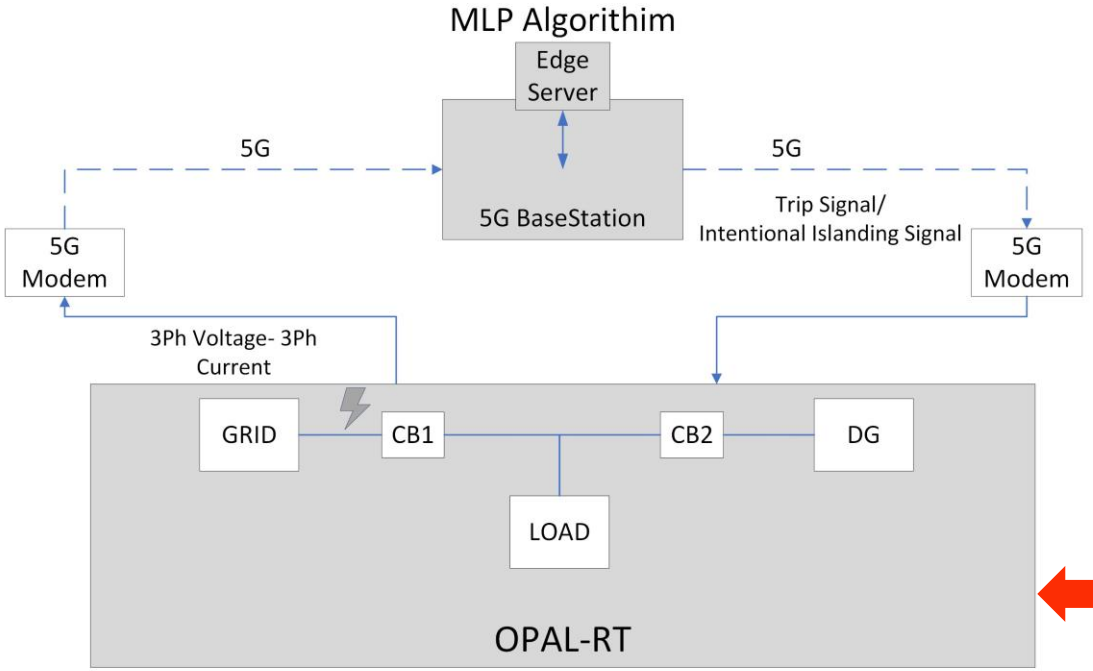
Virtualized Intelligent Relaying of Smart Grid Over 5G

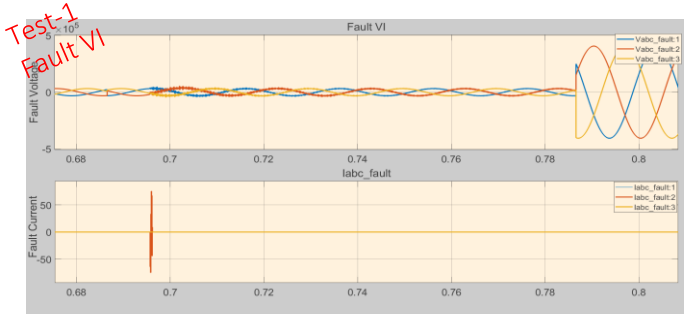
5G Communication

Virtualization

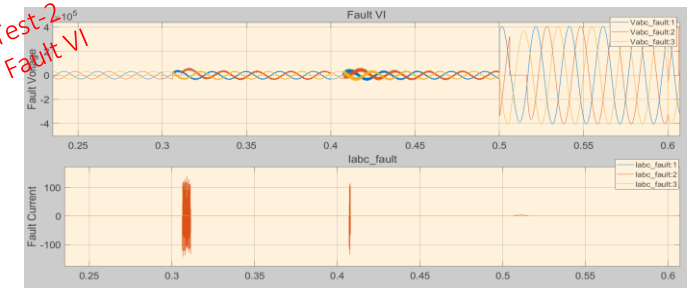


Grid Model

Test-1 Fault VI



Test-2 Fault VI



Fault Prediction Results

Model	Validation Score of Predicted Data	Time Taken
Test 1	100%	≈ 90ms
Test 2	98.75%	≈ 200ms

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Cybersecurity issue with 5G and Line Differential Protection

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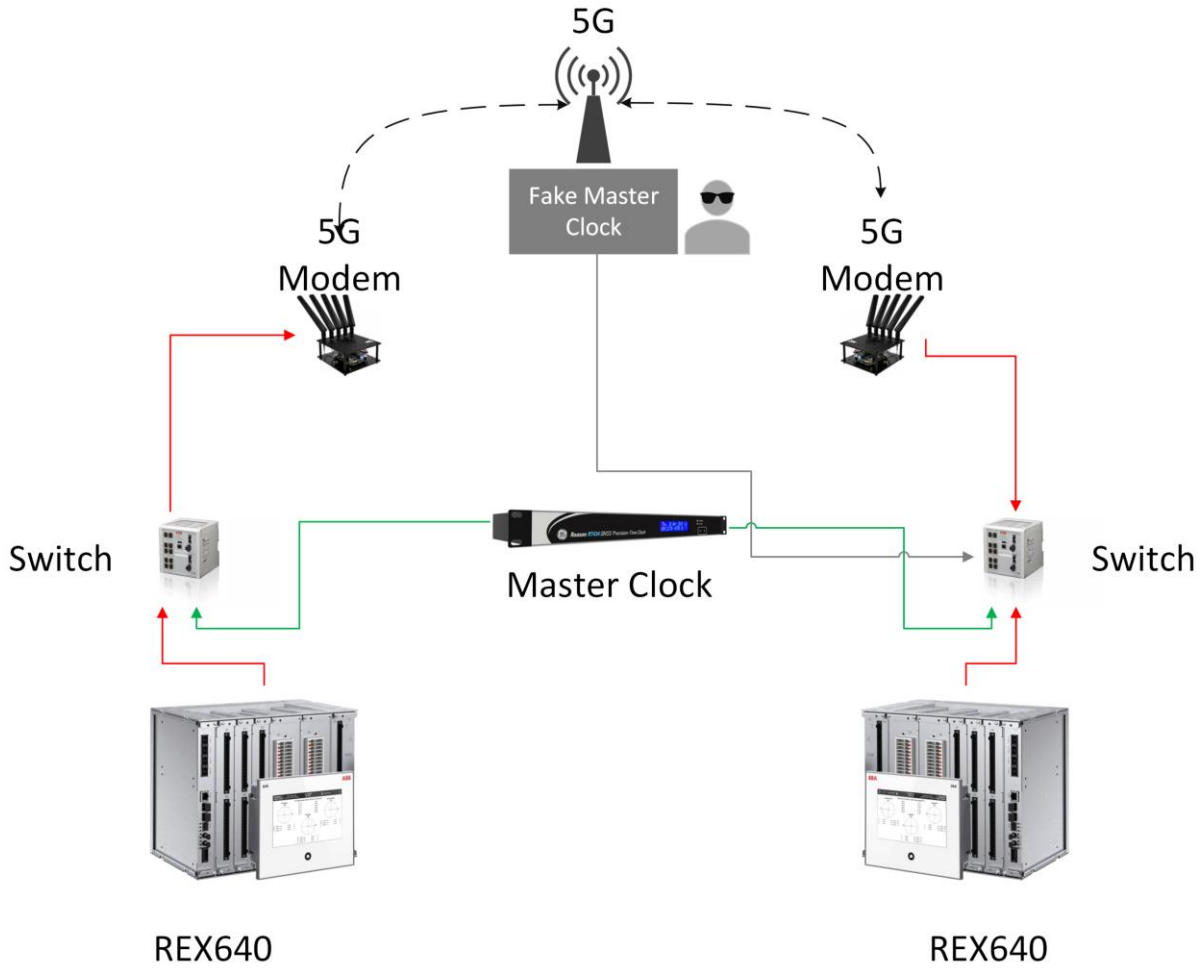
Threat Model

- Line differential protection connected over a 5G network.
- An attacker get access to the 5G basestation or 5G Modem or the network.
- Perform a fake-time-master-clock attack and manipulate time synchrony.

Experimental Setup



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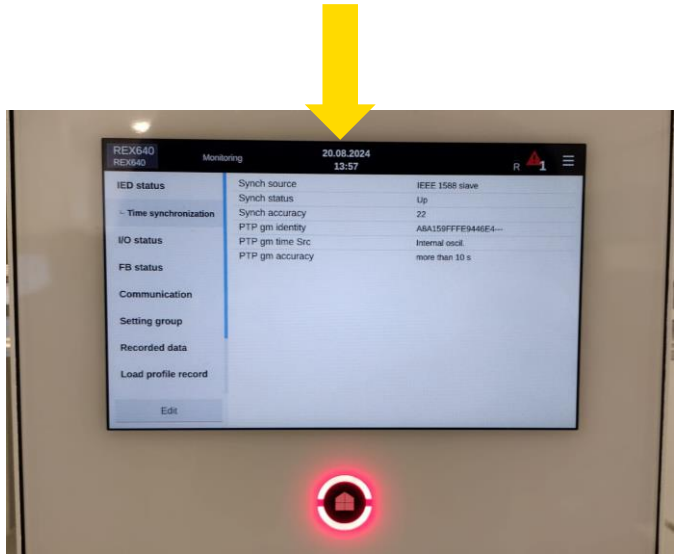
Result of cyberattack

Protection Communication Supervision Alarm (PCSITPC)



Both REX640 raises alarm

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Conclusion

- Implementation of IEC 61850-based centralized protection schemes
- Development of functions such as adaptive protection scheme using HIL setup developed in CIRP5G
- Studying the possibility of developing new functionalities such as intermittent earth fault detection using AI and ML-based algorithms
- The need for digitalization, virtualization, and intelligentization to develop future protection methods
- Cybersecurity related challenges and the measures need to be taken
- Integrating artificial intelligence (AI), 5G communication, and virtualization technology into power systems to facilitate the evolution of smart grids

Thank you!

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