2022 IEEE PES ISGT-Europe
October 10th-12th, 2022, Novi Sad, Serbia
Paper №: 20337

Ground Directional Protection Assessment in Inverter Dominated Distribution Networks

Christos Frangeskou[1,2], Lenos Hadjidemetriou[1], Markos Asprou[1], Christos Panayiotou[1]

[1]KIOS Research and Innovation Center of Excellence and Department of Electrical and Computer Engineering, University of Cyprus

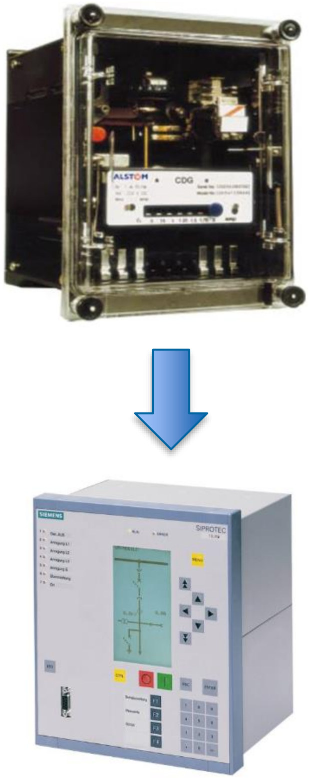
[2]Transmission System Operator Cyprus

Overview

- Introduction
- Description of this work
- Background
- System under Study
- Testbed arrangement
- Case Studies Results

Introduction

- IBRs are challenging traditional line protection systems.
- Protection systems designed over the years have been based on synchronous dominated systems.
- IBRs response under faults is driven by the inverter control design.
- IBRs injection of negative sequence currents vary across designs.
- Most IBRs are three wire interconnected - no zero sequence contribution.



[1]Report - Impact of Inverter Based Resource Negative-Sequence Current Injection on Transmission System Protection, Sandia National Laboratories, Jan. 2020.
[2]Report – Protection Challenges and Practices for Interconnecting Inverter Based Resources to Utility Transmission Systems," PSRC Working Group C32, Jul. 2020.

Description of this work

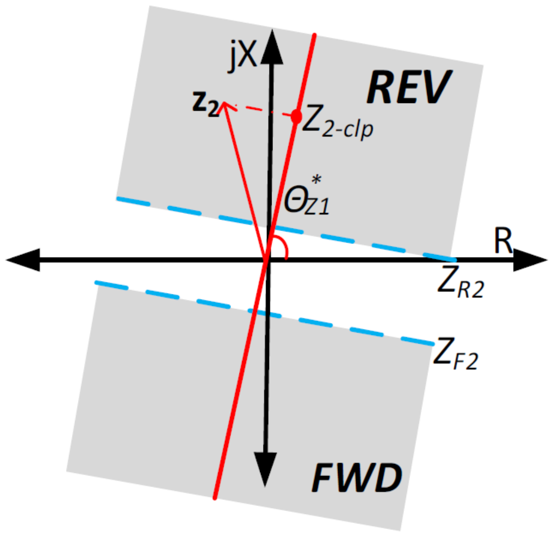
- An industrial oriented investigation for protection systems at the distribution level is performed.
- The performance of ground directional elements used as part of an 11kV blocking scheme is evaluated.
- A study system is modelled and real time HIL tests are performed with commercial protection relays.
- Advanced simulation tools and test setups are required to test protection schemes under the new circumstances.

Background: Directional Protection

- Directional Protection (Negative Sequence Impedance).

$$\mathbf{z}_2 = Z_2 \angle \theta_{z2} = \frac{\mathbf{v}_2}{\mathbf{i}_2}$$

$$Z_{2-clp} = Z_2 \cos(\theta_{z2} - \theta_{z1}^{*})$$



$\boldsymbol{z}_2$,negative sequence impedance

$\mathbf{v}_2$, negative sequence voltage

$\mathbf{i}_2$, negative sequence current

Z_2, negative sequence impedance amplitude

θ_{z2}, negative sequence impedance angle

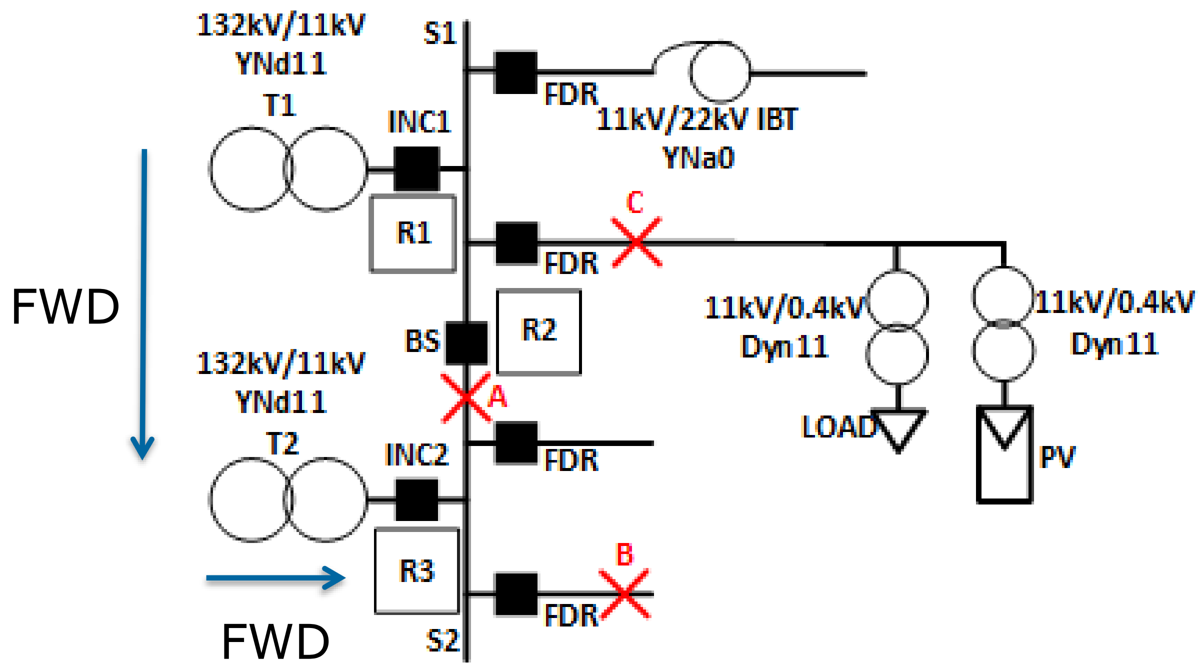
θ_{z1}^{*}, positive sequence impedance angle setting

Z_{2-clp}, co-linear projection of $\boldsymbol{z}_2$ towards the positive sequence impedance

$Z_{\mathrm{R2}}/Z_{\mathrm{F2}}$, Reverse/Forward impedance threshold settings.

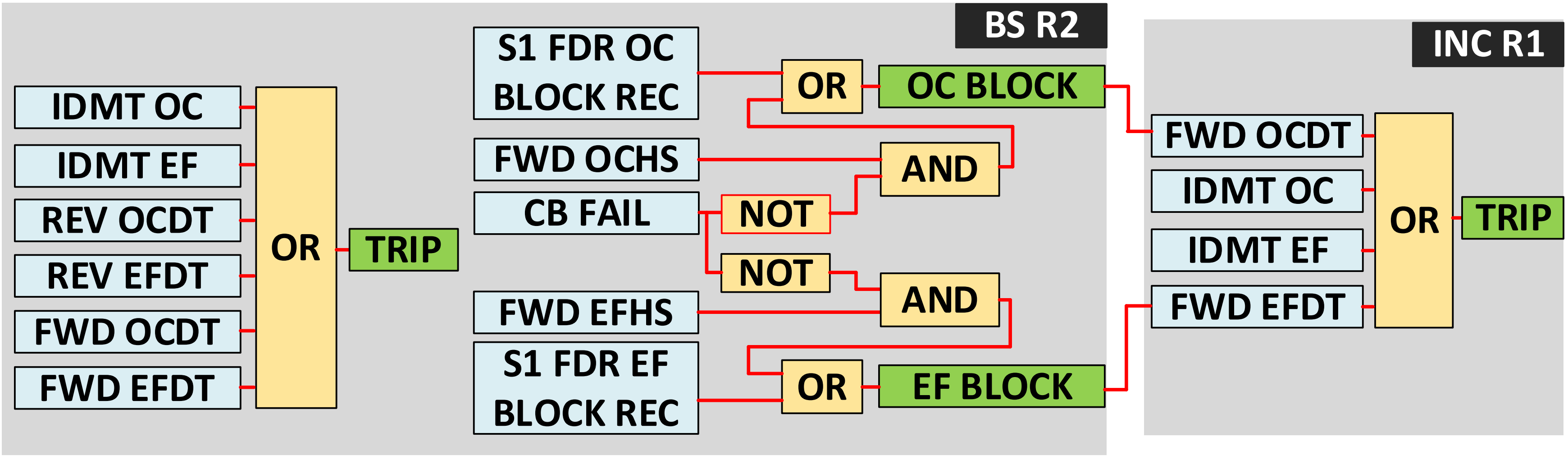
[3] K. Zimmerman and D. Costello, "Fundamentals and Improvements to Directional Relays," in *Proc. Confercence for Protective Relay Engineers,* Mar. 2010.

System under Study



Blocking Scheme

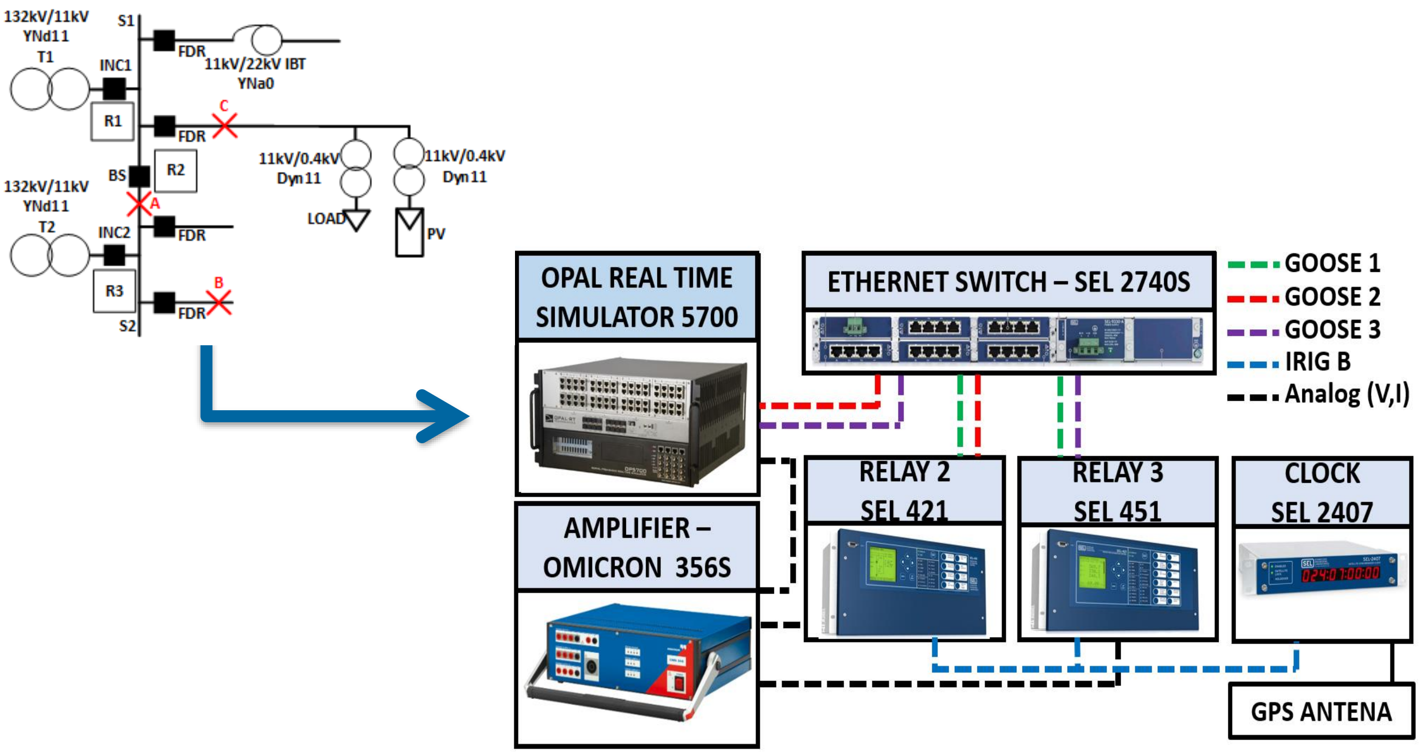
- A pseudo Bus Bar (BB) protection scheme implemented using the IEC 61850 industry standard protocol.
- Main goal is to provide fast clearance for BB faults and discrimination for feeder faults.



Testbed Arrangement (1)

- Substation communication based on IEC 61850.
- GOOSE signals configured between relays for blocking and between relays-real time simulator for tripping.
- Study system modelled and simulated in real time using the OPAL RT real time simulator.
- R3 and R2 represented by commercial relays. R1 is modelled in the real time simulator.
- Omicron Amplifier used to amplify the low level signals from OPAL RT into the protection relays.
- IRIG-B used for synchronization.

Testbed Arrangement (2)



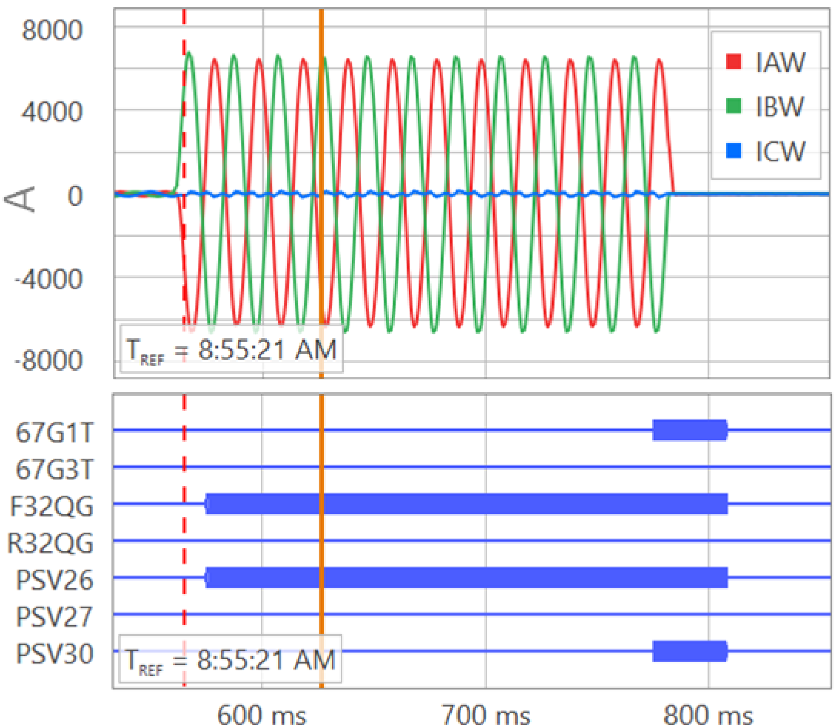
https://www.kios.ucy.ac.cy/power-systemstestbed/

Relay Elements Description

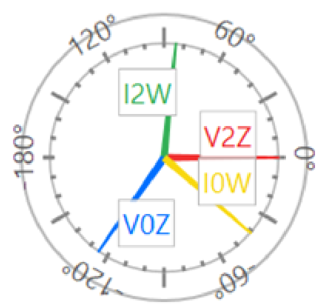
Name	Description	Relay Applied
67G1T	DT residual ground directional overcurrent element. Forward ground conditioned.	SEL 421 SEL 451
67G3T	DT residual ground directional overcurrent element. Reverse ground conditioned.	SEL 421
F32QG /F32V	Forward negative/zero sequence voltage polarized ground directional element.	SEL 421
R32QG /R32V	Reverse negative/zero sequence voltage polarized ground directional element.	SEL 421
PSV26	Protection variable used for communicating a forward block (via GOOSE to incomer 1).	SEL 421
PSV27	Protection variable used for communicating a reverse block (via GOOSE to Incomer 2).	SEL 421
PSV30	Protection variable used to send a BS trip command (via GOOSE to OPAL-RT).	SEL 421
PSV21	Protection variable used to flag a received block.	SEL 451
PSV32	Protection variable used to send an incomer trip command (via GOOSE to OPAL-RT).	SEL 451

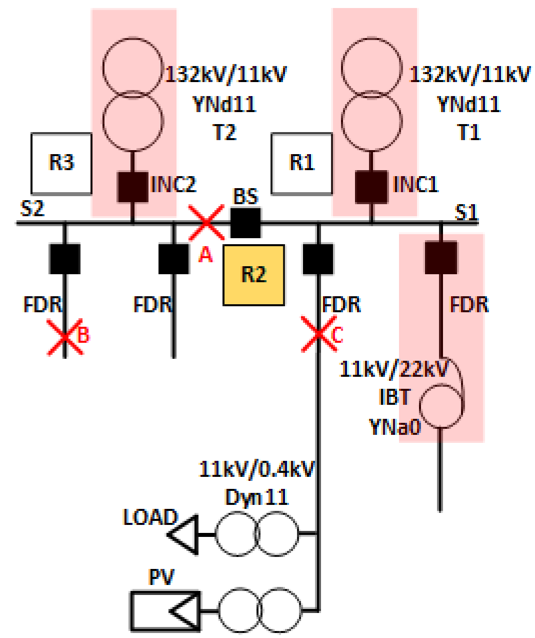
Case Study 1: T1 & T2 Operate in Parallel

- SEL 421 (R2) events (AB-G Fault at location A)



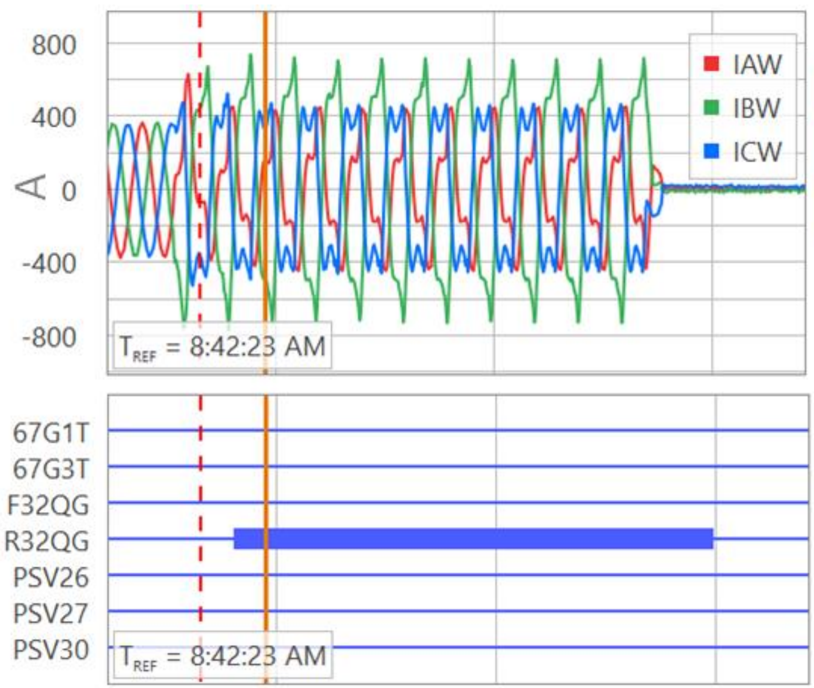
	Name	Mag	Angle
	V2Z	1,90kV	0
	I2W	2324A	84,19
	V0Z	2,08kV	-125
	I0W	614,86A	-41,03



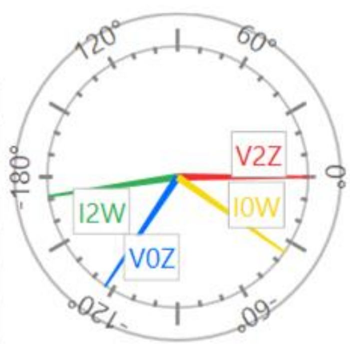


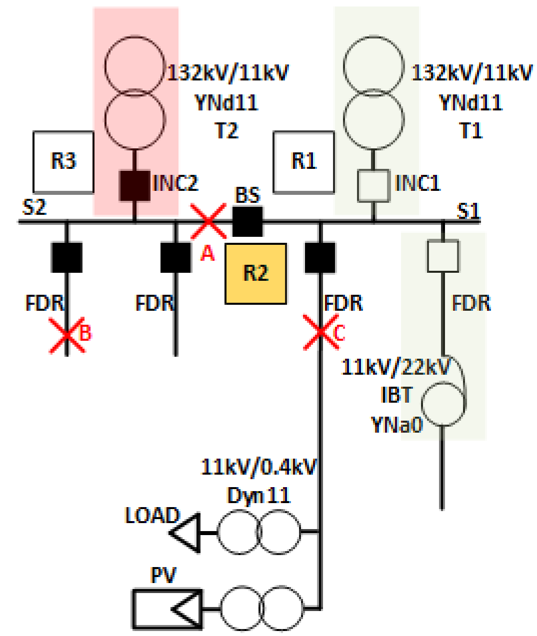
Case Study 2: T1 and IBT out of service

- SEL 421 (R2) events (AB-G Fault at location A)



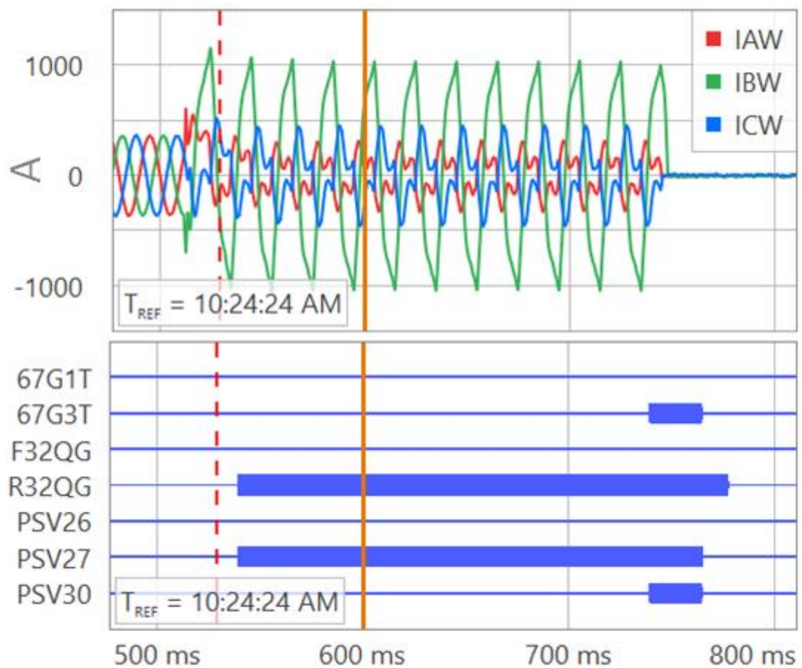
Name	Mag	Angle
V2Z	3,06 kV	0
I2W	141,4 A	-171,5
V0Z	3,22 kV	-123,6
I0W	2,75 A	-35,08



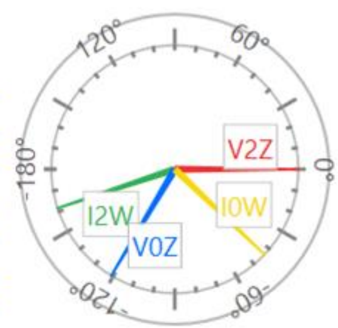


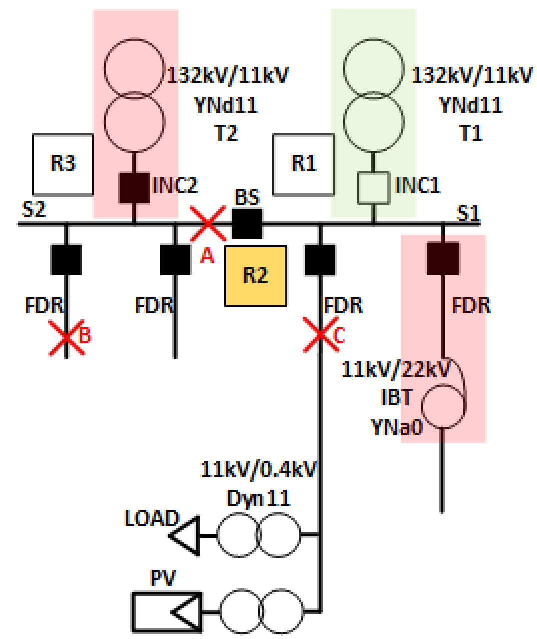
Case Study 3a: T1 out of Service and IBT in service

- SEL 421 (R2) events (AB-G Fault at location A)



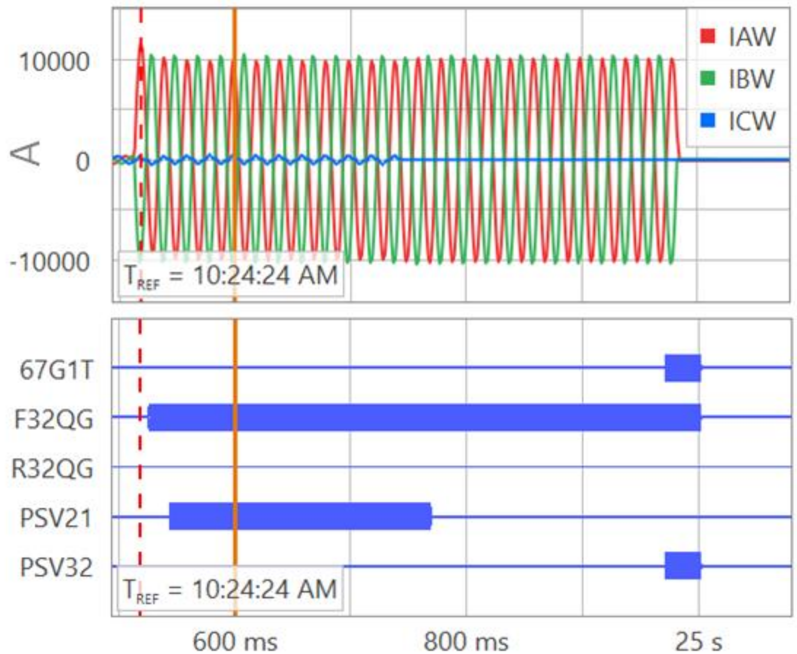
Name	Mag	Angle
V2Z	2,94 kV	0
I2W	221,42 A	-161,7
V0Z	3,00 kV	-121
I0W	233,97 A	-43,5



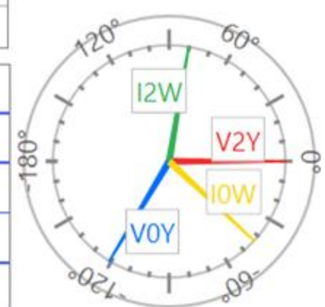


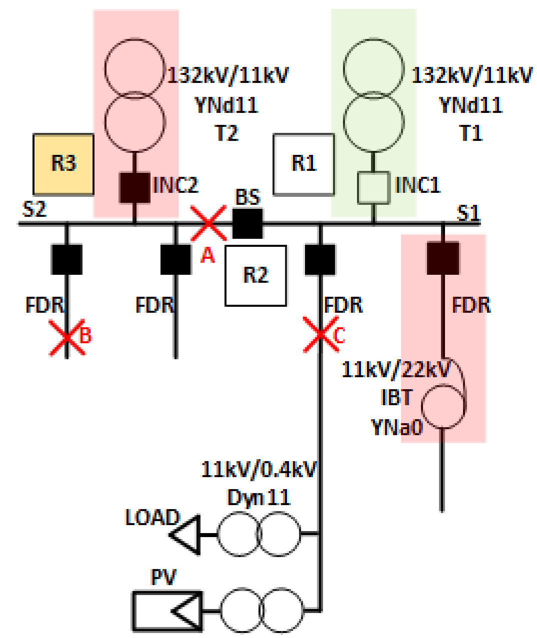
Case Study 3a: T1 out of Service and IBT in service

- SEL 451 (R3) events (AB-G Fault at location A)



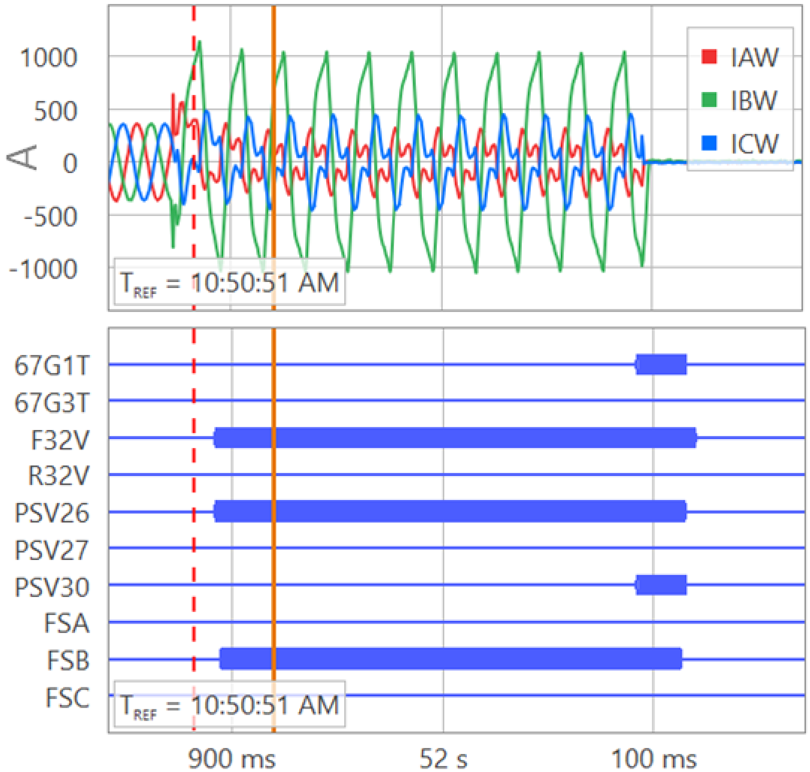
Name	Mag	Angle
V2Y	2,94 kV	0
I2W	3812 A	80.36
V0Z	3,00 kV	-121
I0W	650 A	-43,1



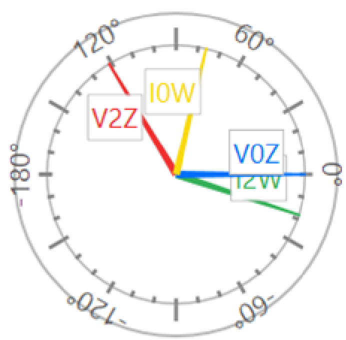


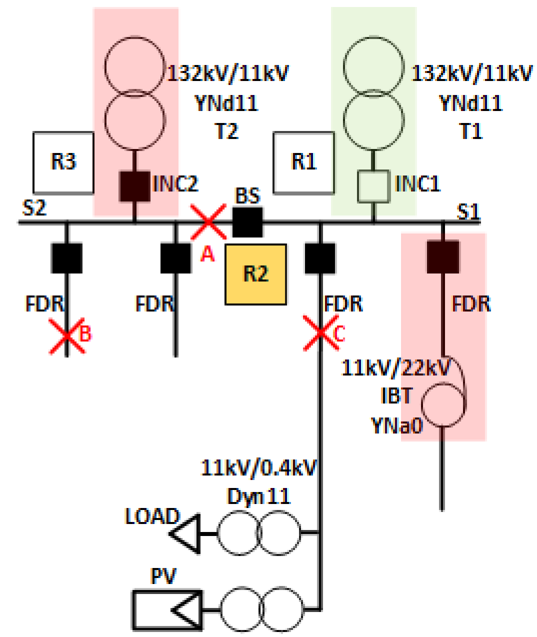
Case Study 3b: T1 out of Service and IBT in service

- SEL 421 (R2) events (zero sequence) - AB-G Fault at location A



Name	Mag	Angle
V2Z	2,93 kV	121,13
I2W	272 A	-18,21
V0Z	2,98 kV	0
I0W	235,9 A	76,47





Conclusions

- Negative sequence directional elements can missoperate when there is no fault contribution from conventional sources.
- Zero Sequence directional elements can be used reliably when the utility transformers are grounded on the utility side.
- The BS relay directional blocking can be disabled to increase sensitivity when one of the incomers is out of service→ Selectivity is affected.
- Increase of Negative and zero sequence overcurrent thresholds above the expected IBR contribution.
- Standardization of inverter control design regarding the negative sequence injection is required.

Thank you!

This work was supported in part by the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 957739 (OneNet), in part by the European Union's Horizon 2020 research and innovation programme under grant agreement No 101016912 (Smart5Grid), and in part by the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 739551 (KIOS CoE - TEAMING) and from the Republic of Cyprus through the Deputy Ministry of Research,Innovation and Digital Policy.

Republic of Cyprus