Equipe SYREL-G2Elab

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Impacts of Inverter Based Resources on Protections for distribution grids

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Classical protection plan

❑ Type of protections :

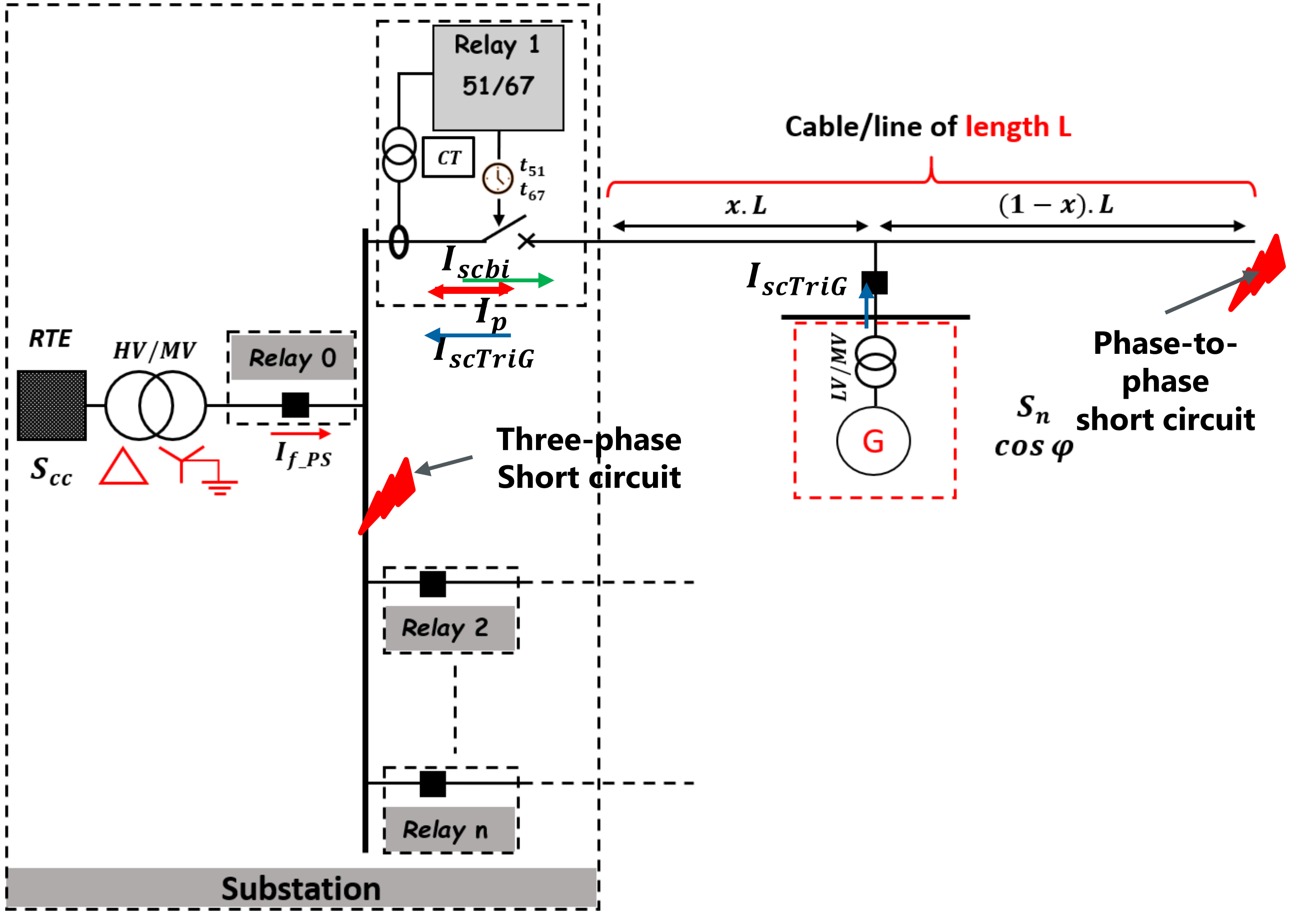
- Non-directional overcurrent protection (51) - PAP
- Directional overcurrent protection (67) - PDP

❑ Choice and setting of these protection relays:

I_{scTriG} :
Maximum short−circuit current at the level of the outgoing protection in the event of a three−phase fault located immediately upstream of the outgoing protection.

I_{scbi} :
Minimum short−circuit current at the level of the outgoing protection in the event of a solid two−phase fault on the outgoing feeder in the presence of generators

I_p :
Maximum steady−state transit current at the protection level during power absorption or discharge



Classical protection plan

The Iscbi, calculated according to the IEC 60909 standard, is the same whether the GCI is present or not, as their contribution is not taken into account!

- **Choice and settings of these protection relays:**

If : $\mathbf{0,8 \times I_{scbi} > 1,2 \times I_{scTriG}}$

- Non-directional OC

$$\max(1{,}3 \times I_p;\ 1{,}2 \times I_{scTriG}) \leq I_{s51} \leq 0{,}8 \times I_{scbi}$$

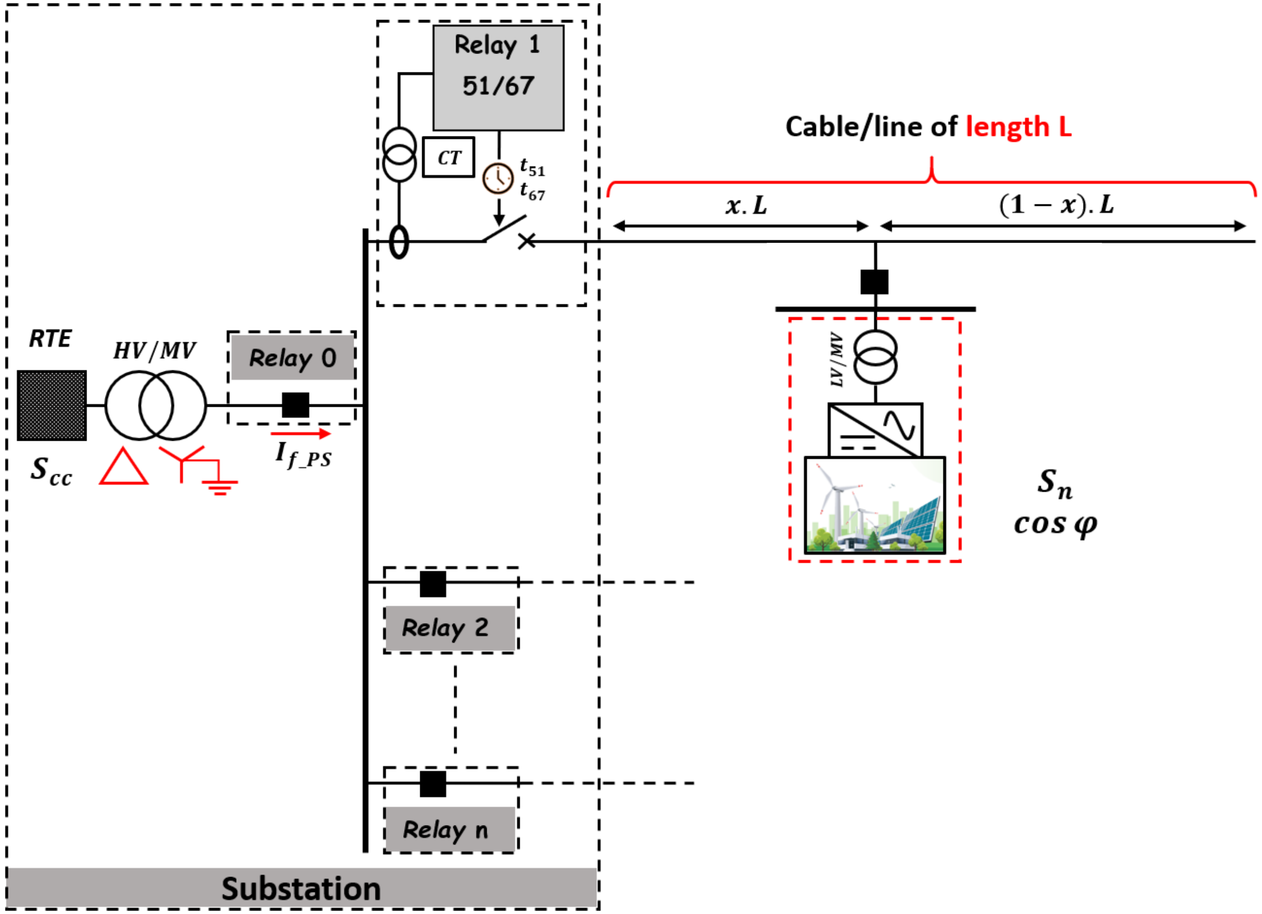
Else : $\mathbf{0,8 \times I_{scbi} \leq 1,2 \times I_{scTriG}}$

- Non-directional OC:

$$1{,}2 \times I_{scTriG} \leq I_{s51}$$

- Directional OC:

$$1{,}3 \times I_p \leq I_{s67} \leq 0{,}8 \times I_{scbi}$$



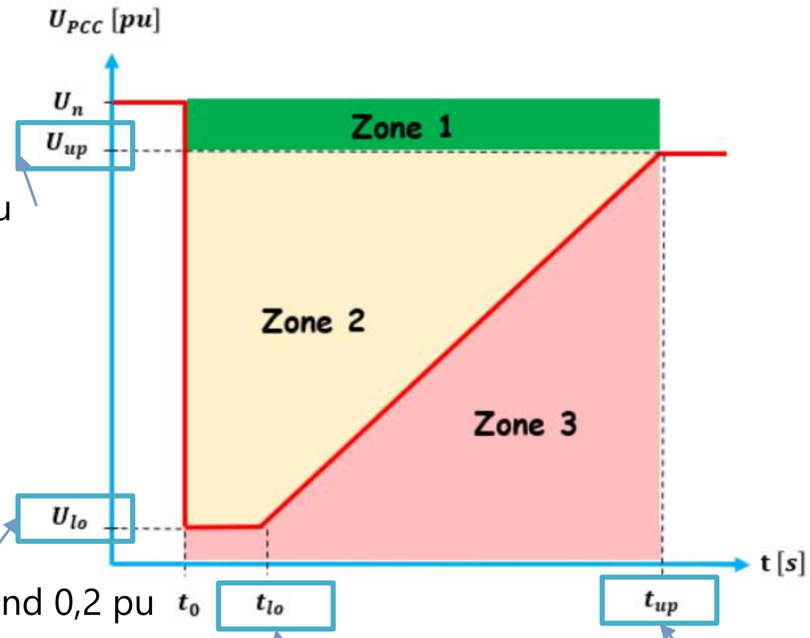
Behaviour of IBR during a fault

Requirements from Distribution System Operators

The DSO formulates some requirements to allow the connection to its grid:

- To remain connectec during a short period when a fault occurs (Low Voltage Ride Through (LVRT)).
- To inject reactive current during this period to support the voltage (Dynamic Voltage Support (DVS)).

Low Voltage Ride Through



Between 0,85 and 0,90 pu

Between 0 and 0,2 pu

Between 0,15 and 0,5 [s]

Between 1,5 and 2 [s]

A summary of several criteria for connecting PVPGS to the power grid

Country Grid Code (GC)	Rated Frequency (Hz)	Grid Frequency Boundries (Hz)	Maximum Allowed Time (Duration)	LVRT Within Fault V1 (%)	LVRT Within Fault t2 (s)	LVRT After Fault V2 (%)	LVRT After Fault t3 (s)	HVRT During Voltage Swell V (%)	HVRT During Voltage Swell t (s)
Germany GC	50	$f_g > 51.5$ $47.5 < f_g < 51.5$ $f_g < 47.5$	Disconnection (Trip) Stay in Operation (No Trip) Disconnection (Trip)	0	0.15	90	1.5	120	0.1
Italy GC	50	ND	ND	0	0.2	85	1.5	125	0.1
Spain GC	50	$f_g > 51.5$ $47.5 < f_g < 51.5$ $48 < f_g < 47.5$ $f_g < 47.5$	Disconnection (Trip) Stay in Operation (No Trip) 3 s Disconnection (Trip)	20	0.5	80	1.0	130	0.25
Australia GC	50	$f_g > 52$ $47.5 < f_g < 52$ $f_g < 47.5$	2 s Stay in Operation (No Trip) 2 s	0	0.45	80	0.45	130	0.06
China GC	50	$f_g > 50.2$ $49.5 < f_g < 50.2$ $48 < f_g < 49.5$ $f_g < 48$	2 min Stay in Operation (No Trip) 10 min Caracteristics of PV Inverter	20	0.15	90	2	ND	ND
Malaysia GC	50	$f_g > 52$ $47 < f_g < 52$ $f_g < 47$	Disconnection (Trip) Stay in Operation (No Trip) Disconnection (Trip)	0	0.15	90	1.5	120	Continuous
South Africa GC	50	$f_g > 52$ $51 < f_g < 52$ $49 < f_g < 51$ $48 < f_g < 49$ $47 < f_g < 48$ $f_g < 47$	4 s 60 s Stay in Operation (No Trip) 60 s 10 s 0.2 s	0	0.15	85	2.0	120	0.15
Enedis	50			5	0.15	85	1.5		

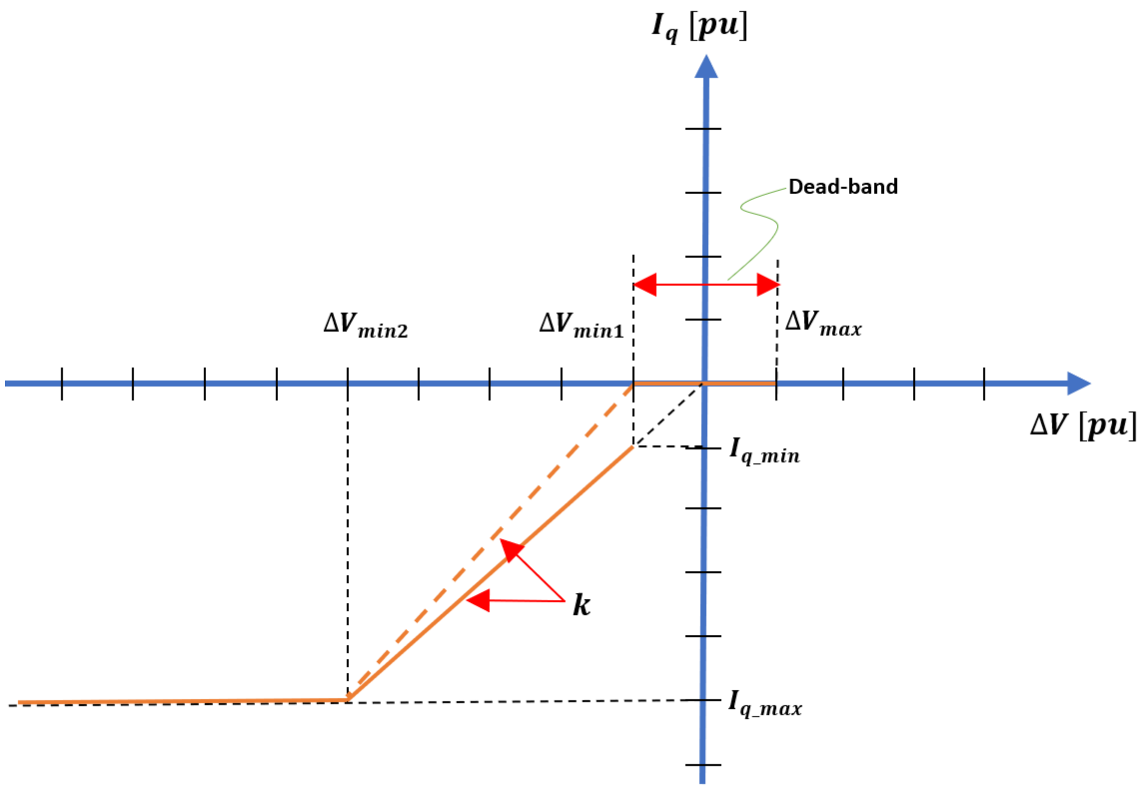
[1] Aboudrar, I, El Hani, S, Mediouni, H, Naseri, N, Daghouri, A. LVRT capability enhancement of a grid connected three phase PV system by ADRC and DSOGI FLL. *Int Trans Electr Energ Syst*. 2021; 31(11):e13059.

Behaviour of IBR during a fault

Requirements from Distribution System Operators

Dynamic Voltage Support (DVS)

Country	$\Delta V_{\min 1}$ [pu]	$Iq_{\min}$ [pu]	$\Delta V_{\min 2}$ [pu]	$Iq_{\max}$ [pu]	$\Delta V_{\max}$ [pu]	k
Germany	-0.1	-0.2	-0.5	-1	0.1	2
Denmark	-0.1	0	-0.5	-1	0.1	2.5
China	-0.1	0	-0.8	- 1.05	0.1	1.57
South Africa	-0.1	0	-0.5	-1	0.1	2.5



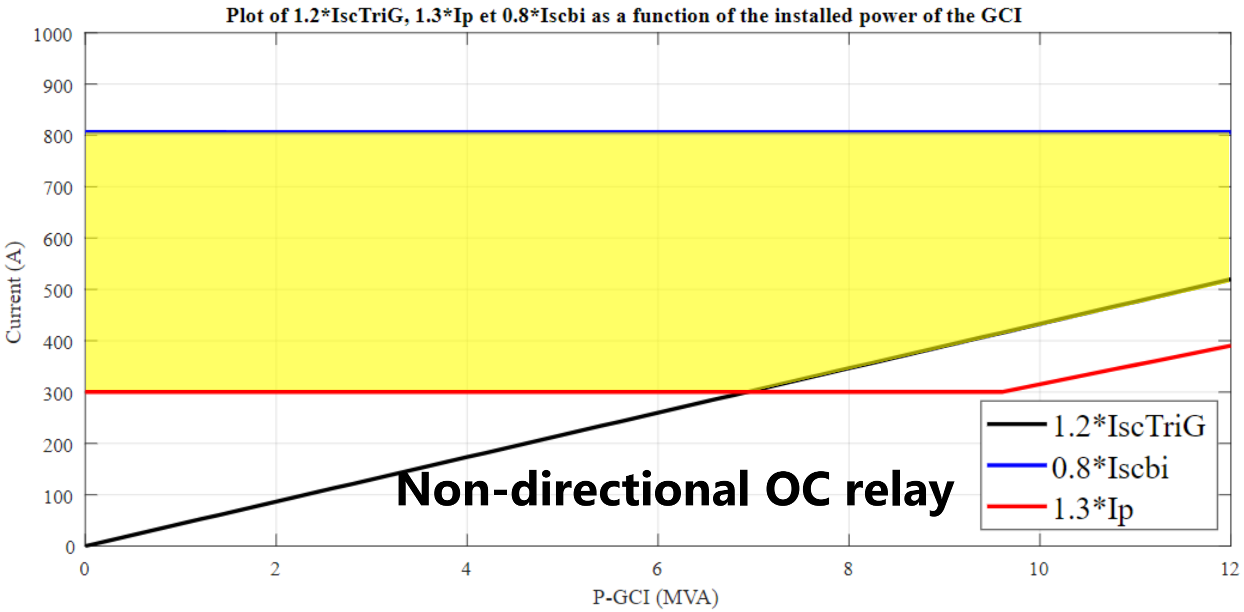
- The factor k influences the amount of reactive current that can be injected. For the countries we have studied, k ranges between 1.5 and 2.5.
- For most countries, the reactive current is saturated at 1 pu.

$$Icc_G = I_{PQ} \qquad [pu] \qquad si: V_{ond1} > 0{,}85$$

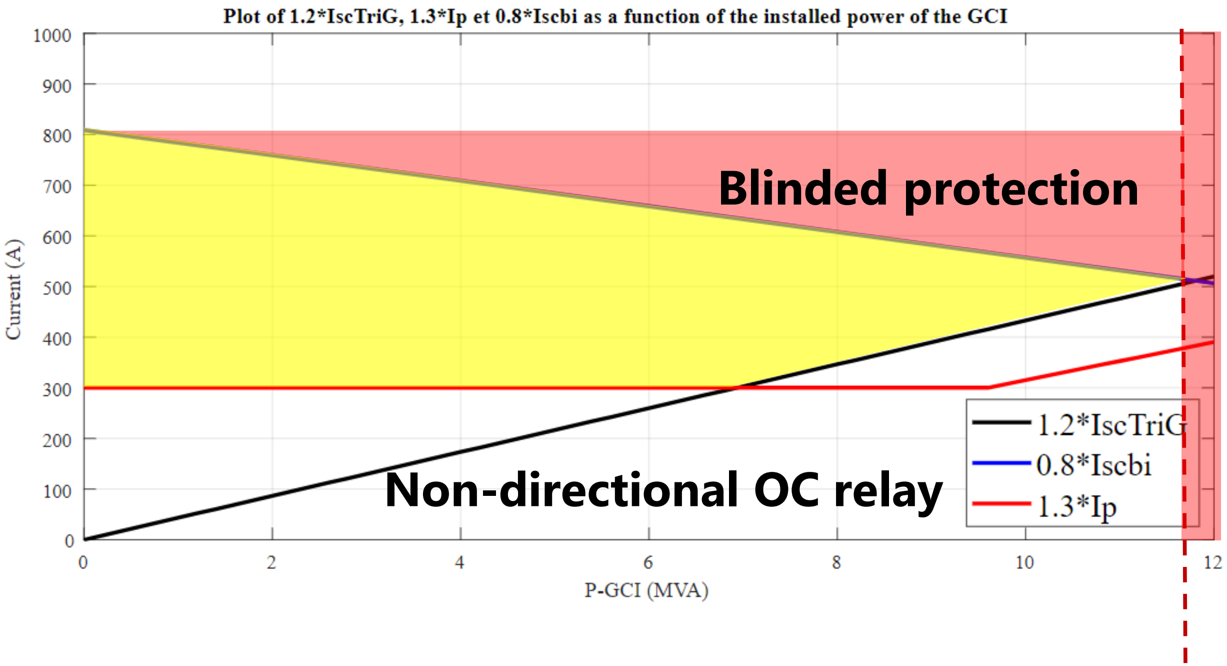
$$Icc_G = \sqrt{I_d^2 + I_q^2} = \begin{cases} I_q = k.\Delta V / V_n \\ I_d = \sqrt{I_{max}^2 - I_q^2} \end{cases} \qquad [pu] \qquad si: V_{ond1} \leq 0{,}85$$

Bad computation of the settings

Adjustment of protections according to the calculations of IEC 60909 standard.



IBR contributes to the fault



Non-directional OC relay settings range

Blinded Protection area

Equipe SYREL-G2Elab

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Impacts of Inverter Based Resources on Protections for transmission grids

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How works a distance protection (PX)

Fault detection

Measurements used:
- ❑ Currents : (Imax, I1, I2, I0, ΔI,…).
- ❑ Voltages : (V_{Phase}, V0, V2, ΔV).
- ❑ Phase angle between V and I.

Faulty phase selection

Methods:
- ❑ Currents : Imax
- ❑ Angle : (between I0 and I2), (between I1 and I2).
- ❑ Derivative of ΔI.

Impedance computation

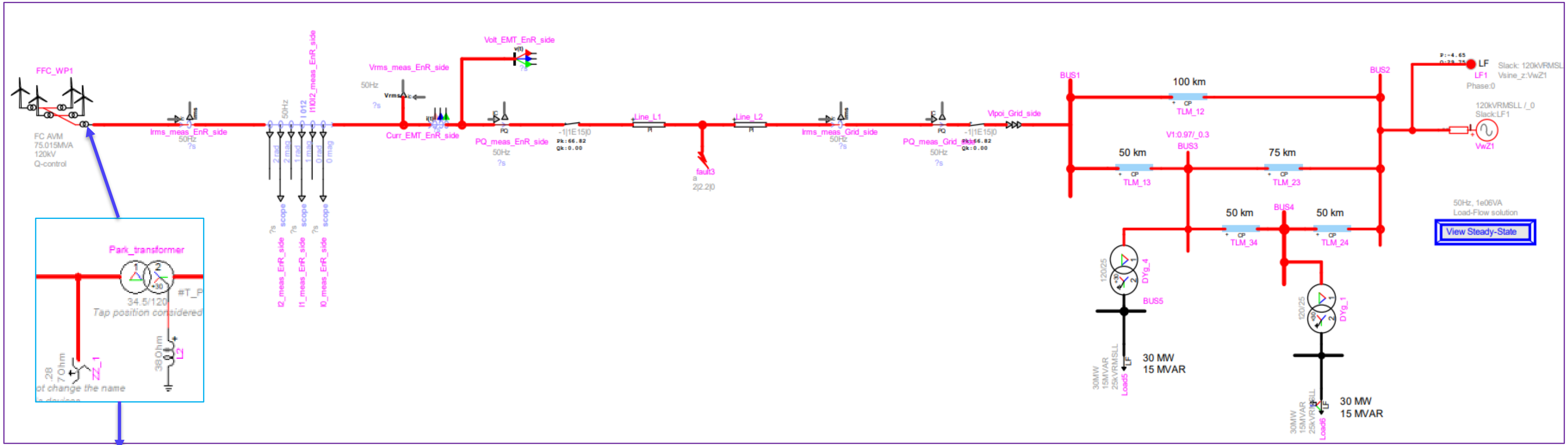
General method:
- ❑ $Z_{F-SLG} = \frac{\underline{V}}{\underline{I}+3k_0 \underline{I}_0}$
- ❑ $Z_{F-LL} = Z_{F-LLG} = \frac{\underline{V}_A - \underline{V}_B}{\underline{I}_A - \underline{I}_B}$
- ❑ $Z_{F-LLL} = \frac{\underline{V}}{\underline{I}}$

Fault direction computation

Methods:
- ❑ Angles : Imax
- ❑ Negative impendace : $Z_2 = -\frac{V_2}{I_2}$
- ❑ Derivative of ΔI.

Tripping if :
- ❑ Fault is forward the relay;
- ❑ Z_F belongs to one protected zone.

Simulation studies



Transformer :

- ❑ Sn = 75MVA ;
- ❑ 34,5/120 kV ;
- ❑ Couplage transfo : dY +30
- ❑ $Z_n = X_n = 38\Omega$;

HV line (PI model), L = 50km :

- ❑ $R_{1L} = 0{,}06\Omega/km$, $X_{1L} = 0{,}4\Omega/km$ et , $C_{1L} = 9{,}2nF/km$;
- ❑ $R_{0L} = 0{,}2\Omega/km$, $X_{0L} = 1{,}34\Omega/km$ et $C_{0L} = 5{,}2nF/km$.

Grid :

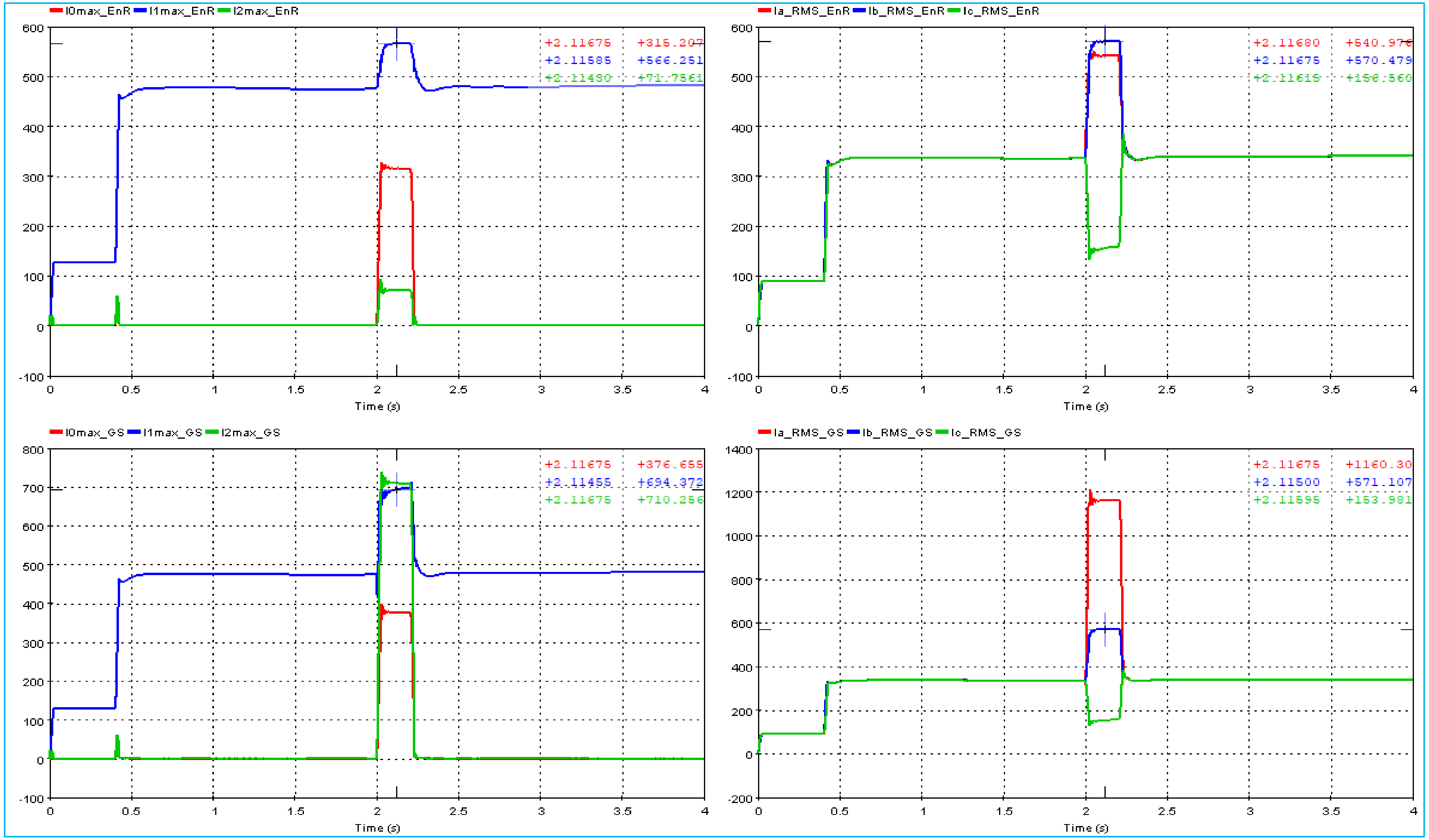
- ❑ Scc = 15906 MVA ;
- ❑ X1/R1 = 17 ;
- ❑ Un = 120 kV

Note that the wind farm is at 90% of its maximum output at the time of the fault. This is an important point, as the level of production of the wind farm has an impact on the short-circuit current supplied by it during the fault. See the study report for more details.

AG short-circuit (Rf=0Ω) - CSC

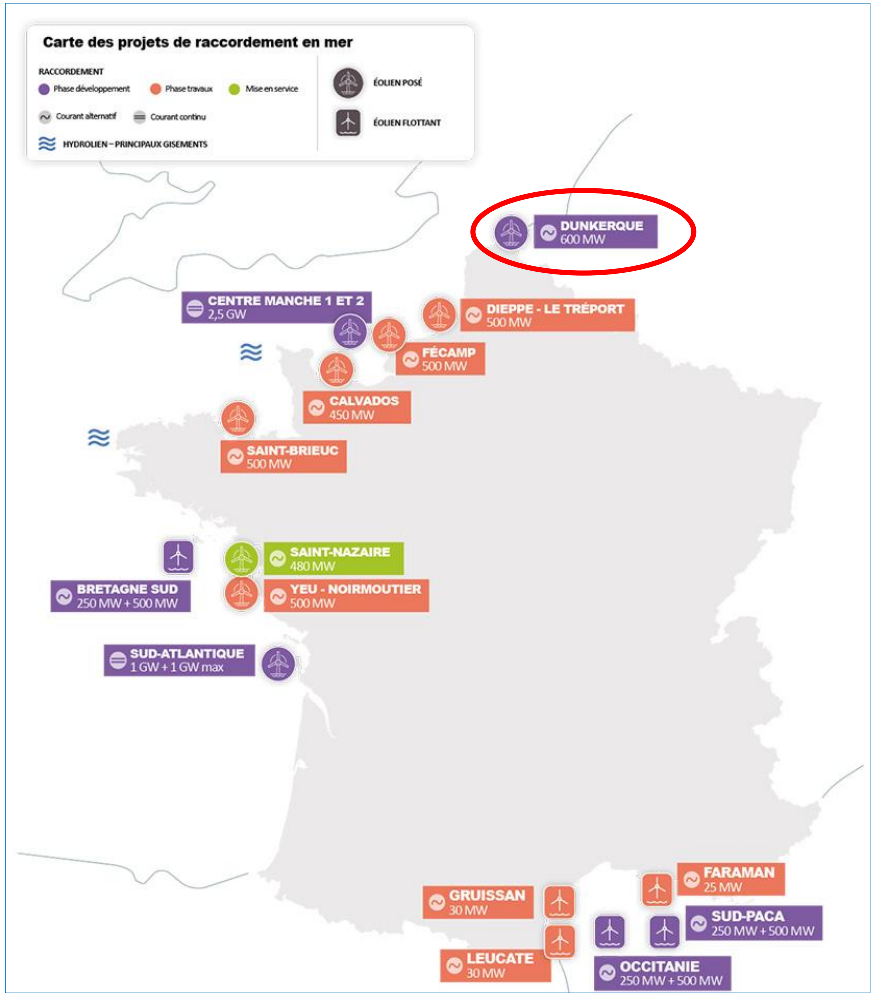
WP park

Grid



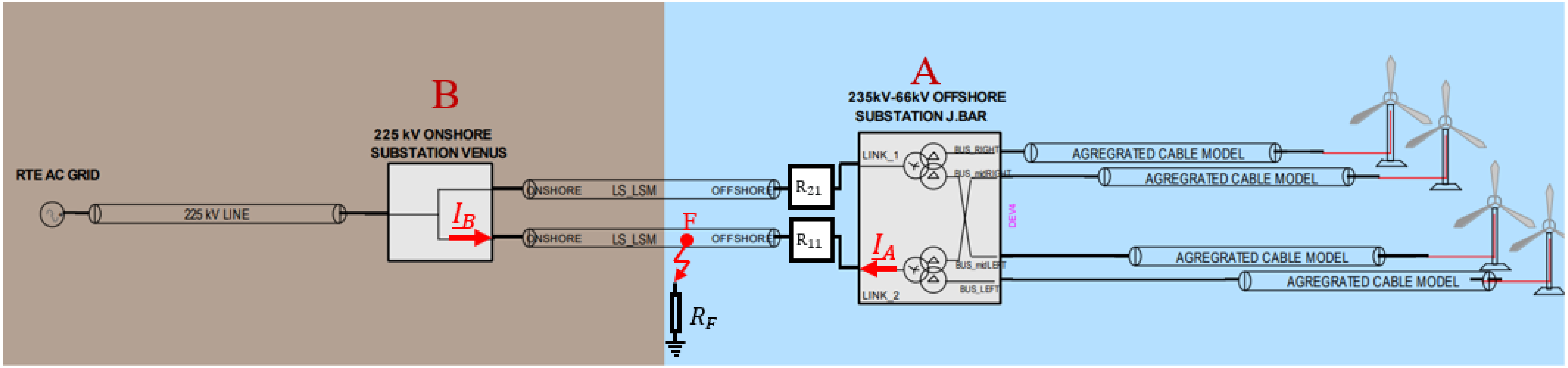
Test of commercial relays

Tests of 3 distance protection relays on AO3 offshore project of RTE.



Test of commercial relays

❑ Test of 3 distance protection relays on AO3 offshore project of RTE.



❑ 3 types of protection relays:

- ❑ 2 scenarios considered: **weak source** (short-circuit current min : 19,78 kA) and **strong source** (short-circuit current max : 27,96 kA).
- ❑ **150 various fault cases** (75 for weak source and 75 for strong source).

Synthesis of the tests

Relay 1	
Pour la source faible (Pcc min)	26,6%
Pour la source forte (Pcc max)	16,0%

Relay 2	
Pour la source faible (Pcc min)	29,3%
Pour la source forte (Pcc max)	21,3%

Relay 3	
Pour la source faible (Pcc min)	36,0%
Pour la source forte (Pcc max)	32,0%

$$Trip\ ratio = \frac{Nb\ \ Trips}{Nb\ Faults}$$

Nb Faults: *number of faults to which the relay should normally trip*

- ❑ **No tripping** for the 3 relays : from $\boldsymbol{R_F} = \mathbf{1}$ **Ω/phase** (phase-to-phase faults).
- ❑ **No tripping** for the 3 relays : from $\boldsymbol{R_F} = \mathbf{9}$ **Ω** (phase to ground faults).

Thank you so much for listning