SYREL Team

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Impacts of Inverter-Based Resources (IBRs) on Distance Protection

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Presentation Plan

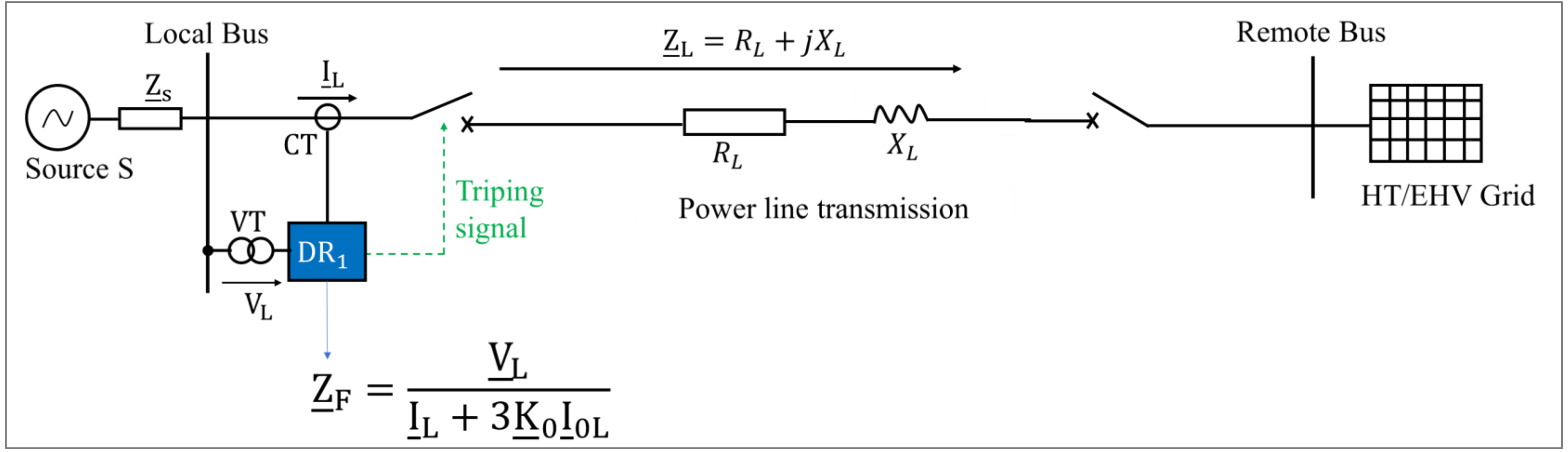
I. General Principle of Distance Protection

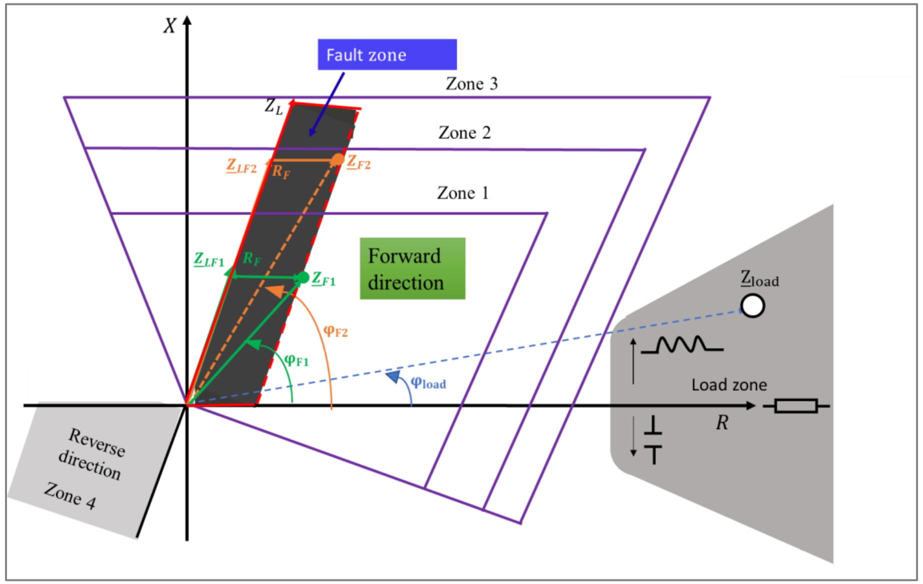
II. Distance Protection Behavior during faults

III. Test results of Distance Relays (DRs) with IBRs

IV. Causes of DRs mis-operations with IBRs

I. General Principles of Distance Protection





❖ **During normal operation:**

$$\underline{Z}_{DR} = \underline{Z}_{1L} + \underline{Z}_{Load}$$

❖ **During Faults :**

$$\underline{Z}_{DR} = \underline{Z}_F = x * \underline{Z}_{1L}$$

Where:

- ❑ $\underline{Z}_{1L}$: Positive sequence of the line impedance
- ❑ x: Fault distance.

I. General Principle of Distance Protection

Fault detection

Some signals used :
- ❑ Currents : (Imax, I0, I1, I2, ΔI,…).
- ❑ Voltages : (V_{Phase}, V0, V2, ΔV).
- ❑ Fault impedance min.
- ❑ Phase Angle.
- ❑ …

Phase Selection

Some signals used:
- ❑ RMS Currents, Angles (I0, I2), and (I1, I2).
- ❑ ΔI.

Fault impedance computation

Conventional Method:
- ❑ $Z_{F-SLG} = \frac{\underline{V}}{\underline{I}+3k_0 I_0}$
- ❑ $Z_{F-LL} = Z_{F-LLG} = \frac{\underline{V}_A - \underline{V}_B}{\underline{I}_A - \underline{I}_B}$

Fault Direction

Methods:
- ❑ Fault impedance
- ❑ Symmetrical components
- ❑ ….

Tripping if:
- ❑ Fault within Zone 1 and Forward Direction;
- ❑ Otherwise, tripping delayed

Behavior of Distance Protection during faults?

II. Distance Relays Behavior in Response to Electrical Faults

1. Behavior of Synchronous Generator (SG) during faults

- The short-circuit current (Isc) of a SG depends on its design and fault conditions (R_F, type of fault).
  - Isc of a SG can exceed 10 p.u.
  - The negative-sequence current can be higher than 1.5p.u.
  - Synchronous generators have **very high inertia**

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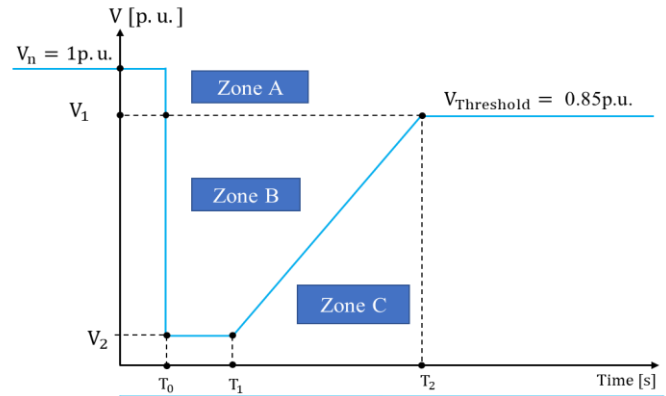
  - Synchronous generators have **very high inertia**

2. Behavior of IBRs (Inverter Based-Ressources) during faults

- The behavior of IBRs during faults depends on the Grid Code of TSO (Transmission System Operator).

LVRT(Low Voltage Right Through)



Voltage [p.u.]		Time [s]	
V_2	0.1	T_0	0
V_2	0.1	T_1	0.085
V_1	0.85	T_2	1.15

Grid code :

- $I_{q1} = k_1 \Delta V_1 = k_1(1 - V_1)$ → for the dynamic voltage support(DVS).
- $I_{q2} = k_1 \Delta V_2 = k_2 V_2$ → to reduce the unbalance of the network.
- $I_d = \min\left(\frac{P_{ref}}{V_d}, \sqrt{Imax^2 - I_q^2}\right)$ → Does not mention in Grid Codes!
- $2 \leq k_1 \leq 6$ and $2 \leq k_2 \leq 6$
- $Imax \leq 1.2p.u.$
- $I_q = |I_{q1}| + |I_{q2}| \leq 1p.u.$

- To confirm the impacts of IBRs on DRs, three DRs (A, B, and C) were tested

II. Distance Relays Behavior in Response to Electrical Faults

3. Conclusion

Type of Source?

Synchronous Generator (GS)

- ❑ High Short-circuit Current.
- ❑ High Negative sequence Current.
- ❑ High Inertia.

Distance relays (DRs) work very well with conventional grids.

IBRs

- ❑ Low Short-circuit Current.
- ❑ Low Negative sequence Current.
- ❑ Low Inertia.

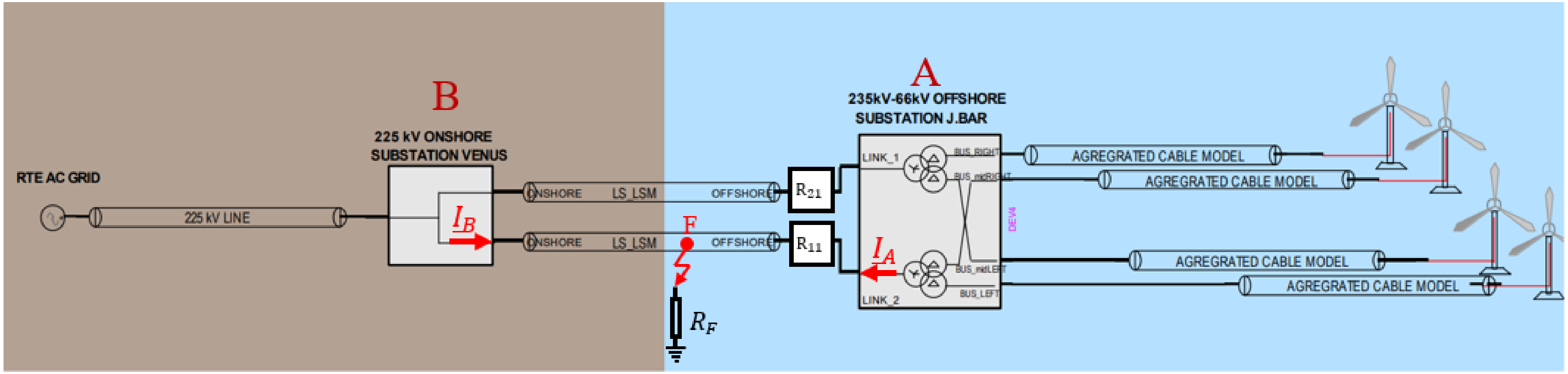
Distance relays face some problems with IBRs.

- ❖ To confirm the misoperations of distance relays with IBRs, we tested the impacts of IBRs on DRs.
- ❖ The DRs used for these tests : A, B, and C.

III. Test results of Distance Relays (DRs) with IBRs

1. Study context

- Three different DRs tested based on the RTE's AO3 Project : Capacity (600MW) in Dunkerque.



- Two scenarios were considered: a **Weak Grid** (Isc min : 19,78 kA) and a Strong Grid (Isc max : 27,96 kA).
- **150 fault cases** (75 for weak grid and 75 for strong grid).
- **Note** :
  - Pilot schemes are not considered in this study.
  - The neutral of the transformer is directly grounded.

More details?

III. Test results of Distance Relays (DRs) with IBRs

1. Study context

Tested faults:

- The 75 faults include:
  - 32 SLG faults;
  - 23 LL faults;
  - 20 LL faults.
- Fault location: 6%, 70%, and 100% of line length .

Cable impedances:

Cables (Cable 1 and 2) parameters					
X1[Ω]	X0[Ω]	R1[Ω]	R0[Ω]	C1 [μF]	C0 [μF]
2.435	17.054	0.732	12.153	485.88	485.6

Fault resistance values:

- SLG faults (R_F) ;
- Multiphase (R_{Ph}).

RF [Ω]		RPh [Ω]	
SLG	0	LL	0
	1		1
	2		2
	3		3
	4		4
	5		5
	6		10
	7		20
	8	LLL	0
	9		1
	10		2
	30		3
	50		4
	100		5
			10
			20

III. Test results of Distance Relays (DRs) with IBRs

2. General Test results

Relay A: Weak Grid	
Tripping Rate (TripR)	26.7%
Fault detection	37.3%
Phase selection	12.0%
Fault direction (Forward direction)	30.7%
Fault location	26.7%

Relay A: Strong Grid	
Tripping Rate (TripR)	16.0%
Fault detection	29.3%
Phase selection	8.0%
Fault direction (Forward direction)	18.7%
Fault location	13.3%

$$\mathrm{Tr} = \frac{\text{Tripping Numbers}}{\text{Faults} \quad \text{Nb}}$$

$\boldsymbol{Tr}$: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

III. Test results of Distance Relays (DRs) with IBRs

2. General Test results

Relay B: Weak Grid	
Tripping Rate (TripR)	29.3%
Fault detection	38.7%
Phase selection	38.7%
Fault direction (Forward direction)	40.0%
Fault location	26.7%

Relay B: Strong Grid	
Tripping Rate (TripR)	21.3%
Fault detection	26.7%
Phase selection	26.7%
Fault direction (Forward direction)	25.3%
Fault location	18.7%

$$\mathrm{Tr} = \frac{\text{Tripping Numbers}}{\text{Faults}\quad \text{Nb}}$$

$\boldsymbol{Tr}$: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

III. Test results of Distance Relays (DRs) with IBRs

2. General Test results

Relay C: Weak Grid	
Tripping Rate (TripR)	36.0%
Fault detection	41.3%
Phase selection	30.7%
Fault direction (Forward direction)	34.7%
Fault location	24.0%

Relay C: Strong Grid	
Tripping Rate (TripR)	32.0%
Fault detection	41.3%
Phase selection	30.7%
Fault direction (Forward direction)	28.0%
Fault location	28.0%

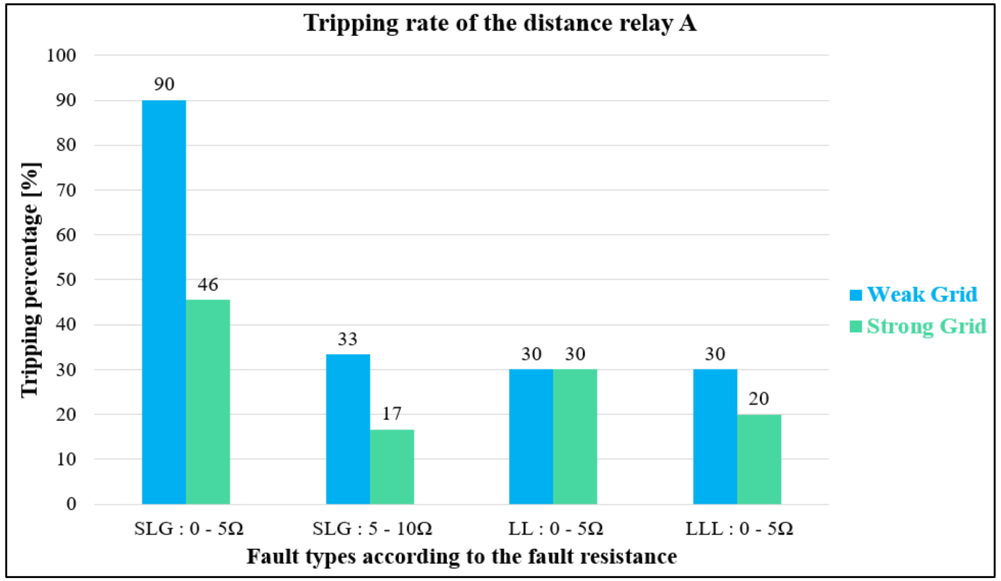
$$\mathrm{Tr} = \frac{\text{Tripping Numbers}}{\text{Faults Nb}}$$

$\boldsymbol{Tr}$: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

III. Test results of Distance Relays (DRs) with IBRs

3. Results of distance relay A per fault type



$$Tr = \frac{\text{Tripping Numbers}}{\text{Faults Nb}}$$

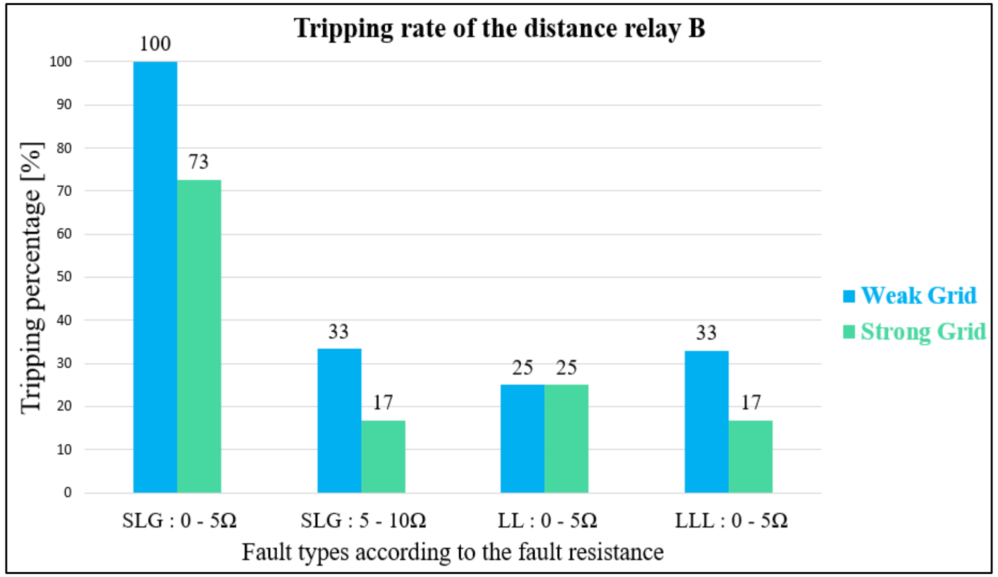
Tr: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

- **Weak grid:**
  - SLG faults: No tripping from $R_F = 6\Omega$;
  - LL and LLL : No tripping from $R_{Ph} = 1\Omega$/phase.
- **Strong grid**:
  - SLG faults: No tripping from $R_F = 3\Omega$;
  - LL and LLL : No tripping from $R_{Ph} = 1\Omega$/phase.

III. Test results of Distance Relays (DRs) with IBRs

3. Results of distance relay B per fault type



$$\text{Tr} = \frac{\text{Tripping Numbers}}{\text{Faults Nb}}$$

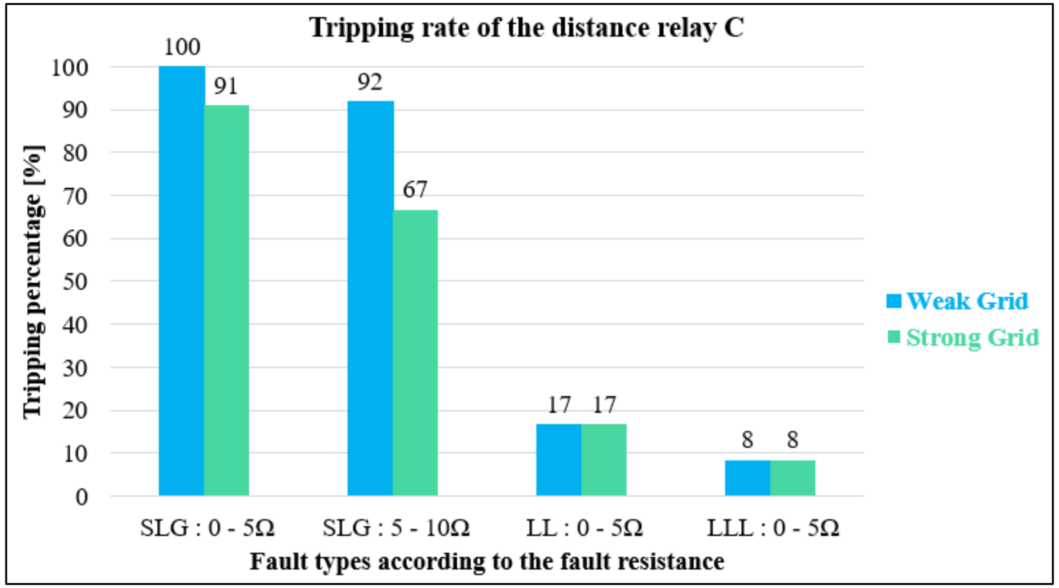
$\boldsymbol{Tr}$: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

- **Weak grid**:
  - SLG faults: No tripping from $R_F = 6\Omega$;
  - LL and LLL : No tripping from $R_{Ph} = 1\Omega$/phase.
- **Strong grid**:
  - SLG faults: No tripping from $R_F = 3\Omega$;
  - LL and LLL : No tripping from $R_{Ph} = 1\Omega$/phase.

III. Test results of Distance Relays (DRs) with IBRs

3. Results of distance relay C per fault type



$$\text{Tr} = \frac{\text{Tripping Numbers}}{\text{Faults Nb}}$$

Tr: *Tripping rate*

- Weak Grid: 19,78kA
- Strong Grid: 27,96 kA

- **Weak grid**:
  - SLG faults: No tripping from $R_F = 10\Omega$;
  - LL and LLL : No tripping from $R_{Ph} = 1\Omega$/phase.
- **Strong grid**:
  - SLG faults: No tripping from $R_F = 9\Omega$;
  - LL and LLL : No tripping from $\mathrm{R_{Ph}} = 1\Omega$/phase.

- Causes of DRs difficulties with IBRs.

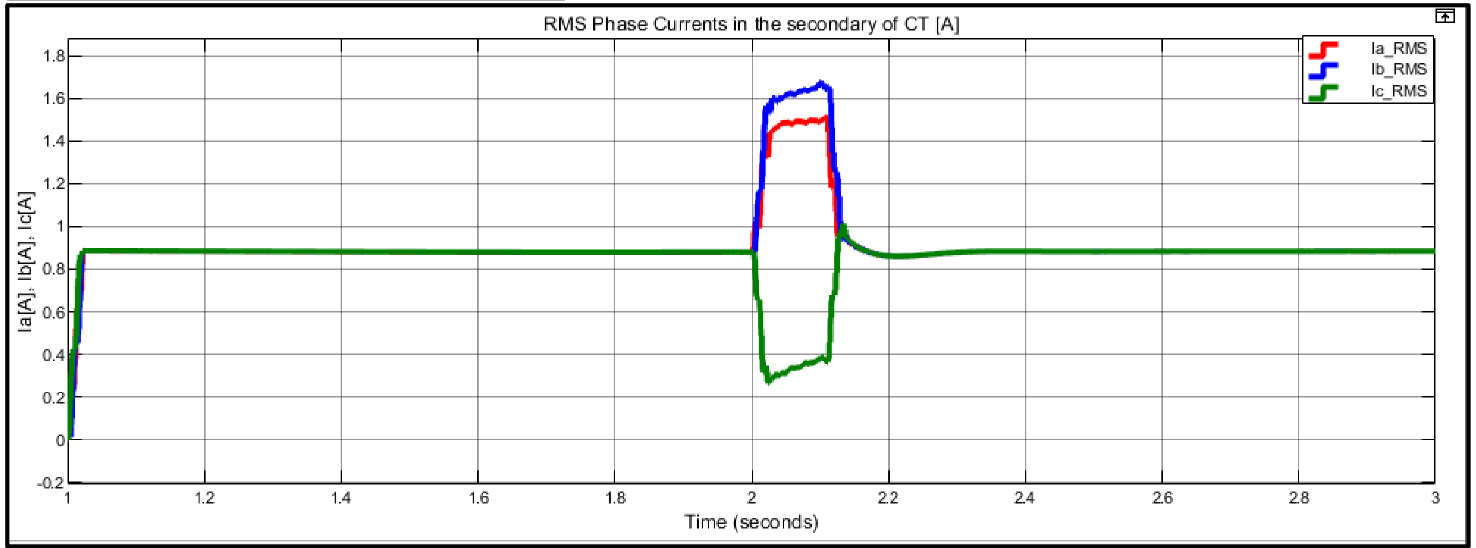
IV. Causes of DR misoperation with IBRs

1. Distance Relays A and B

i. Fault Detection : Currents of IBRs lower than 1.2 p.u.

ii. Phase selection:

RMS phase currents:



- ❖ **AG fault with $R_F = 0\Omega$.**
- ❖ **This could result in a three-phase trip for SLG fault.**

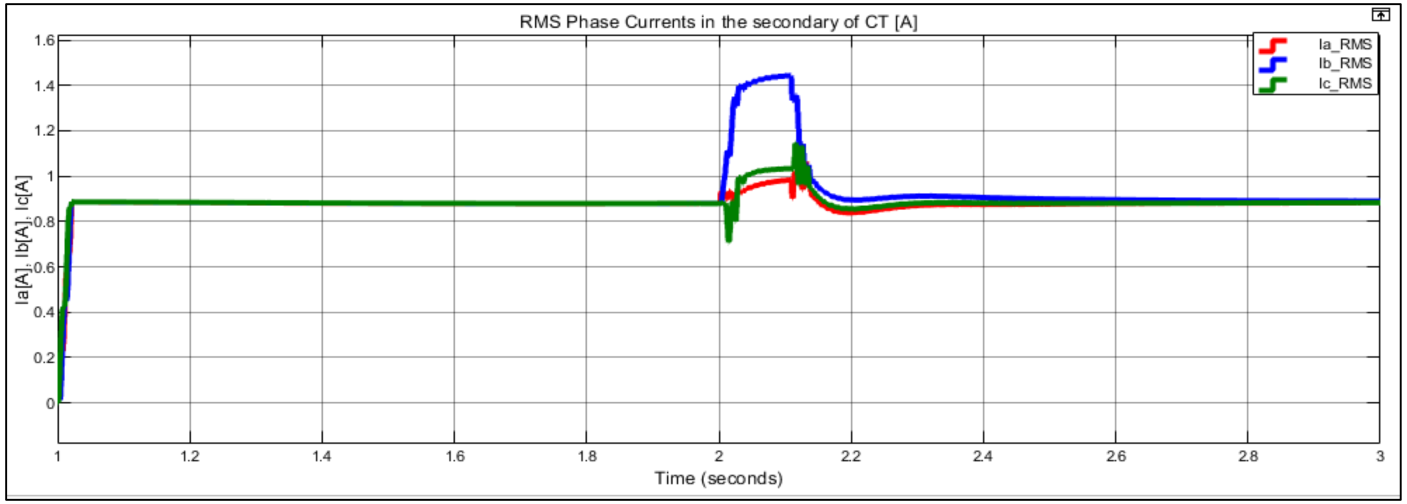
IV. Causes of DR misoperation with IBRs

2. Distance Relay C

i. Fault Detection : **Fault detection**: **up to $R_F = 100\Omega$** → for SLG faults.

ii. Phase selection

- **Distance relay C uses phase currents for the phase selection.**

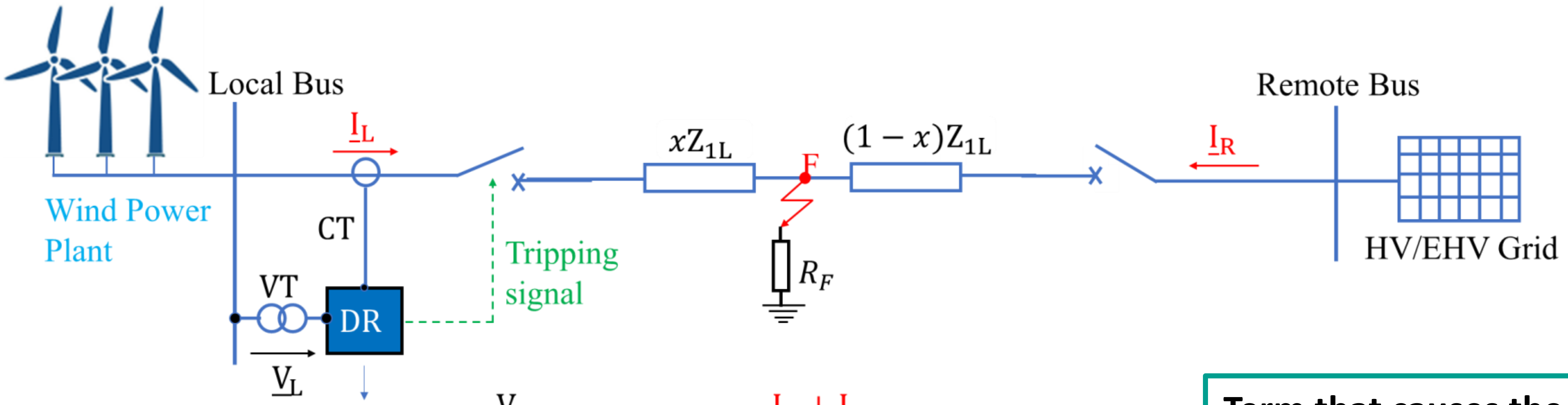


- **AB fault with $R_{Ph} = 0\Omega$.**
- **This could result in only one phase trip for a LL fault.**

IV. Causes of DR misoperation with IBRs

2. Distance Relay C

iii. Fault impedance computation



$$\underline{Z}_F = \frac{\underline{V}_L}{\underline{I}_L + 3k_0\underline{I}_{0L}} = xZ_{1L} + \frac{\underline{I}_L + \underline{I}_R}{\underline{I}_L + 3k_0\underline{I}_{0L}} * R_F$$

Actual impedance

Error factor

Term that causes the underreaching or overreaching of DRs

$$\underline{Z}_F = xR_{1L} + R_{error} + j(xX_{1L} + X_{error})$$

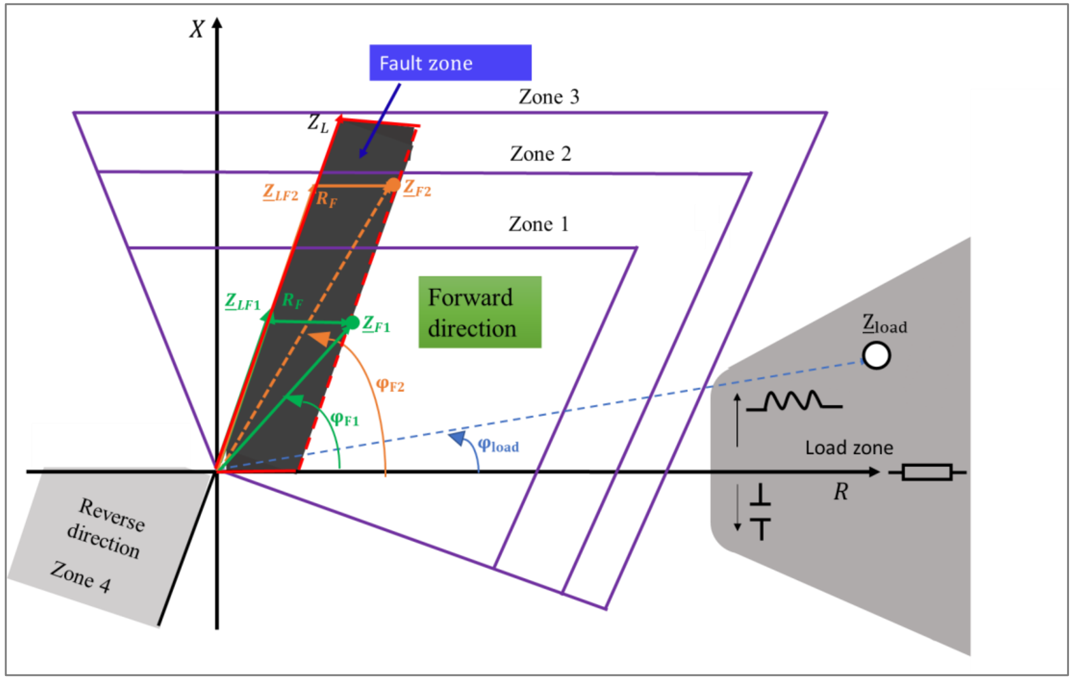
IV. Causes of DR misoperation with IBRs

2. Distance Relay C

iii. Fault impedance computation

$\underline{Z}_F = xR_{1L} + R_{error} + j(xX_{1L} + X_{error})$

- If R_{error} is high ⇒ **No tripping risk**
- If $X_{error} > 0$ ⇒ **Underreaching**
- If $X_{error} < 0$ ⇒ **Overreaching**



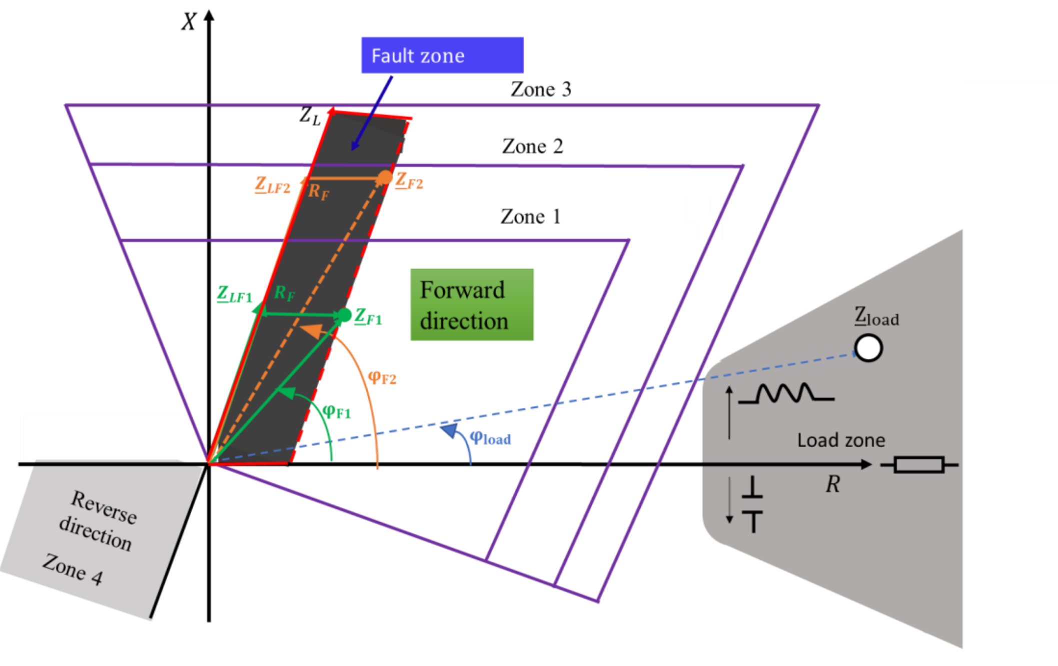
IV. Causes of DR misoperation with IBRs

2. Distance Relay C

iii. Fault impedance computation

$\underline{Z}_F = xR_{1L} + R_{error} + j(xX_{1L} + X_{error})$

- If R_{error} is high $\Rightarrow$ **No tripping risk**
- If $X_{error} > 0$ $\Rightarrow$ **Underreaching**
- If $X_{error} < 0$ $\Rightarrow$ **Overreaching**



For solutions: I invite to you to my PhD defense in November 2025.

Thank you for your attention