Study Committee B5

Protection and Automation

10552 _2022

Testing and Analyzing of Distance Protection of a Realistic Offshore Wind Farm Transmission System

Kasper de Korte[1], Gerwin van Dijk, Yilmaz Yelgin[2], Jose Chavez[3] & Marjan Popov[3]

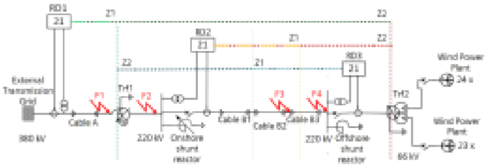
1. Siemens Nederland N.V, 2. Siemens A.G. , 3. Delft University of Technology

How does distance protection behave in an AC wind farm transmission system?

- Protection functions such as **distance protection** are commonly used in traditional transmission grids. However, are these functions suitable for transmission grids with **100% feed-in from RES?**
- What are considerations for the determination of parameters for distance protection in an off-shore wind-farm?
- Classical distance protection is compared to an evolved distance protection method: **Distance protection with reactance method (RMD)?**
- Challenging grid properties such as:
  - **Long cables with high capacitive values.**
  - **Offshore**
  - **Weather depended loading**
  - **DFIG wind turbines (type 3)**

Simulation and testing of 874 dynamic cases

- Electromagnetic transient (**EMT**) simulations were **combined with testing** of real protection relays.
- **874 cases** out of
  - 188 scenarios
  - 3 protection relay locations
  - 2 distance protection methods
- **Automated simulations** of scenarios in DIgSILENT Powerfactory

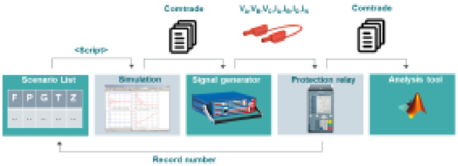


Objects of investigation

- Performance testing of distance protection functions resulting in expected results or the following types of unexpected results:
  - **No trip** at a fault inside the zone. (missed trip);
  - **Trip** at a fault **outside the zone** (Unintended trip).

Partial simulation, partial real equipment testing.

- For each scenario, a dynamic EMT simulation is performed.
- Secondary CT/VT voltages and currents are extracted from the simulation.
- Voltages and currents are synthesized using a signal generator and fed into the protection relay.
- The unexpected results are analyzed with a **self build tool in MATLAB**



- 11% of the test cases had an unexpected result.
- Classic method: 5% of the tested cases resulted in an unintended trip.
- RMD method: 3% of the tested cases resulted in an unintended trip

Discussion

- Extreme cases are chosen.
- Maloperation at low energy production because of a lag of short-circuit current.
- The wind turbine behavior can cause **fast changing impedance** in combination with **voltage angle jump** which makes distance protection less reliable (Scenario A).

Conclusion

- A certain number of unexpected results for classic and RMD methods are comparable. However, RMD has a lower number of unintended trips
- Distance protection is an effective protection function. However, every protection function has its limitation.
- For more comprehensive protection it is recommended to use multiple protection functions in parallel. The selected distance protection method(s) must be fitted to the specific power system to be protected.

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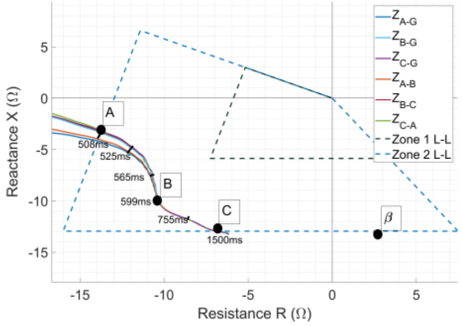
Scenario A

- 3-Phase fault
- Arc-resistance = 1.7 Ω

Protection relay at location RD3

- Missed trip



Protection relay at location RD1

- Unintended trip

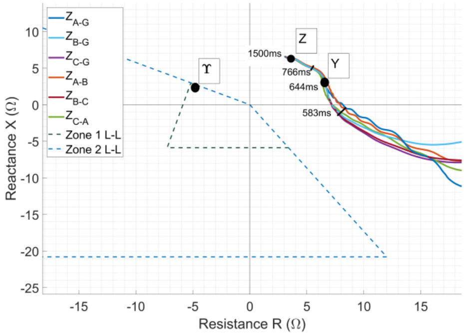


Figure: Impedance trajectory with time points indicated for protection relay at location RD3 (left) and RD1 (right).

Table: Time points described as indicated in impedance trajectory.

Designation	Time (ms)	Description
A	508	The impedance enters the zone. A **pickup** is received for the $L_{A-G}, L_{B-G}, L_{C-G}$ fault loops
B	599	The **pickup** signal is **retracted**
C	1500	End of the simulated fault
Y	644	A pickup signal is received
Y*	674	A **trip** signal is received for zone 1
Z	1500	End of the simulated fault

Observations

- Relatively slow changing impedance.
- Rotation of voltage angle.

Expected cause

Fault ride through control loop controls the reactive power of the wind turbine.

Consequence

(Hypothesis) The algorithm decides to use a pre-fault voltage angle which does not correspond to the real angle. This results in an incorrect interpretation of the impedance.

Observations

- Short activation of wind turbine crowbar.

Expected cause

Rotor current reaches the maximum current value

Consequence

Maximum short-circuit contribution per wind turbine generator will not be exceeded.

Conclusion scenario A

- The fault ride through control of the wind turbines may have an undesirable influence on the distance protection function behavior.
- Pre-fault voltage is not always suited to determine the impedance angle during a fault.

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Scenario B

- Two line to ground fault.
- Arc-resistance = 2.25 Ω.
- Wind turbine power = 10% of P_N .
- Unintended trip with the classic method.
- Distance protection with the RMD method acts as expected.

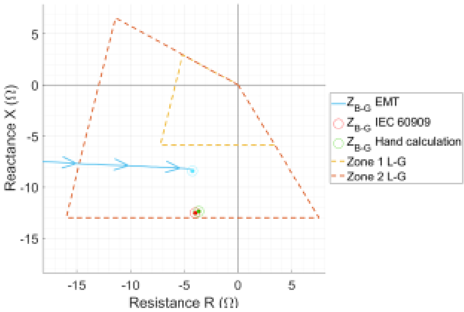


Figure: L-G impedance trajectory measured at protection relay location RD3.

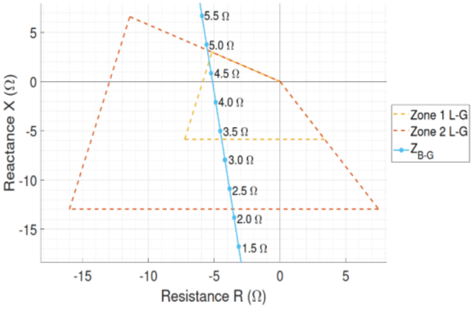


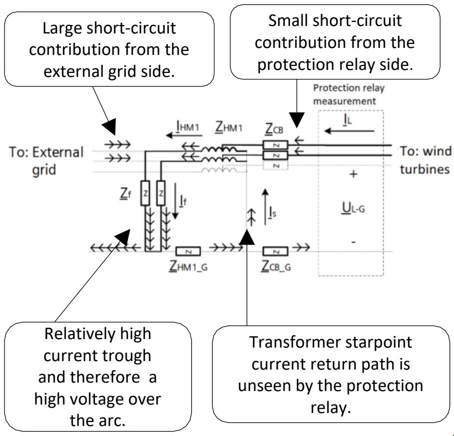
Figure: theoretical impedance for a varying arc-resistances.

Expected cause

- Voltage over arc-resistance can not be measured by the protection relay.
- Line-to-line impedance is found by the protection relay using:

$$Z_{L_A-L_B} = \frac{U_{L_A-G} - U_{L_B-G} - R_F I_F}{I_{L_A} - I_{L_B}}$$

- The classic method does not subtract the Arc-voltage from the impedance calculation. This is suited for a fault scenario where the measured side's current contribution is lower or similar to the opposing side's.
- RMD method makes a more advanced estimation of the arc- resistance. And has therefore a better performance in this scenario.



Conclusion scenario B

- Distance protection in the direction of a high short-circuit current contributor can distort the impedance calculation when a fault impedance is present.
- A transformer with a grounded starpoint in sight of the distance protection relay can distort the impedance calculation.
- Estimating the arc-impedance is therefore vital in the described scenarios

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