Preliminary study of Intersystem faults in hybrid AC/DC lines

Dr. Murari Mohan Saha, Adjunct Professor NTNU

Dr. Raymundo E. Torres, Research scientist SINTEF

Norwegian University of Science and Technology

Introduction of AC/DC hybrid lines

What is AC/DC hybrid lines?

A hybrid solution that combines alternating current (AC) and direct current (DC) in the same tower

Why can be relevant?

They can bring the following benefits:

- To increase the power transmission capacity of a transmission corridor without major modification of the existing infrastructure.
- Better utilization of the existing corridors. No need for a new rigths-of-ways.
- Minimization of the environmental impact.

400 kV DC 380 kV AC 110 kV AC

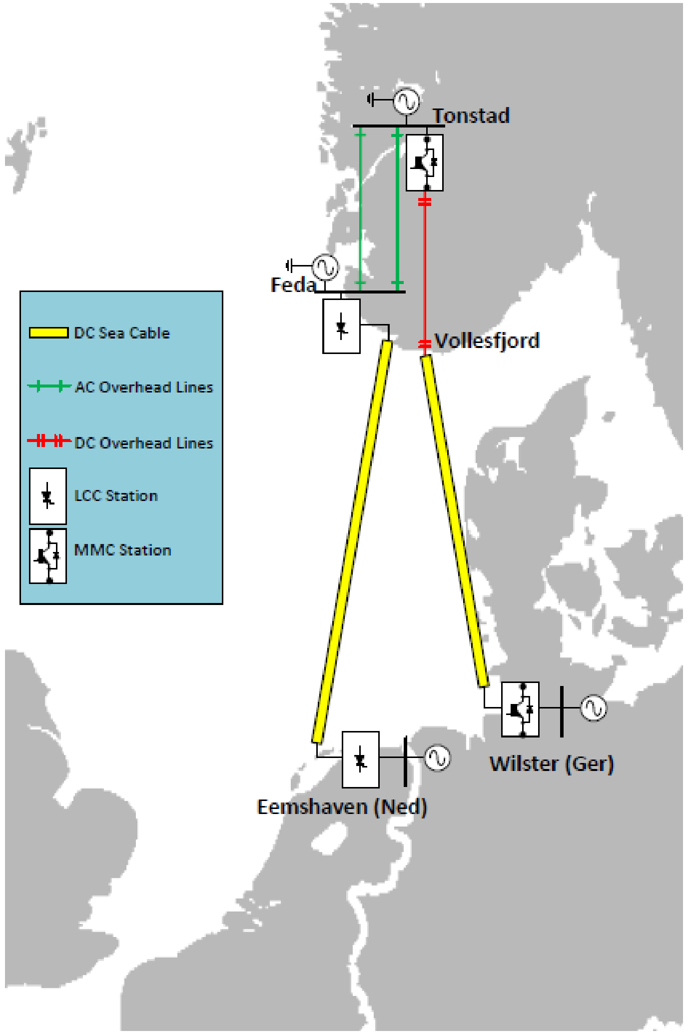
SINTEF NTNU

Introduction of AC/DC hybrid lines

Some examples

- New transmission corridor in Germany using hybrid AC/DC lines
- Project called ULTRANET
- Commisioning 2019

- NORDLINK is under construction
- dc overhead line will partially go in parallel with an existing ac overhead line.



Challenges:AC/DC hybrid lines

Challenges

- Lack of operational experience
- Steady state and transients are influenced from the AC transmission system to the HVDC transmission system or likewise the HVDC system can also affect the AC system under certain system conditions.
- Protection system may be influenced adversely.
- Inter-system faults may occur and they have not been studied deeply.
- Electrical discharges (like corona discharges or dc-ion currents)
- Audible noise

Impact of HVDC Stations on Protection of AC Systems, CIGRE JWG B5/B4.25,December 2011

- HVDC system may bring about different fault characteristics in the HVAC systems, influence the operation of HVAC protection or even cause mal operation.
- When an HVDC scheme is installed, it is recommended that a careful review of protection philosophies and settings in the nearby connected AC networks be made to determine possible adverse affects/risks of mal operation due to the influence of the DC scheme during steady state and transient condition.
- However, proper design of protection scheme can prevent mal operation of AC protection. Alternative protection principles need to be considered for some cases.

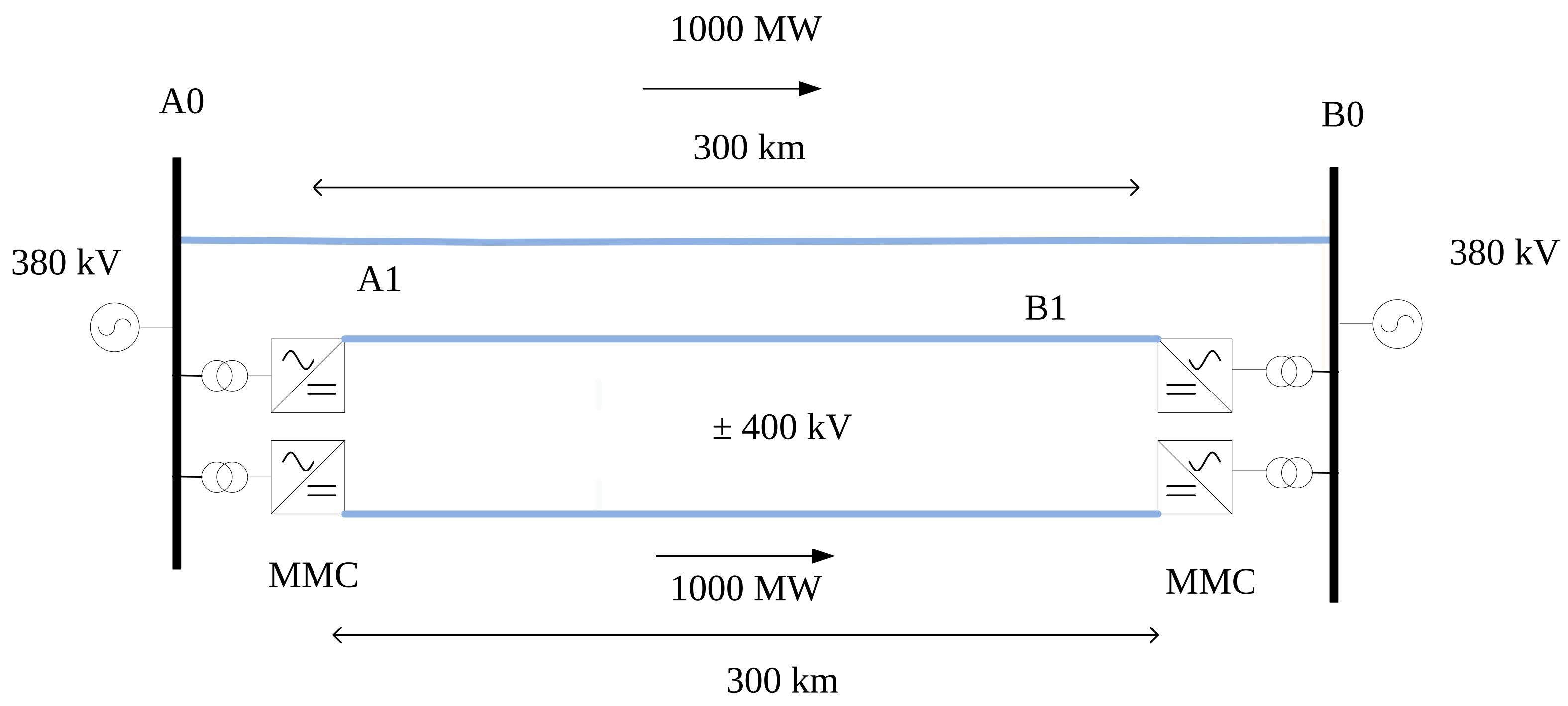
Preliminary research

This preliminary research aim to investigate the consequences of ac and dc overheadlines in the same right-of-way. The intension is to study the behaviour of the protection system.

Methodology

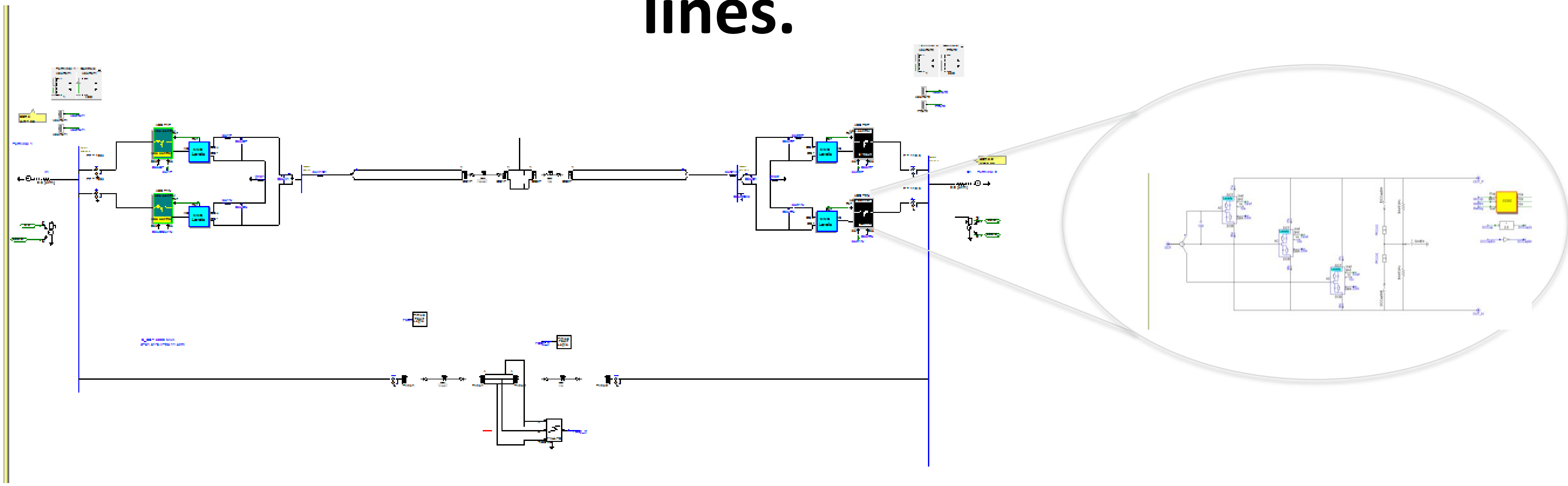
- Select a reference case
- Develop a simulation model of a hybrid AC/DC lines.
- Validate the simulation model
- Study the steady state and transients characteristic of the AC/DC hybrid lines under ac, dc and intersystem faults
- Investigate possible solutions for detecting and clearing of all different faults, specially intersystem faults.
- Validate the solution.

Select a reference case



The selected system consist of one ac transmission system at 380 kV together with a bipolar VSC-based HVDC system. HVDC has a nominal voltage of +-400 kV. Both system transfer 1000 MW.

Develop a simulation model of a hybrid AC/DC lines.



- The reference system has been simulated in PSCAD
- Each convert is a Modular Multilevel Converter (MMC)
- Frequency dependent model for the transmission lines
- The transmission lines are mutually coupled

SINTEF NTNU

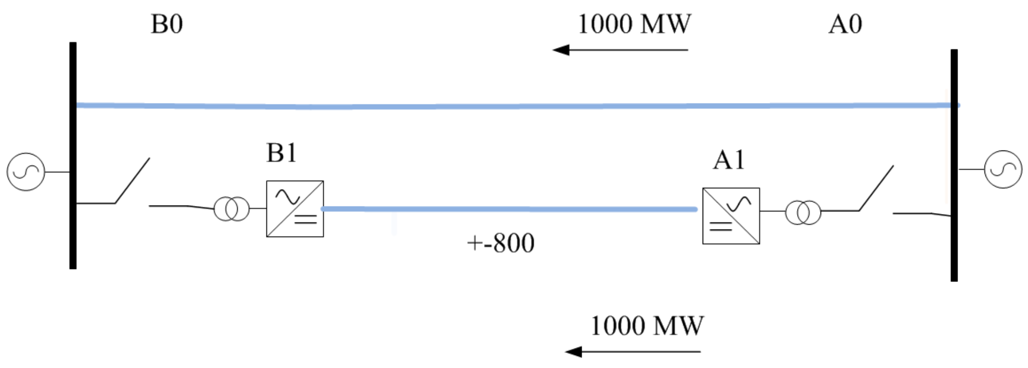
Validate the simulation model

In order to validate the simulation model several cases have been proposed.

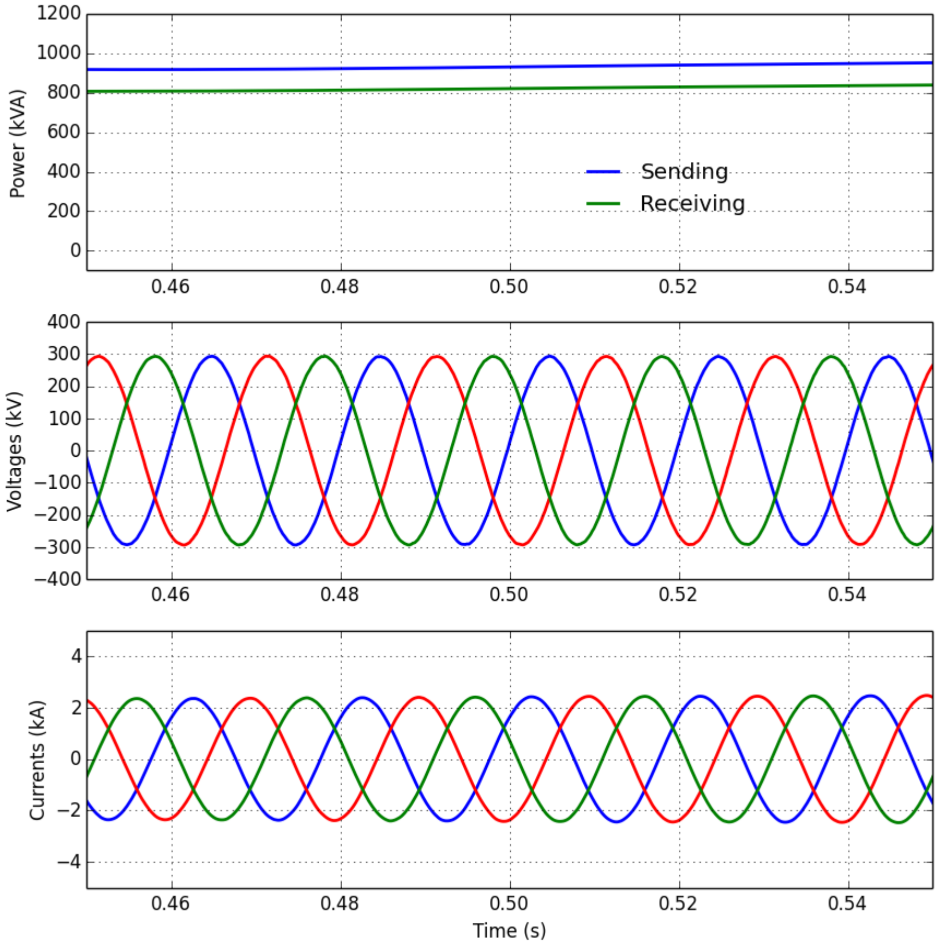
Case	AC	DC	Scenarios
1	Connected	Disconnected	Steady state Three-phase to ground Two-phase to ground Single-phase to ground
2	Disconnected	Connected	Pole-to-ground fault Pole-to-pole fault
3	Connected	Connected	Three-phase to ground (at ac side, results in dc side) Two-phase to ground (at ac side, results in dc side) Single-phase to ground (at ac side, results in dc side) Pole-to-ground fault (at dc side, results in ac side) Pole-to-pole fault (at dc side, results in ac side)
4	Connected	Connected	Faults between AC and DC

SINTEF NTNU

Case 1:Steady state

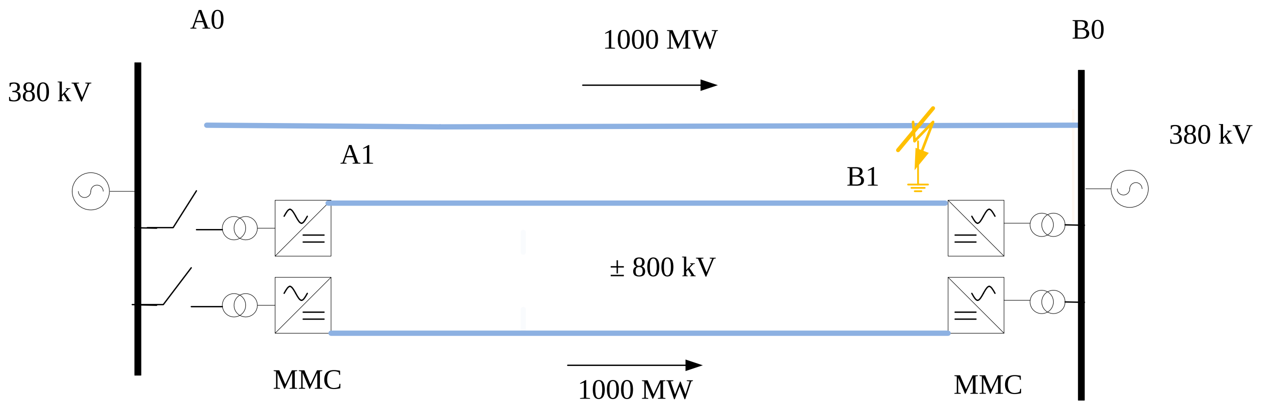


AC side

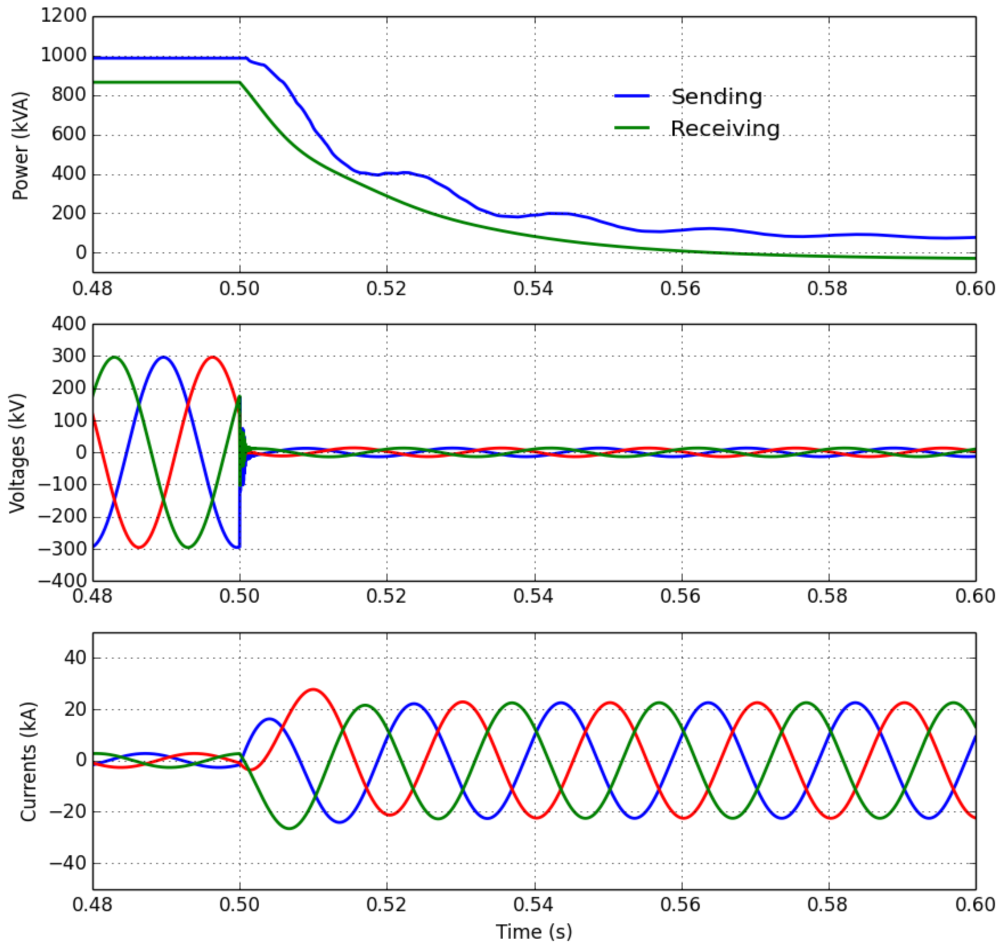


- Figure shows the steady state when DC side is disconnected .
- The system has a SCR=5 and X/R=10
- No reactive compensation has been considered.
- The system is behaving as expected.
- Only receiving side is displayed (B0)

Case 1: Three-phase to ground fault



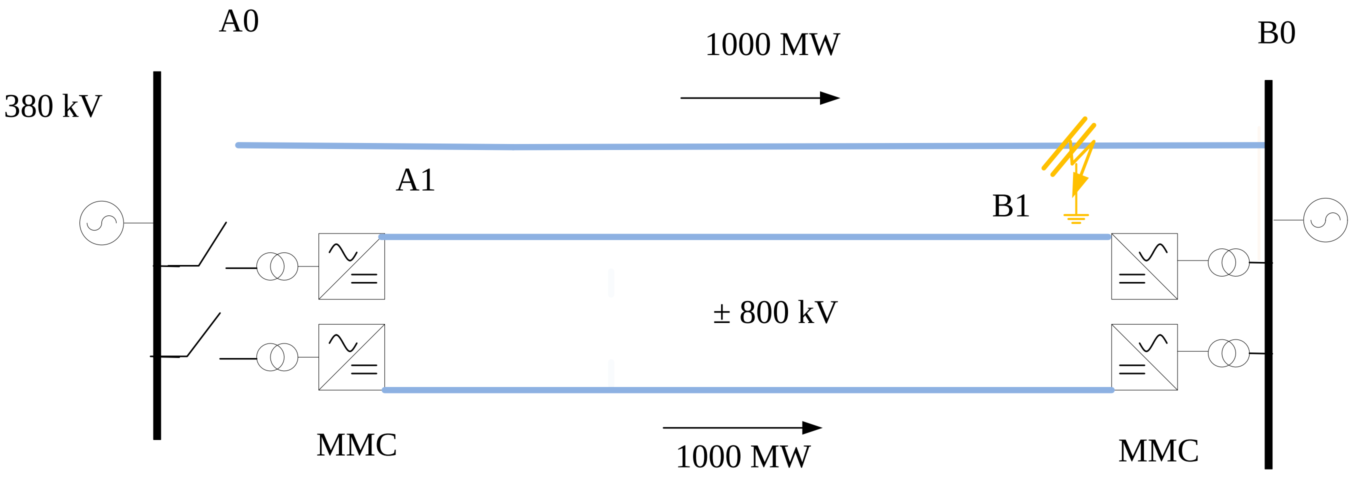
AC side



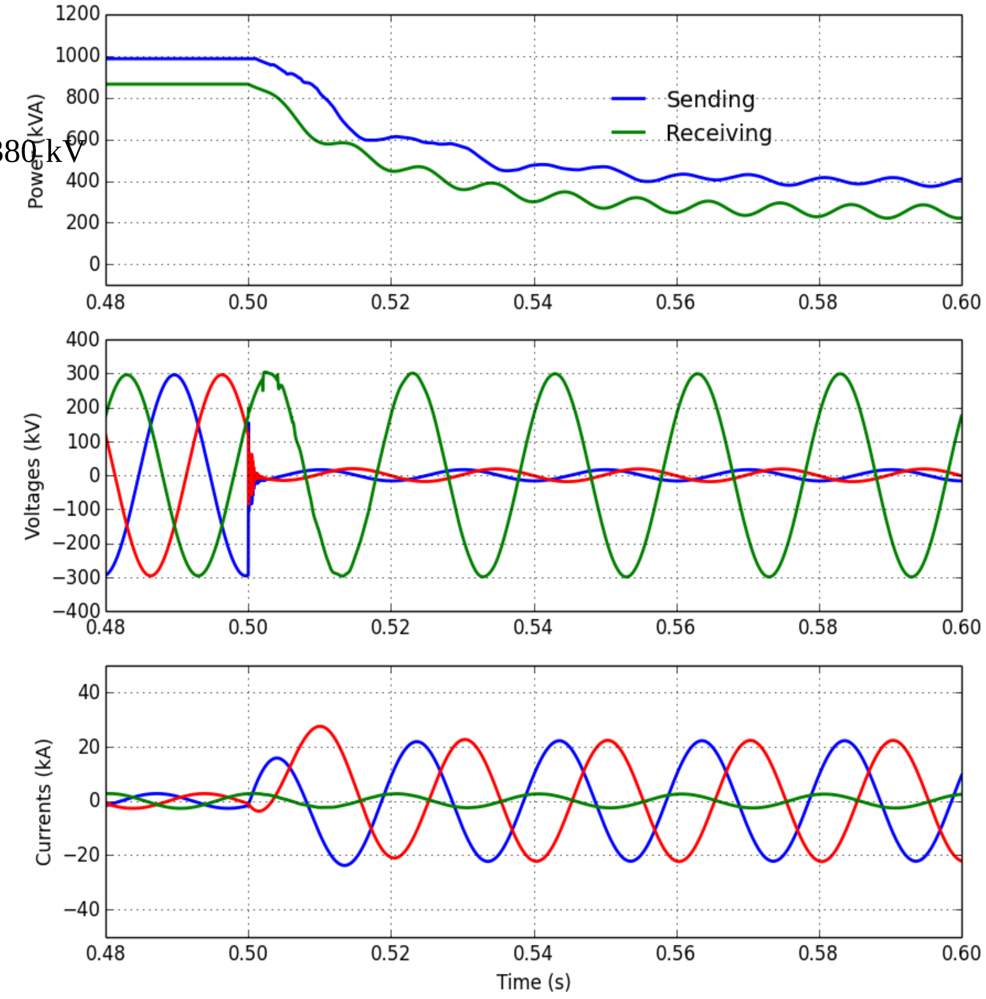
- Three-phase to ground permanent fault occurs at 1 km to system B (receiving side)
- Voltages and currents at receiving side are displayed
- Voltages drop to almost zero, and symmetrical currents are obtained as it is expected.

SINTEF NTNU

Case 1: Two-phase to ground fault

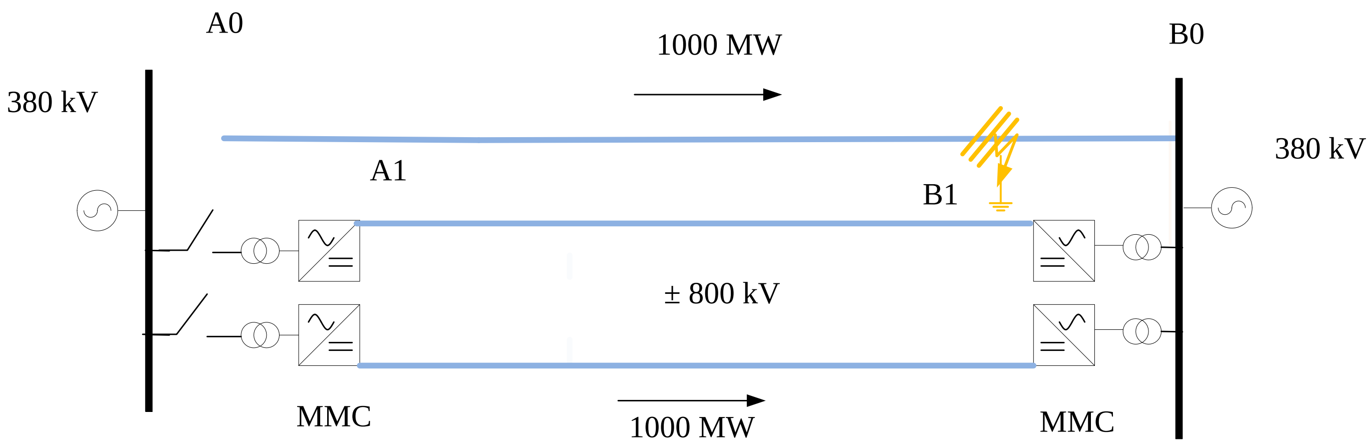


AC side

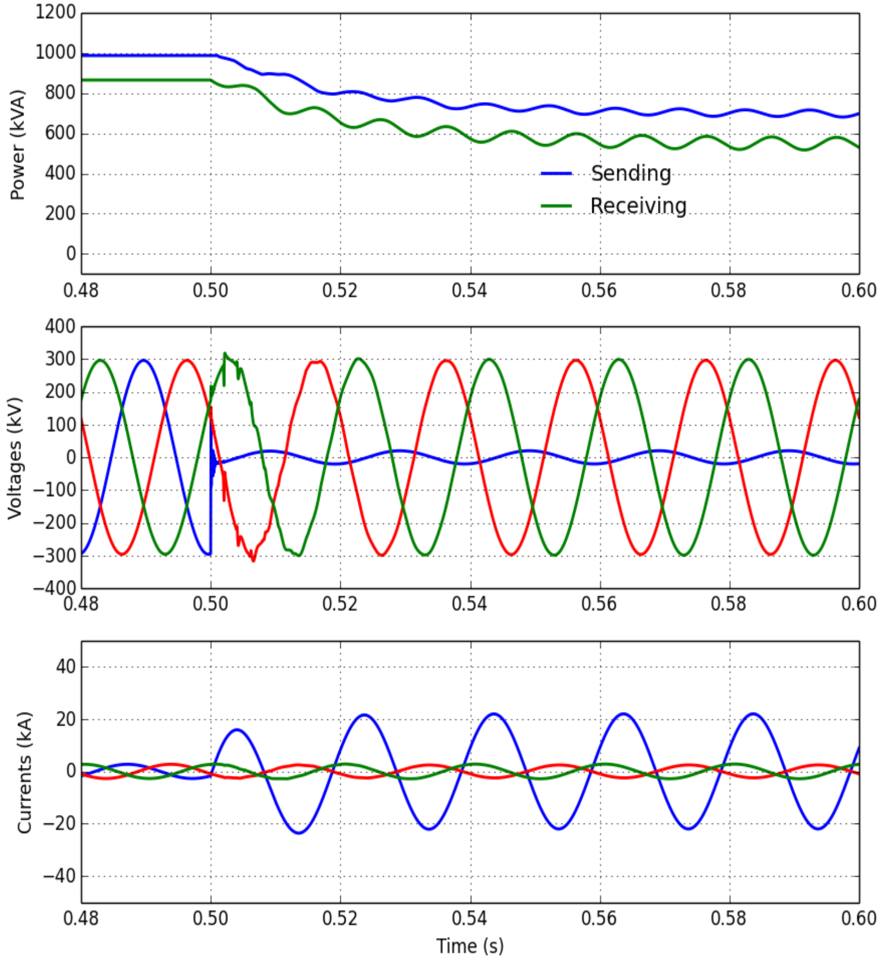


- Two-phase to ground occurs at 1 km to system B (receiving side)
- Voltages and currents at receiving side are displayed
- Voltages drop to almost zero at two phases, and high currents are obtained in the faulted phases as it is expected

Case 1: Single-phase to ground fault

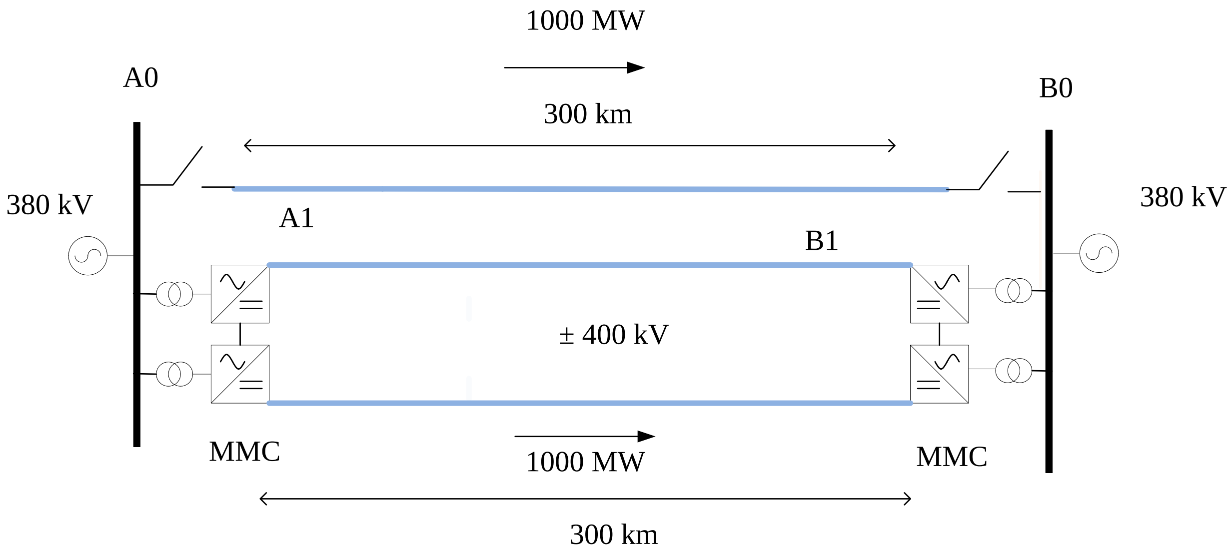


AC side

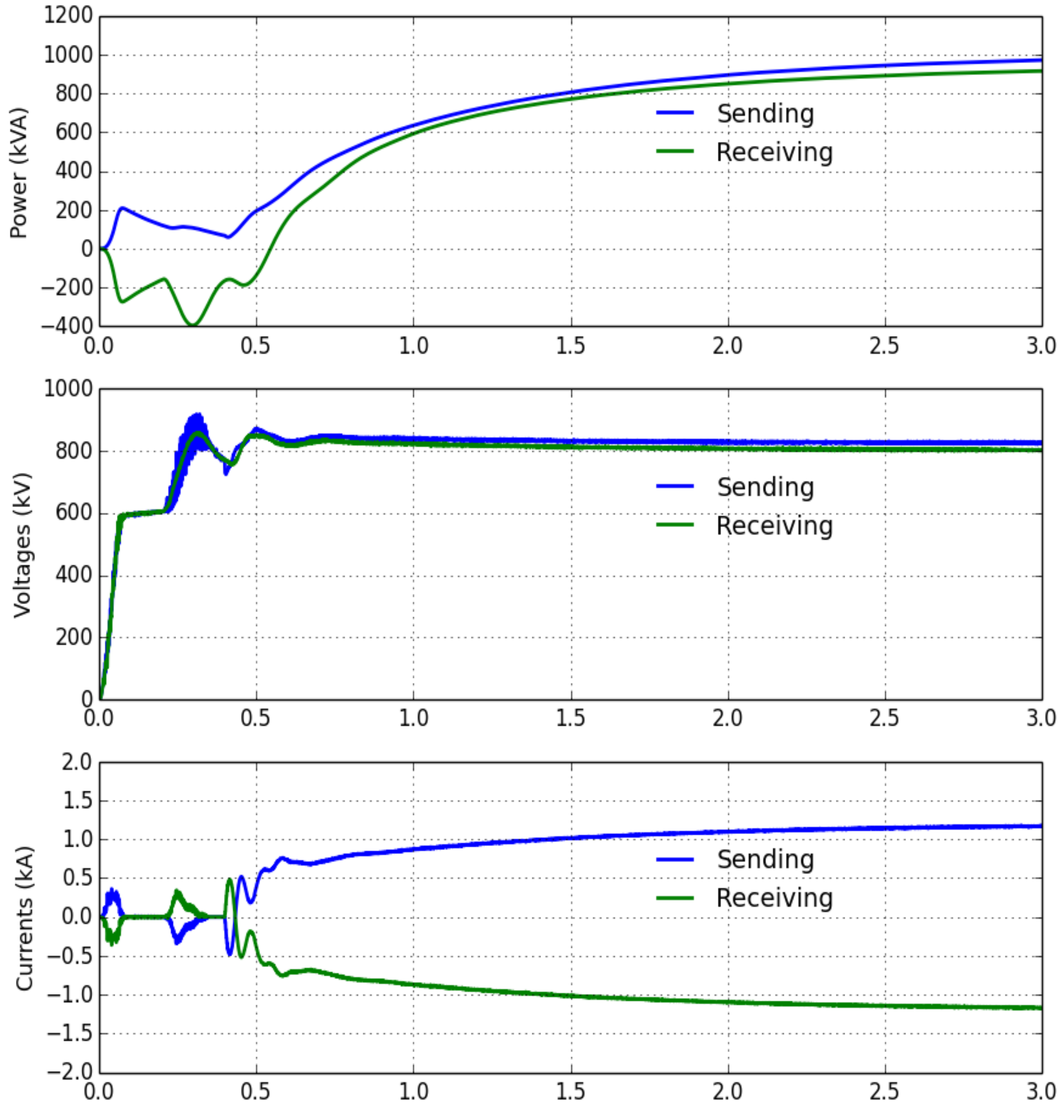


- Single-phase to ground occurs at 1 km to system B (receiving side)
- Voltages and currents at receiving side are displayed
- Voltage drops to almost zero at one of the phases, and high current is produced in the faulted phase as is expected.

Case 2:Steady state

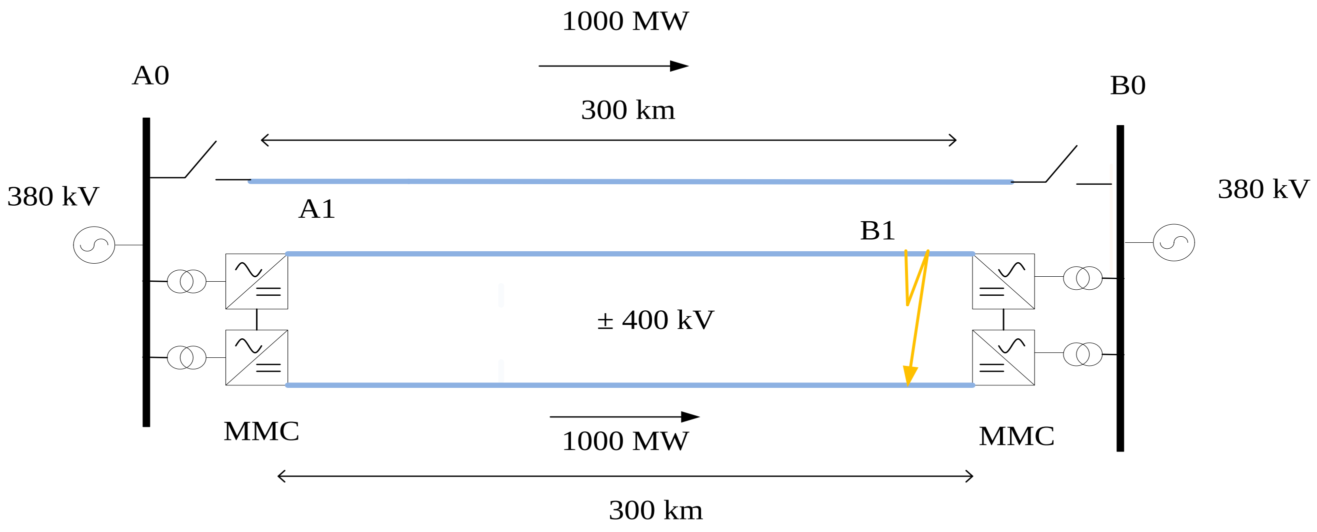


DC side

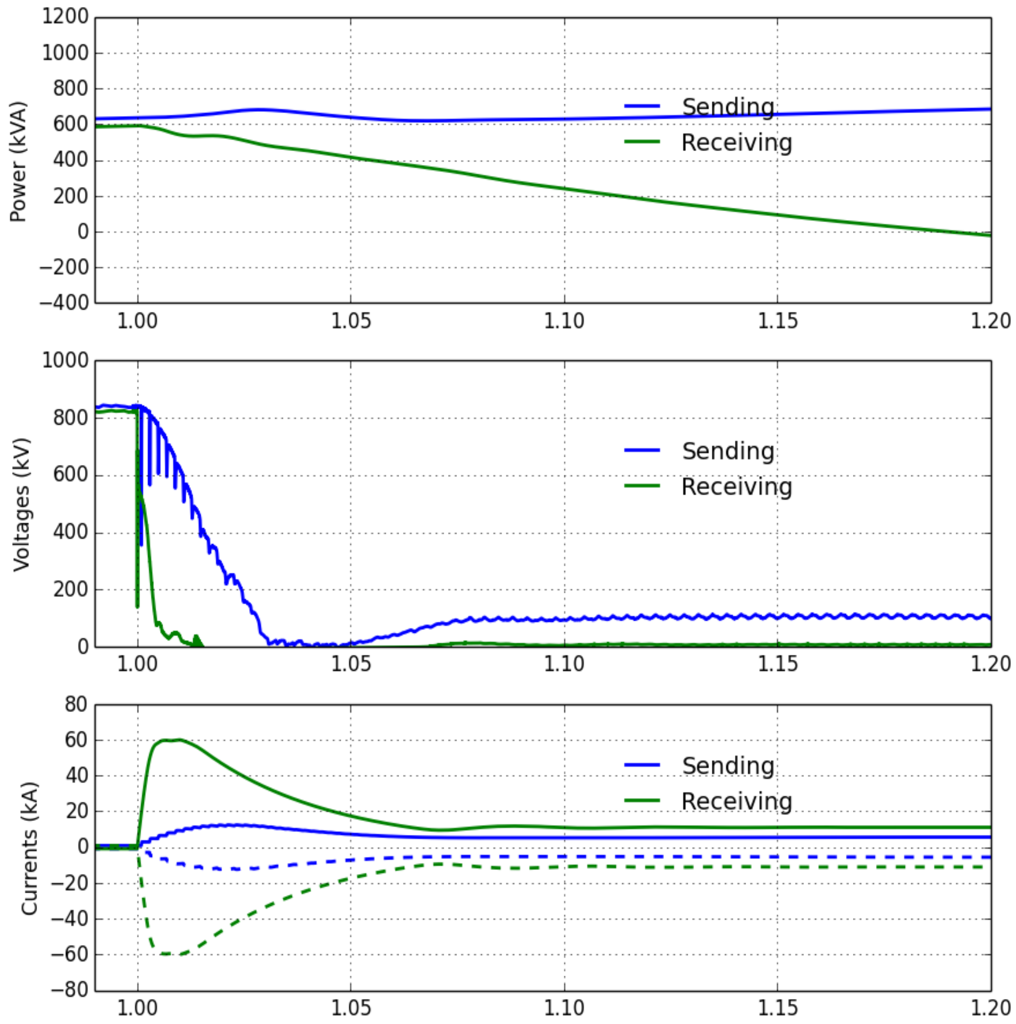


- Figure shows the steady state when AC side is disconnected .
- Both sending and receiving sides are displayed.
- dc voltage reaches its references and the power is regulated toward its reference as well.

Case 2:Pole-pole dc fault

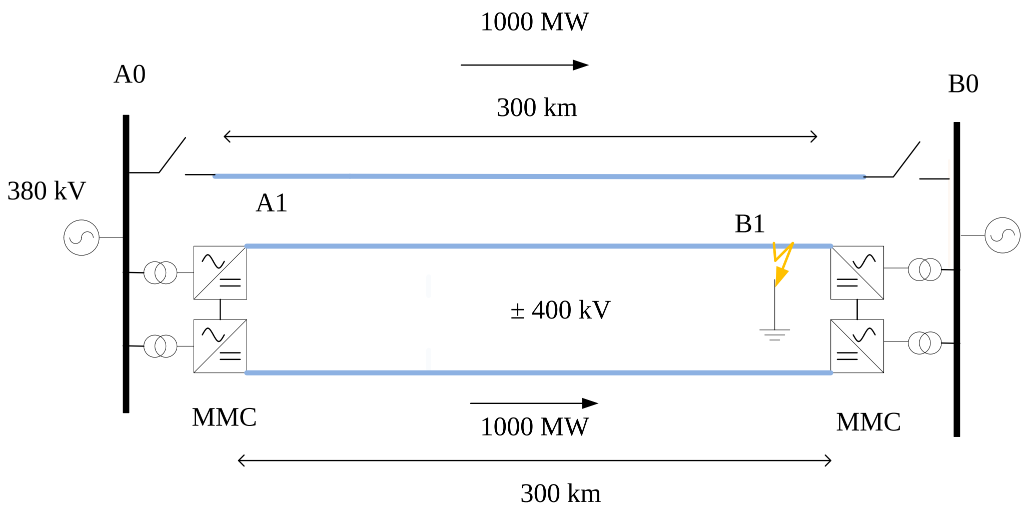


DC side

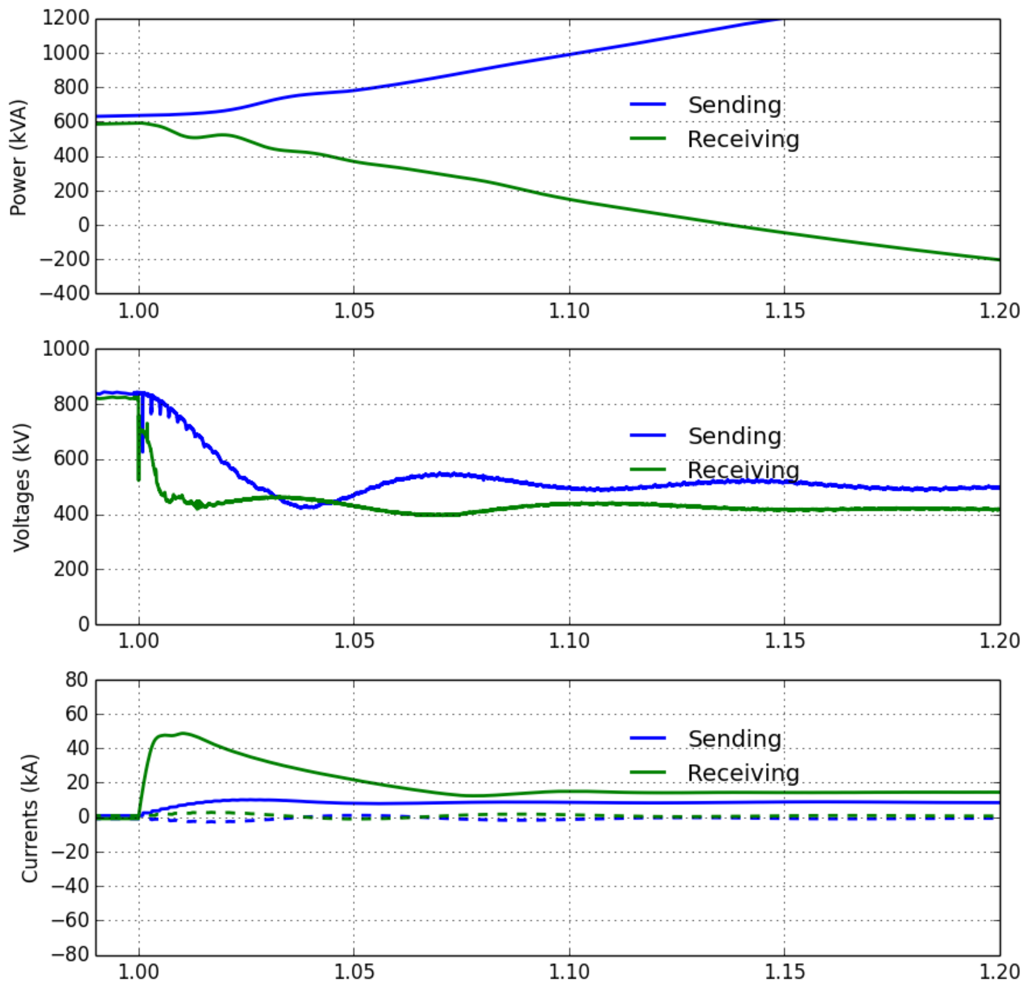


- Figure shows the pole-to-pole dc fault (between positive and negative poles)
- The fault is applied close to the receiving side (1 km from bus B0). This side is regulating the dc voltage
- Voltage dc collapses as is expected.
- A huge overcurrent occurs in the dc side in both poles.

Case 2:Pole-to-ground dc fault

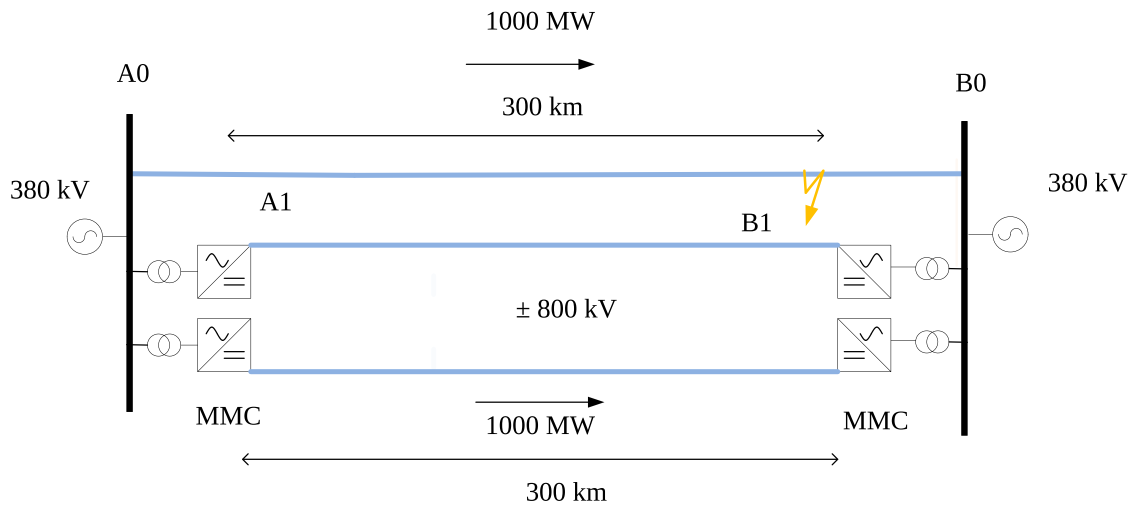


DC side

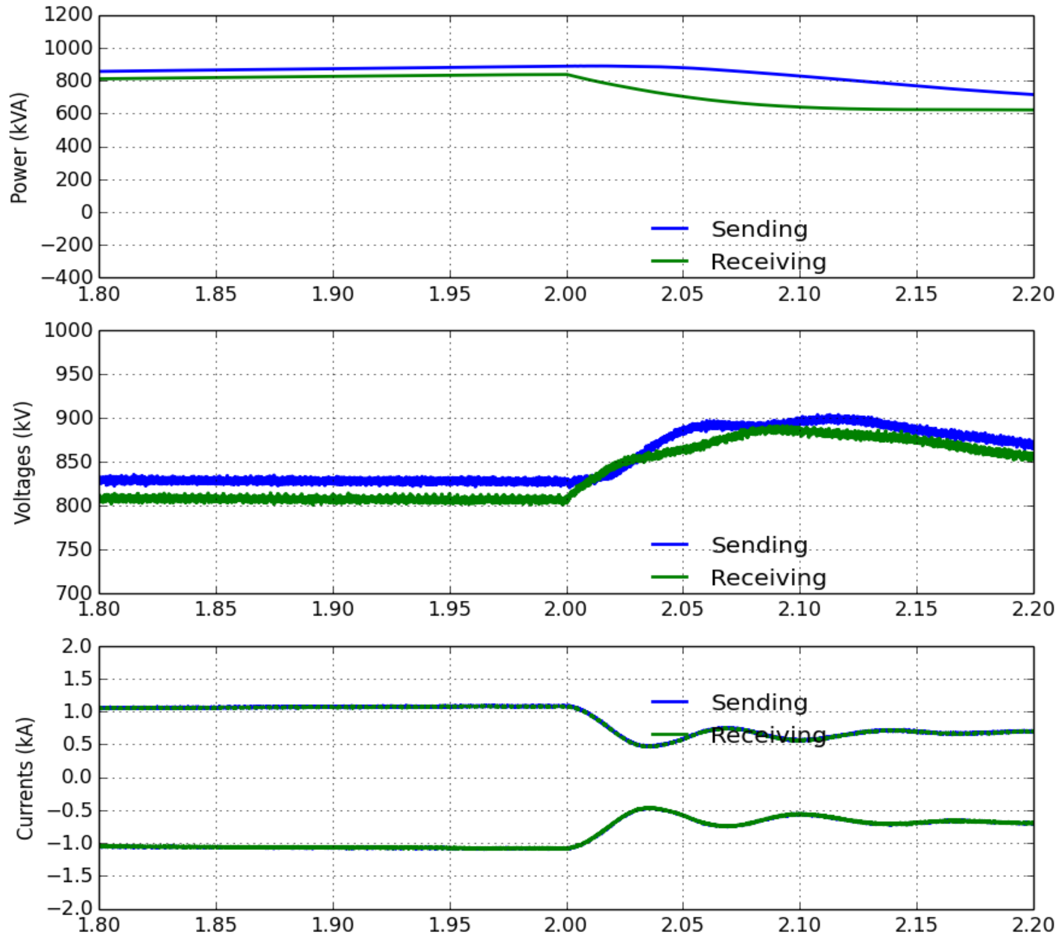


- Figure shows the pole-to-ground dc fault (between positive and ground)
- The fault is applied close to the receiving side (1 km from bus B0). This side is regulating the dc voltage
- Dc voltage drops to half his nominal values as is expected.
- A huge dc current occurs in the positive pole while the negative remains in operation.

Case 3: Effect three phase to ground ac faults on dc side



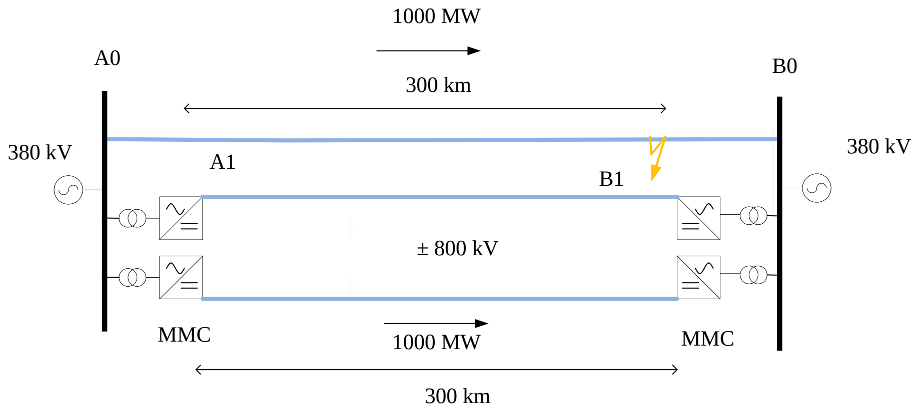
DC side



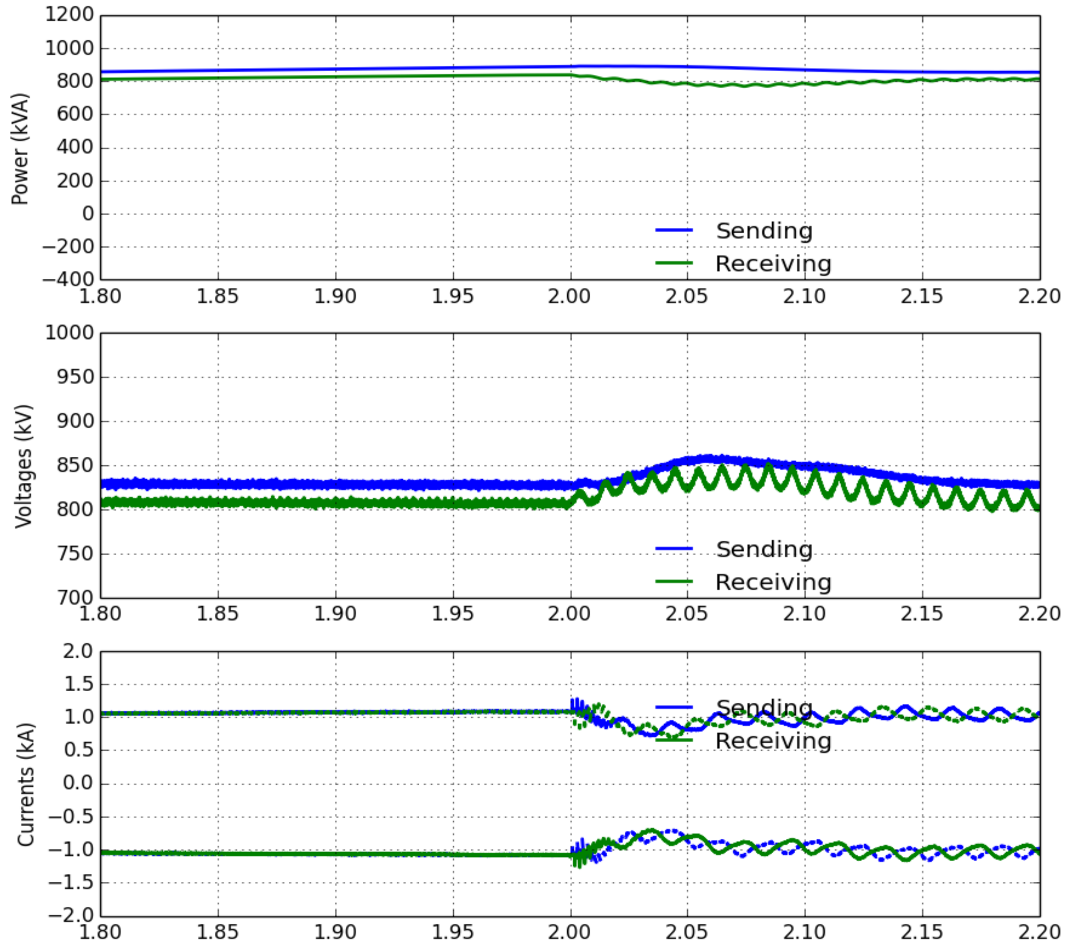
- Figure shows the effect of ac fault on the dc side.
- It is a three-phase to ground fault, which is applied close to the receiving side (1 km from bus B0)
- An overvoltage occurs since the converter is unable to regulate the dc voltage, and the converter A1 transfers power into the system which creates a power unbalance which is reflected in the dc voltage.

SINTEF NTNU

Case 3: Effect single phase to ground ac faults on dc side

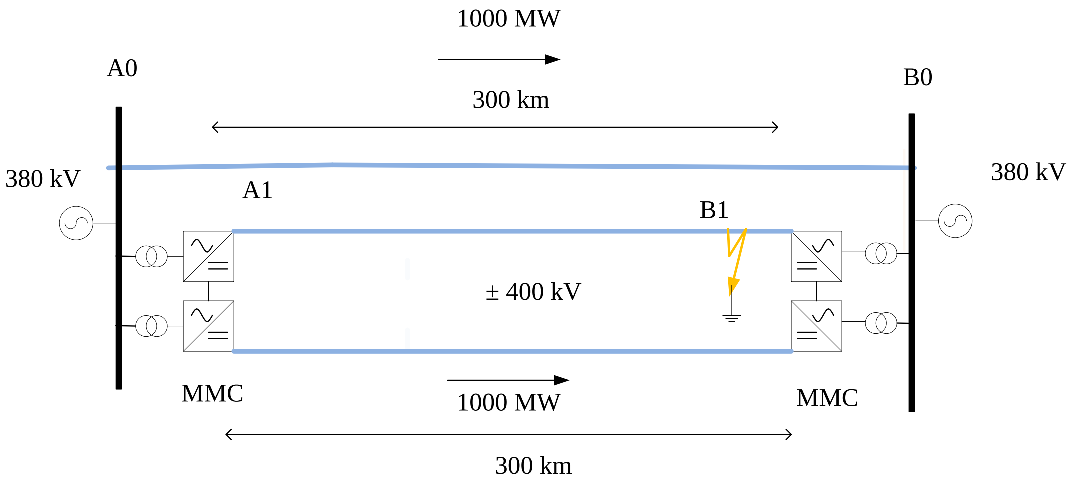


DC side

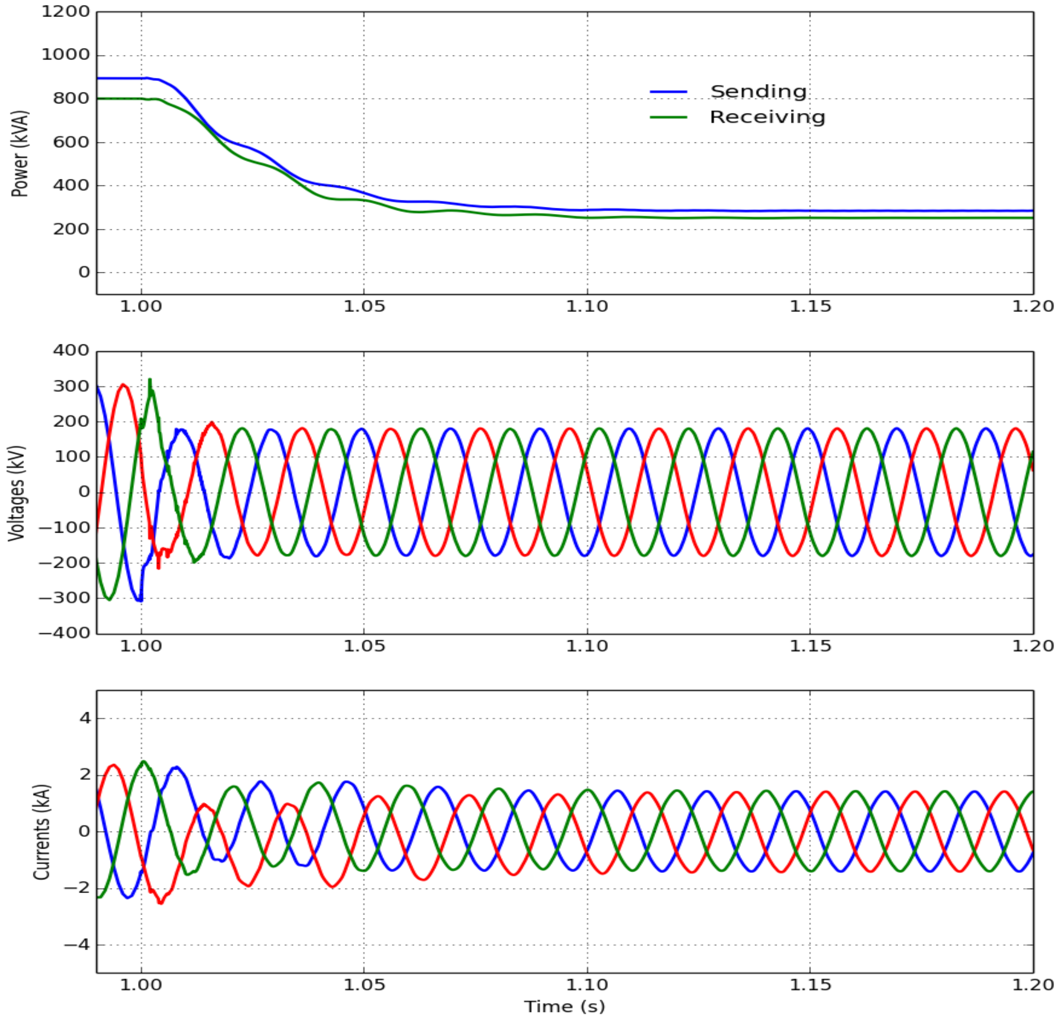


- Figure shows the effect of ac fault on the dc side.
- It is a single-phase to ground fault, which is applied close to the receiving side (1 km from bus B0)
- An overvoltage occurs since the converter is unable to regulate the dc voltage, and the converter A1 transfers power into the system which creates a power unbalance which is reflected in the dc voltage.
- A second harmonic component appears in voltage and current which is characteristic of such a fault.

Case 3: Effect pole-to-ground dc faults on ac side

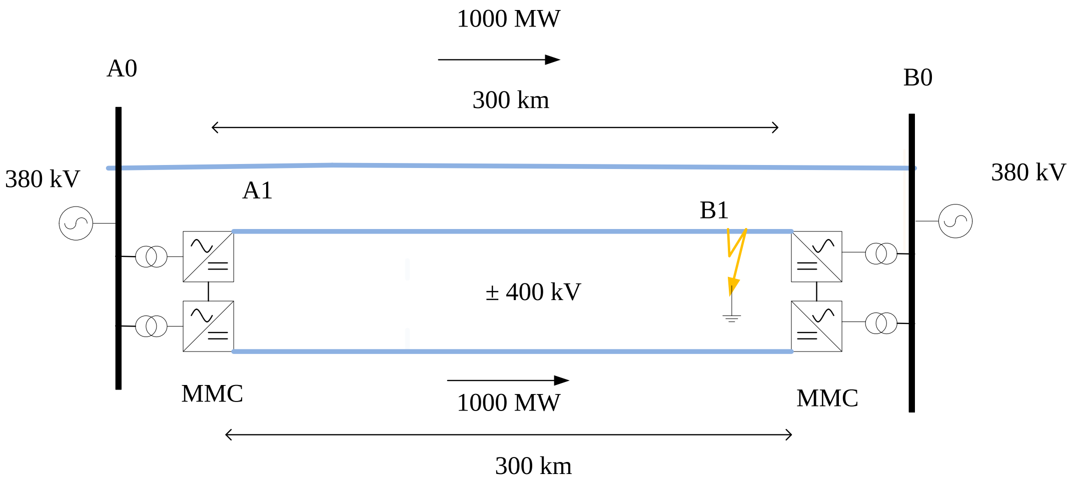


AC side

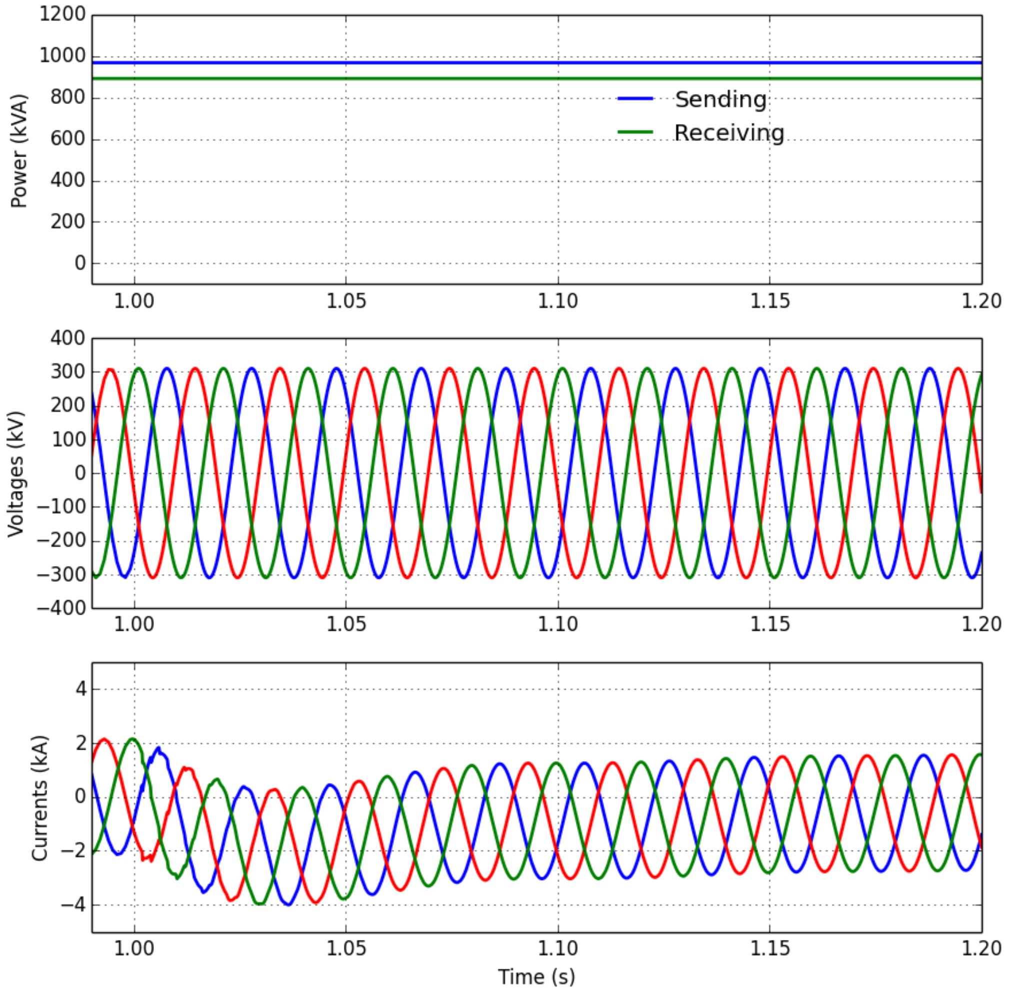


- Figure shows the effect of dc fault on the ac side.
- It is a pole-to-ground dc fault, which is applied close to the receiving side (1 km from bus B0)
- SCR=5 then the converters are supporting the ac grid providing reactive power.
- When the dc fault occurs, the converters are unable to support the grid so a voltage drop occurs as shown in the figure.

Case 3: Effect pole-to-ground dc faults on ac side (stiff grid)



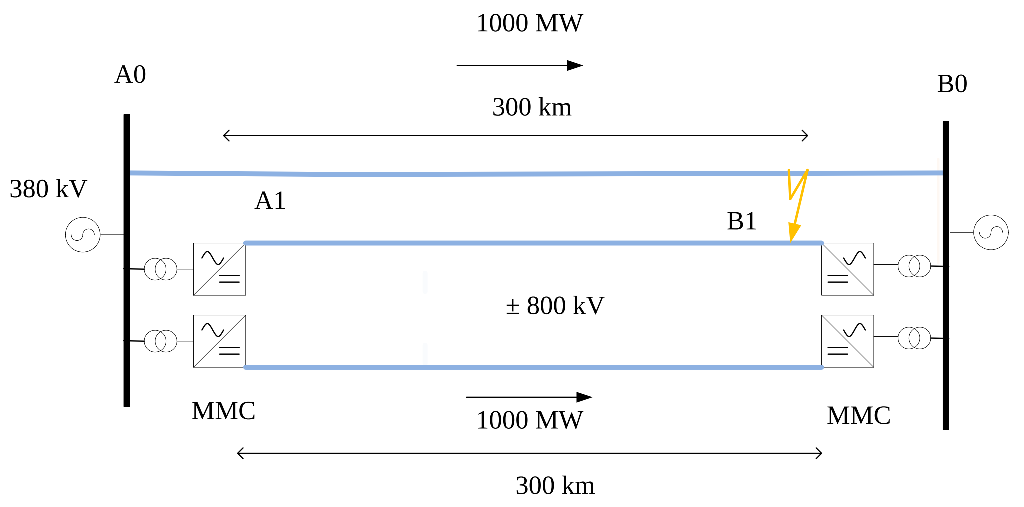
AC side



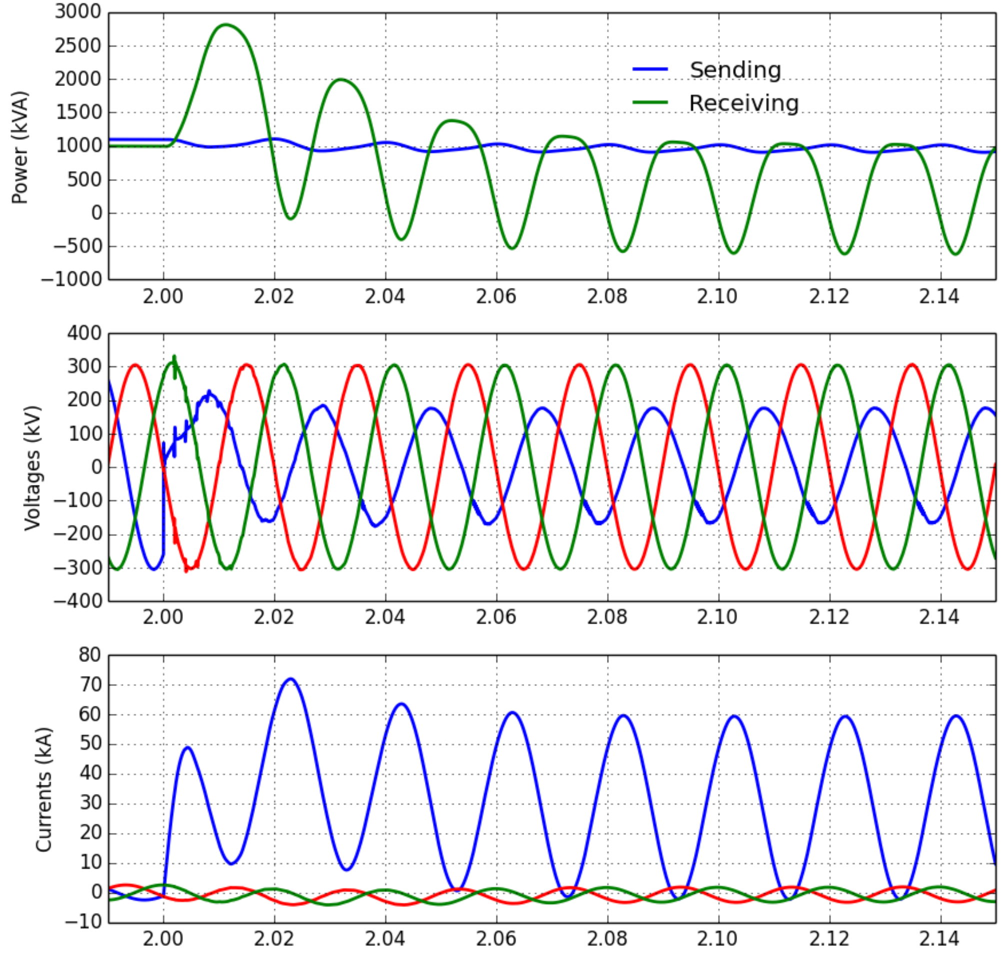
- Figure shows the effect of dc fault on the ac side.
- It a pole-to-ground dc fault, which is applied close to the receiving side (1 km from bus B0)
- Stiff grid
- A dc component is introduced in the ac current as shown in the figure.

SINTEF NTNU

Case 4: Intersystem faults-1phase to one pole

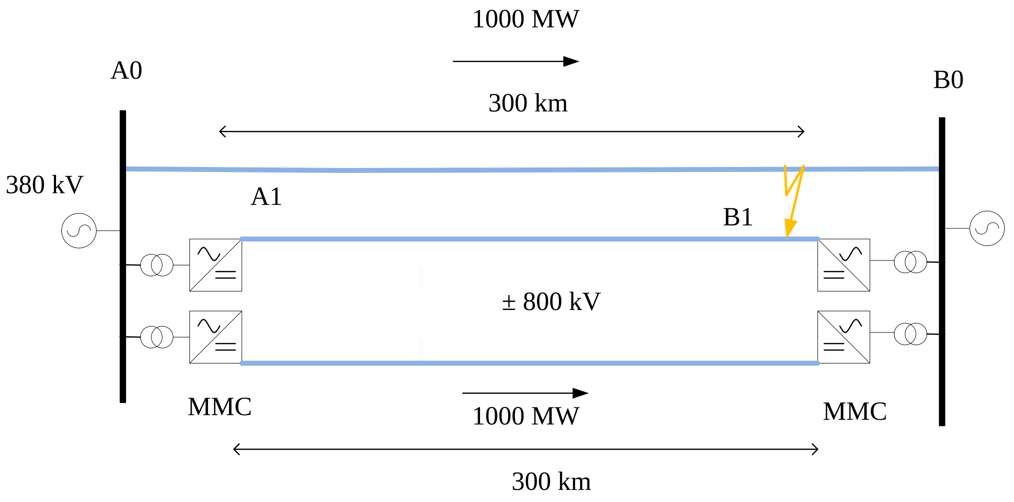


AC side

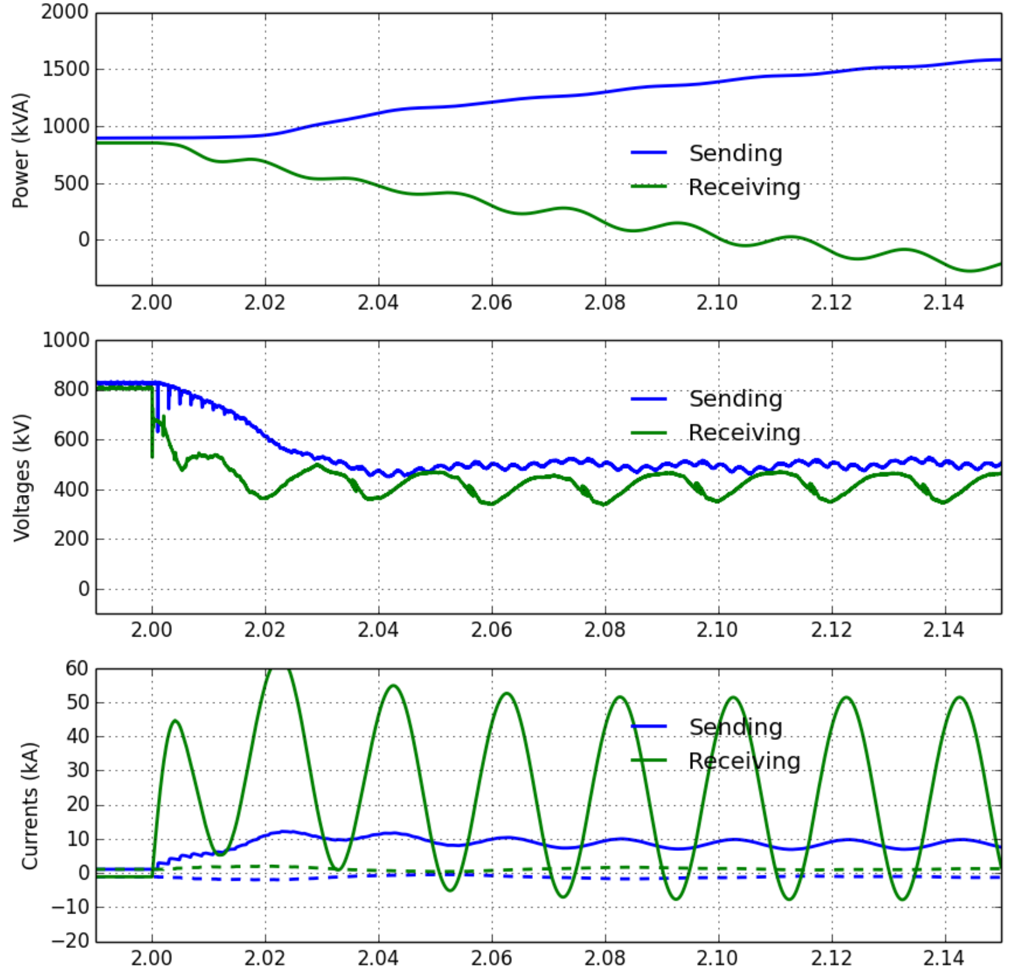


- Figure shows the effect of intersystem on the ac side.
- The fault is applied close to the receiving side (10 km from bus B0)
- A dc component is introduced in the ac current as shown in the figure.

Case 4: Intersystem faults-1phase to one pole



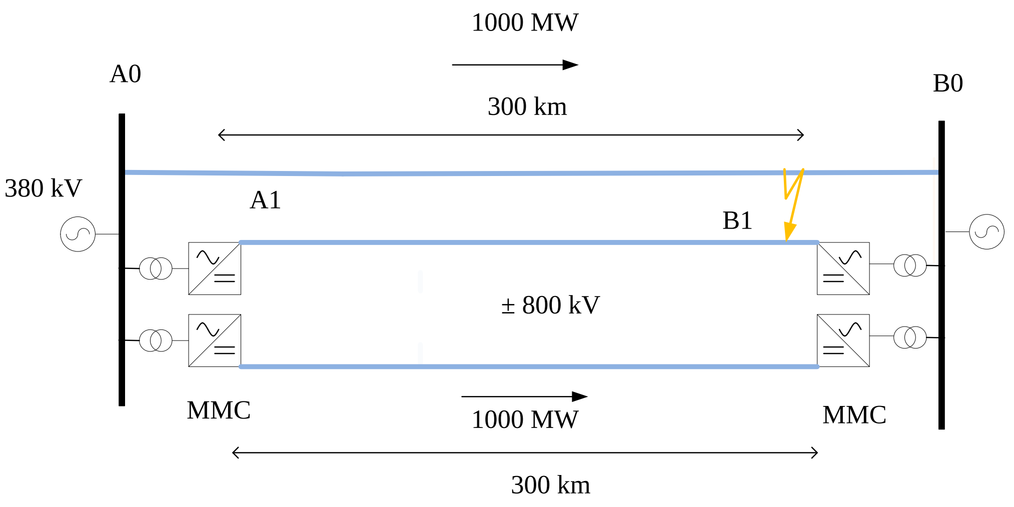
DC side



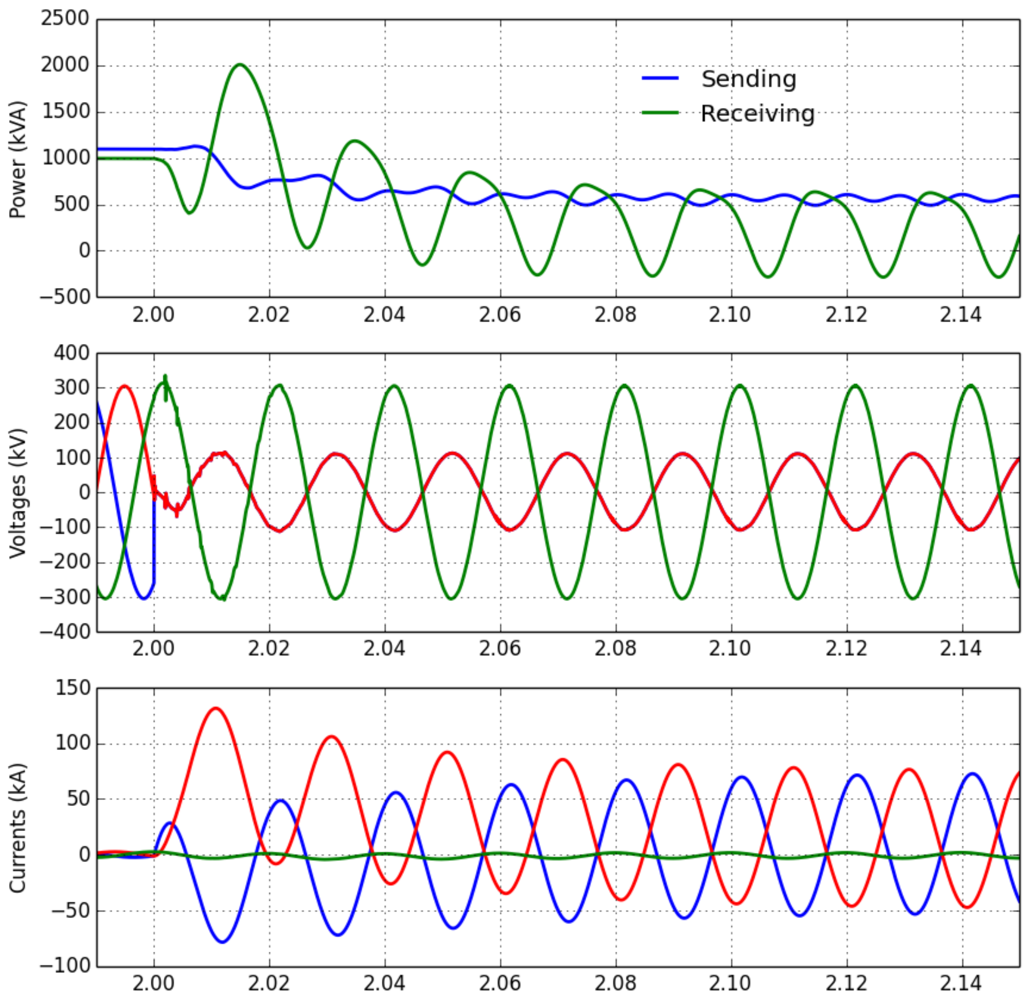
- Figure shows the effect of intersystem fault on the dc side.
- The fault is applied close to the receiving side (10 km from bus B0)
- A 50 Hz component is introduced in the dc current.

SINTEF NTNU

Case 4: Intersystem faults-2phase to one pole

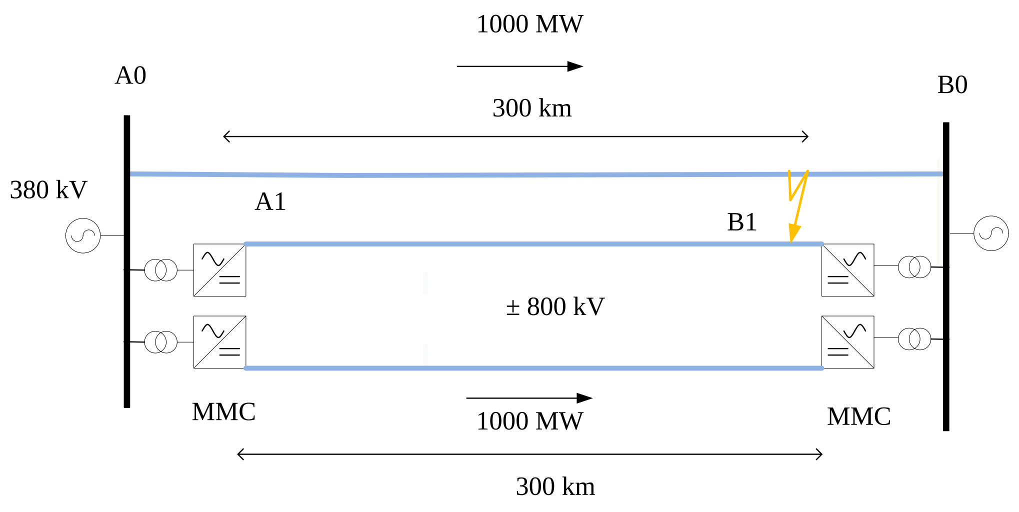


AC side

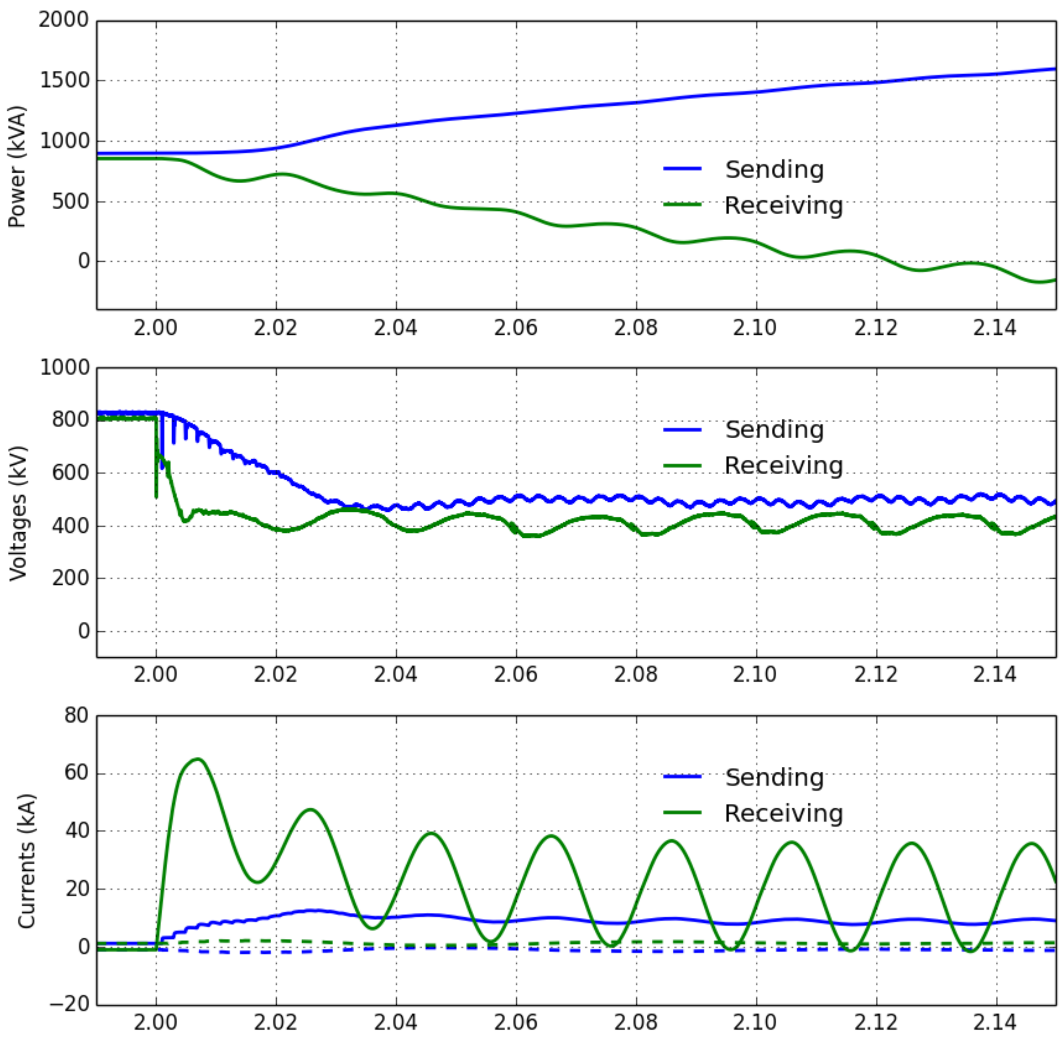


- Figure shows the effect of intersystem on the ac side.
- The fault is applied close to the receiving side (10 km from bus B0)
- A dc component is introduced in the ac current in two of the phases as shown in the figure.

Case 4: Intersystem faults-2phase to one pole



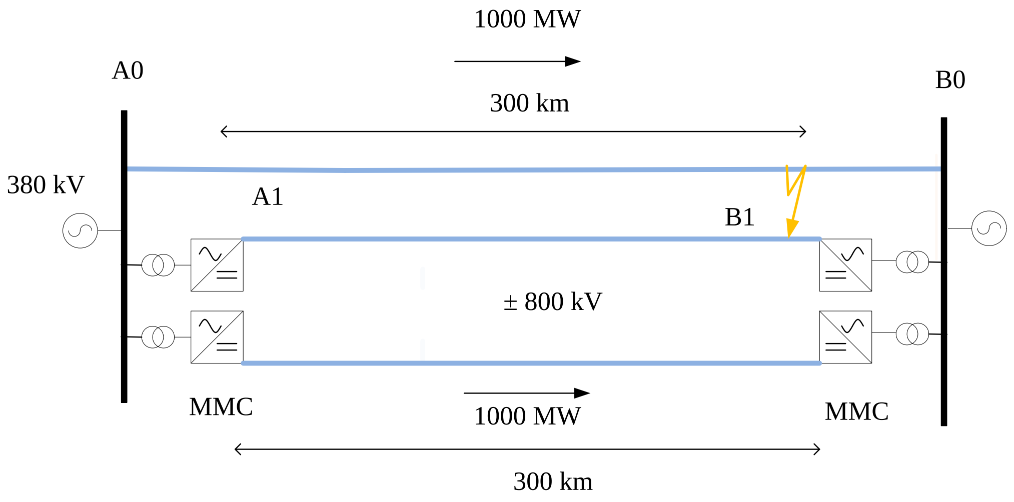
DC side



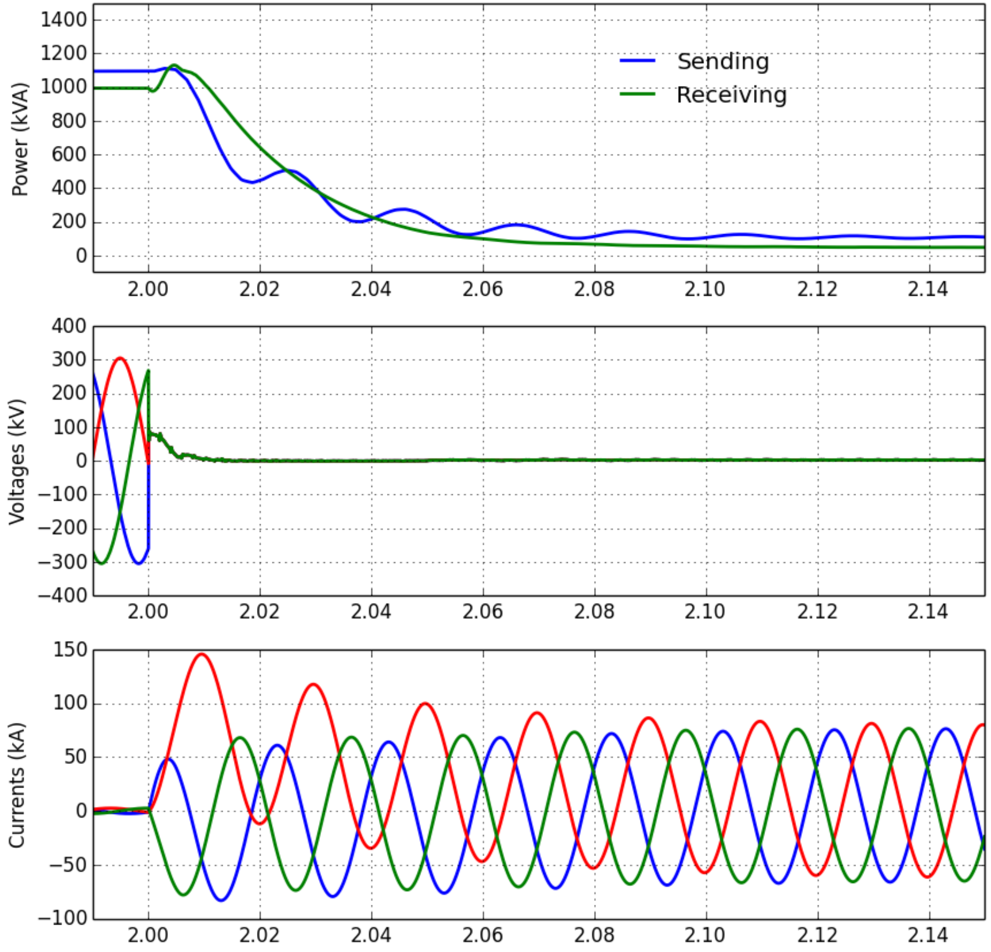
- Figure shows the effect of intersystem fault on the dc side.
- The fault is applied close to the receiving side (10 km from bus B0)
- A 50 Hz component is introduced in the dc current.

SINTEF NTNU

Case 4: Intersystem faults-3phase to one pole

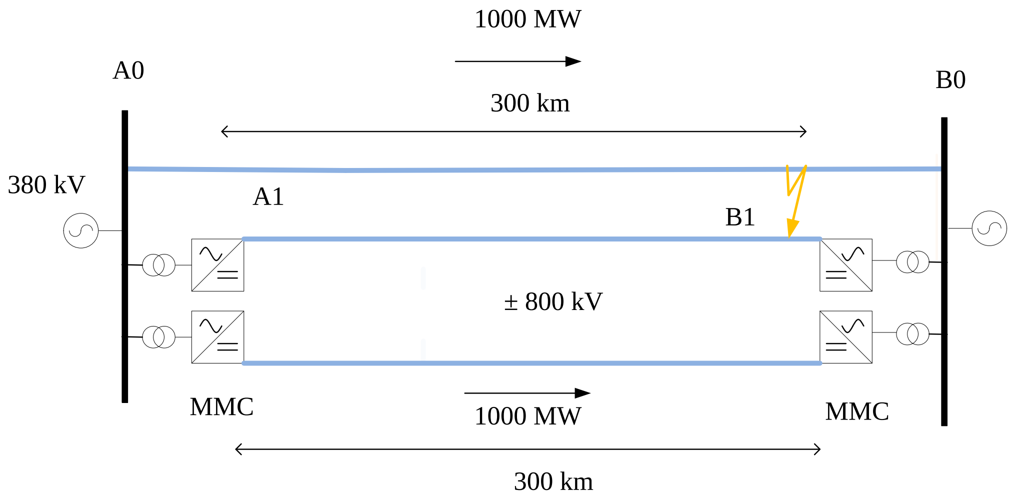


AC side

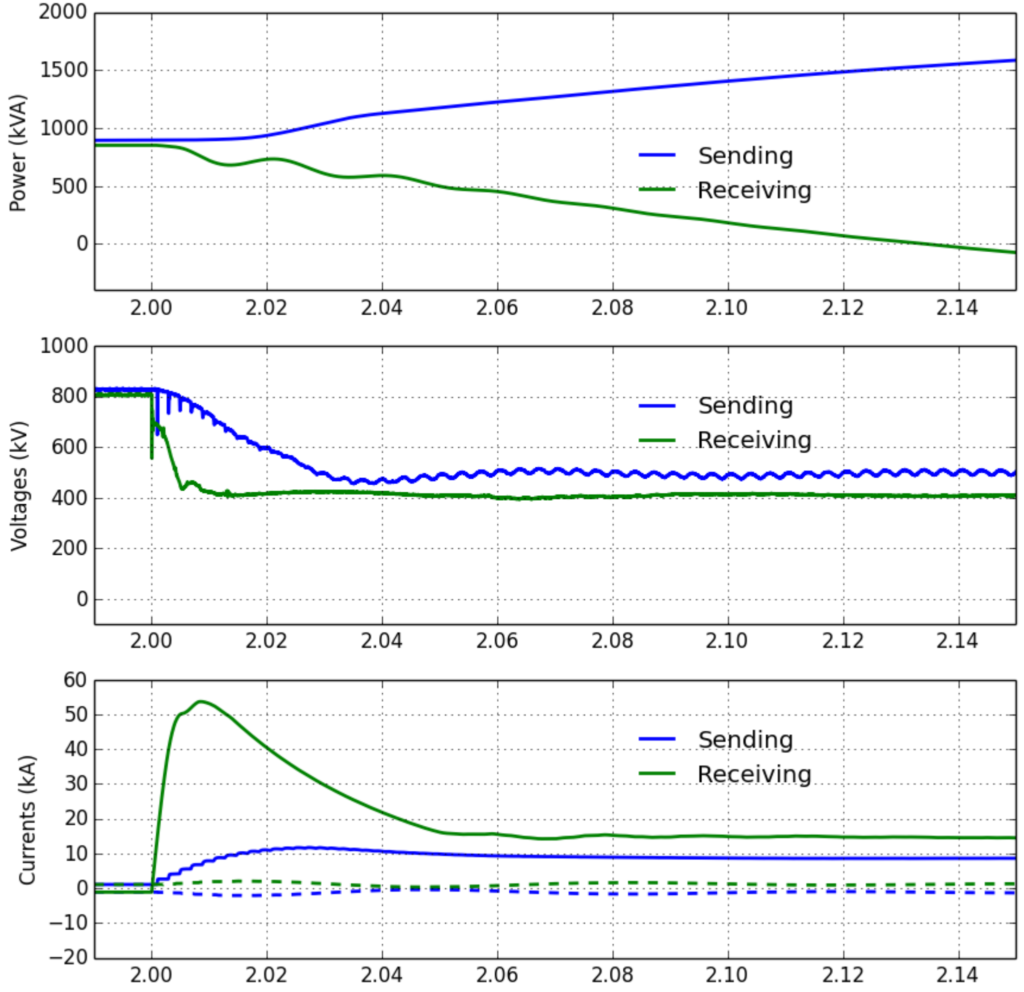


- Figure shows the effect of intersystem fault on the ac side.
- The fault is applied close to the receiving side (10 km from bus B0)
- A dc component is introduced in the ac current the three phases as shown in the figure.

Case 4: Intersystem faults-3phase to one pole



DC side



- Figure shows the effect of intersystem on the dc side.
- The fault is applied close to the receiving side (10 km from bus B0)
- No 50 Hz component is introduced in the dc current

Final Remarks

- A PSCAD simulation model was developed. The system interconnects two ac systems using a hybrid ac/dc line.
- The simulation models have been validated using different scenarios including:
  - case 1: the response of the system when dc line is disconnected,
  - case 2: the response of the system when ac line is disconnected
  - case 3: the effect of ac fault into the dc system and vice versa.
- Inter-system fault cases were investigated. The steady-state and transient interaction are shown. Three cases were studied: one phase to one pole, two phase to one pole and three phases to one pole.
- The mutual interaction is quite visible.
- The phenomena arises need further investigations, especially the consequences with respect to the protection systems.

Next step

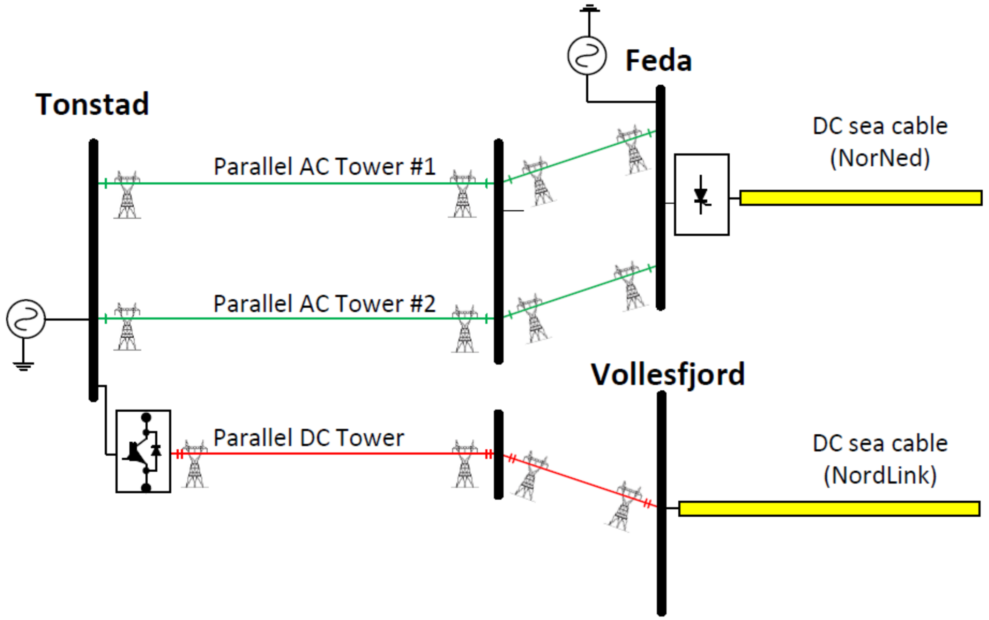
- Refine simulations with real data, and re-validate simulation models.
- Find more relevant scenarios for the inter-system faults, e.g. high impedance inter-system faults, and study the effect on the standard ac protections.
- Investigate new principle for relay protection of intersystem-faults using numerical simulations.
- Prepare technical paper in collaboration with relevant partners.
- Establish a joint project about intersystem faults. A sponsor for more research activities on the related topic is needed.

Other groups in the topic

- http://www.esc.ethz.ch/news/archive/2016/01/hybrid-hvac-hvdc-overhead-lines.html
- http://erc-assoc.org/content/acdc-hybrid-powerful-solution
- http://www.ieee-pes.org/presentations/gm2015/PESGM2015P-002803.pdf

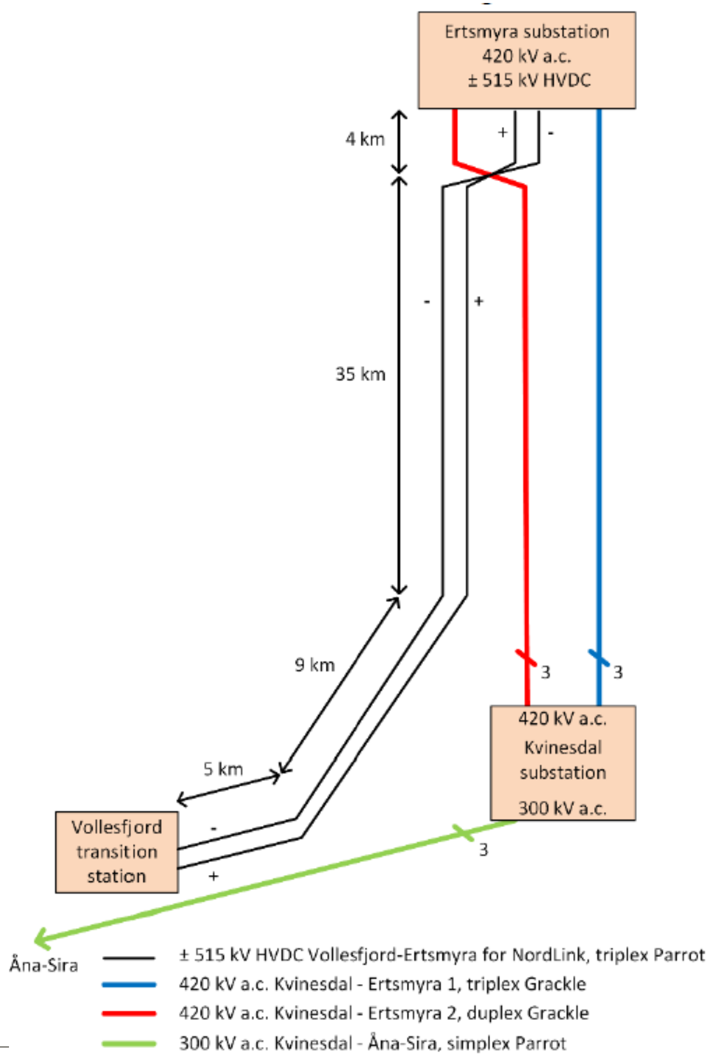
Previous Work

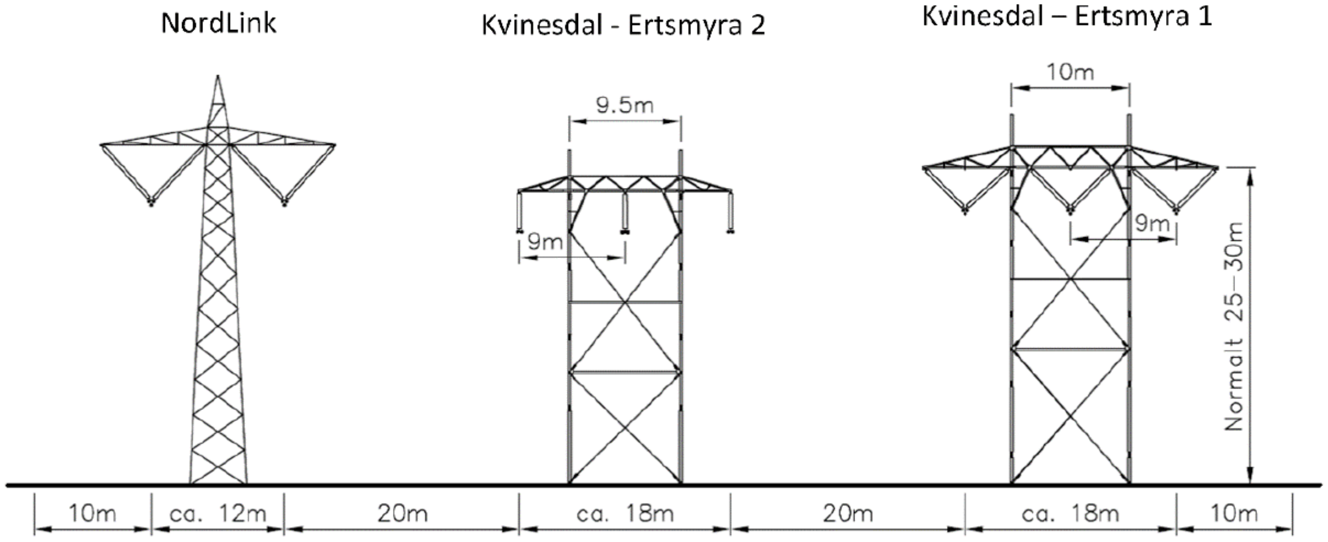
- Analysis of a Multi-Infeed HVDC System in the Norwegian Power System by Alexander Holthe (NTNU, Master Thesis , June 2014)



Overview of the Multi-Infeed Power System in Southern Norway.

- Interaction between parallel HVDC and a.c. overhead lines by Bødal et.al. (Statnett) B4-128 Cigre 2016.





SINTEF NTNU

Thanks for listening

Further queries:
raymundo.torres-olguin@sintef.no