Asymmetrical Fault Analysis at the Offshore Network of HVDC connected Wind Power Plants

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PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Abstract

• Offshore asymmetrical fault response in the **ENTSO-E HVDC code**:
future development at national levels! (for the offshore HVDC and OWPP)

• Need for **guidance** towards grid code requirements and control solutions

<u>In this study</u>:

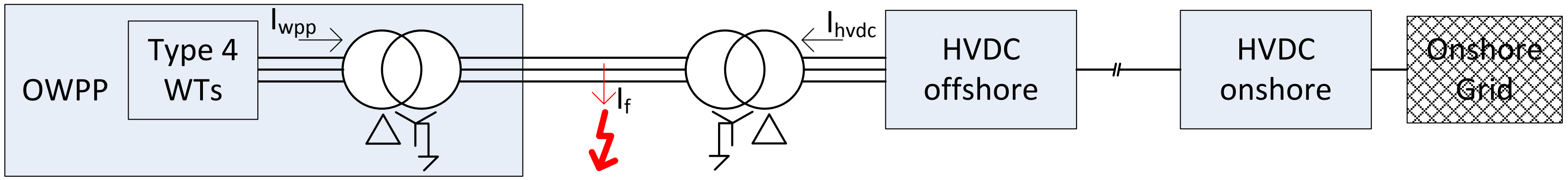
• Response of the offshore HVDC converter and the OWPP
have been investigated via **classical power system fault analysis**

• Shown that **suppression of negative sequence current is not applicable** during the asymmetrical offshore faults

• The HVDC offshore converter and/or the offshore WPP are required to **provide free flow of negative sequence current**

• The steady-state fault analysis is verified with time-domain simulations

Asymmetrical Fault at the Offshore AC Network



- single-line-to-ground
- line-to-line
- double-line-to-ground

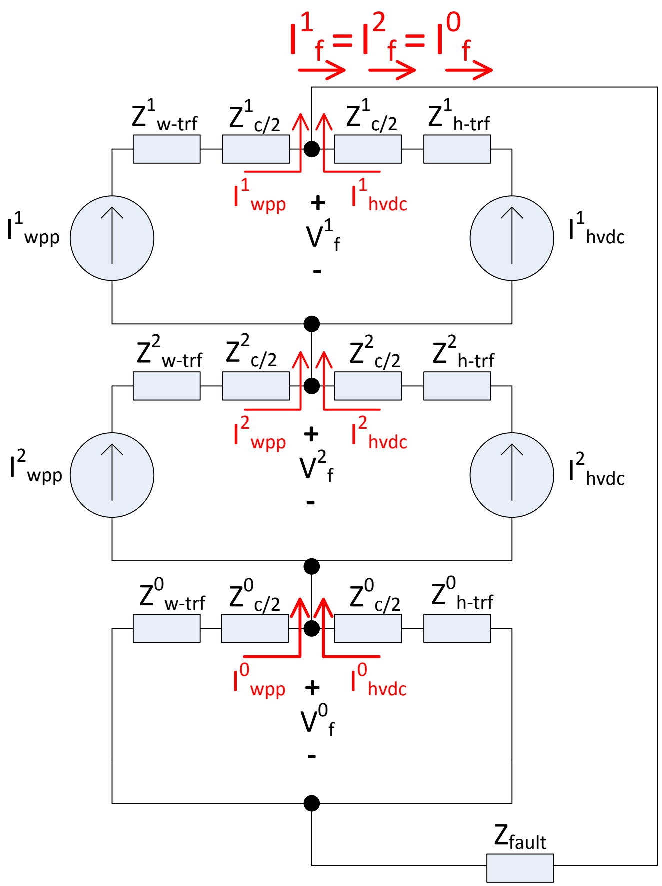
<u>Question</u>:

Can we say that
the HVDC and the OWPP will inject fixed amount of fault currents?

for example $I=k.\Delta V$??   positive and/or negative sequence ?

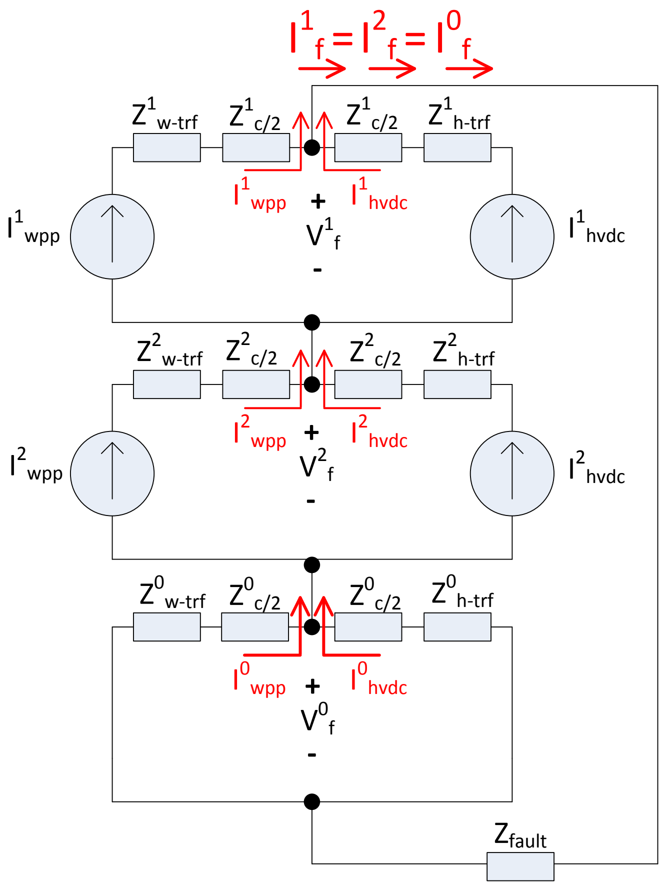
Single-line-to-ground fault equivalent sequence network

classical power system fault analysis based on symmetrical components
rather than purely relying on time-domain simulations



- The equivalent sequence network implies that the positive, negative and zero sequence currents flowing into the fault (from the WPP and HVDC) have to be equal (also in phase) to each other.
- Suppression of negative sequence current implies suppression of the fault current and extremely high voltages in the other sequences.
- The (HVDC and/or WPP) converters have to allow flow of negative sequence current

Single-line-to-ground fault time-domain simulations



<u>Responses from HVDC and OWPP converters</u>:

1. Pure positive sequence voltage by the HVDC (reduced to limit current below 1pu)

→ **no OWPP contribution !!**

2. Pure positive sequence (1pu) current by the HVDC

→ **not possible !!**

3. Equal (0.5pu) magnitude and in-phase positive and negative sequence currents by the HVDC and the OWPP

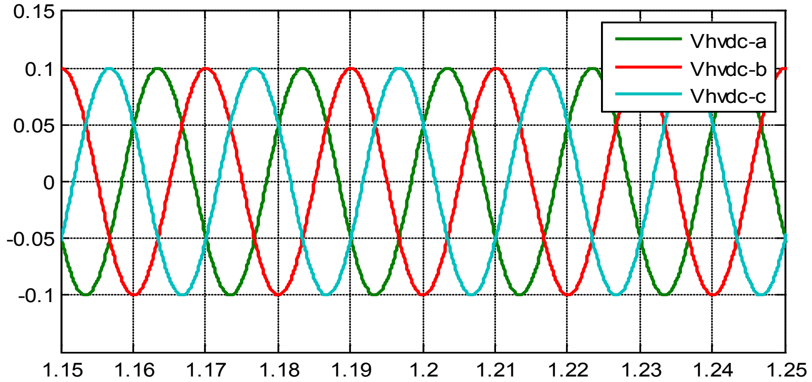
→ **not practical !!**

4. HVDC converter as a positive sequence voltage source allowing negative sequence current, while the OWPP converters contribute with positive and/or negative sequence currents

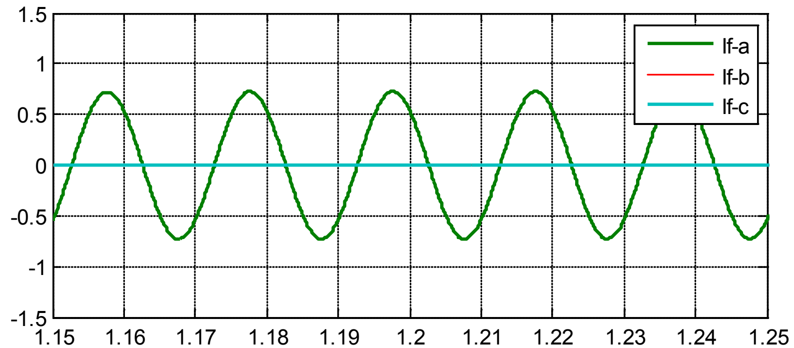
→ **might be feasible (future work)**

Single-line-to-ground fault time-domain simulations – case 1

only fault steady-state period



Phase voltages generated by the HVDC [pu]



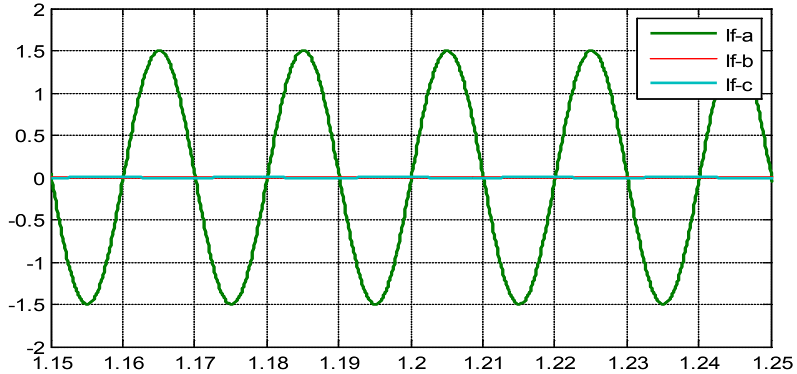
Fault phase currents [pu]

1. Pure positive sequence voltage by the HVDC (reduced to limit current below 1pu)

→ seems to work fine,
but no OWPP contribution !!

Single-line-to-ground fault time-domain simulations – case 2

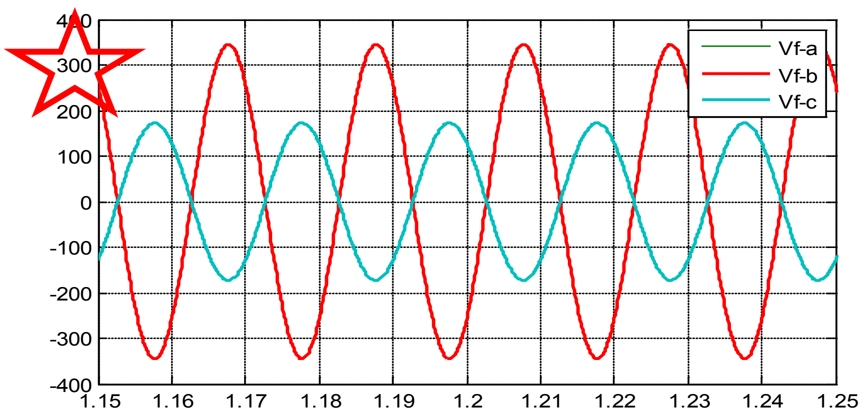
only fault steady-state period



Fault phase currents [pu]

2. Pure positive sequence (1pu) current by the HVDC

→ not possible !!

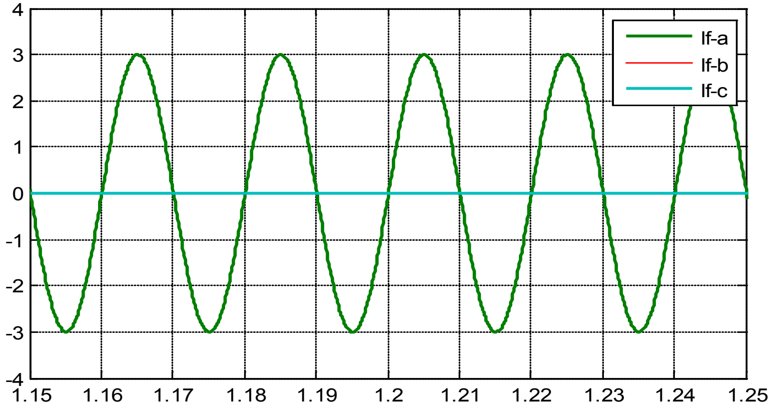


Fault phase voltages [pu]

simulation could converge
only with using snubber resistance and capacitances for the inserted fault (in the simulation toolbox Simulink); otherwise no convergence has been obtained.

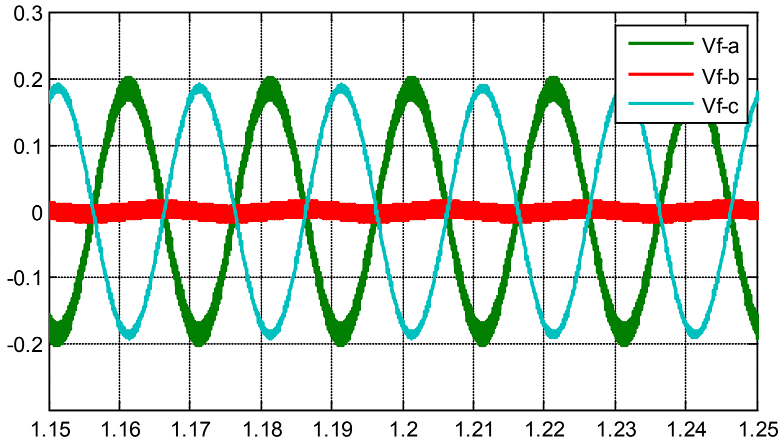
Single-line-to-ground fault time-domain simulations – case 3

only fault steady-state period



Fault phase currents [pu]

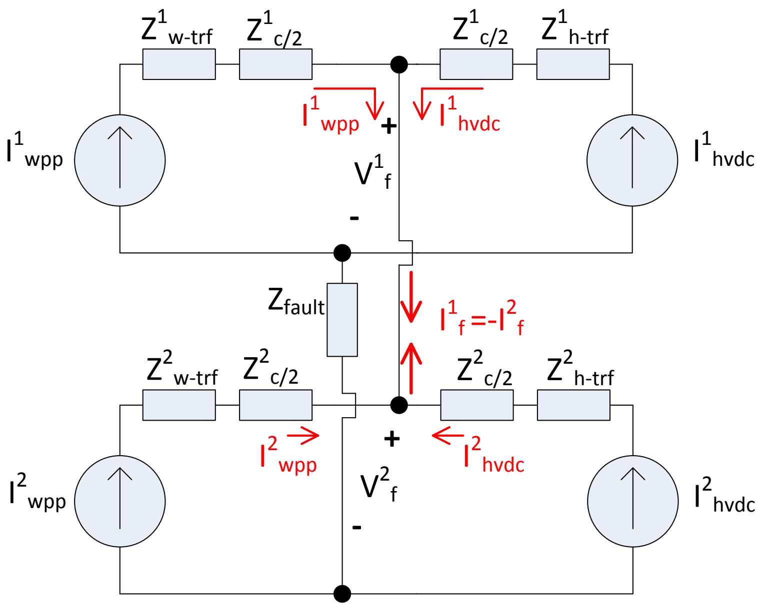
3. Equal (0.5pu) magnitude and in-phase positive and negative sequence currents by the HVDC and the OWPP
→ **not practical !!**



Fault phase voltages [pu]

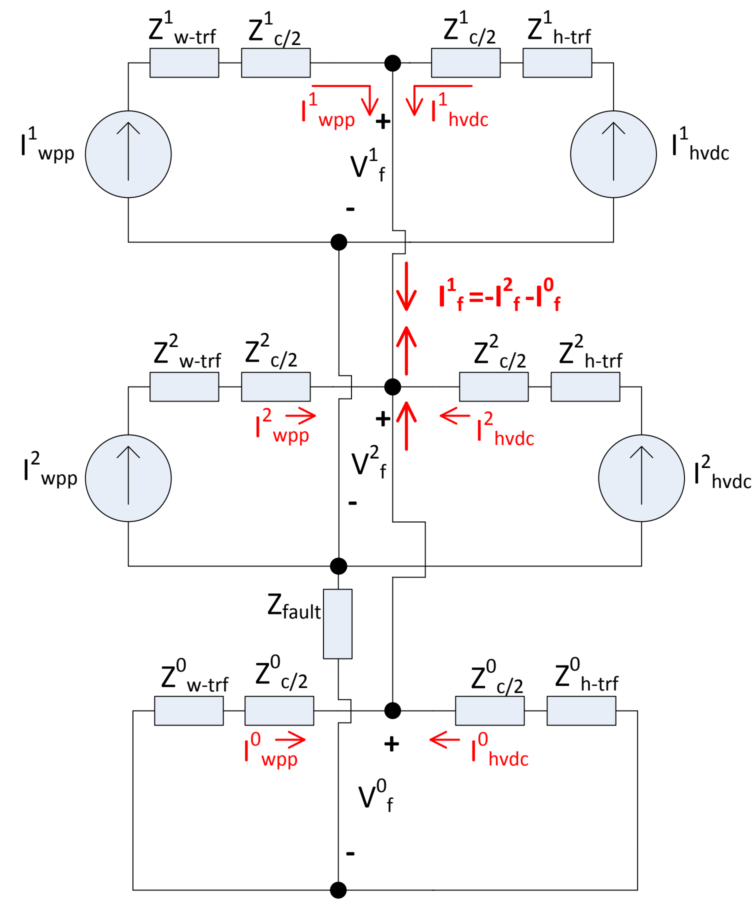
since any deviation from identical current injection
(due to control dynamics for instance)
would result in non-convergence

Line-to-line & double-line-to-ground equivalent sequence networks



Line-to-line fault equivalent sequence network

similar situation as single-line-to-ground !



Double-line-to-ground fault equivalent sequence network

possible to suppress the negative sequence current, but requires fault type detection

Conclusion

- Asymmetrical fault characteristics dictates the characteristic of the current flow; positive and negative sequence current injection by the HVDC and OWPP
- In a converter-only network,
  the converters have to provide the negative sequence current flow
  or
  as minimum must not suppress it
- Future work will be directed towards the development of control schemes that can be applied in reality.

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THANKS !

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