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Bipolar VSC-HVDC: Impact of single-pole DC faults on healthy pole under weak AC network conditions

SC B4 – DC Systems and Power Electronics

PS1-2 – Fault Ride-Through & Clearing in VSC HVDC

Question 1.4

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This contribution refers to the following question (most relevant in bold letters):

Large integration of inverter-based power generation will reduce the power system inertia and short circuit capacity of the AC grid.

- **What impact will this have on the secure and reliable operation of LCC and VSC converters. What design considerations are foreseen to support the reliable operation of HVDC converters with reduced system strength?**
- Papers 10212, 10211 and 10466 propose and exemplify schemes to **accelerate the DC fault clearance and enhance fault recovery** for both asymmetrical VSC-HB monopole and **VSC-HB bipole. Beyond hybrid VSC (FB+HB)**, are there other methods being investigated all over the world regarding fault-tolerant VSC converters?

Acknowledgement:
This contribution is based on conceptual and simulation-based studies performed at the IAEW of RWTH Aachen University in close collaboration with Amprion GmbH.

Detailed description of the contribution :

As described in more detail in paper ID 11087 (« European offshore grid: On protection system design for radial bipolar multi-terminal HVDC networks »), the next generation of VSC-HVDC systems connecting offshore wind farms is planned to be realised in a bipolar configuration with DMR. One of the main aims of the bipolar configuration is to increase the redundancy/availability after single-pole DC cable faults as shown in Figure 1. By the time these systems will be commissioned, not only the available DC-side technologies might have changed, but also the AC networks these HVDC systems are connected to: Both short circuit level and inertia are expected to decrease, and the dynamic system behaviour might be influenced by power electronic converter controls.

In particular, DC faults are considered critical events with regard to dynamic behaviour, temporary power losses, and AC system stability. By HVDC system design and protection, the impact of DC-side faults on the AC network's stability shall be reduced as much as possible. The resulting DC protection requirements are not only challenging for point-to-point links, but – and especially – also for future interconnections towards multi-terminal HVDC networks.

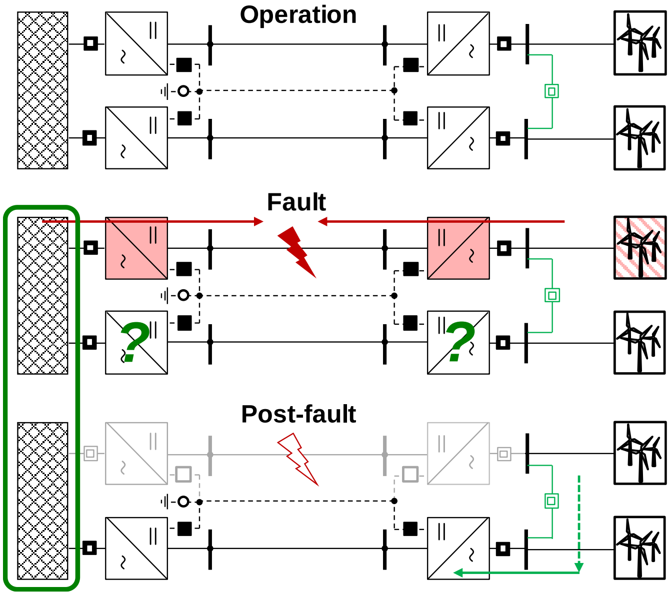

Figure 1 : Overview of bipolar HVDC system with DMR : Normal operation, fault state, and post-fault state

This contribution shows an example of how the AC network conditions do not only set requirements on the desired DC-side protection performance (i.e. the maximum temporary power loss at the AC PoC), but directly influence the DC fault behaviour. In particular, it is shown for a bipolar 2-GW, 525-kV HVDC link that a different fault current level (30 GVA vs. 7.5 GVA) of the onshore AC network has an impact on the interactions between P and N pole during DC faults. The system investigated is based on half-bridge (HB) MMCs, and a full load scenario with 2 GW being transmitted from offshore to onshore is assumed.

Regardless of the AC system strength, the P-pole fault leads to P-pole converter (C1_P) blocking and a subsequent AC fault current infeed (freewheeling state of blocked HB-MMC) until AC circuit breaker opening. On the DC-side, P and N pole are decoupled via opening of the neutral bus switches (NBS) after fault clearing.

As shown in Figure 2 (left), the healthy pole converter(s) remain in normal operation when a strong AC network is simulated, but – contrary to the requirements – block because of self-protection when a weak/moderate AC network is simulated (Figure 2 right).

For a weak grid, the fault current infeed through the blocked P-pole converter leads to a significant AC voltage dip (Figure 3). As a consequence, the AC current of the remaining N-pole converter (in V_{DC} control mode) has to increase in order to keep the same power transmission (N pole wind farm continues to feed power). However, at a certain stage, the converter's current limit (e.g. 1.1 p.u.) is reached, such that the AC-side power transmission is limited, resulting in a power imbalance at the N-pole converter (Figure 4). This imbalance charges the submodules of the converters; consequently, the submodule overvoltage protection triggers converter blocking of C1_N.

A possible mitigation of this issue could be an improved coordination of the DC chopper systems (which are present either way for offshore HVDC links) and the DC fault detection and/or MMC control systems. Other options could be either a higher converter current rating, or the use of fault blocking converters – which would avoid the AC voltage sag causing the observed phenomena.

In this contribution, the effect was demonstrated for a variation of the onshore grid strength. As shown in paper ID 11087, coupling of P and N pole on the offshore AC side of a bipolar HVDC link might be an option to futher increase the post-fault availabilities. As a wind farm can be considered a very weak grid, similar challenges with regard to P and N pole interactions during single-pole DC faults are to be expected.

With regard to future multi-terminal HVDC networks in bipolar configuration, it is necessary to consider the AC-side interactions between P and N pole in order to correctly estimate the temporary power losses seen at the PoC to the AC grid, and thus to design protection systems.

Overall, the change towards an converter-based AC power system does also impact the operation, control and protection of the DC-side of these converters. Further analyses and solutions for AC/DC networks are needed.

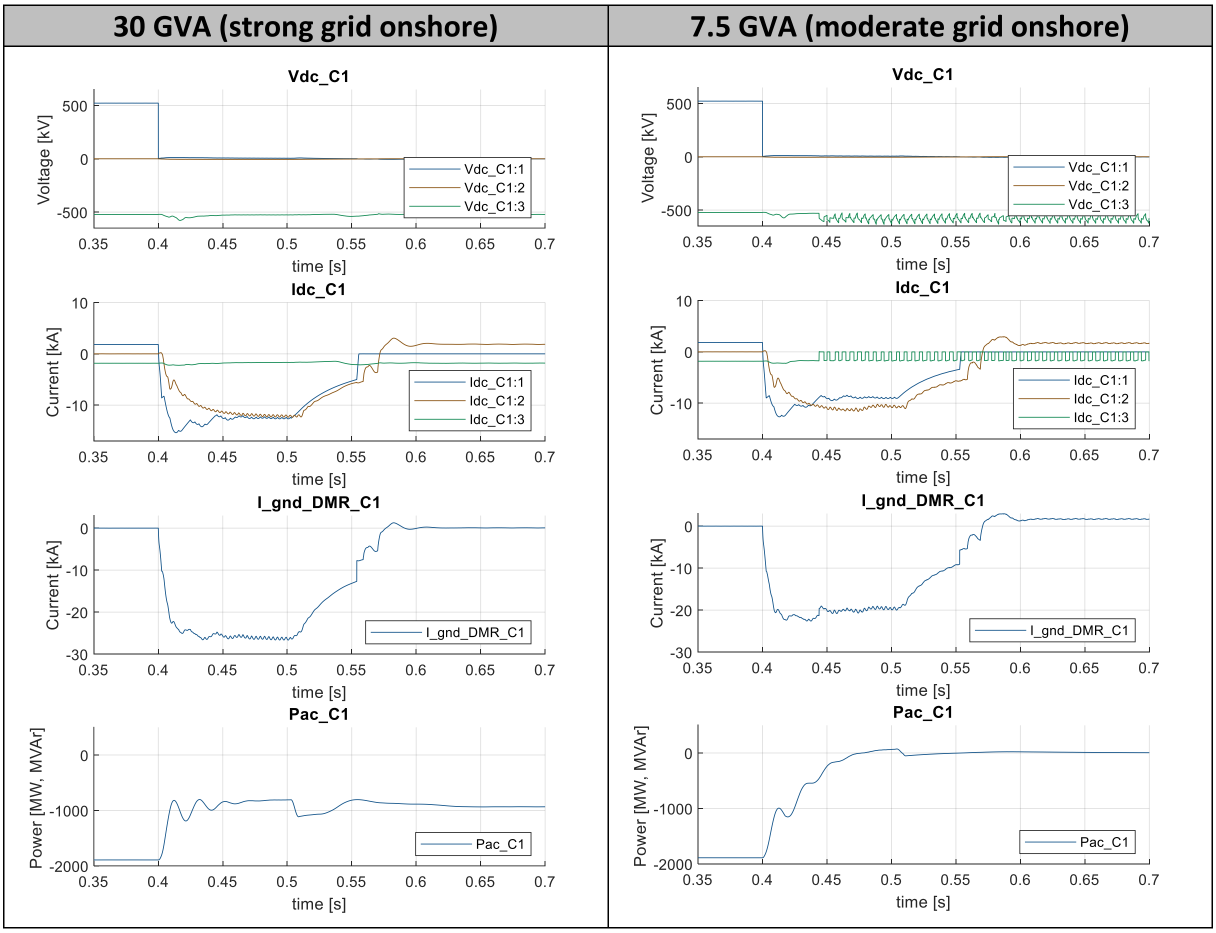

Figure 2 : DC terminal measurements and AC-side active power (at PoC) following a P-pole to ground fault at t=0.4 s

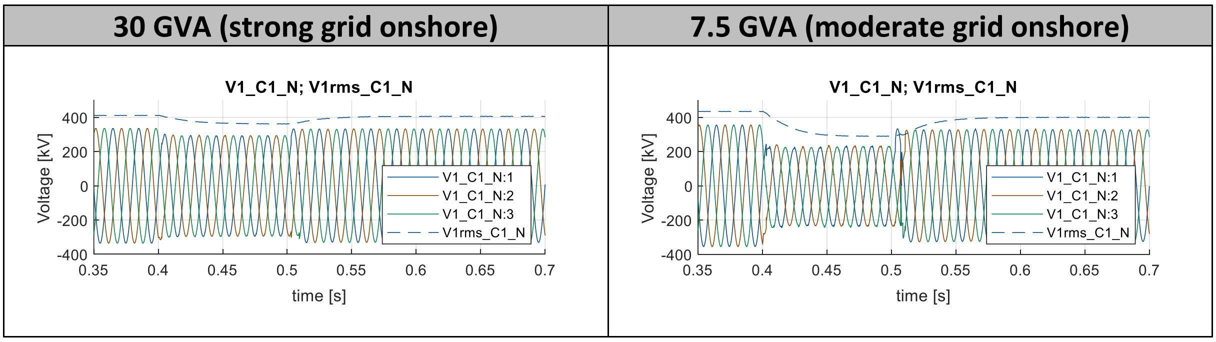

Figure 3 : AC voltage at PoC following a P-pole to ground fault at t=0.4 s

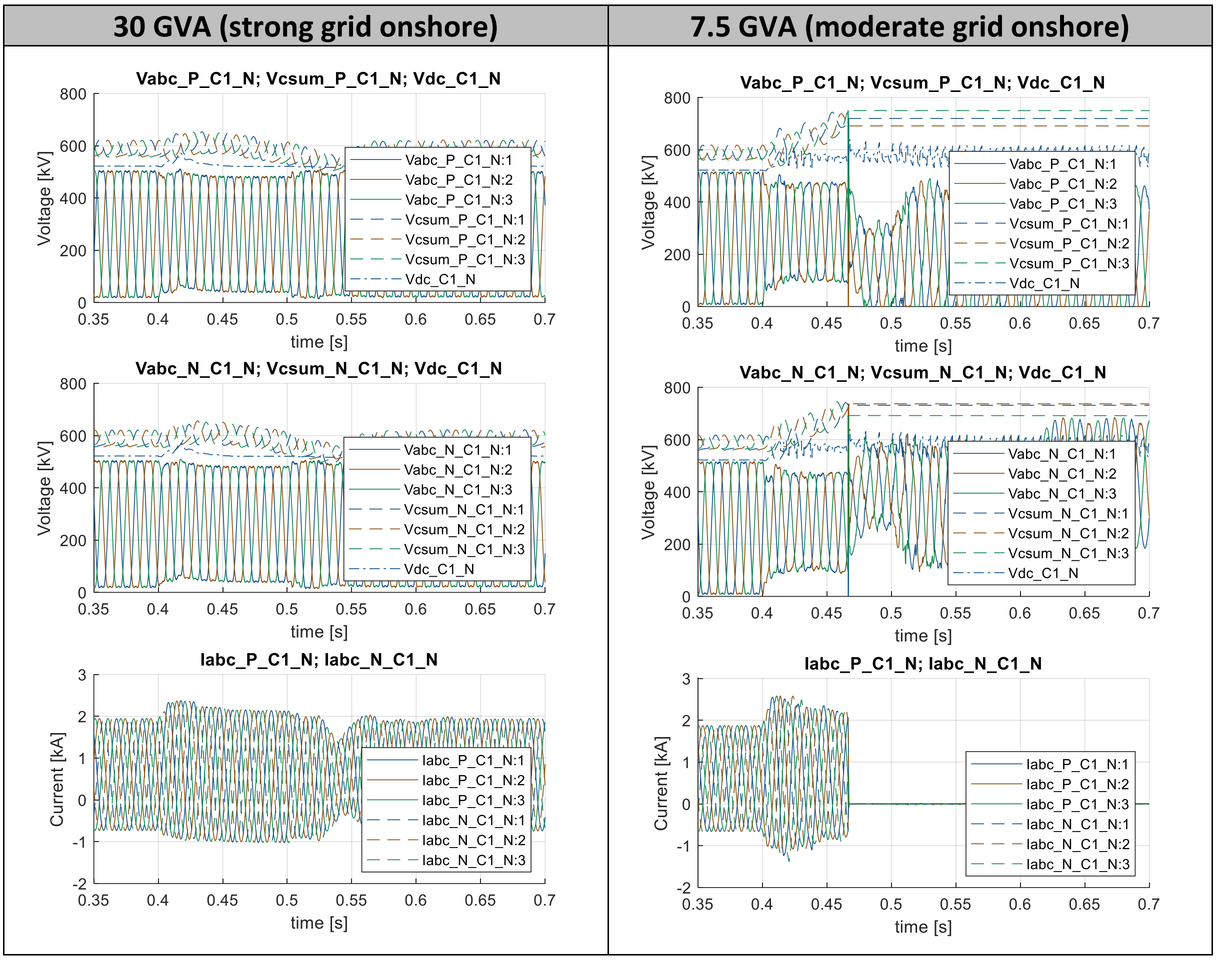

Figure 4 : Converter-internal measurements of N-pole onshore converter following a P-pole to ground fault at t=0.4 s