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PS1. Miscellaneous T&D equipment and systems
Q2: HVDC switching equipment is on the way to become 'standardized' technology.
What are relevant issues or proposals for the standardization of HVDC switchgear?

The concept of DCCB Key Performance Classes (KPC) to enable MTDC protection interoperability

In recent years important progress in DC switchgear development has been made. The operational performance of several DC Circuit Breaker (DCCB) prototypes has been successfully proven to be feasible throughout laboratory tests. However, for the integration of DCCBs into future Multi-Terminal DC (MTDC) grids system aspects must be considered as well in order to ensure an interoperable DC grid protection.

Important aspects for a coordinated HVDC grid protection are shown in Figure 1. The HVDC grid protection strategy has an important influence on the technology requirements. This concerns not only converters, sensors and communications but also the switching equipment including DCCBs. The requirements depend on the system architecture and potential grid extensions must be considered for an adequate sizing of protection equipment. Hence, the performance of DCCBs need to match the requirements of the protection strategy in order to ensure interoperability in an evolving MTDC grid. A classification concept, as proposed in the following, could ease the integration of DCCB and enable MTDC grid protection interoperability.

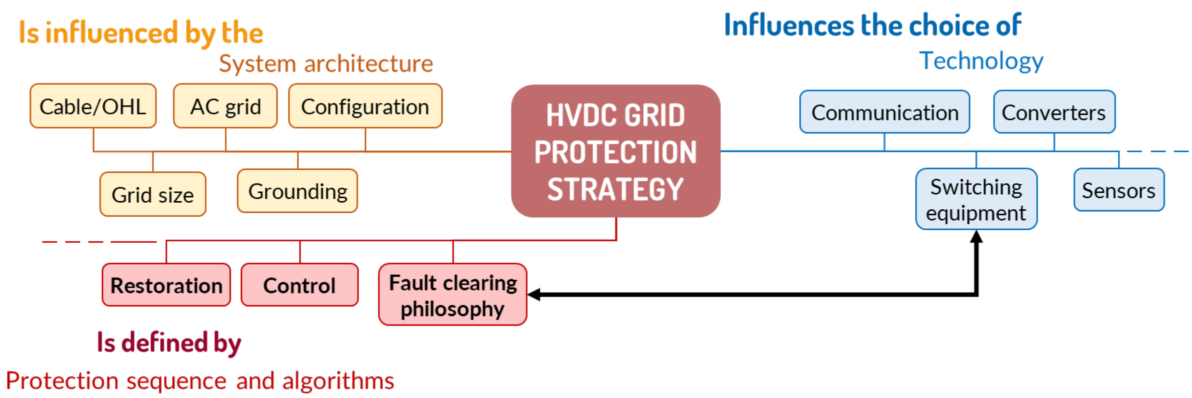

Figure 1 Interoperability aspects for DCCBs in a MTDC grid

Key protection aspects from a system level with an important impact on DCCB performance requirements are the fault clearing philosophy, the type and rating of the fault limiting device, the number of converters allowed to block during a Fault-Ride-Through (FRT) sequence and the overall grid topology including possible grid extensions and operating modes.
Several fault clearing strategies (FCS) have been investigated. In a non-selective FCS the power flow of the entire grid is temporarily completely interrupted, whereas for a fully-selective FCS, the fault is selectively cleared and the operation of the rest of the grid is ensured. In a fully-selective approach the blocking of converters should be avoided in order to keep a maximum

of the grid in operation. In fact, especially offshore converters cannot easily be deblocked as they control the offshore AC grid frequency. However, this is a trade-off between the rating of the fault current limiting device and the overall FRT performance of the grid with consideration of the maximum loss of infeed. DC reactors and SFCL can serve as current limiting devices. The former option of DC reactors impacts the controllability of the DC grid. High DC reactors may have an impact on the stability of DC grid. Last but not least grid configurations and extensions must be considered for an appropriate DC protection strategy. This imposes different constraints on the DC switchgear and in particular on the DCCB.

In the concept of DCCB Key Performance Classes, the most important characteristics for a MTDC protection design should be emphasized in order to compare DCCB rather from a performance point of view than from a technological point of view. A non-exhaustive list of important performance characteristics are listed below:

- Operating time [ms]
- Current breaking capability [kA]
- Energy absorption [MJ]
- Reclosing time [ms]

These DCCB performance requirements can be defined for different protection strategies as illustratively shown in Figure 2. It can be seen that the requirements can vary significantly depending on the protection strategy. For a non-selective FCS relatively slow DCCB operating times may be considered as the power flow will be interrupted anyway. In revanche, the current breaking capability is rather high as no or low fault limiting devices are installed in the system leading to a quicker rise of fault current with high contributions from converters as they are allowed to block. Energy absorption is rather low as no DC reactors are installed. However, the temporary stop of active power should be kept as short as possible such that the reclosing time of the DCCB should be rather fast.
On the other side for fully-selective FCS ultra-fast DCCBs may be required in order to match the acceptable converter blocking criteria and to limit the rise of fault current. Higher energy absorption due to higher DC reactors is required. However, the reclosing time is rather relaxed as the faulty component is selectively isolated by the surrounding DCCBs.
Compared to the second option, a fully-selective FCS in combination with SFCL could relax significantly both operating time and current breaking capability of the DCCB as the fault current is limited by the SFCL device. It further keeps a high controllability of the DC grid as no or small DC reactors are required, which also implies low energy absorption.

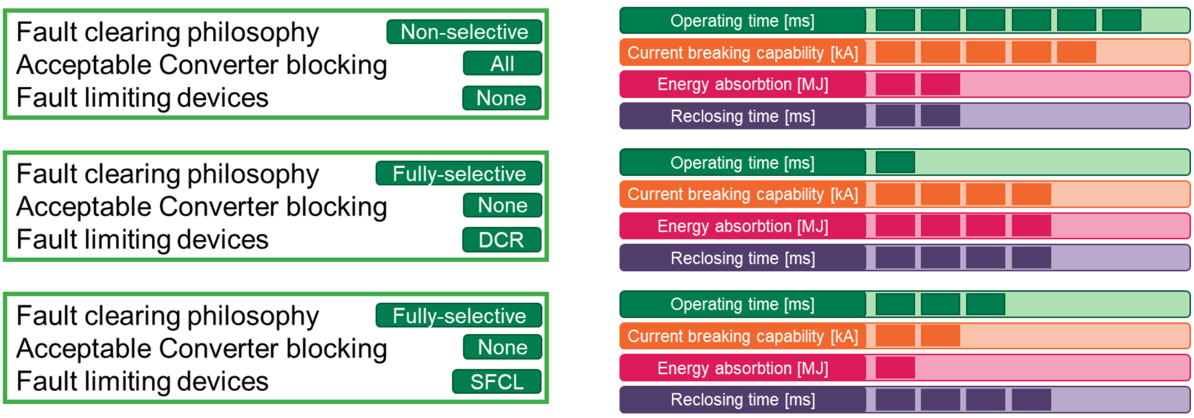

Figure 2 Illustrative examples of DCCB Key Performance Classes for different protection strategies

The above illustrative examples give a first overview on how DCCB Key Performance Classes could be applied to different protection strategies in order to match the MTDC protection requirements on the way to standardization of DC switchgear.

The concept of DCCB Key Performance Classes can accelerate the standardization of DCCBs as it links the protection strategy from a system level perspective with the DC switchgear. In this way, it may help to enable systematic MTDC grid protection rollout and MTDC interoperability.