The expected expansion of high voltage dc (HVDC) systems leads to consider dc/dc converters to provide new interconnection possibilities.

Dc/dc converters can be used to interconnect two HVDC systems with different rated voltages and/or different technologies[1] and/or different link topologies[2]. In this case, the dc/dc converter allows to expand the dc system with additional degrees of freedom: technical choices for new assets can be different from the existing ones. It allows also features like the control of the transferred power between both links or the voltage control of one link, the fault blocking capability[3] or black start[4].

Additionally, dc/dc converters can be used to interconnect an HVDC installation with a medium voltage dc (MVDC) installation. In this case, the power flow can be either from the HVDC system to the MVDC system (e.g. to supply remote communities) or in the opposite direction (e.g. to collect energy from distributed generators). In both cases, no such converter is presently in operation and the needed models for planning and techno-economic studies should be based on simulations. Losses should then be modelled. Most of studies on dc/dc converters to be connected to an HVDC link considers converter topologies using technologies used for HVDC VSC converters: series connection of switches and series connection of submodules. The phenomena leading to losses in such converters are then the same as for ac/dc converters (especially conduction losses, switching losses and losses in inductances and transformers). Then the knowledge and experience related to ac/dc converters at the same ranges of voltage (CIGRE technical brochure 844, 2021) can be used but with some restrictions as explained bellow.

Basically, the proposed topologies of dc/dc converters in the literature can be classified in two main categories: *indirect topologies* which are actually two ac/dc converters connected in a front-to-front arrangement[5] achieving a dc/ac/dc conversion and *direct topologies* in which the dc/dc converter cannot be seen as two ac/dc converters.

For *indirect topologies*, for each ac/dc converter, it can be expected that losses will be in the same range as known ac/dc converters for the same ratings only if the ac waveforms are similar in both cases (if the converter is designed to operate with sinusoidal 50 or 60Hz currents and voltages in the intermediate link).
Firstly, it can be noted that the frequency of the internal ac currents is a degree of freedom for the converter design. Some papers also propose non sinusoidal waveforms allowing for instance soft-switching operation then dramatically reducing switching losses. Different ac waveforms (in frequency and/or in shape) can lead to different technical choices in terms of switches and passive elements[6]. Losses will also be affected by these choices.
Secondly, the converter design is not only driven by normal operation but also by constraints in case of fault. As an example, in case of a dc fault, devices in an ac/dc converter must either withstand high transient currents either be able to stop the contribution of the ac system to the fault current leading to topology changes (e.g. full-bridge submodules in modular multilevel converters (MMCs)). In an indirect dc/dc converter, in case of a dc fault, the contribution to the fault current can be stopped by blocking the switches in both ac/dc converters without additional switches and with devices not sized to withstand high transient current. This can lead to different technological choices for the elements inside the converter and then this will affect its losses.
Finally, it should be also noted that in such a converter the number of phases is an additional degree of freedom compared to grid-connected ac/dc converters.
Due to these different constraints and degrees of freedom, the ac/dc converters used in indirect dc/dc converter can be quite different from the classical grid-connected ac/dc converters as the additional degrees of freedom are opportunities to reduce losses (and cost, footprint…).

For *direct topologies*, the previously mentioned differences with ac/dc converters for indirect topologies also apply (non-sinusoidal waveforms, behavior in case of faults, number of phases) but another difference is worth mention. When these converters are built with arms made of a series connection of submodules, these arms are subject to

[1] Line commutated converters (LCC) or voltage source converters (VSC)
[2] Monopole, bipole or rigid bipole
[3] In case of a fault in one link, currents and voltages on the other link should not reach value out of acceptable ranges and the healthy system should not trip.
[4] An HVDC link can be energized thanks to a dc/dc converter thanks to energy from the other link.
[5] Converters connected at their ac terminals through an intermediate link (this link being a transformer most of the time)
[6] E.g., core material and winding technique (stranded, copper foil…) for inductances and transformers

dc and ac currents and voltages as in MMCs but the ratio dc component vs ac component is not the same. Simulation results show that the switching losses in these conditions are not the same as in classical MMCs and that analytical formulae which are quite accurate to assess switching losses in classical MMCs does not apply in direct dc/dc converters. Then these formulae cannot be used and simulations studies are needed. Development of specific voltage balancing algorithms[7] is also a possible opportunity to reduce switching losses in these arms.

If the phenomena leading to losses are the same in ac/dc and dc/dc converters, the knowledge on ac/dc converters directly applies in a limited number of cases: indirect converters with sinusoidal 50 or 60Hz waveforms. In this case and with the same devices as in an ac/dc converter, losses will be around twice the one of an ac/dc converter plus losses in the transformer. This case corresponds to the use of existing solutions but does not take advantage of existing degrees of freedom (converter topology, waveforms, technical choices and number of phases). Each of these degrees of freedom is an opportunity to reduce losses (and other key performance indicators like cost and footprint). For other cases, the assessment of losses should be adapted considering the specific waveforms and choices for switches and passive elements (waveforms and technological choices being not independent and the second one being also related to expected fault behavior). Methodologies to assess losses in these cases exist. A special care should be dedicated to switching losses as the operational conditions can be quite different from MMCs (soft switching or impact of voltage balancing algorithm in series connected submodules).

[7] The algorithm governing the switching behavior of series connected submodules