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Review on High-Frequency Operation of a DC/AC/DC System for HVDC Application

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Abstract

There is an increasing interest in voltage source converter (VSC) based HVDC grids. The development of DC grids is likely to take place in phased manner with several voltage levels similar to that of the AC grids. These different high voltage DC levels will have to be interconnected with each other which will require DC-DC transformers. Voltage ratings for HVdc point-to-point connections are not standardized and tend to depend on the latest available cable technology. DC/DC conversion at HV is required for inter-connection of such HVdc schemes as well as to interface dc wind farms. This paper revive the High-Frequency Operation of a DC/AC/DC System for HVDC Applications

Index Terms

DC–DC power conversion, HVdc converters, HVdc transmission, multilevel converters.

Introduction

Based on the current crisis of traditional fossil energy, it is an inevitable choice for human society to embark on the road of sustainable development to efficiently develop and fully utilize renewable energy in order to get rid of the heavy dependence on traditional fossil energy. Therefore, many scholars at home and abroad put forward the concept of "wide area network", which integrates new economy, information and energy to promote the efficient conversion between various renewable energy sources. In the energy Internet, it takes the UHV large power grid as the "backbone network", that is to say, in the era of future energy Internet, the power system is the hub of all kinds of energy conversion

A NUMBER of high-voltage dc (HVdc) schemes are currently under development and consideration in Europe.The interest in HVdc is driven by the expansion of renewable generation capacity in places such as Scotland, Germany, and the North Sea as a means to efficiently transmit the gener- ated power to far away load centres. As most of the currently considered (or already built) schemes are of the point-to-point type which, coupled with the absence of a common dc grid code, allows the voltage ratings to be freely chosen by each developer. As a result the voltage rating is often a function of the available cable technology at the time of development.

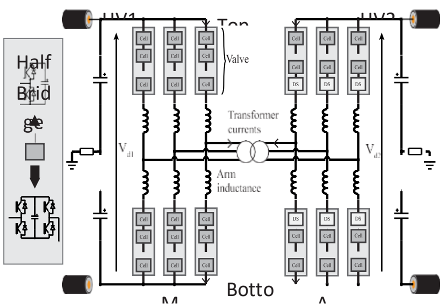
The voltage conversion ratio has important implications on the converter technology as it influences the magnitude of cur- rents and amount of stress imposed on the system. The same nomenclature as defined in [3] has been adopted for this paper. As such, a low step ratio is defined as per (1)

$$V\text{dc high voltage side}/V\text{dc low voltage side} \leq 1.5. \quad (1)$$

A low step ratio could be used to interconnect existing HVdc networks of different nominal voltages. Connections to a dc collection grid of an off-shore wind farm, a number of which are planned in the North Sea, may require a medium step ratio which is defined in (2)

$1.5 < V_{dc\ high\ voltage\ side} / V_{dc\ low\ voltage\ side} \leq 5.$ (2)

Voltage source converters (VSCs) are generally considered to be the best option of for multiterminal HVdc grids as they allow power reversal without having to change the voltage polarity and can connect to weak ac networks. Consequently, two well-studied multilevel VSC topologies are considered for use in the dc/ac/dc system. These converters are the modular multi- level converter (MMC) and the alternate arm converter (AAC) . Both make use of either half-bridge or full-bridge cells in their valves to generate a staircase voltage waveform with small voltage steps. This allows individual switching de- vices in the cells to be at a lower frequency compared to older VSC topologies such as the two-level or three-level convert- ers .Due to this, modular multilevel topologies achieve a significant reduction in switching losses. The AAC differs from the MMC in its mode of operation in that its arms conduct al- ternatively for only half a cycle, allowing fewer cells to be used but at the expense of additional director switches consisting of series-connected IGBTs.



Alternative dc/dc topologies utilizing the multilevel cell blocks are beginning to be considered along with other circuit concepts, such as presented in. These circuits how- ever do not offer the galvanic isolation offered by a transformer which can be useful in some abnormal operating conditions and for separating grounding arrangements for different parts of a dc network. Furthermore, the well-established switch-mode dc/dc converters, typically employed for low-power applications, do not tend to scale very well for high-power applications.

The suggested front-to-front arrangement of two ac/dc con-

for half of the ac cycle. When the other arm is not conducting any current, its director switch opens breaking the current path and blocking the remaining voltage difference between the ac voltage and the cell stack. The valve in the conducting arm is thus responsible for generating the ac waveform.

System Losses

Raising the ac frequency requires the cells to switch at a higher frequency also to generate the ac voltage waveform. This causes increased switching losses.

The system losses have been estimated using the time domain data gained from the case-study simulations. Using device- specific loss data, the conduction and switching losses in the semiconductors were calculated by postprocessing the simula- tion data. Switching occurrences are detected using the gate signals to the cells. Along with these and the current direc- tion and magnitude through the arm a device specific turn-on, turn-off, or diode reverse recovery energy loss is calculated.

The switching device assumed in this paper was Toshiba's MG1200FXF1US53. This method assumes that the losses in- curred in the devices do not significantly affect the voltage and current waveforms in the system as these power losses are ex- pected to be small. The transformer losses were estimated using a simplified analytical model. The transformer was taken to consist of a central limb around which first the primary and then the sec- ondary windings are wound. The magnetic path was closed by two outer limbs each with half the cross-sectional area of the central limb. The flux density was chosen according to be

1.72 T and the current density 4 A/mm^2 . The model calculates the transformer geometry and associated losses across a range of values of three input variables: the number of secondary turns, the winding height, and the magnetizing current magnitude.

Overall the transformer design has not been optimized for 350 Hz operation. The core losses were calculated based on available data sug- gested by a manufacturer (which was available for 50 and 350 Hz) and assuming all of the core is at the same flux den- sity. The winding losses were calculated as the simple resistive losses only using the mean turn length and number of turns for each winding. The skin-effect losses were not modeled at this stage because the skin depth of the copper winding at 350 Hz is 3.5 mm which was not significantly smaller than the wire diameter. Tank losses were also not taken into consideration during the modeling of the transformer losses. The loss results are summarized in Tables VI and VII.

CONCLUSION

This paper introduces an HV dc/ac/dc system suitable for in- terconnecting HVdc networks operated at different dc voltages. The system consists of two front-to-front connected VSCs cou- pled through a transformer. The ac link is internal to the dc/ac/dc system and therefore the operating frequency can be selected freely and used to tradeoff the volume of the passive compo- nents against the power losses in the semiconductor devices.

This study considered modular multilevel converters of ei- ther the MMC or AAC format. When operated at 50 or 60 Hz, these converters require cell capacitors which represent approx- imately 50% of the cell volume. An increase in ac frequency to 350 Hz results in proportionately smaller peak intracycle energy deviations in the cell stacks of both the MMC and AAC. This reduces the minimum capacitance required in both converters and allows a significant reduction in the total system volume. The AAC was found to require a smaller minimum total capaci- tance than the MMC for all ac frequencies. The use of the AAC at either 50 or 350 Hz frequency would therefore minimize the system volume. The higher frequency also leads to a reduction in transformer volume at a rate a little less than proportional.

The MMC was found to have slightly lower power losses than the AAC at 50 Hz operation. This is due to larger con- duction losses in the AAC. At increased ac frequency, however, the switching losses in the MMC were found to increase more quickly than those in the AAC as its operation requires more switching events. The increase in operating frequency changed the balance of core and winding losses in the transformer but did not significantly increase the overall power loss of this component.

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