High-Frequency Operation of a DC/AC/DC System for HVDC Applications

Ms. Bharati Somayya Durgam[1] , Prof. Rashmi S. Singh[2]

[1]Students, Department of Electrical Engineering , Vidarbha Institute Of Technology , Uti, Umrer Road, Nagpur
[2]Project Guide, Department of Electrical Engineering , Vidarbha Institute Of Technology , Uti, Umrer Road, Nagpur

ABSTRACT

This paper presents a dc/ac/dc system using a transformer coupling two modular multilevel VSCs. The system consists of two front-to-front connected VSCs coupled 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 components against the power losses in the semiconductor devices. In such a system, the capacitors occupy a large fraction of the volume of the cells but a significant reduction in volume can be achieved by raising the ac frequency. Using high frequency can also bring benefits to other passive components such as the transformer but also results in higher switching losses due to the higher number of waveform steps per second. The outcome of the study shows that a frequency of 350 Hz provides a significant improvement in volume but also a penalty in losses compared to 50 Hz. This leads to a trade off between volume and losses which has been explored in this study and verified by MATLAB/Simulink results with a transistor level model.

Keywords: DC–DC Power Conversion, HVDC Converters, HVDC Transmission, Multilevel Converters.

1. Introduction

Over the last decade, VSCs and especially modular multilevel topologies have become the new standard in HVDC. The first topology of this last class of VSC is the Modular Multilevel Converter (MMC) and was the first to provide both low switching losses and low AC current distortion. These features contributed to the higher power efficiency and the significant reduction in the size of the AC filters. Recently, hybrid topologies have emerged, some of them exhibiting DC-side fault blocking capability. These topologies have also been used in DC/DC conversion applications and have been shown to have a better distribution of temperature between the IGBT modules. Reduced Dynamic Models have also been developed. However, all these converter topologies rely on charged capacitors inside the numerous cells constituting their stacks in order to generate the required converter voltage. Even when the conditions to keep the average voltage of these cell capacitors at their nominal value are met, the cell voltages will inherently fluctuate during the course of each fundamental cycle because of the current passing through them. As presented in the main solution to prevent these cell capacitors from either overcharging or undercharging consists in sizing them big enough in order to limit their voltage deviation during a fundamental cycle. This paper presents a method to calculate the minimal size which ensures that these cell capacitors have their voltage kept within pre-determined voltage boundaries under ideal steady state normal conditions.

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 generated power to far away load centers. 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. One of the most likely pathways for an HVDC grid to develop is from the interconnection of point-to-point schemes, at some point in the future.

This will require dc/dc voltage conversion technology for HVDC applications. This paper presents a possible dc/dc system for low to medium step-ratio applications. It consists of two ac/dc converters coupled through a transformer in what might be described as “front to front” connection. The transformer provides galvanic separation between the two dc connections as well as the voltage step. Such a system could be used to interconnect existing HVDC schemes in the process of building up a larger HVDC network. It may also be used to tap-into an existing HVDC link to connect an off-shore wind park for example. Furthermore, if interconnection between two HVDC networks is desired with separate grounding arrangements, then the galvanic separation provided by the transformer of this system may allow for this.

2. Problem Statement

Electric power transmission was originally developed with direct current. The availability of transformers and the development and improvement of induction motors at the beginning of the 20th century, led to the use of AC transmission.

DC Transmission now became practical when long distances were to be covered or where cables were required. Thyristors were applied to DC transmission and solid state valves became a reality.

With the fast development of converters (rectifiers and inverters) at higher voltages and larger currents, DC transmission has become a major factor in the planning of the power transmission. In the beginning all HVDC schemes used mercury arc valves, invariably single phase in construction, in contrast to the low voltage polyphase units used for industrial application. About 1960 control electrodes were added to silicon diodes, giving silicon-controlled-rectifiers (SCRs or Thyristors).

The interconnection of two power systems through ac ties requires the automatic generation controllers of both systems to be coordinated using tie line power and frequency signals. Even with coordinated control of interconnected systems, the operation of AC ties can be problematic due to:

1. The presence of large power oscillations which can lead to frequent tripping,
2. Increase in fault level, and
3. Transmission of disturbances from one system to the other.

The fast controllability of power flow in DC lines eliminates all of the above problems. Furthermore, the asynchronous interconnection of two power systems can only be achieved with the use of DC links.

Today, the highest functional DC voltage for DC transmission is +/- 600kV. D.C transmission is now an integral part of the delivery of electricity in many countries throughout the world.

3. Objective

- To perform the DC / AC / DC system to moniotr all paramters of power.
- To study the all concept related to conversion states of DC and AC system.
- To research and study on HVDC system.
- To interconnect HVDC system to perform all DC /AC /DC functions
- To tradeoff between volume and losses which has been explored and verified by simulation results with a transistor level model.
- To obatin design and simulation output for HVDC system.

4. Literature Review

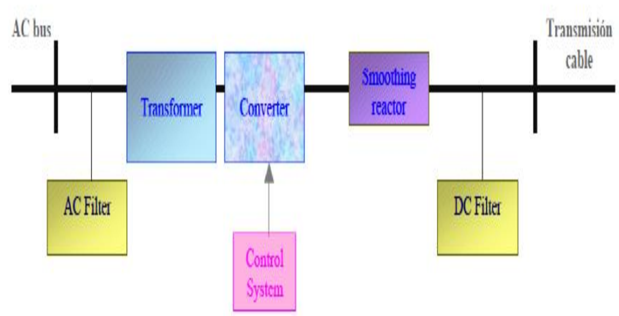
***M. DARSHINI1, T. SALEHA TABASSUM2 1PG Scholar, Dept of EEE (EPS), KSRMCE, Kadapa, AP, India*.**

In this paper, the capacitors occupy a large fraction of the volume of the cells but a significant reduction in volume can be achieved by raising the ac frequency. Using high frequency can also bring benefits to other passive components such as the transformer but also results in higher switching losses due to the higher number of waveform steps per second. The outcome of the study shows that a frequency of 350 Hz provides a significant improvement in volume but also a penalty in losses compared to 50 Hz. This leads to a tradeoff between volume and losses which has been explored in this study and verified by MATLAB/Simulink results with a transistor level model.

Thomas L¨uth, Student Member, IEEE, Micha¨el M. C. Merlin, Member, IEEE.

This paper presents a dc/ac/dc system using a transformer coupling two modular multilevel VSCs. In such a system, the capacitors occupy a large fraction of the volume of the cells but a significant reduction in volume can be achieved by raising the ac frequency. Using high frequency can also bring benefits to other passive components such as the transformer but also results in higher switching losses due to the higher number of waveform steps per second. This leads to a tradeoff between volume and losses which has been explored in this study and verified by simulation results with a transistor level model of 30-MW case study. The outcome of the study shows that a frequency of 350 Hz provides a significant improvement in volume but also a penalty in losses compared to 50 Hz.

5. HVDC Converter Station



The major components of a HVDC transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (Inverter station) are performed.

A point to point transmission requires two converter stations. The role of rectifier and inverter stations can be

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 09 | September - 2022 Impact Factor: 7.185 ISSN: 2582-3930

reversed (resulting in power reversals) by suitable converter control.

6. Formulation Of Work

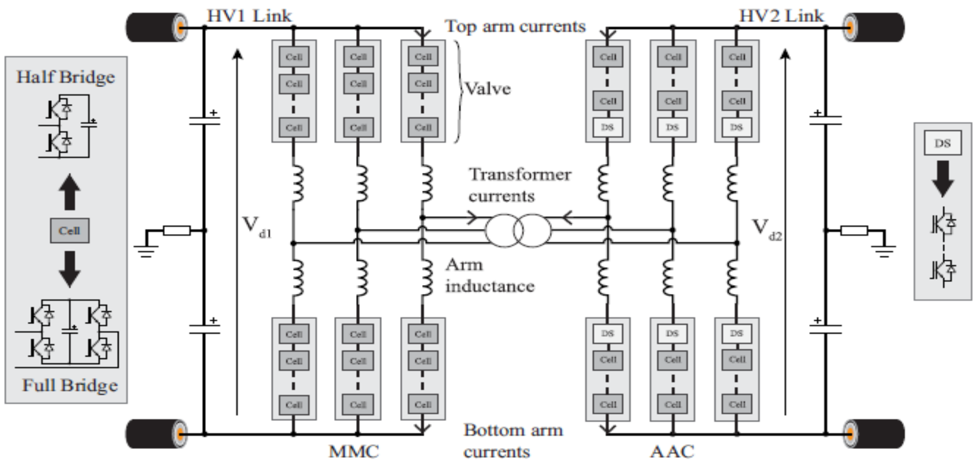


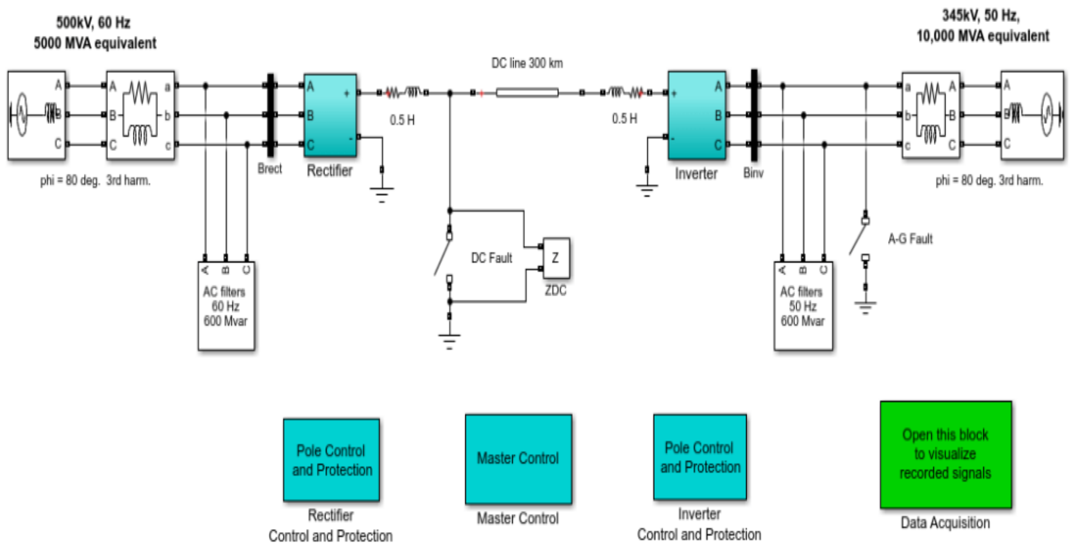
Fig.1. Circuit diagram of a VSC-based transformer coupled dc/ac/dc system. Both VSC topologies considered are shown in the figure: to the left the MMC and to the right the AAC. "DS" in the AAC valve refers to the director switch which replaces some of the cells.

- The suggested front-to-front arrangement of two ac/dc converters is shown in Fig. 1. For the sake of argument both converter types are shown in this diagram. The system topologies investigated use either two MMCs or AACs. Each is connected to one dc link, which are assumed to be of different dc voltages, and are connected together on their ac side through a coupling transformer.
- A three-phase arrangement as shown in Fig. 1 is analyzed in this paper but the number of phases ultimately is a design choice. The number of phases of such a system however remains a tradeoff between the volume required for additional phase legs and dc side filters and the losses incurred. In a three-phase arrangement, the ac currents generated by each phase, combine to form a dc side current with only a small sixth harmonic ripple.
- Fig. 1 depicts both VSCs considered in this project. The main difference in the circuit topology between the two is in the valves (where a valve refers to a combination of cells connected between an ac phase connection and a dc terminal).

- The MMC's valves consist entirely of cells. In the AAC some of the cells are replaced with Director Switches (DS). In both converters, the cells can be either of the full-bridge or half-bridge variety. In the MMC, the energy exchanged between a valve and the ac link is characterized by the ac voltage and current (ΦI is the angle of the ac current with respect to the ac voltage).

- 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.
- This generates several feasible designs and that with minimum power loss was chosen. The same procedure was used for 50 and 350 Hz designs. With the design parameters kept the same, the core volume was reduced by a factor of 7 for the higher frequency case.
- In the transformer model, cooling requirements have not been taken into consideration. These requirements will typically result in a worse than theoretically possible scaling of the volume of the transformer. Overall the transformer design has not been optimized for 350 Hz operation.

7. MATLAB Design



- A simulation model was developed in Simulink to verify the operability of the system. Although this converter topology is suitable for HVDC applications, typically rated for hundreds of kilovolts and hundreds of megawatts, the simulation model was scaled for significantly lower voltage and power levels.
- Indeed, the system has been modeled down to the transistor level and realistic voltage ratings would require a large number of switches to be modeled which would make the simulation too computationally complex to be practical.
- The system was modeled in such a detail to accurately estimate the losses using model specific post processing scripts and to verify the cell level operation. The arm inductance in the AAC is primarily required to control the overlap currents. Thus, scaling it down with frequency incurs very little extra switching losses and makes the ramping of the overlap-currents easier. Scaling down the arm inductance with ac frequency in the MMC in a similar fashion results in noticeably higher switching losses as the dc current flowing through the arms has to be controlled for the full duration of the cycle. The arm inductance values at 50 Hz were arbitrarily chosen to maintain current control in the converters without additional switching by the cells.
- The MMC's valves are continuously in conduction and can therefore be thought of as three series-connected pairs of voltage sources in parallel with a series-connected pair of voltage sources modeling the dc terminals. Small differences in voltage of each of the valve's voltages sources can lead to large dc currents flowing between them.

8. Simulation Output

- The arm inductances serve to counteract this and limit the rate of change of the arm currents. Due to the discontinues, conduction in the arms smaller arm inductances can be used in the AAC as both valves in the same phase are only in conduction simultaneously for a short overlap period during each cycle.
- The system's steady-state operation is demonstrated in Figs. 2 and 3. Fig. 2 depicts a selection of system voltages and currents for the system topology utilizing MMCs operated at 350 Hz.
- Fig. 3 demonstrates the same voltages and currents for a system using AACs at 350. Hz also. Both systems run a 30 MW power flow from the HV1 side to the HV2 side. The cell stacks in the AAC can be seen to generate a much lower peak voltage than those in the MMC as they do not have to support the ac voltage waveform for a full cycle.

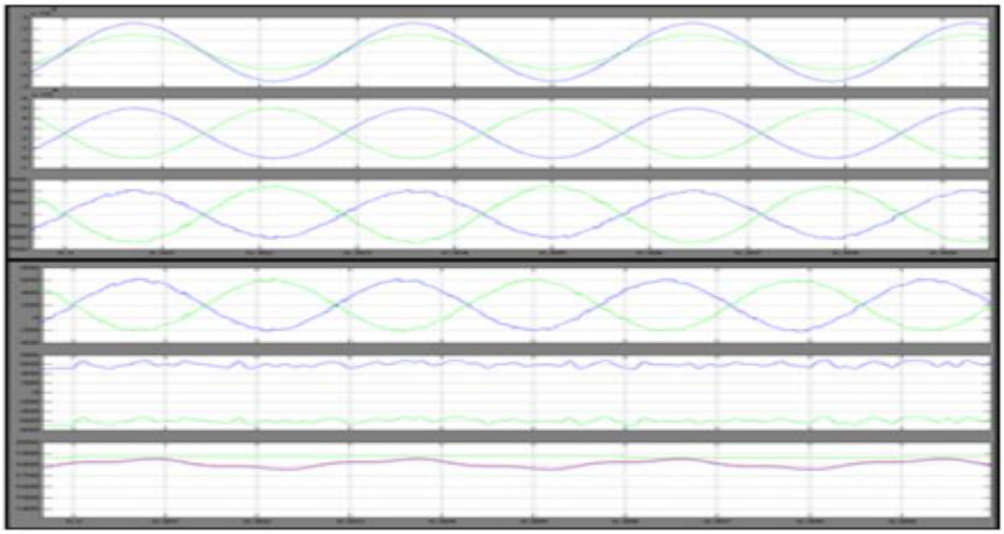


Fig.2. MMC front-to-front system topology voltages and currents for case study system and 350-Hz ac link. Valve voltages and arm currents are shown for a single phase leg of the HV1 MMC. The cell voltages are shown for the top valve in same phase of the HV1 MMC**.**

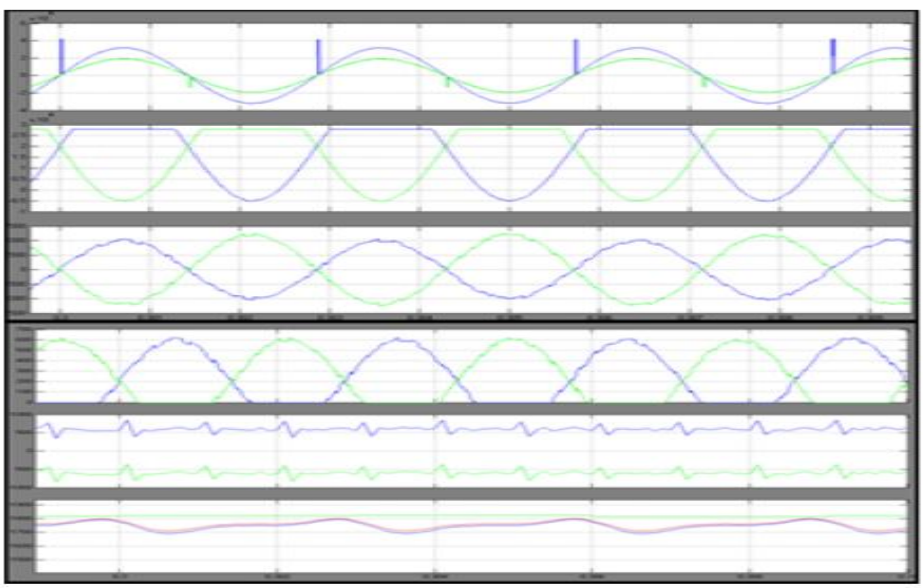


Fig.3. AAC front-to-front system topology voltages and currents for case study system and 350-Hz ac link. Valve voltages and arm currents are shown for a single phase leg of the HV1 AAC. The cell voltages are shown for the top valve in same phase of the HV1 AAC.

- Simulations of a small-scale model show that this converter is able to deliver performance under normal conditions, in terms of efficiency and current waveform quality, and provide rapid responses in the case of ac- or dc- side faults. Its ability to keep control of the current even during dc faults is a significant advantage, especially in multi terminal HVDC applications.
- The main difference in the circuit topology between the two is in the valves (where a valve refers to a combination of cells connected between an ac phase connection and a dc terminal).

- The MMC's valves consist entirely of cells. In the AAC some of the cells are replaced with Director Switches (DS). In both converters, the cells can be either of the full-bridge or half-bridge variety. The fig 4 & 5 shows the waveforms of the MMC and AAC front to front topology system voltages and currents.
- The AAC differs in its operation compared to the MMC by conducting the full ac current through the top or bottom arms alternatively 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.

9. Conclusion

This paper introduces an HV dc/ac/dc system suitable for interconnecting HVdc networks operated at different dc voltages. The system consists of two front-to-front connected VSCs coupled through a transformer. When operated at 50 or 60 Hz, these converters require cell capacitors which represent approximately 50% of the cell volume. An increase in ac frequency to 350 Hz results in proportionately smaller peak intra cycle 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 capacitance 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 conduction 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.

References

[1] T. L¨uth, M. M. C. Merlin, T. C. Green, C. D. Barker, F. Hassan, R. W. Critchley, R. W. Crookes, D. Trainer, and K. Dyke, "Choice of AC operating voltage in HV DC/AC/DC system," presented at IEEE Power and Energy Society General Meeting 2013, Vancouver, Canada, Jul. 21– 25, 2013.

[2] J. A. Ferreira, "The Multilevel Modular DC Converter," IEEE Trans. Power Electron., vol. 28, no. 10, pp. 4460–4465, Oct. 2013.

[3] J. Dorn, H. Gambach, and D. Retzmann, "HVDC transmission technology for sustainable power supply," in Proc. 9th Int. Multi-Conf. Syst., Signals Devices, Mar. 20–23, 2012, pp. 1–6.

[4] C. D. Barker, C. C. Davidosn, D. R. Trainer, and R. S. Whitehouse, "Requirements of DC–DC converters to facilitate large DC grids," Cigre, SC B4 HVDC and Power Electronics, 2012.

[5] G. T. Son, H.-J. Lee, T. S. Nam, Y.-H. Chung, U.-H. Lee, S.-T. Baek, K. Hur, and J.-W. Park, "Design and control of a modular multilevel HVDC converter with redundant power modules for noninterruptible energy transfer," IEEE Trans. Power Delivery, vol. 27, no. 3, pp. 1611–1619, Jul. 2012.

[6] S. Rohner, S. Bernet, M. Hiller, and R. Sommer, "Modulation, losses, and semiconductor requirements of modular multilevel converters," IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2633–2642, Aug. 2010.

[7] S. Allebrod, R. Hamerski, and R. Marquadt, "New transformerless, scalable modular multilevel converters forHVDCtransmisson," in *Proc. IEEE Power Electron. Special. Conf.*, Rhodes, Greece, Jun. 2008, pp. 174–179.

[8] G. P. Adam, T. C. Lim, S. J. Finney, and B. W.Williams, "Voltage source converter in high voltage applications: Multilevel versus two-level converters," in *Proc. 9th IET Int. Conf. AC DC Power Transmiss.*, 2010, pp. 1–5.

[9] G. T. Son, H.-J. Lee, T. S. Nam, Y.-H. Chung, U.-H. Lee, S.-T. Baek, K. Hur, and J.-W. Park, "Design and control of a modular multilevel HVDC converter with redundant power modules for noninterruptible energy transfer," *IEEE Trans. Power Delivery*, vol. 27, no. 3, pp. 1611–1619, Jul. 2012.

[10] J. A. Ferreira, "The Multilevel Modular DC Converter," *IEEE Trans. Power Electron.*, vol. 28, no. 10, pp. 4460–4465, Oct. 2013.