A NOVEL NINE LEVEL MODULAR MULTILEVEL VOLTAGE SOURCE INVERTER

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Abstract— This paper presents a new family of converters for high power interconnection of dc buses with different voltage levels. Proposed converters achieve high voltage dc-dc conversion without an intermediate ac conversion stage. This function is implemented without series connection of active switches, or the use of isolation transformers. The salient features of proposed converters are (i) design and construction simplicity, (ii) low switching losses through soft turn-on and soft turn-off, (iii) single stage dc-dc conversion without high-current chopping, (iv) modular structure, (v) equal voltage sharing among the converter modules.

Three converter circuits are investigated. The first performs unidirectional power transfer from a dc bus with higher voltage to a dc bus with lower voltage. The second performs unidirectional power transfer from a dc bus with lower voltage to a dc bus with higher voltage. Both converters are suitable for interconnecting single pole dc buses with same polarity, or double pole dc buses. A third converter is also presented which performs the function of either the first or the second converter with polarity reversal. The third converter is suitable for interconnecting single pole dc buses with different polarities, or double pole dc buses. By hybrid integration of the proposed three converters, the thesis also investigates other topologies for bidirectional power transfer between two dc buses

Keywords—Low frequency modulation, multi-level inverter, multi-level inverter comparison factor, sinusoidal pulse-width modulation(SPWM),symmetricalDCpowersources,three-phase

I. INTRODUCTION

While high power High Voltage Direct Current (HVDC) transmission is now considered a well-established technology, its application is still dependent on utilizing either Line Commutated Converters (LCC) or Voltage Sourced Converters (VSC). These converters connect dc buses with ac buses and handle power of hundreds of megawatts at voltages of hundreds of kilovolts.

Recently, the subject of dc bus interconnections has started to gain increased interest. This interest is driven by the desire to (i) interface power sources that generate dc on a megawatt power range [1], [2], (ii) integrate windfarms through offshore dc networks [3], (iii) build dc distribution networks and dc microgrids [4]-[6], (iv) build dc back-up energy systems [7], (v) build medium-voltage industrial drives, high-speed train power systems and undersea observatories [8],[9] and (vi) provide additional access points to the existing HVDC lines [10]. Two possible alternatives enable the interconnection of dc buses and are shown in Fig.1-1. The first is by using VSC or LCC systems while the second by direct dc-dc conversion. In contrast to VSC and LCC systems, the use of dc-dc converters will directly interconnects dc buses of different voltage levels without use of intermediate ac conversion stage.

Low-voltage and low-power dc-dc converters have long been studied and implemented. High voltage low-power dc-dc converters are less popular but are used in some applications, such as medical X-ray imaging, radio frequency generation, travelling-wave tubes, lasers and high intensity discharge lamps [11], [12]. High-voltage and high-power dc-dc converters are not available as market products yet, but are subject to research efforts [10],[13]-[15],[37].

Classical dc-dc converter topologies have limitations preventing their use for high-power and high-voltage applications. Since power semiconductors have limited voltage ratings, the high-voltage realization of classical topologies would require series connection of active switches (IGBTs in this case). This requires active gate control to ensure equal voltage sharing between all devices at switching instances [16],[17]. Implementing active gate control techniques results in significant increase in switching losses (up to 36% as in [18]).

Additionally, classical PWM circuits (e.g. buck and boost topologies) require extreme duty cycles at higher conversion ratios. An extreme duty cycle impairs efficiency and may cause malfunctions due to the very short conduction time of power semiconductor devices [19]. Other classical topologies use intermediate isolation transformers, such as the fly-back converter. If the application does not require isolation, the use of a transformer would only increase the cost, the volume, and the losses especially for high power applications, as detailed in [19]-[21]. Specifically, the large number of turns ratio with the need for high voltage isolation increases the leakage inductance and parasitic capacitance of the windings. This causes undesirable voltage and current spikes to switches leading to increased losses and reduced reliability [11]. Proposed transformerless soft-switched topologies for high voltage and high power applications in [10], [13]-[15] have several limitations of unequal voltage stresses on semiconductors as in [13], or restrictions to bipolar dc network interconnections as in [10], [14], [15] with potential shoot-through problems during fault conditions. Moreover, these topologies require the use of high voltage resonant capacitor banks, and long series strings of high voltage active switches.

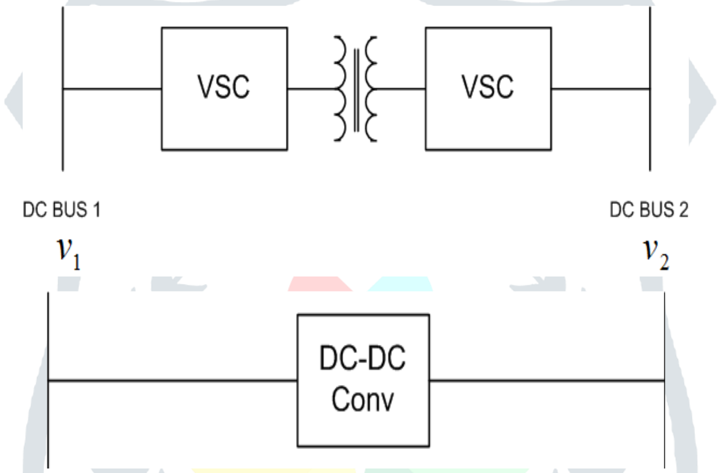


Figure 1 Alternatives for the connection of two dc buses with different voltage levels

II. Modular Multilevel Converters Modeling

The modeling approach for illustrating the operation principles of Modular Multilevel Converters (MMC) including the MMC with half-bridge power cells and the Alternate-Arm Converter (AAC). Modular multilevel converters have emerged as new multilevel converters that can be used especially in High Voltage Direct Current (HVDC) and Medium Voltage Direct Current (MVDC) applications. Generally, the main advantages of the MMC with as compared to other types of multilevel converters are their high modularity and cabability for high voltage scalability, which means that they can be connected directly to the grid without using any transformer . The modular multilevel converter structure is shown in Figure 1. The MMC generally consists of upper and lower arm power cells, which can be half-bridge or full-bridge. The first model of the MMC was generated by replacing the single switches in a two-level converter with a series of power modules. As mentioned, these power modules can be half-bridge or full-bridge; however, due to the higher number of switches and switching power losses, MMC with half-bridge is more oftren developed. In order to eliminate inrush current during switching between modules, additional inductors should be added in series with the power modules in each arm .To have sinusoidal output voltage, the upper arm and lower modules' references should be justified with respect to the DC voltage in order to generate a proper wave-shaping circuit. In the MMC with the half-bridge, the maximum voltage over each module is the DC-link voltage divided by the number of arm modules; however, the MMC with the full-bridge module can work in over-modulation since each module can generate negative voltage as well .

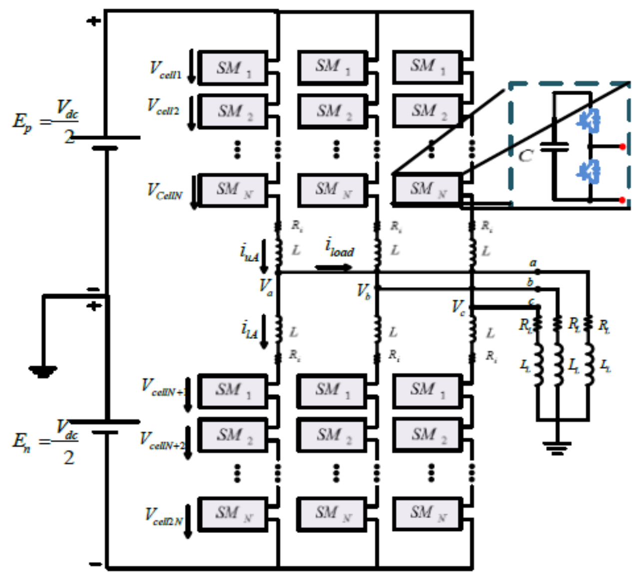


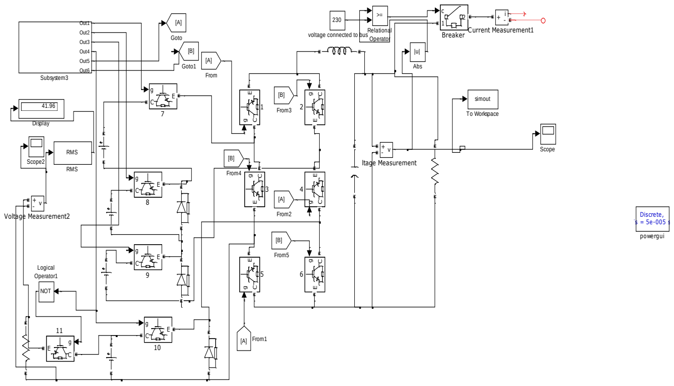
Figure 1: Modular Multilevel Converter topology with each sub-module structure.

One of the disadvantages of the MMC is the existence of relatively high circulating current due to the difference in voltage of the arm inductors. To limit the circulating current, the arm inductor size should be selected to be quite high or the circulating current suppressing controller should be employed. Another issue regarding this topology is the number of capacitor banks required for each module in the MMC, which can lead to a huge space occupied by capacitors and cause reliability issues

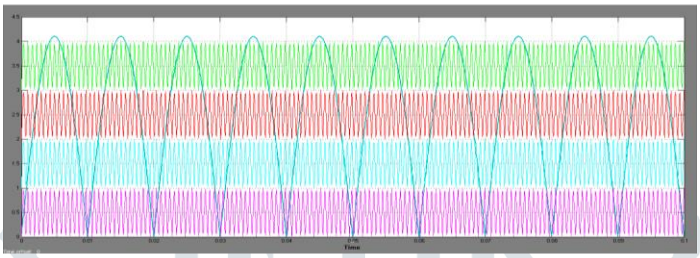
Moreover, having a high number of modules makes the control system more complex. Significant efforts have been dedicated to the modeling of the MMC and to a circuit behavior analysis of the converter. Different modeling approaches for the Modular Multilevel Converter (MMC) have been carried out in the literature. In the state-space switching model of the MMC is developed and the complete derivation procedure of that is given. In reference, a continuous model of a three phase MMC, which is derived from ordinary differential equations, is developed and described. All the other existent models deal with the three-phase average model of the MMC, and the equations are extracted based on the average model.

In this chapter, a new modeling approach based on D-Q frame modeling is proposed for use as a model-based converter of the inner and outer loop control design. DQ modeling of the MMC can provide the relations of the duty cycles and arm quantities as well as the output voltage and current of the converter. Also, the proposed DQ model of the MMC is of great value in developing new control methods for the MMC. To obtain the DQ model, the following procedure should be taken. First of all, a three-phase average model of the converter should be derived from the switching model. Then by applying the Park transformation, the DQ model can be achieved. The second order harmonic circulating current is considered as the dominant component of the circulating current and higher order harmonics are considered to be negligible. Therefore, the MMC system can be divided into three-frames of operation: DC, fundamental frequency, and twice the fundamental frequency frame. By assuming the superposition, each of the parameters can be modeled in these three-frames and finally the results can be added together. Indeed, using this model, DC current and circulating current equations can be
decoupled from the load current. By changing the modeling of MMC into three separate models, one will be able to derive the DQ model in each case.

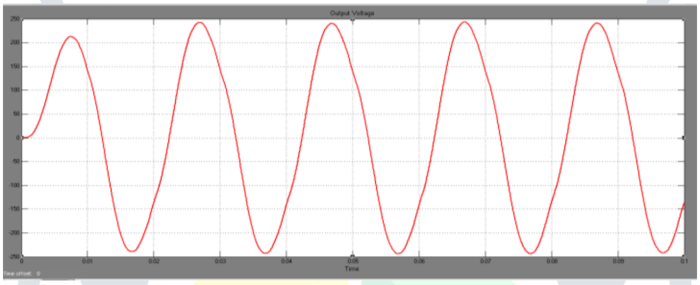
III. Results and Discussions



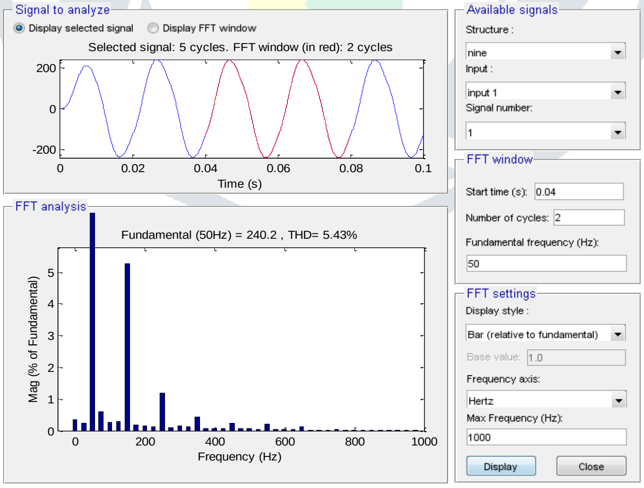
Simulation Circuit of Nine Level MMC



Level Shifted PWM Technique with Full wave converter



Output voltage of MMC



THD Analysis of output Voltage

IV. CONCLUSION

A new transformerless four-leg topology is suggested for shunt compensation, the modular multilevel converters (MMC) based on the half-bridge converters, to achieve higher performance a STATCOM in a distorted and unbalanced medium voltage large-current (MV-LC) system. Both proposals can be controlled

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for various purposes such as reactive power and unbalance compensation, voltage regulation, and harmonic cancellation. Moreover, related control strategies are also suggested for both the MMC and the EMMC to ensure that the source-end three-phase currents are sinusoidal and balanced. Also, the dc-link capacitors of the half-bridge converters are regulated. One interesting application for the EMMC-based STATCOM could be the improvement in power quality and performance of the electrified railway traction power supply system

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