Analysis and Design of Modular Multilevel Converter (MMC) Based on Full Bridge Switching Modules (FBSM) for Harmonic Elimination using POD PWM Control Method

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Abstract. Modular Multilevel Converter (MMC) in HVDC for transmitting the power in longer distance because of high in transmission efficiency rate and cost-effective compared to AC system in many industries. The control of voltage and power is earlier and superior method is modular multilevel converter for HVDC transmission. The use of MMC has reduced the filter size and low frequency. Staircase, carrier-based PWM, space vector and selective harmonic elimination are the method using in MMC system control. Unbalanced networks are studied, and strategies are introduced such that in these circumstances MMC contributes to improving the grid efficiency. It involves the key applications in the transmission of high voltage direct current (HVDC) along with other applications of Medium Voltage (MV) and Low Voltage (LV). The MMC with POD-PWM is built using the MATLAB / Simulink method and concludes the advantages and improvements of converter modulation to reduce the voltage ripple and increase the voltage levels.

Keywords: Harmonics, HVDC, MMC, POD-PWM, Unbalanced Load.

1. Introduction
Due to the long distance bulk transmission system, safe link, short circuit level and underground cable system, current (HVDC) transmission system is advanced to AC network. From the high voltage the converters are used to adjust the voltage and transfer the voltage at the receiving end to the long distance and back to ac. Usage of converters have MMC converters to increase harmonics, regulate direct current voltage and rising flowing current. The MMC has the source [3-4] in modular multilevel, close to the cascaded H bridge converter. The multi-terminal DC provides the possibility of interconnecting lattices between regional power systems and generating renewable energies. Reliability in both AC and DC systems, as well as improving stability, energy transmission and efficient use of cables and converters in HVDC systems.

Reduced harmonics and circulation of current are used by multi modular converter. A MMC step leg consists of two upper arm and lower arm muscles. Growing arm has N identical series connected to a cascaded structure with an arm inductor, arm L and arm resistor, arm R. In converter the fault currents are removing by using the Arm inductor. Because of power losses to the converter the arm resistor should be selected as low as possible. Different circuit structures are consisted by MMC of the each. The
structure is created a capacitor and two IGBTs with opposing similar diodes based on sub element considering half bridge.

However, full-bridge based sub module structure is consisted of a capacitor and four IGBTs with anti-parallel diodes. Unidirectional cell circuit structure is the other one which is formed a capacitor and one IGBT with anti-parallel diode for the upper side otherwise only one diode without IGBT for the lower side [9]. Sub modules are inserted or bypassed depending on the switching positions in each half-bridge circuit. Two switches work in complementary way otherwise lead to short circuit condition. When the upper switch is ON and the lower switch is OFF, sub module is inserted in the arm. Thus; the terminal voltage of the sub module is equal to the capacitor voltage [10-11]. If the arm current direction is positive, sub module capacitors are charged otherwise capacitor voltages are discharged.

The modern inverters are intended for high-power applications with series connected switching units. Such series switching system connections have a problem with high switching stress on each unit [12, 15]. Using more switching devices, higher voltage rates are found. When the number of switching devices goes up, it would be difficult to produce gate signals for the switching devices. So the MMC is a good topology for converters in the near future. [13-14] Analysis and design of Modular Multilevel Converter (MMC) based on Full Bridge Switching Modules (FBSM) using POD-pulse width modulation (POD-PWM) control technique for reduction of total harmonic diction that occurs in the HVDC line with help of MATLAB/Simulink is proposed in this paper.

2. Proposed system

Figure 1. shows the schematics diagram of MMC in HVDC system. The MMC has several inductor-connected modules. The switching modules (SM) are attached to an arm forming an inductor. The two arms are connected and it is known as one phase inverter. The SM has different forms, for example half bridge and full bridge circuit. The MMC is commonly used in transmission system HVDC, Data, and motor drives with high power. The MMC’s advantages are the balance of capacitor voltage, the circulating current power. The capacitor charged when other discharge of the capacitor voltage, the circulating current is positive.

![Figure 1. Basic circuit of switching module of MMC](image-url)

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3. Modelling

3.1 Full Bridge Switching Modules of MMC

The voltage levels are based on the number of switching modules used in each phase of the inverter. Figure 2 displays the complete Multilevel Converter Modular Bridge. Four switches and switching losses are decreased in the full bridge converter compared to twice the half bridge switching modules which fix the dc fault. Voltage of the switching modules depends on the quality of the bipolar transistor isolated gate. The current flows through the SM capacitor in the arm. The control devices switching frequency is less for decreasing the transfer number. MMC's mathematical modeling is voltage and current in the phase converter's upper and lower arm. In equation (1) and (2), the output voltage of phase an upper and lower arm is given.

\[
V_{\text{upper}} = \frac{V_{dc}}{2} - \left( V_{upp} + L \frac{di_{upp}}{dt} \right) 
\]

(1)

\[
V_{\text{lower}} = -\frac{V_{dc}}{2} + \left( V_{\text{low}} + L \frac{di_{\text{low}}}{dt} \right) 
\]

(2)

The dc connection current is divided in a steady state equally into three phase inverter legs. Under the current law of Kirchhoff the current and circulating phase current is defined in equation 3 and 4.

\[
i_{\text{phase}} = i_{\text{upp}} - i_{\text{low}} 
\]

(3)

\[
i_{\text{circuit}} = \frac{i_{\text{upp}} + i_{\text{low}}}{2} = \frac{i_{dc}}{3} 
\]

(4)

Figure 2 Generalized circuit diagram of FB-MMC

4. Control techniques

The control methods of the modular multilevel converter are carrier based pulse width modulation, space vector and selective harmonic elimination. The multi carrier modulation has been commonly used in MMC and is divided into two forms, such as PWM shifted in phase and stage. In level shifted further classified into Phase Disposition (PD), Alternate Phase Opposition Disposition (APOD), and Phase Opposition Disposition (POD). The modular multilevel converter has dq synchronous reference frame for active and reactive power management. The inverter's active and reactive power is given in equations 5 and 6. The block diagram of active and reactive power control method is shown in figure 3.
The value of direct and quadrature current is represented in Eq. 7 and 8.

\[
P_d = \frac{3}{2} (V_{q} i_{q} + V_{d} i_{d})
\]

\[
Q_d = \frac{3}{2} (V_{q} i_{d} - V_{d} i_{q})
\]

The value of direct and quadrature current is represented in Eq. 7 and 8.

\[
i_d^* = \frac{2}{3V_d} P
\]

\[
i_q^* = -\frac{2}{3V_d} Q
\]

The modulation of the pulse width of the carrier disposition has \( n \) equivalent triangular and is symmetrical to zero. Comparing phase carrier voltage with reference, and generating the pulse and feeding into the MMC. The POD-PWM (Phase Opposition Disposition Pulse Width Modulation Technique) is used to reduce the system's THD stage, and is represented in the figure.4. The active power filter based MMC uses the APOD-PWM to reduce the harmonics. The second and other even-order harmonics in the circulating currents are mainly due to the variations in the MMC Sub-Modules (SMs) capacitor voltages.

5. **Simulink results**

The MMC converter has designed and configured to implement the complete POD-PWM control topology configuration of the bridge switching modules. Table 1 reflects the features of a multilevel modular converter based on complete bridge switching modules in the HVDC transmission network. The overall Simulink diagram of the proposed device as well as the active, reactive power with POD-PWM technique are shown in figure.5 and figure. 6.
**Figure 5.** Overall simulink diagram of the proposed DC source fed MMC converter

**Figure 6.** Full bridge switching module with POD-PWM technique

Figure 7 shows the DC link voltage of the proposed system and its value is 500V and settling time of this DC source boost converter is 0.1s.

**Figure 7.** DC link voltage
The generated high DC voltage is fed to the MMC and it produces the 7-level output voltage is shown in figure 8. and its value 350V which is send to the RL load for high power application. Figure 9. shows the %THD of POD-PWM using MMC is 3.98%.

![Figure 8. Multi-level’s of output voltage and current]

![Figure 9. %THD of MMC]

| S.No | SM Circuit       | Voltage levels | Fault handling | Losses |
|------|-----------------|----------------|----------------|--------|
| 1    | Full bridge     | 0, Vc          | Yes            | Low    |

6. Conclusion
The On MMC the concept of modularity was introduced from the switching modules to the system level. For high-power applications for each modular converter type, the modularity principle, complete bridge switching module topologies with POD-PWM control method have been analysed. The MMCs operate
in VSM, and operate in CSM for two series of connected MMCs. The system's output voltage is 5-level and its THD value is 3.98%. This overall system performance has been analyzed by using MATLAB/Simulink.

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