MODULAR MULTILEVEL CONVERTER WITH PS-PWM TECHNIQUE AND SHORTING ALGORITHM FOR BATTERY MANAGEMENT OF AN ELECTRIC VEHICLE

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Abstract: Modular multilevel converter (MMC) has become a promising technology Handling of Electric vehicles (EV) power source by using different techniques and algorithm. Where the battery cells are series connected to enhance the output voltage. In this topology, individual batteries are connected together and become a dc link of the converter subsystem, to allowing the highest flexibility for the discharge and recharge by estimating the State of charge. The battery power has kept in balance by sorting algorithm and the controlling the submodules by PS – PWM techniques. Interactive power management at EVs will make effective utilization of battery power and switching of semiconductor can operate motor into regenerative mode. Simulation study has been done in MATLAB/SIMULINK platform and it is observed the output voltage, THD % values and State -of- Charge (SOC) of batteries are well maintained.

Keywords: Electric Vehicle, Modular Multilevel Converter, Battery Management System, State of-Charge, Total Harmonic Distortion, Phase-Shifted Pulse-width modulation, Half-Bridge Submodules

I. INTRODUCTION

Multilevel Converter have been used extensively in the last few decades starting from high-voltage direct current transmission to injection of renewable energy into the grid. In electric vehicle, higher voltage may be required which cannot be supplied by a single battery. Mostly PD-PWM, POD-PWM, APOD-PWM & PS PWM are implemented to control and balance the dc link voltages of submodules. The voltage balancing is addressed based on the high-frequency component in arm current. An improved PS-PWM method is implemented in for balancing the submodule voltages by alternatively distributing the gating pulses among the submodules within several carrier periods. This effectively increases the time for balancing the DC voltages. The topology actively equalizes the cells therefore improving the battery life. Arm and cell balancing controllers have been implemented for regulating the dc link voltages of the submodules.
A reduced switching-frequency voltage balancing algorithm is introduced to balance the dc link voltages. Control of medium-voltage AC motor drive using MMC is presented for wide speed range region of operation. State-of-Health balancing control mechanism is reported for the battery energy storage system connected with MMC. One of the main drawbacks of MMCs for low-voltage applications is the increased conduction losses, if compared with traditional inverters due to the high number of devices conducting in series. In a battery-powered electric vehicle, regenerative braking is the conversion of the vehicle's kinetic energy into chemical/ electrostatic energy stored in the battery, where it can be used later to drive the vehicle. It is braking because it also serves to slow the vehicle. It is regenerative because the energy is recaptured in the battery where it can be used again. The kinetic energy stored in a moving vehicle is related to the mass and speed of the vehicle by the equation $E = \frac{1}{2}mv^2$. All else being equal, if your car is twice as heavy it has twice the kinetic energy and if it is moving twice as fast it has four times the kinetic energy. Any time your car slows down the kinetic energy stored in the vehicle has to go somewhere. Let's take a look at where this energy goes. There is always some kinetic energy consumed by the rolling resistance, mechanical friction, and aerodynamics of your car. These bits of energy go into heating the road, the surrounding air, and various spinning parts in your car. But the vast majority of the kinetic energy is converted into heat by your brake pads when you stomp on the brakes. Regenerative braking recovers some energy that would otherwise have been wasted in the brakes.

II. LITERATURE SURVEY

Applications of power electronics in power systems are gaining in popularity due to numerous exciting features that have paved the way for this revolution. Power electronics have been used extensively in the last few decades starting from high-voltage direct current (HVDC) transmission to injection of renewable energy into the grid. New areas of a power system have been explored efficiently with the help of power electronics. With the implementation of large scale converters becoming very convenient, traditional pieces of equipment have been replaced with power electronics-based solutions. Mobile power substations (MPS) are traditionally used all over the world exclusively in emergency services, new services, and temporary services. Most of the MPSs are based on 50/60 Hz systems. Major drawbacks of these MPSs are their sizes and weights. Based on their power and voltage rating their sizes and weights can vary significantly. During an emergency condition these MPSs are needed to be transported by road.

In recent times, electric vehicles (EV), with enough penetration in the transportation sector, are expected to reduce that figure, but this is not the only reason bringing this century old and once dead concept back to life, this time as a commercially viable and available product. The next generation power grid, called 'smart grid' is also being developed. EVs are being considered a major contributor to this new power system comprised of renewable generating facilities and advanced grid systems. To achieve high-voltage and high-power conversion, conventional VSC HVDC systems were usually based on two-level or three-level converters with series-connected Insulated Gate Bipolar Transistors, which suffer from high voltage sharing across each power semiconductor device and, in general, poor power quality. As number of level and, consequently, the number of power devices to control grow, the complexity of the modulation algorithm increases. SVM computes the switching times based on the three-phase space vector representation of the reference voltage and the inverter switching states. The reference voltage is generated as a linear combination of the switching state vectors obtaining an averaged output voltage equal to the reference over one switching period. SVM have attracted much attention because it provides significant flexibility to optimize switching waveforms with the objective of improving DC-bus voltage utilization or reducing the common-mode voltage and it is suitable for being implemented in digital signal processors Several authors have work in the development of SVM techniques for multilevel converters. NLM is based on selecting the nearest voltage level that can be generated by the converter to the desired output voltage reference. The article seeks to provide a set of practical criteria for the choice of a modulation method for MMCs. Despite the fact that the three mentioned modulation strategies have been studied in the scientific literature, the authors have not found an article in which the three methods are compared and, in general, there is a gap about their digital implementation for MMCs. The Multilevel Converter topologies named as Diode Clamped Multilevel Converter, Flying Capacitor and Cascaded H-Bridge. Nevertheless, for more than 5 level MMC applications, difficulties related to modularity limits, scalability and stability were encountered. Thus, Modular Multilevel Converter topology was suggested in 2003. This paper is also emphasized different aspects of the MMC than other multilevel converter topologies and that of different circuitry structures of the submodules. High voltage direct current (HVDC) transmission was historically performed using the thyristor-controlled Line Commutated Converter (LCC) [1]. However, it has several limitations. When the two level VSC topologies are used, it presents several problems. To improve these aspects, multi-level VSC has been used.

III. PROPOSED SYSTEM

In this paper, we have proposed a new approach of Modular Multilevel Converters MMC with 6 Sub modules are implemented in which balance the dc link voltages of submodules with easily control technique, low cost for redundancy and fault tolerant operation, low THD voltage balancing is addressed based on the high-frequency component in arm current.
To improve PS-PWM method is implemented in for balancing the submodule voltages by alternatively distributing the gating pulses among the submodules within several carrier periods. This effectively increases the time for balancing the dc voltages.

**MMC System Design:** The topology makes use of energy storage like batteries to exchange power. Depending on the requirement, the batteries can be made to charge or discharge. When the converter is supposed to feed power to the motor (assumed to be connected at the load end of converter), then the batteries operate in discharging mode. When the motor load connected at the output of the converter runs into regenerative mode, then batteries absorb the power and get charged. Furthermore, the converter is assumed to have MOSFETs as the switching devices, as they have very low on-resistance (Rd(on)) at lower voltage levels. Also, as PWM is implemented, this results in MOSFETs to be the best fit for the application. Using MOSFETs may result in optimized losses. The MMC consist of several submodules (SM), which are the building blocks. There are three topologies that have been proposed so far, the half-bridge submodules (HBSM). One of the motivating factors of this research was to design a system with minimal weight. Therefore, the HBSM structure considered here has a lower component count and higher efficiency. However, the HBSM structure is unable to block dc side faults without the help of a breaker. A basic structure of a three-phase MMC terminal is presented in Fig. 1. Each phase of the MMC is termed a “leg” and each leg has one “upper arm” and one “lower arm”. Each arm consists of N SMs; thus, charges the SM whereas negative current discharges the SM. The inductors La are required to minimize the circulating currents. a total number of 6 No’s SMs are required to form a three-phase MMC terminal. Positive current.

**OPERATION MODES**

**Mode-1:** In this mode of operation, the load on the output side receives power from the batteries. As a result, batteries experience a discharging operation. Fig. 2 shows the topological configuration for this mode of operation.

**Mode-2:** In this mode, load on the output side of the converter feeds power to the batteries. As a result, batteries get charged. For this mode to happen, the motor connected on the load side of the converter has to be operated in regenerative mode so that power will be fed back to batteries. The topological configuration for this mode is depicted in Fig. 3.

![Fig. 1. MMC System Architecture](image-url)
OPERATION OF SUB MODULES

The first topology of a switching Sub-module (SM) presented for MMC Half-bridge (HB) topology, which has been the most used. It consists of two MOSFETs, two diodes, and one dc source/battery. The SM is ON when T1 is ON and T2 is OFF (Table 1), while SM is OFF when T1 is OFF and T2 is ON. When the SM is ON, the SM voltage is the same as the SM dc source/battery voltage, while when it is OFF the voltage is zero. According to the SM state (Table 2) explains the operation modes and show the direction of the SM current whether, the current circulates through the capacitor producing its charge/discharge, or it does not circulate through the dc source/battery.

| SM State | T1 State | T2 State | $i_{SM}$ | $\Delta v_c$ | $i_{SM}$ Flow Through | $v_{SM}$ |
|----------|----------|----------|----------|-------------|---------------------|---------|
| ON       | ON       | OFF      | $>0$     | +           | $D_1$               | $U_c$   |
| ON       | ON       | OFF      | $<0$     | -           | $T_1$               | $U_c$   |
| OFF      | OFF      | ON       | $>0$     | 0           | $T_2$               | 0       |
| OFF      | OFF      | ON       | $<0$     | 0           | $D_2$               | 0       |

Table 2 Modes of Operation

| Mode | $S_1$ | $S_2$ | $i_{lm}$ | $u_{lm}$ | State     |
|------|-------|-------|----------|----------|-----------|
| 1    | 1     | 0     | $>0$     | $U_c$    | Charging  |
| 2    | 1     | 0     | $<0$     | $U_c$    | Discharging |
| 3    | 0     | 1     | $>0$     | 0        | Bypass    |
| 4    | 0     | 1     | $<0$     | 0        | Bypass    |

SORTING ALGORITHM

If the arm current through the upper arm is less than zero, then “m” number of submodules (whose voltages are more than n desired) from the sorted list are inserted. Accordingly, N-m number of submodules from lower arm need to be inserted depending on the current direction in the lower arm. Based on the insertion or deletion of submodules, gating signals are generated for the switches. In this way, the dc bus voltages of submodules are controlled and maintained at their desired voltage values. Parameters used for simulation are PWM Pulse generator unit - 1 per arm/phase; Carrier frequency of Half-bridge - 5kHz; Reference frequency - 50Hz; Number of SM in each arm /Phase - 3 (6 MOSFET); Rated voltage of battery pack - 150V (25 V x 6 No’s); Charging cutoff voltage of the pack - 163V; Rated capacity of battery pack - 6.6 Ah; Half-bridge dc voltage Udc - 140 V; Buffer inductance - 5mH; Output filter inductance Lout - 5mH.
Fig. 4. Sorting algorithm flow chart
IV. RESULTS AND DISCUSSION

As shown in THD graphs in Fig. 7-11 of 7 level half H-bridge cascaded MMC inverter with proposed PWM techniques provide the different THD. The THD % with PD-PWM, POD-PWM, APOD-PWM and PS-PWM are 10.71%, 11.45%, 12.31% and 9.57% respectively presented in Table.3 On output side the MMC connected with a motor load in series. The other end of the load connected with ground / neutral earth point for a balanced voltage. And the final output voltage and current measured across shown in Fig. 12-13.

Table 3 THD % Comparison of seven level Half H-bridge cascaded inverter with various PWM techniques

| Sl. | PWM     | THD % |
|-----|---------|-------|
| 1   | PD-PWM  | 10.73%|
| 2   | POD-PWM | 11.45%|
| 3   | APOD-PWM| 12.31%|
| 4   | PS-PWM  | 9.52% |

![Fig.5 Upper Arm Sub Systems](image)

![Fig.6 Lower Arm Sub Systems](image)

![Fig.7 FFT Analysis](image)

![Fig.8 THD Graph of PS-PWM](image)

![Fig.9 THD Graph of PD-PWM](image)

![Fig.10 THD Graph of POD-PWM](image)
V. CONCLUSION

After the detail’s analysis and study, we have reached at a conclusion that by using MMC with PS-PWM technology and multiple levels of the voltage waveform the smoothness of the voltage also increases and THD reduces. It has also been noticed that the Phase-Shifted (PS) PWM is better than the Phase Disposition (PD) PWM, (POD) PWM and (APOD) PWM by using pulse generator, having less THD. Scope for future work will be to analysis the behavior of this methodology together with regenerative braking system (RBS).

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