“A SUBMODULE CAPACITOR VOLTAGE BALANCING TECHNIQUE FOR MMDC TO DRIVE DC SYSTEM WITH REGENERATING CAPABILITY”

[1]Shamili R
Dept. Of Electrical and Electronics
Dr. Ambedkar Institute of Technology

[2]Dr S. Vasudevamurthy
Dept. Of Electrical and Electronics
Dr. Ambedkar Institute of Technology

Abstract – This paper proposes a balancing of sub module capacitor voltage in modular multilevel dc (MMDC) converter. Generally used MMC balancing procedure cannot be used, since arm currents of MMDC changes its direction within each switching cycle. Here the average capacitor voltage of each arm is self balanced within an arm by assigning the gate signals. This 5 level DC-AC-DC converter drives DC system. In regenerative mode of DC motor the energy in the motor winding is released and charges the battery. Battery associated with bi-directional dc/dc converters operate in buck mode while it is charging and in boost mode when discharging. Simulation work for proposed topology is carried in MATLAB/Simulink.

Keywords–Sub modules(SM), Capacitor voltage balancing, sorting, Regenerative breaking.

I. INTRODUCTION

The depletion of fossil fuels, rising environmental concerns, and increasing day-to-day demand for electricity have elevated the need for alternative sources of energy generation. A new wave of interest in industry and research has been generated by multilevel inverters.

A DC-DC converter that is suitable for high-voltage/power is a key enabling technology for future DC networks as power flow control and voltage adjustment must be achieved. Specifically, DC-DC converters for future DC networks need to meet the following requirements: Bidirectional power flow, High efficiency, High voltage/power rating. Multilevel inverters significant features, such as their ability to handle high voltages with reduced stress across individual devices, low switching and conductive losses, transformer less operation, and increased power quality with lower harmonic distortion, have made them an attractive and competent solution for many applications.

Currently, the cascaded H-bridge (CHB), neutral-point-clamped (NPC), modular multilevel converter (MMC), a flying capacitor and their variants are some popular topologies considered to be applicable multilevel inverters. Increasing the number of levels intended to reduce harmonic distortion with superior quality of the waveform profoundly affects the size and cost of the inverter.

II. MODULAR MULTILEVEL CONVERTER

The DC-AC MMC has become the most attractive converter topology for high-voltage and high-power applications. An extensive research effort has been made to address the technical challenges associated with its operation and control. The salient features of the DC-AC MMC make it suitable for various applications including High-voltage DC (HVDC) transmission systems, variable speed drives, flexible AC transmission systems (FACT), and static synchronous compensator (STATCOM). The salient features of the MMC are: Improved reliability enabled by introducing redundant SMs. Low EMI due to low *dv*/*dt* and *di*/*dt*. Low total harmonic distortion (THD) in the output AC waveforms enabled by the multilevel architecture also significantly reduces the requirement for AC side filtering. Fully modular and scalable enabled by the use of identical low-voltage SMs

III. PROPOSED SYSTEM

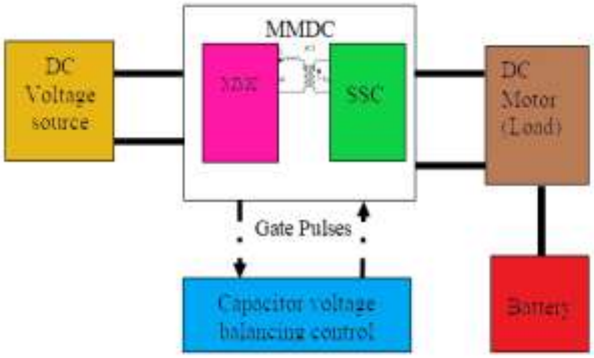

Figure 1: Block Diagram

The MMDC driving DC system is shown in figure 1, in which ideal voltage sources supplies constant voltage/current outputs, Amplitude of source for proposed model is 16kv. The MMDC is derived from an MMC and a DAB converter which is achieved by replacing the primary side power devices of a single phase DAB(Dual active bridge) with series-connected SMs, MMDC topology results. Arm inductors limit circulating current developed between the DC side and legs as SMs are switched in and out of circuit. A coupled inductor is used to balance the ac component in upper and lower arm currents.

Portion of circuit that consumes electric power is called Load, which is DC motor, these motors are capable of maintaining constant speed under variable load conditions. The generated EMF in motor E_b is directed in opposition to supply voltage and is called back emf that counters forward voltage, where it is helpful in producing regenerative breaking. Permanent magnet DC motor is used in the proposed technique.

The device used to store electrostatic energy in the form electric charges in electronic component is capacitor. It is also called as energy storage system. In the proposed model, the battery is associated with bi-directional dc/dc converters which operates is buck mode while charging and in boost mode when discharging.

The sub module(SM) capacitor voltages need to be maintained balanced. Under normal operation of the DC MMC, two types of SM capacitor voltage imbalances exist: Type I: Imbalance amongst the SM capacitor voltages in the same arm.

Type II: Deviation of average SM capacitor voltages between the upper and lower arms.

Type I imbalance, which also exists in the conventional DC-AC MMC, is due to unequal charge/discharge of the SM capacitors in the same arm. Extensive research effort has been made to mitigate Type I imbalance. The most common method of mitigating is the selection method that sorts and selects SMs to be inserted/ bypassed based on the arm current direction.

Type II imbalance that is caused by DC power transfer between the DC links is unique to the DC MMC. The DC power can be transferred bidirectional between the DC links. The energy stored in the SM capacitors of one arm will quickly deplete and saturate the other arm of the same phase-leg, if each arm produces only a DC current. Consequently, the average voltage of the SM capacitors in the upper and lower arms will deviate from the nominal value even though the voltages of SM capacitors are maintained balanced within the same arm. To mitigate Type II imbalance, the DC MMC exploits an AC circulating current to enable active AC power exchange between the upper and lower arms and to offset the voltage deviation of the SM capacitors caused by the DC power transfer. The AC circulating current needs to be actively controlled to maintain the average capacitor voltages of the upper and lower arms at the nominal value. A necessary condition to ensure the proposed operating principle, is balancing of SM capacitor voltages. In order to simplify the analysis the following assumptions are made: (a) All power losses and gate signal delays are ignored. (b)The capacitances of all SMs are the same.

The average voltage of each arm does not change in steady state, hence the voltages among arms are self-balanced and the SM voltage within each arm can be balanced by reassigning the gate signals. Gate signal reassignment is achieved by higher charge difference to SMs with lower capacitor voltages, and vice versa. The charge difference of a SM capacitor can be obtained using ΔQ = CΔV, thus only SM capacitor voltages are required for the voltage balancing control.

IV. REGENERATIVE BREAKING

There are two types of breaking system of DC motor in application; they are Mechanical breaking and Electrical breaking. Compared to mechanical breaking electrical breaking is used to quickly bring down the speed to zero. In electrical breaking the motor works as a generator, developing a negative torque which opposes the motion.

Types of Electrical breaking:

- Plugging
- Dynamic/ Rheostatic breaking
- Regenerative breaking

In regenerative breaking, generated energy is supplied to source, where motor essentially acts as a generator. It is also termed that energy is reabsorbed by motor and converted back to electricity usefully.

EMF equation of dc motor $E_b = V_t - I_a R_a$

Under normal condition: $V_t > E_b$

Under Regenerative breaking condition: $V_t < E_b$

Where, E_b is back emf, V_t is terminal voltage, $I_a R_a$ is armature current and resistance respectively. Below figure shows Regenerative braking characteristics.

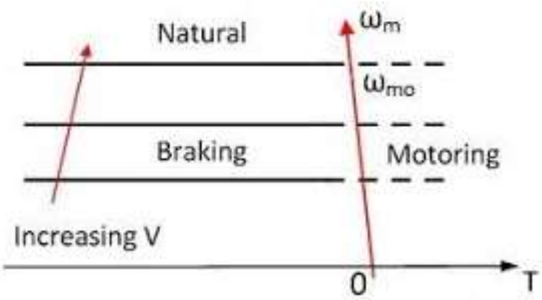

Figure 2: Regenerative braking characteristics

V. FLOW CHART

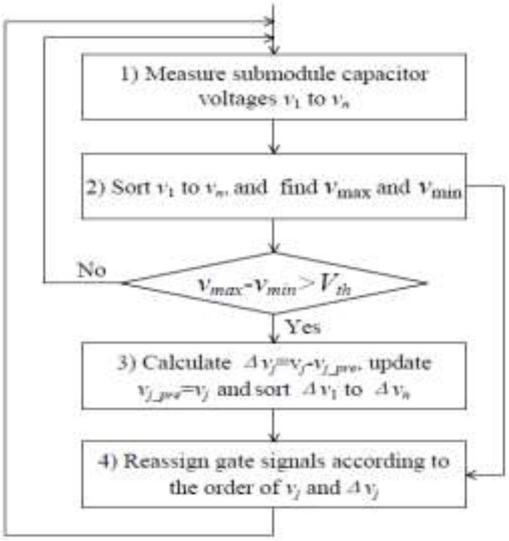

Figure 3: Flow chart for proposed balancing method

There are four main steps to execute:

Step 1: Sub module voltages V1 to Vn in the arm to be measured.

Step 2: Sort V1 to Vn and find the minimum and maximum voltages values Vmin and Vmax; if the difference between Vmax and Vmin is larger than a threshold Vth, go to Step 3, otherwise go to Step 4. (Vth can be chosen as 2.5% of the nominal voltage).

Step 3: Calculate ΔVj = Vj − Vj pre and sort ΔV1 to ΔVn.

Step 4: Reassign gate signals according to the sorting results of Vj and ΔVj : assign gate signals with higher ΔVj to sub modules with lower Vj and vice versa.

The step 1, 2 and 4 are executed every switching cycle, whereas step 3 is executed only when Vmax − Vmin > Vth.

VI. SIMULATION

The conversion of DC–AC-DC is achieved by MMDC Circuit with source of 16KV,50 Hz. The output voltage levels depends on N number of sub modules i.e N+1=4+1=5 Levels which are reveled in figure 4.

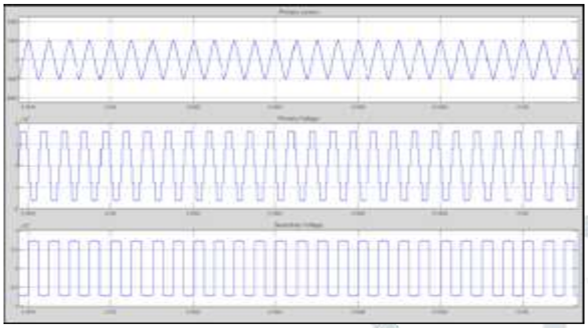

Figure 4: Transformer primary and secondary voltage waveforms

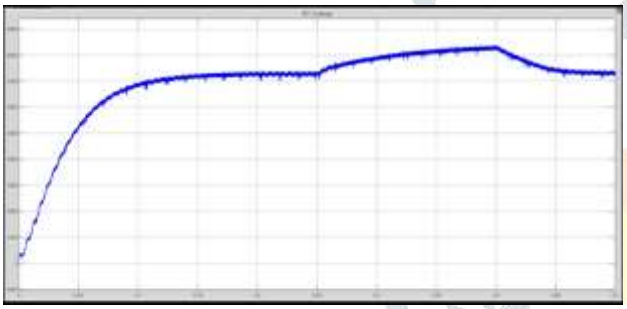

Figure 5: H--Bridge converter output

The AC voltage is converted to DC using H-Bridge converter which is provided in the above graph.

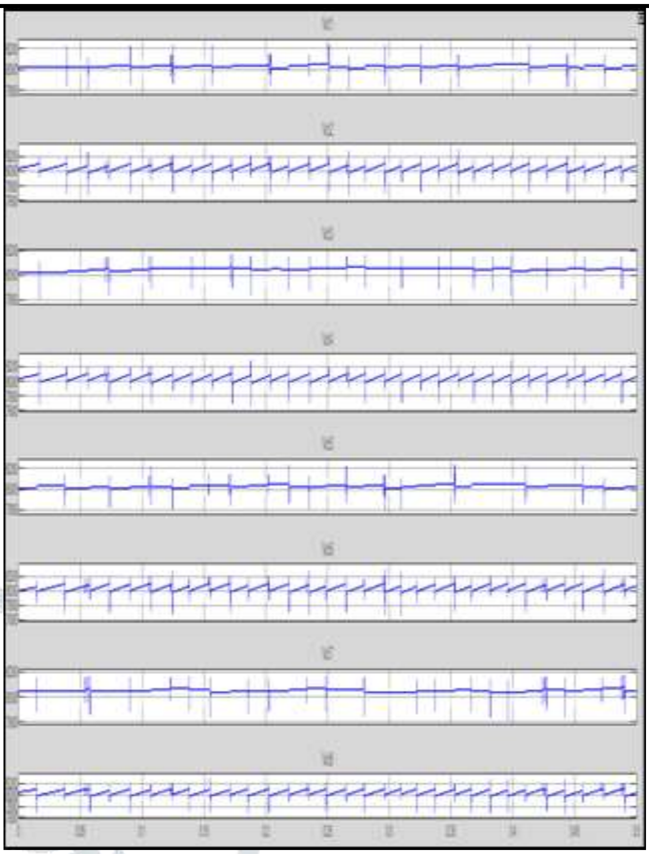

Figure 6: Sub module capacitor voltages

The capacitor connected to the sub-modules is charged and discharged based on the capacitor voltages as shown in figure 6.

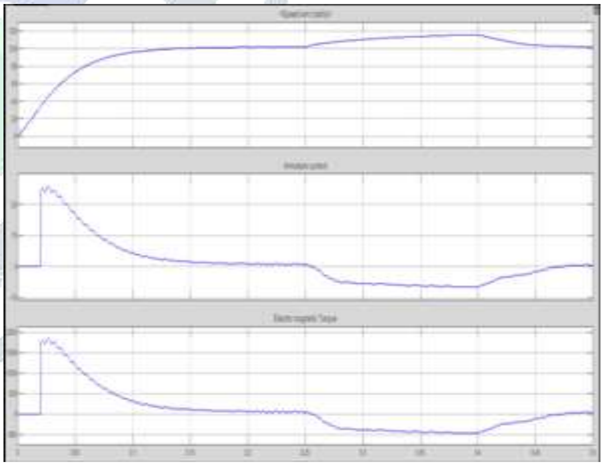

Figure 7: Waveforms of rotor speed with armature current and torque

In figure 7, during traction mode, the dc voltage remains at rated value and when braking is applied, the power flow is reversed and the dc voltage increases and when again the traction mode resumes, the dc voltage returns to rated value. The rotor speed with armature current and torque is provided in the following above waveform

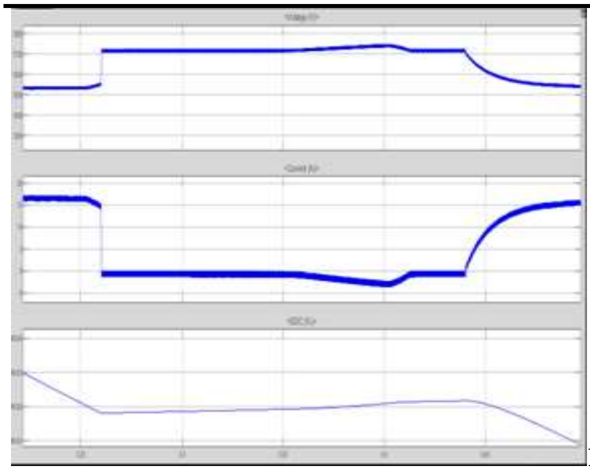

Figure 8: Along with %SOC battery voltage and current waveforms

In the figure 8, the armature current direction is changed due to the regenerative breaking, battery will be charged during this time period. The (%state of charge)%SOC along with battery voltage and current waveforms are provided. Here, the battery is initially discharging and when braking occurs at t =0.25s, the battery start to charge and %SOC of the battery starts to increase and when braking is released again battery starts to discharge.

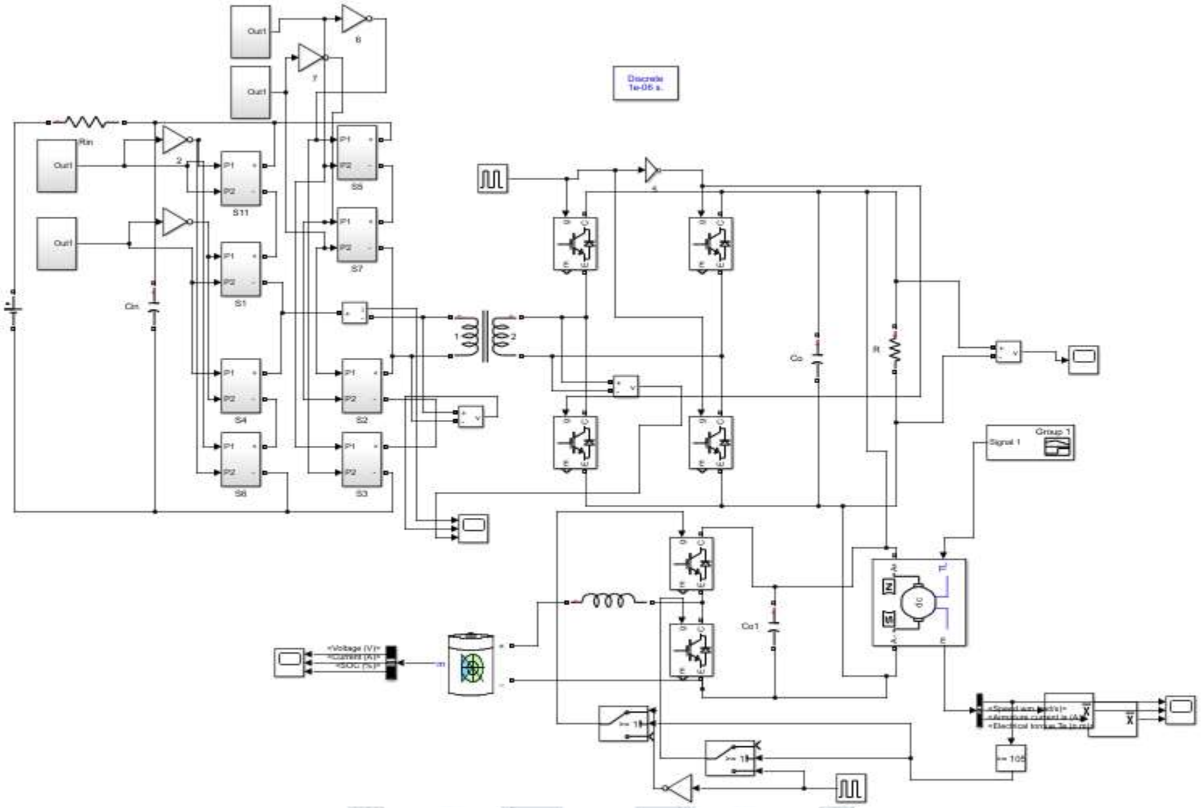

Figure 9: Simulated circuit of proposed 5-level multilevel inverter to drive DC system

CONCLUSION

To ensure stable MMDC operation, a necessary condition is balance of sub module capacitor voltages. The proposed balancing method is reassignment of gate signals with higher charge difference to the sub modules with lower voltages and vice versa. The 5 level DC-AC-DC converter output drives DC system, In regenerative mode the energy in motor winding is released and charges the battery. Simulation and experimental results are shown. The proposed method can be used for both single phase and multi-phase MMDCs.

Future work focus can include Variable control input to control current and voltage of the inverter, and hardware can be implemented by closed loop control.

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