# High Efficiency Cascaded Multilevel Converters PMSM Drive

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**ABSTRACT***:* This paper presents a motor drive system based on Cascaded H-bridge (CHB) multilevel converter using only one isolated power source supply. CHB multilevel converter has been conceived as an effective device to reduce total harmonic distortion (THD) in medium-voltage motor drives. A new permanent-magnet synchronous motor (PMSM) drive system topology is proposed to implement the system harmonic compensation. In this novel system an transformer is used as energy feedback device between the converter and the motor; whereby the PMSM drive system using the feedback power flow to provide the H-bridges, Moreover, CHB multilevel converter take advantages in reduce total harmonic distortion since the transformer is connected in main circuit. Simulation and experimental results are provided to demonstrate the effectiveness of the proposed motor drive system.

**KEYWORDS:** Cascaded H-bridge, energy feedback, transformer, PMSM

## I. INTRODUCTION

TODAY, Cascaded multilevel inverters are progressively more popular in industrial applications [1-8]. The motor drive system with Cascaded H-bridge (CHB) multilevel converter has been found to achieve desirable merits for high-power applications, as well as all-electric vehicle (EV) and hybrid-electric vehicle (HEV) [1, 9-15]. The modular structure is helpful to the cost reduction due to enabling low-cost-semiconductor application, low manufacturing cost, etc. Due to their advantages in terms of low voltage change rates, modularity, and reliability, an d fault tolerance, CHB multilevel converters are the most widely used in motor drive system [9-15].

It is well known that energy feedback technology was drawing more attention in a motor drive system, because it can feedback the power, so system dynamic performance and efficiency are obviously improved [1-8] However, In the process of energy transmission, the energy flows from the batteries all have been used to drive motors through CHB inverters. Energy flow has worked in open -loop model. That energy was not used to enhance the control performance of the whole system, improve running condition and increase efficiency.

This paper proposes a new PMSM drives system based on Cascaded H-bridge multilevel converter configuration. The whole system can be considered as four parts: the energy source, the CHBs, the transformer, and the electric motor, whereby the closed-loop control of energy transmission in the system is achieved. Therefore the whole system could have all the advantages of a closed -loop control system, including stability, split-second control, and working in miniaturized condition. It can achieve an effective real power distribution between four parts of the system, which will reduce the adverse effect of power transients on energy sources, recover the regenerative power from the motor, and improve the system dynamic performance and power quality.

This paper is outlined as follows. After the introduction section, an insightful illustration of the proposed PMSM drives in Section 2. The concept of the energy feedback is also developed in this section. Section 3 presents model of the CHB system. In Section 4, the proposed system is simulated in a MATLAB/Simulink simulation platform. Simulation results are presented to verify the theory of the proposed motor drive. Finally, conclusions are presented in Section 5.
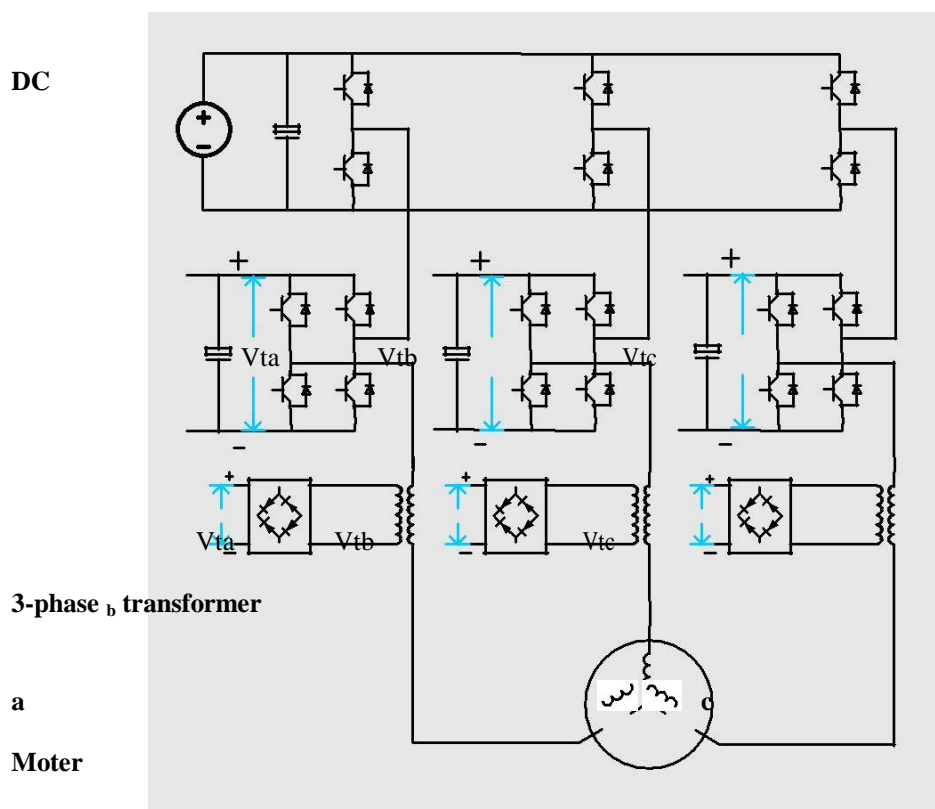
## II. SYSTEM DESCRIPTION



Figure 1. PMSM Drives System Based on CHB-Transformer Configuration

The proposed CHB-transformer motor drive system with energy feedback control system is shown in Figure 1. Different from conventional multilevel converter drive system, the new system configuration works in closed -loop model. The three-phase H-bridge inverter cells connected to the energy source DC and the Ultra Capacitors (UCs) are defined as the "main" inverter and the "auxiliary" inverters, respectively.

The cascaded multilevel-inverter cells include one or more auxiliary inverters and only one main inverter for each phase. The number of auxiliary -inverter cells of each phase can be selected by considering the tradeoff among the cost, the power quality, the power loss and the power compensation capability.

In this configuration, the dc voltages of the auxiliary inverters are supported by the Ultra Capacitors connecting to the transformer secondary winding output rectifiers and lower than the main inverter. With proper calculation and modulation, the rate of the voltage for them can be optimized.

In this system, most of the energy feedback flow is used to drive the motor and adjust the speed of the motor, with part of it to enhance the performance of the motor and improve working condition. For instance, the energy feedback flow could still be used as DC voltages after rectification, significantly reducing the number of isolated power sources needed for the whole system, thus it is suitable especially for EV/HEV.

Figure 2 shows transformer secondary winding connects segmented capacitor as energy sources of auxiliary inverters. The energy feedback flow after rectification can be used as individual battery packs. Compared with traditional cascaded H-bridge multilevel converter which has the same level output, the CHB -transformer configuration has advantages in terms of reduced number of isolated DC sources, simplified topology structure and optimized modulation

control method. The new CHB- transformer configuration would reduce total harmonic distortion of PMSM current at different speed (low, medium and high) with various modulation control method.
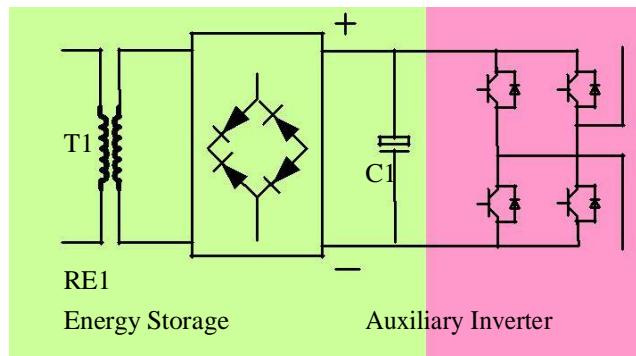


Figure 2. Energy Feedback Flow Configuration

### III. CHB MODEL ANALYSIS

The main inverter switches at fundamental frequency, and the auxiliary inverters operate at a higher switching frequency. The total output voltage of each phase is sum of a quasi-square wave from the main inverter and pulse width-modulation (PWM) waveforms from the auxiliary inverters. Using suitable control method, the dc voltages of all auxiliary inverters are controlled to be symmetrical; otherwise, the inverter output voltage will be generated with an asymmetrical adjacent voltage step, which may lead to the undesired harmonic voltage.

Take the phase A for example, there the n=2, there are two cascade-auxiliary-inverter cells of each phase. The output of each H-bridge is shown in Figure 3. The main inverter switches at fundamental frequency, the auxiliary inverter cell1 operate at a higher switching frequency, and the auxiliary inverter cell1 operate at a highest switching frequency

Each of complete and simplified single-phase topology of CHB multilevel converter includes two H-bridges in the same phase as shown in Figure 3(a). In order to eliminate the system, take the number n is 2; there are two cascade-auxiliary-inverter cells of each phase. At first, it is assumed that all-controlling power electronics switches work in an ideal condition, after-flow process is not considered. Take Master H-bridge A for example, S1~S4 are ideal switches symbol, each of them is controlled by a corresponding electrical signal. If the switch symbol S is defined to 1, the switch is closed. When the switch is opened, the corresponding S equals to 0 PMSM
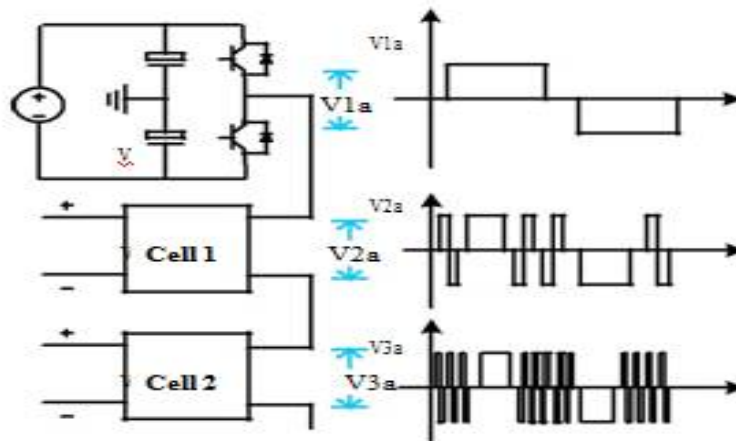


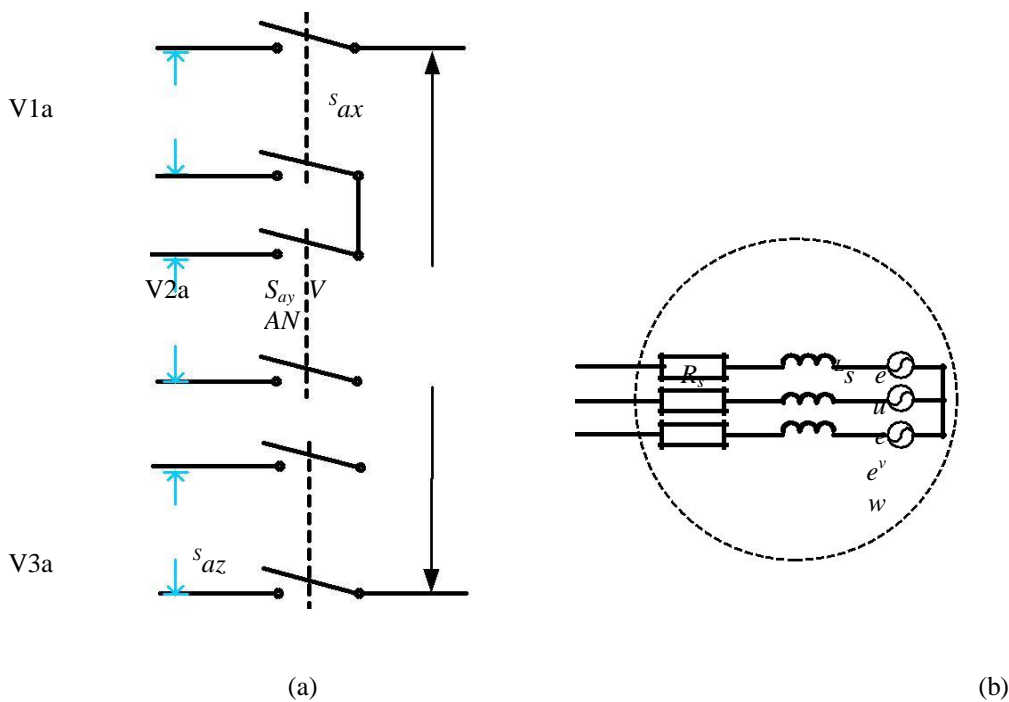**Figure 3. Each H-bridge Output of Phase A**

(a) (b)

**Figure 4. Simplified Model (a) Cascade H-Bridge PMSM**

To define a switching function $S_{ij}$ , where $i \in \{a, b, c\}$ , $j \in \{x, y, z\}$

$$S_{ij} = \begin{cases} 1 & Operating \ model 1 \\ -1 & Operating \ model \ 2 \\ 0 & Operating \ model \ 3 \end{cases} \tag{1}$$

The output of each phase CHB multilevel converter is the sum of every H-bridge outputs at the same phase. Take the phase A for example, as shown in Figure 4, considering the voltage output is the sum of three H-bridge out.

$$V_{AN} = S_{ax} V_{1a} + S_{ay} V_{2a} + S_{az} V_{3a} \tag{2}$$

Complete and simplified topology     of rectifier, the ac source voltages are $e_a$ , $e_b$ and $e_c$ . The ac currents are $i_a$ , $i_b$ and $i_c$ . The ac terminal voltages of the converter are $v_a$ , $v_b$ and $v_c$ . The dc voltage and current are $V_{dc}$ and $I_{dc}$ , respectively. The ac-side impedance is modeled as an L inductor in series with a resistor R. the equation of the rectifier in d-q coordinate is shown:

$$\begin{cases} L\dfrac{d_d}{dt} = u_d - Ri_d + \omega L i_q - e_d \\[2mm] L\dfrac{a_{q}}{dt} = u_q - Ri_q + \omega L i_d - e_q \\[2mm] c\dfrac{d_{udc}}{dt} = i_{dc} - i_L \end{cases} \qquad (3)$$

Complete and simplified topology of PMSM is shown in Figure 4(b), the equation of the PMSM in d-q coordinate is shown:

$$\begin{cases} L_s\dfrac{d}{dt} = u_{sd} - R_s i_{sd} + \omega L_s i_{sq} - e^{vd} \\[2mm] L_s\dfrac{a_{uq}}{dt} = u_{sq} - R_s i_{sq} + \omega L_s i_{sd} - e^{sq} \\[2mm] \dfrac{J}{n_p}\dfrac{d\omega}{dt} = T_e - T_L \end{cases} \qquad (4)$$

### IV. SIMULATION

The modulation control schemes for the multilevel converter can be divided into two categories, fundamental switching frequency and high switching frequency PWM, and both can be used for the CHB multilevel converter. A control system has been also developed, as shown in Figure 5, to achieve the proposed power-distribution strategy. It includes three control subsystems: energy source, transformer, electrical motor.

In this paper, the simulation model based on MATALB/SIMULINK is proposed under the multistep staircase waveform modulate method. Multistep staircase waveform modulate method is the most popular methods because it is easily implemented.

The SIMULINK model for PMSM drives based on CHB energy feedback seven-level converter is shown in Figure 6, including DC source, cascaded H-bridge seven-level converter, energy feedback deviceandPMSM.
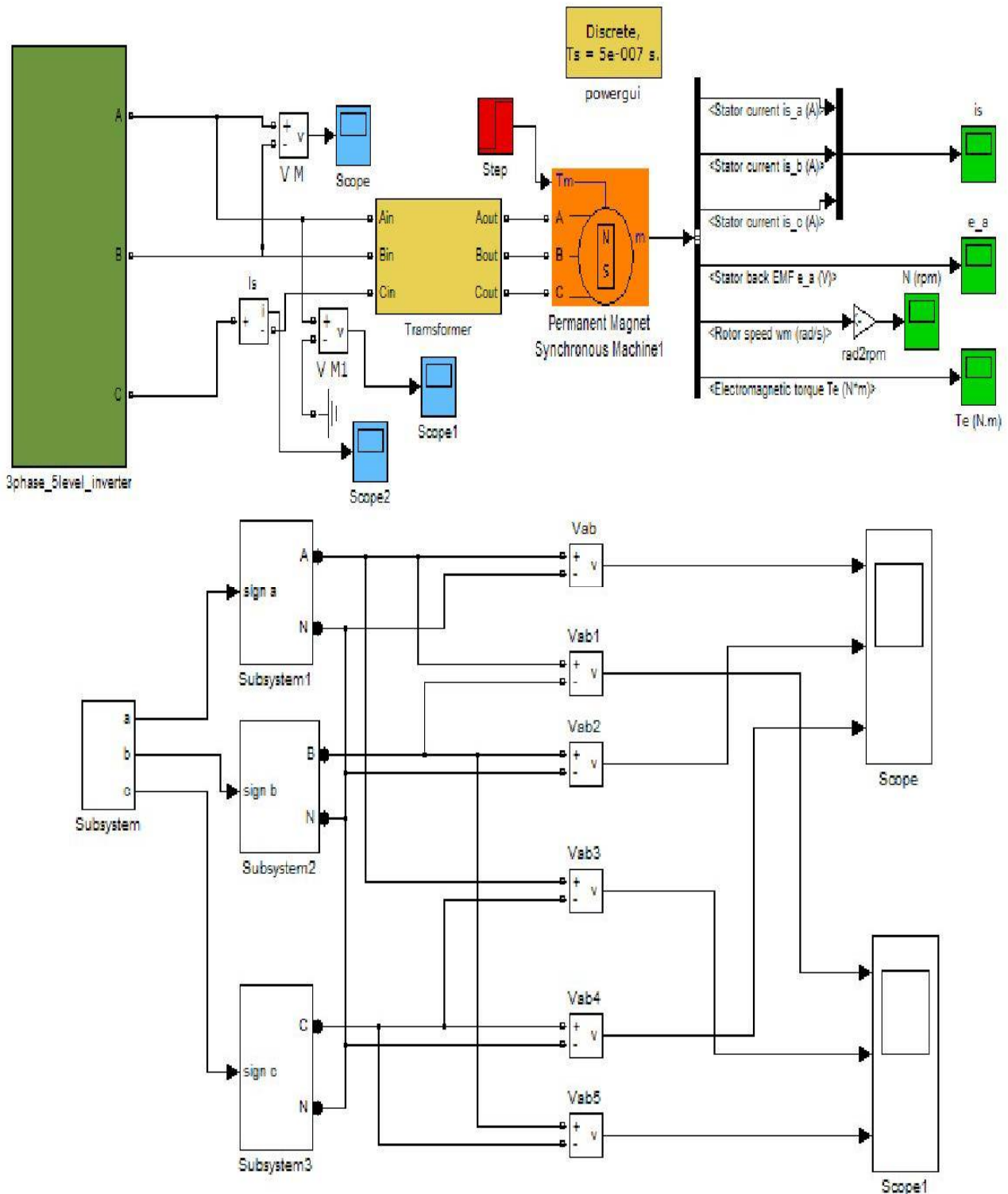
**Figure 5. SIMULINK Control Model for PMSM Drives with Energy Feedback Transformer**

Figure 6 (a) shows the output of the phase voltage under the seven-level converter working with energy feedback device. (b) Shows the torques in different limited current on stabilization state.
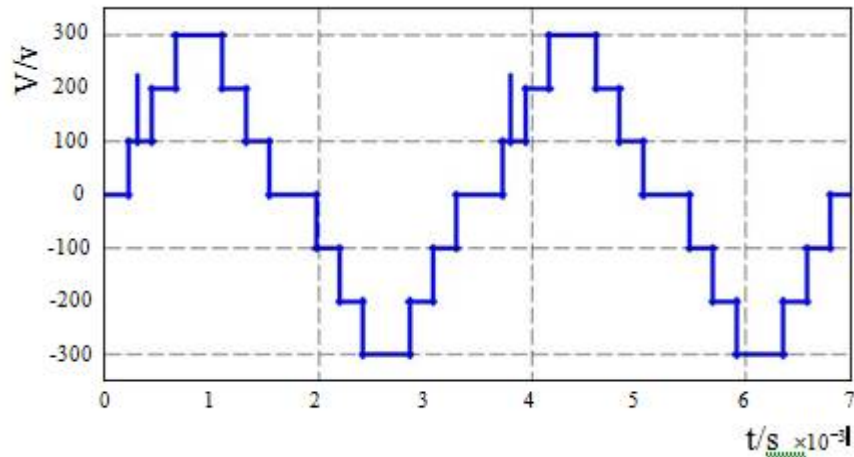


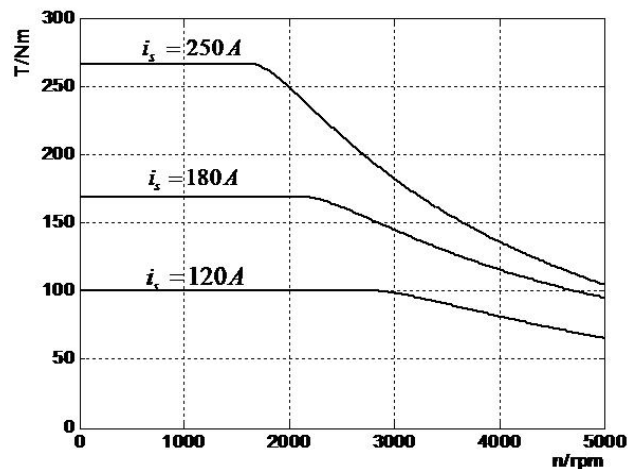**Figure 6. (a) Output Phase Voltage**



**Figure 6. (b) Torques in Different Limited Current**

### V. CONCLUSIONS

A cascaded H-bridge (CHB) multilevel converter with energy feedback device has been proposed for use in PMSM drives. Simulation and experimental results have shown that, with a control strategy that operates the switches at fundamental frequency, these converters have low output voltage THD and high efficiency. In summary, these CHB multilevel converter systems have higher efficiency because the devices can be switched at minimum frequency and the transformer can feed the energy flow back to the converter. With a special topology and switching strategies, the converter can work with only one DC supply, which has advantage in industrial applications widely.

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