Fundamental frequency switching strategies of a seven level hybrid cascaded H-bridge multilevel inverter

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ABSTRACT

This paper presents a novel hybrid cascaded H-bridge multilevel inverter (HCHB MLI) designed to address the growing importance of multilevel inverters in the context of renewable energy sources such as solar, wind, and fuel cells. The proposed topology features eight insulated-gate bipolar transistor (IGBT) switches and utilizes two distinct input direct current (DC) sources: a battery and a capacitor, making it a hybrid system. The control strategy employed in this topology is based on fundamental switching frequency techniques. Simulation results of the proposed topology are conducted using MATLAB/Simulink software, while hardware experimentation with a single-phase H-bridge inverter is also demonstrated in the paper. For pulse generation and IGBT switch control, an Arduino UNO microcontroller is utilized. The output voltage of the single-phase H-bridge inverter is verified through experimentation using a cathode-ray oscilloscope (CRO).

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1. INTRODUCTION

The sliding surface for a single-stage uninterruptible power supplies (UPS) [1] is based on another pivoting sliding mode control approach that combines conventional sliding mode control (SMC) with fuzzy logic control. The proposed procedure offers significant advantages over traditional SMC, such as lower total harmonic distortion (THD), and excellent dynamic responses for the inverter's output voltage and current. Fast terminal sliding mode control (FTSMC) for 1-ph UPS inverters [2] aims to reduce tracking time using a standard target proposed method. Simulation results of the proposed technique were compared with traditional sliding mode control (TSMC), showing that FTSMC achieves faster transition from the initial sliding mode to the equilibrium state. Madark *et al*. [3], a turning sliding line-based SMC is presented, offering advantages such as improved inverter voltage performance during load variations and seasonal changes. A powerful second-order SMC was introduced in [4]. The primary objective of this proposed procedure is to generate sinusoidal current to the grid with low THD, even under varying solar irradiance and load disturbance conditions. Multi-input multi-output-based SMC was introduced in [5], providing various benefits, including robustness against grid variations, reduced gain requirements, zero steady-state errors in the load voltage, and ease of implementation [6].

In the context of a single-phase grid-connected voltage source inverter (VSI), a sliding mode control with a dual-band hysteresis strategy is proposed to enhance the dynamic response of the grid voltage and power.

For a single-phase uninterrupted power supply (UPS) inverter [7], a sliding mode control with a three-level hysteresis sliding function is proposed. The method ensures dynamic response with current fluctuations from 10 A to 20 A and -10 A, offering strong stability. Presents a sliding mode control based direct current (DC)-interface three-phase Z-source inverter [8]. This technique effectively controls both the input DC voltage and output alternating current (AC) voltage, providing superior tracking performance and immunity to input disturbances. Various sliding mode control techniques were implemented for grid-connected single-phase inverters [9]. Chenchireddy *et al*. [10] introduced second-order sliding mode control; while reference [11], [12] introduced adaptive fuzzy sliding mode control. The main objective of this method is to achieve precise control of the output current and reduce current harmonics in the 3-phase multilevel inverter. Analysis results demonstrate negligible steady-state errors, highly dynamic responses, and robustness against power supply variations and load imbalances.

2. HYBRID CASCADED H-BRIDGE MULTILEVEL INVERTER

Figure 1 shows the hybrid cascaded H-bridge multilevel inverter (HCHB MLI). The figure has eight insulated-gate bipolar transistor (IGBT) switches, two different supply DC sources, one source is capacitor and second source is one is battery. The HCHB MLI is generating 5 level output voltage. The Table 1 shows the detail operation HCHB MLI operation. The switches are S1 to S8. The total time is 0.02 sec. the pulse width means the conduction period. Chenchireddy *et al*. [13] presented SMC base direct force control (DPC) of the 3-stage matrix associated MLI. The arranged system controlled dynamic and receptive force independently looked at results of immediate and aberrant choice of exchanging succession all through different responsive and dynamic force references. A space vector alpha-beta sliding mode current regulator is proposed for a 3-phase multilevel inverter [14]. SMC is utilized for direct assurance of exchanging and space vector modulation (SVM) is used for aberrant determination of exchanging successions [15]. SMC-based direct force regulators have great powerful reactions, low affectability to boundary varieties and straightforward execution diverge from Direct power control with space vector modulation (DPC-SVM). Actualized consistent recurrence sliding mode current control base 3-stage matrix associated MLI to the dispersed age framework [16]. The significant goal of the technique decreasing yield current music in a lattice-associated inverter, the network-associated inverter boundary input DC supply [17]–[20]. The outcomes get a great unique reaction in the reference current advance change condition. Introduced sliding mode control for a dynamic unbiased point clipped active neutral point clamped (ANPC) multilevel inverter [21]–[23]. The primary target proposed technique adaptation to internal failure control of the yield voltages of the three-level ANPC inverter. The exploratory outcomes acquired equilibrium three-stage yield flows under shortcoming activity. Introduced SMC based 3-stage 3-level two-leg NPC inverter for circulated age frameworks [24]–[26]. The proposed inverter geography diminished 4 switches, and 2 diodes in contrast with the ordinary three-stage neutral point clamped (NPC) inverter.

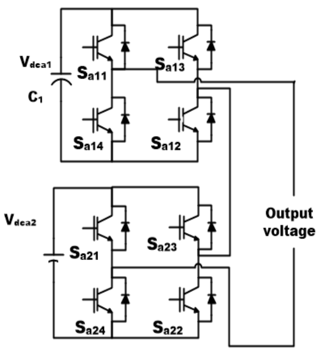


Figure 1. Hybrid CHB MLI

Table 1. Switching table for Hybrid CHB MLI

S.L.	Switches	Time (sec)	Pulse width (%)	Phase delay (sec)
1	S1	0.02	9.09%	0.0142
2	S2	0.02	9.09%	0.0042
3	S3	0.02	25%	0.0028
4	S4	0.02	25%	0.0128
5	S5	0.02	38.46%	0.0114
6	S6	0.02	38.46%	0.0014
7	S7	0.02	38.46%	0.0014
8	S8	0.02	38.46%	0.0114

3. RESULTS AND DISCUSSION

In this section, the multilevel inverter MATLAB/Simulation results are presented, as well as single phase H-bridge inverter hardware results are also presented. The simulation results waveforms and hardware circuit diagram and output waveform presented. The objective of this paper is to provide good quality of power by using multilevel inverter.

3.1. Simulation results

Figure 2 illustrates the MATLAB diagram of half-bridge cascaded H-bridge multilevel inverter (HCHB MLI). This diagram comprises eight IGBT switches, two DC sources, and a resistive load. The conduction times for each switch are detailed in Table 1. In Figure 3, the switching pulse diagram for the inverter is shown. The switches G1 and G2 operate in a complementary manner, with each switch conducting for 9.09%. Likewise, the switches G3 and G4 operate complementarily, conducting for 25% each. The switches G5 and G6 also operate complementarily, with each switch conducting for 38.46%. Similarly, switches G7 and G8 are complementary; with each switch conducting for 38.46%. Figure 4 presents the output voltage and current waveforms of the seven-level inverter. The magnitude of the current waveform is 15 A, and the output voltage magnitude is 80 V. The waveform appears in a step-like manner.

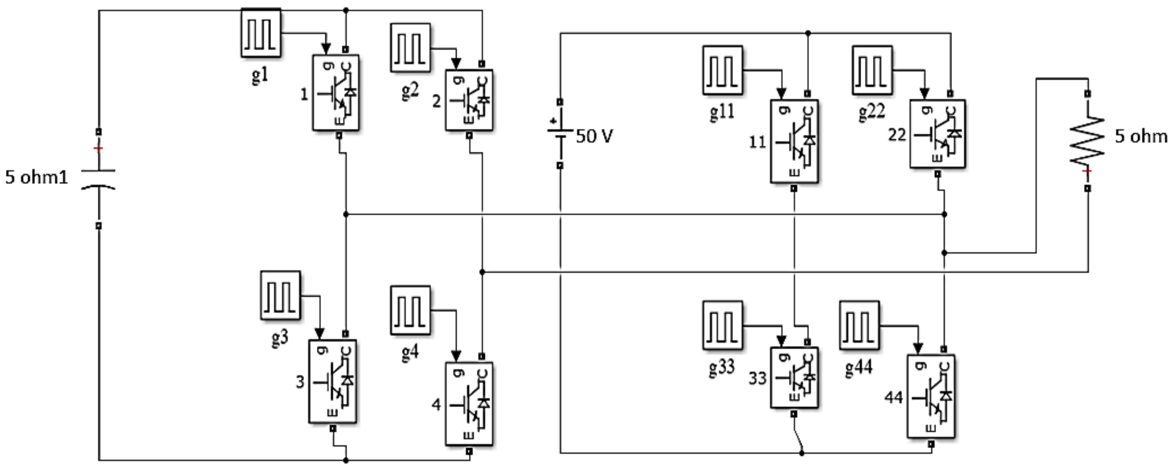
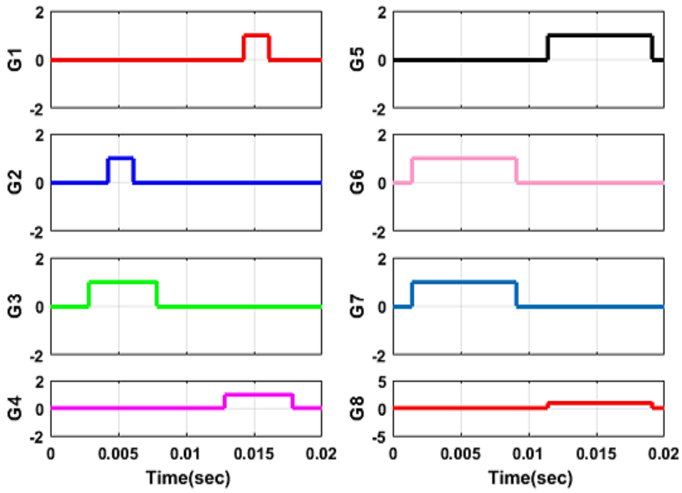


Figure 2. HCHB MLI MATLAB diagram



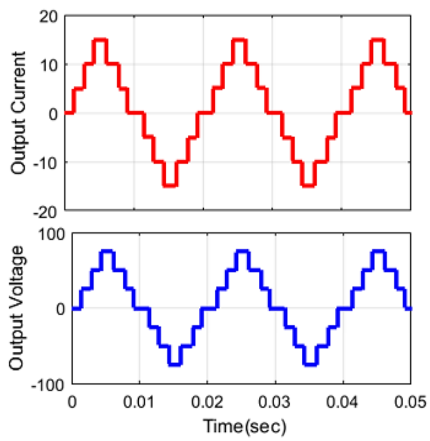


Figure 3. Switching pulses for HCHB MLI

Figure 4. Seven level inverter output voltage

3.2. Hardware implementation

Figure 5 depicts a single-phase half-bridge inverter with a center-tapped transformer. This circuit comprises three 9 V batteries, two IGBT switches, an Arduino UNO, a 1.5 V battery, a single-phase center-tapped transformer, and a lamp load. These components are essential elements in Figure 5. The Arduino generates pulses for the IGBT switches, which are operated in a complementary manner. Moving on to Figure 6, it illustrates a single-phase H-bridge inverter with a parallel hybrid energy source. This figure involves four energy sources: solar, wind, battery, and piezoelectric. The solar power operates during the daytime, while the wind power is generated based on wind availability. Additionally, the center-tapped transformer performs a step-up function from 9 V-0-9 V to 230 V. For inverter control, the Arduino microcontroller generates digital pulse width modulation (PWM) pulses. Figure 7 displays the output voltage waveform of the single-phase H-bridge inverter, exhibiting a square waveform appearance. In this setup, two digital pins are utilized for pulse generation. This paper presents the use of a lamp load for standalone application in the circuit.

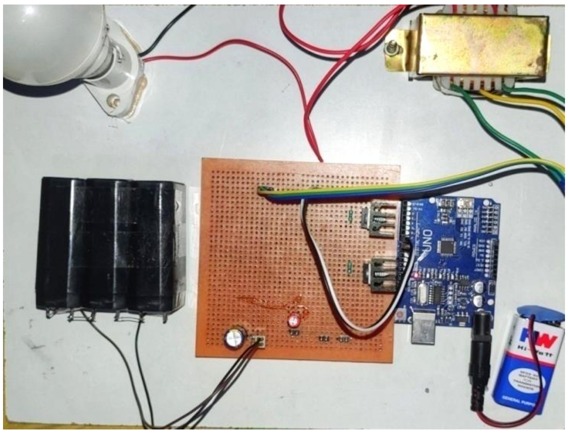


Figure 5. Single phase H-bridge inverter

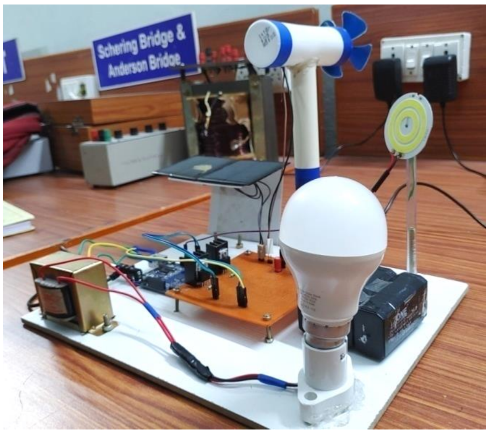


Figure 6. Single phase H-bridge inverter with parallel hybrid energy source

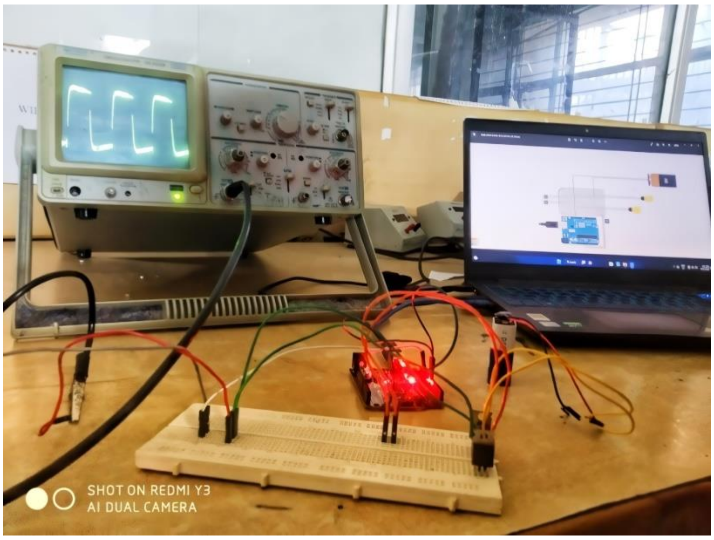


Figure 7. Single phase H-bridge inverter output waveform

4. CONCLUSION

This paper presented a novel hybrid cascaded HCHB MLI designed. The proposed topology features eight IGBT switches and utilizes two distinct input DC sources: a battery and a capacitor, making it a hybrid system. The control strategy employed in this topology is based on fundamental switching frequency techniques. Simulation results of the proposed topology are conducted using MATLAB/Simulink software, while hardware experimentation with a single-phase H-bridge inverter is also demonstrated in the paper. For pulse generation and IGBT switch control, an Arduino UNO microcontroller is utilized. The output voltage of the single-phase H-bridge inverter is verified through experimentation using a cathode-ray oscilloscope (CRO).

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