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A NOVEL MULTILEVEL INVERTER BASED ON SWITCHED-CAPACITOR FOR HIGH-FREQUENCY POWER DISTRIBUTION APPLICATIONS

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Abstract—A novel switched-capacitor-based cascaded multilevel inverter is proposed in this paper, which is constructed by a switched-capacitor frontend and H-Bridge backend. Through the conversion of series and parallel connections, the switched capacitor frontend increases the number of voltage levels. The output harmonics and the component counter can be significantly reduced by the increasing number of voltage levels. Phase opposition disposition technique is used as multicarrier modulation. The circuit topology with intended control strategy is examined for voltages, currents and THD of the system. The proposed system with POD PWM technique is implemented on MATLAB/SIMULINK model design for analysis that confirms the feasibility of proposed multilevel inverter.

Keywords— cascaded multi-level inverter, multi-carrier pulse width modulation, POD, THD.

I. INTRODUCTION

High-frequency ac power distribution system potentially becomes an alternative to traditional dc distribution due to the fewer components and lower cost. The existing applications can be found in computer [1], telecom [2], electric vehicle [3], and renewable energy micro grid [4], [5]. However, HFACPDS has to confront the challenges from large power capacity, high electromagnetic interference (EMI), and severe power losses [6]. A traditional HFAC PDS is made up of a high-frequency (HF) inverter, an HF transmission track, and numerous voltage-regulation modules. HF inverter accomplishes the power conversion to accommodate the requirement of point of load. In order to increase the power capacity, the most popular method is to connect the inverter output in series or in parallel. However, it is impractical for HF inverter, because it is complicated to simultaneously synchronize both amplitude and phase with HF dynamics. Multilevel inverter is an effective solution to increase power capacity without synchronization consideration, so the higher power capacity is easy to be achieved by multilevel inverter with lower switch stress. Non polluted sinusoidal waveform with the lower total harmonic distortion (THD) is critically caused by long track distribution in HFAC PDS. The higher number of voltage levels can effectively decrease total harmonics content of staircase output, thus significantly simplifying the filter design [7].

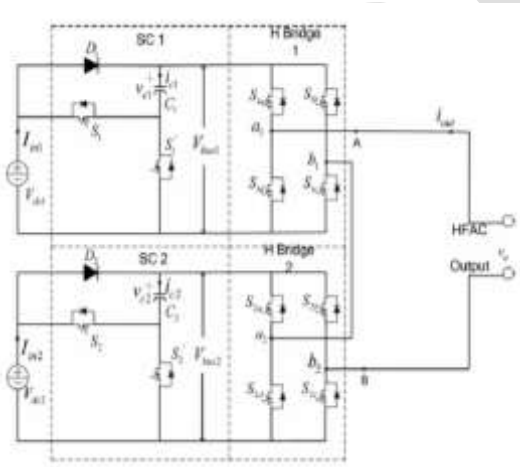
HF power distribution is applicable for small-scale and internal closed electrical network in electric vehicle (EV) due to moderate size of distribution network and effective weight reduction [8]. The consideration of operation frequency has to make compromise between the ac inductance and resistance [9], so multilevel inverter with the output frequency of about 20 kHz is a feasible trial to serve as power source for HF EV application. The traditional topologies of multilevel inverter mainly are diode-clamped and capacitor-clamped type [10], [11]. The former uses diodes to clamp the voltage level, and the latter uses additional capacitors to clamp the voltage. The higher number of voltage levels can then be obtained; however, the circuit becomes extremely complex in these two topologies. Another kind of multilevel inverter is cascaded H-Bridge constructed by the series connection of H-Bridges [12], [13]. The basic circuit is similar to the classical H-bridge DC–DC converter. The cascaded structure increases the system reliability because of the same circuit cell, control structure and modulation. However, the disadvantages confronted by cascaded structure are more switches and a number of inputs. In order to increase two voltage levels in staircase output, an H-Bridge constructed by four power switches and an individual input are needed. Theoretically, cascaded H-Bridge can obtain staircase output with any number of voltage levels, but it is inappropriate to the applications of cost saving and input limitation A number of studies have been performed to increase the number of voltage levels. A switched-capacitor (SC) based multilevel circuit can effectively increase the number of voltage levels. However, the control strategy is complex, and EMI issue becomes worse due to the discontinuous input current single-phase five-level pulse width-modulated (PWM) inverter is constituted by a full bridge of diodes, two capacitors and a switch. However, it only provides output with five voltage levels, and higher number of voltage levels is limited by circuit structure. An SC-based cascaded inverter was presented with SC frontend and full bridge backend. However, both complicated control and increased components limit its application. The further study was presented using series/parallel conversion of SC. However, it is inappropriate

to the applications with HF output because of multicarrier PWM (MPWM). If output frequency is around 20 kHz, the carrier frequency reaches a couple of megahertz. Namely, the carrier frequency in MPWM is dozen times of the output frequency. Since the carrier frequency determines the switching frequency, a high switching loss is inevitable for the sake of high-frequency output. A boost multilevel inverter based in partial charging of SC can increase the number of voltage levels theoretically. However, the control strategy is complicated to implement partial charging.

Therefore, it is a challenging task to present an SC-based multilevel inverter with high-frequency output, low-output harmonics, and high conversion efficiency. Based on the study situation aforementioned, a novel multilevel inverter and simple modulation strategy are presented to serve as HF power source.

The rest of this paper is organized as follows. The discussions of nine-level inverter are presented in Section II, including circuit topology, modulation strategy. The matlab implementation of the topology is discussed in Section III. The voltage, current band THD analysis is discussed in Section IV. The performance evaluation accomplished by simulation and experiment is described.

SWITCHED CAPACITOR BASED CASCADED INVERTER



switched capacitor multi-level inverter using POD technique

The proposed circuit is made up of the Switched Capacitor frontend and cascaded H-Bridge at the backend. If the numbers of voltage levels obtained by switched capacitor frontend and cascaded H-Bridge backend are $m1$ and $m2$, respectively, the number of voltage levels is $2 \times m1 \times m2+1$ in the entire operation cycle.

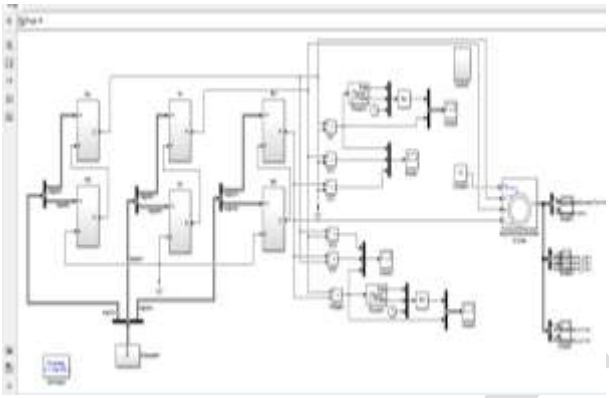
A. Circuit Topology

Fig.1 shows the circuit topology of nine-level inverter for m1 = 2 and m2 = 2 where S1, S2, S_1, S_2 as the switching devices of Switched capacitor circuits SC1 and SC2 are used to convert the series or parallel connection of C1 and C2 . S1a, S1b, S1c, S1d, S2a, S2b, S2c, S2d are the switching devices of cascaded H-Bridge. Vdc1 and Vdc2 are input voltage. D1 and D2 are diodes to restrict the current direction. i_{out} and v_o are the output current and the output voltage, respectively.

It is worth noting that the backend circuit of the proposed inverter is cascaded H-Bridges in series connection. It is significant for H-Bridge to ensure the circuit conducting regardless of the directions of output voltage and current. In other words, H-Bridge has four conducting modes in the conditions of inductive and resistive load, i.e., forward conducting, reverse conducting, forward freewheeling, and reverse freewheeling.

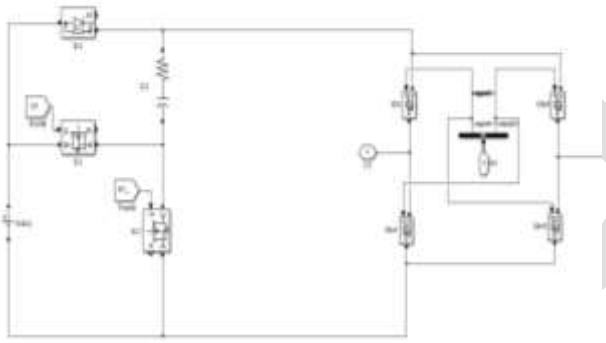
I. MATLAB IMPLEMENTATION OF PROPOSED SYSTEM

The Proposed system is implemented by using MATLAB/SIMULINK model design software as shown in fig.2. Each h-bridge block is associated with small buck/boost circuit which is controlled by PWM control. The input from either solar or battery or fuel cell is not enough to meet the load demand or change in load instantly so in order to have the steady state an extra arrangement of switch before to the each H-bridge converter is used as shown in fig.3

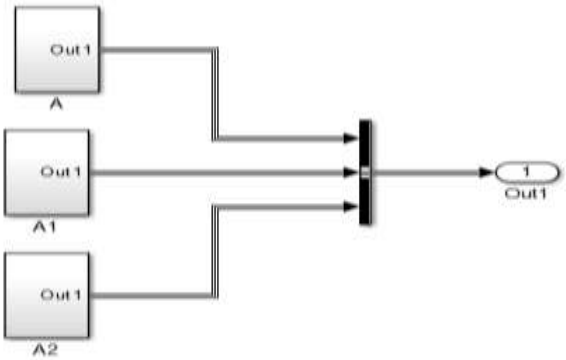


Matlab design of proposed system

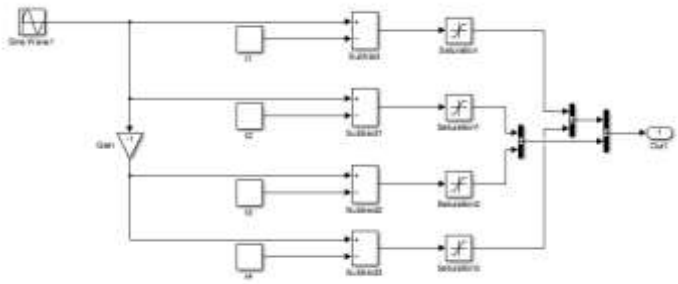
As shown in fig.2 the three phase system of proposed converter with switched capacitor nine-level converter is controlled here by Phase opposition disposition technique. In this technique there will be one reference wave and two carrier waves for each asymmetric H-bridge structure so as have required PWM.



Modified H-bridge cell of single phase



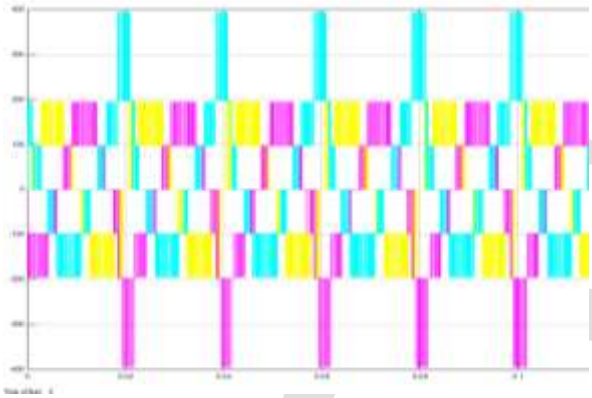
control system of proposed converter



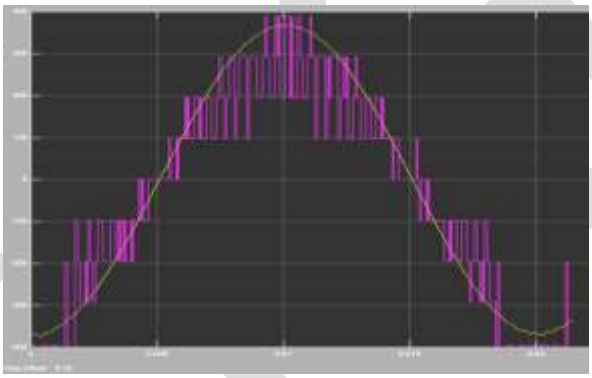
III. POD scheme of multi-carrier modulation using Matlab

IV. RESULTS AND ANALYSIS

The novel design of three phase switched capacitor Multi-level Inverter using Phase of disposition as control strategy has fruitful results. The phase output voltage of the proposed converter feeding the power to Induction motor is as shown in the following figs. The Fig.5 represents the line voltage waveform of the multi-level inverter. Using the asymmetric design of the proposed H-bridge converter the level has improved to nine-level instead of five-level.

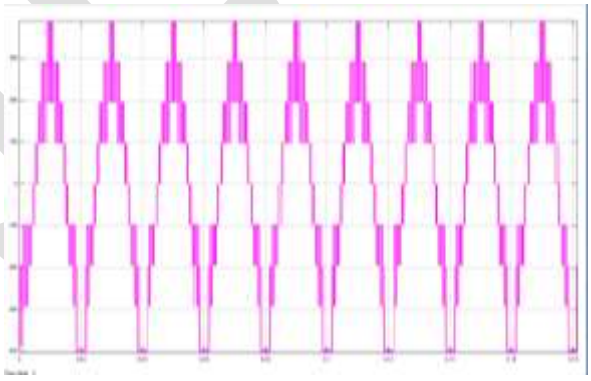


The line voltage waveform of the proposed converter



The line voltage and grid connected voltages of the proposed converter

The fig.7 clearly shows the comparison of the grid connected voltage and line voltage waveform of proposed converter. The nature of the nine-level waveform is almost like sinusoidal with small THD



The none-level phase voltage waveform of the switched capacitor multi-level converter

The fig.8 shows the seven-level waveform of the proposed converter output voltage waveform when using POD modulation technique.

V. CONCLUSION

In this paper a novel Switched Capacitor based cascaded multilevel inverter has proposed. A 9-level circuit topology is examined in depth. Compared with conventional cascaded multilevel inverter, the proposed inverter can greatly decrease the number of switching devices. A phase opposition disposition modulation is used as control technique with the low switching frequency and simple implementation. The accordant results of simulation confirm the feasibility of proposed circuit and modulation method

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