International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802319

A Switched Capacitor (SC) Inverter with Reduced Harmonics

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Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: This paper work addresses the multicarrier modulation technique called alternative phase opposition disposition (APOD) PWM, which is used to control the switched capacitor inverter. The switched capacitor inverter is simulated for various multicarrier based pulse width modulation techniques for a resistive load. The PWM technique includes APODPWM, PD PWM, ISPWM and the harmonics of the output voltages are observed for various modulation indices. The SC inverter outputs larger voltage than the input voltage by switching the capacitor series and parallel. The maximum output voltage of the inverter is determined by the number of capacitor in the circuit. The proposed Inverter does not require inductor, can be smaller than the conventional two stage conversion, consisting of boost converter followed by an inverter bridge. SC inverter output harmonics are reduced by the multilevel output, its harmonics are very less when compared to a conventional single phase full bridge inverter Performance of the chosen SC inverter is confirmed through MATLAB/SIMULINK based simulation.

KEYWORDS: Multi level Inverter, Switched Capacitor Inverter, APODPWM

I. INTRODUCTION

The EVs and the grid connected DG systems need an inverter to convert dc to ac. Boost converters or transformers are widely used in these systems when the input voltage is smaller than the output voltage. However, a transformer or an inductor in the boost converter makes the system large, because the transformer and the inductor must have large and heavy magnetic cores to sustain the high power . As a provision against the issue, a charge pump, which does not have any inductors, is applied to such systems. A charge pump outputs a larger voltage than the input voltage with switched capacitors. When the several capacitors and the input voltage sources are connected in parallel, the capacitors are charged. When the several capacitors and the input voltage sources are connected in series, the capacitors are discharged. The charge pump outputs the sum of the voltages of the capacitors and the input voltage sources.

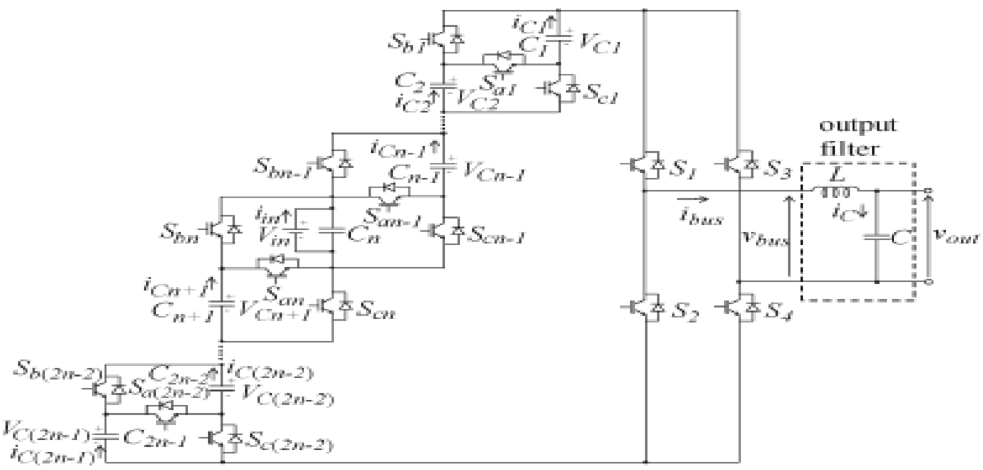

Fig.1. Circuit topology of the switched-capacitor inverter using series-parallel Conversion

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II. SYSTEM DESCRIPTION

Fig. 1 shows a circuit topology of the proposed inverter, where Sak, Sbk, Sck(k = 1, 2, . . . , 2n − 2) are the switching devices which switch the capacitors Ck(k = 1, 2, . . . , 2n − 1) in series and in parallel. Switches S1 − S4 are in the inverter bridge. A voltage source Vin is the input voltage source. A lowpass filter is composed of an inductor L and a capacitor C.

There are many modulation methods to drive a multilevel inverter: the space vector modulation ,the multicarrier pulse width modulation (PWM), the hybrid modulation ,the selective harmonic elimination ,and the nearest level control .In this project, the multicarrier APODPWM method is applied to the inverter

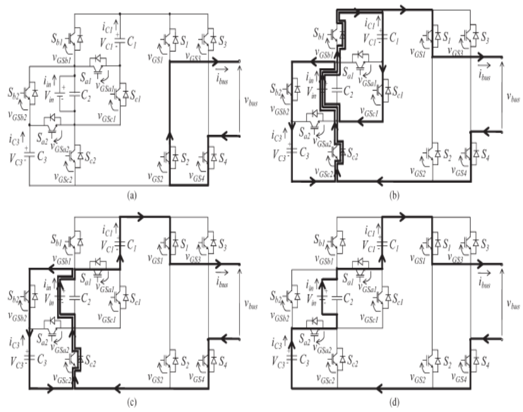

Fig. 2. Current flow of the proposed inverter ($n = 2$) on each state, (a) the current i_{bus} does not flow in the capacitors C_k, (b) all capacitors are connected in parallel, (c) the capacitor C_1 is connected in series and the capacitor C_3 is connected in parallel, and (d) all capacitors are connected in series.

Fig. 2 shows the current flow in the proposed inverter (n = 2) and Fig. 3 shows the modulation method of the proposed inverter (n = 2).When the time t satisfies 0 ≤ t < t1 in Fig. 3, the switches S1 and S2 are driven by the gate-source voltage vGS1 and vGS2, respectively. While the switches S1 and S2 are switched alternately, the other switches are maintained ON or OFF state as shown in Fig. 3. Therefore, the states shown in Fig. 2(a) and (b) are switched alternately and the bus voltage vbus takes 0 or Vin. When the time t satisfies t1 ≤ t < t2 in Fig. 3, the switches Sa1, Sb1, and Sc1 are driven by the gate-source voltage vGSa1, vGSb1, and vGSc1, respectively. While the switches Sa1, Sb1, and Sc1 are switched alternately, the other switches are maintained ON or OFF state as shown in Fig. 3. Therefore, the states shown in Fig. 2(b) and (c) are switched alternately. The capacitor C1 is charged by the current −iC1 as shown in Fig. 2(b) during the state shown in Fig. 2(b). Therefore, the proposed inverter can output the bus voltage vbus while the capacitor C1 is charged. The bus voltage vbus in the state of Fig. 2(c) is

$$vbus = Vin + VC1$$

where VC1 is the voltage of the capacitor C1. Therefore, the proposed inverter outputs Vin or Vin + VC1 alternately in this term. When the time t satisfies t2 ≤ t < t3 in Fig. 3, the switch Sa2, Sb2 and Sc2 are driven by the gate-source voltage vGSa2, vGSb2 and vGSc2, respectively. While the switches Sa2, Sb2, and Sc2 are switched alternately, the other switches are maintained ON or OFF state. Therefore, the states shown in Fig. 2(c) and (d) are switched alternately. The capacitor C3 is charged by the current −iC3 as shown in Fig. 2(c) during the state shown in Fig. 2(c). The bus voltage vbus in the state of Fig. 2(d) is

$$vbus = Vin + VC1 + VC3 \quad (2)$$

where VC3 is the voltage of the capacitor C3. Therefore, the proposed inverter outputs Vin + VC1 or Vin + VC1 + VC3 alternately in this term. After t = t3, the four states shown in Fig. 2 are repeated by turns.

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TABLE I
LIST OF THE ON-STATE SWITCHES ON EACH STATE

Relationship between e_s and e_k	On-state switches	Ideal bus voltage v_{bus}
$e_s > e_1$	S_1, S_4, S_{a1}, S_{a2}	$3V_{in}$
$e_1 \geq e_s > e_2$	$S_1, S_4, S_{a1}, S_{b2}, S_{c2}$	$2V_{in}$
$e_2 \geq e_s > e_3$	$S_1, S_4, S_{b1}, S_{c1}, S_{b2}, S_{c2}$	V_{in}
$e_3 \geq e_s > e_4$	$S_2, S_4, S_{b1}, S_{c1}, S_{b2}, S_{c2}$	0
$e_4 \geq e_s > e_5$	$S_2, S_3, S_{b1}, S_{c1}, S_{b2}, S_{c2}$	$-V_{in}$
$e_5 \geq e_s > e_6$	$S_2, S_3, S_{b1}, S_{c1}, S_{a2}$	$-2V_{in}$
$e_6 \geq e_s$	S_2, S_3, S_{a1}, S_{a2}	$-3V_{in}$

Table I shows the list of the on-state switches when the proposed inverter (n = 2) is driven by the modulation method . The ideal bus voltage vbus in Table I means the bus voltage on each state when VC1 = VC3 = Vin is assumed. As the conventional SC inverter, the proposed inverter has afull bridge which is connected to the high voltage. Therefore, the device stress of the switches S1 − S4 in the full bridge is higher than the other switches as the conventional SC inverter.

The proposed inverter (n = 2) outputs a 7-level voltage by repeating the four states as shown in Fig. 2. Because the driving waveform vGSa1 and vGSa2 change alternately. the capacitors C1 and C3 are equally discharged. Assuming that the number of the capacitors is 2n − 1, the proposed inverter can outputs 4n − 1 levels.

III. BLOCK DIAGRAM

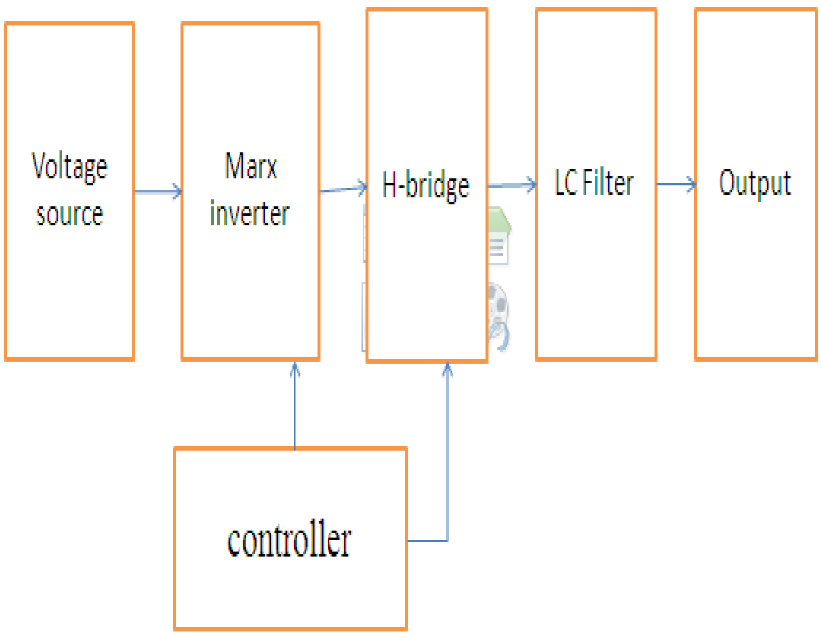

Fig.3 BLOCK DIAGRAM OF THE SYSTEM

A Voltage source Vin is the input voltage source.The inverter consists of Marx inverter and H-bridge. Marx inverter consists of less switching devices which switch the capacitors in series and in parallel. Marx inverter can be regarded as one of the SC inverters because of its operating principle. A Low pass filter consists of an inductor and the capacitor. The output harmonics of the proposed inverter are reduced by the multilevel output. The Marx Inverter is a multilevel inverter that generates its voltage levels by controllably stacking charged capacitors in series.Voltage levels are maintained by placing the capacitors in parallel when the output voltage periodically passes through zero volts. This

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approach has a number of advantages over traditional multilevel inverters that need external voltage balancing circuits or sophisticated control to maintain voltage levels while delivering real power. LC Filter is used to reduce the ripples.

SIMULATION DIAGRAM OF THE SYSTEM

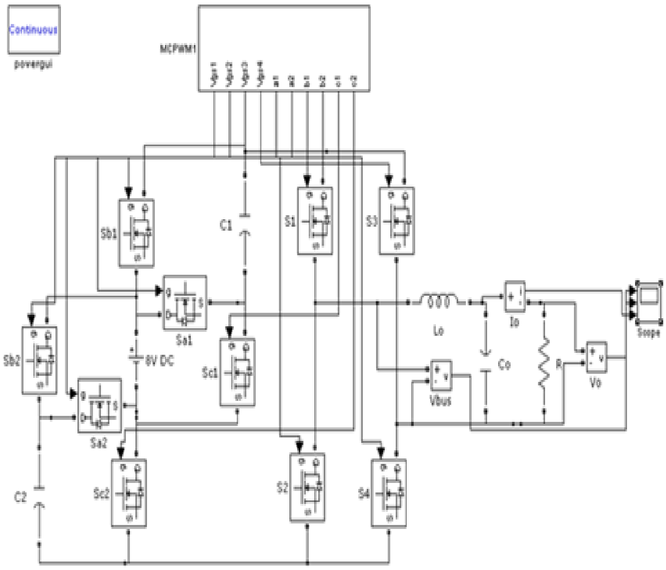
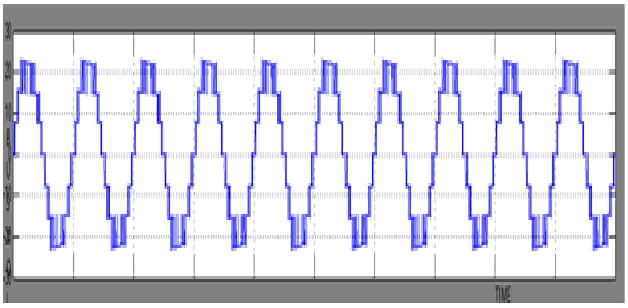
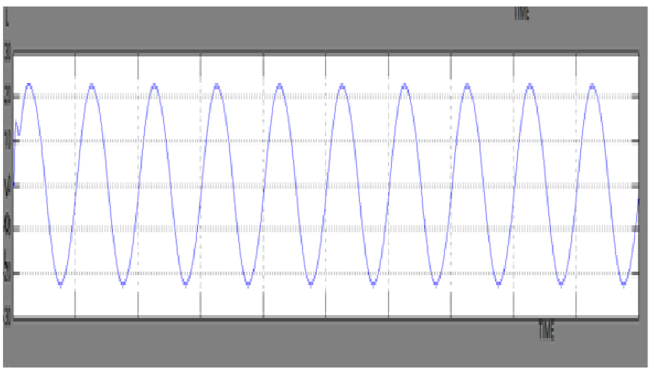


FIG 4 simulation model of the system

SIMULATED WAVEFORM OF THE INVERTER





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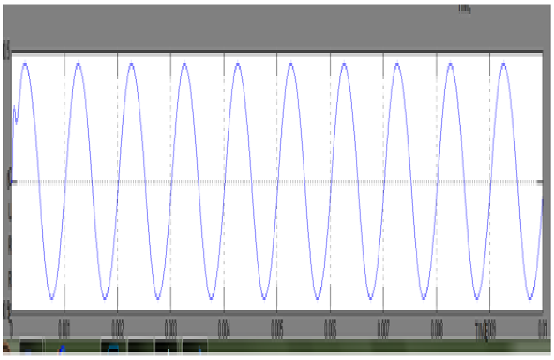

FIG 5 Simulated voltage and current waveforms of the inverter (a)Bus voltage (b) output voltage Vout (c) current

% OF THD

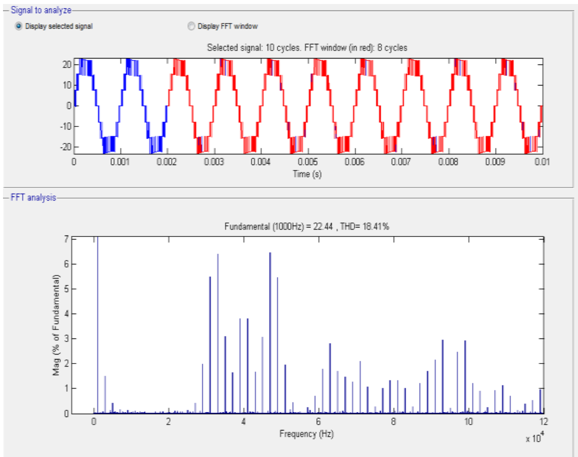

Fig 6 % of THD

MULTICARRIER OUTPUT WAVEFORM

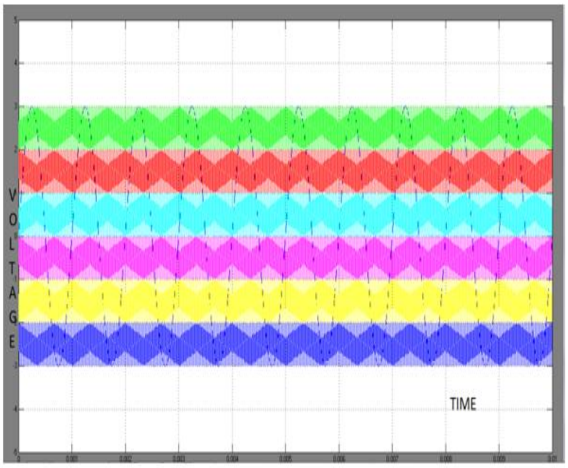

Fig 7 Multicarrier output waveform

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SIMULATION RESULTS

MATLAB/SIMULINK ver. R2010 under the following conditions. The MOSFET models whose internal resistance Ron = 0.54 [Ω] and the snubber resistance Rs = 105 [Ω] were used as the switching devices. The input voltage Vin = 8.00 [V], the output resistance R = 50.0 [Ω], a filter capacitance C, and a filter inductance L were C = 0.450 [μF] and L = 1.13 [mH], the modulation index M = 3.00, the switching frequency f = 40.0 [kHz], and the reference waveform frequency fref = 1.00 [kHz]. From (8), the capacitance C1 and C3 are calculated to C1 = C3 = 143 [μF] The THDs of the proposed inverters are reduced compared to the conventional single phase full bridge inverter.

IV. CONCLUSION

In this paper, a novel boost switched-capacitor inverter was proposed. The circuit topology was introduced. The modulation method, the determination method of the capacitance, and the loss calculation of the existing inverter were shown. The circuit operation of the proposed inverter was confirmed by the simulation results and the experimental results with a resistive load and an inductive load. The existing inverter outputs a larger voltage than the input voltage by switching the capacitors in series and in parallel. The inverter can operate with an inductive load. The structure of the inverter is simpler than the conventional switched-capacitor inverters. THD of the output waveform of the inverter is reduced compared to the conventional single phase full bridge inverter as the conventional multilevel inverter.

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| Volume 8, Issue 2, March - April 2026 |

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