A NEW SWITCHED-CAPACITOR NINE-LEVEL INVERTER

BỘ NGHỊCH LƯU CHUYỂN TỤ ĐIỆN 9 BẬC

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ABSTRACT

This paper proposes a new configuration of the switched-capacitor multilevel inverter (SCMI). The proposed switched-capacitor nine-level inverter configuration uses the capacitors to raise the output voltage level and boost output voltage. Based on switching the capacitors in series and in parallel through the semiconducting switches, the capacitors can be balance without using auxiliary circuit. The proposed topology does not use more power supplies, moreover the proposed inverter of components are used less than the traditional inverter configuration, thereby reducing the cost and size of the system. To verify the circuit operation, PSIM simulation is performed for 9-level configuration. The experimental results are also shown with 9-level inverter configuration.

Keywords: *Multilevel inverter; switched-capacitor; pulse-width modulation (PWM); voltage source inverter (VSI); nine-level.*

TÓM TẮT

Bài báo này đề xuất một cấu hình của bộ nghịch lưu đa bậc chuyển tụ điện. Cấu hình được đưa ra trong bài báo sử dụng các tụ điện để tăng số bậc điện áp ngõ ra và nâng điện áp ngõ ra của mạch. Dựa trên việc chuyển đổi mắc nối tiếp, song song của tụ điện trong mạch thông qua các công tắc chuyển mạch, các tụ điện trong mạch có thể tự cân bằng mà không cần phải sử dụng đến các mạch bổ trợ. Cấu hình này làm giảm số công tắc bán dẫn, nguồn ngõ vào so với các cấu hình nghịch lưu truyền thống, từ đó làm giảm chi phí và kích thước của hệ thống. Bài báo thực hiện mô phỏng trên phần mềm PSIM 9.0 và được làm thực nghiệm tại phòng thực tập điện tử công suất nâng cao D405, Trường Đại học Sư phạm Kỹ thuật TP.HCM với cấu hình nghịch lưu 9 bậc.

Từ khóa: *Nghịch lưu đa bậc; chuyển tụ điện; phương pháp điều chế độ rộng xung; nghịch lưu nguồn áp; chín bậc.*

1. INTRODUCTION

Multilevel inverters are one of the important components in the power electronic field. Today under the development of clean energy sources as solar energy, wind power, the MIs are used to switch DC power to AC power for distribution generation system. Along with the development of technology, the inverters are constantly improved in performance and quality. The multilevel inverter has the following advantages as improved output waveform quality, lower electron magnetic-interface (EMI) and lower device stress [1] - [4].

In the field of motor control, in electric generators, electric vehicles or power distribution systems, inverters are widely used. The MI configurations are commonly used as the NPC clamping diode configuration [5], flying capacitor [6] – [7], Cascade H-bridge [8] – [11]. However, these configurations use a large number of components (semiconductor switches, power

supplies, capacitors, and diode), which increases the cost of the inverter and the control becomes complicated.

To solve the problems in traditional inverters, the switched-capacitor has been developed. The switched-capacitor multilevel inverter (SCMI) uses charging and discharging characteristics of the capacitor to reduce the number of the source in the circuit. The SCMI can be self-balance by switching the capacitors in parallel and in series through the switches. In the parallel mode, the capacitors are charged directly by power supply, while they release store energy during the series mode.

This paper presents a new SCMI configuration which combines with the H-bridge circuit to create output ladder voltage waveform in reducing the number of switches. The proposed inverter does not use any inductors. This paper verifies the operating principle through the simulation result of nine-level configuration by P.SIM 9.0 software. The study results are also demonstrated through experiments with inverter 9-level.

2. PROPOSED SWITCHED-CAPACITOR NINE-LEVEL INVERTER

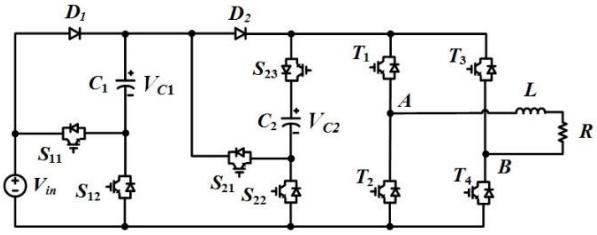

Fig. 1. *The proposed switched-capacitor nine-level inverter.*

2.1 Circuit analysis

Fig 1 is a proposed switched - capacitor nine-levels inverter (PSCNI) schematic. The proposed SCMI is association of the SCMI and H-bridge embrace S_{11}, S_{12}, S_{21}, S_{22} and S_{23} are switched-capacitor switches and T_1, T_2, T_3 and T_4 is the switches of H-bridge, the circuit also uses two capacitors are C_1, C_2, two diodes are D_1, D_2 and an input source is V_{in}.

In the operation circuit, the C_1 capacitor is charged in parallel connection with the input source through S_{12}, while it is discharged in series connection with the input source through S_{11}. Also, the C_2 capacitor is charged in parallel connection with the C_1 capacitor, input source through S_{22} and anti-parallel diode of S_{23}, while it is discharged in series connection with the C_1 capacitor and input source through S_{21}, S_{23}.

2.2 Operating principle

Fig. 2 shows the five operating states of the proposed inverter at the positive period.

+ **State 1**: At this state, the output voltage is V_{AB} = 0 V. The S_{12}, T_1 and T_3 switches are in the ON state,the S_{11}, T_2 and T_4 switches are in the OFF state, the D_1 diode is forward-biased, the D_2 diode is reverse-biased, the C_1 capacitor is charged from the input source and $V_{C1} = V_{in}$.

+ **State 2:** The S_{12}, T_1 and T_4 switches are in the ON state, the S_{11}, T_2 and T_3 switches are in the OFF state, the D_1 and D_2 diodes are forward-biased, the C_1 capacitor is charged from the input source and $V_{C1} = V_{in}$. At this state, the output voltage is $V_{AB} = V_{in}$.

+ **State 3**: The S_{11}, S_{22}, T_1 and T_4 switches are in the ON state, the S_{12}, S_{21}, S_{23}, T_2 and T_3 switches are in the OFF state, the D_1 diode is reverse-biased, the D_2 diode is forward-biased, the C_1 capacitor is discharge, the C_2 capacitor is charged form the input source and the C_1 voltage, $V_{C2} = V_{C1} + V_{in} = 2V_{in}$. In this state, the output voltage is $V_{AB} = V_{C1} + V_{in} = 2V_{in}$.

+ **State 4:** The S_{12}, S_{21}, S_{23}, T_1 and T_4 switches are in the ON state, the S_{11} and S_{22}, T_2 and T_3 switches are in the OFF state, the D_1 diode is forward-biased, the D_2 diode is reverse-biased, the C_1 capacitor is charged from input source and $V_{C1} = V_{in}$, the C_2 capacitor is discharged. In this state, the output voltage is $V_{AB} = V_{C2} + V_{in} = 3V_{in}$.

+ **State 5:** The S_{11}, S_{21}, S_{23}, T_1 and T_4 switches are in the ON state, the S_{12}, S_{22}, T_2 and T_3 switches are in the OFF state, the D_1 and D_2 diodes are reverse-biased, the C_1 and

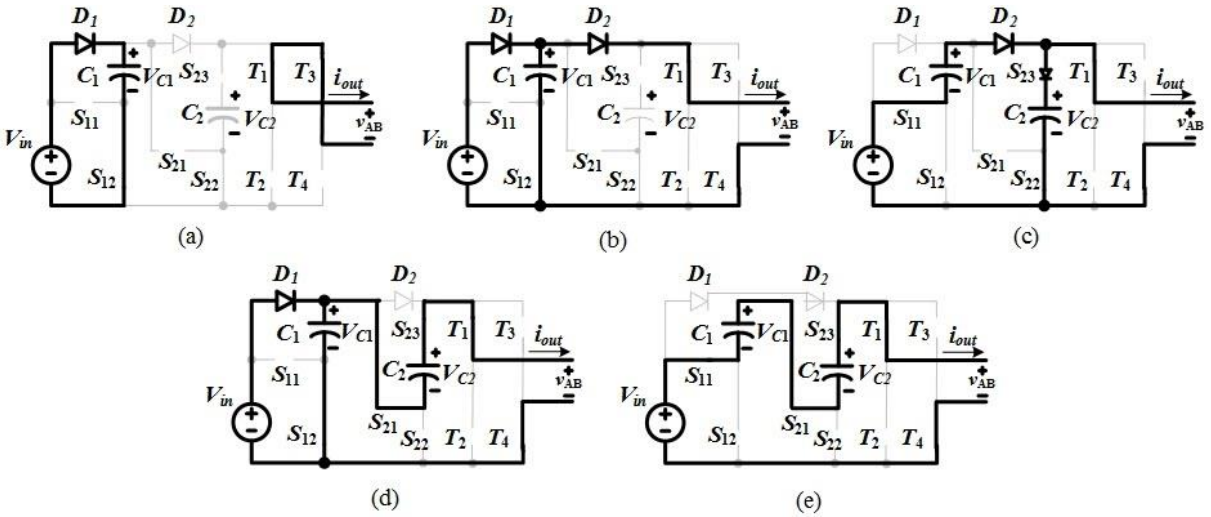

Fig. 2. *Operation states of the proposed inverter in positive period: (a) state 1; (b) state 2; (c) state 3; (d) state 4; (e) state 5.*

C_2 capacitors are discharged. In this state, the output voltage is $V_{AB} = V_{C1} + V_{C2} + V_{in} = 4V_{in}$.

In the negative period, the status of the switches in the H-bridge circuit is opposite with the positive period, the T_2 and T_3 switches are in the ON state, the T_1 and T_4 switches are in the OFF state, the other components the inverter circuit change similar to the positive period in each circuit operation state. All state of the switches and diodes in the proposed topology are shown in Table 1.

Table 1. *The switches and diodes in the ON state*

No	The switches and diodes in the ON state	Output voltage
1	S_{11}, S_{21}, S_{23}, T_1, T_4.	$4V_{in}$
2	S_{12}, S_{21}, S_{23} T_1, T_4, D_1.	$3V_{in}$
3	S_{11}, S_{22}, T_1, T_4, D_2.	$2V_{in}$
4	S_{12}, T_1, T_4, D_1, D_2.	V_{in}
5	S_{12}, T_1, T_3, D_1	0
6	S_{12}, T_2, T_3, D_1, D_2.	$-V_{in}$
7	S_{11}, S_{22}, T_2, T_3, D_2.	$-2V_{in}$
8	S_{12}, S_{21}, S_{23}. T_2, T_3, D_1.	$-3V_{in}$
9	S_{11}, S_{21}, S_{23}, T_2, T_3.	$-4V_{in}$

3. THE SIMULATION AND EXPERIMENT RESULTS

To verify the operation of the proposed switched-capacitor nine-level inverter, the simulations perform by PSIM software and experiments get by Tektronix TDS 2024B. The physical model was built according to the schematic in Fig. 1 with R = 80 Ω, C_1 = C_2 = 2200 µF, V_{in} = 45 V.

3.1 The simulation results

Fig 3 shows the voltage waveform of the C_1 and C_2 capacitors. The maximum and minimum values of the C_1 capacitor voltage (V_{C1}) are 45 V and 42.8 V, respectively. The maximum and minimum values of the C_2 capacitor voltage (V_{C2}) are 90 V and 85.8 V, respectively.

Fig 4 shows the output voltage waveform with the total harmonic distortion is 14 % (Fig 5).

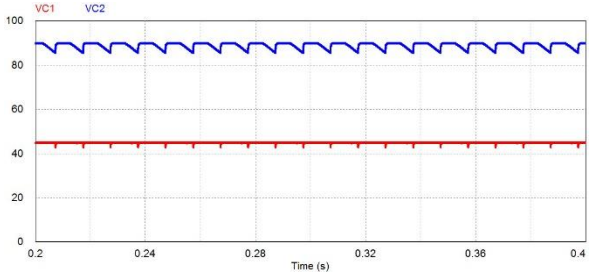

Fig. 3. *The voltage waveform of the C_1 and C_2 capacitors.*

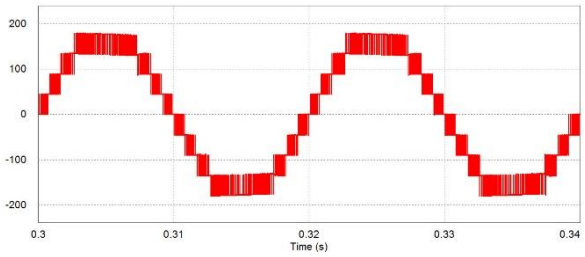

Fig. 4. *The output voltage waveform of the switched-capacitor nine-level inverter.*

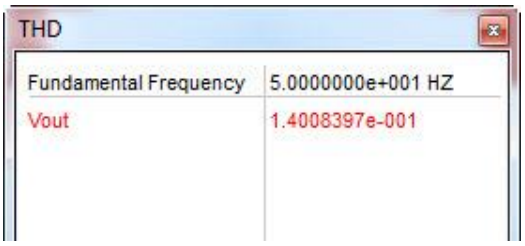

Fig. 5. *The total harmonic distortion of the output voltage waveform.*

3.2 The experiment results

Fig 6 shows the voltage waveform of the C_1 and C_2 capacitors. The maximum and minimum values of the C_1 capacitor voltage (V_{C1}) are 44.1 V and 38.8 V, respectively. The maximum and minimum values of the C_2 capacitor voltage (V_{C2}) are 86.7 V and 79.8 V, respectively.

Fig 7 shows the output voltage waveform with the total harmonic distortion is 9.49 % (Fig 8).

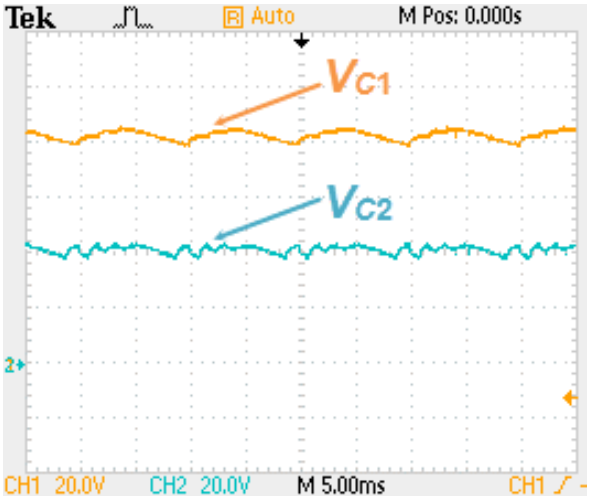

Fig. 6. *The voltage waveform of the C_1 and C_2 capacitors.*

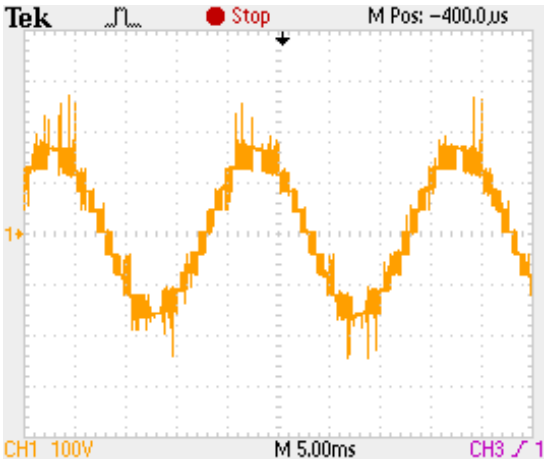

Fig 7. *The output voltage waveform of the switched-capacitor nine-level inverter.*

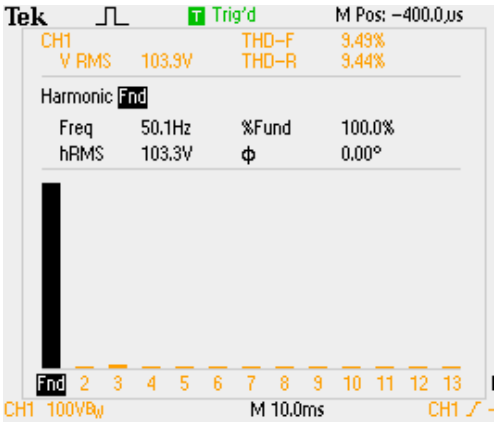

Fig. 8. *The total harmonic distortion of the output voltage waveform.*

4. CONCLUSION

This paper proposes a new switched-capacitor multilevel inverter. This paper presents the operation principle of the switched-capacitor nine-level inverter. Based on theory, the proposed inverter conduct simulation on the software PSIM 9.0 and the circuit operability is also verified by the fact pattern. Overall, the proposed SCMI has the number of components reduced compared with conventional inverter thus saving cost and reducing complexity in control.

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