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Modulation Scheme of An Improved 5-Level Current Source Inverter

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***Abstract*— A 5-level self-balancing current source inverter (CSI) was recently reported. In this inverter, two diodes are used to provide current paths for DC inductors, while they introduce large power loss. Replacing diodes with active switches is a well-proven technology to increase the efficiency of a power converter. However, the use of active switches to replace diodes in this 5-level CSI has a challenge in modulation design. In this work, a novel modulation scheme is developed to accommodate this replacement. By applying the proposed modulation, the 5-level CSI with active switches retains all the advantages of the original version. Experiments are provided to validate the effectiveness of the proposed modulation.**

Keywords—Current source inverter, five-level, modulation, self-balancing

I. INTRODUCTION

Compared with conventional 3-level current source inverters (CSIs), 5-level CSIs have better harmonic performance, contributing to the need for smaller filters [1-12]. However, most of the existing 5-level CSIs suffer current imbalance issues which require the use of extra current balancing controls. Recently, a new 5-level CSI with self-balancing capability was proposed [13]. It achieves DC current balancing without the need for extra balancing controls. However, it employes two diodes to provide paths for the DC currents, resulting in high power loss. Replacing diodes with active switches is a well-proven technology to increase the efficiency of a power converter. However, the use of active switches to replace diodes in this 5-level CSI has a challenge in modulation design. In this work, a novel modulation scheme is developed to accommodate this replacement. By applying the proposed modulation, the 5-level CSI with active switches retains all the advantages of its original version. Experiments are provided to validate the effectiveness of the proposed modulation.

II. PROPOSED IMPROVED 5-LEVEL CURRENT SOURCE INVERTER

Fig. 1 shows the recently proposed 5-level self-balancing CSI. It consists of a conventional H-bridge inverter, an extra switch S_5, two DC inductors L_1 and L_2, and two diodes D_1 and D_2. It has two operating modes: Mode 1 and Mode 2. In Mode 1, S_5 is turned on, while D_1 and D_2 are off. In this mode, the two DC inductors L_1 and L_2 are connected in series, achieving DC currents balancing. In Mode2, S_5 is off, while D_1 and D_2 are turned on to provide current paths for DC inductor currents iL_1, and iL_2.

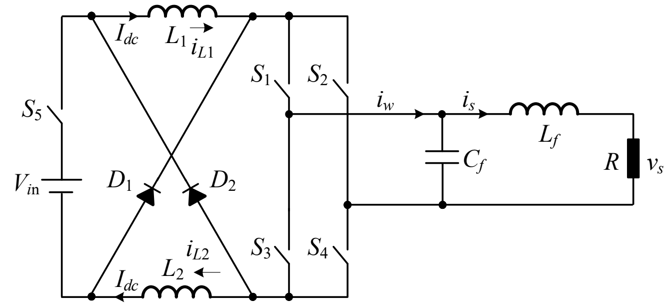

Fig. 1 Self-balancing 5-level CSI [13].

Fig. 2 shows the improved version, where the two diodes (D_1 and D_2) used in the original inverter in Fig. 1 are replaced with two active switches (S_6 and S_7). The use of active switches to replace diodes contributes to improved efficiency. However, the use of two more switches (S_6 and S_7) results in a challenge in modulation scheme design. In this work, a novel modulation scheme is developed to address this challenge.

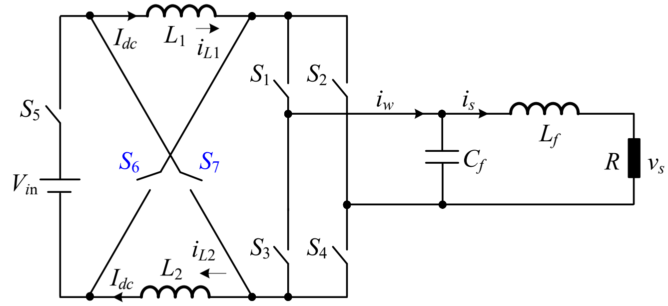

Fig. 2 Proposed improved self-balancing 5-level CSI.

III. Proposed Modulation Scheme

The proposed modulation scheme is shown in Fig. 3, where three groups of switches are switched in a complimentary manner: (S_1 and S_2), (S_3 and S_4), and (S_5, S_6 and S_7). Taking S_4 as an example, two carries waveforms (vc_1 and vc_2) with a phase shift of 180-degree are compared with the modulating waveform respectively and output $S_{4\text{-}1}$ and $S_{4\text{-}2}$. m_a is the modulation index, $\omega = 2\pi f$ is the angular speed, and f is fundamental frequency. S_4 is obtained based on $S_{4\text{-}1} + S_{4\text{-}2}$. In the case of $S_{4\text{-}1} + S_{4\text{-}2} = 2$, $i_w = 2I_{dc}$ and $S_4 = 1$ and $S_5 = 0$. In the case of $S_{4\text{-}1} + S_{4\text{-}2} = 1$, $i_w = I_{dc}$ and $S_4 = 1$ and $S_5 = 0$. In the case of $S_4 + S_{4\text{-}2} = 0$, $i_w = 0$ and $S_4 = 0$ and $S_5 = 1$. Following the above, the switching patterns for switches S_4 and S_5 are achieved. The switching pattern of remaining switches is obtained according to the complimentary manner. Applying the obtained gating signals to the improved inverter, it retains all the advantages of the original inverter as shown in Fig. 3.

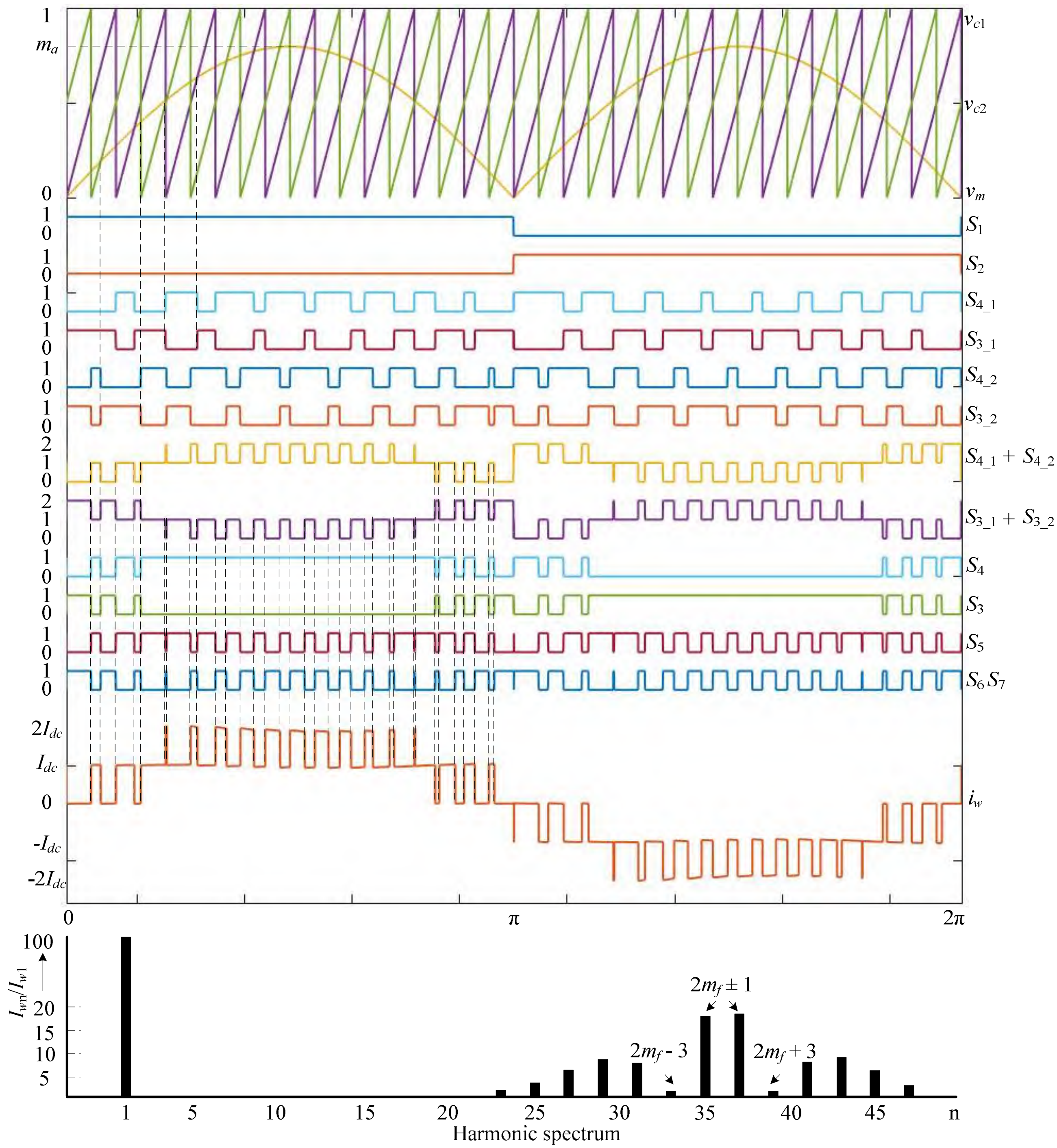

Fig. 3 Proposed modulation over a fundamental-frequency cycle ($m_a = 0.8$, $m_f = 18$).

IV. Experimental Verification

Lab-scale experiments are conducted to verify the performance of the proposed improved inverter and the proposed modulation scheme. Key parameters are listed in Table I. Fig. 4 shows the gating signals over a fundamental-frequency cycle under m_a = 0.8. As shown in the figure, the switching frequencies of the switches are fundamental frequency for switches S_1 and S_2, modulating frequency for S_3 and S_4, and two times modulating frequency for S_5, S_6 and S_7.

Fig. 5 shows the experimental waveforms under both steady and dynamic states at m_a = 0.5 and m_a = 0.8, respectively. As shown in Fig. 5, DC inductor currents (i_{L1} = i_{L2}) are well balanced without balancing controls under both steady and dynamic states. The same as the original inverter, m_a = 0.5 is the boundary, below which, the improved inverter becomes a conventional 3-level CSI, while above which, it is a 5-level CSI.

TABLE I
Experimental Parameters

Currents	Passive components	Switching frequency
I_{dc}=5 A	L_1 = L_2 = 40 mH	f_{s1} = f_{s2} = 50 Hz
I_{L1}=5 A	L_f = 5 mH	f_{s3} = f_{s4} = 900 Hz
I_{L2}=5 A	C_f = 100 μF	f_{s5} = f_{s6} = f_{s7} = 1800 Hz

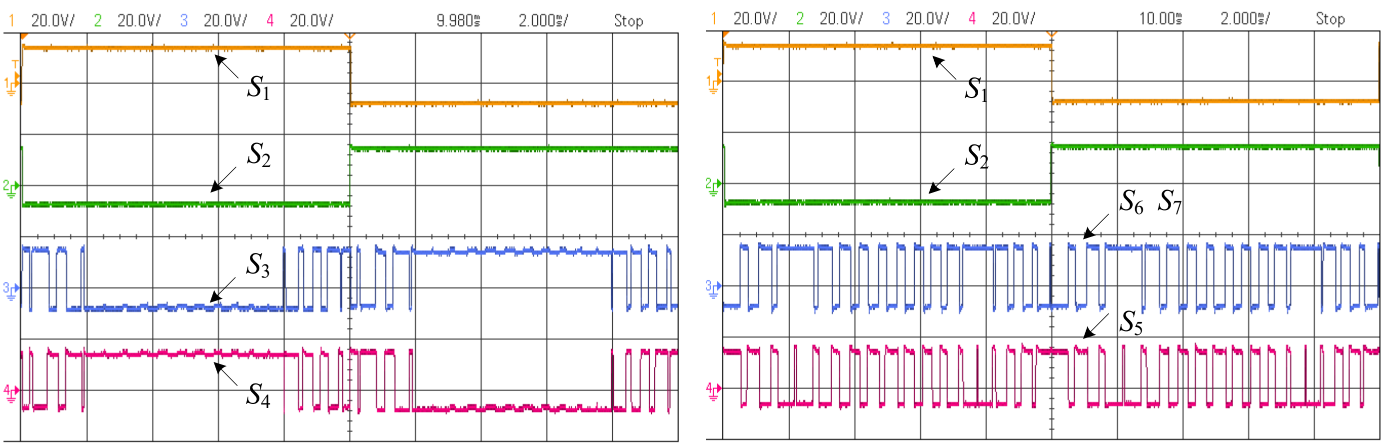

Fig. 4 Gating signals over a fundamental-frequency cycle under m_a = 0.8.

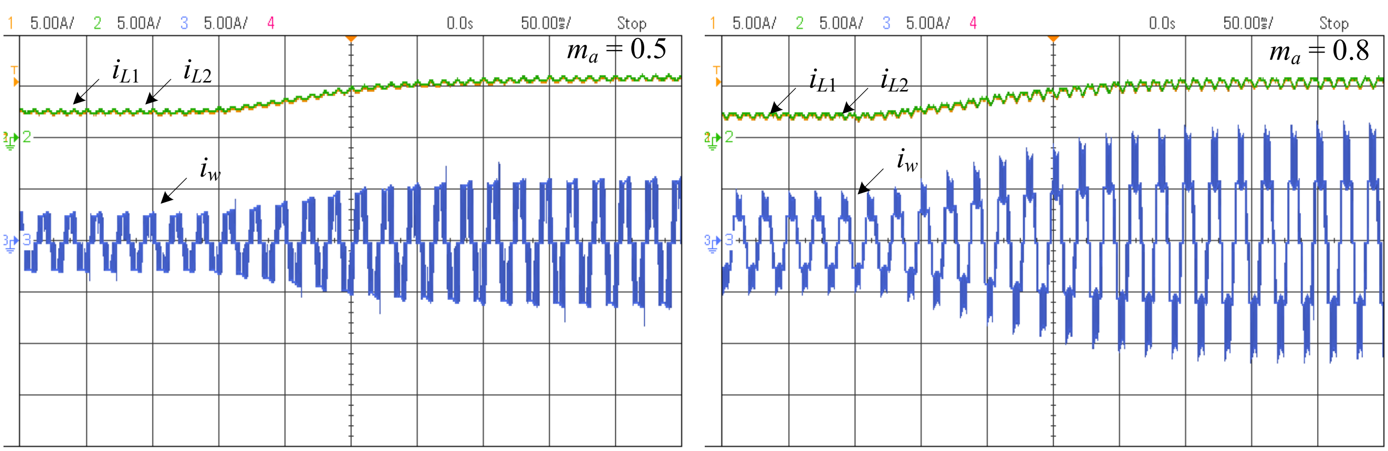

Fig. 5 Experimental waveforms under both steady and dynamic states with different m_a.

V. Conclusions

A modular MFT-based CSC is proposed for the LV An improved 5-level self-balancing CSI is proposed in this work. The two diodes used in the original inverter are replaced with two active switches, thereby improving its power efficiency. A new modulation scheme has therefore been developed for the improved CSI. By applying the proposed new modulation scheme to the improved CSI, all the advantages of the original inverter are retained. Experiments have been conducted to validate the effectiveness of the proposed modulation.

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