A Single-Input Single-Phase Five-Level Current Source Inverter with Reduced DC Inductance Value

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***Abstract*—A single-input, single-phase, five-level current source inverter (CSI) with inherent DC current balancing has been recently reported. However, its main limitation is the requirement for large DC inductors under rated conditions (modulation index = 1), which increases the system size and reduces efficiency. To overcome this limitation, this paper proposes a new single-input, single-phase, five-level CSI that reduces the required DC inductance to one-third of the original value, while retaining the inherent DC current balancing of the original topology. The operating principle of the proposed inverter is analyzed, and its performance is validated by simulations.**

Keywords—current source Inverter, 5-level, DC inductance reduction

I. INTRODUCTION

Five-level current source inverters (CSIs), known for their superior harmonic performance and reduced filter requirements, have gained increasing attention [1-13]. However, a major technical challenge for these converters is DC current imbalance, which necessitates complex current-balancing control schemes. To address this problem, a single-input, single-phase, five-level CSI with inherent self-balancing capability was recently proposed [14], effectively eliminating the need for dedicated balancing controls. Despite this advantage, the topology requires large DC inductors under rated conditions (modulation index = 1), resulting in large size and reduced efficiency. To solve this problem, this paper proposes a new CSI that retains the inherent DC current self-balancing capability of the original inverter, while reducing the required DC inductance to one-third of the original value.

II. PROPOSED FIVE-LEVEL CSI

Fig. 1 shows the five-level self-balancing CSI recently proposed in literature [14]. It is composed of an H-bridge inverter, a switch S_5, two diodes D_1 and D_2, and two DC inductors L_1 and L_2. It operates in two modes: Mode 1 and Mode 2. In Mode 1, S_5 is turned on, where the two DC inductors L_1 and L_2 are connected in series, ensuring DC currents balancing. In Mode2, S_5 is off, and D_1 and D_2 are turned on to provide paths for DC inductor currents i_{L1}, and i_{L2}. The H-bridge operates similar as the conventional H-bridge current source inverter. For example, when the switches S_1 and S_4 are turned on, the output PWM current (i_w) reaches the positive DC current. With S_2 and S_3 turned on, H-bridge outputs negative DC current. And the H-bridge achieves negative DC current when S_1 and S_3 are turned on, or S_2 and S_4 are turned on. The DC input current is determined by the states of the switch S_5.

This single-input single-phase five-level converter can achieve inherent current balancing. While its challenge is that it requires large DC inductors L_1 and L_2 under rated conditions (m_a = 1).

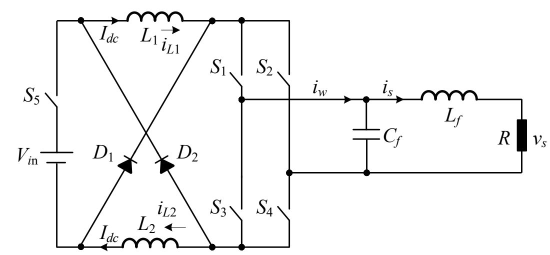

Fig. 1. Single-input, single-phase, five-level CSI [14].

Fig. 2 shows the proposed new five-level CSI. It is composed of an H-bridge inverter, three switches S_5, S_6, and S_7, and two DC inductors L_1 and L_2. It also operates in two modes: Mode 1 and Mode 2.

Fig. 3 shows the two circuits under two modes. In Mode 1, S_6 is turned on, and S_5 and S_7 are off. As a result, the two DC inductors L_1 and L_2 are connected in series, ensuring DC currents balancing, $i_{L1} = i_{L2}$. In Mode 2, S_6 is off, while S_5 and S_7 are turned on. The two DC inductors L_1 and L_2 are connected in parallel, resulting in a double dc current output, that is $I_{dc} = i_{L1}$, and i_{L2}. As a result, the DC input current of the H-bridge contains both I_{dc} and $2I_{dc}$, enabling the generation of a 5-level output PWM current. The H-bridge operates similar to the one used in [14]. The 5 levels and corresponding switching states are listed in Table I.

In both operating modes, the DC inductors are energized by the input voltage V_{in}. During the two operating modes, the inductors are able to be charged. Consequently, compared with the original inverter shown in Fig. 1 [14], where the DC inductors are charged during only one of the two operating modes, the proposed inverter allows a substantial reduction in the required DC inductance under m_a = 1.

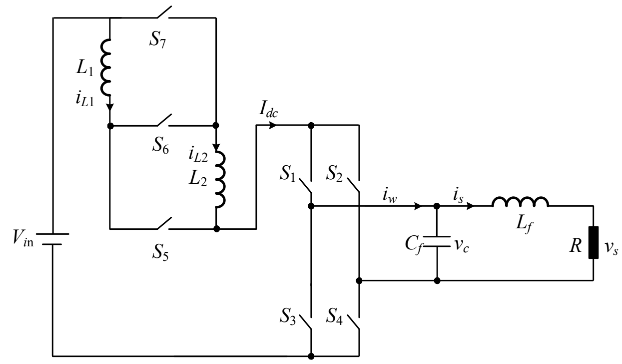

Fig. 2. Proposed new single-input, single-phase, five-level CSI

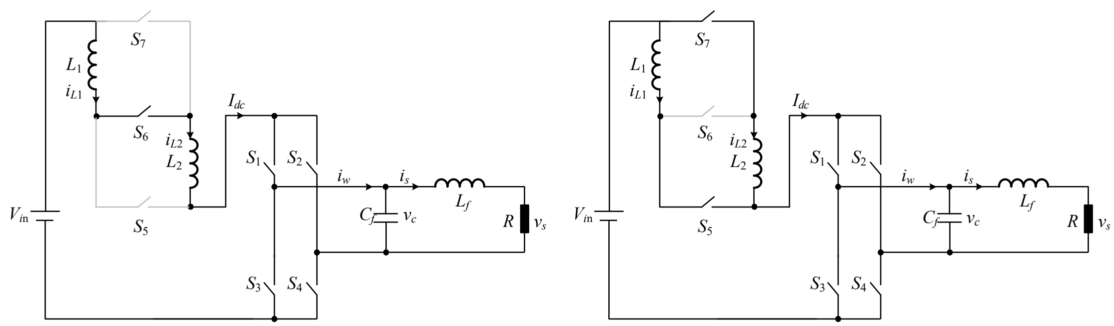

Fig. 3. Two operation modes of the proposed CSI: Left (Mode 1) and right (Mode 2)..

TABLE I. OUTPUT PWM CURRENT LEVEL AND SWITCHEING STATES

Output PWM Current i_w	Switching states						
	Extra switches			*H-bridge*			
	S_5	S_6	S_7	S_1	S_2	S_3	S_4
0	0	1	0	1	0	1	0
	1	0	1	1	0	1	0
	0	1	0	0	1	0	1
	1	0	1	0	1	0	1
	0	1	0	1	0	1	0
	1	0	1	1	0	1	0
	0	1	0	0	1	0	1
	1	0	1	0	1	0	1
I_{dc}	1	0	1	1	0	0	1
$-I_{dc}$	1	0	1	0	1	1	0
$2I_{dc}$	0	1	0	1	0	0	1
$-2I_{dc}$	0	1	0	0	1	1	0

III. SIMULATION RESULTS AND COMPARISON

MATLAB/Simulink-based model is built to investigate the performance of the proposed inverter. Parameters used in the simulation are listed in Table II.

Fig. 4 (a) shows the gating signals of the switches in a fundamental frequency cycle. As shown, S_1 and S_2 are switching with a fundamental frequency, while S_5 and S_7 are switching with a modulating frequency. The switching frequency of S_5 and S_7 is two times the switching frequency of S_3 and S_4. Fig. 4 (b) and (c) show the simulated waveforms of the key parameters including the DC inductor currents (i_{L1}, and i_{L2}), the output PWM current (i_w), load current (i_s), and load voltage (v_c). As shown, DC inductor currents are well balanced under both steady and dynamic states. This is because the two dc currents of the inductors are forced to be equal during their series connection. This converter can achieve inherent current balancing the same as the original single-input single-phase 5-level inverter.

TABLE II. SIMULATION PARAMETERS

Voltage/Currents	Passive components	Switching frequency
V_{in}=1000 V	L_1=L_2=150 mH	f_{s1}=f_{s2}=60 Hz
I_{L1}=50 A	L_f=10 mH, C_f=50 μF	f_{s3}=f_{s4}=1080 Hz
I_{L2}=50 A	R=17 Ω	f_{s5}=f_{s6}=f_{s7}=2160 Hz

Comparison in DC inductance: Fig. 5 shows the DC inductor current ripples of the proposed inverter and the original inverter under rated (m_a = 1) and same conditions including same DC inductance. As shown, the ripple of the original inverter is three times that of the proposed inverter, which in turn proves that the required DC inductance of the proposed inverter is three times reduced. This is because in the original converter the inductors are only charged during its Mode 1. As a result, with the same inductance the resultant current ripple is much higher than that in the proposed 5-level CSI.

Comparison in switches: The proposed inverter uses two more switches than the original inverter. However, as shown in Fig. 3(a) and (b), the voltage stress of switches S_5, S_6, and S_7 in the proposed inverter is (V_{in} + V_c)/2 and their current stress is I_{dc}/2. In contrast, switch S_5 in the original inverter experiences a voltage stress of V_{in} + V_c and a current stress of I_{dc}. Therefore, in practice, no extra burden will be added by the two more switches.

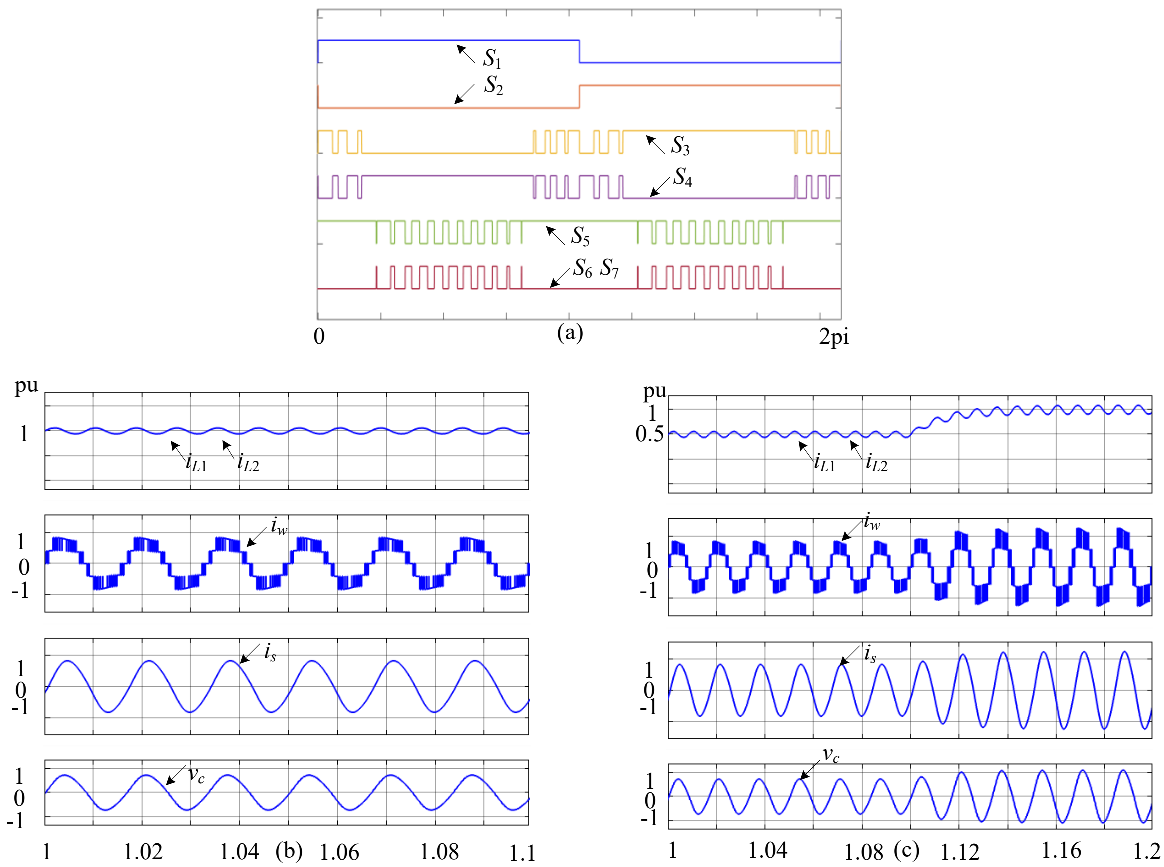

Fig. 4. Simulated waveforms of the proposed CSI.

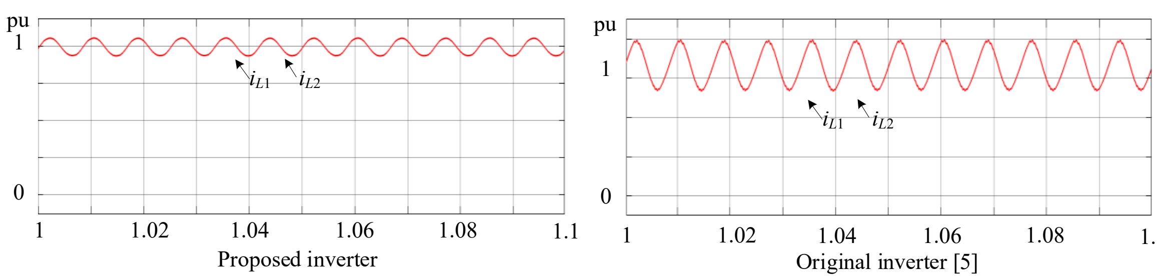

Fig. 5. Simulated DC inductor requirements under rated conditions.

Conclusions and Future Work

A novel single-input, single-phase, five-level CSI is proposed in this work. It retains the DC current self-balancing capability of the original inverter, while reduces the required DC inductance to be one third of the original inverter. No disadvantages are introduced by the addition of two extra switches, thanks to the halved voltage and current stresses. Analysis and simulation have been provided to verify the performance of the proposed inverter. It is a promising candidate for current source-fed applications such as solar energy systems and fuel cell energy systems. Lab-scale experimental work has been started and plans for the final submission of a full paper mainly include adding in-depth analysis and experimental results.

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