A Dual-Buck-Structured Transformerless Inverter with a Common Ground

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***Abstract*—This paper proposes a new common-ground transformerless inverter for a single-phase system. The proposed inverter is derived based on a dual-buck structure, in which a zero leakage current is obtained. The proposed inverter has no shoot-through problem; thus, the inverter's reliability is improved. A comparison study with the conventional common-ground transformerless inverter has been made to evaluate the performance of the proposed inverter. Finally, simulation and experimental verifications are presented to confirm the effectiveness of the proposed inverter.**

***Keywords*— Reliability, dual-buck structure, transformerless inverter, single-phase**

I. INTRODUCTION

Photovoltaic systems are one of the most promising and widely deployed renewable generation sources [1]–[3]. One major technological development for PV systems is transformerless inverters [4], which reduce costs and sizes, and achieve high efficiency. In grid-connected PV inverters, the single-phase inverter system is growing rapidly for both utility-scale and distributed generation applications. However, the non-isolation between the PV system and the inverter can cause large leakage currents. Various research works have been presented recently to eliminate the leakage current using control methods or structure re-configurations [5]–[7]. These inverters can reduce the leakage current in the PV system. However, they require a large number of active and passive devices, leading to an increase in the complexity, cost, and size of the inverter system. A common-ground inverter can effectively suppress the leakage current of the PV system. Common-ground based-H4 inverters were proposed in [9]–[15], which provide the connection between the PV ground and the grid ground. The inverter with two half-bridge circuits was proposed in [10]. This inverter uses two DC input voltages, and the middle point is connected to the ground of the output side. The front half-bridge circuit switches at low frequency and the other half-bridge is for realizing the inverter operation. Similar to the inverter in [10], the T-type in [11] includes a half-bridge circuit and a T-branch circuit, which reduces switching losses and inductor current pulsation. The inverters in [12]–[13] are introduced to reduce the number of power switches in [11] with two half-bridge circuits, in which

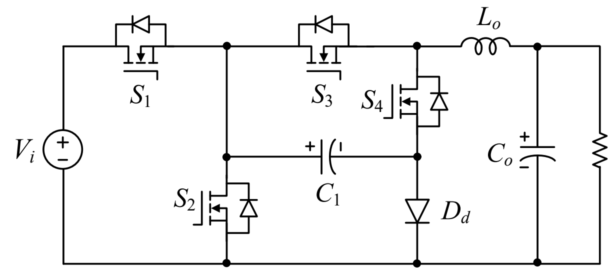


Fig. 1. Conventional common-ground transformer-less inverter [15].

the negative end of the input side is connected with the ground of the load. In addition, new transformerless inverters [14] based on flying inductors for single-phase PV systems are introduced to offer no leakage current. This inverter can provide buck-boost ability. However, five power switches are required. A series of transformerless inverters [15] with flying capacitors are also proposed. Those inverters use only four power switches, one diode, and a flying capacitor, as shown in Fig. 1. The inverter has an acceptable number of power switches, one additional diode, and a flying capacitor. A simple unipolar sinusoidal PWM method was applied for these inverters to improve the efficiency, output current ripple, and filter value.

All of the mentioned common-ground inverters [9]–[15] could be affected by DC link shoot-through problems, which reduce the converter reliability. Different methods have been proposed for solving the problems, such as adding PWM switching deadtimes, RC snubbers, or applying a soft-commutation method for safe operation and Each of these approaches has its own advantages and disadvantages [16]. A inverters and converters based-dual-buck structures were introduced in [17]–[19] to solve the problem from the converter topology's perspective. The converter consists of one switch, one inductor, and an external diode connected in series, and ultimately solves the shoot-through problem as there is no short circuit path.

In this paper, a dual-buck, single-phase, transformerless inverter is proposed to provide a common ground with high reliability. The proposed inverter is employed with a simple unipolar sinusoidal PWM method to reduce the switching loss. The rest of the paper is organized as follows. Section II

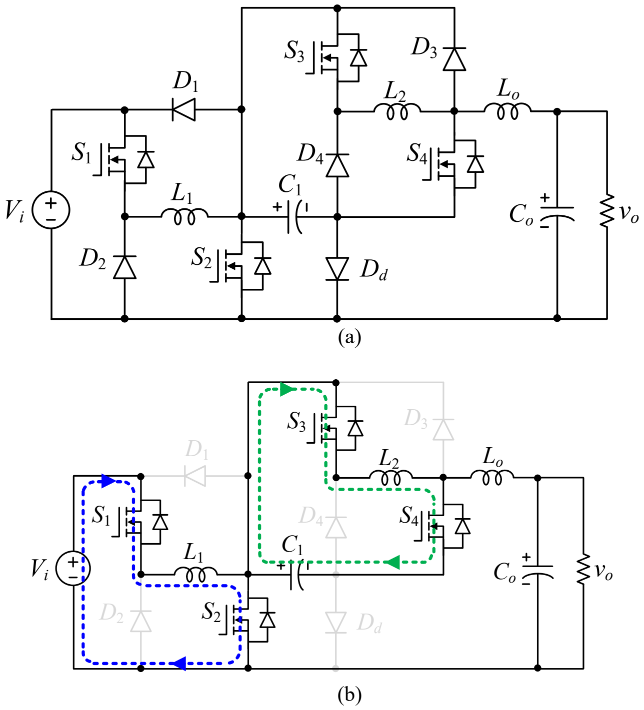


Fig. 2. Proposed DB-CGI. (a) Topology, (b) Equivalent circuit of proposed DB-CGI when all switches are turned on.

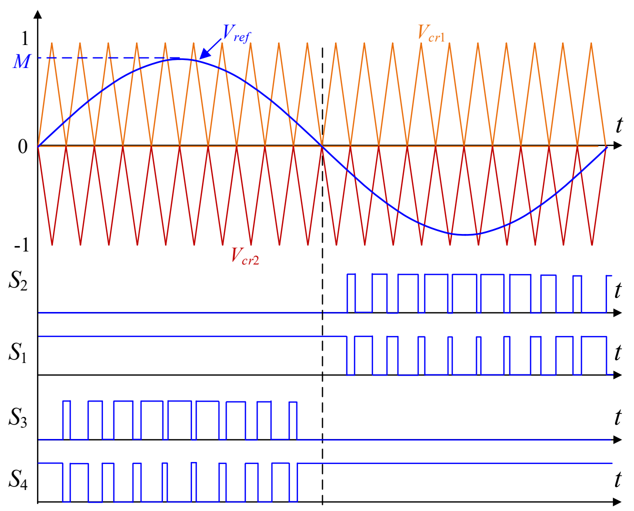


Fig. 3. PWM control signals for the power switches in the proposed DB-CGI.

discusses the circuit of the proposed converter and analysis during different states of operation. In section III, the comparative study of the proposed converter is presented. The theoretical analysis has been validated by simulation and experimental results presented in section IV. Finally, the conclusions drawn from the analysis and results are summarized in section V.

II. Proposed Dual-Buck Common-Ground Inverter

1. Topology

Fig. 2(a) presents the circuit diagram of the proposed dual-buck common-ground inverter (DB-CGI). The topology of the proposed DB-CGI is derived using the half-bridge dual-buck cell and single-phase common-ground transformerless inverter. It is composed of four power switches $S_1 - S_4$, four additional diodes $D_1 - D_4$, two inductors $L_1 - L_2$, flying capacitor C_1, and an LC output filter. It can be noted that two inductors L_1 and L_2 also protect against shoot-through when complementary switches (S_1–S_2), (S_3–S_4) are turned on simultaneously as shown in Fig. 2(b). Thus, the dead time of complementary switches can be eliminated.

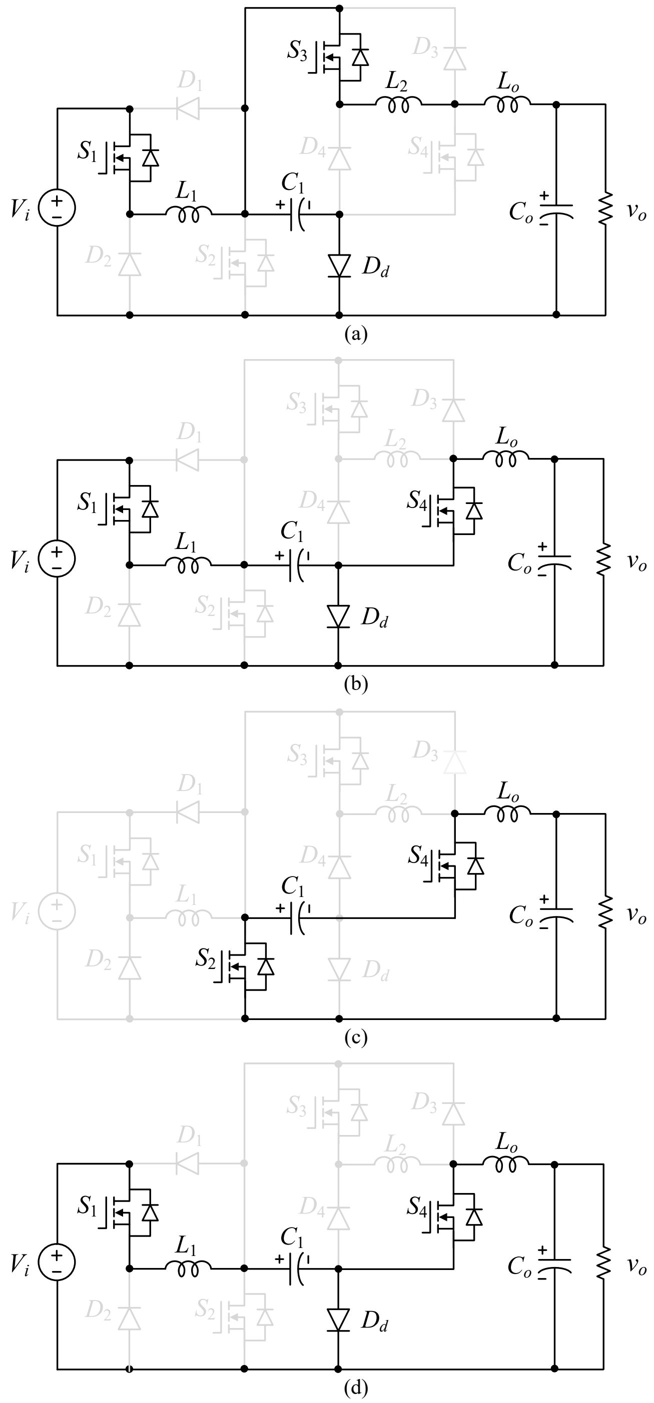


Fig. 4. Operation modes of the proposed DB-CGI, (a) Positive state (active), (b) Positive state (zero), (c) Negative state (active), (d) Negative state (zero).

2. Operating Analysis

The PWM control method based on unipolar sinusoidal PWM for the proposed DB-CGI is shown in Fig. 3. It can be seen that each switch is operated at a high switching frequency in a half-cycle, which can reduce the switching

TABLE I

COMPARISON BETWEEN THE CONVENTIONAL CGI AND PROPOSED DB-CGI

Topology in	Switch	Diode	Inductor	Capacitor	Common-ground feature	Deadtime requirement	Reliability
Conventional CGI [15]	4	1	1	2	Yes	Yes	Low
Proposed DB-CGI	4	5	3	2	Yes	No	High

loss of the power switches. According to the PWM control method, the proposed DB-CGI has four operating modes as depicted in Fig. 4. The corresponding operating modes/circuits are given as follows:

Mode 1 [positive cycle (active), Fig. 4(a)]: In this mode, the output voltage is $+V_i$, which is achieved by the conduction operation of the switch S_1 and diode D_d, resulting in the input voltage connected in series with capacitor C_1, $v_o = V_i$. The switch S_3 is operated at a high switching frequency to generate unipolar positive voltage at the output side.

Mode 2 [positive cycle (zero), Fig. 4(b)]: In this mode, following the above positive active mode, the switch S_3 is off and S_4 is on. The diode D_d is conducted to generate the zero voltage at the output side.

Mode 3 [negative cycle (active), Fig. 4(c)]: In this case, the output voltage is equal $-V_i$ through the conduction operation of the switches S_2 and S_4. The diode D_d is turned off automatically, while the capacitor C_1 discharges and supplies the negative voltage to the output side.

Mode 4 [negative cycle (zero), Fig. 4(d)]: This mode follows the above negative active mode. Switch S_1 is turned on while switch S_4 remains on, and the capacitor C_1 is charged by the input voltage. Diode D_d is conducted to get the zero voltage at the output side.

The modulation index (M) is given as

$$M = \frac{v_{ref}}{v_{cr}} \quad (1)$$

III. COMPARATIVE STUDY

To show the improvement of the proposed DB-CGI topology with the conventional CGI [15], a comparison is shown in Table I. The detailed comparison is given in terms of the number of components, common ground, deadtime requirement, and reliability. For the number of components, the conventional CGI and proposed DB-CGI has the same number of switch and capacitor, but the proposed DB-CGI uses four more diodes and two more inductors. This is because the proposed DB-CGI employs the half-bridge dual-buck structure. In addition, both inverters provide a common ground and eliminate leakage current in the inverter system. In terms of deadtime requirement, a dead time must be used in conventional CGI to avoid the shoot-through problem. On the contrary, the proposed DB-CGI can eliminate or minimize the dead time. Therefore, the proposed DB-CGI has higher reliability.

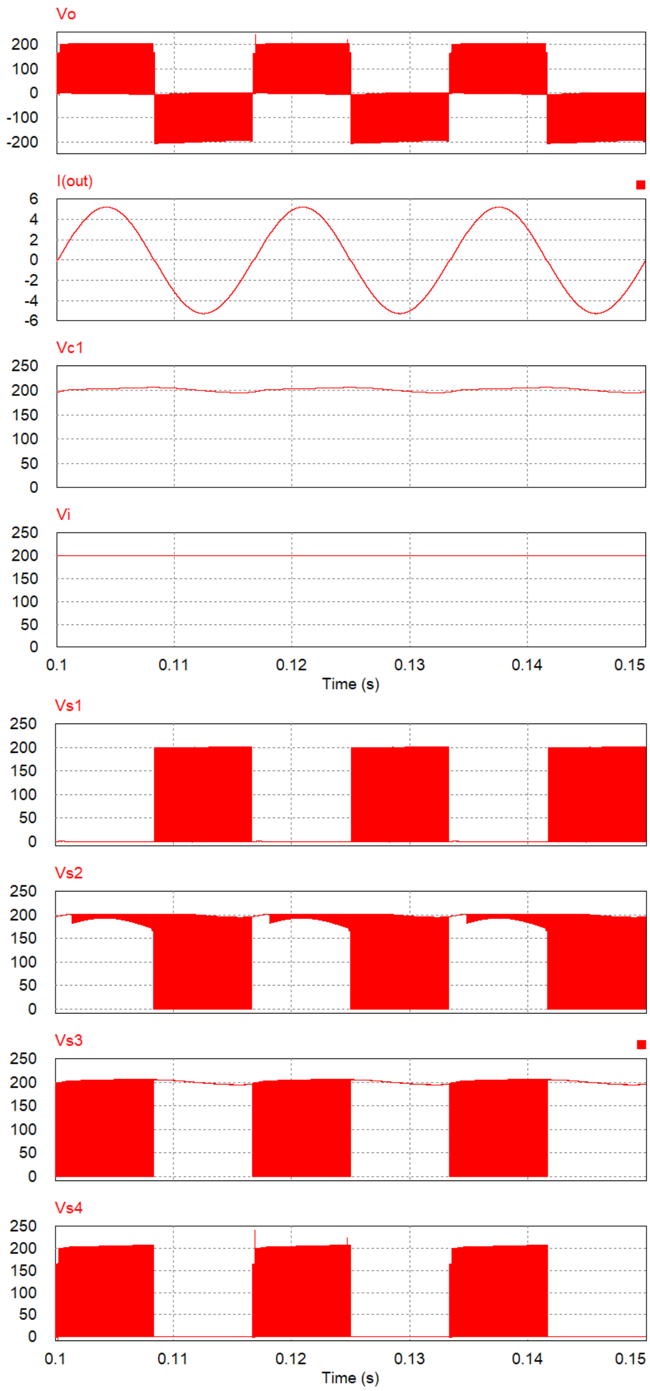
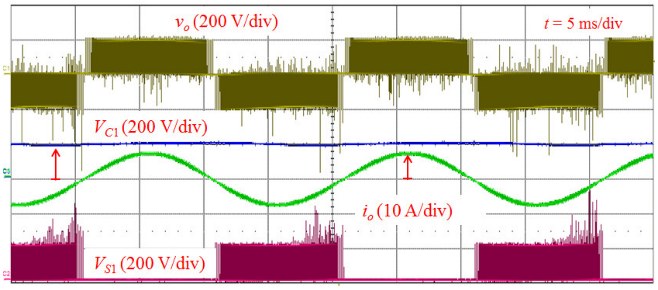


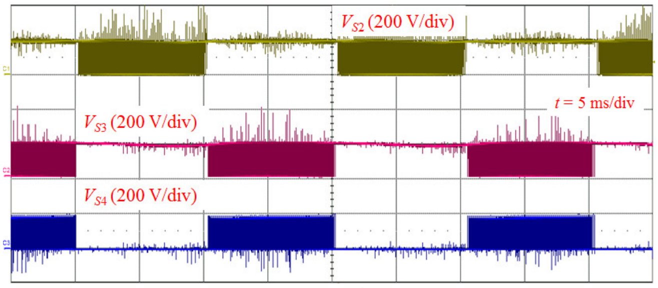
Figure 5. Simulation results of the proposed DB-CGI with $M = 0.8$.

TABLE II
PARAMETERS FOR SIMULATION AND EXPERIMENT

Parameters	Values
Input voltage	200 V
Output voltage	110 Vrms/ 50Hz
Switching frequency	50kHz
Output Power	400 W
Capacitors (C_1, C_o)	1000 µF, 2.2 µF
Inductors (L_1, L_2, L_o)	0.2 mH, 1 mH



(a)



(d)

Figure 6. Experimental waveforms of the proposed DB-CGI with M = 0.8.

IV. Simulation and Experimental Results

To show the efficacy of the proposed DB-CGI, the simulation and experimental results are presented in this section. The simulation and experimental parameters are set up as listed in Table II. The input voltage is set to 200 V, the modulation index is fixed at 0.8 to produce an output voltage of 110 Vrms. The resistive load of 30 Ω is connected to the output side. Figs. 5-6 shows the simulation and experimental results of the output voltage before the output filter, output current, flying capacitor voltage, and switches S_1~S_4 voltage stresses. The maximum values of output voltage and output current are about 200 V and 5.2 A, respectively. The THD value of the output current is 1.2%. The flying capacitor voltage C_1 is maintained at V_i by the charging process. It can be seen that the simulation and experimental results match the theoretical analysis.

V. Conclusion

In this paper, a single-phase DB-CGI topology was proposed. Similar to the conventional CGI, the proposed DB-CGI achieves no leakage current with a common-ground feature. Based on the half-bridge dual-buck circuit, the proposed DB-CGI has high reliability because it has no shoot-through problem, and dead time is not required in the PWM signals for power switches. The PWM control method combining low and high-frequency operation is applied for the proposed DB-CGI. Finally, the simulation and experimental results for a 400-W prototype inverter have been provided to confirm the effectiveness of the proposed DB-CGI.

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