A Transformerless Grid-Connected Photovoltaic System Based on the Coupled Inductor Single-Stage Boost Single-Phase Inverter

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Abstract: This Project presents the modified coupled-inductor single-stage boost inverter (CL-SSBI)-based grid-connected photovoltaic (PV) system. The transformer can be used in line or high frequency, but the line-frequency transformer has large size and weight. The high-frequency transformer is used in PV systems decreasing the efficiency and making the system more complex. This project is to design a transformerless inverter connected to photovoltaic system, so that to design costless PV system using coupled inductor single phase inverter. To maintain the advantages of the impedance network, only a diode is added in the front of the original topology, to block the leakage current loop during the active vectors and open-zero vectors. Simultaneously, the leakage current caused by other transitions can also be reduced due to the fact that the magnitude of common-mode voltages is reduced. Experimental results of the transformer less PV system are presented in two cases modified CL-SSBI topology modulated by maximum constant boost (MCB) control method and PWM. Experimental results for both CLSSBI topology modulated by the MCB control method and modified CL-SSBI topology modulated by PWM are also obtained.

Keywords: Maximum Constant Boost, Leakage Current, Photovoltaic (PV) Power System, Coupled Inductor Single-Stage Boost Inverter, Near State Pulse Width Modulation.

I. INTRODUCTION

The transformer-less photovoltaic (PV) power system has been attracting more and more attention (1) for its lower cost, smaller volume, as well as higher efficiency, compared to the ones with transformer. One of the technical challenge is the safety issue of the leakage current caused by the common mode voltages (CMV), conducting in the loop with parasitic capacitors between the solar panel and the ground. For single stage boost inverter transformer-less PV systems, such as the Z-source inverter-based systems, the modulation strategy is carefully designed to maintain the constant CMV to reduce the leakage current (2). But the OPWM or EPWM method uses only odd or even active vectors to synthesize the output reference voltage, leading to only 57.7% of the maximum magnitude compared to SVPWM, and also to worsen harmonic distortion of the output waveforms.

A coupled inductor single-stage boost inverter (CL-SSBI) is proposed in, which introduced an impedance network, including coupled inductor in the front-end of the inverter bridge (3,4). The structure is simple, while LCD can be viewed as a snubber. The converter uses shoot-through zero vectors to store and transfer energy within the unique impedance network, to step up the bus voltage. Turns ratio of the coupled inductor within the impedance network can also be designed to improve the boost gain. So the ac output voltage can be regulated in a wide range and can be stepped up to a higher value.

Higher power loss and lower efficiency would be unavoidable if higher boost gain is required, which is the disadvantage of inverters of this type. As shoot-through zero vectors evenly distributed among the three phase legs during a switching period, the equivalent switching frequency viewed from the impedance network can be six times the switching frequency of the inverter bridge, which will greatly reduce the power density and cost of the inverter. This presents the method to reduce the leakage current of the transformer-less grid connected PV system based on CLSSBI(4,5). A diode is added in the front of the topology to block the leakage current loop when in the active vectors and open-zero vectors.

In addition, the near-state PWM technique is used with one-leg shoot-through zero vectors to reduce the leakage current caused in the transient states of changing from and to open-zero vectors. And the leakage current caused by other transitions can also be reduced due to the fact that the magnitude of CMVs is reduced. Note that the leakage current can be reduced effectively without lowering the maximum magnitude of the output reference voltage, for the modulation index of NSPWM stays in the high modulation section.
Low frequency transformers are used at output stages of inverter sections in the conventional techniques as shown in Fig. 1.1. The conventional topology normally comprises of a DC source, several single phase low-frequency transformers, two main power switches and some bidirectional switching devices.

The leakage currents to ground constitute another important issue if one of the terminals of the array cannot be grounded, particularly regarding transformer-less concepts (6). Due to their structure, PV modules naturally form a parasitic capacitance between the cells and the grounded frame. High frequency variations of the cell potential in relation to ground shall therefore be avoided in transformer-less circuits since this leads to large charge/discharge currents partially flowing through the circuit to the ground, resulting in an increase of the harmonic content, higher losses, and also, safety and electromagnetic interference problems. Special single phase transformer-less topologies with reduced oscillations has been developed for such purpose.

The requirements for inverter connection include maximum power point, high efficiency, control power injected into the grid, and low total harmonic distortion of the currents injected into the grid. Consequently, the performance of the inverters connected to the grid depends largely on the control strategy applied.

This paper gives an overview of power inverter topologies and control structures for grid connected photovoltaic systems. In the first section, various configurations for grid connected photovoltaic systems and power inverter topologies are described.

The following sections report, investigate and present control structures for single phase and three phase inverters. Some solutions to control the power injected into the grid and functional structures of each configuration are proposed.

**Transformerless Grid-Connected PV System**

The PV dc voltage needs to be step up to a value higher than the amplitude of the grid voltage, because the conventional VSI cannot produce an ac voltage larger than the dc input voltage (7,8). The modified CL-SSBI is shown in Fig 1.2

Figure 1.2: Transformerless grid-connected PV system based on CL-SSBI with an additional diode

Only a diode is added in the front of the topology compared to the original structure, to block the leakage current loop during the active vectors and open-zero vectors because shoot-through of the inverter bridge becomes a normal operation state, the possible switching states include six active vectors ($V_1 - V_6$), two open-zero vectors ($V_0, V_7$), and seven shoot-through zero vectors including one leg shoot through ($V_a$ shoot, $V_b$ shoot, $V_c$ shoot), two-legs shootthrough ($V_{ab}$ shoot, $V_{ac}$ shoot, $V_{bc}$ shoot) and three-legs shoot through ($V_{abc}$ shoot).

For all the odd active vectors ($V_1, V_3, V_5$), all the even active vectors ($V_2, V_4, V_6$), all the open-zero vectors ($V_0, V_7$), and all the shoot-through zero vectors, the commonmode voltages ($V_{cm}$) and voltages ($V_{pn}$ and $V_{nn}$)
of CL-SSBI and CL-SSBI-D within additional diode (CL-SSBI-D) can be derived. For convenience, supposing the turns ratio $N$ of the coupled inductor is 2.5, shoot-through zero duty cycle $D_0$ is 0.17, and the boost factor $B$ is 3, according to the bus voltage expression of $V_B = Bv_{PN}$, and using the maximum constant boost (MCB) control method realized by space vector based PWM control, the switching pattern and CMV of CL-SSBI.

**II. PROPOSED TRANSFORMELESS GRID-CONNECTED PV SYSTEM BASED ON CL-SSBI**

The transformer-less photovoltaic (PV) power system has been attracting more and more attention for its lower cost, smaller volume, as well as higher efficiency, compared to the ones with transformer. One of the technical challenges is the safety issue of the leakage current caused by the common mode voltages (CMV), conducting in the loop with parasitic capacitors between the solar panel and the ground.

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harmonic distortion of the output waveforms. A coupled inductor single-stage boost inverter (CL-SSBI) is proposed in which introduced an impedance network, including coupled inductor in the front-end of the inverter bridge. The structure is simple, while LCD can be viewed as a snubber.

The converter uses shoot-through zero vectors to store and transfer energy within the unique impedance network, to step up the bus voltage. Turns ratio of the coupled inductor within the impedance network can also be designed to improve the boost gain. So the ac output voltage can be regulated in a wide range and can be stepped up to a higher value. Higher power loss and lower efficiency would be unavoidable if higher boost gain is required, which is the disadvantage of inverters of this type.

As shoot-through zero vectors evenly distributed among the three phase legs during a switching period the equivalent switching frequency viewed from the impedance network can be six times the switching frequency of the inverter bridge, which will greatly reduce the power density and cost of the inverter. The circuit layout of the proposed transformer less converter shown in fig 2.2

![Circuit Layout](image1)

**Figure 2.2:** The circuit layout of the proposed transformer less converter

Real implementation

![Real Implementation](image2)

**Figure 2.3:** Real implementation of proposed model
Photovoltaic (in short PV) module is a packaged, connected assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. There are a few solar panels available that are exceeding 19% efficiency. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring. Solar Pannel Input & Output circuit shown in fig 2.4

**III. EXPERIMENTAL RESULT**

The output wave forms at different stages (input voltages) for different circuitry are shown in the following figures. It is plotted for Voltages vs Time at different circuitry for varying input voltages (10 to 12).

**At 10V PV voltage**

![Waveforms Diagram](image_url)

**Figure 3.1: shows waveforms of PV Output & Boosted Output**

Above figure shows the boosted output, for a constant PV input and the output contains a DC which contains ripples as an output of inductor stages as shown in fig 3.1.
Figure 3.2: Waveform of H_{in} & L_{in} Driver input
H_{in}-logic input for high side & L_{in}-logic input for low side gate driver IC IR2110. The high side and low side logic input are in the same phase as shown in figure 6.2. High side logic input is given to pin 10 and Low side logic input is fed to pin 12 of IC IR2110.

Figure 3.3: Waveform of H_{o} & L_{o} Driver output
H_{o}-logic output for high side & L_{o}-logic output for low side gate driver IC IR2110. The high side and low side logic output are 180° out of phase and it given as inverter input to get pulsating ac output waveforms as shown in figure 6.3. High side logic output is given to pin 7 and Low side logic input is fed to pin 1 of IC IR2110.

Figure 3.4: Inverter output waveform
Pulsating ac output voltage from the inverter stage output shows in fig 3.4. Similarly for different PV input voltages (11V & 12V) the following output waveforms are obtained as shown from figure 3.5 to 3.12.
At 11V PV voltage

Figure 3.5: shows waveforms of PV Output & Boosted Output

Figure 3.6: Waveform of Hin & Lin Driver input

Figure 3.7: Waveform of Ho & Lo Driver output

Figure 3.8: Inverter output waveform
At 12V PV voltage

Figure 3.9: shows waveforms of PV Output & Boosted Output

Figure 3.10: Waveform of \(H_{in}\) & \(L_{in}\) Driver input

Figure 3.11: Waveform of \(H_o\) & \(L_o\) Driver output

Figure 3.12: Inverter output waveform
IV. CONCLUSION

This project has presented a transformerless grid-connected PV system based on a coupled inductor single-stage boost single phase inverter. Transformerless inverter use a computerized electronic components to convert dc to high frequency ac. This provides a high boost in cascade & transformerless structure with high efficiency & high power density, and without transformer the inverter becomes much lighter, more compact and more adorable. The leakage current caused in the transient states due to the absence of transformer is reduced by using the PWM technique. Simultaneously, the leakage current caused by other transitions can be further reduced due to the magnitude reduction of the Common Mode Voltage. According to the experimental results, the amplitude and RMS value of the leakage current can be made well below the threshold level. With further modification in this project efficiency can be increased and losses can be reduced.

V. REFERENCES