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Design of Photovoltaic H6 -Type Transformerless Inverter Topology to Minimize Leakage Current

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Abstract

Objectives: A leakage current issue that was mitigated by isolation transformers in a grid-connected photovoltaic system must now be addressed by the converters themselves. The paper presents the H6 inverter topology that solved the leakage current problem at the same time as maintaining a high efficiency and a low total harmonic distortion [THD]. **Methods:** Inverter topology H6 has been designed to reduce leakage current. A comparison of performance has been done using MATLAB/SIMULINK software. Efficiency, leakage currents, and common modes voltage are the primary parameters for analysis. Simulations of H4, H5 and H6 topologies will be carried out and results will be compared. **Findings:** H6 topology suppresses leakage current to a fairly acceptable magnitude when compared to other topologies. A comparison was made between the H6 and the traditional H4 and H5 topology and the leakage current in the H6 topology is 42.47mA as opposed to 46.87mA in H5 and 803.10mA in H4. **Novelty:** SPWM modulation and the H6 inverter topology are presented in the study. Using an H5 topology with an additional switch, an H6 inverter is designed. Direct current in one of the active modes of the H6 topology, fewer switches are required to make current flow, which reduces conduction losses. By maintaining a constant common mode voltage, an H6 inverter eliminates leakage currents. Thus, transformerless grid-connected photovoltaic systems with H6 inverters reduce conduction losses and leakage currents. The simulation results are provided as a means of verifying the topology. The leakage current has been found to be reduced to 42.47mA.

Keywords: Transformerless-Inverter; PV System; Leakage Current; H4; H5; And H6 Inverter

1 Introduction

In a photovoltaic system, PV modules serve as the source while an inverter converts DC to AC and maintains the voltage level. Depending on whether a transformer is present or not in a grid-connected photovoltaic system, there are transformer-based PV systems and transformerless PV systems [1]. PVs and grids are galvanically isolated when a transformer is present, due to this, there is no leakage current. It is, however, heavy, bulky, and expensive to include a transformer in a circuit. As a result, PV systems are less efficient when there is a transformer present[2].

In order to make the system more efficient, compact, and cost-effective, the transformer was intended to be eliminated with the advancement of power electronic devices. Its major drawback, however, is that it cannot provide galvanic isolation. From PV to the grid, a large common mode current is present, which poses a safety concern. The main cause of EMI between PV panels and grids is leakage current circulation because galvanic isolation is missing in transformerless inverters[3,4].

Research is being conducted in order to solve the leakage current problem without an isolation transformer. In order to reduce leakage currents while maintaining efficiency and THD, H6 topologies have been developed. Inverters that are conventionally half-bridges or full-bridges are modified to reduce leakage currents[5,6].

This paper presents a study of the H6 topology to reduce leakage currents while meeting efficient and THD standards. It explains the problem of leakage currents in grid-connected PV systems. The second section focuses on H4, H5, and H6 topologies that tend to solve leakage current issues. The results of the simulation are presented in section 3. Section 4 concludes the paper.

1.1 Leakage Current Analysis

A four-switch full bridge inverter is also known as an H4 inverter (Figure 1). It is the positive terminal that is called P, and the negative terminal is called N. Inverters have two outputs, A and B. The filter transmits the output of the inverter to the grid. Below figure 1 is also shown a parasitic capacitance called Cpv between PV and ground. Equation (1) can be used to calculate the Vcm (common mode voltage), an average voltage is calculated between the output terminal and the negative reference terminal.

$$\mathrm{Vcm} = (\mathrm{V_{AN}} + \mathrm{V_{BN}})/2 \quad (1)$$

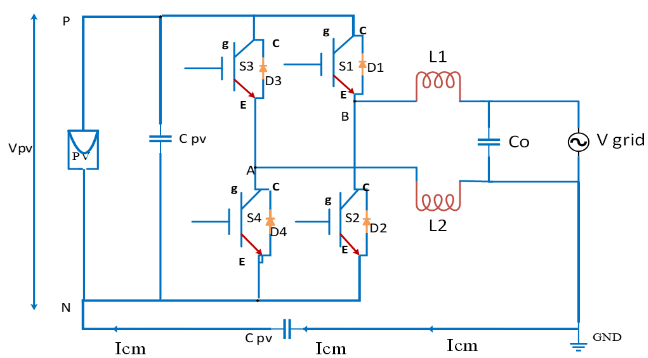

Fig 1. Full-bridge (H4) inverter circuit leakage current analysis

Inverters' differential mode voltages (Vdm) are determined by the difference between their reference negative terminals and their output terminals). Equation (2) shows it.

$$\mathrm{V_{dm}} = \mathrm{V_{AN}} - \mathrm{V_{BN}} \quad (2)$$

Current (ICM) flows due to common mode voltage (CMV). Icm can be expressed using equation (3).

$$\mathrm{Vcm} = \mathrm{Cpv}^{*}\mathrm{dVcm/dt} \quad (3)$$

In eliminating leakage currents and common mode currents, constant common mode voltage is necessary according to Equation (3). There are several factors affecting the values of VAN and VBN in an inverter, including its structure and modulation method. Thus inverter topologies and modulation techniques are crucial to maintaining constant Vcm[7,8].

2 Methodology

2.1 H4 inverter topology

Inverters with full bridges have four switches, as illustrated in Figure 2. Transformerless inverter topologies connect solar photovoltaic modules to the grid galvanically. A resonant circuit created by stray capacitors connects PV modules to the ground.

The most commonly used modulation techniques are unipolar and bipolar modulations. Low losses are produced by unipolar modulation across the filter because three levels of voltage are generated across the filter. Comparing bipolar and unipolar SPWM techniques, the unipolar SPWM technique yields higher efficiency. Due to the two voltage levels generated by bipolar modulation, the filter inductors suffer large core losses and switching losses. In comparison to unipolar modulation, bipolar modulation has a lower efficiency. Leakage currents are low when the common mode voltage is constant. Its (Unipolar modulation) low losses and high efficiency make this technique ideal for generating triggering pulses.

In bipolar modulation, S1 and S4 are conducting in the case of a positive grid voltage, because current flows in one direction. A negative grid voltage causes switches S2 and S3 to conduct, causing grid current to flow in reverse. As a result, the circuit converts DC current to AC current. Despite this, the circuit does not have a freewheeling path to disconnect the DC supply. This results in fluctuating Vcm and leakage currents of significant magnitude [9,10].

In a unipolar modulation system, when the grid voltage is positive, switch S1 conducts, while During switching frequency (fs), switches S3 and S4 conduct, and switch S2 does not conduct. S2 and S4 in freewheeling mode are off while D3 and S1 are on. At switching frequency (fs), S1 and S2 are turned on when the grid voltage is negative while S3 is left on and S4 remains off. S2 and S4 are both OFF in freewheeling mode, while D1 and S3 are on [11,12].

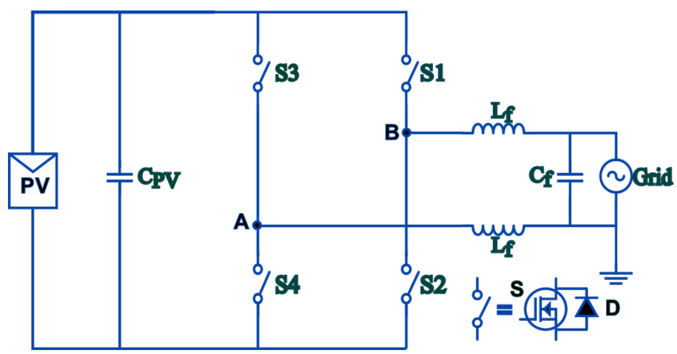

Fig 2. H4 inverter topology

2.2 H5 inverter topology

Compared to a full-bridge inverter, on the DC side of an H5 inverter, there is an additional switch. A total of five switches are in this system, of which switch S5 is used as a DC switch. The H5 inverter schematic diagram is shown in Figure 3. S5, S1, and S4 conduct when the grid voltage is a positive half cycle. An antiparallel diode in switch S3 reflects the current flowing through switch S1, in a freewheeling period. The free-wheeling mode results in reduced leakage current as a result of switch S5, since the DC supply is isolated from the grid. As long as the grid voltage is positive during conduction and freewheeling, switch S1 will remain turned on. The switches S5, S3, and S2 are on during the negative half of the grid voltage cycle. As a freewheeling process occurs, there is current flowing through switches S3, grid, and antiparallel diode of switch S1. The DC supply is again isolated from the grid when S5 is operating in freewheeling mode. Therefore, leakage currents are minimized. A full H-bridge structure uses two switches instead of three, so current flows through three switches instead of two, The conduction loss of H5 is higher [13–15].

2.3 H6 inverter topology

A transformerless H6 inverter with lower leakage current and reduced conduction loss while enhancing efficiency is designed in this paper. Figure 4 illustrates the circuit for this inverter. Adding S6 to the H5 inverter circuit is shown in Figure 4. As a result of freewheeling, PV arrays are disconnected from the grid. The conduction loss has been reduced comparatively, and the efficiency has improved as well, despite the increased number of switches. Common mode voltages are maintained constant to eliminate leakage currents.

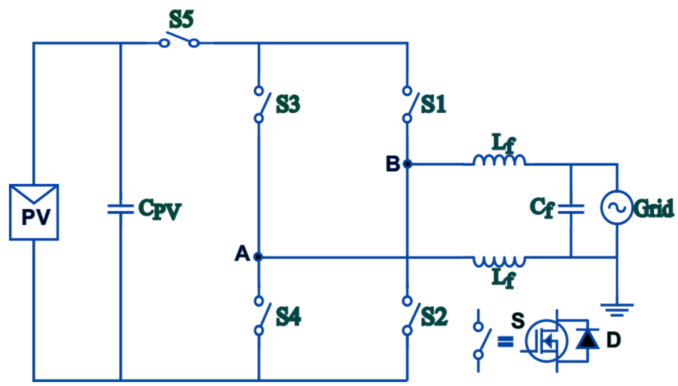

Fig 3. H5 inverter topology

A unipolar sinusoidal PWM modulation technique is used. PV represents a photovoltaic panel. Filtering is performed with an LCL filter. Electric grids are represented by Grid. Capacitance of the input DC link is represented by Cpv. Keeping the common mode voltage constant can eliminate leakage current. Due to the fact that H bridge inverters use transformers, which do not have leakage current issues, a conventional inverter does not have to keep the common-mode-voltage constant. Galvanically connecting PV and grid in the absence of transformers, which results in leakage currents. It is possible to reduce leakage currents in such a situation by maintaining constant common mode voltages[16–20].

The H6 inverter operates in four modes. There are four modes available, with two freewheeling modes and two active modes.

a) Mode-1: Active mode

It is S1, S4, S5 and S6 that conduct in the positive half period's active mode, while S3 and S2 remain off.

b) Mode-2: Freewheeling mode

As the switch S1 operates in freewheeling mode during the positive half of the cycle, current flows through it, and through antiparallel diode S3. Other switches are all off as well.

c) Mode-3: Active mode

S2, S3, S5 and S6 will conduct in active mode for the negative half of the period, whereas a negative half period in active mode will keep S1 and S4 off.

d) Mode-4: Freewheeling mode

Current passes through antiparallel diode S1 and switch S3 in the negative half-period freewheeling mode.

Inverter switches for the H6 are operated as shown in Table 1.

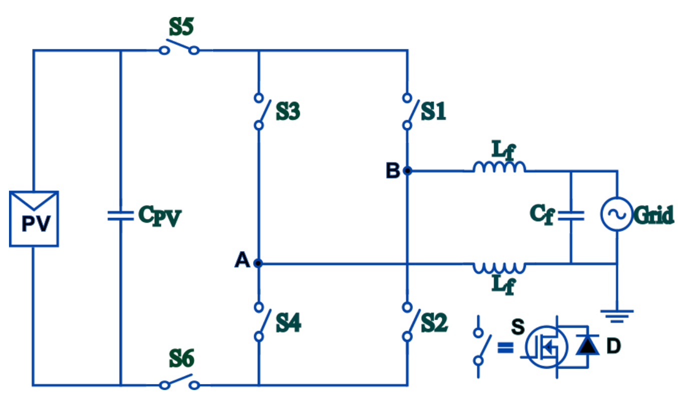

Fig 4. H6 inverter topology

3 Results and Discussion

MATLAB/Simulink is used to simulate H4 inverters, H5 inverters, and H6 inverters. Simulations are used to compare and analyze the inverter's performance. Table 2 lists the parameters used in simulations.

Table 1. Conduction states for h6 inverter

Switches								**Vout**
S1	S2	S3	S4	S5	S6	D1	D3	
1	0	0	1	1	1	0	0	Vin
1	0	0	0	0	0	0	1	0
0	1	1	0	1	1	0	0	-Vin
0	0	1	0	0	0	1	0	0

Table 2. Parameters

DC input voltage	**400Vdc**
Grid Voltage (Vg)	1Ph230 V(RMS),50 Hz
Grid frequency	50 HZ
Rated Power	2 KW
Frequency (Switching)	10 KHZ
Capacitors (Dc-Link)	2200 μF
Inductor	3 mH
Capacitor	6 nF
Capacitor (Stray)	300 nF
Impedance (Ground)	11Ω

3.1 H4 Simulation Output

Figure 5 shows the Vg, Ig, VAB, VAN, VBN, Vcm, and leakage current waveforms of the H4 inverter. In H4 inverter, PV will always be connected to the grid. Therefore, leakage current flows from PV into the grid due to fluctuating common mode voltage.

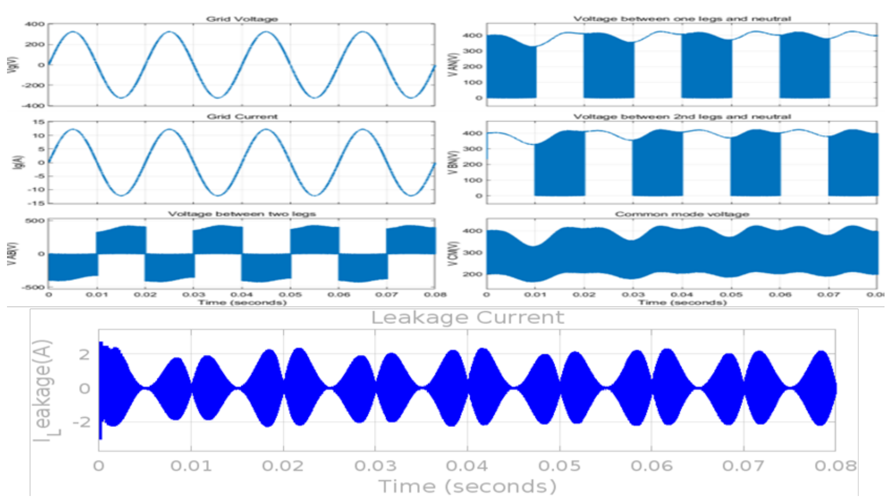

Fig 5. Vg, Ig, VAB, VAN, VBN, Vcm, and leakage current waveforms of the H4 inverter topology with unipolar modulation

3.2 H5 Inverter Simulation Output

As a result of the H5 inverter's constant common-mode voltage, leakage current is significantly reduced by its freewheeling mode. The simulation results can be seen in Figure 6. When an inverter is operating in an active mode, three switches are always conducting, so conduction losses increase and efficiency decreases.

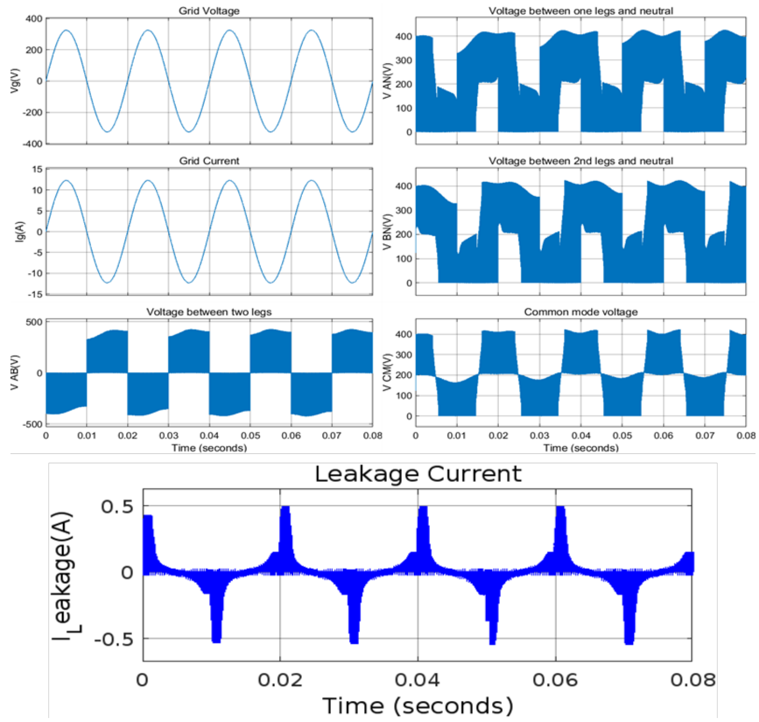

Fig 6. Vg, Ig, VAB, VAN, VBN, Vcm, and leakage current wave forms for H5 inverter topology with unipolar modulation

3.3 H6 Inverter Simulation Output

According to Figure 7, H6 inverters maintain constant common-mode voltages with minimal leakage currents. Comparing the H6 inverter with the H4 & H5, inverters, as a result, its common mode voltage remains more stable and the leakage current stays low during operation inverter efficiency is improved with reduced leakage current. Comparatively, to H4 and H5, H6 inverters have a relatively low conduction loss.

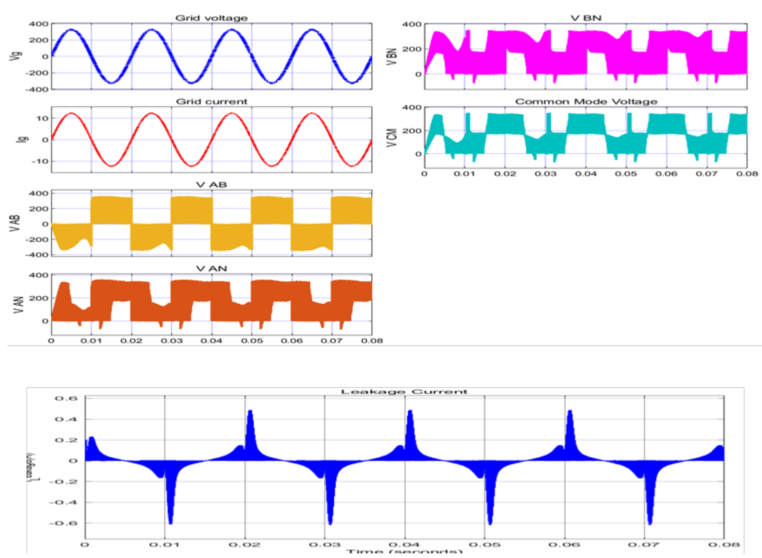

Fig 7. Vg, Ig, VAB, VAN, VBN, Vcm, and leakage current waveforms for H6 inverter topology with unipolar

3.4 Comparison with other Topologies

Table 3 provides the comparison. In this comparison, similar simulation parameters are used to generate the simulation results. H4, H5, and H6 topologies have been selected. H4 and H5 topologies are intended to implement the same isolation and clamping concept, however, simulation results show high leakage currents. These problems can be solved through the H6 topology. Since all parasitic effects cannot be accurately estimated, the actual results may vary. It has been observed that H6 leakage current is 42.47mA at a full load of 2kW, which is acceptable. When all components are considered to be ideal, the efficiency is found 94%. Typically, the system works at over 80% efficiency. 1.59% THD was determined for H6, which is acceptable. Compared to H4 and H5, H6 topology perform better.

Table 3. Simulation Results for the H4, H5 and H6 topologies

Inverter Topologies	**$I_{\_leakage}$ (RMS)**
H4 Topology (Unipolar modulation)	803.10 mA
H5 Topology	46.87 mA
H6	42.47 mA

4 Conclusion

An H6 topology is presented in this study in order to reduce leakage currents. Compared with conventional H4 and H5 topology and other studies conducted on the H6 topology, this study presents the topology of the H6 inverter and the SPWM modulation strategy used. Inverters with the H6 topology have been found to perform very well in terms of leakage current, THD, and efficiency, all of which are highly desirable characteristics. As per all international standards and grid compliance codes, the achieved value is very low and acceptable. Low leakage current and low THD is challenging to achieve. To improve efficiency and reduce THD, further studies may use different modulation schemes.

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