INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Analysis and Design of H5 Topology in Grid-Connected Single-Phase Transformerless Photovoltaic Inverter System

Md Aftab Alam[1], S V A V Prasad[2], Mohammed Asim[3]*

1 Research Scholar, Department of Electronics and Communication Engineering, Lingaya's Vidyapeeth, Nachouli Jasana Road, Faridabad, India
2 Department of Electronics and Communication Engineering, Lingaya's Vidyapeeth, Nachouli Jasana Road, Faridabad, India
3 Department of Electrical Engineering, Integral University, Lucknow, India

OPEN ACCESS

Received: 14-11-2022
Accepted: 17-01-2023
Published: 11-02-2023

Citation: Alam MA, Prasad SVAV, Asim M (2023) Analysis and Design of H5 Topology in Grid-Connected Single-Phase Transformerless Photovoltaic Inverter System. Indian Journal of Science and Technology 16(6): 420-426. https://doi.org/10.17485/IJST/v16i6.2191

* **Corresponding author**.

asimamu@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: The transformerless inverters are more efficient, less bulky and cost-effective. But the system faces the problem of leakage current on account of the elimination of isolation transformers. Thus, the problem needs to be mitigated through the inverter topology itself. The objective of this paper is to study and analyze a topology designed for reducing the leakage current. The H5 inverter significantly reduces the leakage current by checking the variation of common mode voltages. The topology uses only one extra switch apart from the conventional full bridge and is simple to design. **Method:** To reduce the leakage current H5 inverter topology has been designed which works on the basis of decoupling. This work is to be implemented in MATLAB/SIMULINK. The main parameters for analysis are efficiency, leakage current, common mode voltage and their variation with load. H4 and H5 topology will be simulated and results will be compared. **Findings:** The H5 topology has been found to be effective in suppressing the leakage current to a fairly acceptable magnitude. It has been observed that the H5 topology has a lower leakage current than the conventional H4 topology, i.e. 23mA as opposed to 402mA in H4 topology. But the leakage current increases to up to 5 times if the system is used at load less than the full load. **Novelty:** The study presents the H5 inverter topology and its SPWM modulation strategy. In order to verify the topology, simulation results are provided. The performance has been tested for different loads connected to grid. The leakage current has been found to be reduced to 23.37 mA but it rises to about 100mA if used at 10% of the full load.

Keywords: PV Inverters; H5 Inverters; Leakage Current (Common Mode Current); Common-Mode Voltages; Transformerless Power Converters

1 Introduction

With the advancement of research in technology, the solar energy extracted through photovoltaic systems has the capability to meet a significant portion of the total energy demands in future [1]. While the research continues to increase the capability, the problems arising while implementation must also be solved for reliable and efficient operation of the system. The requirements of a grid-connected system are more stringent as compared to standalone system. One of the issues that need to be solved is of the leakage current that exists due to parasitic capacitance of the PV panel. This can be solved by galvanic isolation using isolation transformers. But for bulkiness, cost and efficiency issues elimination of transformers is sought. Then the mitigation of leakage current must be taken up by the inverters [2,3].

Several methods have been tried and topologies have been developed since over a decade to suppress the leakage currents. The H5 topology is one such effective topology developed earlier. It is superior and preferred over other topologies such as NPC and Karschny topologies for its simplicity, low cost, and good efficiency. The topology has been tried and tested over times but gap remains regarding its effectiveness at different loads. As it is common knowledge that the load connected to grid continuously changes. The PV system when it supplies the power to grid will face different load conditions. This study aims to observe the effect of changing load.

A detailed study of H5 topology is presented in this paper, and the simulation results are compared with conventional H4 inverter topology [4–6]. The topology has been simulated in MATLAB/Simulink. The load has been varied in steps and corresponding readings have been recorded. This data is helpful to analyze the performance of the grid-connected system as the load on the grid changes rapidly.

2 Methodology

2.1 H4 inverter topology

Typically, transformerless PV inverters with single-phase full bridge (H4) modulation strategies are unipolar, bipolar, or hybrid. There are number of factors that affect the efficiency, leakage current, and common-mode voltage characteristics depending on the modulation scheme.

A H4 topology contains four active switches (S1-S4) and four anti-parallel body diodes (D1-D4). The core losses are reduced when using unipolar or hybrid modulation, which produce three levels of voltages (+V_{in}, 0, -V_{in}, 0) across the filter. Because of their high-frequency common-mode voltages, they generate high leakage currents [7]. As a result of bipolar modulation, two levels of voltage are generated (+V_{in}, -V_{in}) resulting in higher core losses. Furthermore, it generates a constant common-mode voltage, which reduces leakage current. Leakage current problems can be solved using SPWM (sinusoidal pulse width modulation). Inverters with bipolar SPWM are less efficient than those with unipolar SPWM because of switching loss and core loss [8].

Table 1. H4 PV-inverter switching state (unipolar)

Switches						**V** $_{out}$
S1	S2	S3	S4	D1	D3	
On	off	off	On	Off	off	V_{in}
On	off	off	Off	Off	on	0
Off	on	on	Off	Off	off	-V_{in}
Off	off	on	Off	On	off	0

Table 1 llustrates the unipolar modulation switching pattern for the H4 inverter. In Table 2 illustrates the hybrid modulation switching pattern for the H4 inverter. Therefore, several topologies have been developed that make use of unipolar modulation to produce high-efficiency inverters and low-leakage current inverters. An inverter without a transformer has been developed using unipolar PWM control to reduce ground leakage currents. H4 inverter topology is shown in Figure 1 [9–12].

Table 2. H4 PV-inverter (hybrid modulation) switching state

Switches						V_{out}
S1	S2	S3	S4	D1	D3	
On	Off	Off	On	Off	Off	V_{in}
On	Off	Off	Off	Off	On	0
off	On	On	Off	Off	Off	$-V_{in}$
off	Off	On	Off	On	Off	0

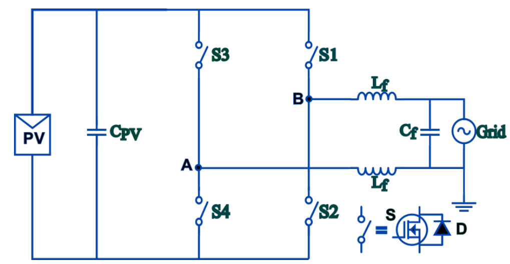

Fig 1. H4 inverter topology

2.2 H5 inverter topology

A transformerless H5 inverter contains five active switches (S1-S5). PV panels are connected to conventional H-bridge inverters by the fifth switch. Both the switch and the utility grid operate at the same frequency. The H5 topology is illustrated in Figure 2 with the SPWM switching strategy [13,14]. Accordingly, switches are commutated at high frequency or grid frequency depending upon the grid voltage polarity. During a positive grid voltage, S1 will always be ON, while S4 and S5 will switch at a high frequency to produce a unipolar voltage. A freewheeling path is created by switching S3 complementary to switch S4. During a negative grid voltage, S3 stays on, S2 and S5 commutate at high frequencies, and S1 commutates complementary to S2 to form a freewheeling path [15,16].

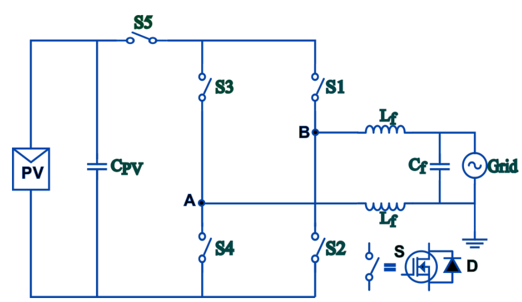

Fig 2. H5 inverter topology

There are four modes of operation for the H5 inverter. Active state mode is the first mode, and current flows from the PV panel to the grid through S5, S3, and S2. The second mode is referred to as zero state mode since no energy is transferred from PV to the grid. In this mode, PV panels are disconnected from the grid as the grid current freewheels through S3 and D1. There is a third active state mode as well. PV current flows through S5, S1, and S4 from the grid to the PV unit. PV panels on the grid are disconnected in the fourth mode of operation, also called the zero-state mode, as a result of freewheeling from S1 and D3. Using S5, PV arrays are disconnected from the grid in zero states, which eliminates leakage current paths. This reduces system leakage current to a great extent. A transformerless H5 inverter is illustrated in Figure 2. An illustration of the H5 inverter's switching pattern is shown in Table 3 [17–19].

3 Results and Discussion

A simulation of the H5 inverter is being conducted using MATLAB/Simulink. As shown in Figures 4 and 5, simulation results for an H4 inverter with unipolar modulation and hybrid modulation are shown. The H5 inverter simulation result is shown in

Table 3. PV-inverter H5 switching state

Switches							**V** $_{out}$
S1	S2	S3	S4	S5	D1	D3	
On	off	off	on	on	off	off	V_{in}
On	off	off	off	off	off	on	0
Off	on	on	off	on	off	off	$-V_{in}$
Off	off	on	off	off	on	off	0

Figure 6. In accordance with the simulation results, with unipolar modulation, the leakage current of the H4 inverter is 0.4015 A, while with hybrid modulation, it is 0.4472 A. Leakage current measure for H5 topology is 0.02337A. All simulations are based on the parameters listed in Table 4.

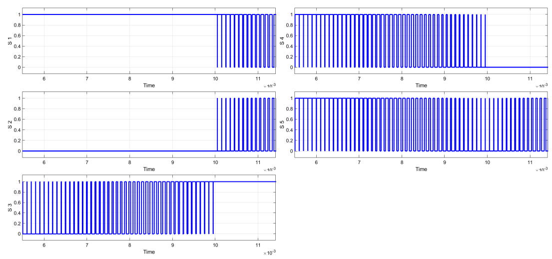

Fig 3. Control signals of H5 inverter switches

Table 4. Parameters used for simulations

DC input voltage	400 V DC
V_g - Grid Voltage	1 Ph 230 V (RMS), 50 Hz
Grid frequency	50 Hz
Rated Power	2kW
Switching Frequency	10kHz
DC-Link capacitors	2200 micro farad
Inductors(Filter)	3 mili Henri
Capacitor (Filter)	6 nano farad
Stray capacitor	300 nano farad
Ground Impedance	11Ω

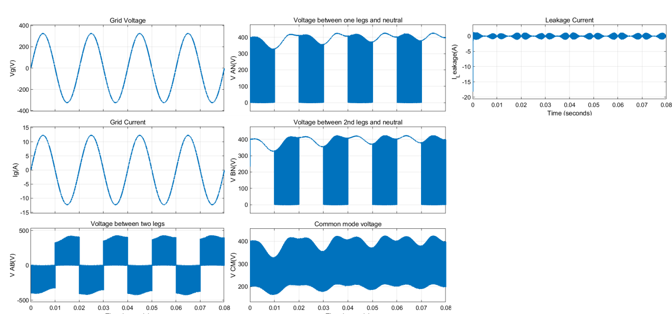

Fig 4. H4 inverter topology result with unipolar modulation in MATLAB/Simulink

The leakage current value for full load of 2kW has been observed to be 23.37 mA. Khan et. al. in [18] state the value of leakage current in H5 topology to be in the range of 100 to 200 mA. The improved value can be accounted for by using higher switching frequency and using the system at full load.

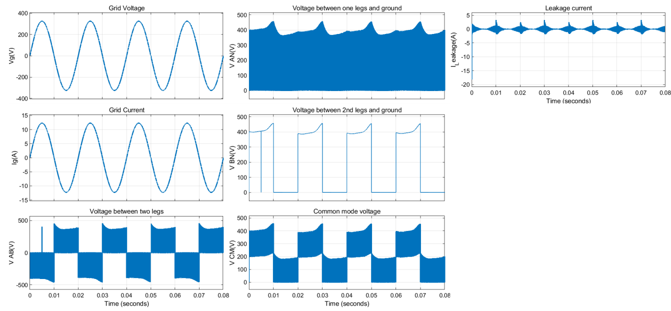

Fig 5. H4 (hybrid modulation) MATLAB/Simulink results

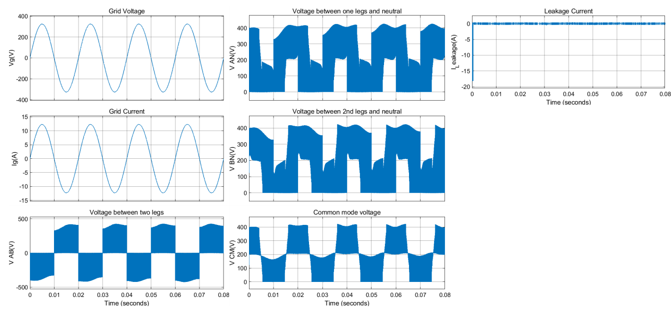

Fig 6. MATLAB/Simulink Result of H5 inverter topology

The efficiency was found to be over 95% which is in line with what is stated in [9,18,20]. This is the maximum efficiency when all the components are considered to be ideal. In practice the system can work at over 80% efficiency. The THD was found to be 5.9% which is an acceptable value and in agreement with standards and near to that attained by Siddiqui et al in [5].

The earlier studies conducted seem to neglect the effect of constantly changing load connected to grid and they measured the value of leakage current for some fixed load only. The grid-connected PV system would be subjected to large changes in differential mode current and hence in the common-mode current as well. This study analyzes the effect of changing load on the leakage current value. The Figure 7 records the change in leakage current value from the minimum load of 200W to the full load possible for the given panel, i.e. 2kW. The variation has been plotted in Figure 8 .

The above data shows that although the H5 topology reduces the leakage current but it is most effective when used at full load. The solution to this issue is to meet the maximum possible demand through PV system and the rest through conventional resources. This would also allow for better utilization of distributed and renewable energy resources.

Load (W)	Leakage Current (mA)
200	75.74
400	55.31
600	43.4
800	36.65
1000	32.45
1200	29.6
1400	27.46
1600	26.24
1800	24.41
2000	23.37

Fig 7. Variation of Leakage Current with Load

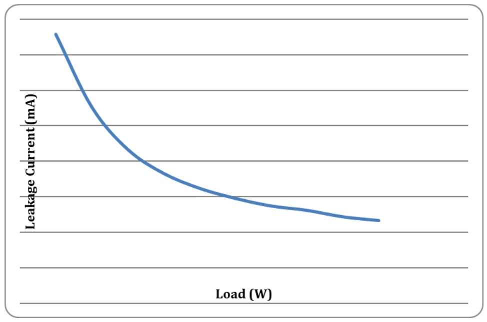

Fig 8. Variation of Leakage Current with Load

4 Conclusion

In this study, the H5 inverter topology has been designed to reduce leakage current. The study presents the H5 inverter topology and its SPWM modulation strategy and the simulation results are compared with conventional H4 inverter topology and with the results of other studies conducted on H5 topology.

It has been observed that the H5 topology has a lower leakage current than the conventional H4 topology. Simulation results are provided for verification of the topology. The achieved value is very low and acceptable according to all international standards and grid compliance codes. The further suppression of leakage current is attributed to higher switching frequency and full utilization of PV source capacity.

It was observed through this study that while the leakage current is reduced to an acceptable value of 23.37mA, using it at lower power level would again increase it to higher levels of upto 100mA which may be unacceptable for some grid compliance requirements.

Achieving low leakage current along with low THD is a challenge. Further studies may concentrate on using different frequencies to achieve better efficiency and lower THD. Also, apart from unipolar or hybrid PWM, special PWM techniques must also be applied to find out the most effective one.

References

1) Ministry of New & Renewable Energy, Government of India. *Physical Progress*. 2022. Available from: https://mnre.gov.in/the-ministry/physical-progress.
2) Verma M. Analysis, Design, and Control of a Single-Phase Single-Stage Grid-Connected Transformerless Solar Inverter. Quebec, Canada. 2019. Available from: https://spectrum.library.concordia.ca/id/eprint/985562.
3) Sonti V, Jain S, Bhattacharya S. Analysis of the Modulation Strategy for the Minimization of the Leakage Current in the PV Grid-Connected Cascaded Multilevel Inverter. *IEEE Transactions on Power Electronics*. 2017;32(2):1156–1169. Available from: https://doi.org/10.1109/TPEL.2016.2550206.
4) Alam MA, Prasad SVAV, Asim M. Comparison and Analysis of Transformer-less Topologies for Grid-Connected PV Systems. *2022 2nd International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET)*. 2022;p. 1–6. Available from: https://doi.org/10.1109/ICEFEET51821.2022.9848108.
5) Siddiqui MI, Khan I, Ali MA. Transformerless Inverter Topologies for Grid-Connected PV System. 2022. Available from: https://icetet.net/downloads/ICETET-2022-Book.pdf.
6) Akhtar I, Asim M, Yadav RK, Agarwal P, Kirmani S. Design of Effective Grid-Connected Solar System. In: Inventive Computation Technologies. Springer International Publishing. 2020;p. 606–614. Available from: https://doi.org/10.1007/978-3-030-33846-6_64.
7) Asim M, Hassan MH, Anis M, Zaid M, Khan FA. Analysis of Integrated DC-DC Converter-Based Grid Connected Transformer-less Photovoltaic Inverter. *2022 2nd International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET)*. 2022;p. 1–5. Available from: https://doi.org/10.1109/ICEFEET51821.2022.9848008.
8) Aljafari B, Loganathan AK, Vairavasundaram I, Ramachadran S, Nagarajan AP. Analysis of a Photovoltaic System Based on a Highly Efficient Single-Phase Transformerless Inverter. *Energies*. 2022;15(17):6145. Available from: https://doi.org/10.3390/en15176145.
9) Zeb K, Khan I, Uddin W, Khan MA, Sathishkumar P, Busarello TDC, et al. A Review on Recent Advances and Future Trends of Transformerless Inverter Structures for Single-Phase Grid-Connected Photovoltaic Systems. *Energies*. 2018;11(8):1968. Available from: https://doi.org/10.3390/en11081968.
10) Janardhan G, Babu NNVS, Srinivas GN. Single phase transformerless inverter for grid connected photovoltaic system with reduced leakage current. *Electrical Engineering & Electromechanics*. 2022;(5):36–40. Available from: https://doi.org/10.20998/2074-272X.2022.5.06.
11) Liu Y, Zhou Y, Guo B, Wang H, Su M, Liang X, et al. Bimodal Transformerless Inverter With Three Switches. *IEEE Transactions on Industrial Electronics*. 2022;69(9):8972–8983. Available from: https://doi.org/10.1109/TIE.2021.3114718.
12) Jayakumar V, Chokkalingam B, Munda JL. A Comprehensive Review on Space Vector Modulation Techniques for Neutral Point Clamped Multi-Level Inverters. *IEEE Access*. 2021;9:112104–112144. Available from: https://doi.org/10.1109/ACCESS.2021.3100346.
13) Asim M, Khan MS, Yadav RK, Mewara HS, Sethy N. Multilevel Inverters Operating with Improved Harmonic Performance Using SVPWM. In: Chanda, K C, Szymanski, R J, Sikander, A, et al., editors. Lecture Notes in Electrical Engineering;vol. 820. Springer Nature Singapore. 2022;p. 149–156. Available from: https://doi.org/10.1007/978-981-16-7274-3_12.

14) Lopez H, Resendiz JR, Guo X, Vazquez N, Carrillo-Serrano RV. Transformerless Common-Mode Current-Source Inverter Grid-Connected for PV Applications. *IEEE Access*. 2018;6:62944–62953. Available from: https://doi.org/10.1109/ACCESS.2018.2873504.
15) Siwakoti YP, Blaabjerg F. H-Bridge transformerless inverter with common ground for single-phase solar-photovoltaic system. In: 2017 IEEE Applied Power Electronics Conference and Exposition (APEC). IEEE. 2017;p. 2610–2614. Available from: https://doi.org/10.1109/APEC.2017.7931066.
16) Albalawi H, Zaid SA. An H5 Transformerless Inverter for Grid Connected PV Systems with Improved Utilization Factor and a Simple Maximum Power Point Algorithm. *Energies*. 2018;11(11):2912–2912. Available from: https://doi.org/10.3390/en11112912.
17) Mahmoudian M, Rodrigues EMG, Pouresmaeil E. An Efficient H7 Single-Phase Photovoltaic Grid Connected Inverter for CMC Conceptualization and Mitigation Method. *Electronics*. 1440;9(9):1440. Available from: https://doi.org/10.3390/electronics9091440.
18) Khan MNH, Forouzesh M, Siwakoti YP, Li L, Kerekes T, Blaabjerg F. A Classification of Single-Phase Transformerless Inverter Topologies for Photovoltaic Applications. In: 2018 IEEE Region Ten Symposium (Tensymp). IEEE. 2018. Available from: https://doi.org/10.1109/TENCONSpring.2018.8692013.
19) Geetha K, Sreenivasappa BV. H5-ZVR Single-Phase Grid-Tied Inverters for Photovoltaic Application. *International Journal of Renewable Energy Research*. 2021;11(v11i3):1178–1187. Available from: https://doi.org/10.20508/ijrer.v11i3.12151.g8249.
20) Saha A, Ahmad S, Mekhilef S, Jhuma UK, Islam H, Chowdhury ZA, et al. Comparative Study of Different Transformer-less Inverter Topologies for Grid-tied Photovoltaic System. *2019 5th International Conference on Advances in Electrical Engineering (ICAEE)*. 2019;p. 783–788. Available from: https://doi.org/10.1109/ICAEE48663.2019.8975675.