

Comparison of Full Bridge Transformerless H5, HERIC, H6 Inverter Topologies

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ABSTRACT: Photovoltaic (PV) generation systems are widely employed in transformer less inverters, in order to achieve the benefits of high efficiency and low cost. Safety requirements of leakage currents are met by proposing the various transformers less inverter topologies. The intrinsic relationship between H5, HERIC and H6 is revealed. The proposed H6 topology has been discussed as Transformerless inverters are widely used in grid-tied photovoltaic (PV) generation systems, due to the benefits of achieving high efficiency and low cost. . Various transformerless inverter topologies have been proposed to meet the safety requirement of leakage currents, such as specified in the VDE-4105 standard. In this paper, a family of H6 transformerless inverter topologies with low leakage currents is proposed, and the intrinsic relationship between H5 topology, HERIC topology and proposed H6 topology has been discussed as well. The power losses and power device costs are compared among the H5, the HERIC and the proposed H6 topologies. A universal prototype is built for these three topologies mentioned for evaluating their performances in terms of power efficiency and leakage currents characteristics. The results are obtained from MATLAB SIMULATION.

KEYWORDS: transformerless inverters, leakage currents, SPWM, ISPWM.

I. INTRODUCTION

Grid-connected photovoltaic (PV) systems, particularly low-power single-phase systems (up to 5 kW), are becoming more important worldwide. They are usually private systems where the owner tries to get the maximum system profitability. Issues such as reliability, high efficiency, small size and weight, and low price are of great importance to the conversion stage of the PV system [1].

A. Background

Quite often, these grid-connected PV systems include a line transformer in the power-conversion stage, which guarantees galvanic isolation between the grid and the PV system, thus providing personal protection. Furthermore, it strongly reduces the leakage currents between the PV system and the ground, ensures that no continuous current is injected into the grid, and can be used to increase the inverter output voltage level. The line transformer makes possible the use of a full-bridge inverter with unipolar pulse width modulation (PWM). It requires only four insulated gate bipolar transistors (IGBTs) and has a good trade-off between efficiency, complexity and price. Due to its low frequency, the line transformer is large, heavy and expensive. Technological evolution has made possible the implementation, within the inverters, of both ground-fault detection systems and solutions to avoid injecting dc current into the grid. The transformer can then be eliminated without impacting system characteristics related to personal safety and grid integration. In addition, the use of a string of PV modules allows maximum power point (MPP) voltages large enough to avoid boosting voltages in the conversion stage. This conversion stage can then consist of a simple buck inverter, with no need of a transformer or boost dc-dc converter, and it is simpler and more efficient [2]. But if no boost dc-dc converter is used, the power fluctuation causes a voltage ripple in the PV side at double the line frequency.

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B. Motivation

This in turn causes a small reduction in the average power generated by the PV arrays due to the variations around the MPP. Applications of distributed photovoltaic (PV) generation systems in both commercial and residential structures have rapidly increased during recent years. Although the price of PV panel has been declined largely, the overall cost of both the investment and generation of PV grid-tied system are still too high, comparing with other renewable energy sources. Therefore, the grid tied inverters need to be carefully designed for achieving the purposes of high efficiency, lowcost, small size, and low weight, especially in the low-power single-phase systems (less than 5kW). From the safety point of view, most of the PV grid-tied inverters employ line-frequency transformers to provide galvanic isolation in commercial structures in the past.

C. Objectives of Project

1. Provide good solution for single phase PV inverters.
2. Eliminate the leakage current of transformerless full bridge inverter.
3. Improve Efficiency, power density of system.

II. REVIEW OF LITERATURE

1. Central inverters

The central inverter system depicted implementation in the past technology [1], where PV plants bigger than 10 kWp were prepared in series or parallel strings and connected to the inverter. The inverters were mostly connected to a three-phase application; thus no decoupling was necessary. The voltage generated by the series connected modules was high enough to satisfy the input voltage condition of the inverter [2]. However, this inverter had some significant disadvantages such as high power losses due to centralized maximum power point tracking (MPPT), high voltage DC cables between PV panels and inverters due to high input voltage, non-flexible design, losses in the string-diodes, and being expensive. Consequently, it was not possible to acquire the advantages of huge production. Furthermore, the power delivered to the grid by the central inverter was of very poor quality involving many current harmonics.

2. String inverter

The string inverter that offers a number of advantages are leading the present technology [5]. It describes the string inverter system, where a single PV string made by series connected solar panels is coupled to an inverter. The string voltage may be sufficient, and thus voltage boosting is not required. The normal operating voltage of string inverter is 340–510 VDC for 230 VAC applications. The opportunity of using less PV modules connected in series is also available if a DC–DC booster or a line frequency transformer has been used. Compared to the central inverter, the string inverter has several advantages such as no string diode losses, individual MPPTs can be applied for every string, lower price due to huge production, and overall higher efficiency [4].

3. Module integrated inverter

The module integrated inverter system is shown where an AC module made by a single solar panel and its own inverter is connected to the grid. There is no mismatch between the PV modules; as a result, the power loss is well minimized. It is also possible to obtain maximum power from the PV module as a result of its own inverter and MPPT [11]. The advantage of an easy expanding of the system is available here due to the modular structure. The main disadvantage is the reduced overall efficiency because of higher voltage amplification and installation cost. However, this can be overcome by huge production, leading to low manufacturing and retail costs.

4. Multi-string inverter

The multi-string inverter is the evaluation of string inverter depicted where each string made of several solar panels is coupled to its own DC-to-DC converter with individual MPPT and feed energy to a common DC to AC inverter. Consequently, each PV power plant with a few modules can be functioned separately. The advantages of string and module integrated inverter is combined here. Since each PV string is controlled individually, the overall efficiency is

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higher. There are several advantages of multi-string inverters such as cost reduction, more flexible, small DC-link capacitor, and high energy reveal due to local MPP tracking and optimum monitoring of the PV system [6].

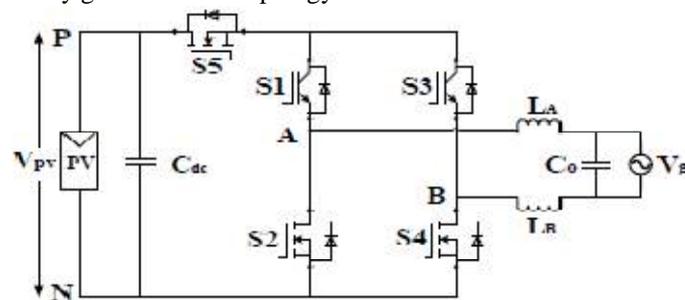
5. Design of grid-tied PV inverter

The PV generates DC voltage; thus, it requires a converter to convert into a voltage of corresponding amplitude at the main frequency for feeding it into utility grid as shown. Most of the countries report installing PV system by counting DC power, but some report AC power also. The inverter role in grid-tied PV system is to be the interface between two energy sources: the PV module on one side and the utility grid on the other side. Since the inverter converts DC power of PV module into AC power for feeding it into utility grid, it is responsible for power quality that needs to be satisfied by the requirement of different standards, which are briefly described in the next section. Depending on the galvanic isolation between the PV module and the grid, the grid-tied PV inverter can be categorized as isolated or non-isolated. The galvanic isolation between the PV module and the grid can be observed by using a line frequency transformer or a high frequency transformer that adjusts converter DC voltage [8]. Due to size, weight and price in favor of high frequency transformers, the tendency of removing the line frequency transformers is low.

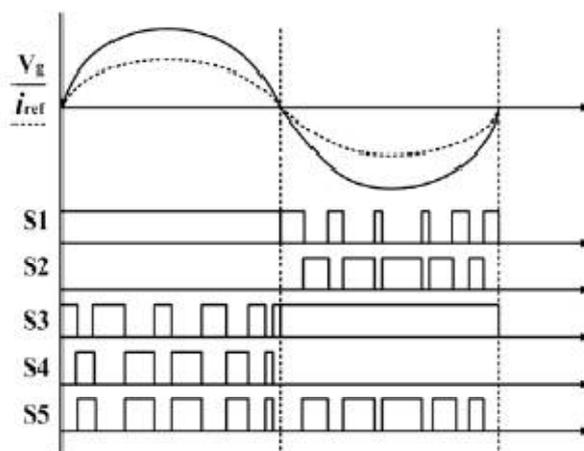
III. COMPARATIVE ANALYSIS ON EXISTING TOPOLOGIES

A. Operation modes of H5 and HERIC

The operation modes of H5 topology and HERIC topology are taken as examples for analysis. There are four operation modes in each period of the utility grid of the H5 topology.



(a)



(b)

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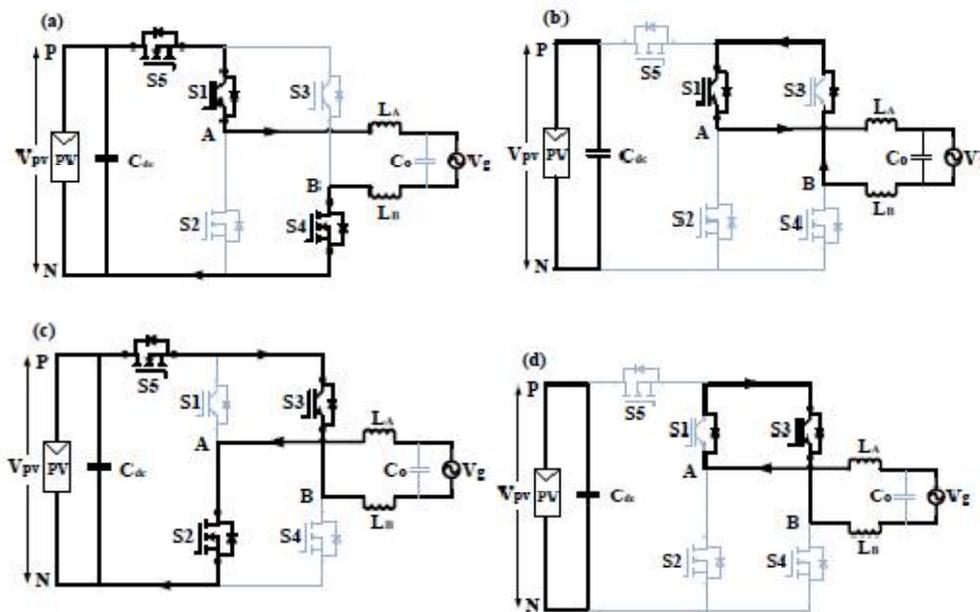


Fig.1. Operation modes of H5 topology. (a) Active mode in the positive half period. (b) Freewheeling mode in the positive half period. (c) Active mode in the negative half period. (d) Freewheeling mode in the negative half period.

Mode I: When S4 and S5 are turned-on, the inductor current i_L , flowing through S1, S4 and S5, is increased. In this mode, $V_{AB} = +V_{dc}$

Mode II: It shows the freewheeling path when S4 and S5 are turned-off. In this mode, V_{AN} falls and V_{BN} rises until their values are equal. Therefore, $V_{AB} = 0$ and the inductor current decreases through S1 and the body diode of S3.

Mode III: This mode starts when S2 and S5 are turned-on and the inductor current increases reversely through S2, S3 and S5. Therefore, the output voltage $V_{AB} = -V_{PV}$

Mode IV: In the negative half-cycle of grid current, freewheeling mode starts when S2 and S5 are turned-off which is shown. In this mode, V_{BN} falls and V_{AN} rises until their values are equal. Therefore, $V_{AB} = 0$ and the inductor current decreases through S3 and the body diode of S1, like as mode 2

There are four operation modes in each period of the utility grid of the HEIRC topology. It can be seen that the inductor current of HERIC topology is always flowing through two switches in the active modes. In the freewheeling modes, the inductor current of HERIC topology is flowing through two switches. Therefore, although the H5 topology features less power devices than the HERIC topology, its conduction loss is higher than that of the HERIC topology. Moreover, the conduction losses of the H6-type topology and the Hybrid-bridge topology are also higher than that of the HERIC topology due to extra switches in the DC side. As a result, the conduction losses of H5 topology, H6-type topology and Hybrid-bridge topology should be reduced for the harvest of higher efficiency.

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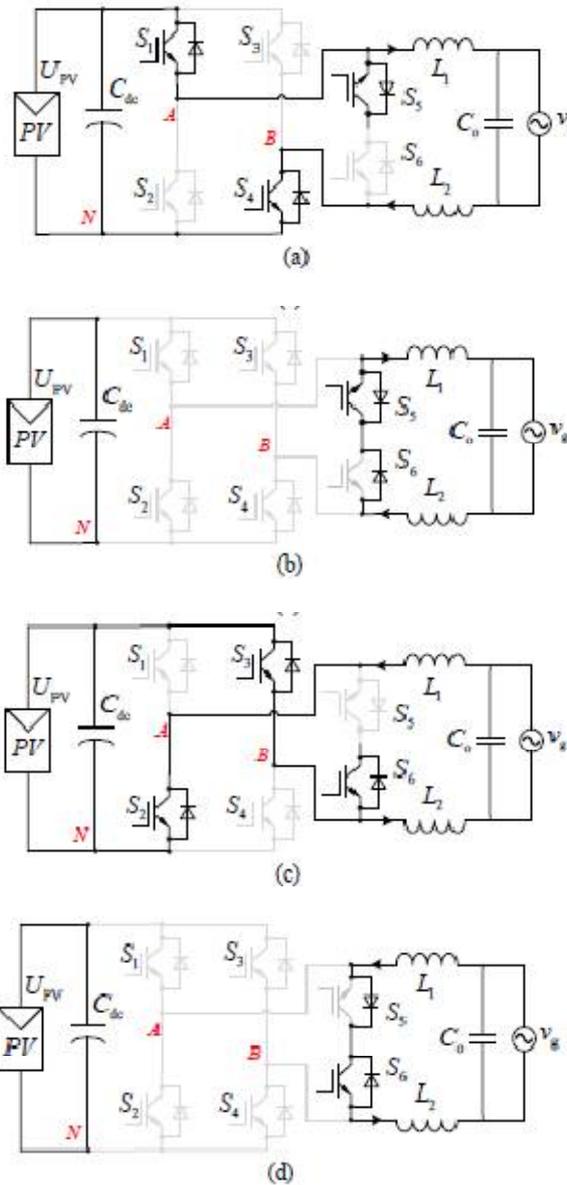


Fig.2. Operation modes of HERIC topology. (a) Active mode in the positive half period. (b) Freewheeling mode in the positive half period. (c) Active mode in the negative half period. (d) Freewheeling mode in the negative half period.

IV. ANALYSIS ON THE H6 TOPOLOGY

A. Novel H6 Topology

From the analysis above, an extra switch S6 is introduced into the H5 inverter topology between the positive terminal of the PV array and the terminal (B) to form a new current path. As a result, a novel H6 transformerless full-bridge inverter topology is derived. Similarly, the extra switch S6 can be introduced into the H5 inverter topology between the

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positive terminal of the PV array and the terminal (A) to form a new current path as well, as shown. Therefore, a new circuit structure of novel H6 inverter is presented. As a result, the conduction loss of the proposed H6 topologies is higher than HERIC topology and less than H5 topology.

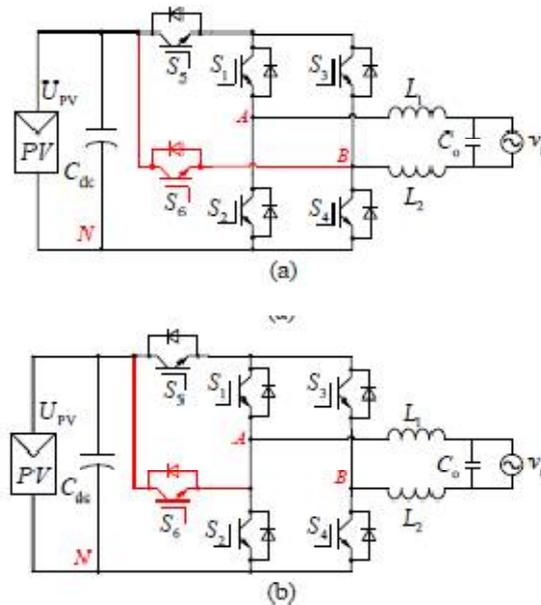


Fig. 3. A family of proposed H6-type inverter topologies. (a). Circuit structure A. (b) Circuit structure B.

B. Operation Mode Analysis

The circuit structure of proposed novel H6 inverter topologies showed it taken as an example to analysis. PV grid-tied systems usually operate with unity power factor. The waveforms of the gate drive signals for the proposed novel H6 topology are shown, where v_g is the voltage of utility grid. i_{ref} is the inductor current reference. v_{gs1} to v_{gs6} represent the gate drive signals of switches S1 to S6, respectively.

There are four operation modes in each period of the utility grid, where v_{AN} represents the voltage between terminal (A) and terminal (N), and v_{BN} represents the voltage between terminal (B) and terminal (N). v_{AB} is the differential-mode voltage of the topology, $v_{AB} = v_{AN} - v_{BN}$. The CM voltage $v_{CM} = 0.5(v_{AN} + v_{BN})$.

a) **Mode I** is the active mode in the positive half period of the utility grid voltage, as shown. S1, S4, and S5 are turned ON, and the other switches are turned OFF. The inductor current is flowing through S1, S4, and S5. $v_{AN} = U_{PV}$, $v_{BN} = 0$, thus, $v_{AB} = U_{PV}$, and the CM voltage $v_{CM} = (v_{AN} + v_{BN})/2 = 0.5U_{PV}$.

b) **Mode II** is the freewheeling mode in the positive half period of the utility grid voltage, as shown. S1 is turned ON, the other switches are turned OFF. The inductor current is flowing through S1 and the anti-parallel diode of S3. $v_{AN} = v_{BN} \approx 0.5U_{PV}$, thus, $v_{AB} = 0$, and the CM voltage $v_{CM} = (v_{AN} + v_{BN})/2 \approx 0.5U_{PV}$.

(c) **Mode III** is the active mode in the negative half period of the utility grid voltage, as shown. S2, S3, and S6 are turned ON, the other switches are turned OFF. The inductor current is flowing through S2 and S6. Although S3 is turned ON, there is no current flowing through it, and the switch S3 has no conduction loss in this mode. Nevertheless, in the H5 topology, the inductor current flows through S2, S3, and S5. Therefore, the conduction loss of proposed topology is less than that of H5 topology. In this mode, $v_{AN} = 0$, $v_{BN} = U_{PV}$, thus, $v_{AB} = -U_{PV}$, and the CM voltage $v_{CM} = (v_{AN} + v_{BN})/2 = 0.5U_{PV}$.

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(d) **Mode IV** is the freewheeling mode in the negative half period of the utility grid voltage, as shown. S3 is turned ON, and the other switches are turned OFF. The inductor current is flowing through S3 and the anti-paralleled diode of S1. $v_{AN} = v_{BN} \approx 0.5U_{PV}$, thus, $v_{AB} = 0$, and the CM voltage $v_{CM} = (v_{AN} + v_{BN})/2 \approx 0.5U_{PV}$.

Based on the above analysis, the PV array can be disconnected from the utility grid when the output voltage of the proposed H6 inverter is at zero voltage level, and the leakage current path is cut off. The CM voltage of the proposed topology in each operation mode is equals to $0.5U_{PV}$, and it results in low leakage current characteristic of the proposed H6 topologies.

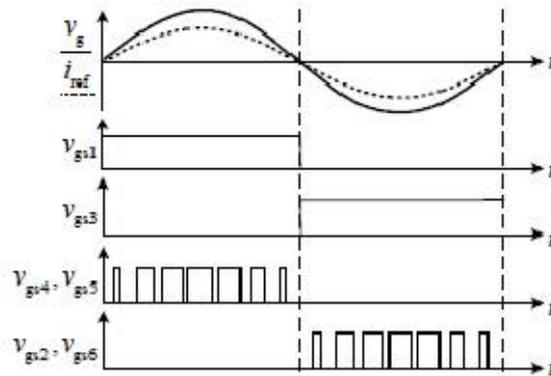
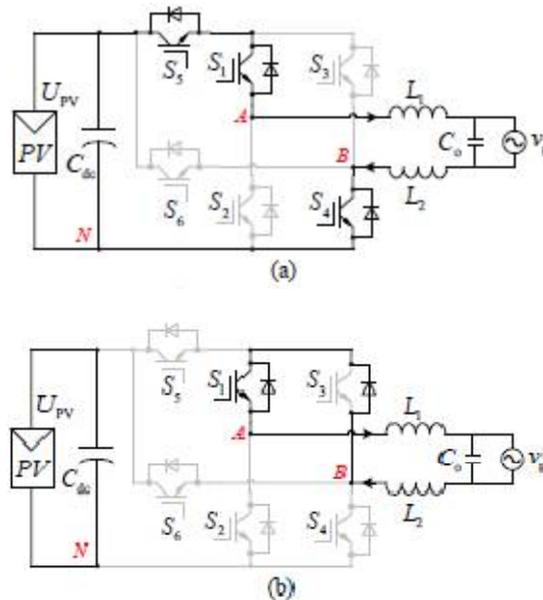


Fig. 4. Schematic of gate drive signals with unity power factor



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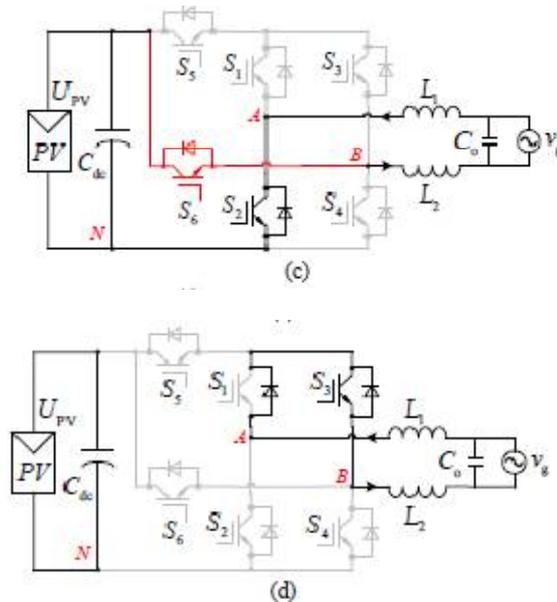


Fig.5. Operation modes of H6 topology. (a) Active mode in the positive half period. (b) Freewheeling mode in the positive half period. (c) Active mode in the negative half period. (d) Freewheeling mode in the negative half period.

V. MATLAB SIMULATION OF H5, HERIC AND H6 TOPOLOGY

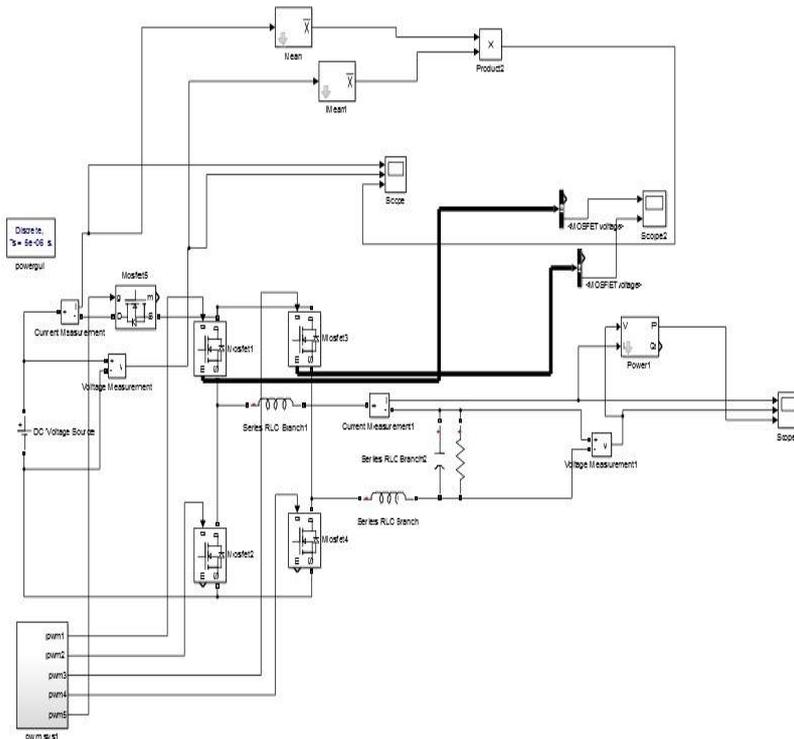


Fig. 6. Simulation of H5 Topology

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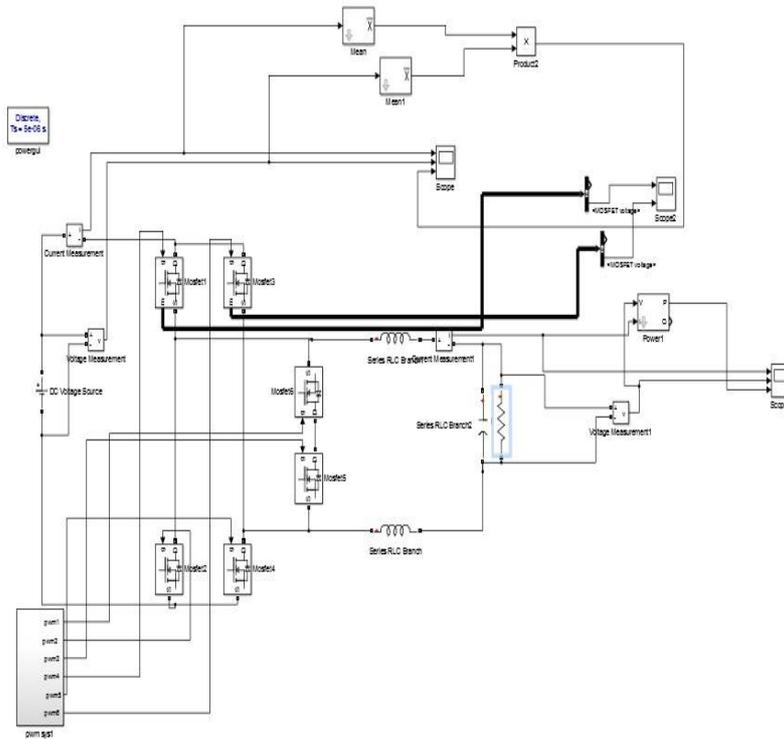


Fig. 7. Simulation of HERIC Topology

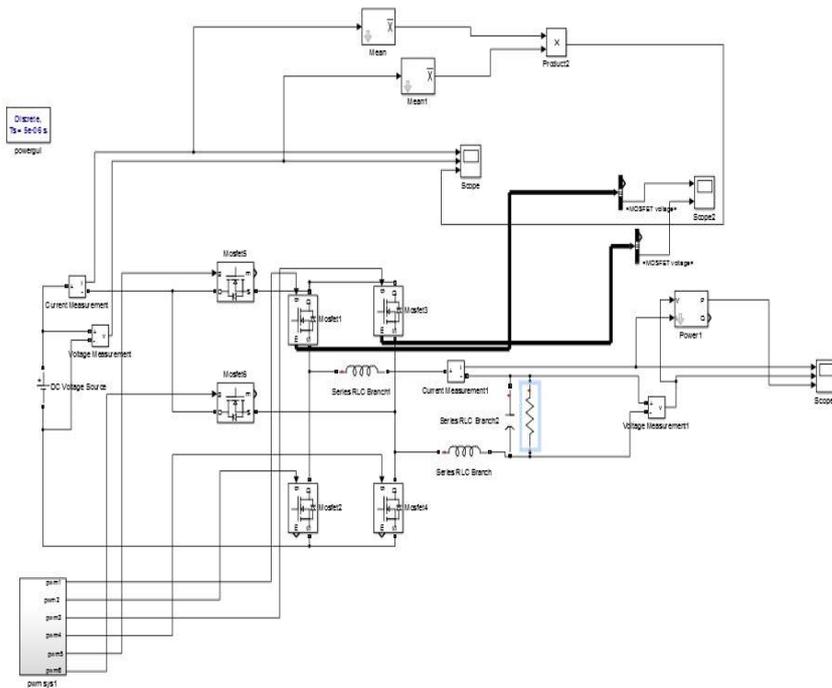


Fig. 8 Simulation of H6 Topology

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VI. SIMULATED OUTPUTS AND RESULTS OF H5, HERIC AND H6 TOPOLOGY

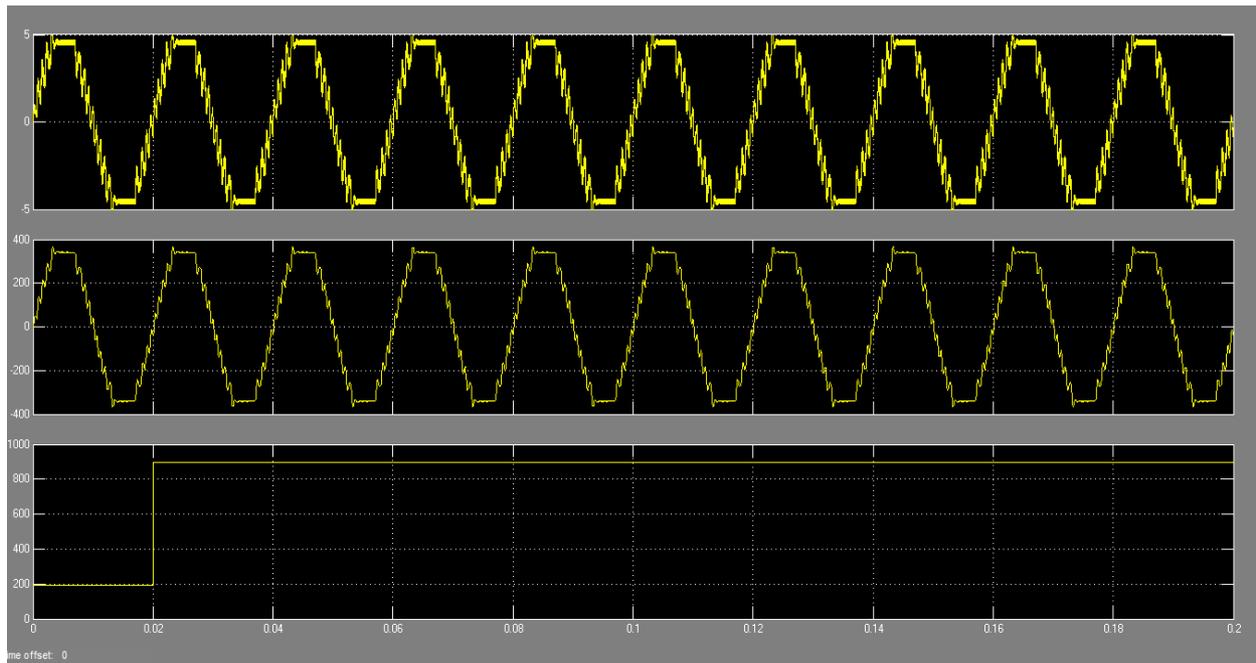


Fig. 9. Simulated Output of H5 Topology

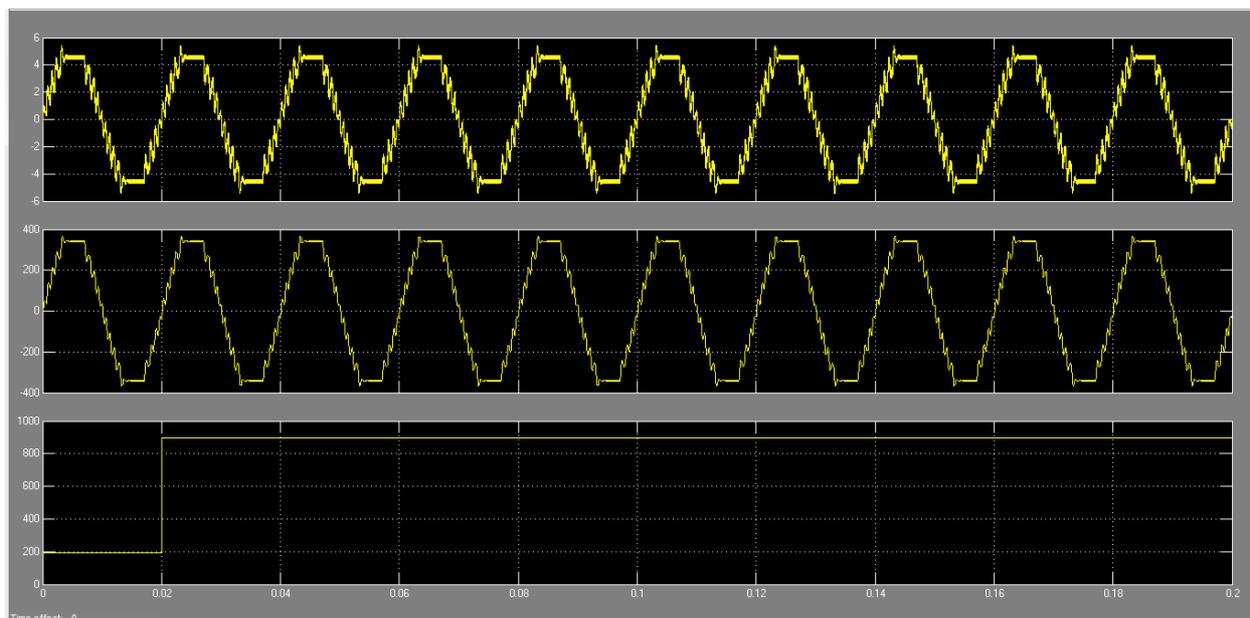


Fig. 10. Simulated Output of HERIC Topology

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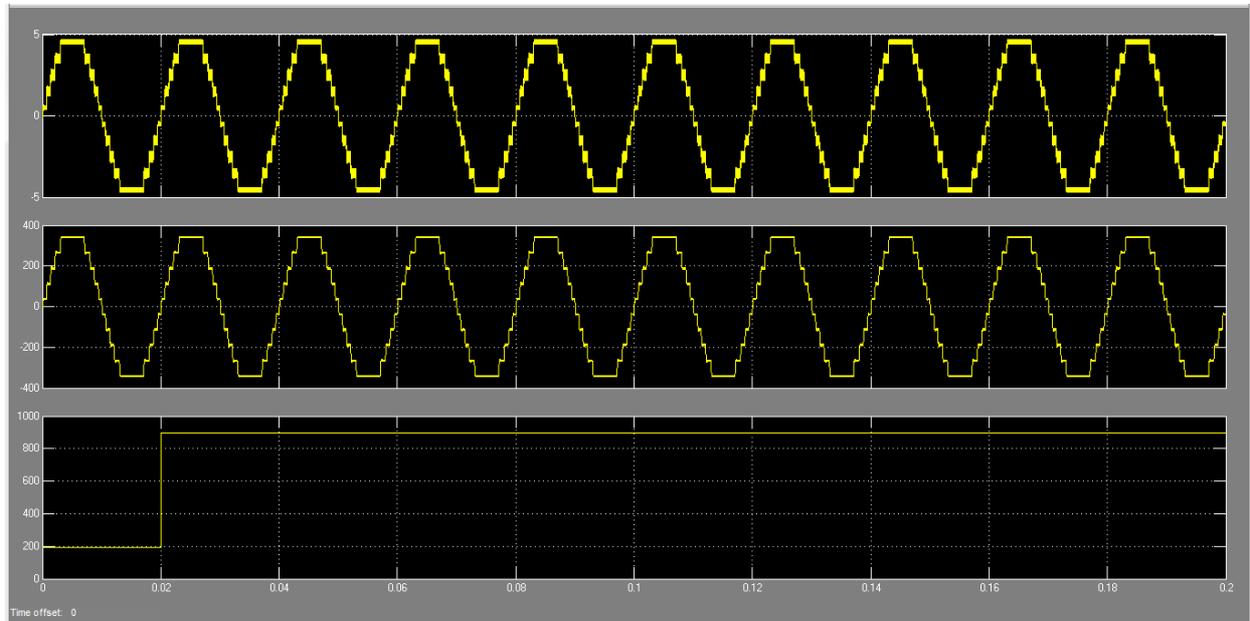


Fig. 11. Simulated Output of H6 Topology

Comparison of efficiencies of these three technologies with different power ratings is given in the table I. These efficiencies are calculated on the basis of simulated results.

TABLE I. Comparison of Efficiencies of These Three Topologies.

Power	H5	HERIC	H6
1000W	98.77%	98.65%	98.93%
2000W	99.15%	99.12%	99.14%
3000W	99.16%	99.18%	99.15%
4000W	99.08%	99.14%	99.07%
5000W	98.97%	99.08%	98.97%

VII. CONCLUSION

In this report, from the topological relationship point of view, the intrinsic relationship between H5 topology and HERIC topology is revealed. The HERIC topology can be derived from H5, H6-type, and Hybrid Bridge topologies by the idea of reducing conduction loss. Moreover, based on the H5 topology, a new current path is formed by inserting a power device between the terminals of PV array and the midpoint of one of bridge legs. As a result, a family of single-phase transformerless full-bridge H6 inverter topologies with low leakage currents is derived. The proposed H6 topologies have the following advantages:

- 1) The conversion efficiency of the novel H6 topology is better than that of the H5 topology, and its thermal stress distribution is better than that of the H5 topology.
- 2) The leakage current is almost the same as HERIC topology, and meets the safety standard.

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