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Improve Performance on H6 Full-Bridge PV Grid-Tied Inverters

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Abstract: Transformerless inverters are widely employed in grid-tied photovoltaic (PV) era techniques, because of the benefits of achieving high proficiency and cheap. Numerous transformerless inverter topologies happen to be planned in order to meet the actual safety dependence on loss currents, for instance specific in the VDE-4105 typical. Throughout that report, children involving H6 transformerless inverter topologies together with lower loss currents is planned, and also the inbuilt connection among H5 topology, very successful and trustworthy inverter notion (HERIC) topology, and also the planned H6 topology continues to be talked about as well. One of many planned H6 inverter topologies is taken to give an example for detail investigation together with operation methods and modulation method. The facility loss and energy product costs usually are in comparison one of several H5, the actual HERIC, and also the planned H6 topologies. Some sort of general prototype is built for these kind of 3 topologies stated for analyzing their performances when it comes to energy proficiency and loss currents characteristics. Trial and error benefits show which the actual planned H6 topology and also the HERIC attain comparable efficiency within loss currents, that is a bit more serious when compared with which involving the actual H5 topology, but it really attributes larger proficiency when compared with which involving H5 topology.

Keywords: H5 Topology, HERIC, PV, CUK Converter, Buck-Boost Converter.

I. INTRODUCTION

The renewable energy such as photovoltaic (PV) and wind has created various electric energy sources with different electrical characteristics for the modern power system. The 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, low cost, small size, and low weight, especially in the low-power single-phase systems (less than 5 kW). This project designsH6 and H5 transformerless PV Grid Tied inverters which are designed to meet the safety requirement of leakage currents, such as specified in the VDE-4105 standard. Among dc – dc converters buck, boost, buck–boost, and Cuk converters are the four basic dc–dc non isolating converters that have found wide applications in industry. The buck converter can step down the dc voltage, whereas the boost converter is capable to perform a step-up function. In applications where both step-up and step-down conversion ratios are required, the buck–boost and Cuk converters can be used.

II.SOLAR CELL MODEL

A. Photons In, Electrons out: The Photovoltaic Effect:

Solar photovoltaic energy conversion is a one-step conversion process which generates electrical energy from light energy. The explanation relies on ideas from quantum theory. Light is made up of packets of energy, called photons, whose energy depends only upon the frequency or colour of the light. The energy of visible photons is sufficient to excite electrons, bound into solids, up to higher energy levels where they are more free to move. An extreme example of this is the photoelectric effect, the celebrated experiment which was explained by Einstein in 1905, where blue or ultraviolet light provides enough energy for electrons to escape completely from the surface of a metal. Normally, when light is absorbed by matter, photons are given up to excite electrons to higher energy states within the material, but the excited electrons quickly relax back to their ground state. In a photovoltaic device, however, there is some built-in asymmetry which pulls the excited electrons away before they can relax, and feeds them to an external circuit. The extra energy of the excited electrons generates a potential difference, or electromotive force (e.m.f.). This force drives the electrons through a load in the external circuit to do electrical work.

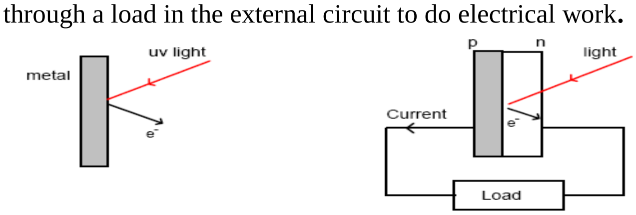

Fig1. Comparison of the photoelectric effect (left), where uv light liberates electrons from the surface of a metal, with the photovoltaic effect in a solar cell (right). The photovoltaic cell needs to have some spatial asymmetry, such as contacts with different electronic properties, to drive the excited electrons through the external circuit.

B. Photovoltaic Cells, Modules and Systems

The solar cell is the basic building block of solar photovoltaics. The cell can be considered as a two terminal device which conducts like a diode in the dark and generates a photo voltage when charged by the sun. Usually it is a thin slice of semiconductor material of around 100 cm2 in area. The surface is treated to react as little visible light as possible and appears dark blue or black. A pattern of metal contacts is imprinted on the surface to make electrical contact1(a) 28 to 36 cells in series, to generate a dc output voltage of 12 V in standard illumination conditions (Fig2(b)). The 12 V modules can be used singly, or connected in parallel and series into an array with a larger current and voltage output, according to the power demanded by the application (Fig2(c)).

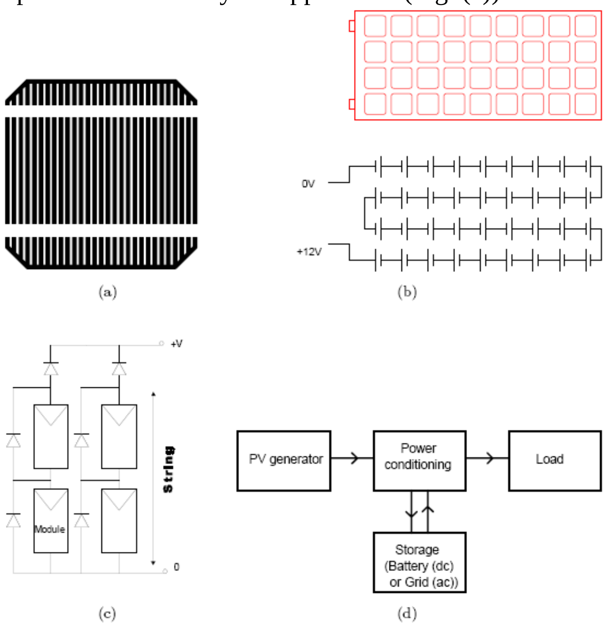

Fig2.(a)Photovoltaic Cell Showing Surface Contact Patterns, (b) In A Module, Cells Are Usually Connected In Series To Give A Standard Dc Voltage of 12V, (c) For Any Application, Modules Are Connected In Series Into Strings And Then In Parallel Into An Array, Which Produces Sufficient Current And Voltage To Meet The Demand. (d) In Most Cases The Photovoltaic Array Should Be Integrated With Components For Charge Regulation And Storage.

III.DESCRIPTION OF H5 AND H6 TRANSFOR MERLESS PHOTOVOLTAIC GRID TIED INVERTERS

A. Basic Transformerless PV Grid Tied Inverter

From the safety point of view, most of the PV grid-tied inverters employ line-frequency transformers to provide galvanic isolaion in commercial structures in the past. However, line-frequency transformers are large and heavy, making the whole system bulky and hard to install. Compared with line-frequency isolation, inverters with high-frequency isolation transformers have lower cost, smaller size and weight. However, the inverters with high-frequency transformers have several power stages, which increase the system complexity and reduce the system efficiency

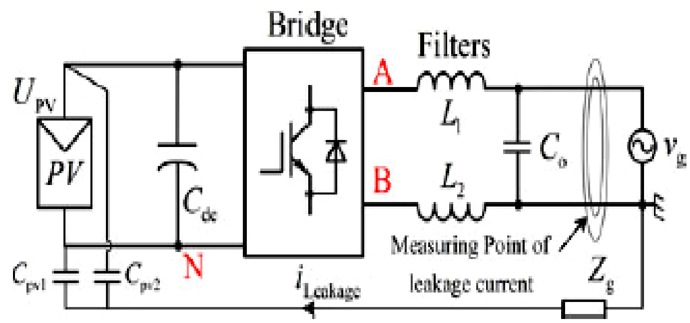

Fig3. Leakage current path for transformerless PV Inverters.

As a result, the transformerless PV grid-tied inverters, as shown in Fig3, are widely installed in the low-power distributed PV generation systems. Unfortunately, when the transformer is removed, the common mode (CM) leakage currents ($i_{Leakagee}$) may appear in the system and flow through the parasitic capacitances between the PV panels and the ground. Moreover, the leakage currents lead to serious safety and radiated interference issues. Therefore, they must be limited within a reasonable range. As shown in Fig.3, the leakage current$i_{Leakagee}$ is flowing through the loop consisting of the parasitic capacitances (C_{PV1} and C_{PV2}), bridge, filters (L_1 and L_2), utility grid, and ground impedance Z_g. The leakage current path is equivalent to an LC resonant circuit in series with the CM voltage, and the CM voltage v_{CM} is defined as

$$v_{CM} = \frac{v_{AN} + v_{BN}}{2} + (v_{AN} - v_{BN})\frac{L_2 - L_1}{2(L_1 + L_2)} \qquad (1)$$

Where V_{AN} is the voltage difference between points A and N, V_{BN} is the voltage difference between points B and N. L_1 and L_2 are the output filter inductors.

In order to eliminate leakage currents, the CM voltage must be kept constant or only varied at low frequency, such as 50 Hz/30 Hz. The conventional solution employs the half-bridge inverter. The filter inductor L_2 is zero in the half bridge inverters. Therefore, (1) is simplified as

$$v_{CM} = \frac{v_{AN} + v_{BN}}{2} - \frac{(v_{AN} - v_{BN})}{2} = v_{BN}. \qquad (2)$$

The Common Mode voltage V_{CM} is constant due to the neutral line of the utility grid connecting to the midpoint of the split dc-link capacitors directly. However, a drawback of half-bridge inverters is that, the dc voltage utilization of half-bridge type topologies is half of the full-bridge topologies. As a result, either large numbers of PV panels in series are involved or a boost dc/dc converter with extremely high voltage transfer ratio is required as the first power conditioning stage, which could decrease the system efficiency. The full-bridge inverters only need half of the input voltage value demanded by the half-bridge topology, and the filter inductors L_1 and L_2 are usually with the same value. As a result, (1) is simplified as

$$v_{CM} = \frac{v_{AN} + v_{BN}}{2}. \quad (3)$$

Many solutions have been implemented to realize CM voltage constant in the full-bridge transformerless inverters. A traditional method is to apply the full-bridge inverter with the bipolar sinusoidal pulse width modulation (SPWM). The CM voltage of this inverter is kept constant during all operating modes. Thus, it features excellent leakage currents characteristic. However, the current ripples across the filter inductors and the switching losses are likely to be large. The full-bridge inverters with unipolar SPWM control are attractive due to the excellent differential-mode (DM) characteristics such as smaller inductor current ripple, and higher conversion efficiency. However, the CM voltage of conventional unipolar SPWM full bridge inverter varies at switching frequency, which leads to high leakage currents. Two solutions could be applied to solve this problem.

One solution is to connect the PV negative terminal with the neutral line of the utility grid directly, such as the Karschny inverter derived from buck–boost converter, and the inverters derived from virtual dc-bus concept. The CM voltage is kept constant by these full-bridge topologies with unipolar modulation methods. Another solution is to disconnect the dc and ac sides of the full-bridge inverter in the freewheeling modes. Various topologies have been developed and researched based on this method for keeping the CM voltage constant, such as the H5 topology, the H3-type topology, and the hybrid-bridge topology, etc., are shown. Fig.4(a) shows the H5 topology. It employs an extra switch on the dc side of inverter. As a result, the PV array is disconnected from the utility grid when the inverter output voltage is at zero voltage level, and the leakage current path is cut off.

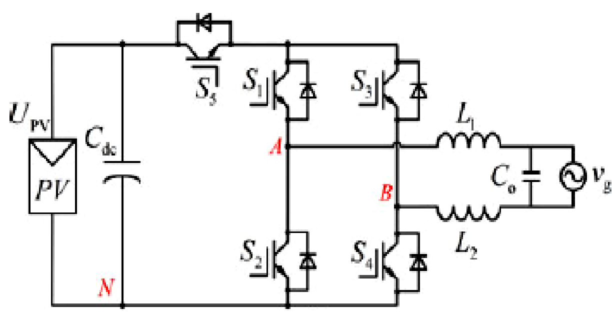

Fig4(a). H5 Topology.

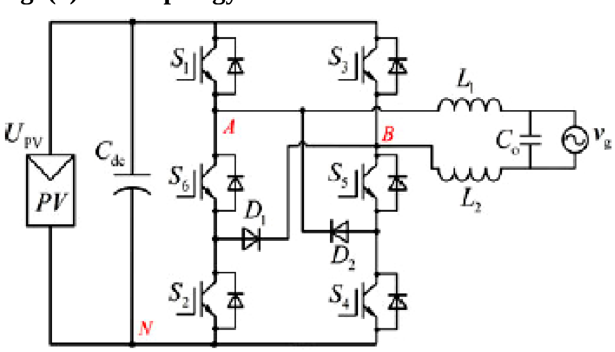

Fig4(b). H3 Topology.

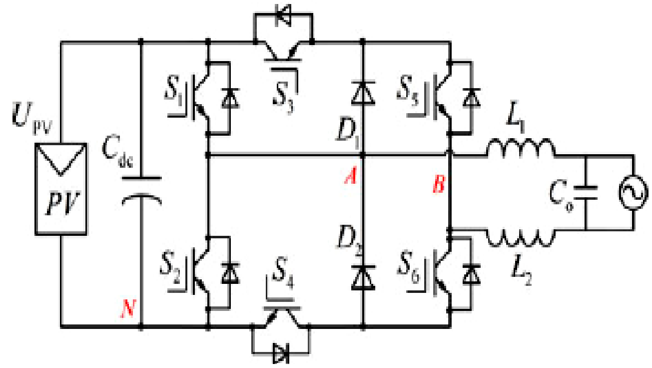

Fig4(c). Hybrid Bridge Topology.

Fig4(b) and (c) shows the H3-type topology and the hybrid-bridge topology respectively. Comparing with a full-bridge inverter, two extra switches are employed in the dc sides of these two topologies. However, these topologies have never been analyzed form the point of view of topological relationships. In this project, a family of H3 full-bridge topologies is implemented for the transformer-less PV grid-tied inverters. An extra switch is inserted to the H5 topology for forming a new current path and for reducing conduction loss. Therefore, in the active modes, the inductor current of the implemented H3 topology flows through two switches during one of the halfline periods and through three switches during another half-line period. Implemented H3 topology has achieved the minimum conduction loss, and also has featured with low leakage currents. A family of H3 topologies is implemented. H3 topologies are taken as an example for analysis in detail with operational principle and modulation strategy.

IV. OUTPUT RESULTS AND COMPARISONS OF H5 AND H6 INVERTER TOPOLOGIES

The power losses of power switches of the implemented H6 topology, H5 topology are calculated with the same parameters as given in Table VI, and are illustrated in Table IV. The comparisons of operating devices in these two topologies are summarized in Table V. The main power losses of switches in each operation mode include the turn-ON/OFF loss, conduction loss, diode freewheeling loss, diode reverse recovery loss, and gate loss. From Tables IV and V, it can be seen that the H5 topology only has five power devices. Thus, it has the lowest device cost. The switching loss, diode freewheeling loss, diode reverse recovery loss, and gate drive loss of these two topologies are the same. However, H5 topology has the highest conduction loss

Table IV. Calculated Power Losses on Device

	S1 (w)	S2 (w)	S3 (w)	S4 (w)	S5 (w)	S6 (w)	Total losses(w)
H5	4.911	4.472	4.911	4.472	8.944	N.C.	27.71
HERIC	4.472	4.472	4.472	4.472	2.571	2.571	23.03
H6	4.911	4.472	2.571	4.472	4.472	4.472	25.37

Table V. Comparison of Operating Devices in two topologies

		H5	HERIC	H6
Total device number		5	6	6
Isolated power supply for devices		4	3	4
Switching device number		2	2	2
Conducting device number	$v_g>0$	3	2	3
	$v_g<0$	3	2	2
Diodes number with freewheeling		2	2	2
Diodes number with reverse recovery		1	1	1
Gate drive number		2	2	2

A. Simulation Results of H5 Topology

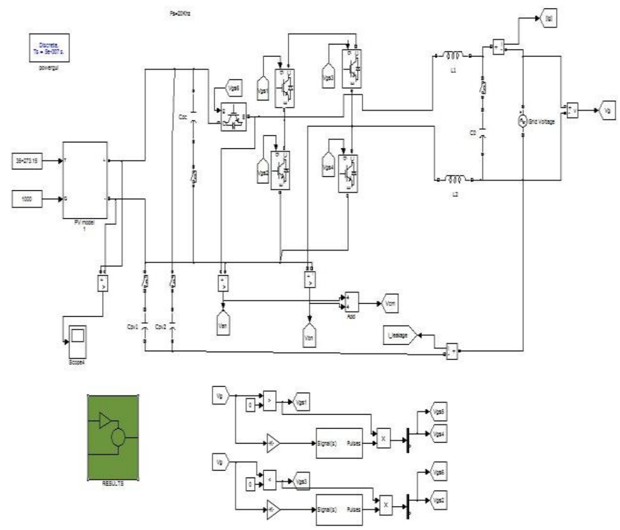

Fig5.Simulation Model of H5 Topology.

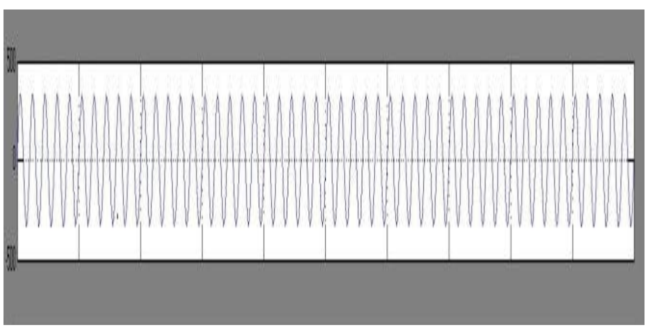

Fig6. Grid Voltage V_g(400V/div) Time(4ms/div).

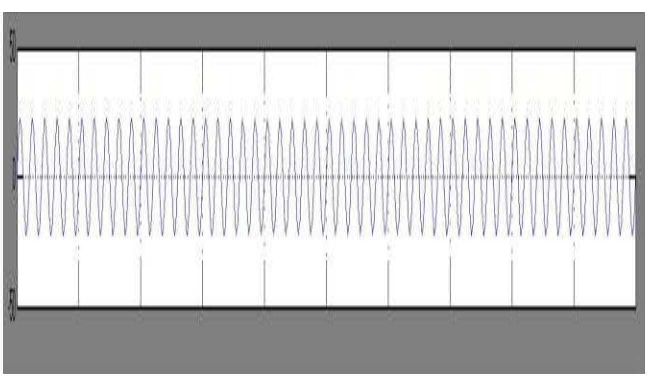

Fig7. Grid Current(10A/div) Time(4ms/div).

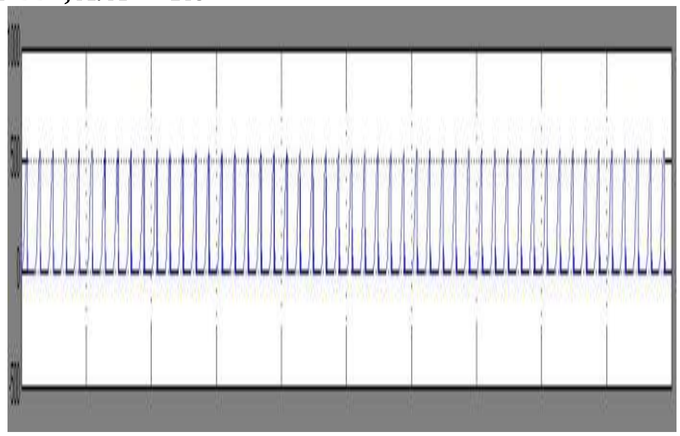

Fig8. V_{AN}(400V/div) Time(4ms/div).

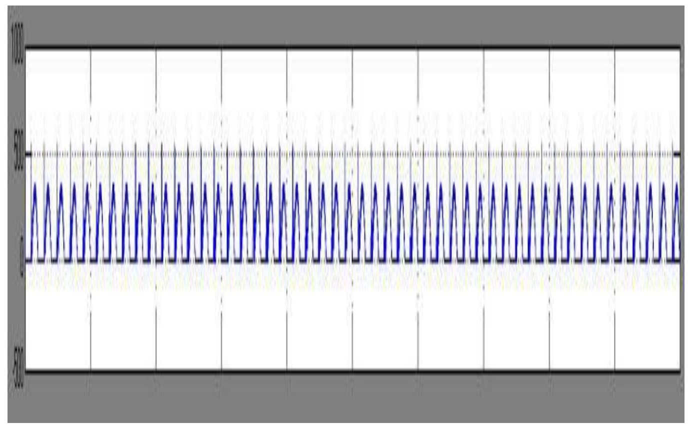

Fig9. V_{BN}(400V/div) Time(4ms/div).

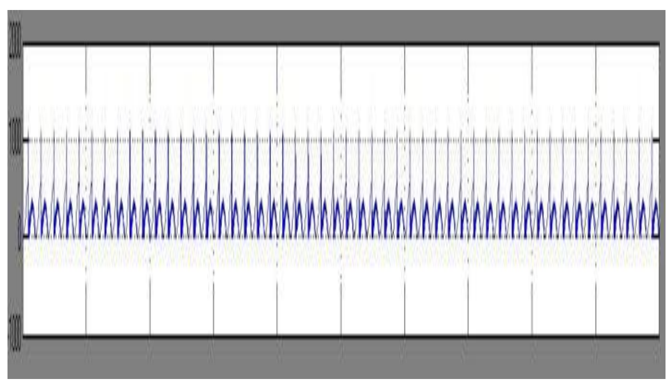

Fig10. Common Mode Voltage(V_{cm}(400v/Div) Time (4ms/Div).

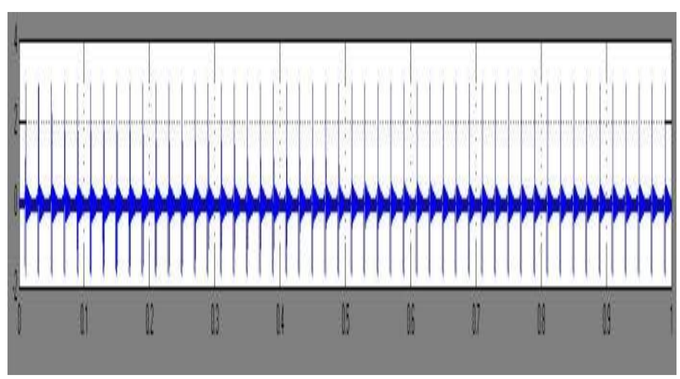

Fig11. leakage Current($I_{leakage}$)(10a/Div) Time(4ms/Div).

B. Simulation Results of H6 Topology

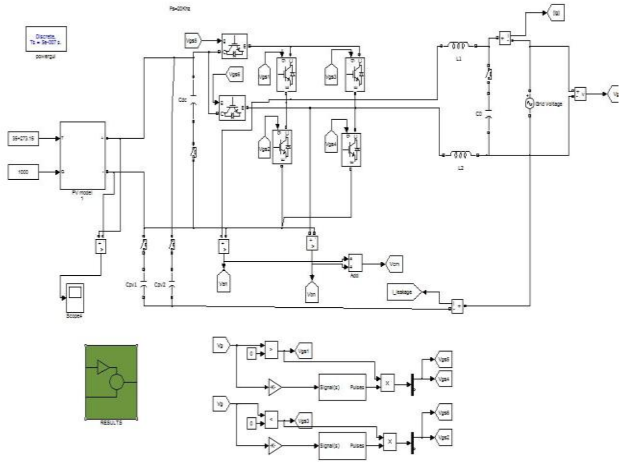

Fig12. Simulation Model of H6 Topology.

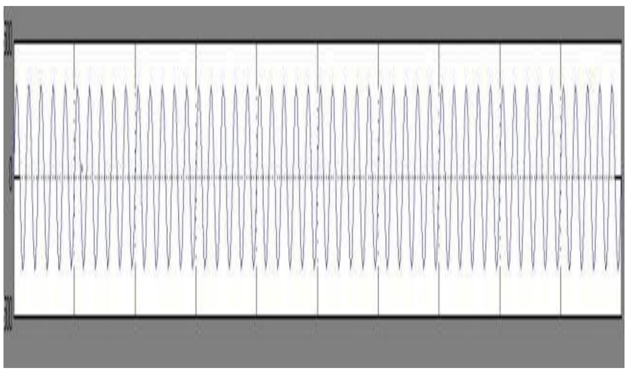

Fig13. Grid Voltage V_g(400V/div) Time(4ms/div).

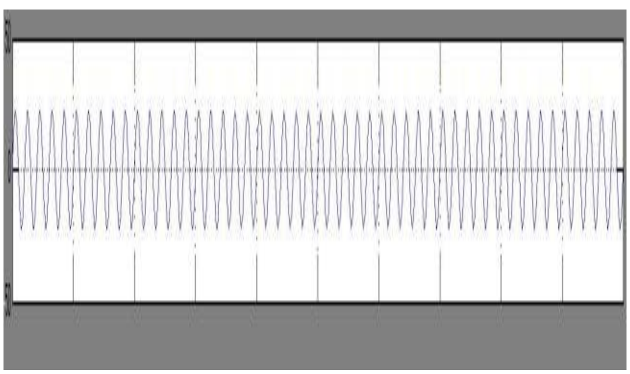

Fig14. Grid current(10A/div) Time(4ms/div).

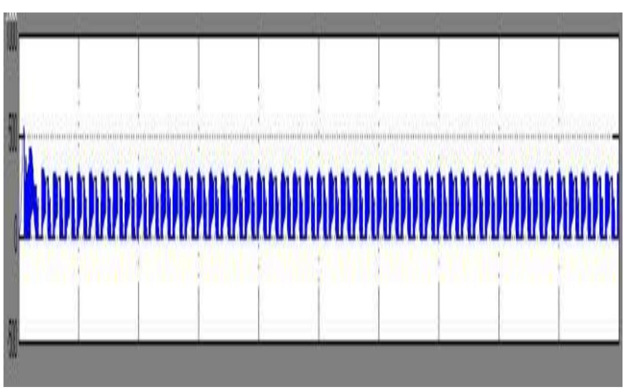

Fig15. V_{AN}(400V/div) Time(4ms/div) V_{BN}(400V/div).

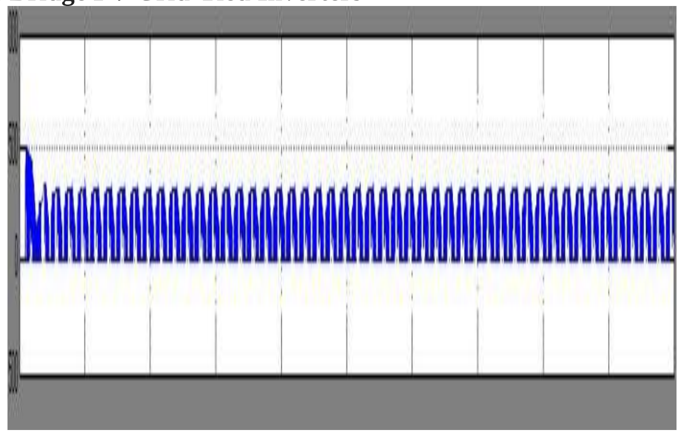

Fig16.V_{BN}(400V/div) Time(4ms/div).

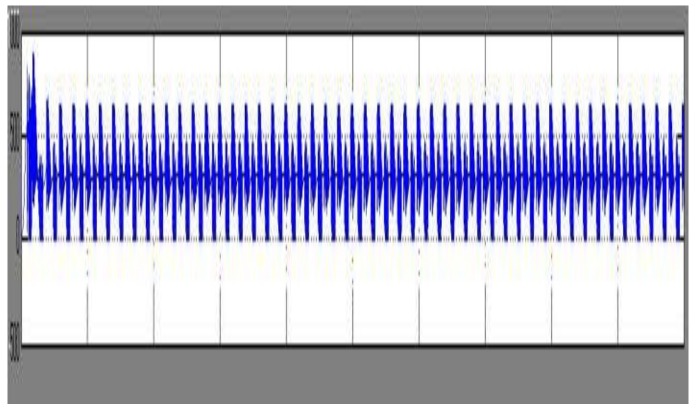

Fig17. Common Mode Voltage (V_{cm}(400v/Div) Time (4ms/Div).

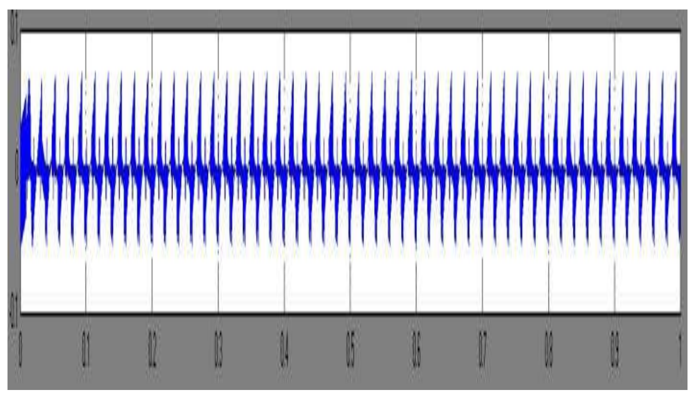

Fig18. Leakage Current($I_{leakage}$)(10a/Div) Time(4ms/Div).

V. CONCLUSION

In this project, from the topological relationship point of view, the intrinsic relationship between H5 topology and H6 topology is revealed. 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 inductor losses in the two topologies are the same due to the same v_{AB} modulation. Therefore, the inductor losses of these two topologies are regardless. The implemented H6 topologies have the following advantages and evaluated by simulation results:

1. The conversion efficiency of the 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 implemented H6 topologies are good solutions for the single phase transformerless PV grid-tied inverters.

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