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H6 Transformer less Topology and Its Modulation Strategy for Mitigating Cm Currents in Pv Grid Connected Inverters

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Abstract
MATLABbasedsingle-phase three-level topology for a transformer less photovoltaic system is presented in this paper. Compared with the conventional H-bridge topology, it only needs two additional asymmetrically distributed switches, and the system common-mode voltage can be kept constant with a simple modulation scheme. Family of H6 transformer less inverter topologies with low leakage currents is proposed and highly efficient and reliable inverter concept
(HERIC) topology is also presented in this paper. The proposed inverter can also operate with high frequency by retaining high efficiency which enables reduced cooling system. Finally, the proposed new topology is simulated by MATLAB/Simulink software to validate the accuracy of the theoretical explanation.
Keywords: Solar PV, Transformer less inverter, Common-mode voltage, Leakage current, Current Ripples, Switching control, PWM.

I. INTRODUCTION

The interest in renewable-energy sources is successivelyincreasing because of rising demand of the world's energy andincreasing price of the other energy sources, together withconsidering the environmental pollution. Many renewableenergy sources are now available; among them, PV is the mostup-to-date technique to address the energy problems.Photovoltaic (PV) power generation systems are receivedmore and more attention in recent years. Due tothe large-scale manufacturing capability of the PV module, itis becoming increasingly cheaper during these last years. Sothe attempt to decrease the total grid-tied PV system cost ismostly depend on the price of grid-tied inverter [1-3]. GridtiedPV inverters which consists a line frequency transformerare large in size; make the entire system extensive and difficultto install. It is also a challenging task to increase the efficiencyand reduce the cost by using high frequency transformerwhich requires several power stages [4, 5]. On the other hand,transformer-less grid-tied inverters have the benefits of lowercost, higher efficiency, smaller size, and weight [6-12].However, there exist a galvanic connection between the powergrid and the PV module due to the exclusion of transformerwhich form a CM leakage current. This CM leakage currentincreases the grid current harmonics and system losses andalso creates strong conducted and radiated electromagnetic interference.However, the transformerless inverter creates a common-mode resonant circuit including the filter, theinverter, the impedance of the grid and the DC source ground parasitic capacitance as illustrated in Figure 1. In this case, a common-mode current is generated and superimposed to the grid, henceincreasing its harmonics content [7, 12-16] and causing an electromagnetic interference (EMI) betweenthe PV system and the grid. In addition, the leakage current through the parasitic capacitance can reachconsiderable levels affecting therefore the safety when a human touches the PV system.To eliminate these currents, topologies that do not generate variant common-mode voltage are necessaryfor implementing transformerless PV inverter.

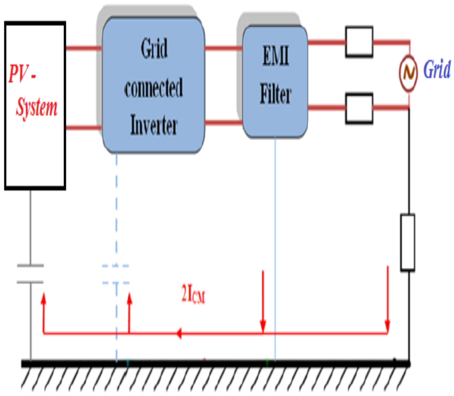

Fig.1. Ttransformerless PV system

On the other hand, the transformerless PV systems havebeen received more attention due to cost and sizereduction, as well as efficiency improvement compared withthe conventional transformer ones. A number of technicalchallengesmay arise with increased grid-connectedtransformerless PV systems.

One of the most importantissues is how to reduce or eliminate the leakage currentsthrough the parasitic capacitor between the PV array andthe ground [3-10]. In general, the leakage current can besignificantly mitigated from the viewpoint of system topologyor modulation schemes. For example, the single-phase H-bridgetopology with the bipolar modulation has the inherentfeature of the leakage current reduction. However, it leadsto the relatively more high frequency ripples due to the two-leveloutput voltage.On the other hand, the unipolarmodulation with three-level output voltage is beneficial interms of low voltage ripples and small filter size, but theleakage current is significantly increased due to the timevaryinghigh frequency common mode voltage.

In order to solve the abovementioned problem, manyinteresting topologies have been reported in the past fewyears. The basic idea behind them is to keep the systemcommon mode voltage constant to eliminate the leakagecurrents. With the basic idea, a new single-phase three-leveltopology for transformerless photovoltaic systems ispresented in this paper. Compared with the conventional H-bridgetopology, it only needs two additional asymmetricallydistributed switches, and the system common-mode voltagecan be kept constant with a simple modulation scheme. Thetheoretical analysis and test results demonstrated that theproposed topology is very promising for transformerless PVsystems.

II. PROPOSED TOPOLOGY

Fig. 2.employs two extra switches on the ac side of inverter, so the leakage current path is cut off as well. Fig. 3 and Fig.4 shows the H6-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.

In the active modes, the inductor current of the proposed H6 topology flows through two switches during one of the half-line periods and through three switches during another half-line period. As a result, for comparing with the topologies presented in [17], [19], and [20], the proposed H6 topology has achieved the minimum conduction loss, and also has featured with low leakage currents.

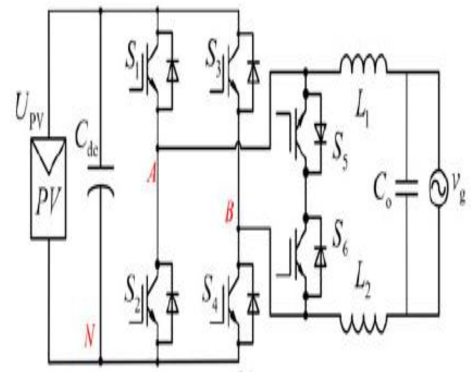

Fig.2.Transformerless full-bridge inverter-(HERIC) Topology

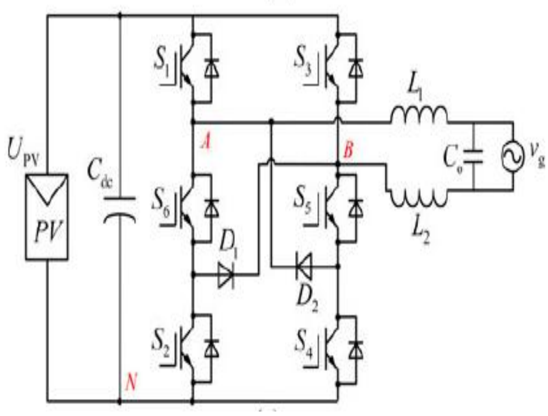

Fig.3. Transformerless full-bridge inverter- H6-Type

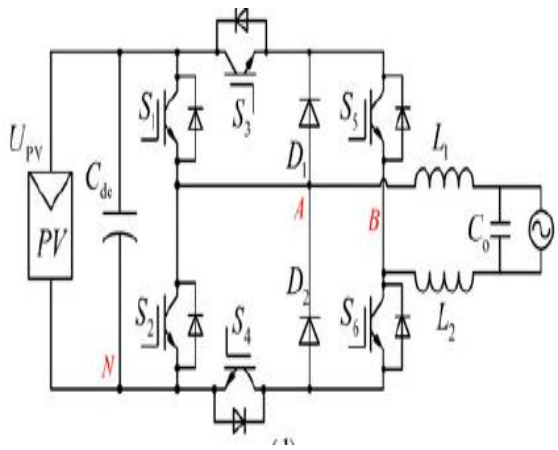

Fig.4. Transformerless full-bridge inverter- Hybrid Type

1. *Modes of operations :*

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 in Fig.5.

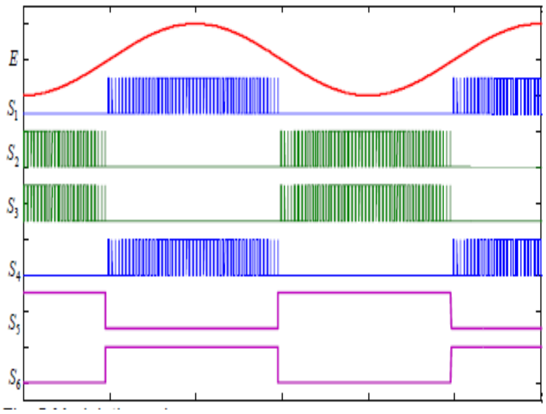

Fig.5. Modulation Scheme for gate drive signals with unity power factor.

In the proposed H6 inverter topologies, there are four operation modes in each period of the utilitygrid. The four modes of operations are explained bellow

Mode 1 :Mode1I is the active mode in the positive half period ofthe utility grid voltage, as shown in Fig. 6. *S*1, *S*4 ,and *S*5 are turned ON, and the other switches are turnedOFF. The inductor current is flowing through *S*1, *S*4 , and*S*5 . *v*AN = *U*PV, *v*BN = 0; thus, *v*AB = *U*PV, and the CMvoltage *v*CM= (*v*AN + *v*BN)/2 = 0.5*U*PV.

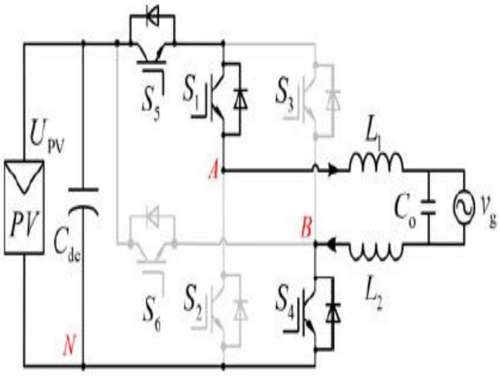

Fig.6. Equivalent circuits of operation mode-Active mode in the positive half period(Mode1)

Mode 2 : Mode 2 is the freewheeling mode in the positive half periodof the utility grid voltage, as shown in Fig.7. *S*1is turned ON; the other switches are turned OFF. The inductorcurrent is flowing through *S*1 and the antiparalleleddiode of *S*3 .*v*AN = *v*BN≈ 0.5*U*PV; thus, *v*AB = 0, andthe CM voltage *v*CM = (*v*AN + *v*BN)/2 ≈ 0.5*U*PV.

Mode.3:Mode 3 is the active mode in the negative half period ofthe utility grid voltage, as shown in Fig.8. *S*2, *S*3, and*S*6 are turned ON; the other switches are turned OFF. Theinductor current is flowing through *S*2 and *S*6 . Although*S*3 is turned ON, there is no current flowing through it, andthe switch *S*3 has no conduction loss in this mode. Nevertheless,in the H5 topology, the inductor current flowsthrough *S*2, *S*3 , and *S*5 . Therefore, the conduction loss ofproposed topology is less than that of H5 topology. In thismode, *v*AN = 0, *v*BN = *U*PV; thus, *v*AB = −*U*PV, and theCM voltage *v*CM = (*v*AN + *v*BN)/2 = 0.5*U*PV.

Mode.4: Mode 4 is the freewheeling mode in the negative half periodof the utility grid voltage, as shown in Fig.9. *S*3is turned ON, and the other switches are turned OFF. The inductor current is flowing through *S*3 and the antiparalleleddiode of *S*1 .*v*AN = *v*BN≈ 0.5*U*PV; thus, *v*AB = 0,and the CM voltage *v*CM = (*v*AN + *v*BN)/2 ≈ 0.5*U*PV.

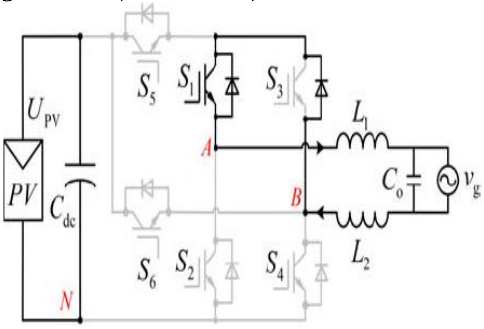

Fig.7.Equivalent circuits of operation mode-Freewheeling mode in the positive half period (Mode 2)

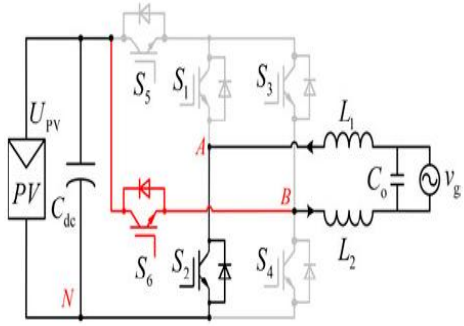

Fig.8.Equivalent circuits of operation mode-Active modein the negative half period. (Mode 3)

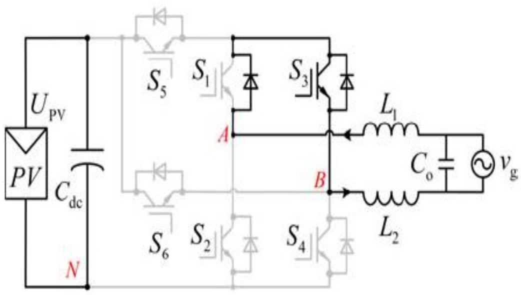

Fig.9.Equivalent circuits of operation mode-Freewheeling mode in the negative half period(Mode 4)

From the four modes of operations, i.e., from Fig.6 to Fig.9 , V_{AN}represents the voltagebetween terminal (A) and terminal (N) and V_{BN}represents thevoltage between terminal (B) and terminal (N). $V_{AN}$is the DMvoltage of the topology, $V_{AB} = V_{AN} - V_{BN}$. The CM voltage $V_{CN} = 0.5(V_{AN} + V_{BN})$.

The full-bridge inverters only need half of the input voltagevalue demanded by the half-bridge topology, and the filter inductors$L1$ and $L2$ are usually with the same value. Hence, V_{CM} is given by

$$V_{CM} = \frac{V_{AN} + V_{BN}}{2}$$

Fig.10. shows the modulation strategy of the proposed modes of operation for gate pulses of converters .

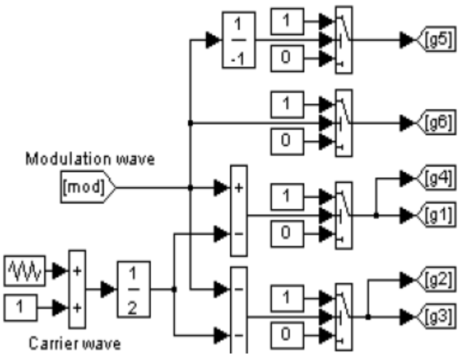

Fig.10.Modulation strategy of the proposed topology

III. MATLAB BASED SIMULATIONOFPROPOSED TOPOLOGY

MATLAB based simulation diagram of proposed system is shown in Fig.11.

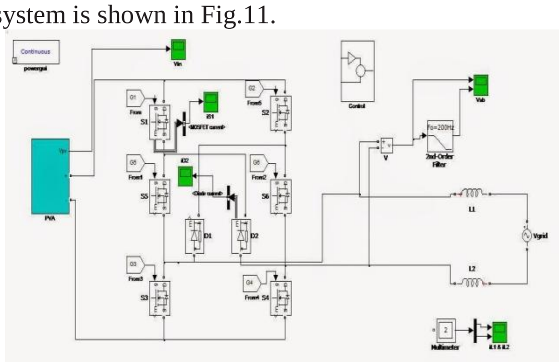

Fig.11. MATLAB based simulation diagram of proposed system.

Fig.12 shows the Voltage stress on $S5$ and$S6$ of Drain–source voltages in H6 topology. Fig.13 shows the DM characteristic of H6 topology.

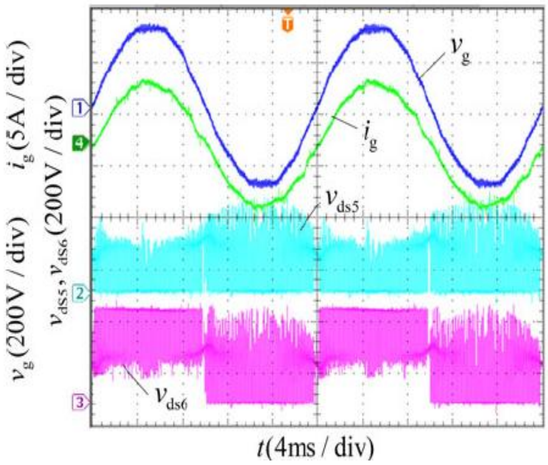

Fig.12.Voltage stress on $S5$ and$S6$ of Drain–source voltages

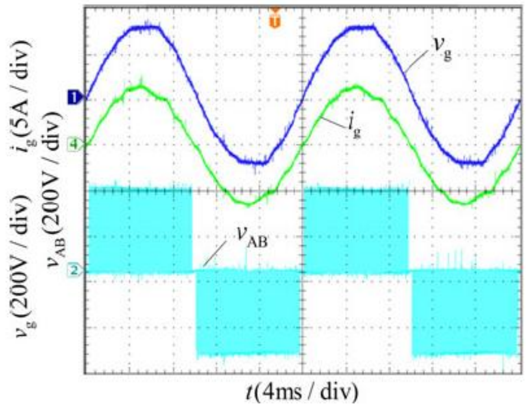

Fig.13. DM characteristic of H6 topology.

TABLE1.SIMULATION SPECIFICATIONS

Parameter	*Rating*
Input Voltage	380-700 V
Output Power	1kW
Grid Voltage	230V
Grid Frequency	50 Hz
Input Capacitance	940µF
Filter inductances	3mH
Filter capacitance	0.1 µF

IV. CONCLUSION

Transformer less inverter topologies are being used to overcome the deficiencies of inverters with transformers. This paper proposes a novel 3-phase inverter with H6-type configuration as a part of a wide input range, high efficiency, and long lifetime PV non-isolated module. Experimental results verify the validity of the novel circuit and show high efficiency. Furthermore, the switching voltages of all commutating switches are half of the input dcvoltage and the switching losses are reduced greatly.Finally , theoretical analysis and performance evaluation resultsindicate that the proposed topology can effectively reducethe leakage current to an acceptable level.

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