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An Improved Transformerless Inverter Topology for Grid Connected Photovoltaic System

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***Abstract*- Transformerless inverters are gaining importance in grid integration of PV power due to high efficiency, compact size and low cost. Leakage current is the major issue in these inverters which needs to be eliminated. The leakage current depends on common mode voltage (CMV), PV module parasitic capacitances and stray switches junction capacitances. In this paper, an improved common mode voltage clamped transformerless inverter topology has been proposed. Unlike H5 and HERIC topologies, the proposed topology generates constant CMV during both power transfer and freewheeling periods. As a result, leakage current is eliminated. Moreover, the proposed topology is compared with classic full bridge and H5 topologies. The analysis of the proposed topology is carried out in Matlab Simulink. A 2.7 kW grid connected inverter prototype was developed in Matlab Simulink environment.**

Keywords—Transformerless, photovoltaic, leakage current, CMV

I. Introduction

Recently, a large share of electrical energy demand is being fulfilled by the renewable energy resources which are solar, wind, biomass, oceanic thermal, hydro and tidal etc. Among these resources, contribution of solar photovoltaic power has been increasing rapidly. From the report published by the International Energy Agency (IEA), global PV market in 2016 was approximately 75 GW with a growth rate of 50% compared to 2015. A cumulative total power capacity has been raised from 6.5 GW in 2005 to 302 GW in 2016, which is at least 46 times higher than that in 2005, and presents around 1.8% of global electricity demand [1]. This substantial growth has been possible because of several factors such as increased environmental awareness, market expansion, modules cost reduction, government incentives and advancement of power electronics and semiconductor technology.

PV systems are generally classified into two groups: grid tied and off-grid or stand-alone) system. In case of off-grid systems , power generated by the PV modules is directly fed to the electrical loads which can be ac or dc. OFF grid PV systems are integrated with storage system to have a balance between power supply and load. However, grid connected PV system inject the generated power directly into the utility grid which eliminate the requirement of energy storage system [2]. As a result, grid tied PV system is economical and free from maintenance which represent around 99% of the global installed PV power as shown in Fig. 1.

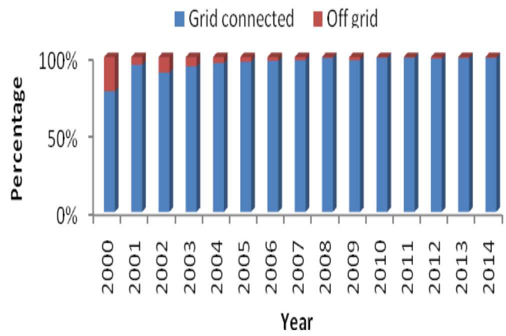


Fig. 1. hare of grid-connected and off-grid installations

The PV generated power should not be wasted as PV module efficiency is low. The inverters which convert PV dc power into ac and inject to the grid should exhibits high efficiency. Grid connected PV inverters are classified on the basis of electrical isolation as transformerless and transformer type. Transformer provides isolation and amplification of the voltage level. However, it causes reduction in efficiency, increase in size and cost of the system [3]. On the other hand transformerless inverters have many advantages such as high efficiency, compact size and low cost. The major drawback of transformerless inverters is leakage current which flows from PV modules to grid. The leakage current introduces system losses, grid current distortion, electromagnetic interference and threat to working personnel [4-5]. Its magnitude depends on CMV parasitic module capacitances.

Leakage current can be eliminated by using half bridge or full bridge inverter topology with bipolar modulation. However, in case of half bridge topology double input voltage is required compared to full bridge. Full bridge inverter with bipolar modulation produces twice voltage across filter inductor, more power loss and big filter size compared to unipolar modulation [6]. H4 topology with unipolar modulation strategy exhibits good differential mode characteristics, highest efficiency, smaller filter size. But it generates high leakage current. Hence, in order to achieve high efficiency and low leakage current, various topologies have been presented in literature [2-11]. The unclamped CMV topologies such as H6 families, HERIC and H5 are not able to generate constant CMV due to presence of junction capacitance of switches. The value of capacitor form across switches varies in the range of nano to pico Farads. As a result, these topologies generate high leakage current [4].

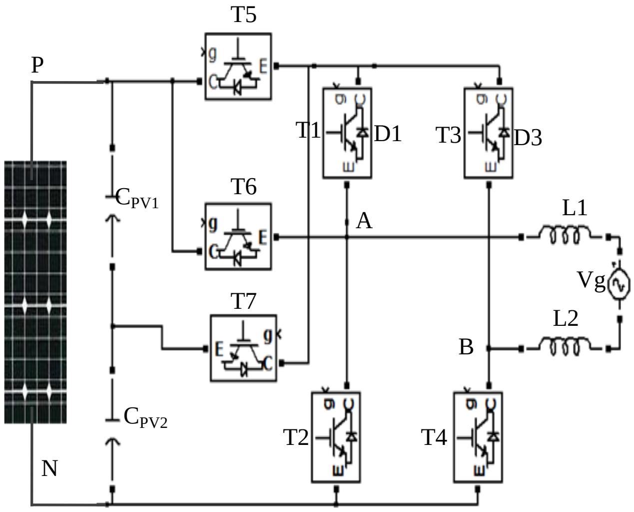
In order to eliminate the leakage current problems, an improved CMV clamped PV inverter topology has been proposed. The proposed topology generates three-level unipolar inverter output voltage which reduces the filter size, power loss and current ripples.

The paper organization is divided into five sections. The proposed topology and modulation strategy are discussed in Section 2. The Section 3 presents operation analysis of the proposed topology. Section 4 presents Simulation analysis and results. Finally, section 5 concludes the paper.

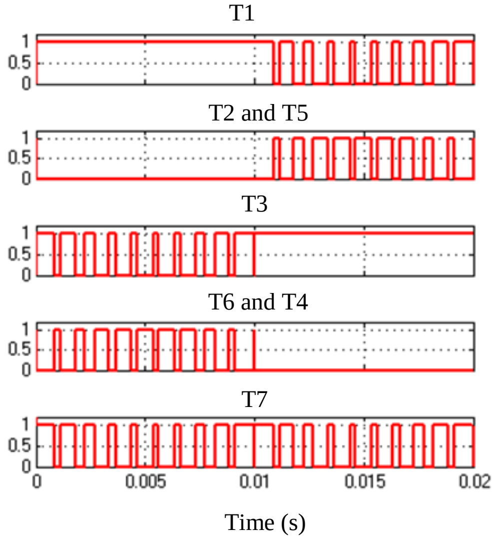
II. PROPOSED TOPOLOGY

A. *Structure and modulation strategy*

The structure and modulation strategy of the proposed PV inverter topology are shown in Fig. 2 (a) and 2(b). The proposed topology is composed of seven transistors (IGBT) switches, two dc link capacitors and filter inductors. The switches T1 and T3 provide freewheeling path for current to flow during zero voltage periods. Switches T6 and T5 are turned OFF during freewheeling time and isolate the PV modules from grid. At same instant, Switch T7 turned ON and clamped the CMV to half of dc dink voltage. Thus, CMV dependent leakage current is eliminated. In case of H5 three switches are conducting while in H6 four switches are ON during power transfer states. But in proposed topology, only two switches T6 and T4 are conducting during power transfer in positive grid voltage. Hence, proposed topology has lower conduction loss.



(a)



(b)

Fig. 2. (a) Proposed CMV clamped topology and (b) modulation strategy

B. *Operation of proposed topology*

The operation modes of the proposed topology are described as follows.

Mode – I: Power transfer states during positive grid voltage

The switches T6 and T4 are turned ON while T2, T3, T5, T7 are turned OFF. The grid current flows through T6, L1, grid, L2 and T4 as depicted in Fig. 3 (a).

Mode – II: Freewheeling states during positive grid voltage

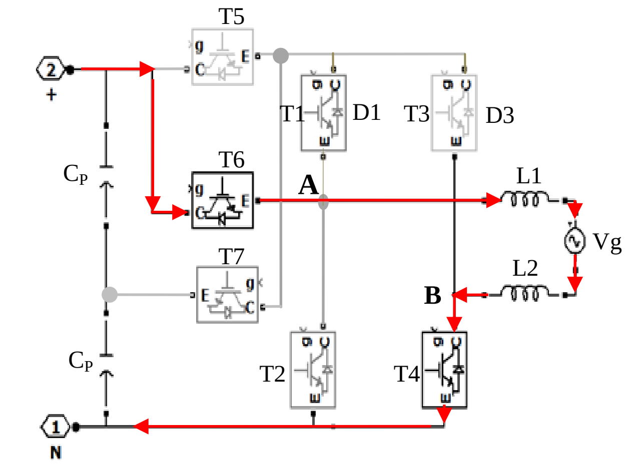
Switch T1 is always ON and switch T3 and T7 are switched at switching frequency. The grid current Freewheels through L1, grid, L2, anti-parallel diode D3 and switch T1 as illustrated in Fig. 3 (b). The inverter output voltages are clamped by T7 to half of VPV.

Mode – III: Power transfer states during negative grid voltage

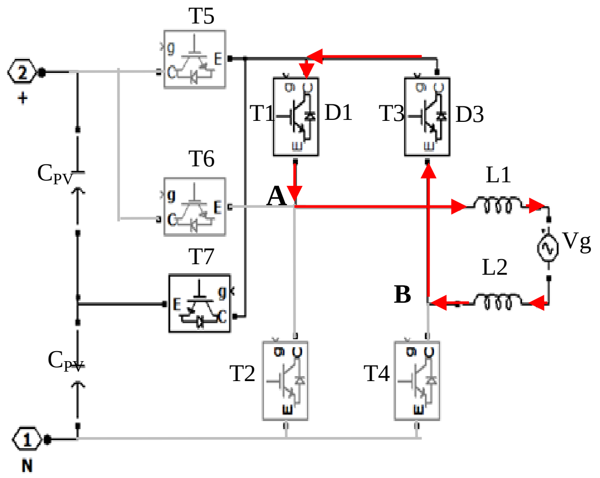
The switches T5, T3 and T2 are ON while T4, T6 and T7 are OFF. The grid current flows through T5, T3, L1, grid, L2 and T2 shown in Fig. 3 (c)

Mode – IV: Freewheeling during negative grid voltage

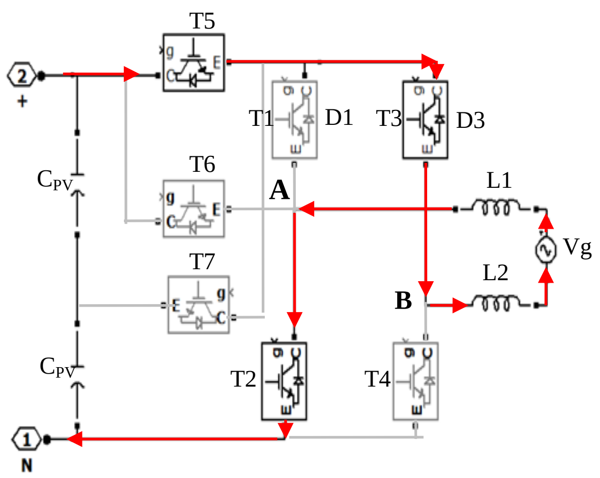
Switch T1 is always ON and switch T3 and T7 are switched at switching frequency. The grid current Freewheels through L2, grid, L1, anti-parallel diode D1 and switch T3 as given in Fig. 3 (d). The inverter output voltages and are clamped by T7 to half of VPV.



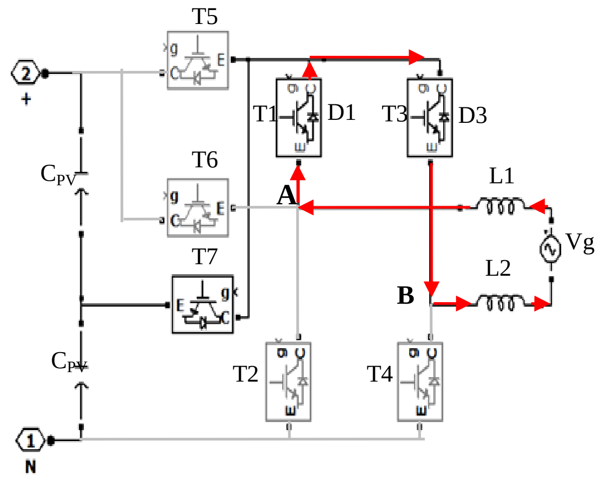
(a)



(b)



(c)



(d)

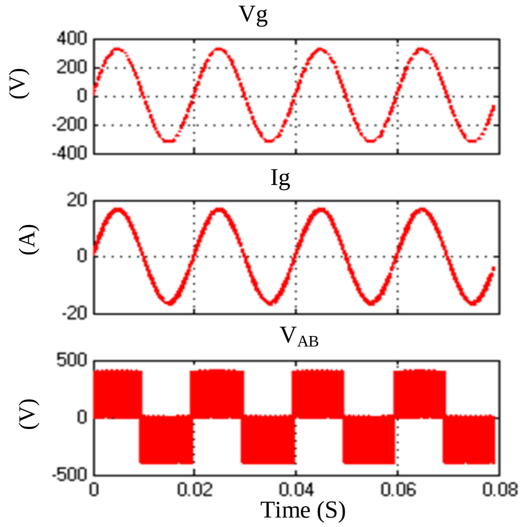
Fig. 3. operations modes of the proposed topology (a) *Power transfer states during positive grid voltage (b) Freewheeling states during positive grid voltage (c) Power transfer states during* negative *grid voltage and (d) Freewheeling during negative grid voltage*

III. Simulation Analysis and Results

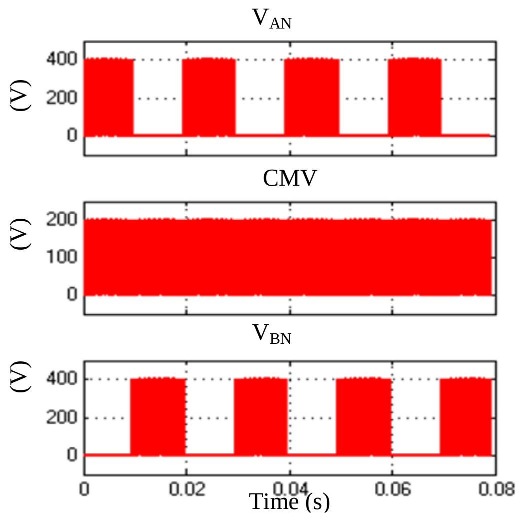
The proposed topology has been analyzed by developing a model in Matlab Simulink. A prototype inverter of rating 2.7 kW was developed. Twelve Sanyo HIP-225 HDE1 modules are connected in series to achieve the 400 dc input voltage. Two dc link capacitors of 3000 µF have been used. The module parasitic capacitors of 300 nF are considered and connected between positive and negative terminals of modules to ground. The single phase grid voltage and frequency of 230 V and 50 Hz are taken respectively. Switches are commutated at 10 kHz switching frequency.

Differential mode (DM) and common mode (CM) waveforms of classical H4, H5 and proposed topology are illustrated in Fig. 4 (a) and (b), Fig. 5 (a) and (b) and Fig. 6 (a) and (b) respectively. These topologies have generated similar DM characteristics, Sinusoidal grid injected current and unipolar voltage at inverter output terminal as illustrated in Fig. 4 (a), Fig. 5 (a) and Fig. 6 (a). However, the CM characteristics are different. The topologies H4 and H5 have generated CMV with high frequency components as shown in Fig. 4 (b) and Fig. 5 (b). As a result, CMV dependent leakage current cannot be eliminated. In contrast, the proposed topology has generated constant CMV as depicted in Fig. 6 (b). Hence, the proposed CMV clamped topology eliminates the leakage current.

Fig. 7 (a), Fig. 7 (b) and Fig. 7 (c) present leakage current waveforms of H4, H5 and the proposed topology respectively. It can be seen that H4 and H5 topologies have produce large value of leakage current. While, leakage current is almost zero in the proposed topology.

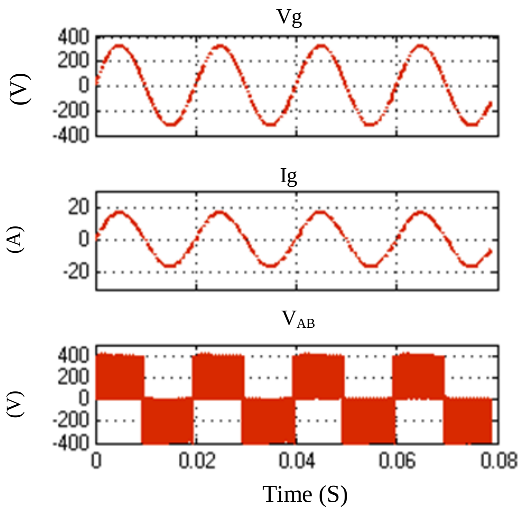


(a)

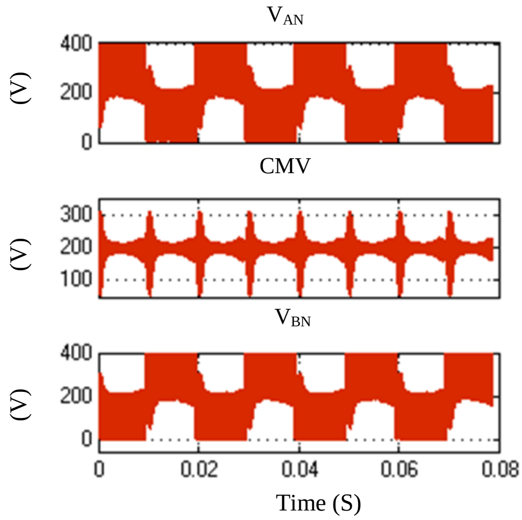


(b)

Fig. 4. (a) DM characteristics of H4 topology and (b) CM characteristics of H4 topology

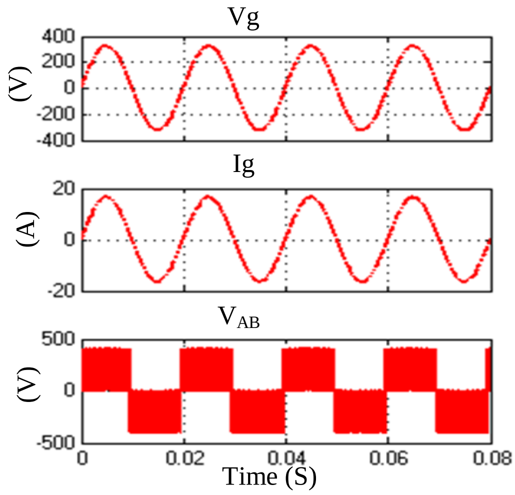


(a)

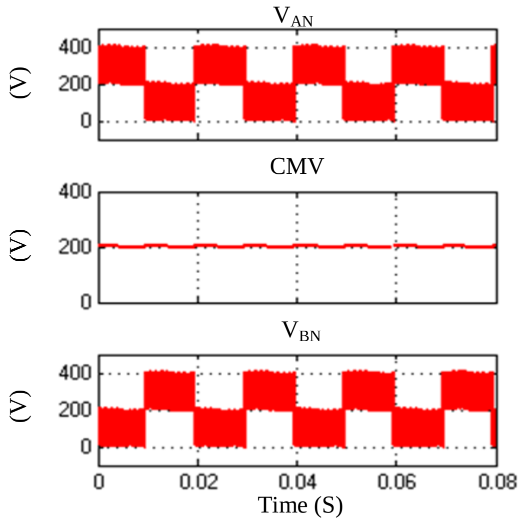


(b)

Fig. 5. (a) DM characteristics and (b) CM characteristics



(a)



(b)

Fig. 6. (a) DM characteristics of proposed topology and (b) CM characteristics of proposed topology

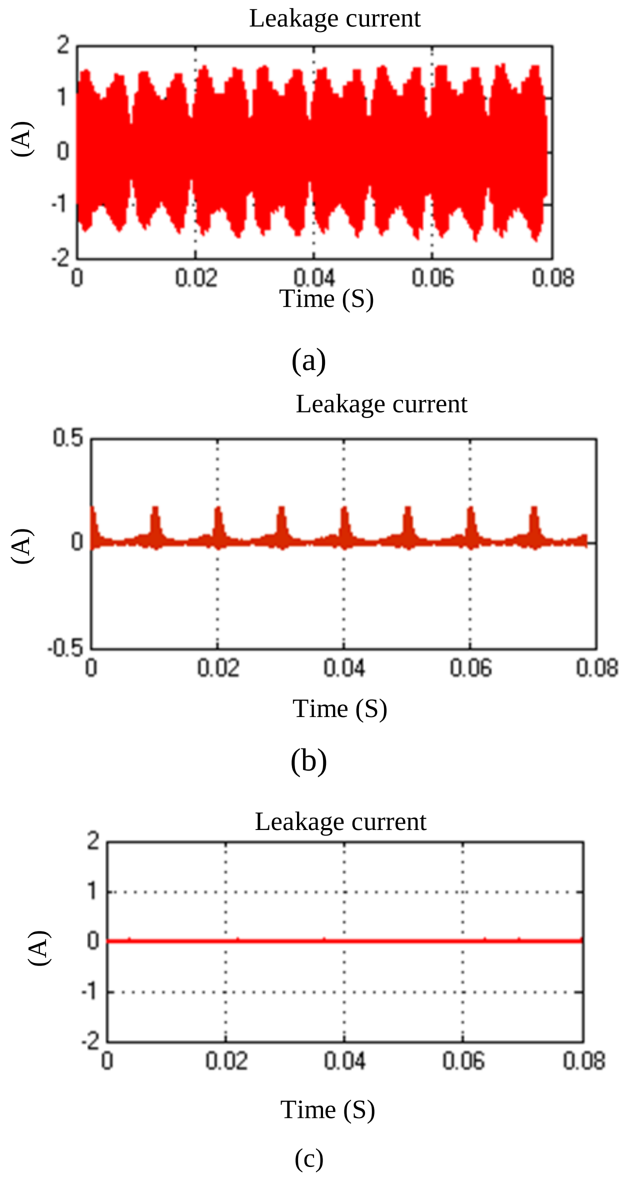


Fig. 7. Leakage current (a) H4 topology with unipolar modulation (b) H5 topology and (c) proposed topology.

IV. CONCLUSION

In this study, a new CMV clamped topology for grid connected PV system is presented. The performance of the topology was compared with H4 and H5 topologies. In order to analyze the topology, a prototype of the proposed system was modeled in Matlab/Simulink. The merits of the proposed topology are summarized as follows.

1. CMV is constant during both power transfer and freewheeling periods.
2. Leakage current problem is completely eliminated.
3. AS only two switches are in conduction during power transfer in positive grid voltage. Hence, conduction losses are lower.

Hence, the proposed topology is suitable for transformerless PV applications.

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