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An Improved Efficiency of Single Phase Transformer Less PV Inverter Topology by NPC System

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ABSTRACT

This paper an improved efficiency of single phase transformer less PV inverter topology by neutral point clamping system proposes how to improve the efficiency of single phase PV inverter topology without using of transformer. If we use a photovoltaic inverter connected to direct loads through transformer the efficiency is largely decreased due to the power losses and the line transformer is large, heavy and expensive. There is a strong trend in the photovoltaic inverter technology to use transformer less topologies in order to acquire higher efficiencies combining with very low ground leakage current. In this paper, a new topology, based on the H-bridge designed with IGBTs midpoint grounding by sequence diode switching is proposed (NPC). In this topology without use ac bypass circuit consisting of a diode rectifier and a switch with clamping to the dc midpoint we can achieve the improvement in efficiency while conversion and low leakage current. The topology is simulated and experimentally validated, and a comparison with other existing topologies is performed. High conversion efficiency and low leakage current are verified. The proposed topology is verified using MATLAB and the all results are validated.

1. INRODUCTION

Photovoltaic (PV) inverters become more and more widespread within both private and commercial circles. These grid-connected inverters convert the available direct current supplied by the PV panels and feed it into the utility grid. According to the latest report on installed PV power, during 2007, there has been a total of 2.25GWof installed PV systems, out of which the majority (90%) has been installed in Germany, Spain, U.S., and Japan. At the end of 2007, the total installed PV capacity has reached 7.9 GW of which around 92% is grid connected.

There are two main topology groups used in the case of grid-connected PV systems, namely, with and without galvanic isolation. Galvanic isolation can be on the dc side in the form of a high-frequency dc–dc transformer or on the grid side in the form of a big bulky ac transformer. Both of these solutions offer the safety and advantage of galvanic isolation, but the efficiency of the whole system is decreased due to power losses in these extra components. In case the transformer is omitted, the efficiency of the whole PV system can be increased with an extra 1%–2%. The most important advantages of transformer less PV systems can be observed in Fig. 1, such as higher efficiency and smaller size and weight compared to the PV systems that have galvanic isolation (either on the dc or ac side). Fig. 1 has been made from the database of more than 400 commercially available PV inverters, presented in a commercial magazine about PV systems. Transformer less inverters are represented by the dots (transformer less), the triangles represent the inverters that have a low-frequency transformer on the grid side (LF-transformer), and last, the stars represent the topologies, including a high-frequency dc–dc transformer (HF-transformer), adding a galvanic isolation between the PV and grid. The conclusion drawn from these graphs is that transformer less inverters have higher efficiency and smaller weight and size than their counterparts with galvanic separation.

Transformer less PV inverters use different solutions to minimize the leakage ground current and improve the efficiency of the whole system, an issue that has previously beans treated in many papers. In order to minimize the ground leakage current through the parasitic capacitance of the PV array, several techniques have been used. One of them is to connect the midpoint of the dc-link capacitors to the neutral of the grid, like the half-bridge, neutral point clamped (NPC), or three-phase full bridge with a split capacitor topology, thereby continuously clamping the PV array to the neutral connector of the utility grid. Half-bridge and NPC type of converters have very high efficiency, above 97%, as shown.

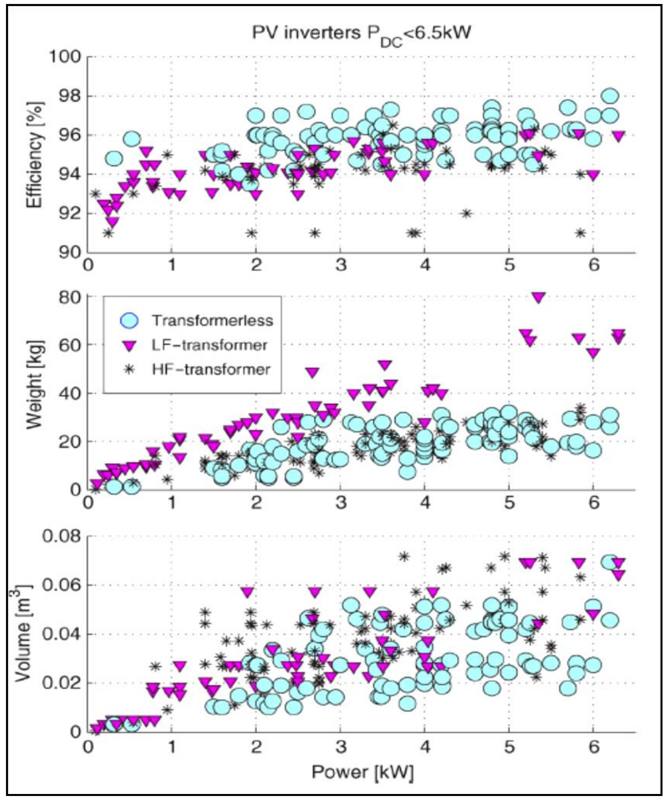

Fig.1. Advantages and drawback of different inverter topologies

Furthermore, the topology proposed reduces the dc current injection, which is an important issue in the case of transformer less topologies and is limited by different standards. An extra control loop is introduced that compensates for any dc current injection, by controlling the voltage of both capacitive dividers to be equal. A disadvantage of half-bridge and NPC type of converters is that, for single-phase grid connection, they need a 700-V dc link.

Another solution is to disconnect the PV array from the grid, in the case of H-bridge (HB) inverters, when the zero vector is applied to the load (grid). This disconnection can be done either on the dc side of the inverter (like the topology from and H5 topology from Solar Technologies AG) or on the ac side (like the Highly Efficient and Reliable Inverter Concept (HERIC) topology from Sun ways). In case of HB zero-voltage state rectifier (HB-ZVR) the midpoint of the dc link is clamped to the inverter only during the zero-state period by means of a diode rectifier and one switch.

In this paper, a new topology called NPC of HB inverter is proposed to minimize the ground leakage currents and improve the load current wave shape.

1.1 System Design

There are two main system configurations– stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid. It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as 'hybrid' systems. Figure 2 illustrate the schematic diagrams of the stand-alone system.

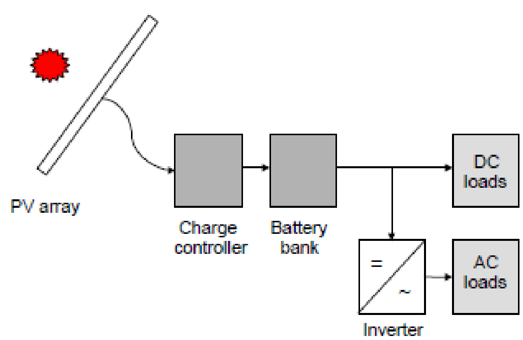

Fig. 2 Schematic diagram of a stand-alone photovoltaic system

1.2 Photovoltaic Inverter

The inverter is the heart of the PV system and is the focus of all utility-interconnection codes and standards. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV array is a dc source, an inverter is required to convert the dc power to normal ac power that is used in our homes and offices. To save energy they run only when the sun is up and should be located in cool locations away from direct sunlight. The PCU is a general term for all the equipment involved including the inverter and the interface with the PV (and battery system if used) and the utility grid. It is very important to point out that inverters are by design much safer than rotating generators. Of particular concern to utility engineers is how much current a generator can deliver during a fault on their system. Inverters generally produce less than 20% of the fault current as a synchronous generator of the same nameplate capacity. This is a very significant difference.

2. MODELING OF CASE STUDY TRANSFORMERLESS TOPOLOGY ANALYSIS:

As discussed in previous works, the common-mode voltage generated by a topology and modulation strategy can greatly influence the ground leakage current that flows through the parasitic capacitance of the PV array. Generally, the utility grid does not influence the common-mode behavior of the system, so it can be concluded that the generated common mode voltage of a certain inverter topology and modulation strategy can be shown using a simple resistor as load. Therefore, in the case of simulations, only a resistive load is used, and the common-mode voltage is measured between the dc+ terminal of the dc source and the grounded middle point of the resistor as shown in Fig. 3.

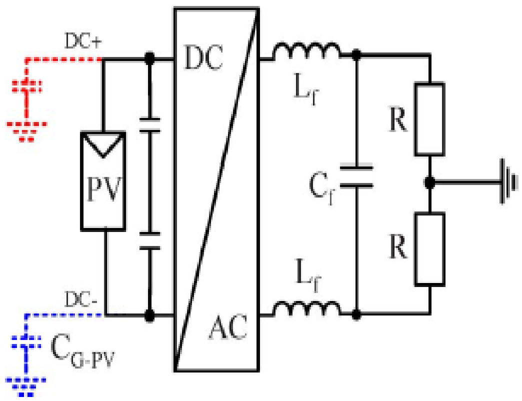

Fig. 3. Test setup used for common-mode voltage measurement.

In the following, simulation results obtained using MATLAB/**SIMULINK** with the PLECS toolbox are shown. The simulation step size is 0.1 μs, with an 8-kHz switching frequency.

Simulation parameters:

Lf = 1.8 mH filter inductance;

Cf = 2 μF filter capacitance;

R = 7.5 Ω load resistance;

Vdc = 350 V input dc voltage;

Cdc = 250 μF dc-link capacitance;

CG−PV = 100 nF parasitic capacitance of PV array;

Fsw = 8 kHz switching frequency for all cases except that the switching frequency for unipolar Pulse width modulation (PWM) has been chosen to be Fsw = 4 kHz, so the output voltage of the inverter has the same frequency for all cases.

2.1. HB with Unipolar Switching:

Most single-phase HB inverters use unipolar switching in order to improve the injected current quality of the inverter, which is done by modulating the output voltage to have three levels with twice the switching frequency. Moreover, this type of modulation reduces the stress on the output filter and decreases the losses in the inverter. The positive active vector is applied to the load by turning on S1 and S4, as shown in Fig. 4.

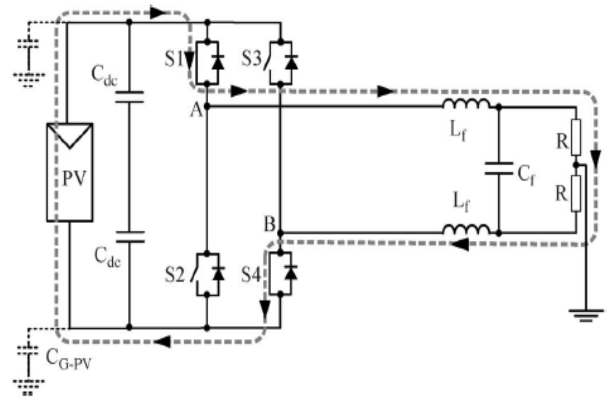

Fig.4. HB-Unip topology: Active vector applied to load, using S1 and S4 for positive voltage**.**

The negative active vector is done similarly, but in this case, S2 and S3 are turned on

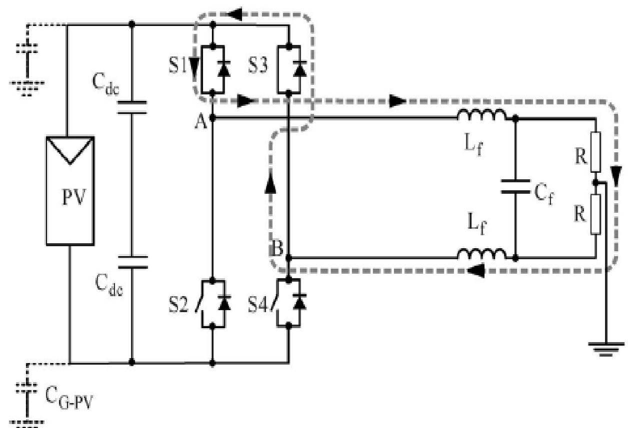

Fig.5. HB-Unip topology: Zero vector applied to load, using S1 and S3 for positive voltage.

As shown in Fig. 5, the zero-voltage state is achieved by short circuiting the output of the inverter for the case of the unipolar switching pattern. The waveforms for this case are detailed in Fig. 6, and it can be seen that the output voltage has three levels: +V, 0, and −V due to the unipolar switching pattern.

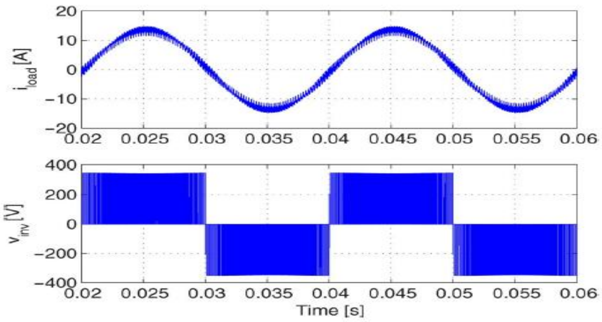

Fig. 6. HB-Unip topology: Load current and inverter output voltage

As shown in Fig. 7, in the case of a transformer less PV system using this type of topology and modulation, the high frequency common-mode voltage, measured across *C*G−PV, will lead to a very high leakage ground current, making it unsafe and therefore not usable (recommended) for transformer less PV applications.

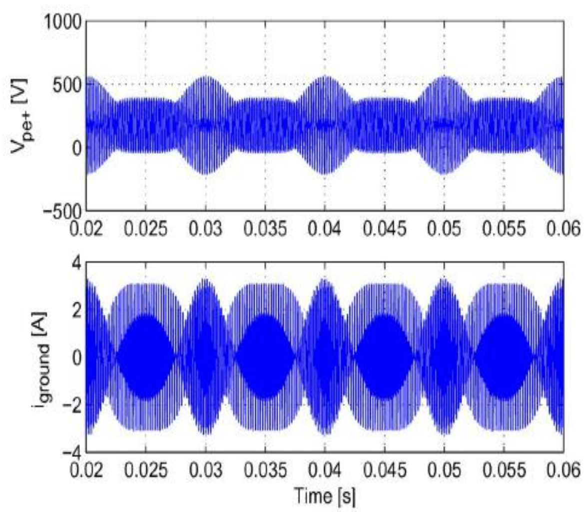

Fig. 7. HB-Unip topology: Voltage to ground and ground leakage current.

2.2. HERIC:

This topology, shown in Fig. 8, combines the advantages of the three-level output voltage of the unipolar modulation with the reduced common-mode voltage, as in the case of bipolar modulation. This way, the efficiency of the inverter is increased, without compromising the common-mode behavior of the whole system.

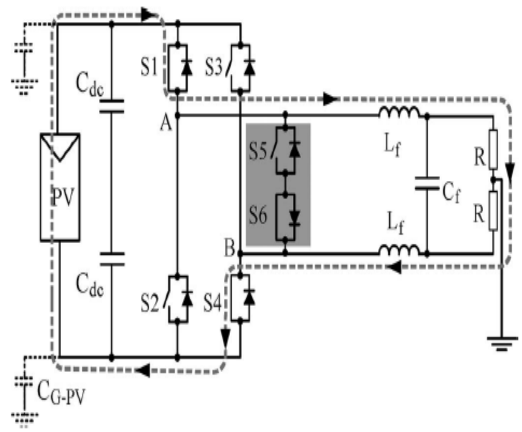

Fig. 8. HERIC topology: Active vector applied to load, using S1 and S4 during positive half-wave.

The zero-voltage state is realized using a bidirectional switch shown with a gray background in Fig. 8. This bidirectional switch is made up of two insulated-gate bipolar transistors (IGBTs) and two diodes (S5 and S6). During the positive half wave of the load (grid) voltage, S6 is switched on and is used during the freewheeling period of S1 and S4. On the other hand, during the negative half-wave, S5 is switched on and is used during the freewheeling period of S2 and S3.

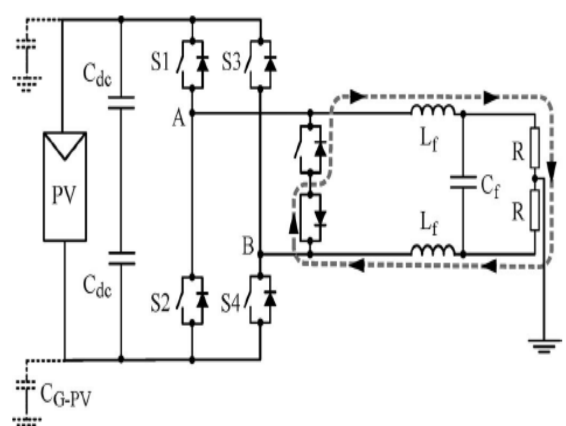

Fig. 9. HERIC topology: Zero vector applied to load, using S6 during positive half-wave.

This way, using S5 or S6 as shown in Fig. 9, the zero-voltage state is realized by short-circuiting the output of the inverter, during which period the PV is separated from the grid, because S1–S4 or S2–S3 are turned off.

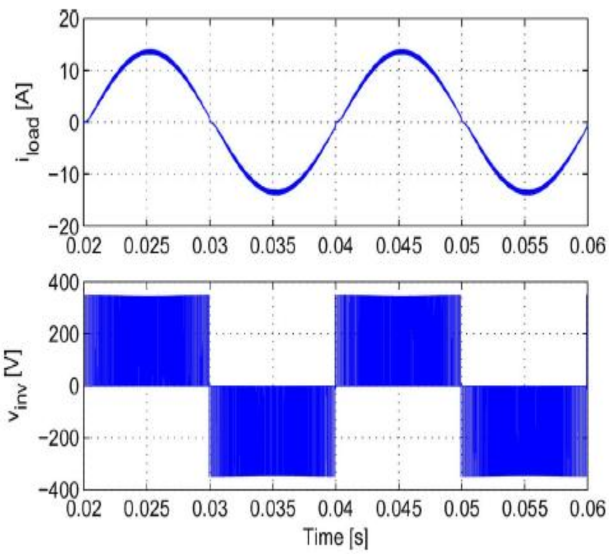

Fig.10. HERIC topology: Load current and inverter output voltage.

As shown in Fig.10, the output voltage of the inverter has three levels and the load current ripple is very small, although, in this case, the frequency of the current is equal to the switching frequency. As shown in Fig. 11, the inverter generates no common-mode voltage; therefore, the leakage current through the parasitic capacitance of the PV would be very small.

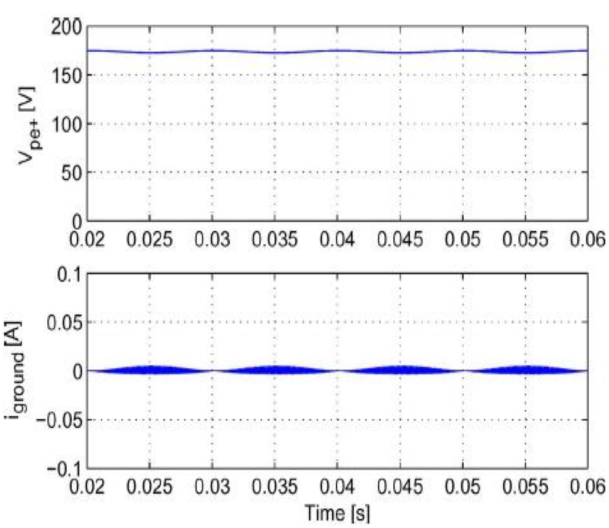

Fig.11. HERIC topology: Voltage to ground and ground leakage current.

2.3. HB-ZVR Topology: Proposed

Another solution for generating the zero-voltage state can be done using a bidirectional switch made of one IGBT and one Diode Bridge. The topology is detailed in Fig. 12, showing the bidirectional switch as an auxiliary component with a gray background. This bidirectional switch is clamped to the midpoint of the dc-link capacitors in order to fix the potential of the PV array also during the zero-voltage vector when S1–S4 and S2–S3 are open. An extra diode is used to protect from short-circuiting the lower dc-link capacitor.

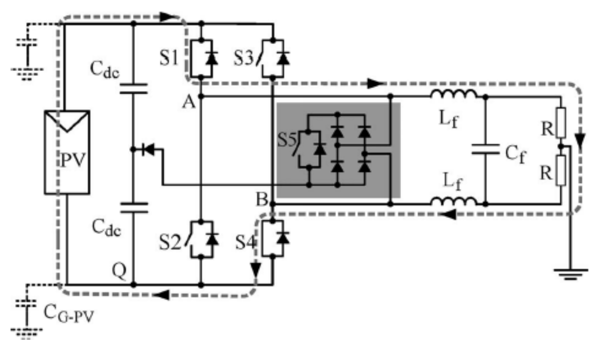

Fig. 12. HB-ZVR topology: Active vector applied to load, using S1 and S4 during positive half-wave.

During the positive half-wave, S1 and S4 are used to generate the active state, supplying a positive voltage to the load, as shown in Fig. 12. The zero-voltage state is achieved by turning on S5 when S1 and S4 are turned off, as shown in Fig. 13. The gate signal for S5 will be the complementary gate signal of S1 and S4, with a small dead time to avoid short-circuiting the input capacitor. By using S5, it is possible for the grid current to flow in both directions; this way, the inverter can also feed reactive power to the grid, if necessary.

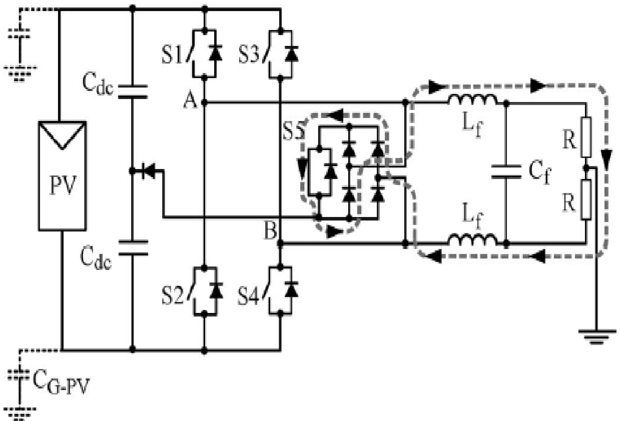

Fig. 13. HB-ZVR topology: Zero vector applied to load, using S5 during positive half-wave.

During the negative half-wave of the load voltage, S2 and S3 are used to generate the active vector and S5 is controlled using the complementary signal of S2 and S3 and generates the zero voltage state, by short-circuiting the outputs of the inverter and clamping them to the midpoint of the dc-link.

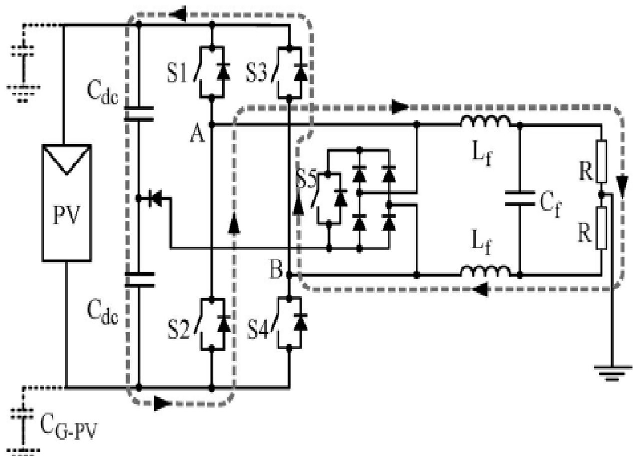

Fig.14. HB-ZVR topology: Dead time between turnoff of S1 and S4 and turn on of S5 during positive half-wave.

During the dead time, between the active state and the zero state, there is a short period when the freewheeling current finds its path through the anti parallel diodes to the input capacitor while all the switches are turned off. This is shown in Fig. 14 and leads to higher losses, compared to the HERIC topology, where the freewheeling current finds its path through the bidirectional switch, either through S5 or S6, depending on the sign of the current.

As shown in Fig. 15, the output voltage of the inverter has three levels, taking into account the freewheeling part during dead time. In this case also, the load current ripple is very small and the frequency is equal to the switching frequency.

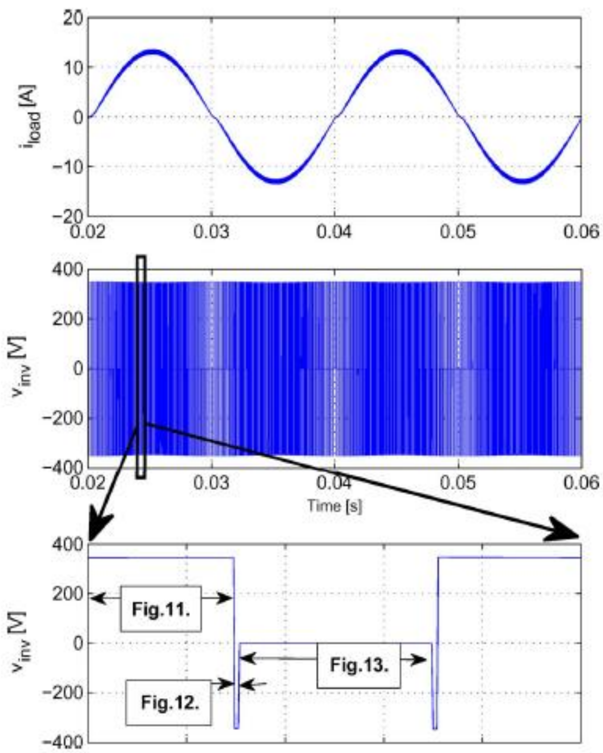

Fig. 15. HB-ZVR load current and inverter output voltage.

To show that this topology does not generate a varying common-mode voltage, V_{cm} has been calculated for the switching states regarding the positive, zero, and negative vectors

$$V_{cm} = \frac{V_{AQ} + V_{BQ}}{2} \quad \text{-------------------------(1)}$$

Positive:

$$V_{AQ} = V_{dc};\ V_{BQ} = 0 \Rightarrow V_{cm} = \frac{V_{dc}}{2} \quad \text{------ (2)}$$

Zero:

$$V_{AQ} = \frac{V_{dc}}{2};\ V_{BQ} = \frac{V_{dc}}{2} \Rightarrow V_{cm} = \frac{V_{dc}}{2} \quad \text{--------(3)}$$

Negative:

$$V_{AQ} = 0;\ V_{BQ} = V_{dc} \Rightarrow V_{cm} = \frac{V_{dc}}{2} \quad \text{-------(4)}$$

As detailed by (1)–(4), the common-mode voltage is constant for all switching states of the converter. Therefore, the leakage current through the parasitic capacitance of the PV would be very small, as shown in Fig. 16.

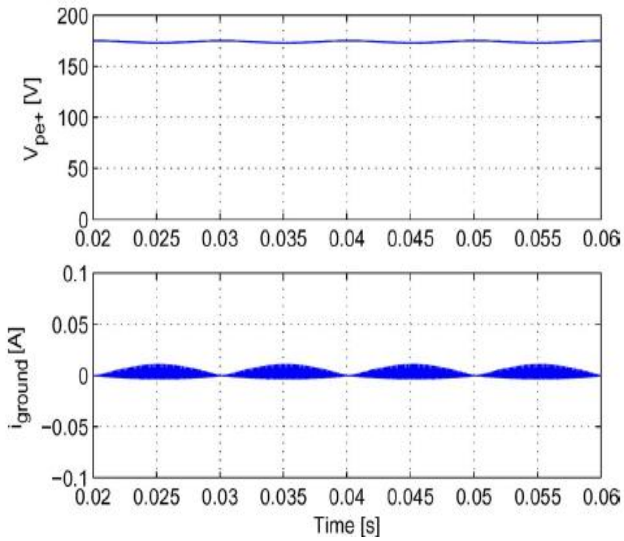

Fig.16. HB-ZVR topology: Voltage to ground and ground leakage current.

2.4) Proposed NPC - HB invertor:

This topology, shown in Fig. 17, improves the advantages of the HB-ZVR topology. Hear a midpoint of the H bridge inverter is connected to ground with a proper switching operation of S1, S2, S3and S4.the operation modes is similar to HB-ZVR topology but we are using midpoint grounding in the pleas of diode clamping system, with this we can achieve output voltage with the no common-mode voltage. This way, the efficiency of the inverter is increased, without compromising the common-mode behavior of the whole system.

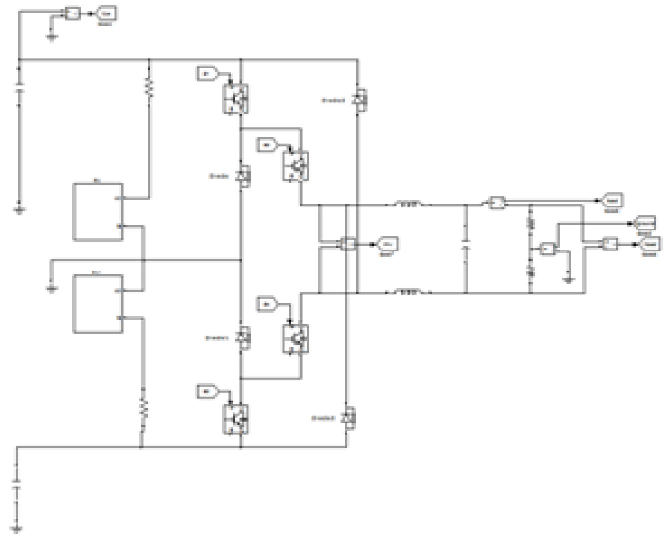

Fig 17. Midpoint Grounding HB with Unipolar Switching

3. MATLAB DESIGN OF CASE STUDY AND RESULTS

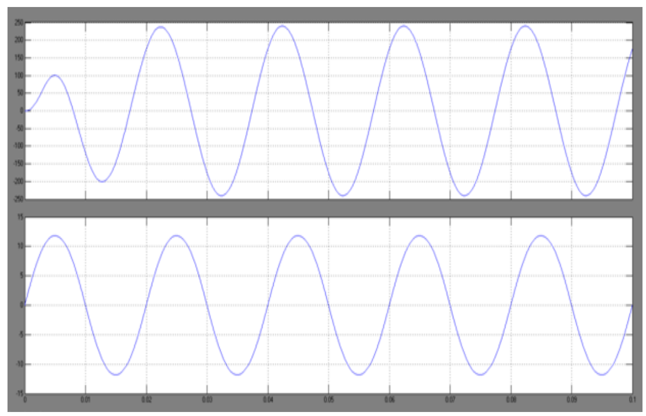

Fig. 18 xxxxxxx

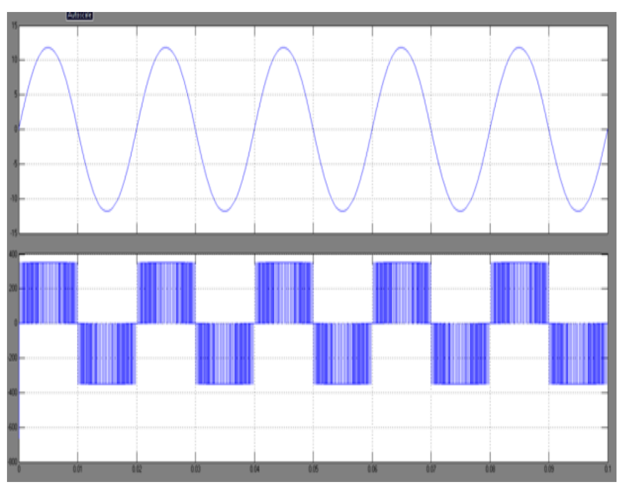

Fig. 19 inverter current and voltage

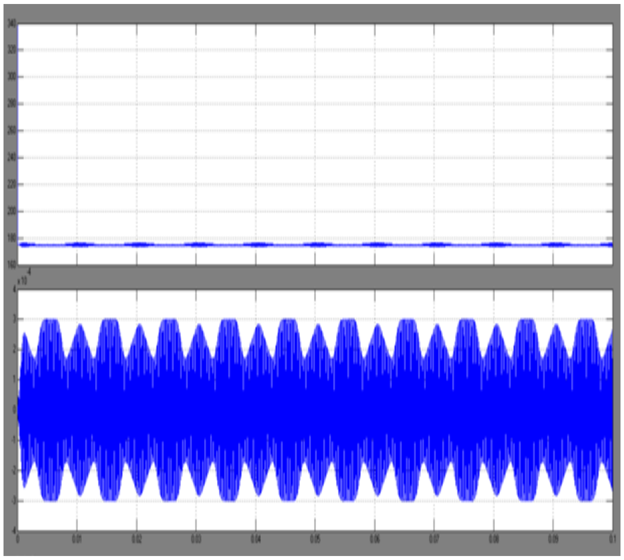

Fig.20 common mode voltage (V_{pe+}) and ground current (I_{gnd})

From the above MATLAB circuits and Results we can understand Transformer less inverters offer a better efficiency, compared to those inverters that have a galvanic isolation. On the other hand, in case the transformer is omitted, the generated common-mode behavior of the inverter topology greatly influences the ground leakage current through the parasitic capacitance of the PV.

Bipolar PWM generates a constant common-mode voltage, but the efficiency of the converter is low, due to the two level output voltage. By using unipolar PWM modulation, the output of the converter will have three levels, but in this case, the generated common-mode voltage will have high-frequency components, which will lead to very high ground leakage currents. If we consider

The constant common-mode voltage of the HB-ZVR topology and its high efficiency make it an attractive solution for transformer less PV applications but the cost and circuit complexity is high so we transformer less NPC inverter gives good results.

4. CONCLUSION

This paper has introduced a transformer less topology and given an alternative solution for generates the zero-voltage state. The Neutral point clamping HB inverter topology gives high efficiency make it an attractive solution for transformer less PV applications compare to HB unipolar, HB-HERIC Topology and constant common-mode voltage of the HB-ZVR topology.

using this topology is reduced to a greater extend and other added advantage is during all modes of operation it is maintaining the common mode voltage as half of the input supply voltage which leads to the excellent leakage current characteristics. So it can be concluded that NPC topology is best option for single phase inverters. Using MATLAB all results are validated.

By further modifying usage of switching cells as PN-NPC HB Inverter there is chance to extend this topology to get Pure sinusoidal output voltage.

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