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Transformer less Grid Connected Inverter with Leakage Current Elimination

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Abstract: **Solar inverters which are transformer less possess high efficiency when compared to that of an isolation link. A major issue with this is the leakage current issue. In this paper we propose a single phase with six switch transformer less inverter topologies along with an ac bypass circuit. With the help of these circuits the two unidirectional freewheeling current units are embedded in the midpoint of a full bridge inverter. This is done to attain a freewheeling current path, to separate the solar panels from the grid in the freewheeling state. The advantage of freewheeling is that it consists of very few devices and avoids the poor performance body diodes which lead to higher efficiency. It is also not required to add a voltage balancing control system as that of a half bridge inverter. In this paper, simulations are also added in order to validate the proposed topologies.**

Keywords: **Solar panel, Single phase six-switch transformerless inverter, Leakage current, Grid connected inverter.**

1. INTRODUCTION

In present years, demand for energy is increasingly highly due to which there is tremendous development in the alternative power sources. Some of them to be named are the photovoltaic (PV) modules, wind turbines and fuel cells. In specific PV modules are in much of attraction as they belong to the renewable sources. Other attributes of PV modules are, small in size, easy installation, noiseless operation, it is possible to install them closer to the user.

When it comes to the PV (photovoltaic) power systems, transformer less inverters are of great uses in terms of efficiency, structure, reliability, cost and many more. But these non-isolated inverters do have their own faultier sides like ground leakage or common-mode voltage issue between the grid and the PV system [1]. It is strictly restricted if the leakage current to ground is greater than 300mA, in that case the disconnection has to happen within 0.3s[2].

This paved way for many researches to take place on leakage current issue in non-isolated grid-connected PV inverters. Based on the full bridge structure, an auxiliary circuit is introduced to divert the direction of flow of freewheel current and hence helping the leakage current problem to be resolved. Based on this new proposed method the solar panel is separated from the grid in the freewheel stage. Based on the above proposed alteration, many structures are been proposed. A H5 inverter is also introduced by SMA solar Technology AG [3].

As few devices are used in this structure it greatly reduces the cost. However, freewheel diodes have the problem of reverse recovery.

This makes it difficult to work on improving the efficiency of the structure. Hence it is required to have a full bridge inverter with dc bypass circuit, this is to produce low current ripple in the ac and reduce the chances of converter loss. The connected inverters are in the form of national standards. Let's consider German standard DIN VDE 0126-1-1, transformer less PV inverters are connected to the grid. A voltage balance control will be necessary because of the midpoint by voltage dividing of the dc link capacitor. The study around the results or influence of this control is not been analyzed in this paper. It is observed that the difficulty of the control is increased. The common-mode (CM) voltage and leakage current are being restrained using the bipolar modulation scheme. This results in unipolar modulation effect.

The topology considered in this paper work has body diodes in the current path which has limitation in performance. Hence a H6 inverter topologies with ac bypass circuit with two unidirectional freewheel cells are being embedded in between the midpoints of the full bridge inverter to produce a result of freewheel path. This separates the solar panel from the grid in the freewheel stage. This structure contains few devices and also avoids the poor-performance of the body diodes in the freewheeling path. This helps in obtaining a high efficiency. Hence removing the voltage balance control from the system. Verification and results of the proposed method are discussed in other sections of the paper.

2. SOLAR PV

Solar energy is the energy that we receive from the sun. The energy that we receive is radiated from the sun. The sun can generate tremendous amount of energy just in a second. This energy is generated within the sun. The sun is just like other stars which are made up of gas like hydrogen and helium. The energy is produced due to a process called the nuclear fusion.

During this chemical process in the sun, high pressure and hot temperature makes the hydrogen atoms to fuse or combine the nuclei. During this process some of the matter is lost into the space as radiant energy. The energy from the sun's core to reach the solar surface takes around millions of years.

After which it takes eight minutes to travel the 93 million miles to earth. This solar energy travels at a speed of 186,000 miles per second, the speed of light to travel to the earth.

The energy that we receive in earth is just a small portion of the energy radiated by the sun into space that is one part in two billion.

Still we find that this is a huge amount of energy received by earth. Everyday enough energy strikes the earth where in United States this solar energy supplies the countries need for one and a half year. 15 percent of sun's energy is reflected back to the space.

30 percent is being used in the process of evaporation which causes rainfall. Land, plants and the oceans absorb solar energy and the rest is used by human beings to supply our daily needs.

Photovoltaic (PV) is the technology that deals with converting sun energy (sunlight, ultra violet radiation) into electricity. The growing demand for solar energy and other clean sources of energy has put a high demand on the manufacturers of solar cells and photovoltaic arrays to expand dramatically. This high demand has doubled the production of solar energy every year with an increase of 48% each year since 2002 and hence it is the highest growing energy technology. In the global, PV installation reached 15,200 megawatts in the end of 2008.

Around 90% of these PV installations are grid tied electrical systems. Most of the installations are ground-mounted (like farming and grazing) or even built on the roof or walls of buildings which is known as Building Integrated Photovoltaic or

BIPV in short. Financial incentives and net metering like preferential feed-in tariffs for solar electricity has increased the solar PV installations in countries like Germany, Japan, Australia, and Israel and in the US.

3. SINGLE STAGE GRID CONNECTED PV SYSTEM

The grid connected photovoltaic (GPV) installations consists of DC-AC power processing system and PV panels. The most required are of research when it comes to GPV system is the way the elements of the GPV inverter are arranged (PV panels and the power converter stage or stages). The efficiency of the PV module can vary according to the design of the arrangement of these devices. Let's consider an example of the most commonly used "central inverter". In this configuration all the devices are series -parallel connected to the input of a single full-bridge power inverter. In this kind of approach the cost of the complete system is comparatively less as only one power conditioning module is required. Also the central inverter configuration needs a minimum of passive filter elements. The ease of this structure and the flexibility to easily add other power converter stages, we are considering this power conditioning structure in the present work.

There are a few points to be adhered to attain efficient energy transfer. The below control objectives are to be adhered by the control strategy of the power inverter that interfaces the PV array with the utility grid.

The conversion of DC input power into an AC output current should be proper and injected to the grid.

- This output current injected to the grid should be of low harmonic contents and in phase with the grid voltage to attain power transfer as unity power factor.

- The maximum power extraction depends on the PV array and the solar panels maximum power point (MPP) which varies with the solar irradiance and the PV panels' temperature.

The above mentioned requirements can be met by a strategy based on two cascaded control loops with the help of pulse-width modulation (PWM) scheme as seen in Figure 2.2. The inner control loop handles the duty ratio for the production of sinusoidal output current which is in phase with the grid voltage.

The outer control loop helps to settle the PV array operating point at its maximum power value for any temperature and irradiance variation. This is done with the help of maximum power point tracking (MPPT) algorithms like the Perturb and Observer or other advanced ones. The outer loop provides the inner control loop the current reference amplitude corresponding to the PV array maximum power and hence ensuring power transfer to the grid.

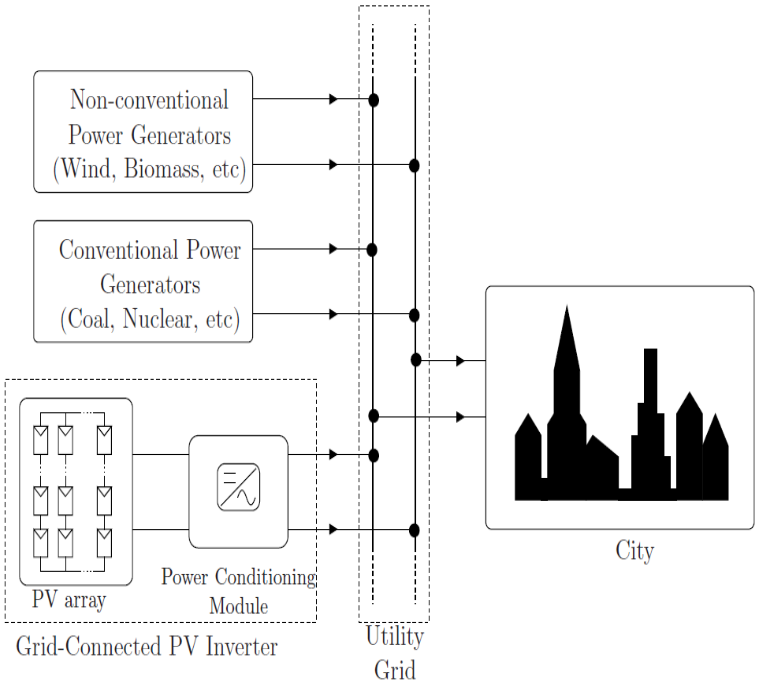

Figure 1 Grid-Connected Photovoltaic

4. SYSTEM BLOCK DIAGRAM

H6 inverter topology with bypass circuit is also being used based on the full bridge structure. This proposed structure has unipolar PWM output waveforms and also eliminates the high frequency pulsates of the CM voltage. This leads to variation of low frequency of the CM voltage which only has low level leakage current and that can be neglected.

Other existing methods used for minimizing leakage current uses the body diodes in the current path which is eliminated in the proposed method. Voltage balance control and voltage dividing capacitors are also not required in our new method. These advantages help in improving the conversion efficiency and reliability of the proposed system.

The experimental results and the simulations have practically proved that the proposed structure shows good performance. It minimizes leakage current and has high-quality output voltage waveforms for the grid. High conversion efficiency is also obtained.

5. EXISTING SYSTEM

In the existing system full bridge structure is used and auxiliary circuit is used to solve the leakage current problem by forcing the freewheeling current to change its flowing path. This helps to separate the solar panel from the grid in the freewheeling stage. There are various structures based on the above mentioned concept. A H5 inverter with few devices and minimum cost are used. But freewheeling diodes have the problem of reverse recovery problem. Due to which it is a challenge to work on the efficiency of the structure.

In this method we use a full bridge with dc bypass circuit, this shows low current ripple in the ac side and a reduced converter loss. A voltage balance control is being used and a voltage dividing in the dc link capacitor. The results of this control are not being analyzed.

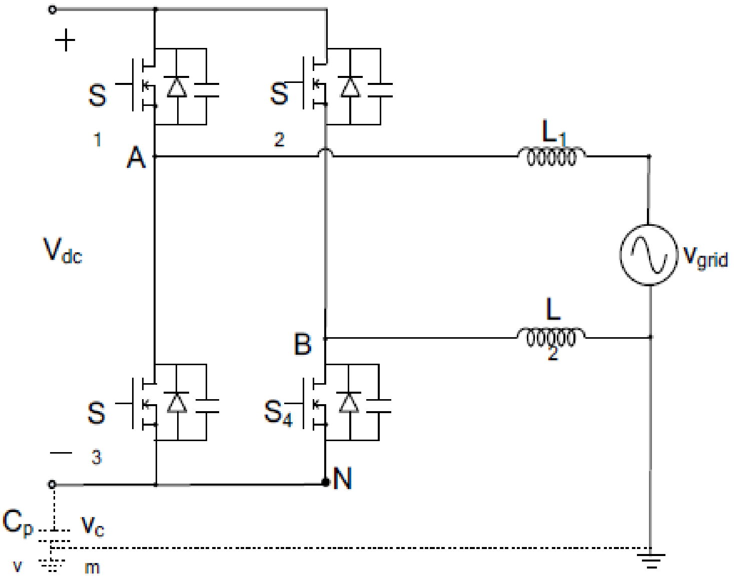

Fig.2. Single phase full-bridge inverter

6. PROPOSED SYSTEM

In the proposed method, H6 inverter topology is used with an ac bypass circuit, two unidirectional freewheel cells are embedded between the midpoint of the full bridge. This helps to separate the solar panel from the grid in the freewheeling stage. In this structure, few devices are used and no poor performance body diodes are involved in the freewheeling path. Hence high efficiency is being obtained. In this method, voltage balance is not required. Hence the reliability and the conversion efficiency are achieved. The proposed structure also minimizes the leakage current and has high quality output voltage waveforms for the grid. The MPPT boost converter stage also introduced at the input stage especially in residential PV applications. High conversion efficiency is also obtained.

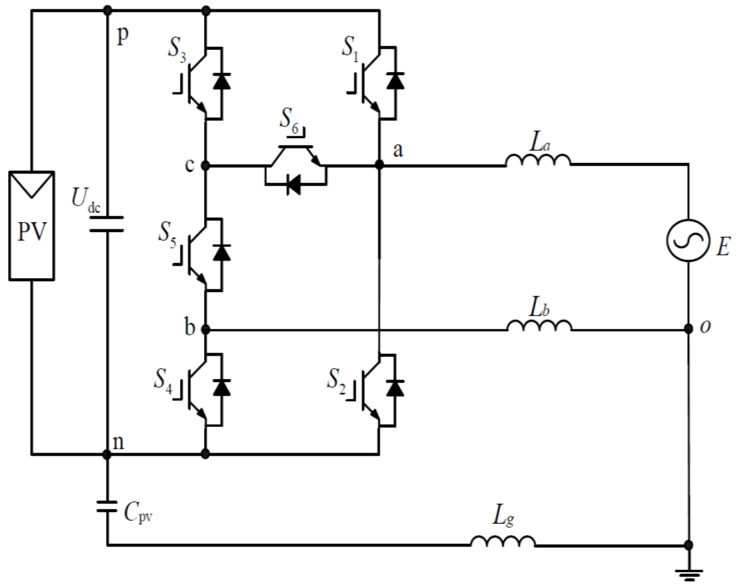

Fig. 3 The proposed H6 inverter

Fig. 3 illustrates the schematic diagram of the proposed topologies, where E is the grid voltage. L_a and L_b are the filter inductors. C_{pv} is the stray capacitance between the PV array and ground, and its value depends on the PV panel and frame structure, weather conditions, etc [6]. Lg is the inductance between the ground connection of the inverter and the grid. In order to clarify how the leakage current generates, a generic common mode model is presented in Fig.4. In Fig.4, the common mode voltage $U_{cm\_}ab$ and differential mode voltage $U_{dm\_}ab$ are defined as follows:

$$U_{cm\_ab} = \frac{U_{an} + U_{bn}}{2} \quad \text{--------1}$$

$$U_{dm\_ab} = \frac{(U_{an} - U_{bn})(L_a - L_b)}{2(L_a + L_b)} \quad \text{--------2}$$

The total common-mode voltage can be derived from Fig.4 as follows:

$$U_{tcm} = U_{cm\_ab} + U_{dm\_ab} = \frac{U_{an} + U_{bn}}{2} + \frac{U_{ab}(L_a - L_b)}{2(L_a + L_b)} \quad \text{--- 3}$$

Equation (3) indicates that the filter inductors should be symmetrically distributed in the loop, that is, $L_a = L_b$. Under this assumption, the system common mode voltage can be rewritten as follows:

$$U_{cm} = \frac{U_{an} + U_{bn}}{2} \quad \text{----------4}$$

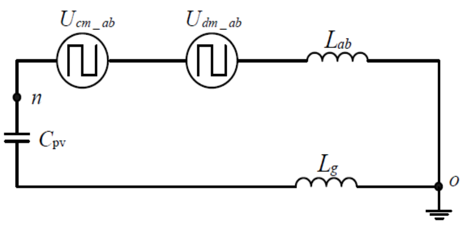

Fig. 4 System common mode model

6.1 Operation Analysis

Fig.5 shows the four operation modes of the proposed six-switch inverter. During the positive half cycle, $S6$ is on and $S2$, $S3$ and $S5$ are off. $S1$ and S4 commutate at the switching frequency, as depicted in Fig.5.

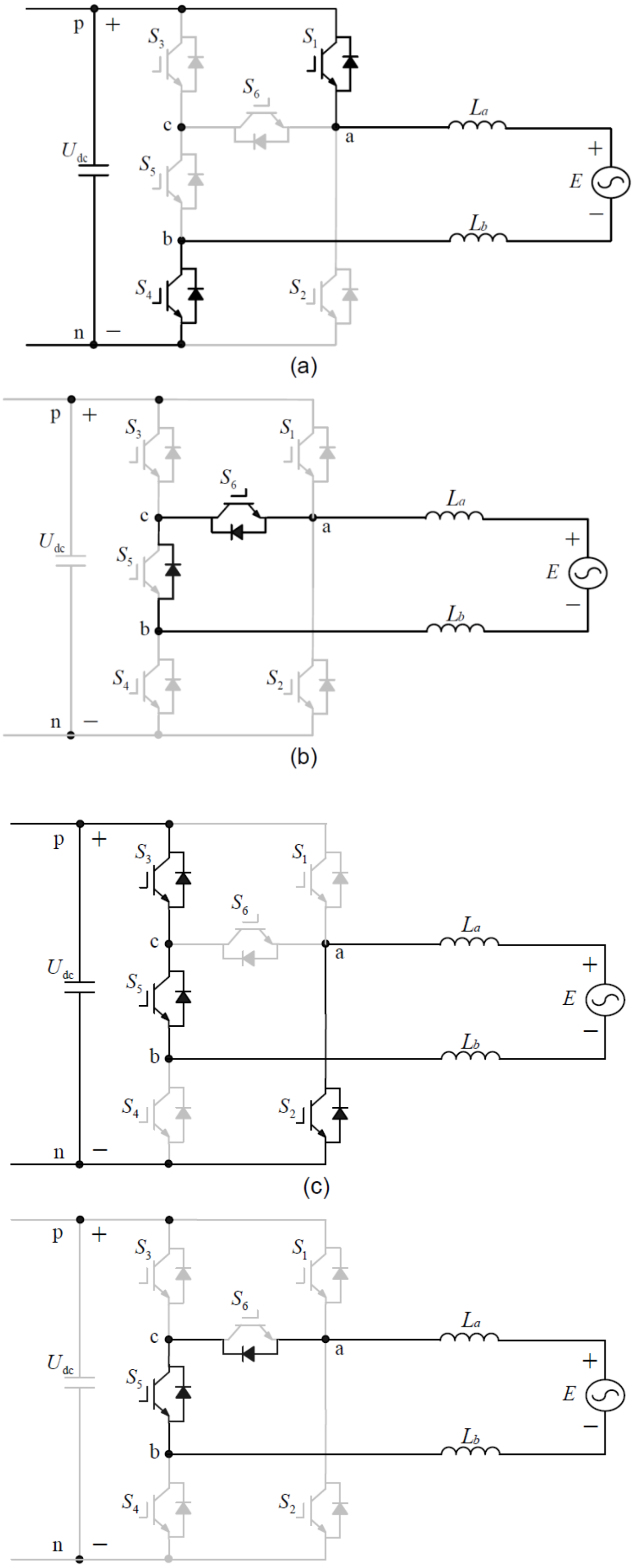

Fig. 5 Operation modes

The common mode voltages in this case observed are that the common voltages remain unchanged during the positive half cycle. In the similar manner, during the negative half cycle, *S*5 *is* on and *S*1, *S*4 *S*6 is off. *S*2 and S3 commutate at the switching frequency, as depicted in Fig.6. The common mode voltages remain unchanged in this case.

7. SIMULATION RESULTS

In order to validate the theoretical analysis, the various simulation tests of the transformer less grid-connected PV system with leakage current elimination were constructed by using MATLAB/Simulink tools. The PV frame and the neutral point of the grid are grounded. The simulation parameters are shown in Table I. Fig. 4.1 shows the simulation diagram of the grid-connected inverter without introduction of MPPT converter. Fig 7 shows the simulation diagram of the grid-connected inverter with and without the introduction of MPPT converter. The various simulation results for the modified proposed topology are shown in succeeding figures 8 to 13.

Table 1 Simulation parameters

Parameter	Specifications
PV output voltage	120V
DC bus voltage	340V
Grid phase voltage and frequency	220v/50Hz
Ground parasitic capacitance C_{PV}	100nF
Input capacitor C_{PN}	470uF
Grid interface inductor(L_f)	2mH
Switching frequency	25KHz
Boost inductor (L)	500uH
Power switch	IRFP450
High frequency diodes	MUR1560

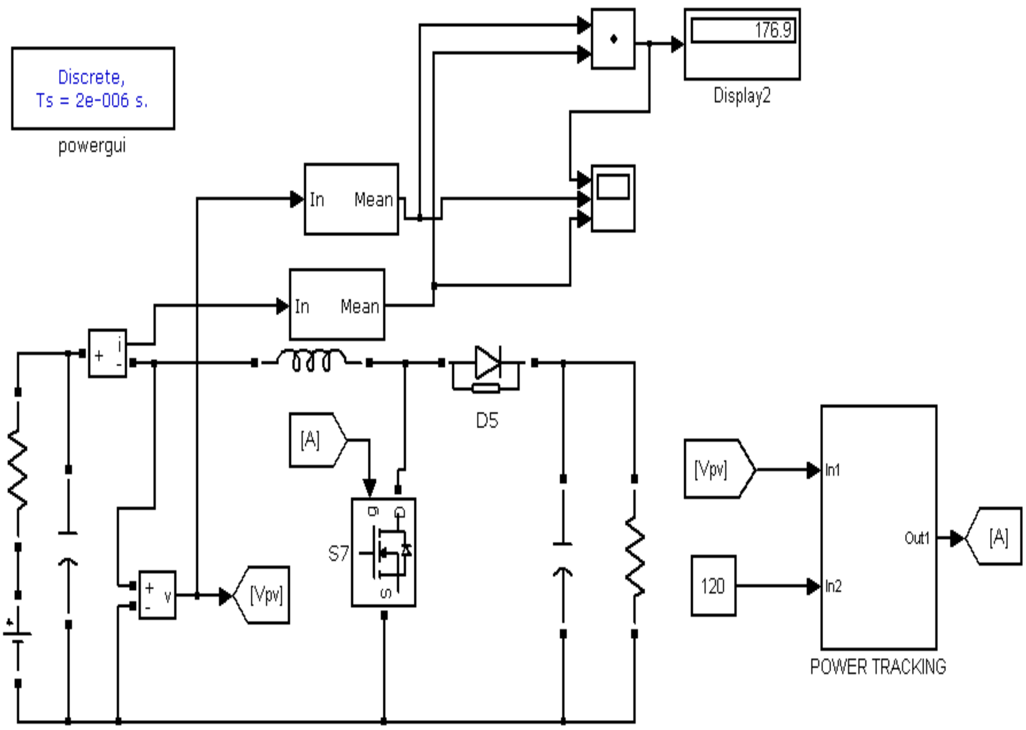

Fig 6 simulated MPPT converter for input to the grid connected inverter for leakage current elimination

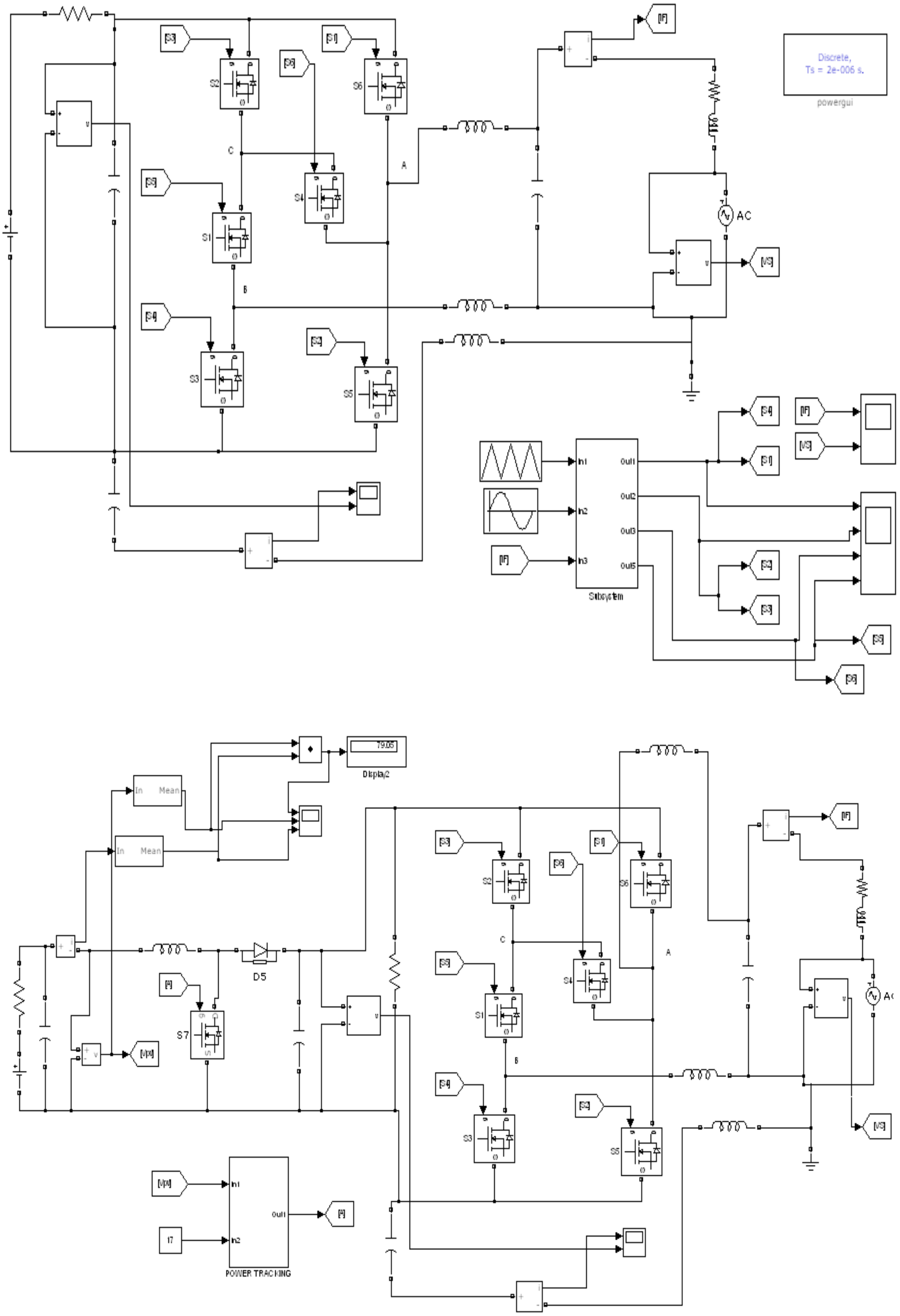

Fig 7.complete simulation schematic of proposed grid Inverter With and without MPPT converter

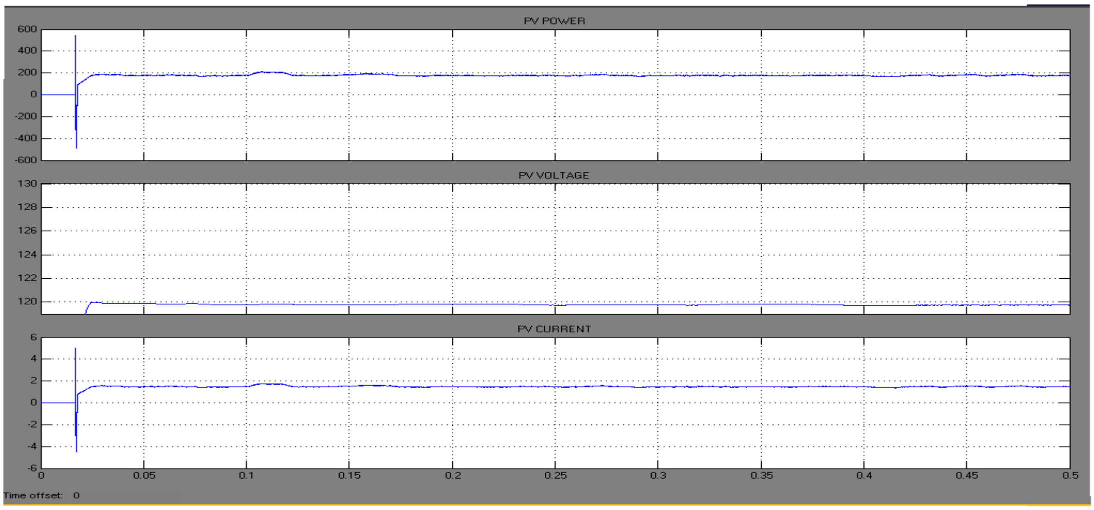

Fig 8 Simulated PV power, Voltage and Current of MPPT converter

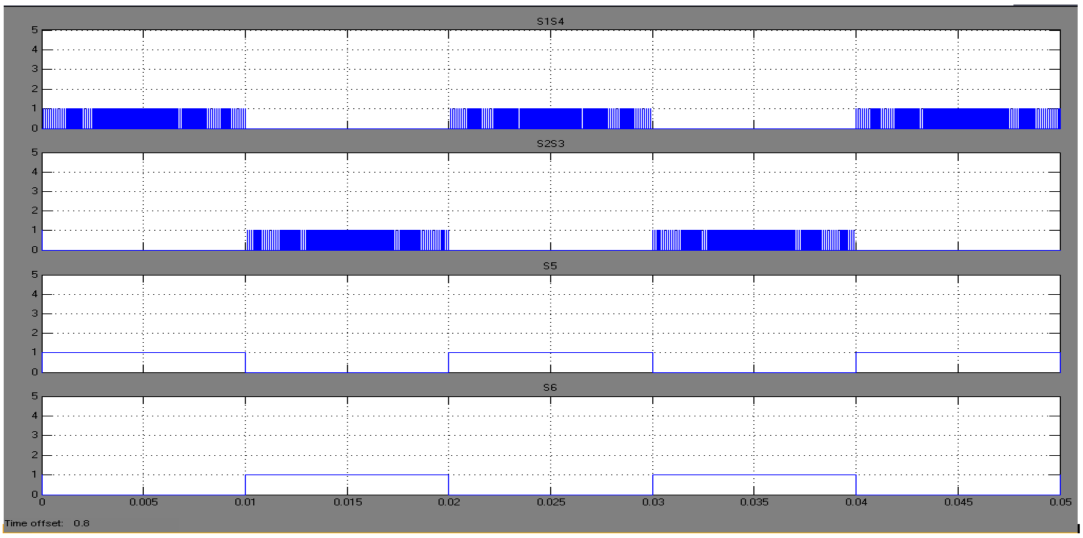

Fig 9 Modulation scheme of proposed Topology

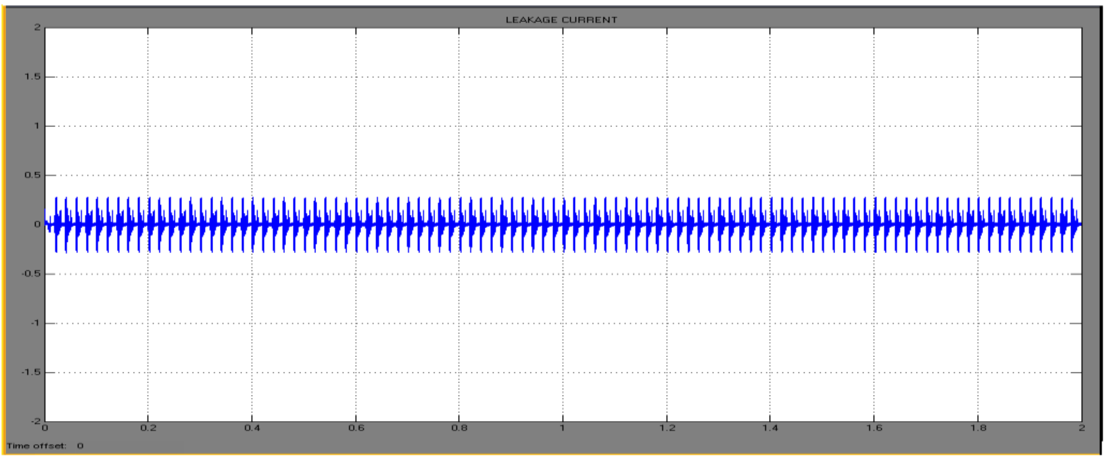

Fig 10 Leakage current of proposed topology

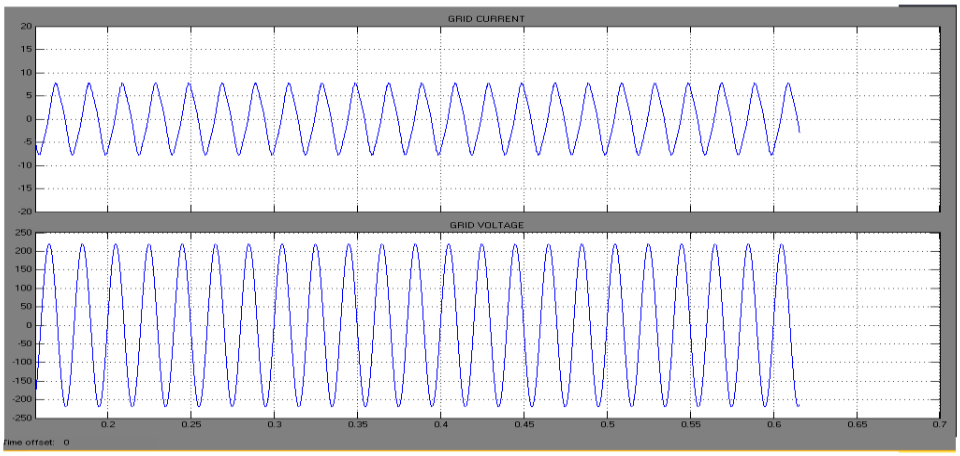

Fig 11 Grid current and voltage of proposed converter

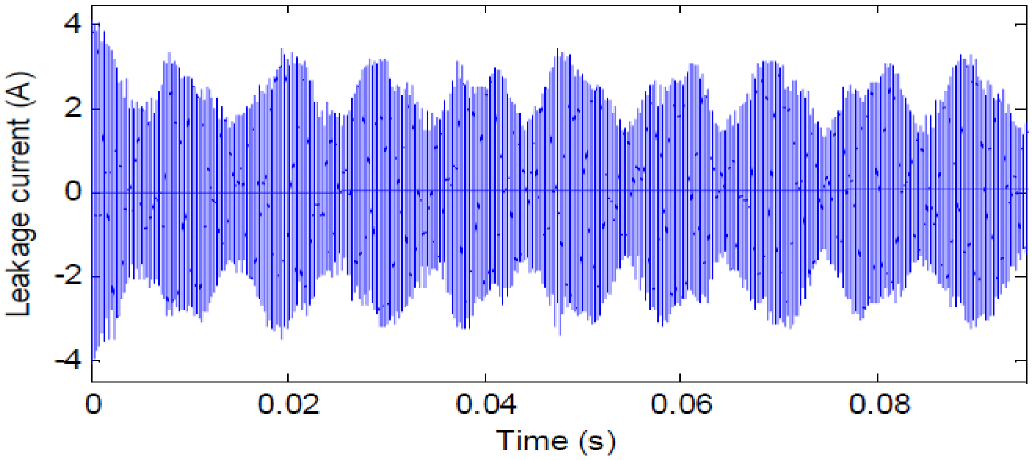

Fig 12 Leakage current of conventional H-bridge inverter

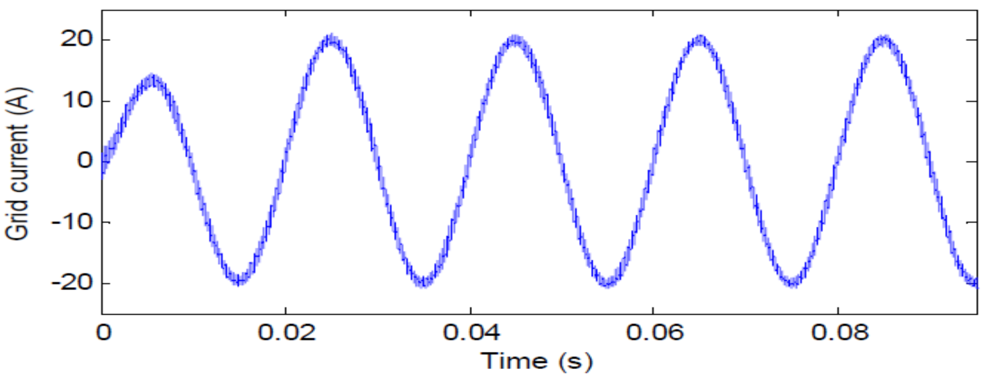

Fig 13 Grid current of conventional H-bridge inverter

8. CONCLUSION

H6 inverter topology with bypass circuit is also being used based on the full bridge structure. This proposed structure has unipolar PWM output waveforms and also eliminates the high frequency pulsates of the CM voltage. This leads to variation of low frequency of the CM voltage which only has low level leakage current and that can be neglected. Other existing methods used for minimizing leakage current uses the body diodes in the current path which is eliminated in the proposed method. Voltage balance control and voltage dividing capacitors are also not required in our new method. These advantages help in improving the conversion efficiency and reliability of the proposed system. The experimental results and the simulations have practically proved that the proposed structure shows good performance. It minimizes leakage current and has high-quality output voltage waveforms for the grid. High conversion efficiency is also obtained.

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