

Photovoltaic Grid-Connected System for Uninterruptible Power Supply in Residential Applications

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ABSTRACT: This paper presents the high efficiency soft-switching snubberless high step-up converter. Zero current commutation of current fed device is novel and makes the converter snubberless and fully soft-switched with natural voltage clamping. In the primary side of the circuit, zero current switching is achieved and zero voltage switching is achieved in the secondary side of the circuit. There is a single phase full bridge inverter in the secondary side of the circuit which provides ac output voltage. In our proposed system, the supply to the load will be uninterrupted by efficiently utilizing any one of the sources like panel or battery or grid (or any two). Output voltage of the panel is fed to the converter if panel produce nominal voltage, if it fails then higher voltage magnitude from any source like battery or grid will provide the required load voltage.

KEYWORDS: Natural Voltage Clamping (NVC), Zero Current switching (ZVS), Zero Voltage Switching (ZVS), Soft Switching, uninterruptible Power Supply (UPS).

I. INTRODUCTION

Scientists have known of the photovoltaic effect for more than 150 years. PV power generation does not considered practical until the arrival of the space program.. The development of solar cells for this purpose led to their eventual use in other applications. Less than 1% of electricity was generated by photovoltaic. However, there are some few applications in which PV power was economical. Renewable energy installed capacity of 673 GW around the globe. From that 177 GW of energy gained through solar. Current Installed capacity of solar energy in India is 3744 MW but Solar potential stands at 748 GW.

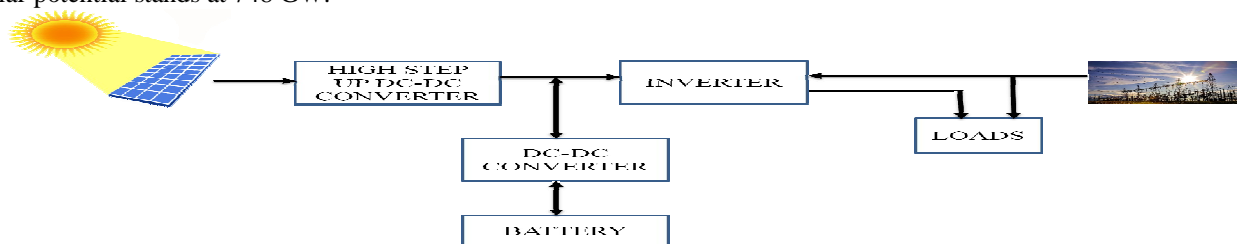


Fig.1. Diagram of a PV grid-connected power system for uninterruptible power supply in residential applications.

Fig.1. shows the photovoltaic grid-connected power system consisting of an inverter with high step-up front-end dc-dc converter and energy storage device with a bidirectional dc-dc converter.

The input to the front-end high step-up dc-dc converter is fed from the solar panel. The converter converts the variable solar-panel dc voltage into regulated and useful form. The converter used to step-up the voltage magnitude. There are

various topologies of converter and inverter schemes have been proposed in literature. A review of non-isolated high-step-up dc/dc converters is presented in [4] for a grid-connected inverter, including the analysis of multilevel converters [5], [6], cascaded boost converters [7], switched capacitor converters [8], [9], boost converters integrated with a coupled inductor to achieve high-step-up conversion [10], [11], combination of coupled inductor, and switched capacitor. Device parasitic and diode reverse recovery are the main issues and constraints for these converters, which limit the efficiency and voltage gain. Compared with voltage-fed converters, current-fed converters are demonstrated and verified for lower input voltage with wide variation. However, the major limitations of such converters are hard switching and snubber requirement to absorb the voltage spike to limit the device voltage. But snubber leads to low efficiency. A flyback snubber was introduced to recycle the absorbed energy with increased circuit and control complexity.

In this paper a two stage dc-ac inverter is done for the PV residential power system which is shown in Fig.2. It is composed of a novel high-step-up front-end dc-dc converter in the primary side and a standard full-bridge inverter with voltage doubler in the secondary stage. The shunt capacitors C7-C10 are the parasitic capacitance, and shunt diodes D7-D10 are the external diodes connected

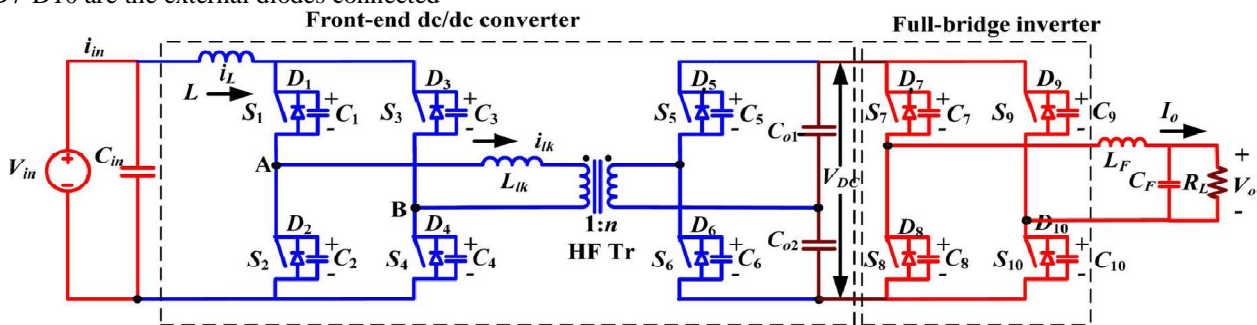


Fig.2 Proposed inverter snubberless high-step-up converter-fed full-bridge dc-dc voltage doubler

to the insulated-gate bipolar transistors. The necessity of active clamp or snubber circuit is eliminated by naturally clamping the voltage across the primary device using the secondary modulation technique, which is required in the conventional current-fed topologies. This technique results in the ZCS turn off or natural -commutation of devices. Switching losses are reduced significantly owing to ZCS of primary side switches and ZVS of secondary side switches, which permits higher switching frequency operation with smaller magnetic. At high switching frequency soft switching techniques (ZVS or ZCS) are used to achieve good efficiency and reduced switching stress. In Zero-Voltage Switching (ZVS), the voltage across device is zero just before turn – on. On the other hand in Zero-Current Switching (ZCS), the current through device is zero just before turn-off. For the secondary side of the front-end converter, a voltage doubler or a half-bridge is selected to reduce the number of the switches and transformer turns ratio. The inverter in the secondary side is a bidirectional and therefore permits energy flow from the grid to storage when solar energy is not available.

The main objective of this paper is to have the uninterrupted flow of power to the load by using the battery storage, panel and grid. To have the high-step-up conversion, snubberless soft-switching converter is used in the uninterrupted photovoltaic power system. In this system, if the voltage magnitude of the PV panel lowers the nominal voltage value at the same time the voltage magnitude of battery is higher compare to the panel then battery drains to provide the required power to the load. If both the panel and battery lowers the nominal voltage level, then grid will provide the required power to the load. The paper is outlined as follows. The steady-state operation of the converter is explained in Section II. The design of the converter is illustrated in Section III. Simulation results are presented to verify the proposed operation, analysis, and design.

II. RELATED WORK

S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," IEEE Trans.Industry Applications, vol. 41, pp. 1292-1306, 2005.

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In this paper the operation of the single phase grid connected systems are studied in this paper. The PV system is configured and this is fed as input to the system.

MPPT and Simulation for a Grid-Connected Photovoltaic System K.Manohar, P.SobhaRani Scholar M.Tech, Department of Electrical and Electronics Engineering, NBKRIST, AP, India, 2, Associate Professor, Department of Electrical and Electronics Engineering, NBKRIST, AP, India.

Maximum power point tracking (MPPT) can effectively improve the solar energy conversion efficiency of PV systems. In this paper, Perturb-and-observe (P&O) method is used to achieve this function.

Grid-Connected Photovoltaic Power System Using Boost-Half-Bridge Converter R.Deepa1, K.K.Poongodi PG Scholar, Dept. of Electrical and Electronics Engineering, Paavai Engineering College, India Assistant Professor, Dept. of Electrical and Electronics Engineering, Paavai Engineering College, India.

Renewable energy systems generate low voltage output, and thus, high step-up dc/dc converters have been widely employed in many renewable energy applications such fuel cells, wind power generation, and photovoltaic (PV) systems. Such systems transform energy from renewable sources into electrical energy and convert low voltage into high voltage via a step-up converter, which can convert energy into electricity using a grid-by-grid inverter or dc micro grid.

A Review of Single-Phase Grid-Connected Inverter for Photovoltaic Modules

Unique requirements for small distributed power generation (DG) systems include low cost, high efficiency, and tolerance for an extremely wide range of input voltage variations. The inverters in such systems not only perform functions such as normal dc-ac conversion, output power quality assurance, various protections and system controls, but also meet these requirements, which have driven the inverter development toward simpler topologies and Structures, lower component counts, and tighter modular design.

III. OPERATION AND ANALYSIS OF CONVERTER

In this section, steady-state operation and analysis of the proposed front-end current-fed converter have been explained. To simplify the analysis, the following assumptions are made: 1) Boost inductor L is large enough to maintain constant current through it; 2) all the components are ideal; 3) inductor L_{lk} (ilk) includes the leakage inductance of the transformer; and 4) magnetizing inductance of the transformer is infinitely large.

The concept of zero current commutation (ZCS), soft-switching, natural voltage clamping (NVC) and corresponding modulation technique have been explained. In this circuit system any one anti-parallel switch get turned on or off at a time. Before turning off of a diagonal switch pair of primary-side switches (e.g., S1-S4), other pair (e.g., S2-S3) is turned on. Reflected output voltage $V_{DC}/2n$ appears across the transformer primary side. It diverts the current from one switch pair to the other pair through the transformer, causing the current through the triggered switch pair to rise and the current through the conducting switch pair to fall to zero naturally, resulting in ZCC. Later, the body diodes of the outgoing switches start conducting, and their gating signals are removed, leading to their ZCS turn off. Commutated device capacitance starts charging with NVC.

IV. DESIGN OF THE CONVERTER

In this section, the procedure for the design of converter is explained below by a design sample for the following specification. The maximum open-circuit voltage of PV V_{oc} , max=50 V, the voltage of the PV panel at MPP V_{in} =22-41 V, peak output power P_o =200 W, voltage at dc link V_{DC} =200 V, output voltage V_o =110 Vrms, device switching frequency of dc/dc converter f_s =100 kHz, and switching frequency of inverter f_{si} =20 kHz. The design equations are presented to determine or calculate the components' rating. It helps in selecting the components and predicting the converter's performance analytically.

The average input current is $I_{in} = P_o/(V_{in})$. Assuming an efficiency of nearly 95%, $I_{in} = 9.6$ A.

The maximum voltage across the primary switches is

$$V_{P, SW} = \frac{V_{DC}}{2.n} \quad (1)$$

Where, n is the turn's ratio of the HF transformer.

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The voltage conversion ratio is given as

$$VDC = \frac{n \cdot Vin}{1 - d} \quad (2)$$

Where, d is the duty cycle of the gating signal for the primary devices of the front-end converter.

The leakage inductance of the HF transformer or series inductance Llk is calculated using

$$Llk = \frac{VDC \cdot (d - 0.5)}{4 \cdot n \cdot lin \cdot fs} \quad (3)$$

The RMS current through the primary switches of the front-end converter is given by

$$Is1, rms = lin \sqrt{\frac{2 - d}{3}} \quad (4)$$

The transformer turns ratio is selected based on the conduction losses or, in other words, the converter efficiency, which mainly depends upon the losses in primary switches because they carry higher currents in the converter. Transformer with higher turns ratio requires lower voltage switches [using (1)], which have low ON state resistance. On the contrary, higher turns ratio results in higher switch RMS current [using (4)]. Therefore, an optimum turns ratio (and duty cycle), resulting in minimum conduction loss of primary switches, needs to be selected. MOSFETs having low ON-state resistance have been selected for this application. Turns ratio of $n = 2$ and duty ratio $d = 0.8$ result in overall low conduction losses. From series inductance $Llk = 7.5 \mu H$ for the given values.

The RMS current through the primary winding of the HF transformer is given by

$$ILlk, rms = lin \sqrt{\frac{5 - 4d}{3}} \quad (5)$$

The calculated value is $ILlk, rms = 7.4$ A.

The value of the boost inductor is given by

$$L = \frac{Vin \cdot (d - 0.5)}{\Delta lin \cdot fs} \quad (6)$$

8) The RMS current through secondary-side switches is given by

$$IS5, rms = \frac{lin}{n} \sqrt{\frac{5 - 4d}{6}} \quad (7)$$

The calculated value $IS5, rms = 2.4$ A.

The volt ampere rating of the HF transformer is given by

$$VAx - mer = VDC \cdot \frac{lin}{2 \cdot n} \sqrt{\left(2 \cdot (5 - 4d) \cdot \frac{1 - d}{3}\right)} \quad (8)$$

These equations are derived on the condition that diode conduction time is quite short and negligible with the intention to ensure ZCS of primary switches without significantly increasing the peak current through the remaining two switches. However, when the load is light and the diode conduction time is comparatively large, (2) is no longer valid. Due to the existence of longer anti-parallel diode conduction period, the output voltage is boosted to a higher value than that of the nominal boost converter. For such cases, (2) is modified into the following

$$VDC = \frac{n \cdot Vin}{1 - d - d'} \quad (9)$$

Where, d is given by

$$d' = d - 0.5 - \frac{n \cdot Vin \cdot 4 \cdot n \cdot lin \cdot Llk \cdot fs}{VDC} \quad (10)$$

From (10), it can be observed that, for a given value of Llk and VDC, d increases as the load is decreased. At full load, $d = 0$, and (9) is converted into (2).

The average current through the full-bridge inverter switches is given by

$$Is7, avg = \frac{\sqrt{2} \cdot Po}{\pi \cdot Vo} \quad (11)$$

The peak current through the inverter switches is

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$$I_{s7, peak} = \frac{\sqrt{2} \cdot P_o}{V_o} \quad (12)$$

The average and peak currents through the switch are obtained as $I_{S7, avg} = 0.82$ A and $I_{S7, peak} = 2.6$ A. Switches have to be rated for the dc link voltage, i.e., 200 V.

The filter inductor is calculated such that the voltage drop across the inductor is less than 2% of the nominal voltage, i.e.

$$L_f = \frac{V_o \cdot 0.02}{2\pi \cdot f_o \cdot I_o} \quad (13)$$

Where, f_o and I_o are the output frequency and output current. For the given specifications, a value is obtained as 3.8 mH. The filter capacitor is decided according to the cutoff frequency of the low-pass filter. For this application, one tenth of inverter switching frequency f_{si} is selected as the cutoff frequency. The capacitor is calculated as

$$C_F = \frac{1}{4\pi^2 \cdot f_c \cdot L_f} \quad (14)$$

Where, f_c is the cutoff frequency of the filter. For $f_c = 2$ kHz, capacitor C_F is obtained as 1.6 μ F.

V. UNINTERRUPTIBLE POWER SUPPLY

An uninterruptible power supply, also uninterruptible power source, UPS or battery/flywheel backup is electrical apparatus that provides emergency power to a load when the input power source, typically mains power, fails. In this paper, the supply to the load is efficiently utilized by any one of the sources like panel or battery or grid (or any two). Output voltage of the panel is fed to the load if panel produce sufficient energy, if it fails then higher voltage magnitude from any source like battery or grid will provide the required load voltage.

VI. SIMULATION RESULTS

The designed converter rated for 200W was simulated using MATLAB Software to verify the analysis, design and performance of the converter. The simulation result for two input voltages at peak power had been taken. Since PV modules have nonlinear V -I characteristics, its MPP varies dramatically with environmental factors such as solar irradiance and temperature. For a typical PV module, the MPP voltage ranges from 20 to 45 V at a power range of 100 to 300 W. The power generation has high variability that can drop by 80% due to shading and clouds. To achieve high efficiency, the power converter must show high performance for such varying conditions. The results have been taken for charging and discharging condition of battery.

Fig.5. Shows the proposed system comprises of panel, battery and grid. Simulation circuit of proposed system has three mode of operation. In mode-1 panel supplies the power to both the load and battery to charge. In mode-2, battery supply power to the load if panel fails. Grid from the other end power the load if both fails.



Fig.3. $V_{in}=41$ V is the output voltage of PV panel.

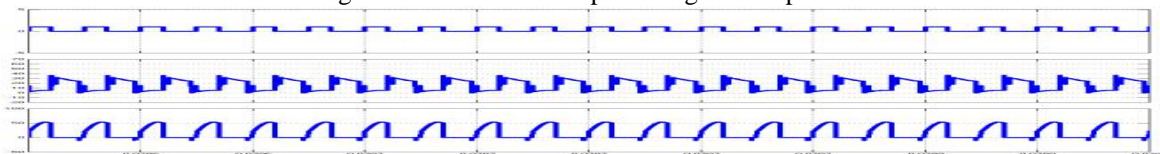


Fig.4. Experimental waveforms at $V_{in} = 41$ V and peak power. (a) Primary-switch voltages $v_{gs,S2}$ (10 V/div) and $v_{ds,S2}$ (50 V/div), and current i_{S2} (5 A/div).

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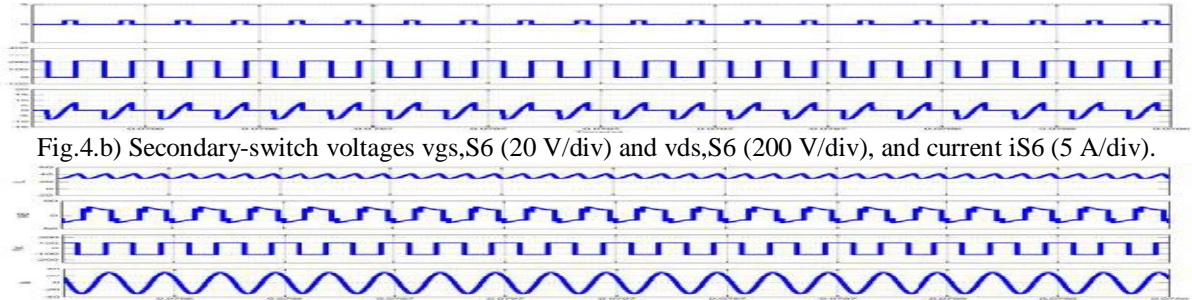


Fig.4. (c) Input boost inductor currents i_L (2 A/div), voltage V_{AB} (100 V/div), voltage across the secondary side of transformer V_{sec} (200 V/div), and series inductor current i_{lk} (5 A/div).

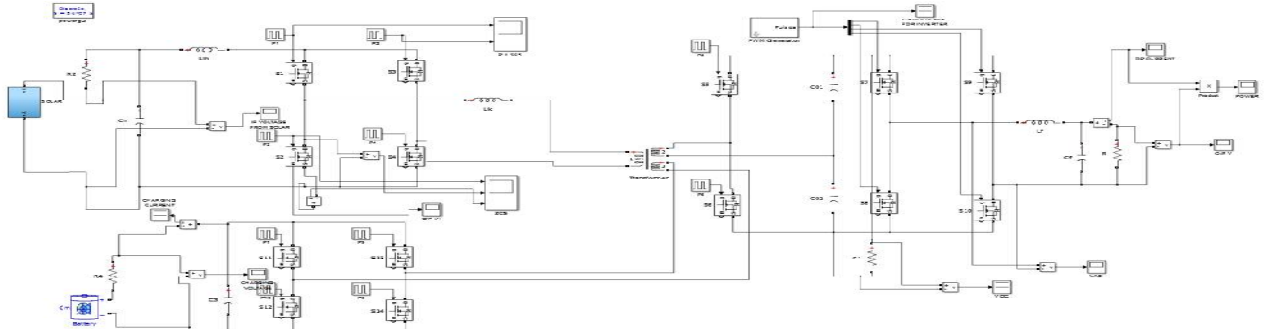


Fig.5. Simulation circuit of proposed system (Uninterruptible Power Supply)

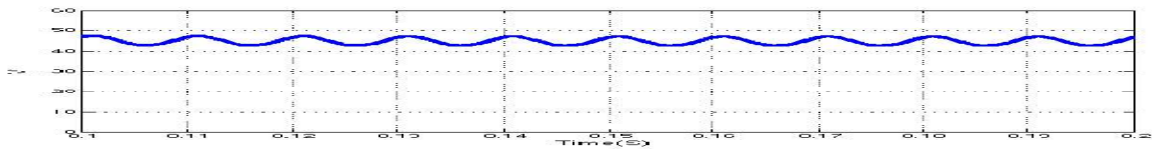


Fig.6.(a) Battery charging voltage,

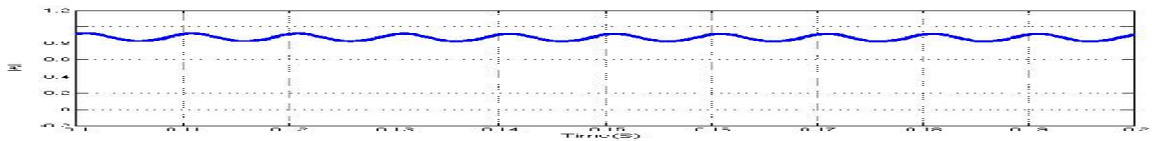


Fig.6.(b) Battery charging current

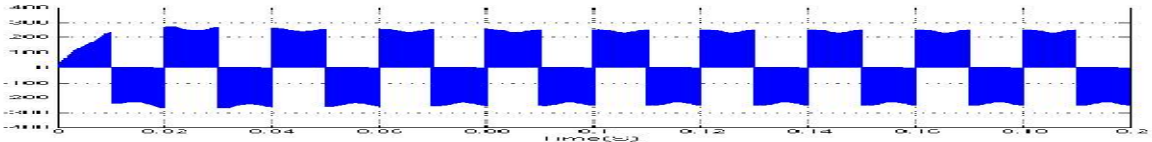


Fig.6 (c) V_{ab} (secondary side voltage) for mode-1.

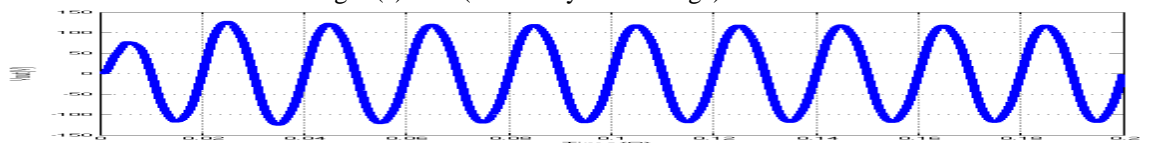


Fig7. (a) Output voltage,

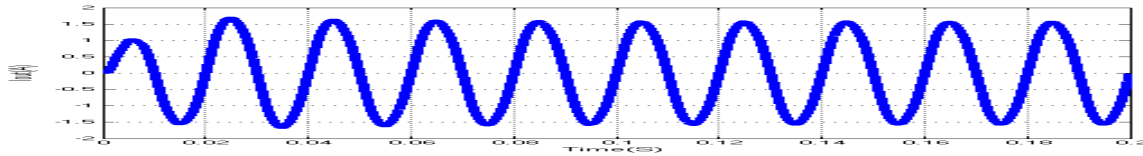


Fig7. (b) Output current

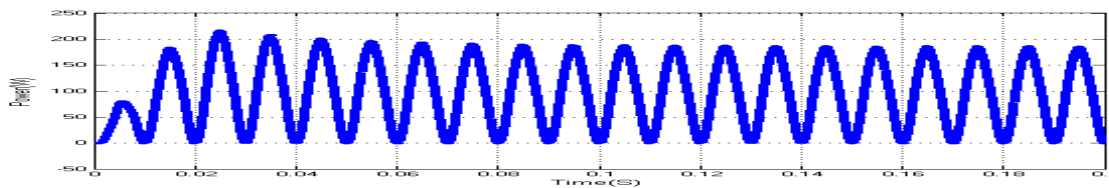


Fig7. (c) Output power for mode-1.

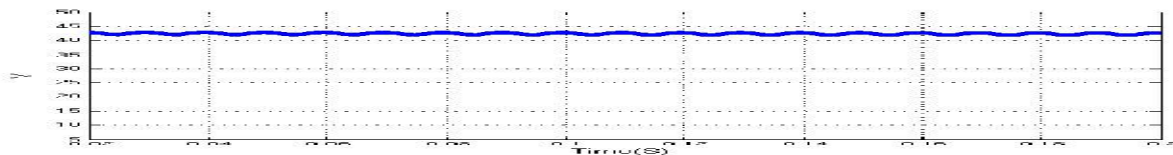


Fig.8. (a) Input voltage from battery backup,

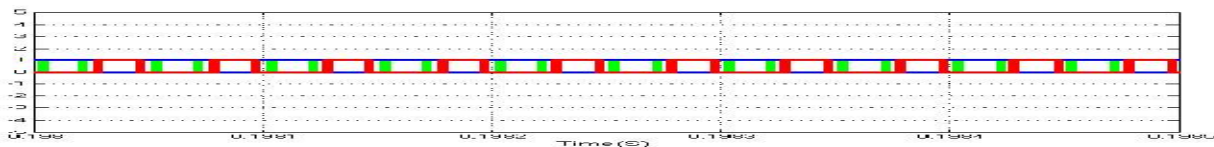


Fig.8. (b) Gate pulses for inverter

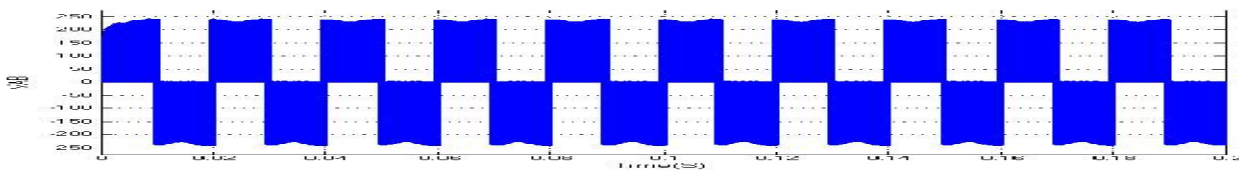


Fig.8. (c) Vab (secondary side voltage) for mode-2.

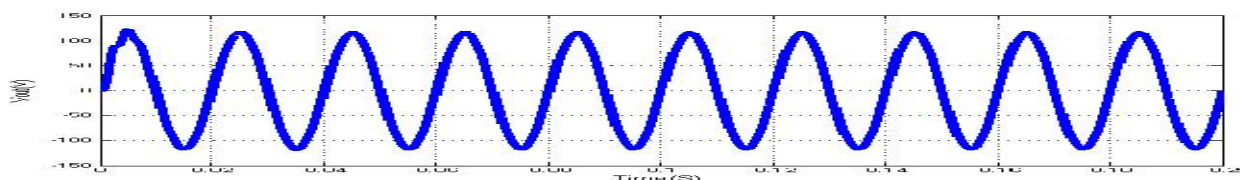


Fig.9. (a) Output voltage,

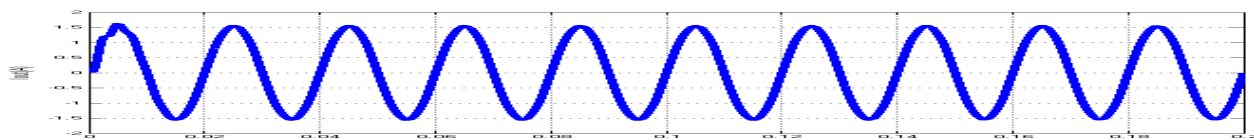


Fig.9 (b) Output current,

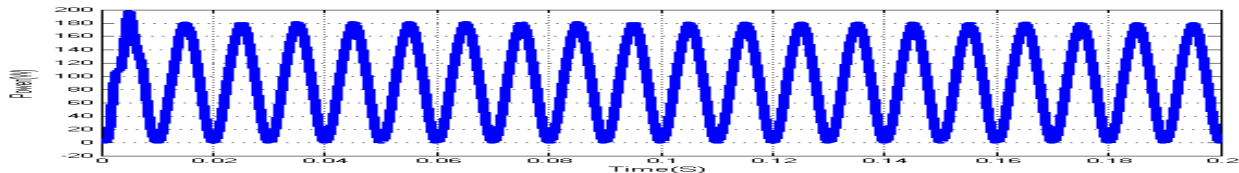


Fig.9 (c) Output power for mode-2.

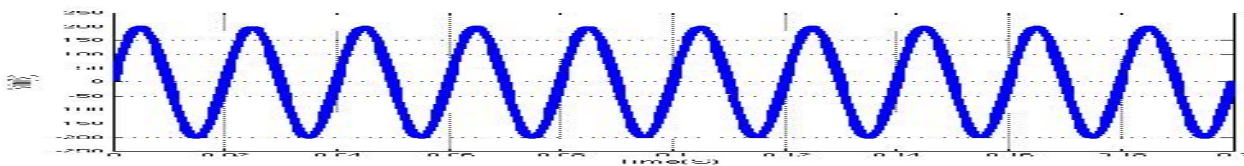


Fig.10. (a) AC input voltage,

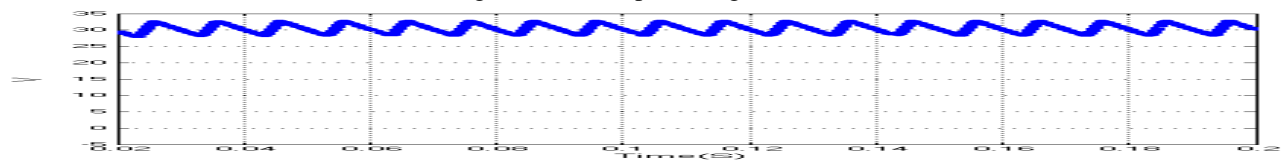


Fig.10. (b) Charging voltage of battery,

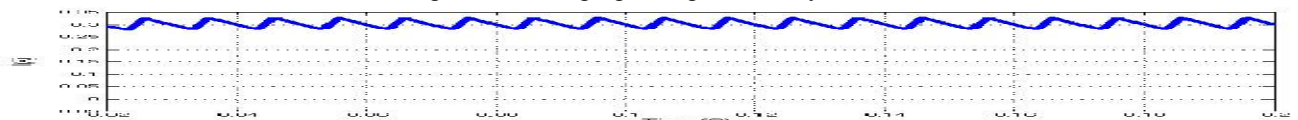


Fig.10. (c) Charging current of battery for mode-3

VII. CONCLUSION

This modulation achieves the NVC of the devices with zero-current commutation without modifying the topology, keeping the originality of the circuit without adding any components/snubber. In addition, this modulation achieves soft switching of all semiconductor devices. Natural device voltage clamping relieves the need for an additional snubber or an active clamp, making it novel and snubberless. The converter has successfully implemented an efficient high step up conversion through soft-switching technique for PV application. Uninterruptible power system has been briefly explained with three modes of operation, power to the load is efficiently provided with the help of PV panel, battery storage device and grid.

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BIOGRAPHY

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