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A High Step up DC-DC Converter with Coupled Inductor for AC AND DC Module Applications

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Abstracts

The grid connected AC module is an alternative solution in photovoltaic (PV) generation systems. It combines a PV panel and a micro inverter connected to grid. A high step up converter is used because the input is about 15V to 40V for a single PV panel.

The proposed converter employs a zeta converter and a coupled inductor without extreme duty ratios generally needed for coupled inductor to achieve high step up voltage conversion,the leakage inductor energy of the coupled inductor is efficiently recycled to the load.

A 25V input voltage, 200V output voltage and 250 W of the output power circuit of the proposed converter is implemented.

Keywords: AC Module, zeta converter, leakage inductance, step up converter.

Introduction

Renewable energy is the emerging trend to be incorporated to increase the consumption of green power. Several types of energy like hydro, wind, geo thermal and use of photo voltaic cell have contributed in generation of power. pv systems connected to the grid in distribution energy systems will become important and the pv inverter is also increasing their demand in the market. Generally an ac module consists of single pv panel and a microinverter. In pv cells their will be a variation in energy due to change in irradiance, temperature and the dynamic resistance, so a fixed input is difficult to obtain. In order to increase the output a high step up dc to dc converter is to be used.The use of dual stage micro inverter uses a high step up dc to dc converter and a dc to ac inverter which is able to achieve efficiency as high as conventional PV string type inverter.Conventional PV string type inverters are connected in seried and parallel combination with more PV modules to obtain higher dc link voltage to the main electricity through a dc to ac inverter. Usually a single PV cell can produce 15 to 40V depending upon the irradiance, shadowing effect, temperature, dynamic resistance. So inorder to meet the demands of the consumer as the power obtained from an inverter is fed to main electricity supply systems a new converter called as a zeta converter is employed as here the ordinary inductor of a conventional boost converter is replaced by a coupled inductor along with an addition of a capacitor multipliers to increase the energy storage in the circuit by increasing the energy storage components.Several factors will effect the overall performance of the system like the ESR of capacitors and the voltage stresses on the active switch as due to turn on and off the switch voltage spikes is produced and this voltage stress can be reduced by considering the leakage inductance energy recycling to the load such that the voltage stresses can be restrained. The use of coupled inductors increase the voltage gain and a high step up voltage conversion is possible.The use of coupled inductors is helpful to reduce the power supply dimensions.

Several MPPT techniques can be used to increase the PV cell voltage to satisfy the output demand. Here a non inverting buck boost converter called as inverse Sepic converter is used for increasing the output voltage. When the duty cycle is above 0.5 the converter performs like boost operation and it behaves like boost converter.When the duty cycle is below 0.5 the converter performs buck operation. Here the boost zeta converter is operated in CCM(continuous conduction mode).

The fig1 shows a the block diagram of a solar PV cell connected to a micro inverter combination of a high step up DC-DC converter. The PV cell is modelled in matlab with 50 number of cells per module, 5 series connected module per string and a 66 number of parallel strings. A single PV panel of 15V – 45V with 100W – 300W can be connected to provide a good electricity when the AC module is connected to electricity mains.Generally a DC-DC boost converter.

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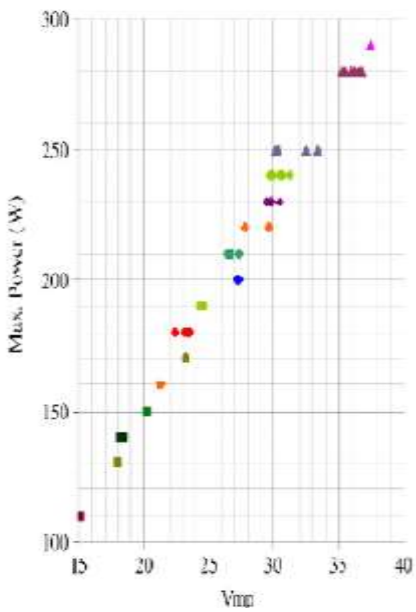

Fig 2. MPP voltage (Vmp) verses various power capabilities

100W – 300W can be connected to provide a good electricity when the AC module is connected to electricity mains.Generally a DC-DC boost converter is used for step up voltage applications like charging the batteries, providing a good support to boost the voltage for helicopter take off , so it is used as booster. Here the proposed boost Zeta converter is operated with a high duty ratio for high voltage gain. Several Zeta and flyback circuit combinations can be used to increase the output range[3],[5] . Further several soft switching

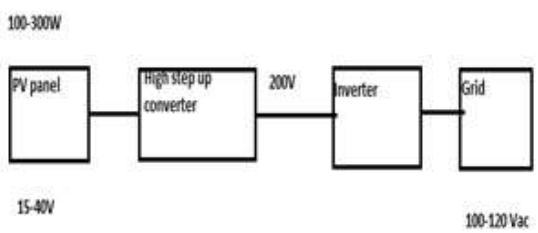

Fig 1 A PV grid connected module.

techniques can be provided like Zero voltage switching and Zero current switching for Zeta converter. So many research works have been carried out in this related field [6], [7].

The micro inverter transforms the low dc voltage obtained from a PV panel into high dc voltage inturn converted to an AC voltage using an inverter.

The fig 2 shows the MPP maximum power point for a power rating between 100 to 300W over a voltage range of 15 to 40 V. So from the graph an MPP voltage of 25 V is taken for a PV cell.Many works have been carried out to get a very good efficient way of switching and less power dissipation and to increase high step up voltage conversion like replacing ordinary inductor by a coupled inductor Transformerless boost capacitor type].

The fig 3 shows a proposed circuit of Zeta converter where compared to a conventional boost converter, the changes done here is the switching position of diode, and a input inductor is been replaced by coupled inductor.The circuit configuration is made up of an input voltage , coupled inductor T1 , floating switch S1, diodes D1,D2,D3.

The capacitor C1 and diode D1 are recycling the leakage inductor energy from primary turns of coupled inductor N1. The features of the proposed circuit are

- The recycle of leakage inductor energy and thus it helps in increasing the efficiency.
- The floating switch helps in isolation of the energy obtained from the PV panel when the switch is non operational.
- Increase in safety avoiding human hazards.

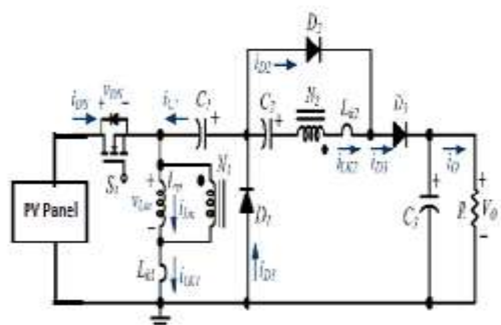

Fig 3. The proposed circuit configuration.

From Fig 3. V_{DS} represents the voltage across switch S1, L_m is the main magnetizing inductance, L_{k1} is the primary magnetizing inductance of coupled inductor, L_{k2} is the secondary magnetizing inductance, I_{lk1} is the primary leakage inductance current, I_{lk2} is the secondary leakage inductance current, i_{Lm} is the main magnetizing inductor current.

Operating principle of a proposed circuit.

The following assumptions is carried out for proposed circuit configuration, they are:-

- All components are ideal except the leakage inductance of the coupled inductor T_1.
- The parasitic capacitances of main switch S_1 are neglected.

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- The capacitors C_1 and C_3 are sufficiently large such that the voltage across them is constant.
- The ESR of capacitances $C_1 - C_3$ and parasitic resistance are neglected.
- The turns ratio of coupled inductor T_1 is equal to N_2/N_1.

The Fig 4. shows the operation of a proposed circuit in continuous conduction mode (CCM) of operation.
The entire operation is divided into 5 modes of operation. They are:-

- ❖ Mode 1 for time interval t0 to t1.
- ❖ Mode 2 for time interval t1 to t2.
- ❖ Mode 3 for time interval t2 to t3.
- ❖ Mode 4 for time interval t3 to t4.
- ❖ Mode 5 for time interval t4 to t5.

All the modes are included within one cycle duration of ON and OFF.

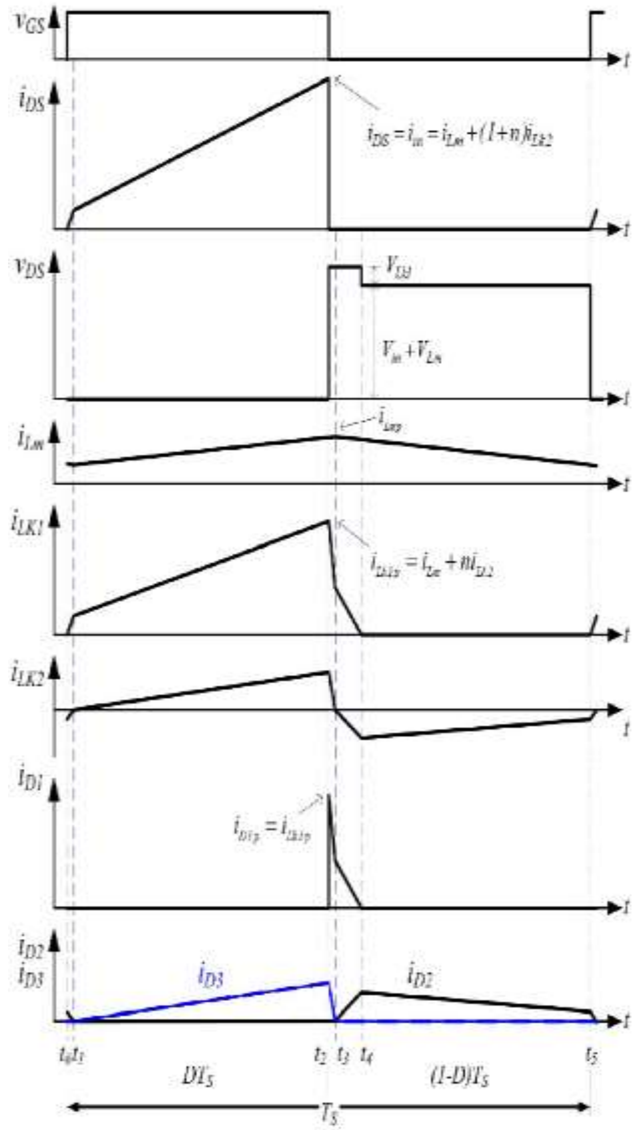

Fig.4 Typical waveforms of a proposed converter at CCM mode.

A. *CCM Operation*.

- ▪ Mode 1 (t0-t1).

The L_{k2} releases energy to C_2 , the floating switch S_1 and diode D_2 is said to be forward bias and it conducts. As seen from Fig 4 and Fig 5(a) i_{Lm} is decreasing till t0-t1 because Vin is applied across L_m and L_{k1}. L_m is releasing energy to secondary winding and also charging capacitor C_2 and decreasing the diode current i_{D2}.

IDin = IDs=ILK1………………………………..1

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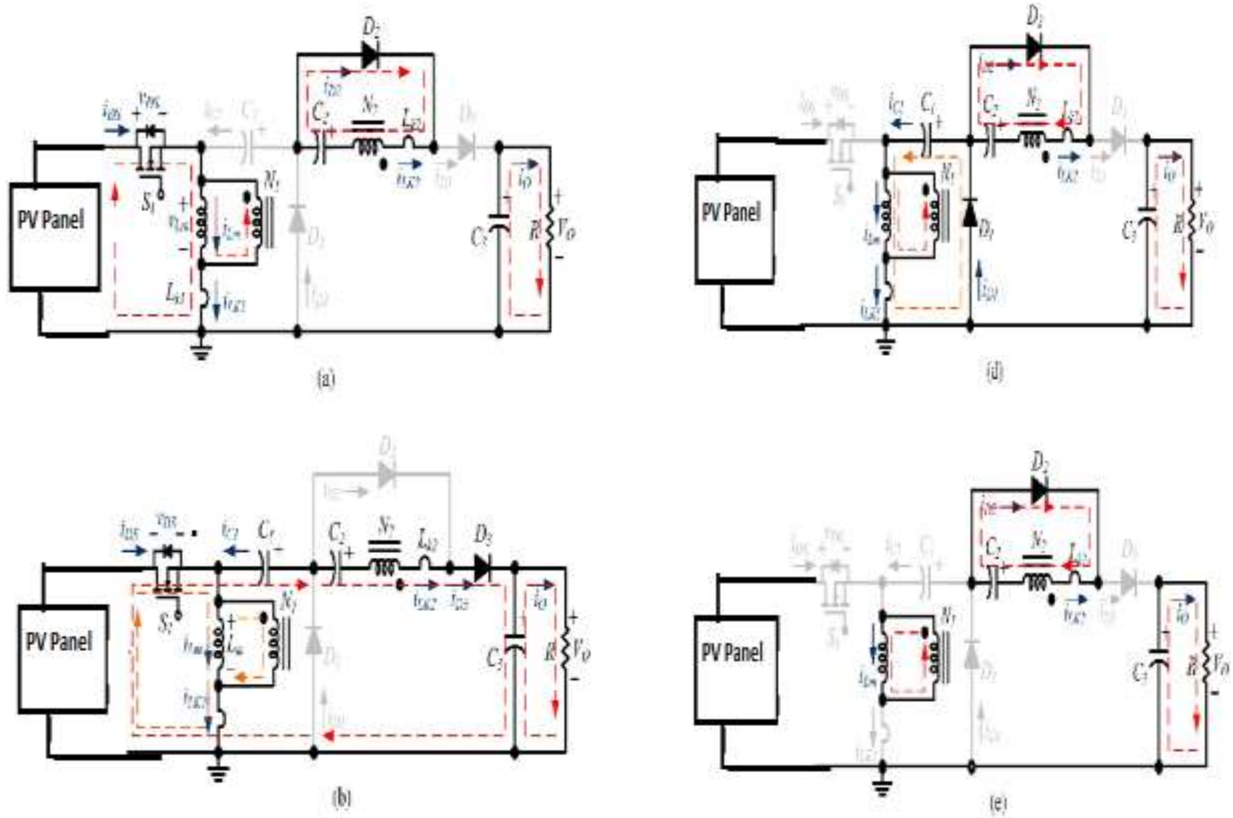

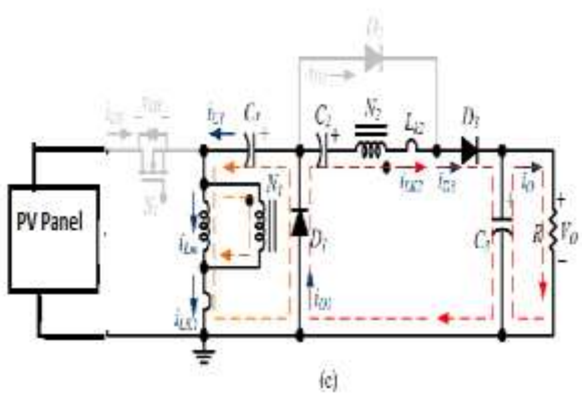

Fig.5 Current flow path in five operating modes during one switching period in CCM operation

- Mode 2 (t1-t2).

The input voltage from PV panel is series connected with capacitor C_1 and C_2 , N_2 , L_{k2} such that now V_{in} is ready to charge C_3 and load R. The magnetizing inductance L_m is also receiving energy from Vin.
The switch S1 is ON and diode D_3 is ON whereas the diode D_2 and D_1 is off. From Fig 5 (b) i_{Lm},i_{Lk1}, and i_{D3} are increasing because Vin is crossing L_{k1},L_m and primary winding N_1. L_m and L_{k1} are storing energy from Vin. Vin is series with N_2 of a coupled inductor T1 and with capacitors C_1 and C_2 are discharging their energy to capacitor C_3 which will lead to an increase in i_{Lm} , i_{Lk1},I_{ds}, and i_{D3}. This mode ends at t=t2 when the switch S1 is off.

- Mode 3 (t2-t3).

During this interval of time secondary leakage inductor L_{k2} keeps charging C_3 when the switch S1 is off. The current flow path is shown in Fig. 5(c), and now the diodes D_1 and D_2 will be conducting. The energy stored in the leakage inductor L_{k1} flows through diode D_1 to charge capacitor C_1 continously when S1 is turns off. Currents i_{Lk1} and i_{Lk2} are rapidly declining but i_{Lm} is increasing because Lm is receiving energy from L_{k2}.

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This mode will ends down when i_{Lk2} falls to zero this mode ends at t=t3.

- Mode 4 (t3-t4).

The energy stored in the magnetizing inductor L_m gets releases into C_1 and C_2. The current flow path is shown in Fig. 5(d) only diode D_1 and D_2 are conducting. The currents i_{Lk1} and i_{D1} are decreased because the leakage energy still flows through diode D_1 and continuous charging capacitor C1. The Lm is releasing its energy through T1 and D2 to charge capacitor C_2. The energy stored in capacitor C_3 is constantly discharged to the load R. The voltage across S1 is same as in previous mode. The currents i_{Lk1} and i_{Lm} are decreasing but i_{D2} is increasing. This mode ends when current i_{Lk1} is zero at t=t4.

- Mode 5 (t4-t5).

During this interval of time magnetizing inductor Lm is constantly transferring energy to C2. The current direction is shown in Fig. 5(e), and here only diode D2 is conducting. The iLm is decreasing due to magnetizing inductor energy flowing continuously through a coupled inductor T1 to secondary winding N2 and D2 to charge capacitor C2. The voltage across S1 is the summation of Vin and VLm. This mode ends when the switch S1 is turned ON at next beginning of cycle. The Table 1 shows the component details used for simulation in MATLAB.

TABLE1. SPECIFICATIONS OF PROPOSED CIRCUIT.

Output Power	250W
Input Voltage Vin	25V
Output Voltage,V0	200V
Switching Frequency,fs	50kHz
Capacitor C1	47 µF
Capacitor C2	100µF

Simulation model and results using matlab

The fig.6 shows the matlab model consisting of a PV panel, a proposed converter which can be called as a zeta converter .A Required output is been obtained for different modes of operation for particular interval of time and we are able to provide a good isolation to the circuit and their by using a coupled inductor the leakage inductor energy is also fed back in the operation to increase the energy efficiency by recycling the energy to the load. The Simulink model is used to run the model and to obtain the output voltage of 200V. so a high step up voltage conversion is done from 25V to 200V.

A MATLAB SIMULATION FOR PV MODEL WITH A ZETA CONVERTER.

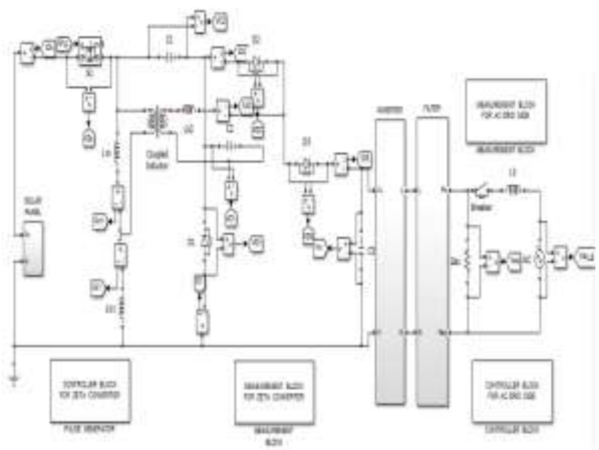

Fig.6 Simulation model using Matlab

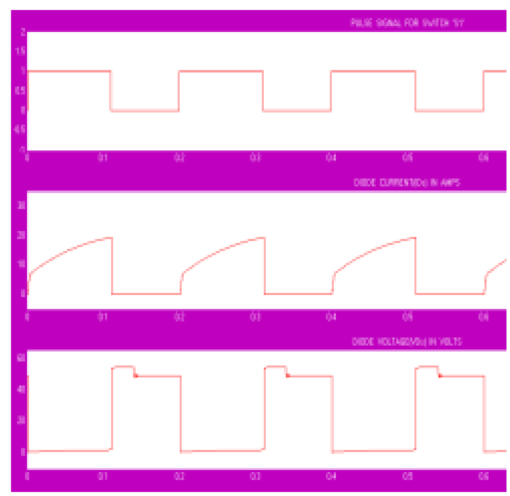

Fig.7 Simulation output of diode current IDs and diode voltage VDs.

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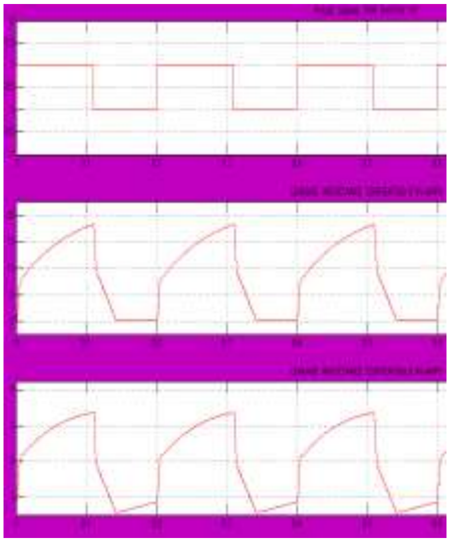

Fig.8 Simulation results of leakage inductance current ILk1 and ILK2

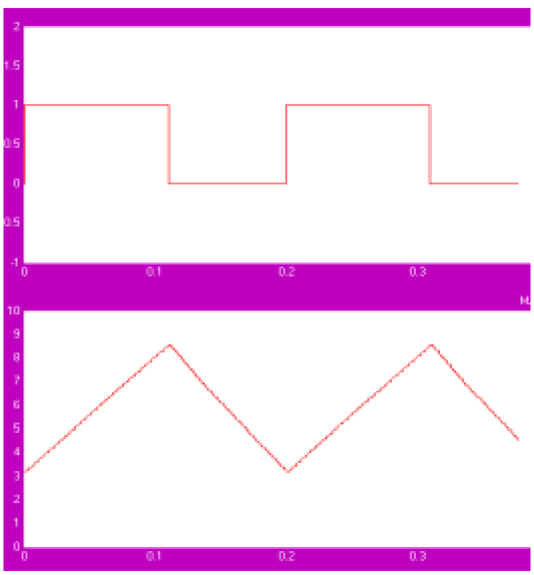

Fig.9 Simulation result of magnetizing current ILm.

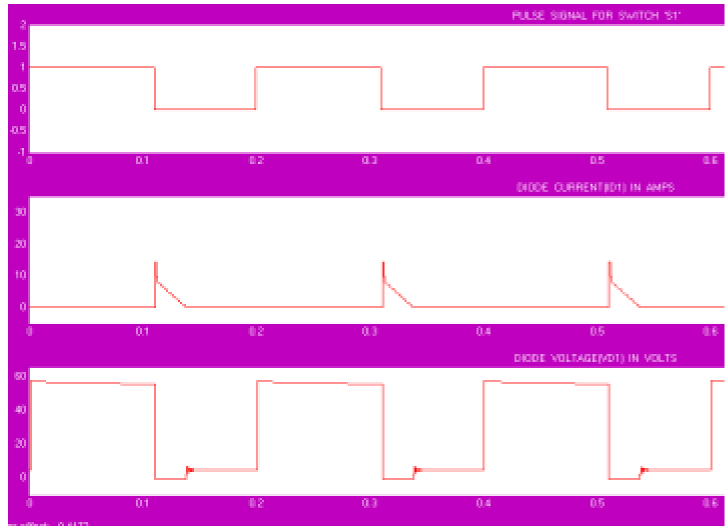

Fig 10 Simulation results of diode current IL1 and diode voltage VD1

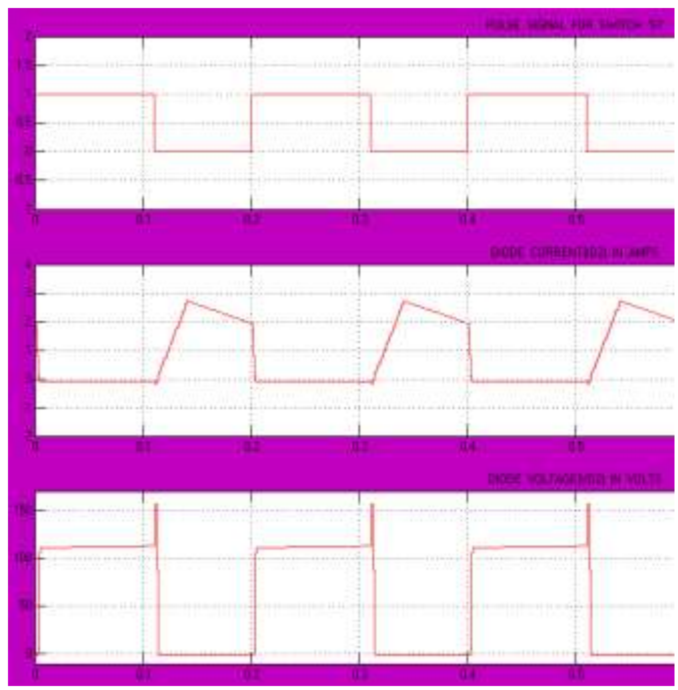

Fig 11 Simulation results of diode current IL2 and diode voltage VD2.

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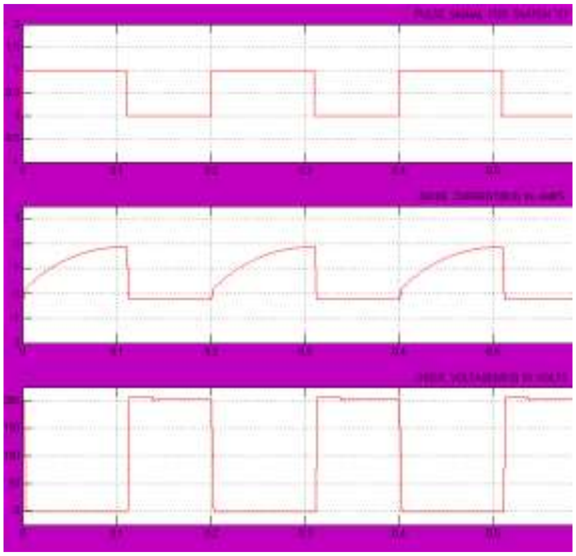

Fig 12 Simulation results of diode current IL3 and diode voltage VD3.

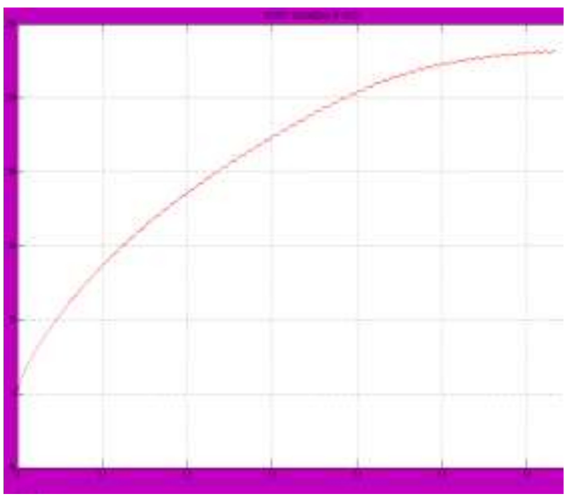

Fig 11. Simulation results of output voltage when PV panel is input source.

The Fig 11 shows the output voltage with input as pavel panel and output taken across the capacitor C3

I. SIMULATION OF A ZETA CONVERTER WITH INPUT DC SUPPLY.

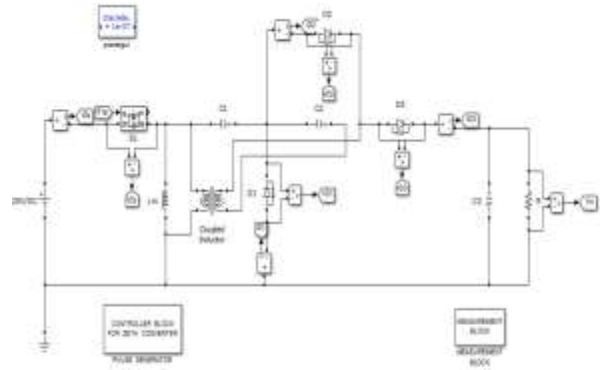

Fig 13. Simulation model of a zeta converter taken across the load RL

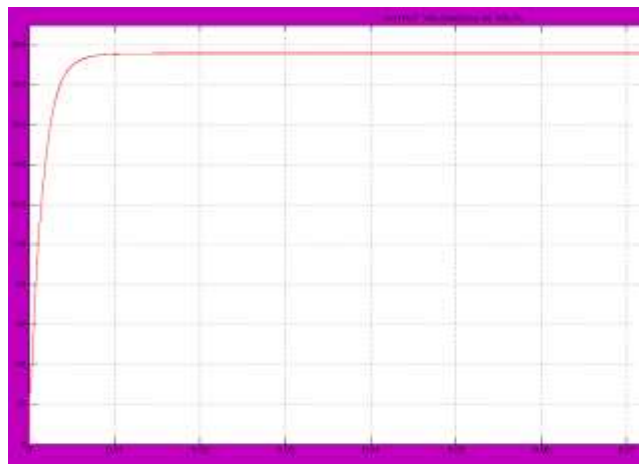

Fig.12 Result of output voltage taken across load resistance RL The output voltage obtained is of 200V by using a dc source

Conclusion

The proposed converter employs the turns ratio of coupled inductor to achieve high step up voltge, using a zeta converter. This helps in isolating the energy from the PV panel when the converter is non operational and this helps to prevent injury to humans .The energy of the coupled inductor is recycled and the voltage stress has been overcome. So that low R_{DS}(on) on state resistance is selected.

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