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Simulation of Micro Inverter with High Efficiency High Step Up Dc-Dc Converter

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Abstract- An alternative solution in PV generation systems is the grid connected AC module. PV panel and micro inverter connected to the grid forms this combination. The power processing interface between the PV source and the electrical grid is high step-up converter and DC-AC inverter. The energy injected to the grid depends on the efficient conversion of high step-up converter and efficient inversion by the DC-AC inverter. The proposed configuration boosts the low array voltage by tracking maximum power from the PV array and converts the high DC power to high quality AC, feeding it to the grid. In this paper a ZETA converter with coupled inductor is used to efficiently recycle the leakage inductor energy. Further the overall safety to the system is enhanced since the PV array appears as an floating source. A discussion about the operating principle, steady state analysis, stress on active components of converter are done in this paper. All the simulation results are presented that verify the maximum PV energy is injected into the grid.

Index Terms- Micro inverter, coupled-inductor, ZETA converter, High Efficiency.

I. INTRODUCTION

PV inverter will play an irreplaceable role in the increasing market in near future. As the world's power demand is increasing more visibility is gained by the photovoltaic power supplied to the utility grid. The necessity for the user to extract maximum power from the PV system is high initial investment and limited life span of the photovoltaic array. Further it is necessary to use maximum power point tracking due to rotation and revolution of earth and nonlinear characteristics of the PV array. It is not necessary for an battery back up to ensure MPPT [1] in this grid connected PV systems, which make it more popular. Conventionally to obtain higher dc link voltage PV string-type inverters with numerous modules were used [2], [3]. This system had advantages like easy system monitoring and repair but the efficiency was reduced due to module mismatch and dc connection cable losses [4]-[6].

A dual stage grid connected PV system is proposed to overcome these problems. A single PV and a micro-inverter forms this ac module which feeds quality power from the solar to the grid. A low dc voltage from the PV panel is given as input to the micro inverter, like the small scale inverters these micro-inverters would transform this dc voltage to ac feeding it to the grid. Inoculation of yield loss by shadow effect is made by this swap solution. User's budget is also reduced by flexible installation options [7]-[8]. A single stage micro-inverter which was proposed earlier required high input source and efficiency was also less. A dual stage micro-inverter as developed which is integral structure of high step-up dc-dc converter and dc-ac inverters.

II. BLOCK DIAGRAM

Fig. 1 shows the general configuration of grid-connected ac module. Micro-inverter integrates an high step-up dc-dc converter and dc-ac inverter. The block diagram depicts an dual stage micro-inverter. The input to the converter is fed from the PV module. High stepped-up dc voltage is given as input to the inverter. The output of the inverter is given to the grid or any ac module.

An single panel is used to feed an input dc of 25V. The high step up, high efficient dc-dc converter is an zeta converter with coupled inductor which efficiently steps up input 25V dc to 200V dc. The inverter is an single phase which inverts 200V dc to 220V ac.

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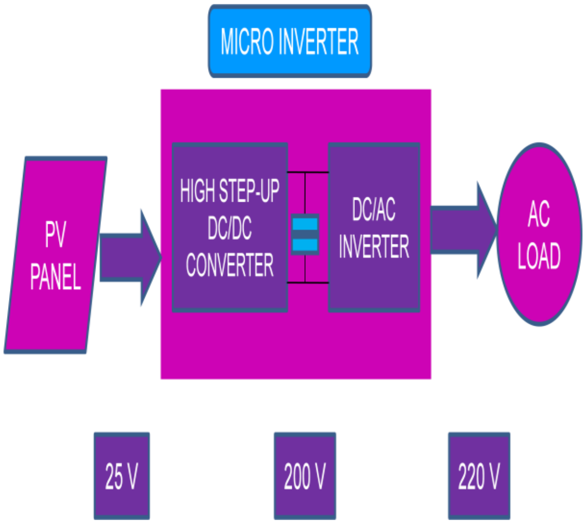

Fig. 1. Block diagram of grid connected ac module.

The micro-inverter shown in Fig. 1 which is placed at rear end of the PV panel is fed with a 25V dc from the PV panel. 200V boosted dc voltage is inverted to 220V ac by an dc-ac inverter. The efficiency of this is as high as conservative string type inverters.

II CHOICE OF CONVERTER

Many configuration of converters were projected to increase the conversion efficiency. However each of it had its own drawbacks which allowed it not to achieve the required efficiency. Like the buck-boost and SEPIC converter topologies Zeta converters performs either step-up or step-down operation. Fig.2 shows the comparison of boost converters in terms of input current T.HD, power factor, output ripple and efficiency. It is clear that the efficiency of Zeta converter is high compared to other boost converters. Normally configuration of Zeta converter is two inductors, a series capacitor and a diode. Research works were developed to increase the efficiency of this Zeta converter. The inductor was replaced by an coupled inductor this reduced the dimension of the circuit [9] and increased the conversion ratio.

Combinations of converters like combining boost and flyback converters were made to extend the range of output [10]-[12]. Examination of switched-inductor type, switched-capacitor type [13]-[15], voltage lift type was done [16]. Due to issues like parasitic effect reverse recovery issues of diodes, equivalent series resistance of capacitor and parasitic resistance of the inductor the overall efficiency is reduced.

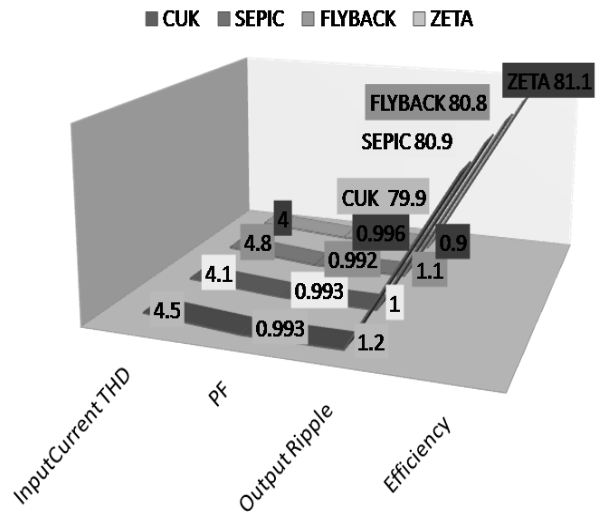

Fig. 2. Comparison of boost converters.

Voltage stress on the active switch should also be reduced. By recycling the coupled inductor energy stress on the switch can be reduced by achieving voltage lift. This is done by replacing two inductors of Zeta converter by an coupled inductor without intense duty ratio and high turns quotient.

III. EVOLUTION OF INVERTERS

The inverters which feeds the grid by receiving input from the PV module has a chief errand of feeding sinusoidal input to the grid. The technologies used to design such inverters were centralized inverters, string technology, multi-string technologies [18]. At present micro-inverter technology is used.

A. Centralized Inverters

A large number of PV modules were interfaced to the grid in centralized inverters as shown in Fig. 3(a). The PV modules were in a form of string, which are series connections of modules. There was no need of amplification since each module generated sufficiently high voltage.

Then higher power levels were reached by parallel connections of string through diodes. This topology had limitations like dc cable losses, PV modules mismatch, loss of power due to centralized MPPT and complexity in designing. These increased the investment cost and decreased the efficiency. Alternate modules were developed to overcome these disadvantages.

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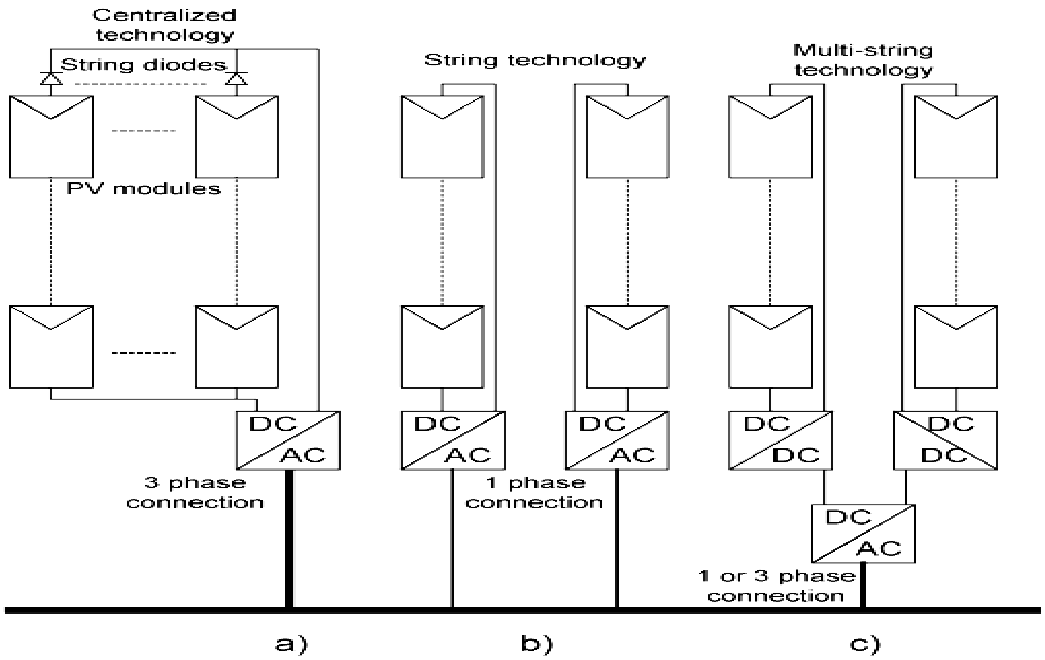

Fig. 3. Evolution of inverters. (a) Centralized technology, (b) String technology, (c) Multi-string technology.

B. String Inverters

Fig. 3(b) shows the string technology. In this only single string is connected to the inverter. Voltage amplification is not necessary since the input is high enough. Here there are no losses due to diodes here the overall efficiency is increased and installation cost is reduced. However enlarging this system is complex due to its structure.

C. Multi-string Inverters

Fig. 3(c) depicts the multi-string inverter. Here each string has its own converter all of which is connected to an common inverter. Here each string can be controlled individually, it requires only few PV modules. It is easy to extend this system by just plugging in dc-dc converter into existing plant. Efficiency is more and designing is also flexible. Finally micro-inverter was developed were only one PV module is connected to the inverter. The challenge is to develop an new converter concept which would require low input voltage, then boost it up to a very high value. The inversion of this is done to feed the grid. In the proposed system a Zeta converter with coupled inductor is used to achieve this.

III. PRINCIPLE OF OPERATION OF PROPOSED CONVERTER

Fig. 4 shows the simplified circuit of proposed converter. It is modified from an Zeta converter, were the input inductor is replaced by an coupled inductor. The voltage gain is increased by the turns ratio of the coupled inductor. The voltage is further increased since the secondary winding of the coupled inductor is in series with a switched capacitor.

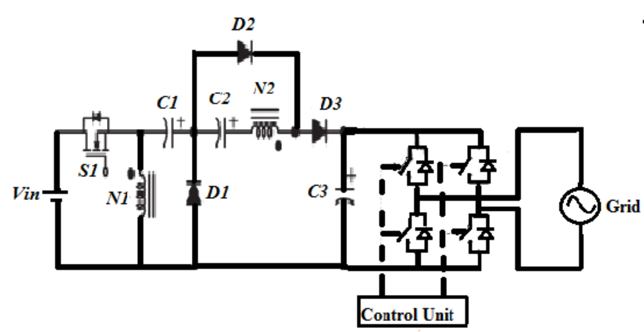

Fig. 4. Simplified circuit of micro-inverter

The capacitor C_1 and diode D_1 recycling components which recycles the inductor energy from N_1.The coupled inductor Zeta converter has an floating switch S_1 which isolates the source from the circuit under non-operating conditions. The secondary of the coupled inductor N_2 is connected to capacitor C_2 and diode D_2 all of which are connected in series with N_1. Diode D_3 connects capacitor C_3 and resistive load R. It is seen that the circuit model is similar to the conventional boost converter, except that the leakage inductor energy is recycled.

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The coupled inductor comprises of primary winding N_1, secondary winding N_2, leakage inductors L_{k1} and L_{k2} and magnetizing inductor L_m. For simplified analysis the assumptions made are,

a) Except leakage inductor all the other components are ideal.
b) The equivalent series resistance of capacitors and parasitic resistance of inductors are neglected.
c) Turns ratio of the coupled inductor is $n = N_2/N_1$.
d) Capacitors are large enough such that the voltage across them is constant.

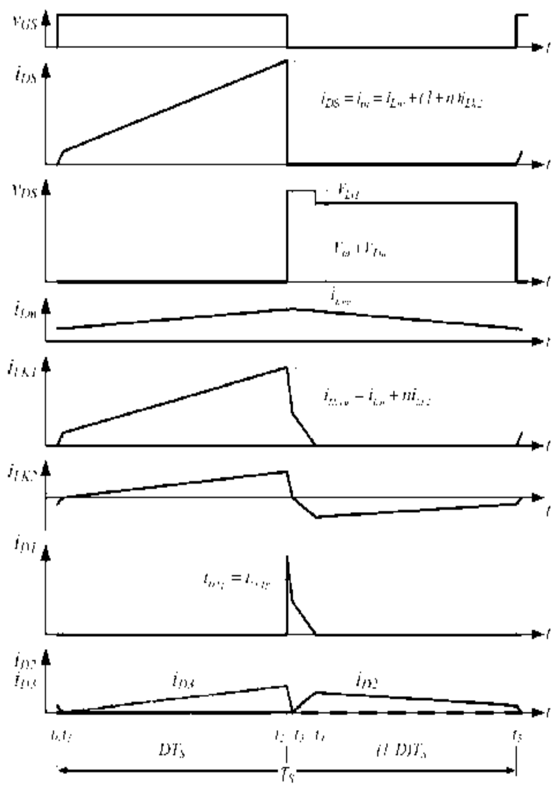

Fig. 5. Waveforms of converter at CCM operation

The features are:

a) The leakage inductor energy is recycled.
b) Voltage spike on switch is reduced
c) Efficiency is increased due to recycling technique.
d) Active switch isolates the source during non-operating conditions.

Fig. 5 shows the operation under continuous conduction mode (CCM). Waveform of one switching period is shown.

A. Mode I (t_0,t_1) [Fig 6(a)]

In this the conducting devices are switch S_1 and diode D_2. The capacitor C_2 is continuously charged by L_{k2} and L_m. Hence energy of the inductor decreases along with decrease in currents i_{D2}, i_{C2} and i_{Lk2}. But i_{Lk1} increases since V_{in} is applied to the inductor primary. When $i_{Lk1} = i_{Lk2}$ this mode terminates.

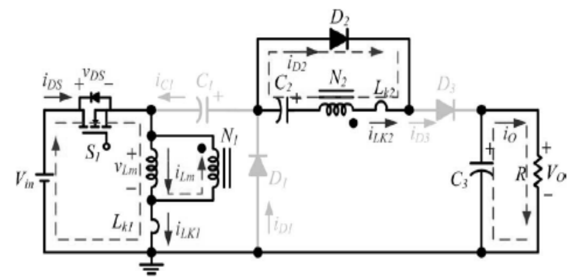

Fig. 6(a). Mode I CCM operation

B. Mode II (t_1-t_2) [Fig. 6(b)]

The conducting devices in this mode is switch S_1 and diode D_3. The output capacitor C_3 and load R is charged by L_{k2} and by discharge of C_1 and C_2. Since V_{in} is applied i_{L1}, i_{k1}, i_{D3} increases and L_m and L_{k1} are storing energy. This leads to increase in i_{Lm}, i_{Lk1},i_{DS} and i_{D3}. When S_1 is turned off this mode ends.

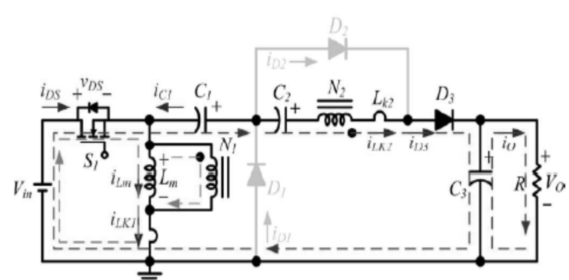

Fig. 6(b). Mode II CCM operation

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C. Mode III (t_2-t_3) [Fig. 6(c)]

Switch S_1 is turned off at this mode. The conducting devices are D_1 and D_3. Capacitor C_1 is instantly charged by stored energy of L_{k1} which flows through diode D_1, as soon as switched S_1 is turned off. Now the voltage across the switch is summation of $V_{in,}$ V_{Lk1}, and V_{Lm}. Currents i_{Lk1} and i_{Lk2} decreases with increase in i_{Lm}. This mode ends when i_{Lk2}=0.

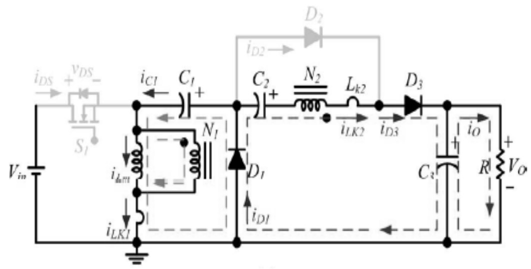

Fig . 6(c). Mode III CCM operation

D. Mode IV(t_3-t_4) [Fig. 6(d)]

The conducting devices are D_1 and D_2. Capacitors C_1 and C_2 are charged by magnetizing inductor L_m. Since C_1 is continuously charged through T_1 and D_2 the energy of L_m decreases. The voltage across is same as mode III. Currents i_{Lk1} and i_{Lm} decreases with increase in i_{D2}. When i_{Lk1}=0 this mode ends.

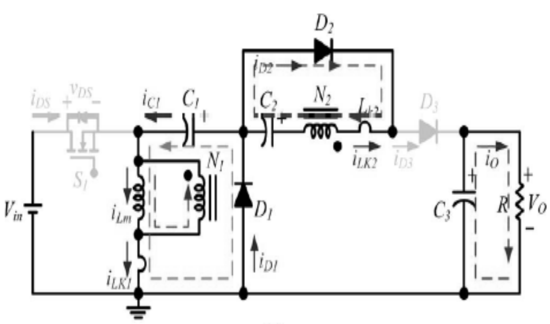

Fig. 6(d). Mode IV CCM operation

E. Mode V(t_4-t_5) [Fig. 6(e)]

The conducting devices in this mode is diode $D_{2.}$ Capacitor C_2 is constantly charged by magnetizing inductor L_m. Capacitor C_3 discharges through load R. Now the voltage across switch S_1 is summation of V_{in} and V_{Lm}. When switch S_1 is turned on this mode ends.

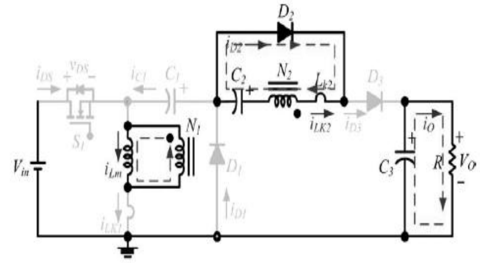

Fig 6(e). Mode V CCM operation

The micro-inverter shown in Fig. 1 which is placed at rear end of the PV panel is fed with a 25V dc from the PV panel. 200V boosted dc voltage is inverted to 220V ac by an dc-ac inverter. The efficiency of this is as high as conservative string type inverters.

IV. DESIGN CONSIDERATIONS OF CONVERTER

TABLE I

SPECIFICATIONS OF PROTOTYPE

Output Power	250 W
Input Voltage	25 V
Output Voltage	200 V
Switching Frequency	50 kHz

TABLE II

COMPONENTS USED IN SIMULATION

<table>
<tr><th colspan="2">COMPONENTS</th><th>RATING</th></tr>
<tr><td colspan="2">Magnetizing Inductor</td><td>50.78 µH</td></tr>
<tr><td rowspan="3">Capacitors</td><td>C1</td><td>47 µF</td></tr>
<tr><td>C2</td><td>47 µF</td></tr>
<tr><td>C3</td><td>100 µF</td></tr>
<tr><td rowspan="2">Coupled Inductor</td><td>Duty Ratio (D)</td><td>50%</td></tr>
<tr><td>Turns Ratio (n)</td><td>3</td></tr>
</table>

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V. SIMULATION RESULTS

The simulated circuit of proposed micro inverter ia shown in Fig 7. The wave forms in Fig. 8 depicts the voltage and current waveforms of switch S_1, diodes D_1, D_2, D_3 and output voltage V_0 of the converter, inverter output voltage V_{go} and load current I_o. It is seen that from a very low dc input 230V ac output is obtained in micro-inverter, which can be connected to the grid.

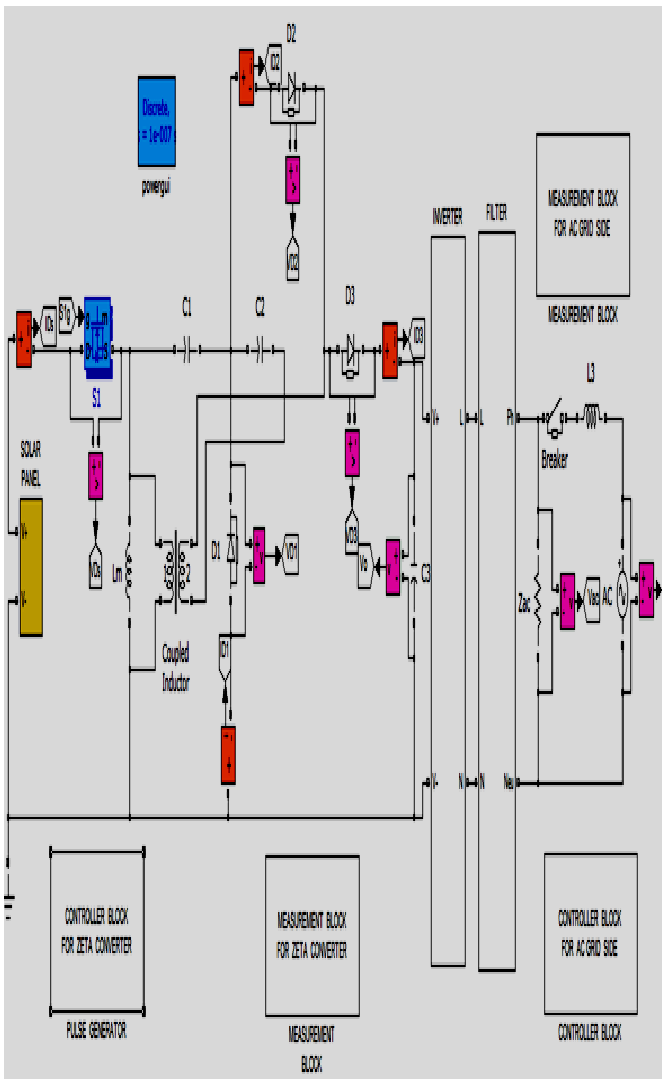
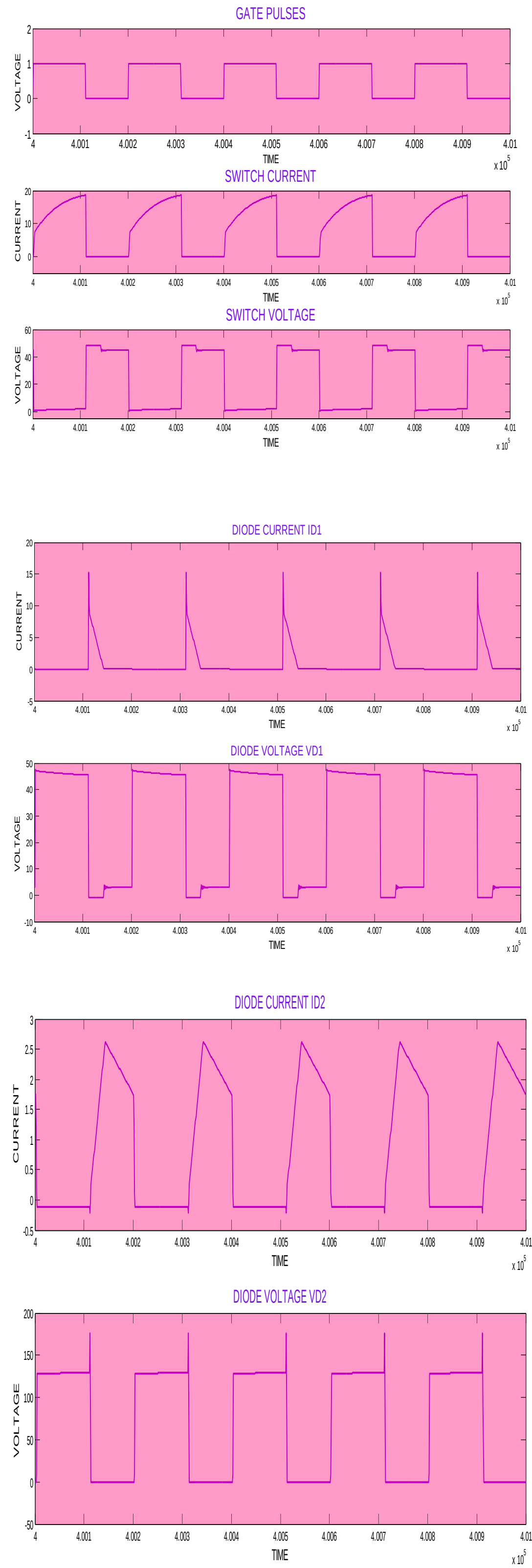


Fig. 7. Simulated Circuit of Micro-Inverter



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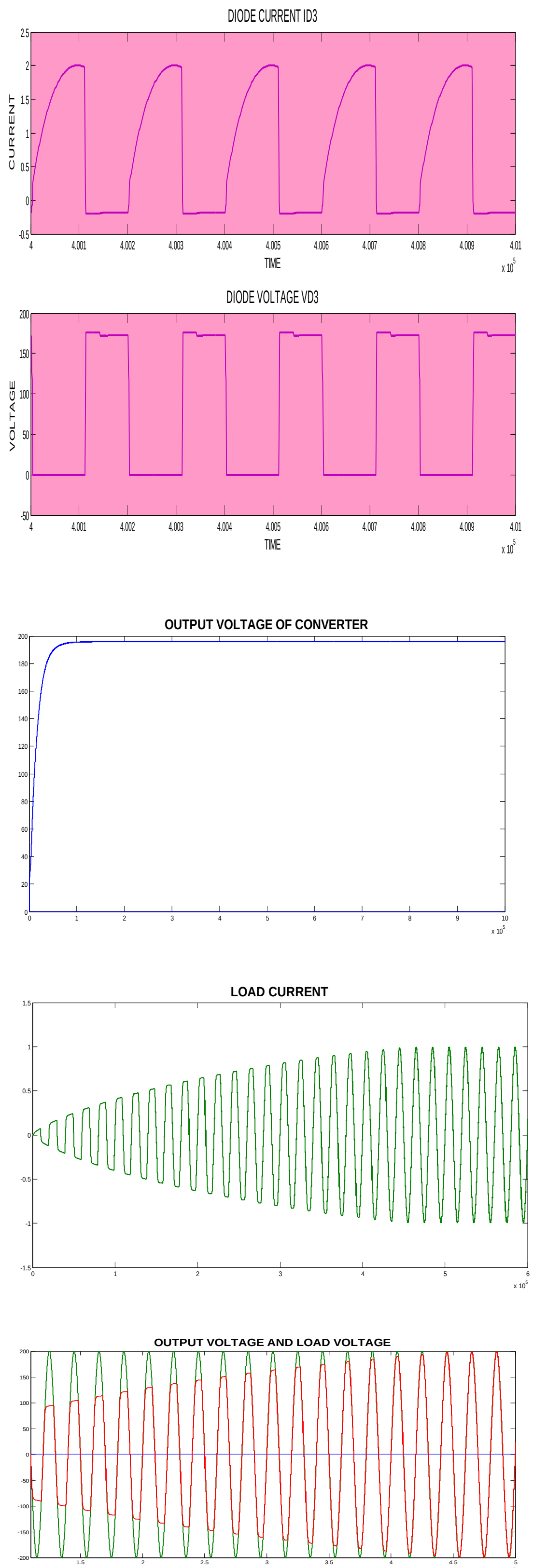

Fig . 8. Simulated waveforms for the condition $f_s = 50$ kHz, $V_{in} = 25$V, output 250W.

VI. CONCLUSION

High Voltage gain is achieved by coupled inductor technique. The proposed model is a floating switch structure whish isolates the source during non-operating conditions avoiding any hazards to humans. The coupled inductor energy is recycles increasing the efficiency. The input dc is stepped up eight times and fed to inverter Synchronization of single phase inverter yields 230V ac to feed the grid. Hence with a single PV panel dc a 230V ac output is obtained.

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