IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676 Volume 5, Issue 1 (Mar. - Apr. 2013), PP 17-22
www.iosrjournals.org

Analysis and Design of High Step-Up DC-DC Converter for Photovoltaic Application

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Abstract: *Now a day's Photovoltaic power generation is essential for the developing countries to meet their electricity demand. The power generated from the (PV) module has been connected to the panel through the proper channel of DC-DC converter and DC-AC inverter. This paper proposes a new high step up DC-DC converter with floating active switch which acts as a high state drive. This floating active switch isolates energy from the PV panel when the ac module is off. It also regulates the DC interface between the DC-AC converters. The high step up voltage conversion ratio is achieved with numerous turns ratio of a coupled inductor and appropriate duty ratios. The energy stored in the leakage inductor with the help of magnetizing inductor of a coupled inductor is efficiently recycled to the load through the output capacitor. With an input voltage of (Vin) 15V and 250V output voltage is obtained. An output power of 97W is also obtained from the designed converter circuit. Its maximum full load efficiency is better than conventional convert model.*
Keywords*-AC Module, floating active switch, coupled inductor, high step up Voltage conversion ratio.*

I. Introduction

Non-conventional energy is becoming increasingly important and prevalent in distribution systems. The uses of alternative sources of energy like fuel and solar requires a large step up conversion of their low voltage level to the required level of voltage. A PV array is a serial connection of numerous panels to obtain a higher DC-link voltage.

This dc voltage can be utilized for the main electricity through the DC-AC inverter [1],[30]. An ac module is a micro inverter configured on the rear bezel of PV panel, this will immunizes against the yield loss by shadow effect. The prior works have proposed the converter with single switch and fewer components to fit the dimensions of the bezel of the ac module, but their efficiency levels are low. The power capacity range of 50W to 250W and the maximum power point voltage range is 12V to 40V which will give as input.

In case if the voltage derived from the PV panel is lower, then it is difficult for the ac module to reach the high efficiency. However employing a high step-up DC-DC converter in front of the inverter, which improves the power conversion efficiency from one level to another level and it also provides the stable DC link to the inverter.

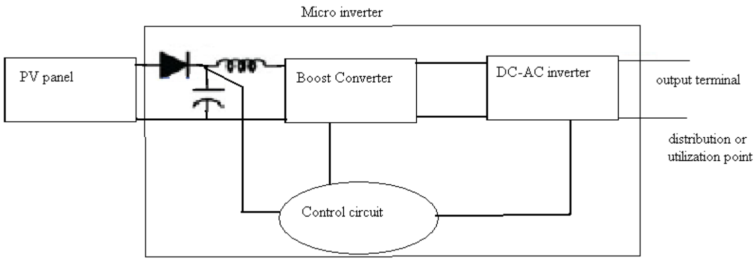

Fig 1. Conventional block diagram

During the installation of PV panel generation system during day light, for safety reason the AC module outputs zero voltage [4], [5]. While installing the ac module, the potential difference could pose hazards to both the worker and the facilities. A floating active switch is designed to isolate the DC from the PV panel, for when the AC module is off grid as well as non operating condition. This isolation ensures the operation of the internal components without any residential energy being transferred to the terminals, which could be unsafe. Use of active clamp technique not only recycles the leakage inductor energy but also it constraints the voltage stress across the switch. This means the coupled inductor employed in voltage liter or voltage multiplier technique in a circuit.

The DC-DC converter requires a large step-up voltage conversion from low voltage obtained from the panel low voltage to the required voltage level for the application. In the previous research on various converters for high step-up applications has included analyses of the switched – capacitor type [6], [7], [8], [9], [29]; the voltage-lift type [12]; the capacitor-diode voltage multiplier [13]; and the boost type integrated with coupled inductor [10], [11], these converters by increasing turns ratio of coupled inductor obtain higher voltage gain than conventional boost converter. Some converters successfully combined boost and flyback converters, some converters, since various converter combinations are developed to carryout high step up voltage gain by using the coupled-inductor technique [14]-[19], [27], [28]. The efficiency and voltage gain of the DC-DC boost converter are constrained by either switches or the reverse recovery issues of the diodes.

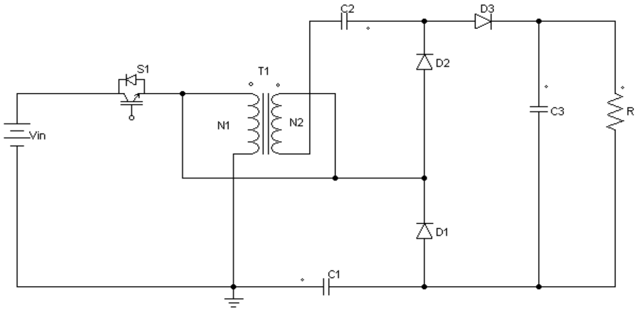

Fig.2. Circuit configuration of proposed converter

The proposed converter is shown in figure.2. It consists of coupled inductor $T_1$with floating active switch S_1. The primary winding N_1 of a coupled inductor T_1 is similar to the input inductor of the conventional boost converter and capacitor C_1 and diode D_1 receive leakage inductor energy from N_1. The secondary winding N_2 of Coupled inductor T_1 is connected with another pair of capacitor C_2 and diode D_2, which are in series with N_1 in order to further enlarge the boost voltage. The diode D_3 is a diode rectifier which is connected to the output capacitor C_3 and load.

II. Operating Principles Of The Proposed Converter

In order to analysis the circuit of the proposed converter, the following assumptions are made.

1) All the components are ideal expect for the leakage inductance of coupled inductor T_1.
2) The on-state resistance $R_{DS(on)}$ and all the snubber capacitance of S_1 are neglected.
3) The capacitors $C1$˜ $C3$ are sufficiently large that the voltages across them are considered to be constant.
4) The ESR of capacitors $C1$ ˜ $C3$ and the parasitic resistance of coupled inductor $T1$ are neglected.
5) The turn ratio n of the coupled inductor $T1$ windings is equal to $N2$ /$N1$.

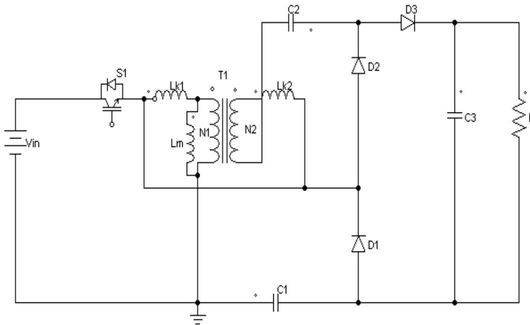

Fig.3. Polarity definitions of voltage and current in proposed converter.

The designed converter can be worked in two modes of operation, they are

i) Continuous conduction mode
ii) Discontinuous conduction mode.
iii)

2.1. Continuous Conduction Mode Operation (CCM)

In the continuous conduction mode there are many transition intervals will takes place. Initially whenever the supply is applied and made the switch S_1 to turned ON, then the magnetizing inductor L_m continuously charges capacitor C_2 through coupled inductor T_1. The current i_{Lm} is continuously decreases because the source voltage V_{in} crosses the magnetizing inductor L_m and primary leakage inductor L_{k1} during this time the i_{D2} and i_{c2} are decreasing. Once the leakage current equals the decreasing i_{Lm}, then the V_{in} is series connected with N_2, C_1 and C_2 to charges the output capacitor C_3 and load R. The rectifier diode D_3 is conducting but diode D_2 will not conduct. The i_{Lm}, i_{Lk1}, and i_{d3} are increasing because the V_{in} is crossing L_{k1}, L_m and primary winding N_1. The discharging current $|i_{c1}|$ and $|i_{c2}|$ are increasing.

When the switch S_1 is made off, instantly the energy stored in the inductor L_{k1} will flows through the diode D_1 to charge the capacitor C_1 meanwhile the energy stored in the leakage inductor L_{k2} is series connected with C_2 to charge the capacitor C_3 and the load R. L_{k1} and L_{k2} are far smaller than L_m due to this the i_{Lm} is increasing with energy receiving from i_{Lk1} and i_{Lk2} decreases rapidly to zero. Once i_{Lk2} reaches the zero, the L_m

released its energy to C_1 and C_2. Simultaneously diodes D_1 and D_2 are conducting. The energy stored in the capacitor C_3 is constantly discharged to the load R. This process will continue for each turn on and turn off Switch $S_{1.}$

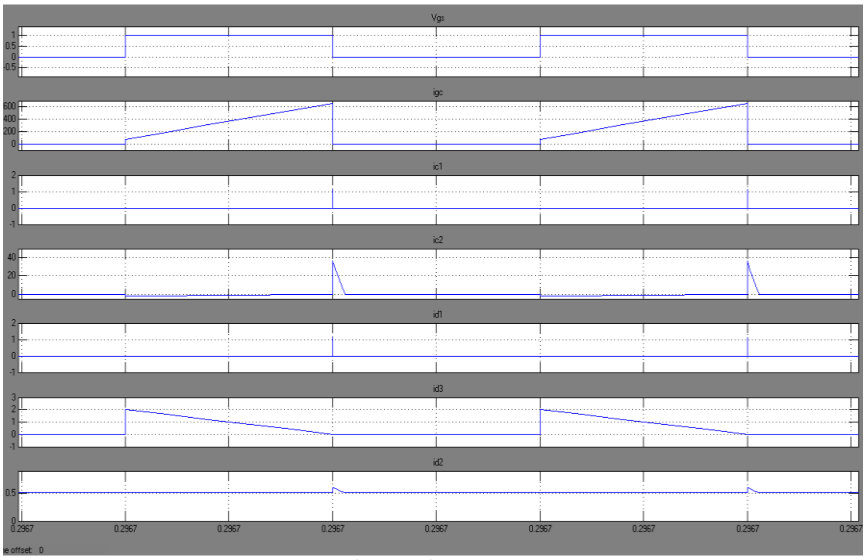

Fig.4. current wave forms of proposed converter at CCM

2.2. Dis-Continuous Conduction Mode Operation

In the discontinuous mode there are many transition intervals will takes place. Initially when the switch S_1 is made ON with input source V_{in}. The inV0put source V_{in} is series connected with N_2, C_1 and C_2 to charge the output capacitor C_3 and load R. Meanwhile L_m is also receiving energy from V_{in}. The $i_{Lm,}$ i_{Lk1} and i_{D3} are increasing because the V_{in} is increasing L_{k1}, L_m and primary winding N_1. The discharging current $|i_{c1}|$ and $|i_{c2}|$ are increasing.

When the switch S_2 made off then instantly the energy stored in the leakage inductor L_{k1} flows through diode D_1 to charge the capacitor C_1. $|i_{c1}|$ and $|i_{c2}|$ increases and current through i_{D3} also increase. Then the current $i_{lk1}$and i_{D1} are continuously decreased because the leakage energy flows through D_1 keeps charging a capacitor C_1. The energy stored in capacitor C_3 is constantly discharged to the load R. These energy transfers results in decrease in i_{Lk1} and i_{Lm} but increases in i_{Lk2}. L_m only constantly releasing its energy to C_2 and only Diode D_2 is conducting. The i_{Lm} is decreasing due to the magnetizing inductor energy flowing through the coupled inductor T_1 to secondary winding N_2 and D_2 continuous to charge capacitor C_2. The energy stored in capacitor C_2 is continued to be discharge to the load. This process will continue for each turn on and turn off Switch S_1.

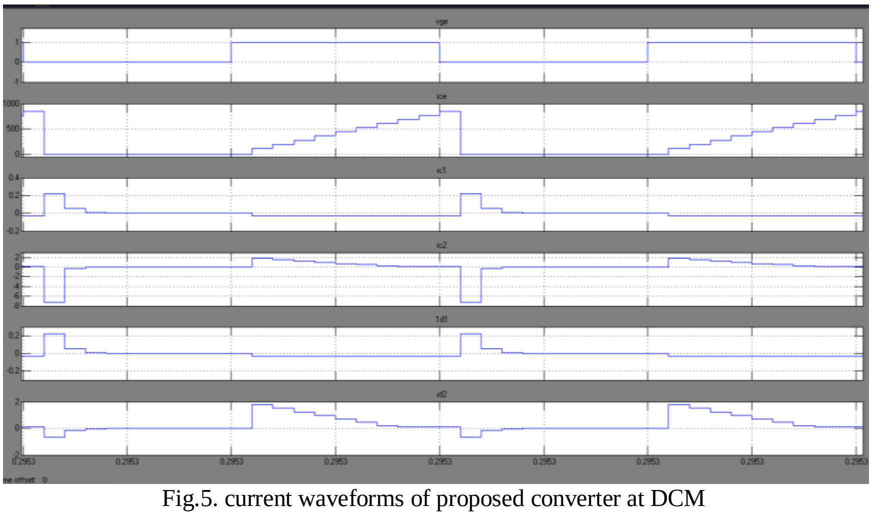

Fig.5. current waveforms of proposed converter at DCM

III. Analysis Of Proposed Converter

3.1. CCM Operation

For the steady state analysis of converter the two switching instants are considered, S_1 ON and OFF instants.

During S_1 ON

$V_{Lm}=V_{in}$

$V_{N2}=nV_{in}$

During S_1 OFF

$V_{Lm}=-V_{c1}$

$V_{N2}=-V_{c2}.$

The voltage across C_1 and C_2 are obtained as

$V_{c1}=(D|1-D)V_{in}$

$V_{c2}=(nD|1-D)V_{in}$

The output voltage of the converter during switch S_1 on is given by

$V_0=V_{in}+V_{N2}+V_{C2}+V_{C1};$

$V_0=V_{in}+nV_{in}+(nD|1-D)V_{in}+(D|1-D)V_{in}$

$MCCM=V_0/V_{in}=(1+n|1-D)$

3.2. DCM Operation

For the steady state analysis of the converter at two switching instants are considered, S_1 ON and OFF instants.

During S_1 ON

$V_{Lm}=V_{in}$

$V_{N2}=nV_{in}$

During S_1 OFF

$V_{Lm}=-V_{c1}$

$-V_{N2}=V_{c2}$

The voltage across C_1 and C_2 are

$V_{c1}=(D|DL)V_{in}$

$V_{c2}=(nD|DL)V_{in}$

$(V0|vin)=((n+1)|(D+DL))/D_L$

IV. Simulation Results

The designed high step-up DC-DC converter consists of single active switch, which acts as high state drive. It also contains the coupled inductor, 2diodes and 2capacitors used to step-up the voltage level and it also recycles the leakage energy. One diode is used as rectifier diode.

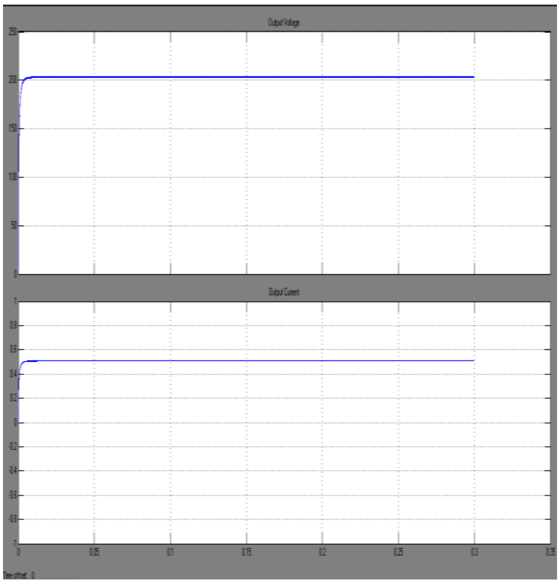

Fig.6. output voltage and current waveform at CCM

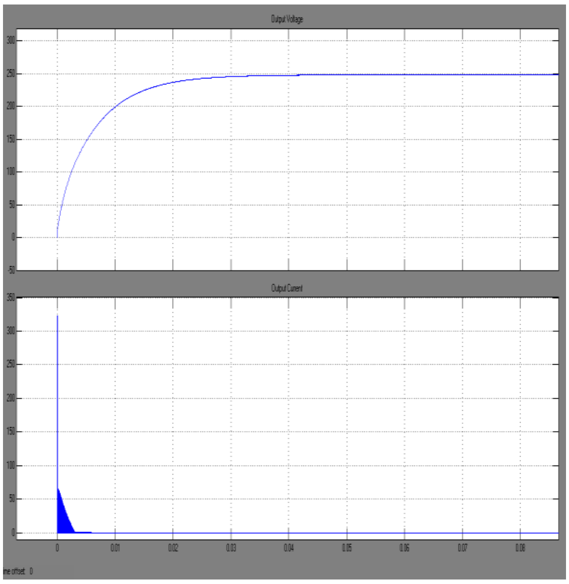

Fig.7. output voltage and current waveform at DCM

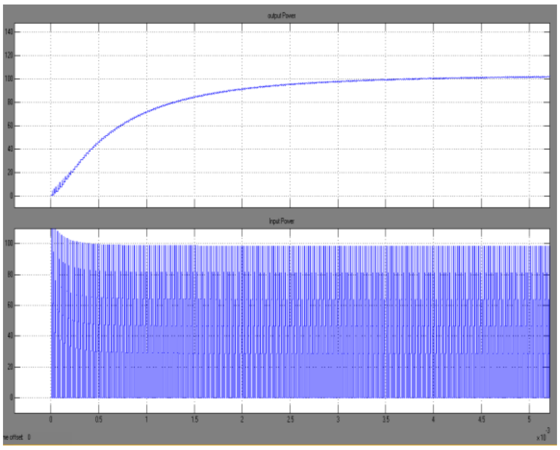

Fig.8. output and input power of proposed converter

MODE	Parameter	Input	Output
CCM	Voltage(peak to peak)	15 v	203 V
	Current(Peak to Peak)	6.5 A	0.5 A
	Power(Peak to Peak)	99W	97W
DCM	Voltage(peak to peak)	15 V	250 V
	Current(Peak to Peak)	1.5A	0.5 A

Table.1. Input and output from simulation

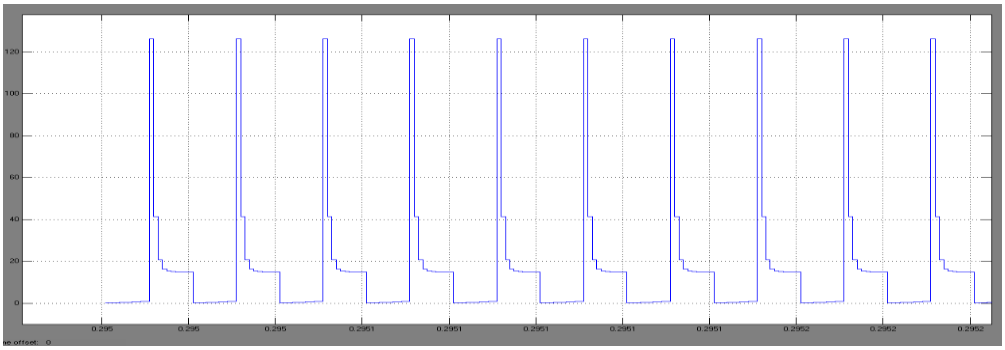

Fig.9.Voltage stress across the switch

These are the various results obtained from the proposed converter with the electrical specifications of the circuit components with an applied voltage V_{in}=15V, f_s=50kHz, and full load resistance of R=400Ω. The major components with the values of $C_1=C_2$=47µF and C_3=220µF, the switch used for the simulation is IGBT, for recycling and rectifying diodes are used. The turns ration of the mutual inductor is assumed to be n=5, and the duty ratio D is derived as 50%. The magnetizing inductor of the coupled inductor L_m >30.54 for the full load. The maximum full load efficiency of the proposed converter at continuous conduction mode is given by 97%, this will be better than conventional converter. The proposed converter shows the wide range of efficiency.

V. Conclusion

The energy of leakage inductor's has been effectively recycled and the voltage stress across the switch is constrained. The switch here acts as an high state drive and also it protects panel and installers from the electrical hazardous while the switch is in off state. The switching action is performed well by floating active switch during the system operation at all the condition with eliminating the residential energy effectively during non operating condition. Without an extreme duty ratio and with an numerous turns ratio the proposed converter achieved high voltage step-up gain. Thus improvements to the efficiency of the proposed converter have achieved.

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