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PV FED STEP-UP DC-DC CONVERTER BASED ON THREE WINDING COUPLED INDUCTOR

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***Abstract*-The main objective of this paper is to design and implement a novel converter topology using voltage multiplier module for photovoltaic system. The converter makes use of coupled inductor and voltage multiplier cell to reach the desired high step-up voltage gain. The main advantages of the proposed converter are simple topology, high step-up voltage gain, continuous input current, recycling the energy of the leakage inductance of the coupled inductor, and utilizing only one active switch with reduced voltage stress. Reduced switch voltage stress results in selection of switch with low on-resistance which improves the efficiency. Operational principles of the converterin steady state are studied and an analytical approach is used to attain voltage gain and switch voltage stress. Some of the determinant factors are compared with similar coupled inductor converters. Finally appropriate performance of the proposed topology is verified by simulating a 30V/400V, 750W converter. Also a bidirectional inverter is implemented to maintain the DC grid voltage.**

***Keywords*-DC-DC boost converter; high step-up;coupledinductor;highvoltageconversionratio; bidirectional inverter; maximum power point(MPP).**

I . INTRODUCTION

At the threshold of opportunity to grow ,India has expanded its role in PV adoption and manufacturing. Recently the use of step-up DC-DC converters withhighvoltage ratio has been increased. That is due to thegrowingusageofthistypeofconvertersina widerangeofapplicationssuch as fuel cell stacks (FC), photovoltaic (PV)cells,uninterruptable power supplies (UPS), etc. [1]-[4]. The major problems of PV system is that the output voltage of PV panels is highly dependent on solar irradiance and ambient temperature. Unfortunately,once there is a partial shadow on some panels, the systems energy yields becomes significantly reduced[5]. Hence loads cannot be connected directly to the output PV panels.Inthesesorts of applications high step-up converters are usedtoconvert the low level varying primary voltage to thedesiredregulatedhighvoltageoutput.

The main drawbacks of PV energy is the high cost of silicon solar panels and low conversion efficiency. Some latest technologies like the use of crystalline panels and effective power converter design, it is possible to make a PV project cost effective. Also the conversion of the output voltage from a solar panel into usable DC or AC voltage can be done at its maximumpower point, or MPP. MPP is the PV output voltage at which the module delivers maximum energy to load.

To practically achieve high voltage

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conversion ratiosseveral topologies for high step-up boost converters hasbeenproposed [6]. One of the interesting types of these convertersisswitched capacitor converters [7] - [9]. Theseconverterspossess the advantage of having low size andweight.However, the drawbacks are high number of switchesandcapacitors,highcurrentstressan dcomplexityofcontrol.

Utilizing three state switching cells (3SSC) is anotherwaytoreachthehighvoltagegainwhic hisspeciallyusedinpowerfactor correction (PFC) applications [10], [11]. Reducingsizeand weight is one of the main advantages in theseconverters.Also in this kind of converters low current of switchesresultsin lower cost. However in each operation state currentpassesthrough four semiconductor devices which resultsinefficiencyreduction.One of the main strategies to achieve high step-upvoltageratio is to utilize voltage multiplier cells inconventionalconverters. But the step-up ratio reached in this method isnotenough. So to get to the desired ratio one shouldutilizemultiplecells,whichincreasest hecomplexityandoverallcostoftheconverter [12].

The high step up converter is connected from the PV supply to the DC grid. After the DC load gets the high amount of voltage from the step up converter, a bidirectional inverter converts DC voltage into AC voltage given to the AC load.

If there is no energy from the PV module due to the weather conditions, the bidirectional inverter acts as the rectifier which gets the source from the AC source and rectifier which converts AC voltage into DC voltage and to maintain the DC grid voltage.

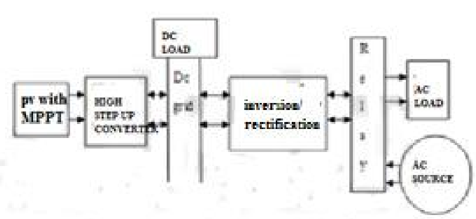

Fig. 1: Proposed System Block Diagram.

Figure 1 shows the block diagram of proposed system. In this paper the simulation and analysis of a highly efficient step-up converter for photovoltaic application is performed.

II.CIRCUIT CONFIGURATION AND OPERATION PRINCIPLE OF CONVERTER

The proposed topology is used to obtain step-up voltage gain using low voltage diodes and capacitors. The circuit configuration is shown below as figure 2.

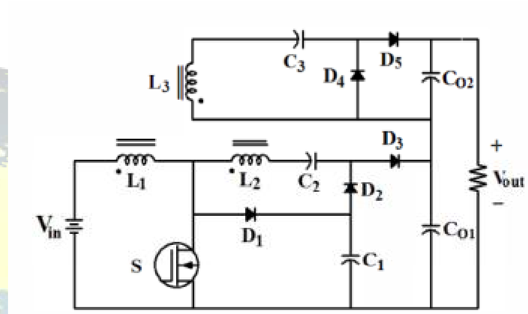

Fig 2:Circuit configuration of proposed system

The operation principles for the continuous conduction mode (CCM) are explained in this section. The coupled inductor can be modelled by an ideal transformer with primary winding N_1 two secondary windings i.e. N_2 and N_3, a magnetizing inductance L_m and a leakage inductance l_k. Operation of the converter is divided into four intervals and is discussed hereafter. Circuit topology in each interval and the current-flow paths are illustrated in Fig. 3.

Interval 1 [t_0-t_1]: This interval begins with turning the switch S on. In this interval which is shown in Fig. 2(a) the voltage across the magnetizing and leakage inductances equals V_{in}. Thus the current in Lm is increasing linearly. This interval is reverse recovery mode of the two diodes D_3 and D_5 and lasts until their currents reaches zero and they stop conducting. In this interval both of the output capacitors C_{o1} and C_{O2} are discharging their energy to the load. This mode is ended at $t=t_1$.

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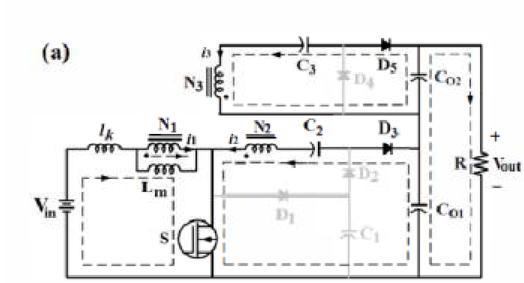
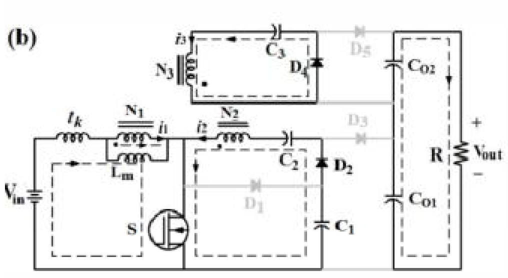
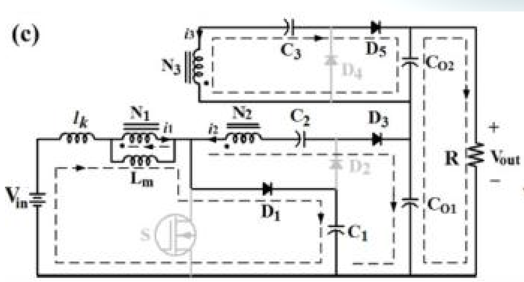




Interval 2 [t_1-t_2]: This interval begins when reverse recovery process of diodes D_3 and D_5 is ended. Unlike the former interval this interval is the main conduction interval when S is on. Due to conduction of the switch S energy of the input voltage source Vin is supplied to magnetizing inductance resulting in linear increase of the L_m current. Diodes D_2 and D_4 are conducting from the beginning of this interval. Thus the energy stored in capacitor C_1, which is the energy of the leakage inductance of the coupled inductor, recycles into the circuit. The load is isolated from input source and the output capacitors are supplying the load. This interval lasts until the switch S is turned off at t=t_2, Fig. 2(b) shows the current-flow path of this mode of operation.



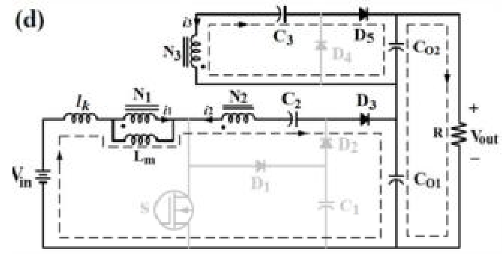


Fig. 3. Circuit topology and current paths in each operation interval (a) Interval I, (b) Interval 2, (c) Interval 3, (d) Interval 4.

Interval 3 [t_2-t_3]: This interval begins by turning switch S off. Input current, which is equal to leakage inductance current, charges the parasitic capacitor of the switch and builds up its voltage. Thus diode D_1 conducts and the energy of the leakage inductance is stored in capacitor C_1 to avoidoccurrence of high voltage spikes on power switch. Voltage of the magnetizing inductor is negative and its current is reducing. Output capacitors C_{O1} and C_{O2} are charging from input source. This interval lasts till C_I absorbs the energy of the leakage inductance. After that the input current equals thesecondary current i_2 and D_1 is reverse biased and turned off in zero current. The circuit topology and path of current are shown in Fig. 2. This mode end at t=t_3.

Interval 4 [t_3-t_4]: In this interval the switch S is stillturned off. Magnetizing inductor current is reducing. DiodesD_3 and D_5 are still conducting and feeding load and outputcapacitors. The input current is equal to secondary current i_2•The input source, primary and secondary windings of thecoupled inductor (N_1 and N_2) and capacitor C_2 are connectedin series to charge the output capacitor through diode D_3•Finally when the switch S is turned on this interval is endedand Interval 1 of the next switching cycle begins. The currentflowpath of this interval is illustrated in Fig. 2(d).

III. STEADY TATE ANALYSIS OF THE PROPOSED CONVERTER

Voltage gain of the proposed boost converter can be calculated in this section. For the simplicity of the analysis, the leakage inductance of the coupled inductorcan be neglected. Allcapacitors are of high values, so their voltages can be considered constant. From Fig. 1 the overall output

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voltage of the converter is the sum of the voltages across output capacitors C_{OI} and C_{O2}.

$$V_{out} = V_{c01} + V_{c02} \quad (1)$$

Applying Kirchhoff's law across magnetizing inductance L_m in switched conduction interval DT_s we get

$$V_{Lm}(DT_s) + n_{21} V_{Lm}(DT_s) = V_{in} + V_{c2} - V_{c1} \quad (2)$$

During OFF state the expression becomes

$$V_{Lm}(D'T_s) + n_{21} V_{Lm}(D'T_s) = V_{in} - V_{c01} + V_{c2} \quad (3)$$

Using Kirchhoff's law in fig 2(b) and fig 2(c) voltage across C_1 and C_2 becomes ;

$$V_{C1} = \frac{V_{C01} - V_{IN} - V_{C2}}{1+n_{21}} + V_{in} \quad (4)$$

$$V_{C2} = V_{C1} + n_{21} V_{in} \quad (5)$$

Solving equation (4) we get

$$V_{C1} = \frac{V_{C01}}{2+n_{21}} = V_{DS} \quad (6)$$

Where V_{DS} is the switch off voltage of the active switch S.

$$V_{C2} = \frac{V_{C01}}{2+n_{21}} + n_{21} V_{in} \quad (7)$$

Substituting V_{C1} and V_{C2} from (6) and (7) in (2) and (3) and also taking volt-second balance for magnetizing inductance ;

$$\langle V_{Lm}\rangle_{TS} = DT_S V_{Lm}(DT_S) + D'T_S V_{Lm}(D'T_S) = 0 \quad (8)$$

Where $\langle V_{Lm}\rangle_{TS}$ is the average value of the magnetizing inductance voltage in one switching period.

$$\therefore \quad V_{C01} = \frac{2+n_{21}}{1-D} V_{in} \quad (9)$$

Now for calculating V_{CO2} consider switching conduction interval DT_S ; here V_{C3} can be calculated as

$$V_{C3} = V_3 = n_{31} V_{Lm}(DT_S) = n_{31} V_{in} \quad (10)$$

Where V_3 is the voltage at the secondary winding n_3 . Using KCL in OFF interval $D'T_S$, V_{C02} can be calculated as given

$$V_{C02} = -V_3 (D'T_S) - V_{C3} \quad (11)$$

$$= -n_{31} V_{Lm}(DT_S) - V_{C3} \quad (12)$$

From figure 3(d) using (9) $V_{Lm}(D'T_S)$ is obtained as

$$V_{Lm}(D'T_S) = -V_{in} \frac{D}{1-D} \quad (13)$$

Finally from the equations the overall voltage of the proposed converter in continuous conduction mode (CCM) can be expressed as

$$M_{CCM} = \frac{V_{OUT}}{V_{IN}} = \frac{n_{31} + n_{21} + 2}{1-D} \quad (14)$$

[NB :- The turns ratio of the coupled inductor are considered as 2 in the converter]

III. DESIGN OF PV PANEL WITH MPPT

The harnessing of solar energy using PV module comes with its own insulation problems which indirectly effects the efficiency and output power of the PV module . a great deal of research has been undergone to improve the efficiency of PV modules. A number of methods of how to track maximum power point of a PV module have been proposed to solve the problem of efficiency. First method is to determine the electrical behavior of the PV module with respect to change in environmental parameter ie; insolation , keeping the cell temperature constant . When this generalized photovoltaic module is used ,due to mismatch between loadline and operating characteristics of the solar cells, the power available from solar cells is not always fully extracted [13].A MPPT is used for extracting maximum power from the solar PV module and transferring that power to the load . The step up converter serves the purpose of transferring maximum power from the solar PV module to the load.by changing the duty cycle, the load impedance as seen from the is varied and matched at the point of peak power with the source so as to transfer the maximum power .

Maximum power point tracking (MPPT) is a control technique to adjust the terminal voltage of PV panels so that maximum power can be extracted. MPPT's find and maintain operation at

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the maximum power point, using an MPPT algorithm. Many algorithms has been derived among which one particular algorithm is selected here due to its simplicity of operation ; the perturb-and-observe (P&O) method [14]- [15]. This is essentially a trial and error method . Figure 4 shows the program flow chart for P&O method. This method is also highly reliable and efficiently trackable [16].

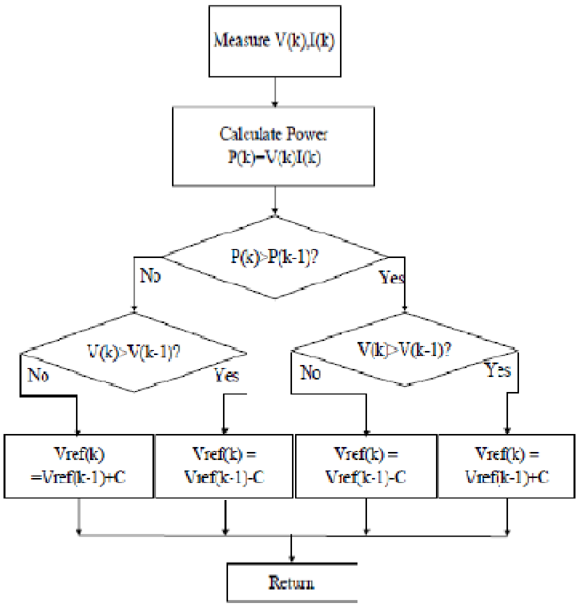


Fig 4: P&O method flow chart

IV. SIMULATION RESULTS AND ANALYSIS

In order to verify the performance of the proposed converter and theoretical analysis, a 30V/400V case issimulated in MATLAB. Maximum output power and operating frequency of the simulated converter are 750W and 100 kHz respectively. Other specifications and parameters used for the simulation are,input voltage of 30V, three winding coupled inductor and voltage multiplier consisting of 5 diodes and 5 capacitors used to step up the voltage level and it also recycles the leakage enegy.

A .PARAMETER SELECTION

The parameters used for simulation are input voltage 30V, output voltage 400V. The active switch is a MOSFET. Since turns ratio assigned is n = 2, the duty ratio D derived as 55%.

Switching frequency = 50KHz

Full-load resistance, R = 1000 Ω

$C_1 = C_{01} = C_{02} = 22\mu F$

C2 = 10µF

C3 = 47 µF

Steady state simulation results are given in Fig. 5. The input voltage is 30V so the voltage gain is about 13.4.

B .SIMULATION RESULTS&WAVEFORMS

MATLAB/Simulink model of the converter with PV panel is shown in figure 5. And with PV panel and MPPT is shown in figure 6& 7. The switch used for simulation is MOSFET. The output voltage obtained is 400V for an input of 30V.

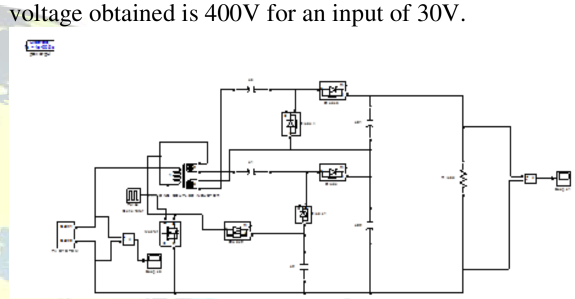


Fig 5:MATLAB/Simulation model of the converter with generalized PV panel

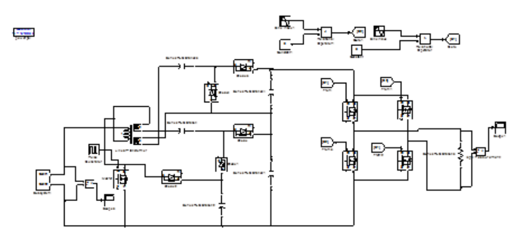


Fig 6: MATLAB/Simulation model of the converter with PV & MPPT

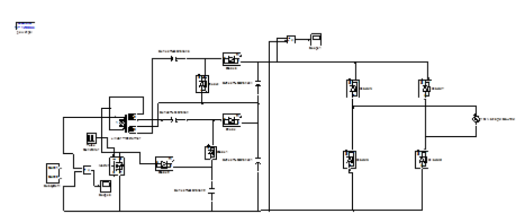


Fig 6: MATLAB/Simulation model of the system connected through rectifier to DC load.

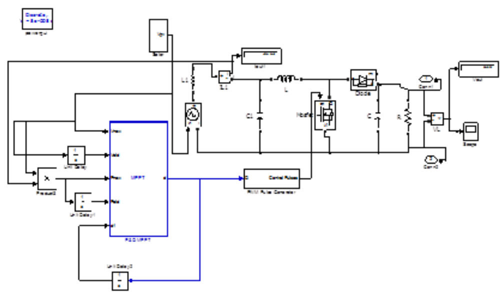
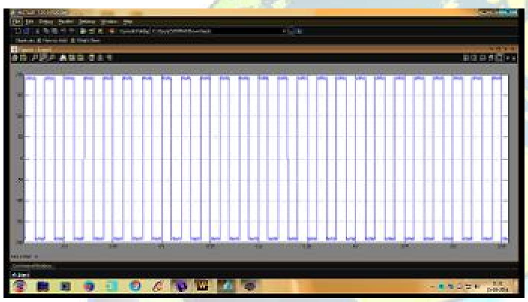
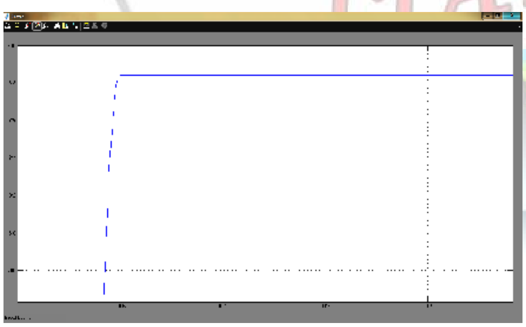


Fig 8: MATLAB/Simulink model of MPPT by P& O method

The waveforms obtained during simulation is given below in figure 9.



(a) AC output waveform at 30V input voltage with full load condition



(b) DC output waveform rectified from AC source for DC load

Fig 9: (a), & (b) shows the waveforms of the proposed system

V. CONCLUSION

In this paper a novel topology for high step-up DC-DC converters is presented. It is based on coupled inductor and diode-capacitor voltage multiplier cells. Principles and steady state analysis of the proposed converter in CCM is discussed. Simplicity of control and implementation due to utilizing only one active switch is on of the advantages of the proposed topology. Recycling theenergy of the leakage inductance of the coupled inductor leads to an improved efficiency. Reduction of voltage stress for active switch results in use of switch with low on-resistance which leads to further increase in the overall efficiency. The proposed converter can be generalized for achieving more step-up voltage gain using low voltage diodes and capacitors.

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