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Grid Connected Photovoltaic System using High Gain DC-DC Converter with Voltage Multiplier Circuit

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***Abstract*—In this paper, a high step – up converter which is suitable for renewable energy system connected to grid is proposed. Conventional step – up converters required for grid application cannot achieve high step – up conversion with high efficiency because of the resistances of elements or leakage inductance. The proposed converter is a conventional interleaved boost converter with voltage multiplier module which not only reduces the current stress but also constrains the input current ripple which decreases the conduction losses and lengthens the lifetime of the input sources.**

***Index Terms*— high step-up; photovoltaic (PV) system; voltage multiplier module.**

I. INTRODUCTION

Nowadays, renewable energy is increasingly valued and employed worldwide because of energy shortage and environmental contamination [1]-[3]. 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 [4]-[6].Such systems transforms low voltage to high voltage via step up converter and produce ac using grid tie inverter. Fig 1 shows a typical renewable energy system that consists of renewable energy sources, a step-up converter, and an inverter for ac application. Output of renewable resources are very low, in order to achieve grid application a very high input is required for the inverter. This can be achieved by using power electronics converters. In order to achieve high step up conversion, it may require two-stage converters with cascade structure for enough step-up gain, which decreases the efficiency and increases the cost. Thus, a high step-up converter is seen as an important stage in the system because such a system requires a sufficiently high step-up conversion with high efficiency.

Conventional converters like boost converter has limited step up gain and voltage stress across the switch is same as that of the output voltage. Despite these advances, high step-up single-switch converters are unsuitable to operate at heavy load given a large input current ripple, which increases conduction losses. The conventional interleaved boost converter is an excellent candidate for high-power applications and power factor correction. Unfortunately, the step-up gain is limited, and the voltage stresses on semiconductor components are equal to output voltage. Hence, based on the aforementioned considerations, modifying a conventional interleaved boost converter for high step-up and high-power application is a suitable approach.

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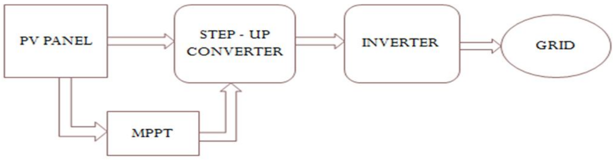

Fig.1.Block diagram of photovoltaic system connected to grid

The proposed converter is a conventional interleaved boost Converter integrated with a voltage multiplier module, and the voltage multiplier module is composed of switched capacitors and coupled inductors. The coupled inductors can be designed to extend step-up gain, and the switched capacitors offer extra voltage conversion ratio which is required for grid application. In proposed scheme, PV array is tied with grid through Single phase Voltage source Inverter (VSI). High gain dc-dc converter is placed between PV array and inverter. The maximum power in PV array is tracked using incremental conductance based MPPT controller. The MPPT controller controls duty cycle of the converter. PLL is used to get the phase and frequency information of grid voltage.

II. SYSTEM DESCRIPTION

A. Modeling of PV panel

By connecting the PV cells in series and parallel can produce desired output power. PV panel is modeled with the help of design equations. The terminal equation for the current and voltage of the array is given by

$$I = NpIph - NpIs[\exp(\frac{q(\frac{V}{Ns}+\frac{IRs}{Np})}{KTcA})-1]-\frac{\frac{NpV}{Ns}+IRs}{Rsh}$$

Np and Ns are no of parallel and series cells. Iph is the photocurrent ,Is is the cell saturation current, q is an electron charge and Tc is the working temperature, A is an ideal factor, Rsh is a shunt resistance and Rs is a series resistance of solar cell.

$$Iph = [Isc + Ki(Tc - Tref)]\ H$$

Where,
Isc is the short circuit current, Ki is the short circuit current temperature coefficient, Tref cell reference temperature and His the solar insolation in KW/m^2
Cell’s saturation current varies with the cell temperature which is given by

$$Is = IRs\ (Tc/Tref)^3 \exp[qEG(Tc - Tref)/TrefTckA$$

IRS is the cell’s reverse saturation current at a reference temperature and standard solar radiation. EG is the band gap energy of the semiconductor used in the cell.

B. Incremental conductance for MPPT

Incremental conductance Algorithm for mppt is used to track the maximum power Point (mpp) of the photovoltaic panels, and generate the control signal for the high gain dc- dc converter. The algorithm compares the actual conductance – Ipv/Vpv and the incremental conductance $dIpv/dVpv$ [7].

$$\text{If}\quad dIpv/dVpv. > -Ipv/Vpv$$

Then the operating point is on the left of the MPP so, α is varied to increase *Vpv*

$$\text{If}\quad dIpv/dVpv. < -Ipv/Vpv$$

Then the operating point is on the right of the MPP, so α is varied to decrease *Vpv*

$$\text{If } dIpv/\, dVpv. = -\, Ipv/\, Vpv$$

Then the operating point is in the MPP, so, the value of α is maintained.
Where *dIpv* and *dVpv* are the PV current and voltage variations, respectively. Thus, the duty cycle α, used to generate the PWM signal for the MOSFET switching.

III. HIGH STEP-UP INTERLEAVED CONVERTER WITH A VOLTAGE MULTIPLIER MODULE

A. High gain dc – dc converter

The proposed high step-up interleaved converter with a voltage multiplier module is shown in Fig. 2. The voltage multiplier module is composed of two coupled inductors and two switched capacitors and is inserted between a conventional interleaved boost converter to form a modified boost–flyback–forward interleaved structure. When the switches turn off by turn, the phase whose switch is in OFF state performs as a fly back converter, and the other phase whose switch is in ON state performs as a forward converter. Primary windings of the coupled inductors with *Np* turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with *Ns* turns are connected in series to extend voltage gain. The turn ratios of the coupled inductors are the same.
The equivalent circuit of the proposed converter is shown in Figure 3, where Lm1 and Lm2 are the magnetizing inductors, Lk1 and Lk2 represent the leakage inductors, S1 and S2 denote the power switches, Cb is the voltage-lift capacitor, and n is defined as a turns ratio Ns/Np. The duty cycles of the power switches during steady operation are interleaved with an 180^0 phase shift and the key steady waveforms in one switching period of the converter contain six modes.

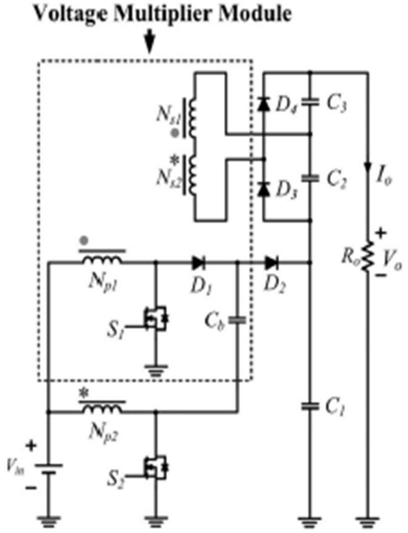

Fig. 2. Proposed high step-up converter

B. Model Analysis

Operation of the converter can be explained in six modes. Steady state waveform is given in Fig 4.
Mode 1 [t_0, t_1]: At t= t_0, the power switches S_1 and S_2 are both turned ON. All the diodes are reversed-biased. Magnetizing inductors L_{m1} and L_{m2} as well as leakage inductors L_{k1} and L_{k2} are linearly charged by the input voltage source V_{in}.
Mode 2 [t_1, t_2]: At t= t_1, the power switch S_2 is switched OFF, thereby turning ON diodes D_2 and D_4. The energy that magnetizing inductor L_{m2} has stored is transferred to the secondary side charging the output filter capacitor C_3. The input voltage source, magnetizing inductor L_{m2}, leakage inductor L_{k2}, and voltage-lift capacitor Cb release energy to the output filter capacitor C_1 via diode D_2, thereby extends the voltage on C_1.

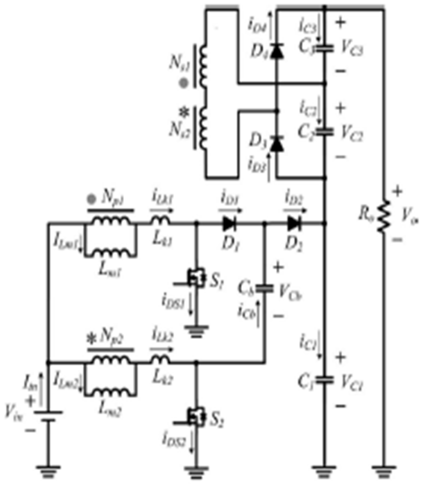

Figure 3: Equivalent Circuit

Mode 3 [t_2, t_3]: At t= t_2, diode D_2 automatically switches OFF because the total energy of leakage inductor L_{k2} has been completely released to the output filter capacitor C_1. Magnetizing inductor L_{m2} transfers energy to the secondary side, charging the output filter capacitor C_3 via diode D_4 until t_3.

Mode 4 [t_3, t_4]: At t= t_3, the power switch S_2 is switched ON and all the diodes are turned OFF. The operating states of modes 1 and 4 are similar.

Mode 5 [t_4, t_5]: At t= t_4, the power switch S_1 is switched OFF, which turns ON diodes D_1 and D_3. The energy stored in magnetizing inductor L_{m1} is transferred to the secondary side charging the output filter capacitor C_2. The input voltage source and magnetizing inductor L_{m1} release energy to voltage-lift capacitor Cb via diode D_1, which stores extra energy in Cb.

Mode 6 [t_5, t_0]: At t= t_5, diode D_1 is automatically turned OFF because the total energy of leakage inductor L_{k1} has been completely released to voltage-lift capacitor Cb. Magnetizing inductor L_{m1} transfers energy to the secondary side charging the output filter capacitor C_2 via diode D_3 until t_0.

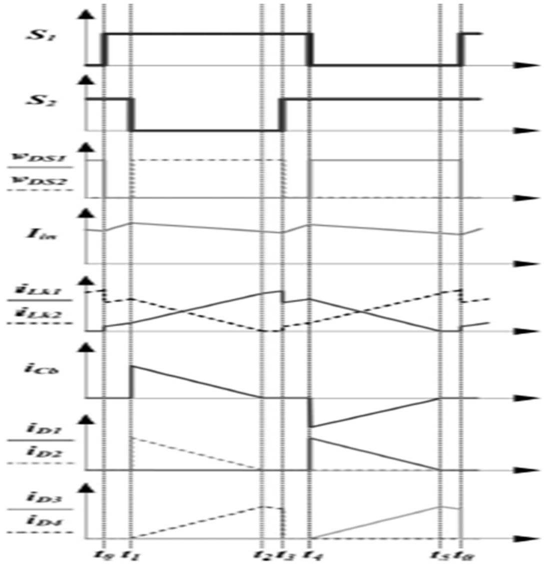

Fig 4 steady state waveform

C. Design

The electrical specifications are Vin = 40 V, Vo = 300 V, and fs = 40 kHz. The major components have been chosen as follows: Magnetizing inductors $Lm1$ and $Lm2$ =133 μH; turn ratio n = 1; capacitors $Cc1$, $Cc2$, $C2$, and $C3$ = 220 μF; and $C1$ = 470 μF. Leakage inductors $Lk1$ and $Lk2$ are 1.6 μH.

IV. SINGLE PHASE DC – AC INVERTER

A full bridge inverter is used to convert DC voltage and current to AC voltage and current. The inverter is controlled by a PWM signal, which in turn controls the inverter switches [8].

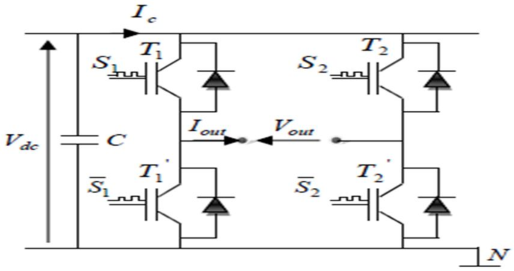

Fig.5 Single-phase full bridge inverter

V. SIMULATION

The system consists of solar panel, converter to step up the output voltage of solar panel, inverter which is connected to single phase grid. Solar panel produces an output voltage of 33.5V which is step up to 300V using high gain dc – dc converter with voltage multiplier circuit. The output dc is converted into ac using single phase inverter.

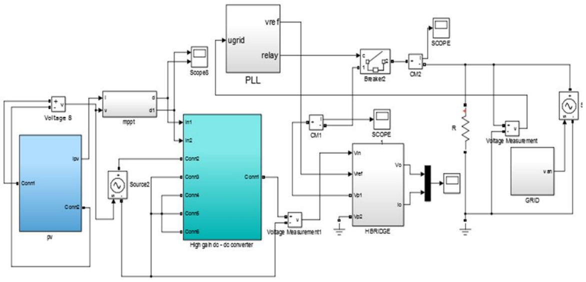

Fig 6. Simulation circuit of full system

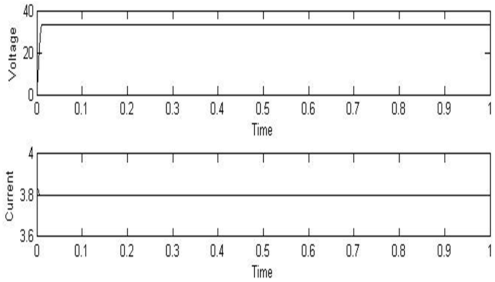

Fig. 7 Solar output voltage and current

Ac is given to the grid through a LCL filter. The grid voltage is sensed and given to the PLL circuit, from there a reference sine wave is produced having frequency same as the grid voltage is given as the reference for SPWM. The generated pulses control the inverter and change the parameter and produce an output which is synchronizing with the grid.

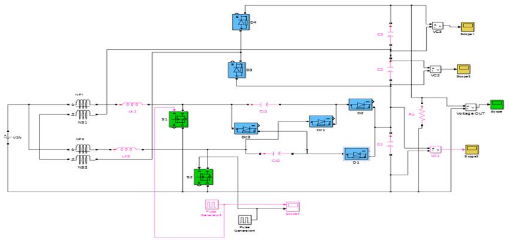

Fig 8. Simulation circuit for high gain dc - dc converter

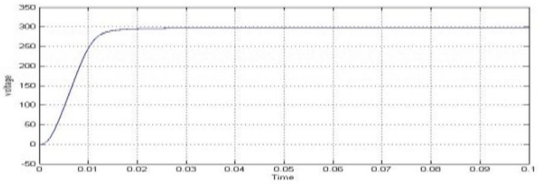

Fig 9. Converter output voltage

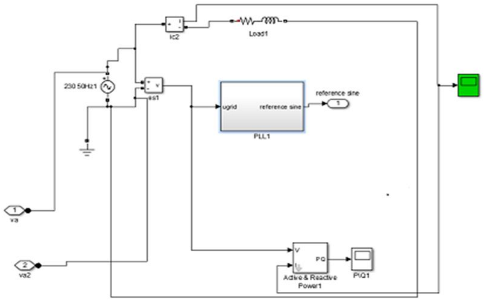

Fig10 Reference sine wave generation

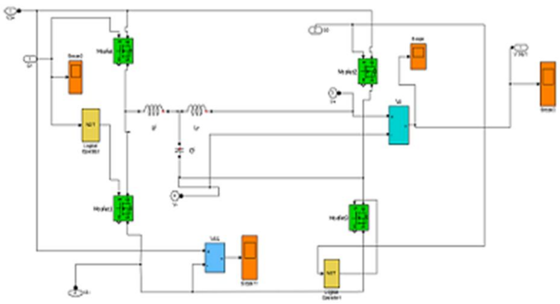

Fig 11 Inverter circuit

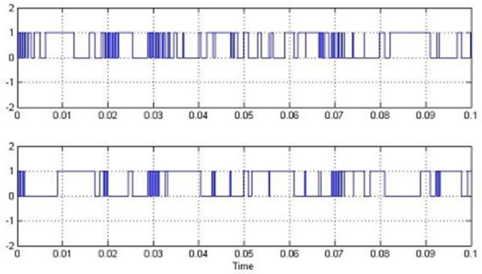

Fig 12 Control pulses for inverter switches

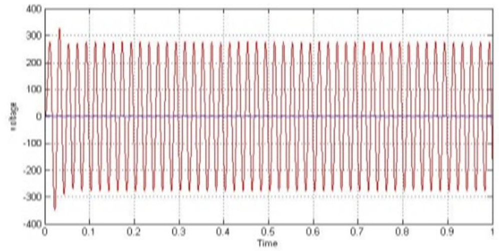

Fig 13 Inverter output voltage

VI. CONCLUSION

The grid connected solar power plant can be done in place where excess solar energy is available. Simulation of photovoltaic system connected to single phase grid using high gain dc-dc converter is presented. By using this converter the duty ratio of power switches and power conversion rate can be maintained in an acceptable range. It shows high conversion rate as compared to conventional boost converter.

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