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A Double Stage Booster for Single Phase Photovoltaic Applications

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***Abstract*— this paper presents a double stage boosting mechanism that can be used in single phase stand-alone as well as grid-connected photovoltaic (PV) applications under low voltage output from photovoltaic (PV) panels. In the first part a basic Maximum Power Point Tracking (MPPT) method is used which ensures the maximum power output from the photovoltaic panel even under varying environmental conditions. The remaining part covers the double stage boosting mechanism. First stage is a boost converter which raises the PV voltage to an optimum level. The final stage is the most important part the push-pull inverter doing the final step of boosting the voltage. It offers too many advantages like natural isolation, less switching losses etc, when compared to normal H-bridge inverter.**

***Index Terms*—Boost converter, Maximum Power point tracker, Photovoltaic panel, Push-pull inverter.**

I. INTRODUCTION

In this era of energy crisis, renewable energy sources like solar energy, wind energy etc are becoming popular day by day. The most technological advancements are introduced in the solar energy sector. This paper also deals with a similar advancement. This paper presents a double stage boosting method that can be implemented in single phase photovoltaic applications under low voltage output from the panel. The initial part of the paper covers the Power-Voltage (P-V) and Current-Voltage (I-V) characteristics of a PV panel. The rest of the paper deals with the double stage boosting strategy for very low output conditions of a PV panel. In the double stage booster, the first stage is a boost converter operated by MPPT controlled PWM. This is followed by an inverter stage which is the most important and the advantageous part of this system. A push-pull inverter performs the final stage of boosting process. When compared to a single phase H-bridge inverter a push-pull inverter offers many advantageous features. Among them is the natural isolation between the input and output stage, elimination of high level switches, less switching losses etc. The strategy presented in this paper can be used both in the stand-alone and grid-connected single phase photovoltaic applications.

II. THE PROPOSED SYSTEM

A. Photovoltaic Panel

Photo voltaic refer to a method of generating electricity from solar energy. A photovoltaic cell is a device used for converting solar radiation into direct current electricity.

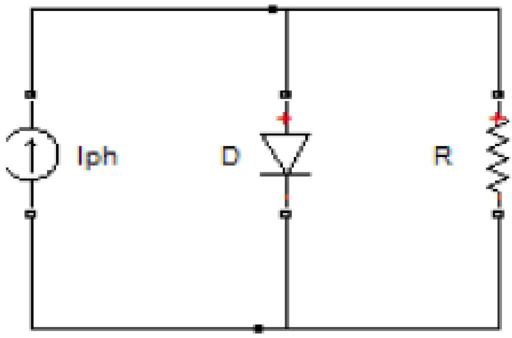

Fig. 1. Single diode model of PV panel.

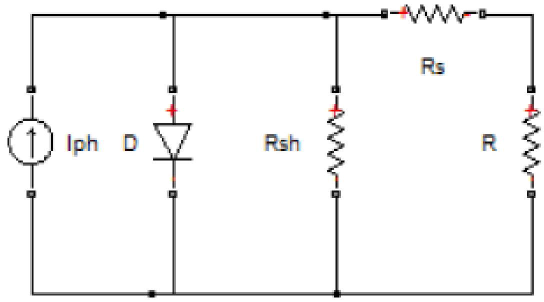

Fig. 2. Single diode model of PV panel with the intrinsic series and shunt resistances included

Here, the paper here uses the single diode model of photovoltaic cell in order to understand its characteristics [1],[2],[3]. The single diode model consists of a current source in parallel with a diode under ideal condition. So, the I-V characteristics under the ideal condition is given by

$$I = I_{Ph} - I_d \quad (1)$$

$$I = I_{Ph} - I_O[(qV/\exp(mkT)) - 1] \quad (2)$$

Where,
I_{Ph}: Generated photon current
I_O: Diode reverse saturation current
I: Output current
q: Electron charge
m: Diode ideality factor
k: Boltzmann constant
T: Cell temperature

In practice, it is necessary to consider the internal resistances of the PV cell i.e., the intrinsic series and shunt resistances represent the losses in PV cell. So now, the output current equation gets modified as below

$$I = I_{Ph} - I_O[\exp(q(V + IR_s)/mkT) - ((V + IR_s)/R_{sh})] \quad (3)$$

Where,
R_s : internal series resistance of the panel

R_{sh} : internal shunt resistance of the panel

B. *Maximum Power Point Tracking*

In any photovoltaic cell, the output power is not always steady. It dynamically changes depending on many factors like temperature, insolation, size of the PV panel, surface of the panel etc. So a basic MPPT algorithm i.e., the incremental conductance algorithm is used to keep the working of the photovoltaic panel at the maximum power transferring point of the power-voltage characteristics of the PV panel. The basis of incremental conductance algorithm lies in the fact that the slope of the PV array curve is zero at the maximum power point (MPP).Also, the slope becomes positive on the left of the MPP and negative on the right of MPP. In this algorithm every time, the system calculates the incremental conductance as well as the instantaneous conductance [4],[5].

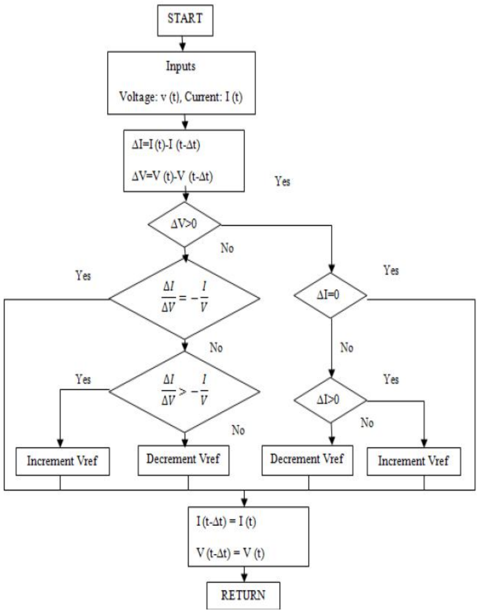

Fig. 3. Flow Chart of the incremental conductance algorithm [5].

Thus the method of tracking MPP is done by comparing both at every instant as shown in the flowchart. The incremental conductance algorithm offers better speed of tracking the maximum power point when compared to perturb and observe algorithm.

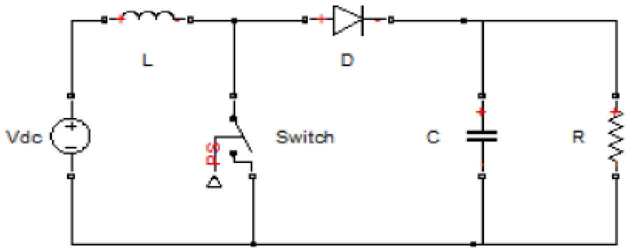

Fig. 4. A boost converter

C. *First Stage Of Boosting Strategy*

The photovoltaic panel is immediately followed by a dc-dc converter. As already known, a dc-dc converter performs the conversion of dc voltage at one level to another level. Here a simple boost converter is used, whose duty cycle is controlled by the MPPT algorithm. The boost converter raises the PV output voltage to a much higher level.

The circuit diagram of the boost converter is as shown. The power obtained at the output terminals of the converter varies depending on the state of the switch of the converter. i.e., by varying the duty cycle, [6],[7] the output power is varied. In the steady state, the input-output voltage is related by the equation

$$V_o/V_{in} = 1/(1-D) \tag{4}$$

D. *Second Stage of Boosting Strategy*

The second stage of the boosting mechanism is accomplished through a push-pull inverter. Unlike the normal H-bridge inverters, the push-pull inverter not only converts dc to ac, but also boosts the output voltage to a high level [8],[9]. This inverter makes use of a centre-tapped transformer which boosts the voltage and provides a natural isolation between the input and the output stage. Push-pull inverter uses a centre-tapped transformer. Its analysis requires two states.

- T1 is ON

Voltage across primary winding

$$V_1 = V_d \tag{5}$$

Now the diode D1 is forward biased and D2 is reverse biased.
Output Voltage

$$V_o = V_d/n \tag{6}$$

- T2 is ON

Voltage across primary winding

$$V_1 = -V_d \tag{7}$$

Diode D2 is forward biased and D1 is reverse biased.
Output voltage

$$V_o = -V_d/n \tag{8}$$

Where,
n : turns ratio of transformer

$$n = N_2/N_1 \tag{9}$$

N_1 : Number of turns in primary winding
N_2 : Number of turns in secondary winding

The push-pull inverter offers many advantages over the normal H-bridge inverter. Firstly this type of inverter does not use high level switches. This reduces the switching losses. It also improves the efficiency but in single phase H-bridge the voltage drop across more than one switch in series reduces the efficiency. In addition a push-pull inverter uses a high frequency transformer which provides natural isolation between the input and output stage. This is a great benefit for grid connected photovoltaic applications. Here, the push-pull inverter is driven by the sinusoidal pulse width modulation. So with this doubling strategy even if the PV output voltage comes in very low range, it can be stepped up to the working level of push-pull inverter by means of a boost converter.

III. SIMULATION RESULTS

The simulation of the system was carried out in MATLAB/SIMULINK environment. The simulation blocks

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and the results obtained are shown for each stage.

A. *Photovoltaic Panel*

The photovoltaic panel was modeled in SIMULINK based on the single diode model. For different input values of temperature and solar irradiance, the power-voltage characteristics and the current-voltage characteristics were plotted under normal solar irradiance and temperature conditions.

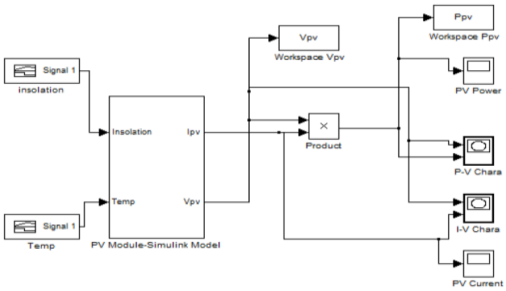

Fig. 6. Simulink Model of a Photovoltaic Panel Based On the Single Diode Model

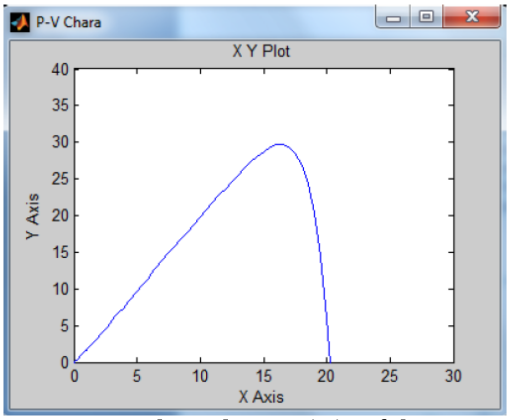

Fig. 7 Power Vs Voltage characteristics of the PV panel

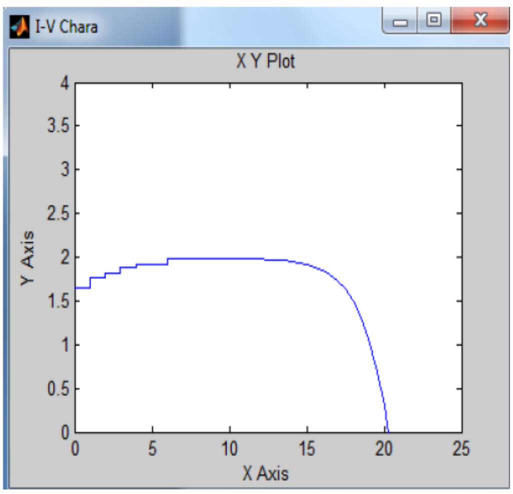

Fig. 8.Current Vs Voltage characteristics of the PV panel

B. *Maximum Power Point Tracker (MPPT)*

The incremental conductance algorithm was implemented as an embedded MATLAB program to generate the optimum duty cycle required in extracting the maximum power output from the photovoltaic panel. Based on this a look up table is created so as to generate the pulses for the first stage of booster i.e., the boost converter.

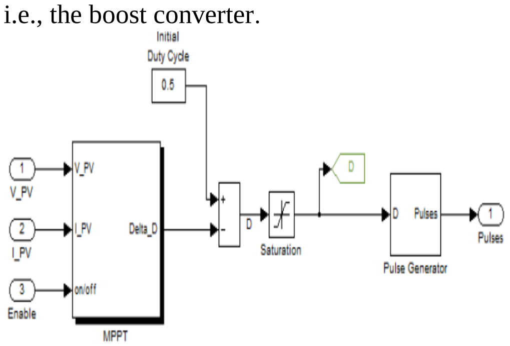

Fig. 9.Simulink model of Maximum Power Point Tracker (MPPT)

C. *Boost Converter*

The MPPT algorithm calculates the optimum duty cycle for maximum power transfer from the panel. Based on this, the pulses for the dc-dc converter are generated.

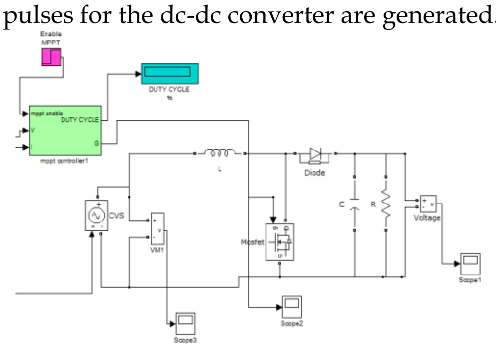

Fig. 10. Simulink model of Boost converter.

D. *Push-pull Inverter*

The push-pull inverter is driven by the sinusoidal pulse width modulation where a reference sine wave is compared with a carrier wave. By increasing the frequency of the carrier wave a better output is obtained from the push-pull inverter.

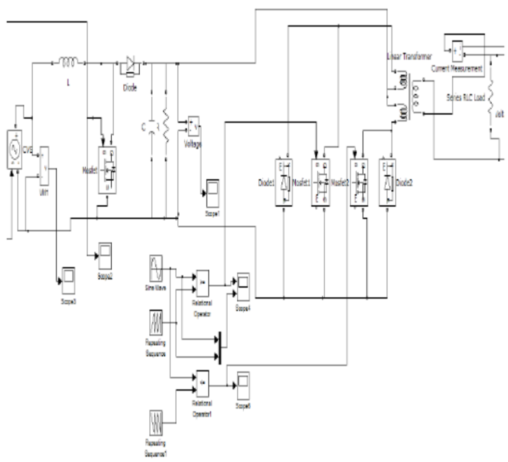

Fig.11.Simulink model of push-pull inverter fed by the boost converter output

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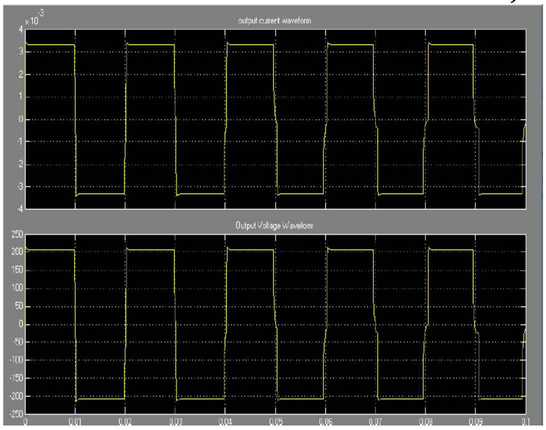

Fig.12.Output current and voltage waveforms of the push-pull inverter for a resistive load.

IV. CONCLUSION

The paper presents a double stage boosting strategy for single phase photovoltaic applications under low voltage output conditions of the photovoltaic panel. In the initial part of the paper the P-V and I-V characteristics of the photovoltaic panel is studied using the basic single diode model. The next part deals with the double boosting strategy composed of the boost converter and the push-pull inverter. Here, even if the photovoltaic output comes in very low range, it can be stepped up to the working level of push-pull inverter by means of a boost converter and the push-pull inverter is designed to facilitate a conversion even from the range of 10-12 Volts to the range of 230Volts. This system can be well-utilized for both standalone and grid connected photovoltaic applications.

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