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Full-Bridge DC-DC Converter with Voltage Doubler for Photovoltaic Applications

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Abstract - *In this paper Maximum Power Point Tracking (MPPT) algorithm for photovoltaic (PV) system with current fed DC-DC converter is proposed. Various techniques have been proposed for tracking the maximum power from the photovoltaic (PV) cell to obtain the high efficiency and to protect the systems from the variations of the temperature and irradiance. In this paper Incremental Conductance (IC) MPPT algorithm is used to track maximum output power. The PV output is fed to the current fed DC-DC converter to obtain the high output voltage and it is controlled by the Proportional Integral (PI) controller. Soft switching technique is also implemented to improve the performance of converter. The Zero Voltage Switching (ZVS) is maintained for all switches in the converter. Additionally voltage doubler is connected in the secondary side which results in twice the amount of input voltage with reduced components. The MATLAB/Simulink toolbox is used to model the PV system with current fed full-bridge DC-DC converter and simulation results validate the working of the proposed system.*

Keywords: *Incremental Conductance, PV array model, current fed DC-DC converter, soft switching, voltage doubler, PI controller.*

I INTRODUCTION

The entire world is facing a challenge to overcome the energy demand because of non-renewable energy sources such as gas, oil, fossil fuel etc. are rapidly decreasing and it will be depleted in few decades. To overcome this problem, the solar energy is an alternative energy source and which is available in the free of cost. If there is a sufficient irradiance condition efficiently will generate maximum power while MPPT algorithm is widely used with PV system. A lot of MPPT algorithm has been developed by the research and industrial persons. They are perturbation and observation method, voltage feedback method, hill clamping method, Incremental Conductance (IC) method and so on. In this paper IC method is used and it is based on the incremental and instantaneous conductance. The photovoltaic system is directly converts sunlight into electricity based on the photovoltaic effect. The photovoltaic array is group of panels or modules. The solar cells are grouped into form a panel or module. In general, the photovoltaic effect is defined as generation of potential at junction of difference between two materials in response to irradiance. In PV effect consists of various processes involved i.e., subsequent separation of the photo generated charge carrier and collection of photo-generated charge carrier in the junction.

In general, solar cell structure consists of absorptions layer which are efficiently absorbs the photons results in creation of electron-hole pair. The generated electron and holes are separated by the semi permeable membrane. The important requirement of semi permeable membrane is that they allow only selected one type of charge carrier pass through. The major issue in the design of solar cell requires thickness of the absorption layer of smaller than the diffusion length of the charge carrier. The main parameters are used to characterize the solar cells. They are open circuit voltage (V_{OC}), short circuit current (Isc) and Fill Factor (FF). The short-circuit current (I_{SC}) is the current that flows through the external circuit when the electrodes of the solar cell are short circuited. It gives the

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maximum current of that solar cell. The open-circuit voltage is the voltage at which no current flows through the external circuit. It is the maximum voltage that a solar cell can deliver. The Fill Factor is defined as the ratio between the maximum power generated by a solar cell and the product of Voc and Jsc. The voltage generated from the solar cell is low which is directly used for small loads such as lighting system and DC motors. For other applications it must be boosted. This requires the converter to boosting output of PV system. There are two major types of converters are available. They are non-isolated and isolated based on the separation of input source and load. In this paper isolated current fed DC-DC converters are used for boosting operation and it can be achieved without high turns ratio in transformer with soft switching techniques.

II. PV Array Model

The two key parameters are used to characterize the PV cell. They are its short circuit current (I_{SC}) and its open circuit voltage ( ). The module manufacture usually provides the values of their parameters in datasheet. The simple equivalent circuit of PV cell is shown in Fig. 1.

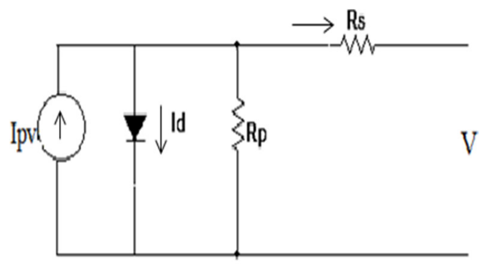

Fig. 1. Equivalent circuit of PV cell

By applying kirchoff's current law to this circuit

$$I = I_{sc} - I_d \qquad (1)$$

where,
Isc is the short circuit current that is equal to the photon generated current is the current shunted through intrinsic diode.
The diode current is given by the shockley's diode equation

$$I_d = I_0(e^{qv/KT} - 1) \qquad (2)$$

Where, is the diode saturation current (A) q is the electron charge [$1.602 * 10^{-19}$ C] k is the Boltzmann constant [$1.3806 * 10^{-23}$ J/K] V is the voltage across the PV cell (V) T is the junction temperature in kelvin (K) Combining the diode equation (1) and output current equation (2) of PV cell, we get

$$I = I_{SC} - I_0(e^{qv/KT} - 1) \qquad (3)$$

The reverse saturation current) is constant under constant temperature. Now I=0 substitute in equation (1), it becomes

From the above equation we get,

$$I_{SC} = I_0(e^{qv/KT} - 1)$$

$$I_0 = I_{SC} / (e^{qv/KT} - 1) \qquad (4)$$

Taking into account the series resistance ( ) and shunt resistance ( ), the equation becomes

$$I = I_{SC} - I_0(e^{qv/KT} - 1) - (V + IR_S)/R_P \qquad (5)$$

Short circuit current and open circuit voltage of PV cell characteristics is shown in Fig. 5. Practical arrays are composed of several

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connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic array requires the inclusion of additional parameters to the basic equation.

$$I = I_{PV} - I_0[\exp(\frac{v + IR_S}{V_t a}) - 1] - \frac{V + IR_S}{R_P} \quad (6)$$

Where, a is the diode ideality constant $V_t = N_s KT/q$, is the thermal voltage of array with cells connected in series.

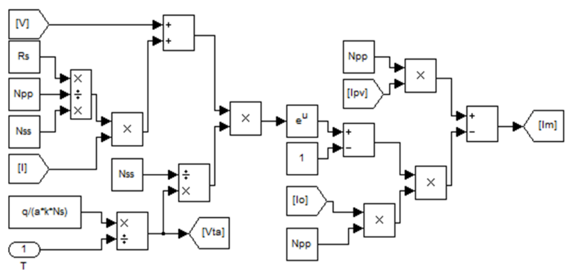

Fig. 2. Simulation of PV system in MATLAB/Simulink

Advantages:

- Pollution free in environment.
- It does not produce any harmful emissions.

Disadvantages:

- The solar energy is not produced in the night time. It requires storage device to use in night time.
- Produced voltage must be converted into AC. It requires additional circuits which makes circuit complex.

III. MPPT Algorithm

The most frequently used algorithm is to track the maximum power is Perturb and Observe (P&O) because of its simple structure and fewer requirements of parameters. In this methods iteratively perturbing, observing and comparing the power generation in the PV modules MPP is achieved is presented. The P&O method have possibility of miscalculation for determining the perturbing and tracking direction. The another disadvantage of P&O algorithm is it does not compare the array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation. To overcome this drawbacks IC algorithm is proposed [3]. This algorithm has advantages of exact perturbing; tracking direction and the array terminal voltage is always adjusted according to the MPP voltage due to this IC is more competitive than other method. The equation as given below and corresponding characteristics are shown in the Fig 5:

$$\frac{dI}{dv} = -\frac{I}{v} \text{, at MPP}$$

$$\frac{dI}{dv} > -\frac{I}{v} \text{, left of MPP}$$

$$\frac{dI}{dv} < -\frac{I}{V} \text{, right of MPP}$$

The MPP of the PV output can be achieved when its dp/dv reaches zero. This condition was shown in Fig. 3.The controller calculates dp/dv based on measured PV incremental output power and voltage. If dp/dv is not close zero, the controller will adjust the PV voltage step by step until approaches zero, at which the PV array reaches its maximum output. When the operating behavior of PV modules is within the constant current area, the output power is proportional to the terminal voltage. i.e., the output power increases linearly with increasing the terminal voltage of the PV modules.

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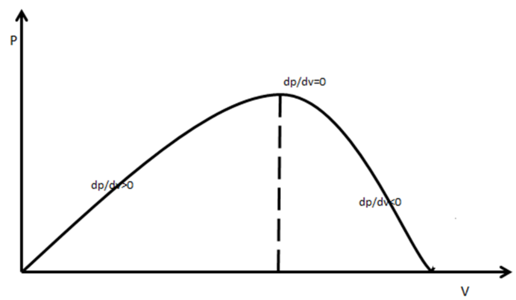

Fig. 3. Incremental Conductance PV module curve

IV. Current Fed Converter

The converters are major classified into isolated and non-isolated converter. Isolated converter has more over the non-isolated converter because the input source is isolated from the load which eliminates the conduction losses, input current ripples and increases the efficiency of the converter. In non-isolated converter requires high duty cycle to obtain high output voltage.

There are various isolated converters such as push-pull converter, fly-back converter and current fed converter and so on. Voltage fed converters suffered by duty cycle loss, high switching losses and large input ripple current. It is not a simpler solution to achieve the better efficiency which requires the large filter circuit to mitigate these problems and thereby using current fed full bridge DC-DC converter high efficiency is achieved.

The input voltage varied with respect to an irradiation and temperature. Photovoltaic cell works on the principle of the photovoltaic effect. The voltage across the photovoltaic cell terminal is low and it is directly suitable for low voltage application such as lamps and DC motors. In some applications requires the converter to process the electricity across the photovoltaic cell.

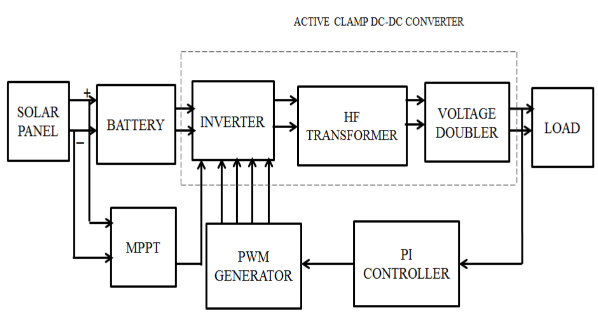

Fig. 4. Typical block diagram of DC-DC converter with PV system

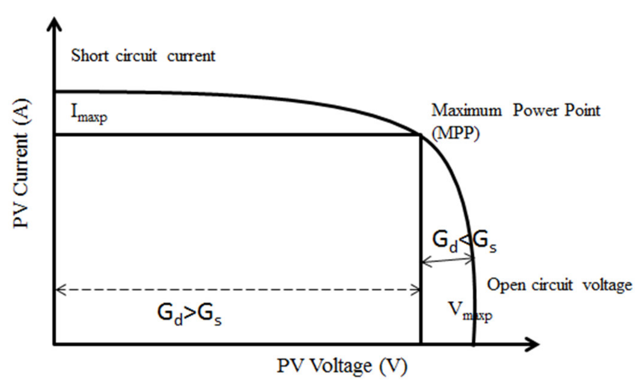

Fig. 5. I-V characteristics of PV cells

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In this proposed system soft switching converter is preferred for boosting the voltage available across the PV panel. In this current fed full bridge converter is used, the full bridge inverter used to convert DC voltage across the output of PV equivalent into AC which is fed to primary of the transformer. The switches in full bridge are controlled by the PWM generator with PI controller. The transformer step-up the voltage with reduced turns ratio ($N_2/N_1 = 6$) and given to the voltage doubler. This selected converter has reduced switching losses, duty cycle loss, EMI and mitigates the diode's reverse recovery problem. The auxiliary switch is used in the inverter bridge and the switch is turned on with twice the main switches frequency. In soft switching either the voltage or current is zero to reduce losses.

There are two types of switching are available. Zero Voltage Switching (ZVS) is preferable over the Zero Current Switching (ZCS) because of operation in high switching frequencies. By isolating the input and output conduction losses are reduced. Hence, isolated converters are most suitable for applications. In this High Frequency (HF) transformer is plays vital role to isolate the source and load. The voltage doubler is converts output voltage across the transformer into DC and doubles which is equal to twice the AC voltage across the rectifier

IV. Simulation of PV Array with DC-DC Converter

There are different types of dc-dc converters, buck, boost, buck-boost and cuk converters are developed to meet different applications. The important requirement of DC–DC converter used in the MPPT scheme should have low current ripple.

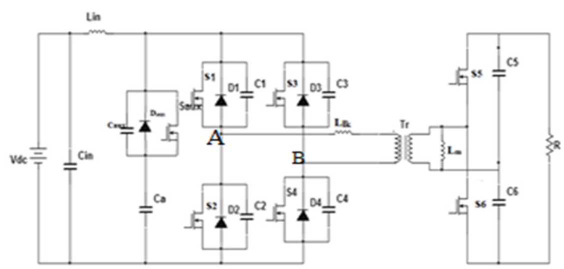

Fig. 6. Proposed converter circuit diagram

In this current fed full bridge DC-DC converter is selected which is shown in Fig. 6. In the proposed converter, there are following assumptions are made to achieve the high output voltage. They are

- Boost inductor is large to maintain the current constant
- Active clamp capacitor (Ca) is connected in series with auxiliary circuit is large to maintain the constant voltage across it.

Boost converters have low ripple on the PV, so in this simulation current fed DC-DC converter is used. Simulation of PV array with DC-DC converter is developed by using MATLAB/Simulink which contains various blocks of PV array, MPPT, DC-DC converter. General simulation block diagram is shown in Fig. 4.The PV array module is simulated by using the given mathematical equations (3), (4), (5). The MPPT regulates the PWM control signal to the DC-DC boost converter until the converter condition satisfies. The Maximum Power Point Tracking (MPPT) of the simulation representation is shown in Fig. 7. When this incremental and instantaneous conductance is equal maximum power is tracked which is used to trigger auxiliary clamp circuit. The DC-DC converter converts the output of the PV array voltage into equivalent AC and step-up the voltage the voltage which is again converted into DC.

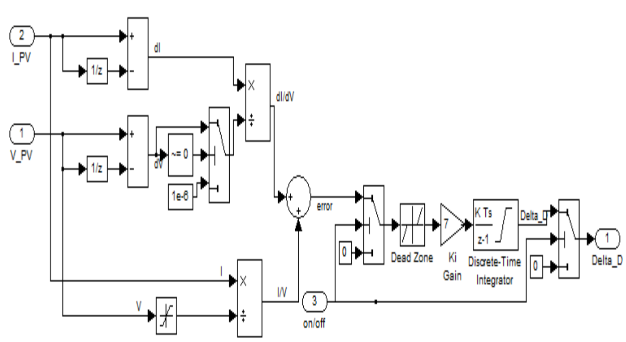

Fig. 7. Simulation diagram of MPPT function

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V. Simulation Results

The model of PV modules used in PV simulation system is simulated according to the mathematical equations given in section II. The PV module output is given to the DC-DC converter. The tracking of maximum power is explained through flow chart shown in the Fig. 9.

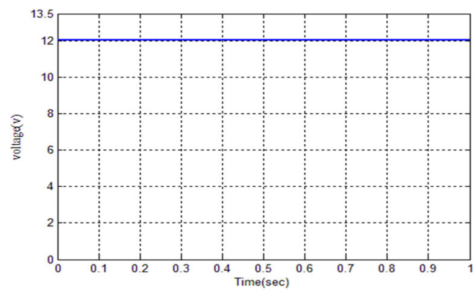

Fig. 8. Output voltage of PV cell

The output voltage of PV cell is shown in Fig.89. It is generated based on the standard values provided for poly crystalline solar cell in the data sheet. The temperature is 25°C. The voltage is fed to the converter and controller simultaneously. The duty cycle is adjusted directly in the algorithm. Change in duty cycle is shown in Fig. 10. Then which is used to turn on the auxiliary switch. The inverted output is given to the HF transformer. Finally, the voltage available across the transformer secondary converted into DC and it is doubled by the voltage doubler.

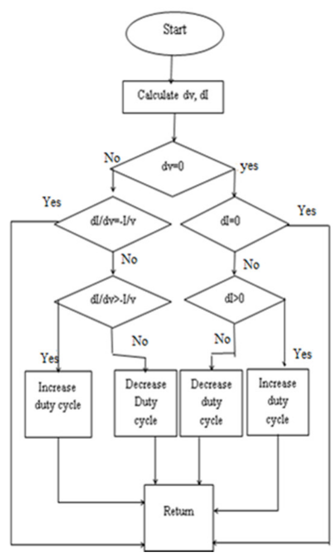

Fig. 9. Incremental conductance algorithm flow chart

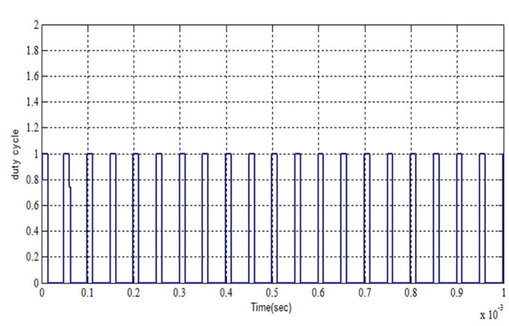

Fig. 10. Change in duty cycle

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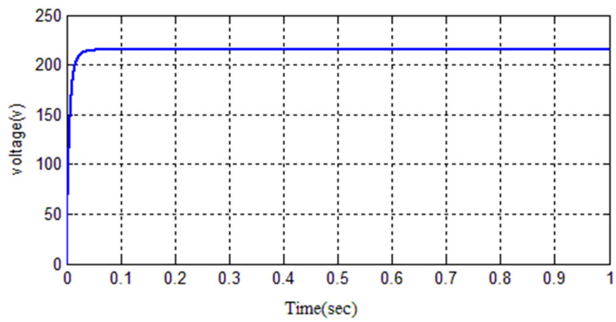

Fig. 11. Output voltage and current waveform of voltage doubler

VI. Conclusion

In this paper, Incremental Conductance method of MPPT for photovoltaic system with DC-DC converter is proposed for tracking the maximum power. This method offers good tracking efficiency and high response. The PV module output is generated which is fed to the current fed DC-DC converter, Full bridge inverter is controlled by the pulses generated from the PWM generator with the help of PI controller. Soft switching is achieved in the main switches and auxiliary switch recycles the energy stored in the transformer inductance.

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