CURRENT FED FULL-BRIDGE CONVERTER WITH VOLTAGE DOUBLER FOR PHOTOVOLTAIC SYSTEM 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. For getting the high output voltage, Proportional Integral (PI) controller is used to control the DC-DC converter and Zero Voltage Switching (ZVS) is also implemented for all switches to improve the performance of converter. Additionally voltage doubler is connected in the secondary side which results in twice the amount of output voltage with reduced components. The simulation is carried out by using the MATLAB/Simulink software tools to demonstrate the working of the proposed system. The effectiveness of the system is also verified by using the hardware implementation.*

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

1. Introduction

Due to the growing energy demand in the past few decades, the entire world is facing many challenges because of the depletion of non-renewable energy sources. To overcome this problem, the solar energy is used as primary energy source since it is availed at free of cost. Based on the solar radiation the energy is harvested and used. The maximum power can be utilized from PV cell by using the MPPT algorithm. There are many algorithms in literature viz., perturbation and observation method, voltage feedback method, hill clamping method, Incremental Conductance (IC) method. Among such methods a special attention has been given to the Incremental Conductance (IC) method based on tracking of maximum power for solar cell.

The output from the PV cell is low and it given into DC-DC converter for boosting the output voltage. There are two major types of converters are available. (1) Non-isolated and (2) Isolated based on the separation of input source and load. In this paper isolated current fed DC-DC converters [8] are used for boosting operation and it can be achieved without high turns ratio in transformer with soft switching techniques. This soft switching eliminates the conduction loss of the switches, ripples and improves the efficiency. In the soft switching converter, voltage or current across the switches are made zero during the transition, which results in the elimination of large magnetic components and filters. In this paper Zero voltage switching is achieved for the converter and it act as an active clamp circuit.

This paper organized as follows: Section II describes equivalent circuit of PV array, PV system modeling and its advantages. Section III shows the simulation of PV with MPPT algorithm. Section IV describes the DC-DC converter with PI controller. Section V shows the simulation results of proposed system.

2. PV System Model

Photovoltaic (PV) is one of the major source of power, becoming more available and reliable comparing the other conventional power sources. The photovoltaic effect makes the conversion of solar power to direct current electricity by the use of semiconductors. The photovoltaic array is group of panels or modules. The solar cells are grouped to form a panel or module inorder

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to have the enough conversion of power based on requirement of the applications.

Hence it will be connected in series and parallel to get high current and high voltage. The solar cell is modelled

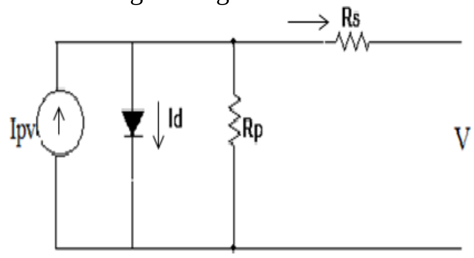

Figure 1. Equivalent circuit of PV cell

by using MATLAB/ Simulink tool box, it consists of a current source parallel with diode which shows the PN junction nonlinear impedance. Also a intrinsic resistance which is small in series connection and high in parallel connection with the diode. To model this PV module, the parameters are obtained from SANYO-240HDE4 datasheet.

The equivalent circuit of PV cell is shown in Fig. 1. By applying kirchoff's current law to this circuit

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

where,

Isc is the short circuit current that is equal to the photon generated current

I_d is the current shunted through intrinsic diode.

The diode current Id is given by the shockley's diode equation

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

Where,

I_0 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

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

The reverse saturation current (I_0) is constant under constant temperature. Now I=0 substitute in equation (1), it becomes

From the above equation we get,

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

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

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

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

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

The equations from (1) to (6) are used to simulate PV system in MATLAB/Simulink. Simulated PV system in MATLAB is shown in Fig. 2.

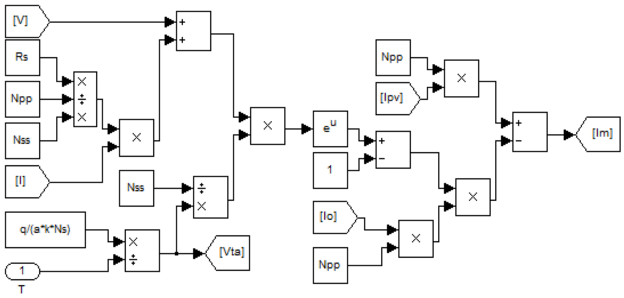

Figure 2. MATLAB/Simulink model for PV system

3. InCond MPPT Algorithm

Perturb and Observe (P&O) is the most frequently used algorithm is to track the maximum power, because of its simple structure and fewer requirements of parameters. In this method, the iteration is carried out for perturbing, observing and comparing the power generation in the PV modules and the MPP is achieved [2]. In this method, there is a possibility of miscalculation for determining the perturbing and tracking direction. It also does not compare the PV array terminal voltage with the actual MPP voltage and here the array terminal voltage perturbation is a result of the change in power. To overcome this drawbacks Incremental conductance (InCond)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:

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

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

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

When dp/dv reaches zero, the MPP of PV output can be achieved and it is shown in Fig. 3. Based on measured PV incremental output power and voltage, the controller calculates the dp/dv. If dp/dv is not close zero, the controller will adjust the PV voltage step by step until, dp/dv 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.

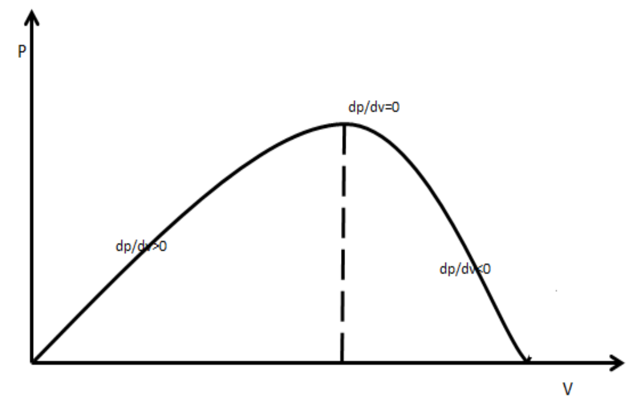

Figure 3. Incremental Conductance PV module curve

4. Proposed Active Clamp DC/DC Converter

The isolated DC-DC converter is selected since its input source is isolated from the load. Also, this has some merits due to isolation like, elimination of conduction losses, input current ripples and increase in efficiency of converter. The Block diagram of proposed DC-DC converter with PV system is shown in Fig. 4. There are various isolated converters available such as push-pull converter, voltage fed converter, forward converter, fly-back converter and current fed converter and so on. Among such converters, the voltage fed converters suffered by high switching losses and large input ripple current [5]. To have a solution for the problems, a large filter is required. The proposed current fed DC-DC converter mitigates the above drawbacks. It consists of full bridge inverter connected to a high frequency transformer. For having high voltage at the output end, a voltage doubler is connected to the secondary side of the HF transformer. The inverter connected to voltage doubler through HF transformer is called Active clamp DC-DC converter and this act as a mitigation circuit for losses and improves the overall efficiency.

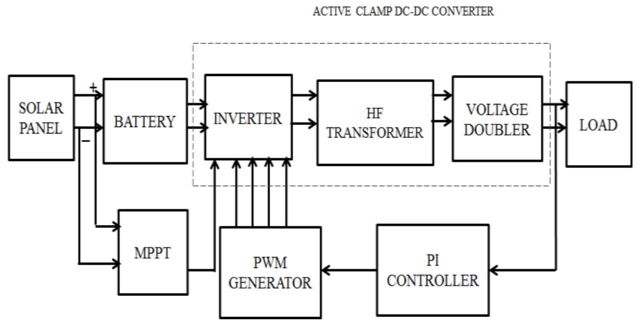

Figure 4. Typical block diagram of proposed PV based DC-DC converter

The proposed system has a PV cell connected to a battery and the power is tracked by InCond MPPT algorithm.

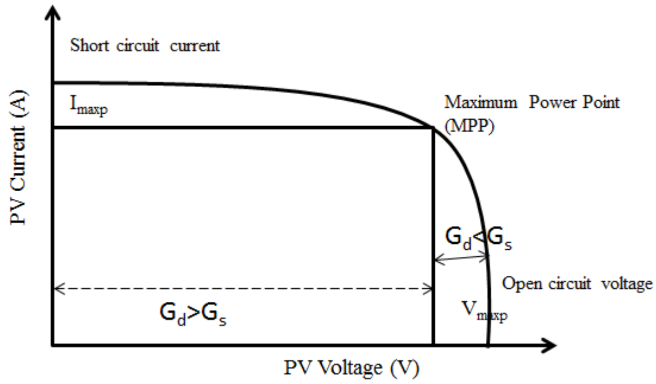

Figure 5. I-V characteristics of PV cells

In this proposed system, soft switching is also introduced for improving the efficiency of the overall system. The voltage generated from the PV cell is given to inverter. The conduction of the inverter switches are controlled to give the output voltage according to the requirement of the load and for that the Proportional integral controller is employed. The inverter is made to work in the Zero Voltage Switching (ZVS) condition by operating the auxiliary switch. The Zero Voltage Switching (ZVS) is preferred over the Zero Current Switching (ZCS) because converters can operate in high switching frequencies. The voltage doubler converts the output voltage across the transformer into DC and doubles which is equal to twice the AC voltage i.e., secondary side voltage of HF transformer.

5. Simulation Of Pv Array With Dc-Dc Converter

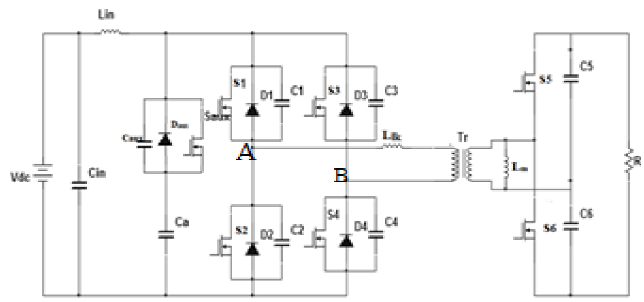

Figure 6. Simualtion circuit diagram of converter

The simulation circuit of the current fed full bridge DC-DC converter is shown in Fig. 6. The Metal Oxide Semiconductor Field Effect Transistor (MOSFET) switch is employed for all converters used due to its low conduction losses. The converter has the following assumptions made in order to achieve the high output voltage.

1. Boost inductor is large to maintain the current constant
2. Active clamp capacitor (C_a) is connected in series with auxiliary circuit is large to maintain the constant voltage across it.
3. All the MOSFETs and diodes are used in this converter is considered ideal.

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 like PV array, InCond MPPT, Inverter and HF transformer. Based on the equations (3), (4), (5), the PV array module is modeled and simulated. The PWM pulses are regulated according to the MPPT Function and DC-DC converter is operated. The simulation block for InCond MPPT is shown in Fig. 7. When this incremental and instantaneous conductance is equal, maximum power is tracked. The overall simulation circuit of PV based current fed DC-DC converter with MPPT function and PI controller is shown in Fig. 8.

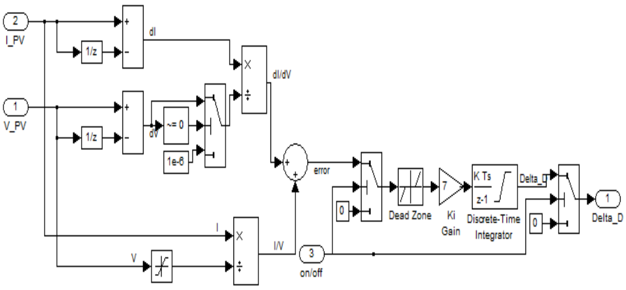

Figure 7. Simulation diagram of MPPT function

The components for the soft switching DC-DC converter used in the simulation are as follows:

For photovoltaic system circuit model is simulated using mathematical equations, nominal values and variation with temperature (K) and irradiance ($\frac{W}{m^2}$). The switches (MOSFET) are considered to be ideal values.

Switching frequency : 100 KHz
Switch : Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
Capacitor (C_{in}) : 0.64µF
Inductor (L_{in}) : 4.9mH
Resistive load(R_L) : 500Ω
PI controller : K_p=0.1, K_i=1

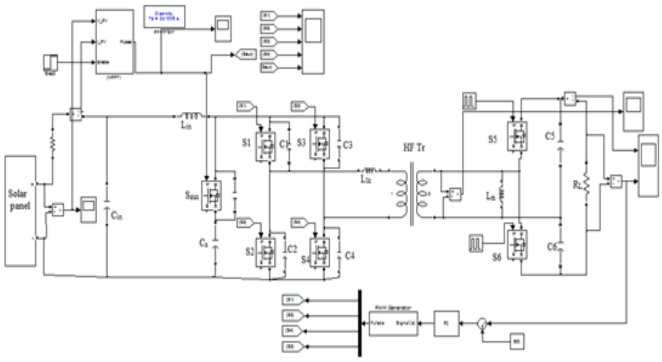

Figure 8. Simulation of DC-DC converter with MPPT function

6. Results And Discussions

The MATLAB simulation is carried out and the maximum power point tracker (MPPT) introduced to increase the output of the PV module. The PV module output obtained is 12V DC and it is shown in Fig. 9.

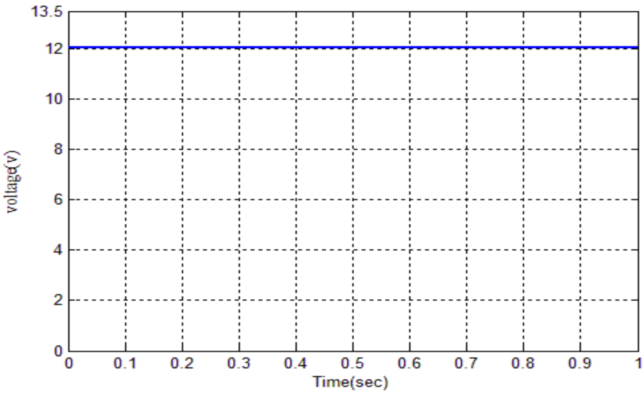

Figure 9. PV cell Output voltage

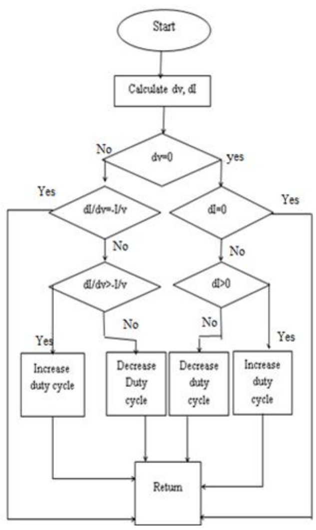

Figure 10. Flow chart of Incremental conductance MPPT algorithm

The tracking of maximum power is explained through flow chart shown in the Fig. 10. The solar cell selected is the temperature of 25°C. The voltage from the PV module is fed to the DC-DC converter continuously. The duty cycle is controlled by the MPPT algorithm and so maximum of output is delivered.

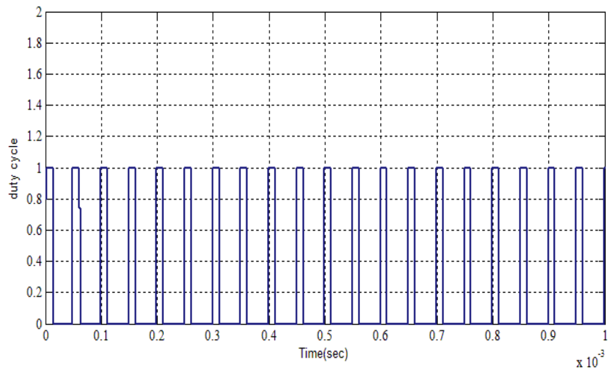

Figure 11. Change in duty cycle.

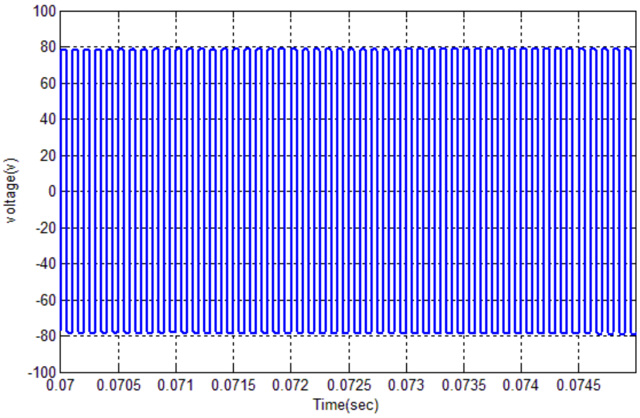

Figure 12. Stepped up Output voltage waveform

The change of duty cycle is represented in Fig. 11. The auxiliary switch is turned ON and the inverted output is given to the HF transformer. The stepped up voltage waveform is also shown in the Fig. 12. Then, this voltage is doubled by using the voltage doubler. The obtained Output voltage and current waveform from the simulation of voltage doubler is shown in Fig. 13.

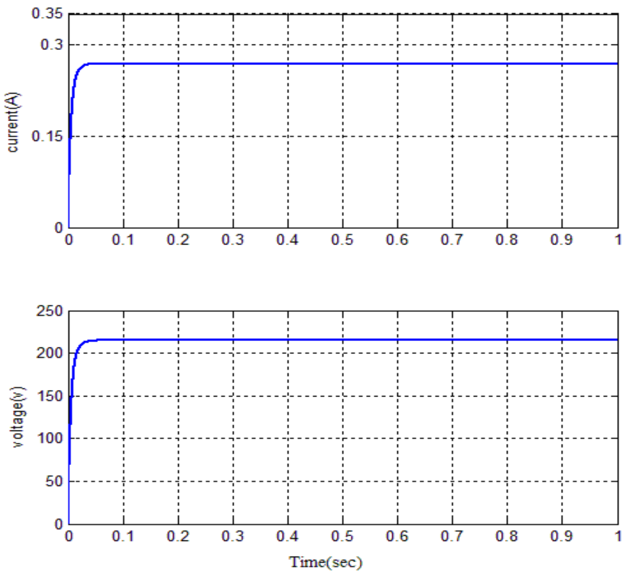

Figure 13. Output voltage and current waveform of voltage doubler

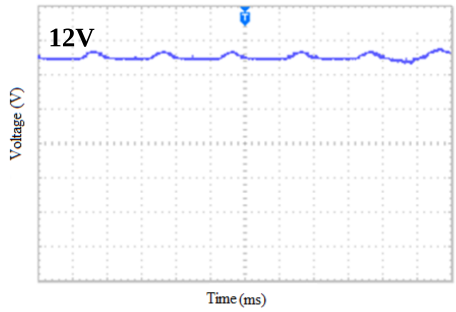

Figure 14. Solar pannel out(12V)

The prototype hardware implementation for the simulation circuit is carried out and the results are oberved.

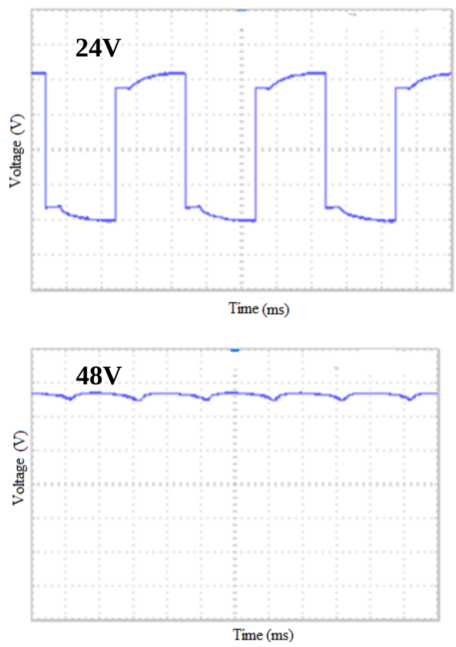

Figure 15. (a)Output waveformfrom the inverter,
(b) Outputwaveform from the voltage doubler

The ARM LPC 2148 is implemented for controlling the switching of the converter circuits and for improving the efficieny of the overall circuit. The input to the boost converter from the solar panel is 12V and it is shown in the Fig. 14.It is boosted to 24V and it is given to inverter. The stepped waveform from the inverter is shown in the Fig.15(a). This stepped voltgae is transferred to voltage doubler. The voltage doubler doubles the input voltage from 24V to 48V. Fig.15(b) shows the output waveform of the voltage doubler.

7. Conclusion

The performance of the current fed DC-DC converter based on PV system is simulated by using the MATLAB/SIMULINK software. The incremental conductance method of MPPT is used for tracking the maximum power from the PV cell. The output from the converter is fed to a full bridge inverter and a PI controller is employed for controlling it. The voltage doubler connected to the inverter increases the output voltage which is double that of the input DC voltage. It is observed that the proposed active clamp converter which is a combination of full bridge inverter and voltage doubler increases the efficiency with reduced number of components compared to that of conventional DC-DC system.

8. References

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