

A Simplified Design and Modeling of Boost Converter for Photovoltaic System

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ABSTRACT

The Photovoltaic standalone system is gaining its high importance mostly for rural application like pv water pumping, solar lighting, battery charging etc. Considering environmental effects and scarcity of fossil fuel the trend has developed towards the use of more and more renewable energy. In this paper a basic circuit of boost converter is designed in MATLAB/Simulink with constant dc source voltage. However a comparative study has also been done for the converter connected with pv system directly with the converter connected with mppt tracking technique. Perturb and Observance (P&O) algorithm is implemented for providing the necessary duty pulse and makes the system operate at maximum power point. The boost converter connected with PV system without mppt operates at any other point other than the maximum power point and hence the output voltage decreases. But with mppt the proposed system performs better.

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1. INTRODUCTION

The over dependence of renewable energy like coal, oil, gas causes global warming and environmental degradation which greatly affects the world population. In comparison to other renewable energy photovoltaic source is a biggest source of contribution to world electricity generation [1], [2]. Solar power can be utilized in two ways solar photovoltaics and solar thermal. Due to varying weather condition the output of the panel always varies depending on irradiance and temperature. As a result of which a constant dc voltage cannot be supplied to the load. Hence boost converters are used to boost up the variable dc voltage to fixed dc as desired by the load. But in case of ac load an additional inverter is used to convert dc voltage to ac voltage [3], [4]. The output performance of the solar cells in terms of efficiency depends on various factors like temperature, soiling, shading which reduces the performances. Hence maximum power point tracking is the solution for operating the PV system at a unique point called knee point which provides the maximum power irrespective of any weather or load conditions [5]. Various authors have suggested different types of MPPT techniques. Some are like Perturb and observance method, Incremental conductance method, constant voltage method, shortcircuit current, fuzzy logic method and ANN method [6]. Among all this methods P and O technique is simple and most widely used. The Inc method operates more successfully during the changing weather conditions but at the same time the complexity of the circuit also increases [7-10]. The other methods are also used depending on their computational time and system requirement.

For MPPT implementation a dc-dc converter is needed in the system. When the load requirement is higher voltage we can go for either boost converter or buck-boost converter or cuk converter but simple boost converter is more efficient due to less complex circuitry in comparison to other converters. S. Daison et al

has designed a converter with a floating switch in active state which can isolate the input from the PV panel under the condition when the ac unit is in off state. This efficiency of this converter is found to be around 95.3%. However this increases the complexity in the circuit [11]. This paper represents the design of boost converter to get increased voltage. As shown in Figure 1 a photovoltaic system is used to supply the step up converter and further the boost converter is connected to the load. The necessary duty pulse to the converter switch is obtained from mppt unit by using Pand O algorithm.

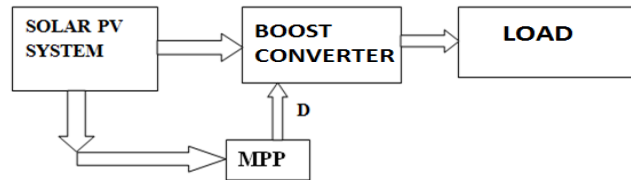


Figure 1. Representation of Boost converter connected with solar pv system in block diagram

2. BOOST CONVERTER: FUNDAMENTAL PRINCIPLE

Boost converter is a highly efficient power electronic device in which the input voltage is stepped up without the use of transformer. But in the process of step-up the total power input to the system is maintained fixed to that of the output of the system which is achieved by reducing the current. The process of energy transfer is carried out by various elements like inductor, power switch, diode and filter capacitor. The electronic switch taken here is mostly power MOSFET but studies also shows that IGBT can also be used for switching purpose. Generally for simple design circuits pulse width modulation techniques are used for switching purpose. There are two different modes of operation of Boost converter i.e Continuous conduction mode, CCM and Discontinuous conduction mode, DCM. Figure 2 shows the basic diagram showing the working of boost converter

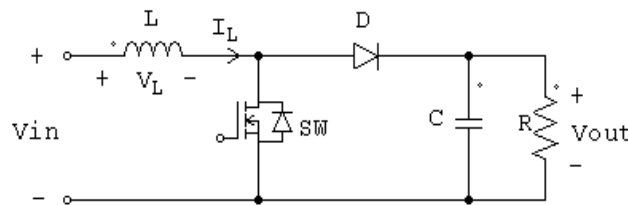


Figure 2. Basic diagram showing the working of boost converter

3. BOOST CONVERTER: OPERATION ANALYSIS

The DC-DC step up converter operates in two modes. The basic difference in both the modes is the flow of inductor current. In the first mode the current through the inductor flows continuously where as in the second mode the current through the inductor comes to zero for an interval of time before the next turn on of the switch (Figure 5 and Figure 6). Again the CCM mode operates in two ways i.e TURN ON mode (Mode 1) and TURN OFF mode (Mode 2). During mode 1 the power switch is made ON as depicted in Figure 3. As a result with the turning on of the switch the supply current input to the circuit follows a path through the inductor connected in series and the power switch. In this mode the energy gets stored in the Inductor where as the resistive load as shown in the Figure 3 is supplied by the capacitor current. Mode 2 operation starts as power switch is switched OFF. In this mode as the switch is turned off no more current will flow through this path where as the current will take the path through inductor, diode, capacitor and resistive load. Figure 4 shows the path of flow of current during turn off process. Again during this period the energy which was store in the inductor during on time gets discharged to the resistive load. Thus the voltage at the terminal is higher than the supply voltage as the name suggest step up or boost converter.

In the CCM mode the current flowing through the inductor never comes to zero. Hence value of Inductance can be calculated by the given equation as shown below:

$$L_{min} = [(1 - D)^2 \times D \times R_o] \div (2 \times F_s) \quad (1)$$

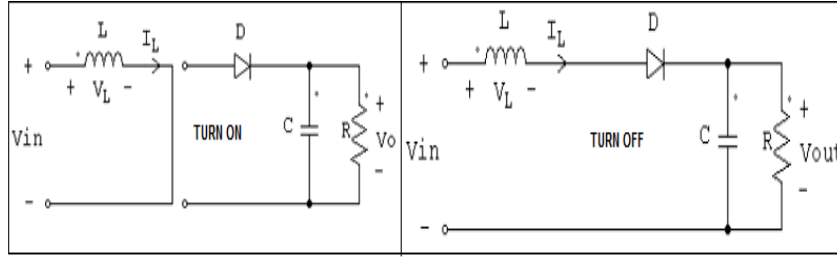


Figure 3. Turn ON/OFF operation

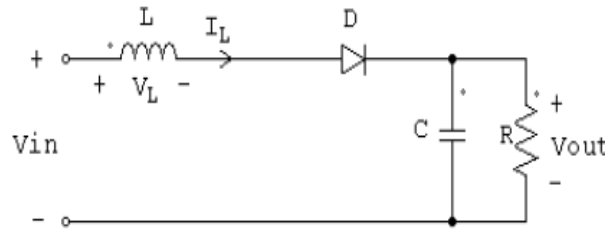


Figure 4. Turn OFF operation

In the Equation (1) L_{min} is the minimum value of inductance, so while calculating the value of inductance of inductor care should be taken that the value is more than the minimum value. R_o represents is the resistance of the load and F_s the switching frequency. Similarly the capacitance least allowed value i.e. C_{min} is given by the relation:

$$C_{min} = D \div (R_o \times V_{rf} \times F_s) \tag{2}$$

From the Equation (2) V_{rf} is the voltage ripple factor which is given by the expression

$$V_{rf} = \frac{\Delta V_o}{V_o} \tag{3}$$

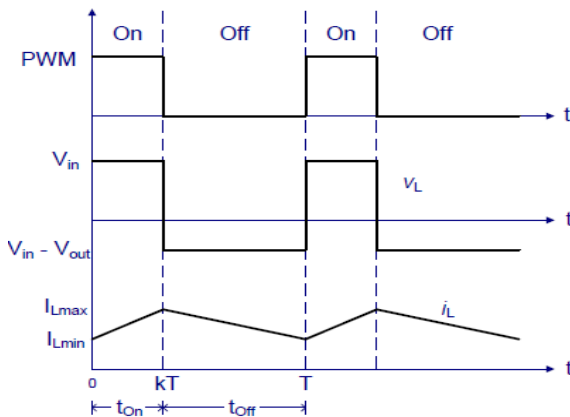


Figure 5. Waveforms at Continuous conduction mode of Boost converter

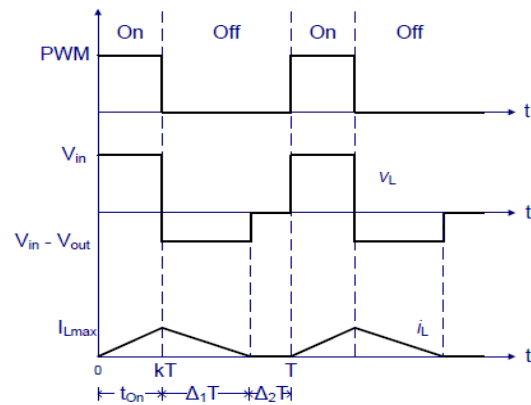


Figure 6. Waveforms at Discontinuous conduction mode of Boost converter

Figure 5 and Figure 6 represents the waveforms of voltage and current in the operation of boost converter in CCM and DCM mode. In DCM mode from Figure 6 it is clearly seen that the current through the has finite value during negative inductor voltahe but goes zero during the time period of zero inductor voltage.

4. PROPOSED SYSTEM

A basic step up dc-dc converter is designed operating in continuous state. Initially this work shows modeling of a simple boost converter with fixed dc input voltage to study the stepping up function of the converter and its various parameters calculation procedure. In the second approach the converter is given supply from the pv system without the use of constant dc source. In both the cases the duty pulses are given from PWM pulse generator. Finally the Boost converter is modeled with a pv panel as input and Maximum power point tracking system i.e Perturb and Observance method for providing the necessary duty pulse to the converter switch.

4.1. Selection of Power switch

As shown in Figure 2 the power switch considered must be having higher voltage and current rating than the input. Hence in this system the IGBT is used for switching purpose. For the design purpose the values of internal resistance taken is 1000mΩ and the snubber resistance is taken as 10⁵ Ω.

4.2. Selection of Diode

In this system forward biased diode is considered. The various other characteristics required for the selection of diode are like fast switching, sufficient peak and average current handling capacity, less forward voltage drop [15]. Thus the value of resistance of diode is set as 0.001Ω and snubber resistance as 500 Ω.

4.3. Parameter Calculation

In this paper five basic parameters are calculated for the modelling of the proposed system. The data under consideration are Output voltage V_o is 164 volt, Input voltage V_{in} as 43 volt, Output current I_o is 1 ampere, switching frequency (F_s): 25kHz, Voltage ripple factor 5% and as per IEC standard the current ripple factor must remain within 30% hence for this study it is choosed as 20%.

4.3.1. Duty Cycle (D)

$$D = 1 - \frac{V_{in}}{V_o} \quad (4)$$

$$D = 1 - \frac{43}{164} = 0.74 \quad (5)$$

4.3.2. Ripple Current (ΔI_o)

$$\Delta I_o = 20\% \times I_o = 0.2 \text{ amp} \quad (6)$$

4.3.3. Value of Inductor (L)

$$L = \frac{V_{in} \times D}{F_s \times \Delta I_o} \quad (7)$$

$$L = \frac{43 \times 0.74}{25000 \times 0.2} = 6.3 \text{ mH} \quad (8)$$

4.3.4. Load Resistnace (R_o)

$$R_o = \frac{V_o}{I_o} \quad (9)$$

$$R_o = \frac{164}{1} = 164 \text{ ohm} \quad (10)$$

4.3.5. Capacitance (C)

$$C = \frac{I_o \times D}{F_s \times \Delta V_o} = 4400 \mu F \quad (11)$$

4.4. PV System and MPPT Technique

The PV system is designed in such a way that 12 channels are conneceted in series with each six number of solar cells in series connection to give a total output voltage of 43.2 volt. The short circuit current of each solar cell is 7.34 ampere and the open circuit voltage is 0.6 volt. The solar irradiance value taken is

1000 watt/m². The system produces a maximum voltage of 240 watt. The MPPT system uses Perturb and Observance algorithm as shown in Figure 7. This method is simple, easy to implement and low cost hence used in this system. In this approach the instantaneous values of voltage and current are recorded and then the output power is calculated. Then the operating point is perturbed by a small amount. If the power increases then it checks whether change in voltage is positive, if yes it increments the duty cycle or else it moves in the opposite direction.

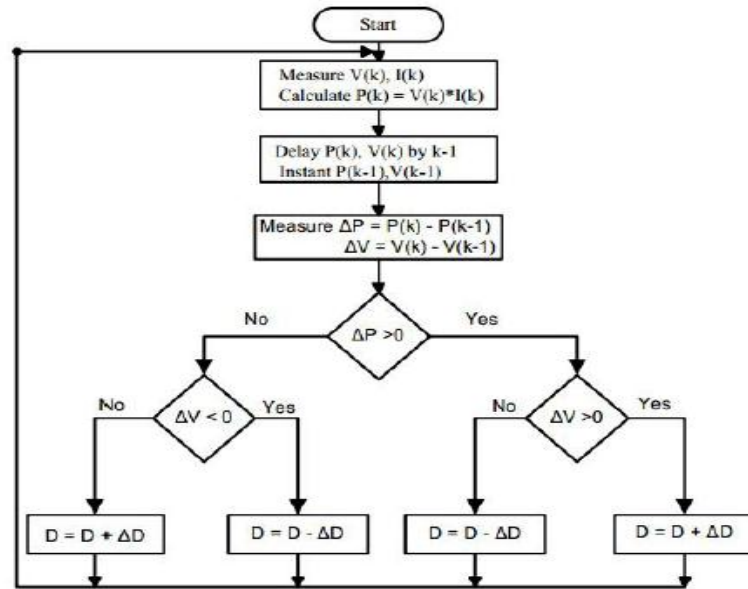


Figure 7. Algorithm of P&O method

5. MODELLING AND SIMULATION

The design of the proposed system is done using MATLAB using various blocks of Sim powersystems. In the below shown Figure 8 represents the simulation design of a constant dc source fed step up converter with simple resistive load. IGBT switch is used as power switch for circuit on and off process. The necessary gate pulse for triggering the circuit is provided by pwm pulse generator. In Figure 9 the converter is connected to the solar system made of series connected solar cells. Figure 10 represents clearly the proposed model of the step up converter connected with pv system and the MPPT control unit. Figure 11 and Figure 12 shows the subsystem for pv system and mppt control unit.

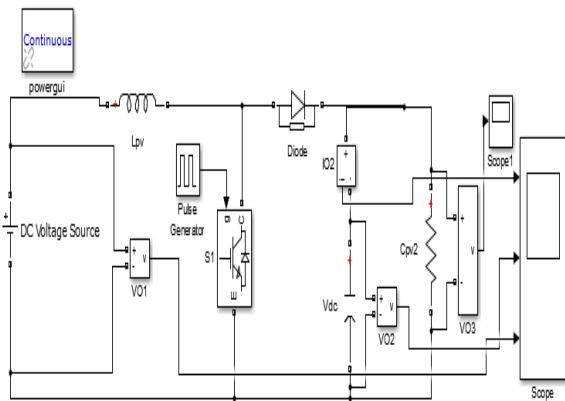


Figure 8. Model of basic converter (Boost) in Simulink

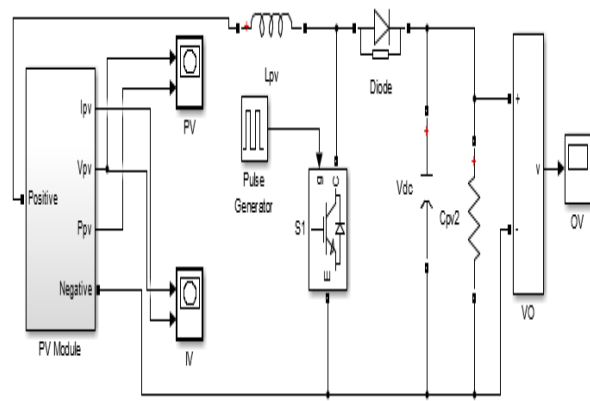


Figure 9. PV system connected boost converter without mppt

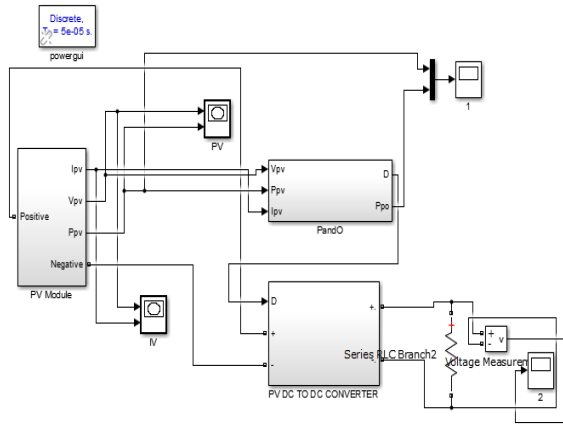


Figure 10. Proposed model in Simulink

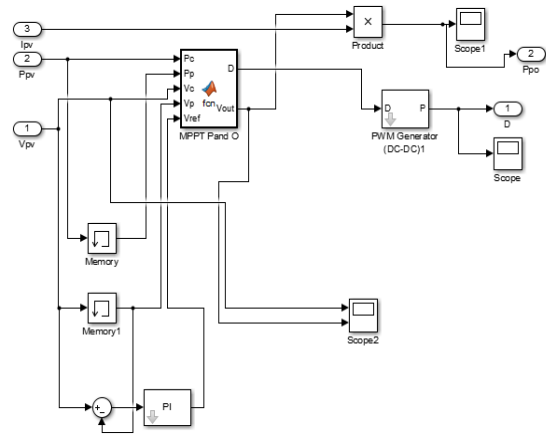


Figure 11. Simulink model of the MPPT system using Pand O technique

6. RESULTS AND ANALYSIS

The analysis has been carried out to verify the operation of boost converter with the parameters calculated as above and compare the performance of the proposed system i.e the converter with the controlled pulses (mppt) and that the system without mppt. Figure 12 shows the output voltage waveform of the simulation as shown in Figure 8 for resistive load. With the calculated parameters of the Inductor, capacitor, load resistance and appropriate choice of voltage and current ripple factor it is found that the output voltage across the resistive load is 164 volt with fixed dc input voltage taken as 43 volt. Hence the designed step up converter steps up the dc voltage.

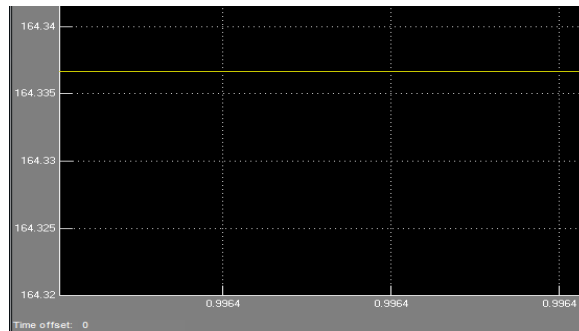


Figure 12. Output voltage waveform of simple boost converter

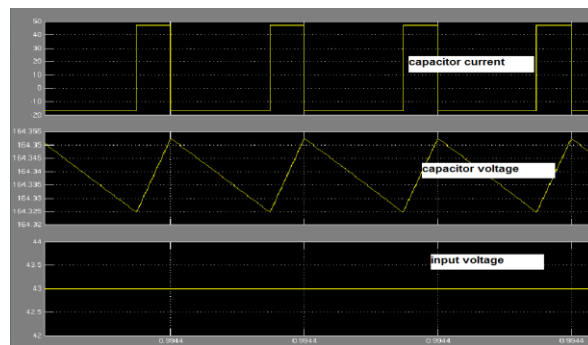


Figure 13. Waveforms of capacitor current, voltage across capacitor and input voltage for the simulation as shown in Figure 8

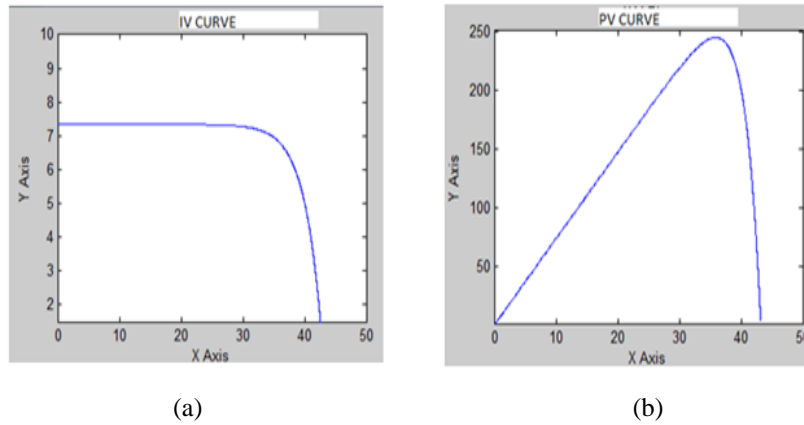


Figure 14. (a) IV curve for thge PV system, (b) PV curve for the system

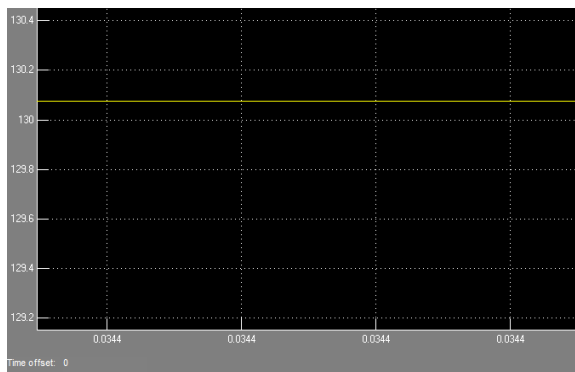


Figure 15. Output voltage waveform of converter as shown in Figure 9

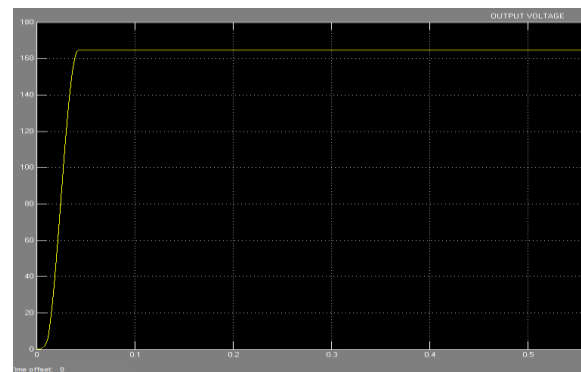


Figure 16. Output voltage waveform of the proposed model as represented in Figure 10

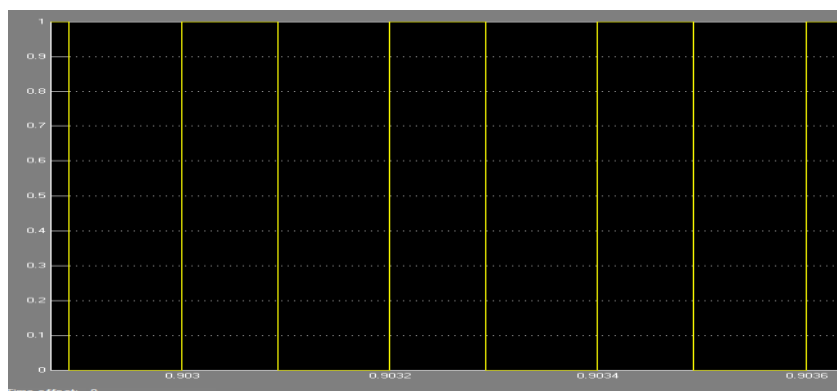


Figure 17. Duty pulses generated using P and O technique

Figure 13 shows the capacitor voltage, capacitor current, fixed dc input voltage and compares the nature of the waveform with that of figure 5 shown for continuous conduction mode. Figure 14(a) and Figure 14(b) shows the pv and iv curve of the photovoltaic module designed considering 72 solar cells in series. Figure 15 shows the output voltage of the converter i.e. is 130.1 volt for the system designed without using mppt. Figure 16 represents the output voltage waveform of the designed model as proposed i.e the boost converter connected with pv and mppt system. From the figure the voltage is found to be 164 volt for a resistive load. Figure 18 shows the duty pulses generated as per the simulation shown in Figure 12.

7. CONCLUSION

The basic function of boost converter to step up voltage from a lower fixed value to a higher value can be used for various photovoltaic standalone as well as grid connected applications. In grid system use of inverter is required to convert dc to ac. But here in this study fundamental circuit is considered for simplicity in design and to make the system less complex. Detailed analysis of the Boost converter was done in this paper. The basic boost converter was designed as per the calculated parameters. PWM pulses are used for switching the circuit. In the proposed model using mppt control algorithm the output voltage is more than the converter design connected with PV without mppt. As mppt technique helps to track the maximum power point making the system to operate at the unique point all the time irrespective of the load and weather conditions. But in the converter without mppt can get the input voltage from PV at any other point other than mpp point. Hence the system efficiency decreases. Further it is suggested that various other mppt methods can be implemented in the proposed system to get better results.

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REFERENCES

- [1] E. Figueres, G. Garcera, J. Sandia, F. Gonzalez-Espin, and J. C. Rubio, "Sensitivity study of the dynamics of three-phase photovoltaic inverters with an LCL grid filter," *IEEE Trans. Ind. Electron.*, vol. 56, no. 3, pp. 706–717, Mar. 2009.
- [2] Q. Li and P. Wolfs, "A review of the single phase photovoltaic module integrated converter topologies with three different dc link configurations," *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1320–1333, May 2008.
- [3] E. Koutroulis, K. Kalaitzakis and N. C. Voulgaris, "Development of a microcontroller based photovoltaic maximum power point tracking system," *IEEE Trans. On Power Electronics*, vol. 16, no. 1, pp. 46-54, 2001.
- [4] S. C. Tan, "Constant-Frequency Reduced-State Sliding Mode Current Controller for Cuk Converters," *IET Power Electronics*, Vol. 1, No. 4, 2008, pp. 466-477.
- [5] Saravana Selvan, Pratap Nair, Umayal Umayal, "A Review on Photo Voltaic MPPT Algorithms" *International Journal of Electrical and Computer Engineering, IJECE*, Vol 6, No 2, pp.567-582, April 2016.
- [6] J. Knight, S. Shirsavar and W. Holderbaum, "An Improved Reliability Cuk Based Solar Inverter with Sliding Mode Control," *IEEE Transactions on Power Electronics*, Vol. 21, No. 4, 2006, pp. 1107-1115.
- [7] D. B. Costa and C. M. C. Duarte, "The ZVS-PWM Active-Clamping Cuk Converter," *IEEE Transactions on Industrial Electronics*, Vol. 51, No. 1, 2004, pp. 54-60.
- [8] B. R. McGee and R. M. Nelms, "Using a Cuk Converter to Interface a Pulsed Load to a Fuel Cell," Energy Conversion Engineering Conference, 29-31 July 2004, pp. 313-318.
- [9] Nur Mohammad, M. Quamruzzaman, M. R. T. Hossain, M. R. Alam, 2013, "Parasitic Effects on the Performance of SEPIC Converter in Photovoltaic Maximum Power Point Tracking Applications", *International Journal of Smart Grid Renewable Energy*, Vol. 4, No. 1, pp. 113-121, USA.
- [10] N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimizing Sampling Rate of P&O MPPT Technique," Proceedings of IEEE Power Electronical Special Conference, Vol. 3, 2004, pp. 1945-1949.
- [11] S.Daison Stallon, K.Vinoth Kumar, S.Suresh Kumar, "High Efficient Module of Boost Converter in PV Module, *International Journal of Electrical and Computer Engineering, IJECE* Vol 2, No 6, pp 758-765, December 2012.
- [12] C.-X. Liu and L.-Q. Liu, "An Improved Perturbation and Observation MPPT Method of Photovoltaic Generate System," 4th IEEE Conference on Industrial Electronics and Applications, 25-27 May 2009, pp. 2966-2970.
- [13] Amirullah Amirullah, Agus Kiswanto, "Power Quality Enhancement of Integration Photovoltaic Generator to Grid under Variable Solar Irradiance Level using MPPT-Fuzzy", *International Journal of Electrical and Computer Engineering, IJECE*, Vol 6, No 6, pp 2629-2642, December 2016.
- [14] J. H. R. Enslin, M. S. Wolf, D. B. Snyman and W. Swiegers, "Integrated photovoltaic maximum power point tracking converter," *IEEE Trans. On Industrial Electronics*, vol 44, no. 6, pp. 769-773, 1997.
- [15] Arjyadhara Pradhan, Dr. S.M.Ali, "Analysis of solar PV performance with change in temperature" *International Journal of Applied Engineering Research*, Volume 11, Issue 7, 1 May 2016.
- [16] Arjyadhara Pradhan, S.M.Ali, S.K.S Parashar, Gaurav Banerjee "Effect of panel orientation on the performance of PV system", *Journal of Advancement in Material Engineering*, Volume 3, Issue 1 pp-1-6, May 2016.
- [17] A.Pradhan, R.Bhol, S.M Ali, "Environmental effect assesment on performance of PV panel.", *IEEE International Conference on Circuit, Power and Computing Technologies, ICCPCT 2015*, Kanyakumari, Tamilnadu, 19 March.
- [18] Arjyadhara Pradhan, Dr.S.M.Ali, Dr.S.K.S Parashar "Study of various methods for improving the performance of solar PV module" *IEEE SCOPES-2016*, 3-5th October at Parlekhumdi.

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