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Optimization of Solar Photovoltaic Converters for Maximum Energy Efficiency

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Performance of a SPV system is dependent on temperature, array configuration, solar insolation, shading across it etc. The conversion of solar energy using SPV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the SPV modules. For improving the efficiency of conversion of solar energy can be done by tracking the maximum power point of a PV module. There are so many types of MPPT charge controllers for doing this important work in SPV system. A dc-dc converter is essential in SPV system as it acts as an interface between the load and the SPV module. Three different basic types of converters are explained in this paper without any non-idealities. There are other types of dc-dc converters as well, but these converters from these three basic converters. Further by using these dc-dc converters the performance of the MPPT algorithms can be done for improving the overall efficiency of the SPV system.

Keywords: *Maximum power point tracking (MPPT), Solar photovoltaic (SPV) characteristics, DC to DC converter*

1.0 INTRODUCTION

With growing population, economic and industrial development, the need to examine alternative sources for generating electricity has become very important. Solar Photovoltaic (SPV) system is gaining increased importance as a renewable source due to advantages such as the absence of fuel cost, little maintenance and no noise and wear due to the absence of moving parts. But there are still two principal barriers to the use of photovoltaic systems: the high installation cost and the low energy conversion efficiency. [1]. Solar energy has the advantages of clean emission free production and continuous supply during day time while being portable and scalable. Photovoltaic is the process of converting sunlight directly into electricity using solar cells. It basically comprises of two steps. The first step is the absorption of solar radiation within the semiconductor. In the second step, transformation to electrical energy is made by generating current and voltage by the incident solar radiation on the solar cells that produces electrons-hole pairs. The conversion of solar energy using SPV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the SPV modules [2-4]. A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers [2-4].A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load [5-6]. A dc/dc converter (step up/ step down) serves the purpose of transferring

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maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module Figure 1 [6]. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power [6]. Therefore MPPT techniques are needed to maintain the SPV array's operating at its MPP [7-8]. The main basic dc-dc converters are buck converter, boost converter and buck-boost converter. From these basic converters other types of converters have been derived.

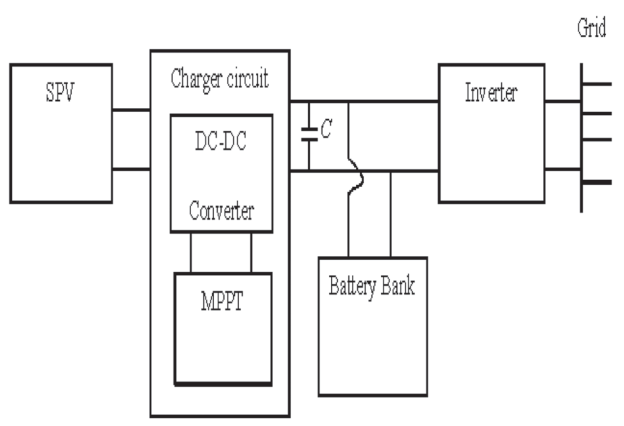

FIG. 1 BLOCK DIAGRAM OF THE SOLAR PHOTOVOLTAIC SYSTEM

2.0 SOLAR ARRAY CHARACTERISTICS

A solar photovoltaic (SPV) array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array as Figure 2.

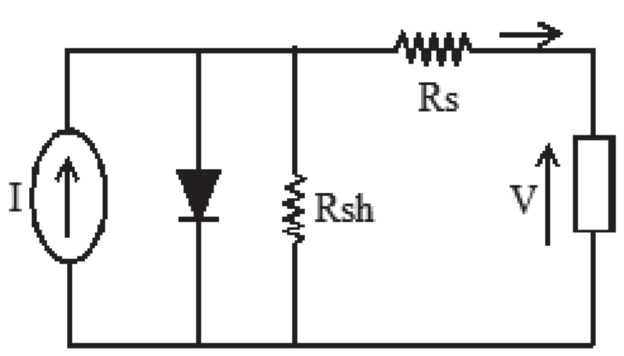

FIG. 2 SINGLE DIODE MODEL OF A SPV CELL [9]

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

The output current from the photovoltaic array is

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

$$I_d = I_o(e^{qV_d/kT} - 1) \quad ....(2)$$

Where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38 * 10-19 J/K) and T is the junction temperature in Kelvin (K) [9].

From equation (1) and (2)

$$I = I_{sc} - I_o(e^{qV_d/kT} - 1) \quad ....(3)$$

$$I = I_{sc} - I_o(e^{q((V+IR_s)/nkT)} - 1) \quad ....(4)$$

Where, I is the photovoltaic cell current, V is the SPV cell voltage; T is the temperature (in Kelvin) and n is the diode ideality factor Table 1.

TABLE 1
MODULE PARAMETERS

Module parameters	Values
Short circuit current	3.75 A
Series resistance of cell	0.001 Ω
Reference cell operating temperature	20 °C
Reference voltage	17.1 V
Reference current	3.5 A
Number of modules connected in series (N_s)	60
Number of modules connected in Parallel (N_p)	4

The maximum power point of a solar panel changes in accordance with changes in the solar irradiance intensity, angle and panel temperature. Figure 3 and Figure 4.

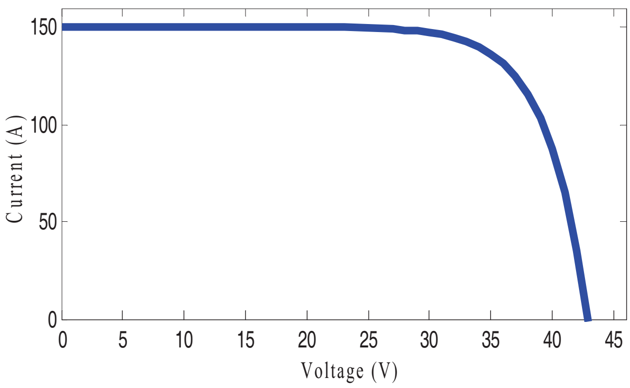

FIG. 3 I-V CHARACTERISTICS OF A SOLAR PANEL

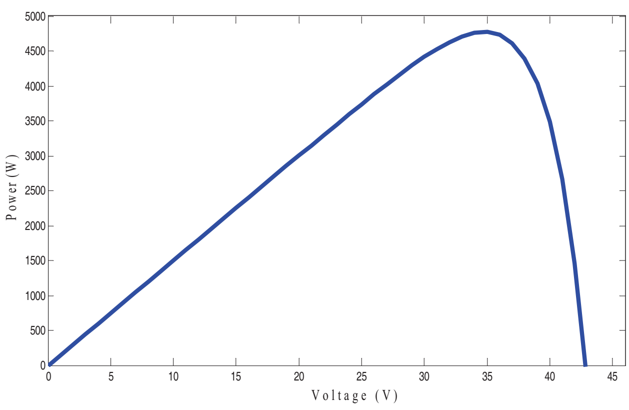

FIG. 4 P-V CHARACTERISTICS OF A SOLAR PANEL

3.0 DC TO DC CONVERTER

A DC-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. The DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drives applications. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. The heart of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

A switching converter consists of capacitors, inductors, and switches. All these devices ideally do not consume any power, which is the reason for the high efficiencies of switching converters. The switch is realized with a switched mode semiconductor device, usually a MOSFET. If the semiconductor device is in the on state, its current is zero and hence its power dissipation is zero. If the device is in the on-state, the voltage drop across it will be close to zero and hence the dissipated power will be very small. During the operation of the converter, the switch will be switched at a constant frequency f_s with an on-time of DTs, and an off time of $(1 - D)T_s$, where T_s isthe switching period $1/f_s$ and D is the duty ratio of the switch ($D \in [0; 1]$) as shown in Figure 5.

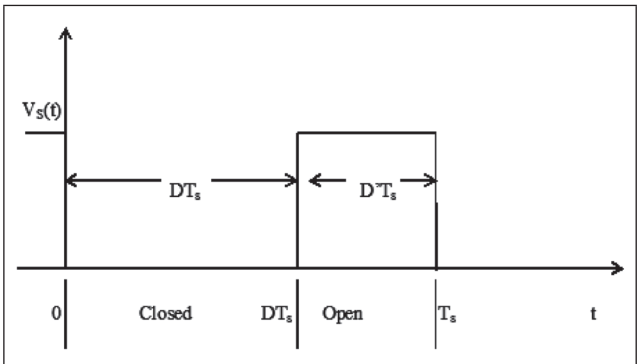

FIG. 5 IDEAL SWITCH VOLTAGE VS(T), DUTY RATIO D, AND SWITCHING PERIOD TS

3.1 Buck Converter

The buck converter can be found in the literature as the step down converter [10]. This gives a hint of its typical application of converting its input voltage into a lower output voltage, where the conversion ratio M = Vo/Vi varies with the duty ratio D of the switch [10-12].

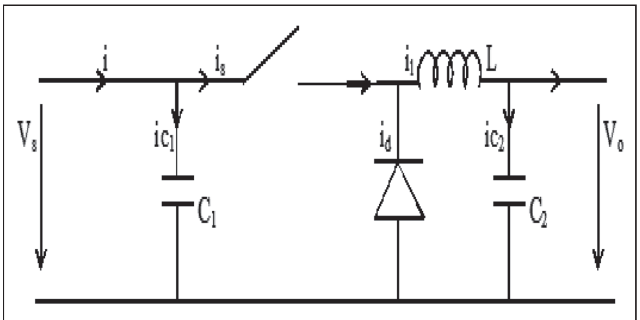

FIG. 6 IDEAL BUCK CONVERTER CIRCUIT

When the switch in Figure 6 is closed ($t \in (0;DTs)$), the diode will be reversebiased and a current flows through the inductor into the load. As soon as the switch is open ($t \in (DTs; Ts)$), the inductor will maintain the current flow to the load, but the loop closes through the now forward biased diode.

3.2 Boost Converter

The boost converter is also known as the step-up converter as shown in Figure 7. The name implies it's typically application of converting a low input-voltage to a high out-put voltage, essentially functioning like a reversed buck converter [10-12].

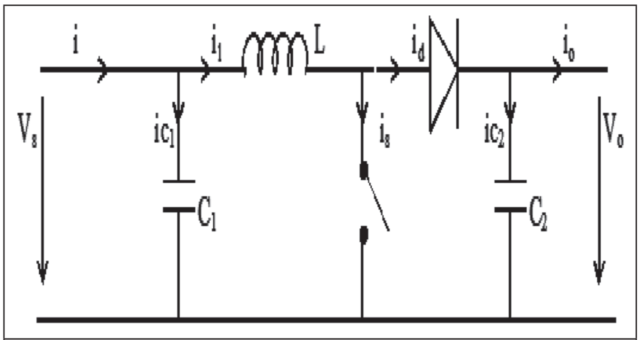

FIG. 7 IDEAL BOOST CONVERTER CIRCUIT

During the on time interval DTs of the switching period Ts, the closed switch connects the input through the inductor to ground and a high current starts to flow. The diode is reverse biased so no inductor current flows through the load. After the switch is opened in the off time interval DTs of the switching period, the nature of the inductor objects to the discontinuity in the current flow, and the high current through the now forward biased diode leads to a high voltage rise which is applied across the load.

3.3 Buck-Boost Converter

The buck-boost converter combines the properties of the buck and boost configurations. It can be used to ideally transform any dc input voltage into any desired dc output voltage. In practical usage the ideality is of course limited by component losses.

Figure 8 shows the ideal equivalent circuit diagram of the buck-boost converter. If the switch is closed during the first time interval DTs of the switching period Ts, a current starts flowing from the input source through the inductor to ground. After the switch opens at the beginning of the second time interval D'Ts, this current flow is maintained by the nature of the inductor. The current loop closes through the load and the diode. Since the current is forced to flow backwards through the load, the output voltage V_o of the buck-boost converter is negative. Variation of the duty ratio D will vary the conversion ratio between output and input voltage V_o/V_i.

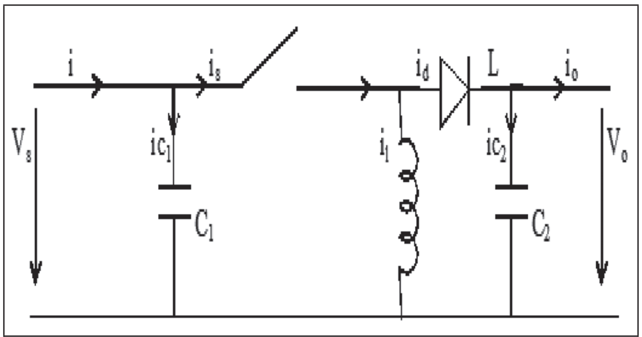

FIG. 8 IDEAL BUCK-BOOST CONVERTER CIRCUIT

4.0 CONCLUSIONS

This paper has presented the different basic types of DC-DC converters like Buck converter, Boost converter and Buck-Boost converter. As per the literature in simulation the buck converter show the best performance the controller work at the best condition.

One simple solar panel that has standard value of insolation and temperature has been shown.

By using these basic converters the different types of MPPT algorithm can be simulated and the performance of these MPPT algorithms can be analyzed.

REFERENCES

[1] M. G. Simoes and N. Franceschetti, "Fuzzy Optimization based control of a Solar Array System," in *IEE - Proceedings, Electr Power Appl, Vol.146 No. 5*, pp. 552-558, August 2002.

[2] R. S. Lewis, "Antartic Research and Relevant of Science," in *Bulletin of the Atomic Scientists*, vol. 26, 1970, pp. 2.

[3] Y. H. Chang and C. Y. Chang, "A Maximum Power Point Tracking of PV System by Scaling Fuzzy Control," presented at

International Multi Conference of Engineers and Computer Scientists, Hong Kong, 2010.

[4] S. Mekhilef, "Performance of grid connected inverter with maximum power point tracker and power factor control,"*International Journal of Power Electronics*, vol. 1, pp. 49-62,2008.

[5] M. E. Ahmad and S. Mekhilef, "Design and Implementation of a Multi-Level Three-Phase Inverter with Less Switches and Low Output Voltage Distortation," *Journal of Power Electronics*, vol. 9, pp. 594-604, 2009.

[6] S. Chin, J. Gadson, and K. Nordstrom, "Maximum Power Point Tracker," Tufts University Department of Electrical Engineering and Computer Science, 2003, pp. 1-66.

[7] R. Faranda and S. Leva, "Energy Comparison of MPPT techniques for PV Systems," *WSES Transaction on Power Systems*, vol. 3, pp.446-455, 2008.

[8] Trishan Esram and Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," *IEEE* Tr*ansactions on Energy Conversion*, Vol. 22, No. 2, June 2007.

[9] Marcelo Gradella Villavla, Jones Rafael Gazoli, Ernesto Ruppert Filho, "Comprehensive approach to modeling and simulation of Photovoltaic arrays"

[10] H. Knopf, "Analysis, Simulation, And Evaluation of Maximum Power Point Tracking (MPPT) Methods for a solar power vehicle,"in *Electrical and Computer Engineering*, vol. Master of Science in Electrical and Computer Engineering: Portland State University 1999, pp. 177.

[11] T. S. Ustun and S. Mekhilef, "Effects of a Static Synchronous Series Compensator (SSSC) Based on Soft Switching 48 Pulse PWM Inverter on the Power Demand from the Grid," *Journal of Power Electronics*, vol. 10, pp. 85-90, 2010.

[12] Hairul Nissah Zainudin and Saad Mekhilef, "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems", Proc. of the 14th International Middle East Power Systems Conference,Cairo University, Egypt, December 19-21, 2010.