Comparison of DC to DC Converter for PV System to Track MPP

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Abstract - Now a day Photo-Voltaic (PV) power generation is essential because it has more advantages over conventional methods. It is environment friendly, i.e., free from pollution, less maintenance cost and free fuel energy. But, the major obstacles are high initial cost and low energy conservation. The purpose of this project is to design and optimize DC-DC converter for battery charging which will extract maximum power from solar panel. The single ended primary inductor converter (SEPIC) performance is comparatively better than the other traditional converters. A Cuk converter which is also known as a better performance converter is compared. For the application of solar, both the converters are compared to each other with simulation.

Keywords – Photo-Voltaic, DC to DC converter, Cuk converter, SEPIC converter, MPPT.

I. INTRODUCTION

Renewable energy sources like solar, wind and fuel cells are more important as they are environmental friendly as that of conventional energy sources. But these sources are difficult to tap, store and use. These resources of energy are freely available, it is necessary to utilize them, but it requires high initial cost. Their energy conservation efficiency is less. The motivation for this project is to increase the efficiency in conservation and energy storage.

All the solar power systems use batteries to store energy. Batteries provide power to the load when solar energy is less. In such a case there may be deep discharge of battery takes place. When solar power is more it may cause over charging of battery. For such situation battery life get reduces. Generally batteries used are lead acid batteries as its cost is less but it requires more maintenance and less life. Nickel-cadmium batteries can be used instead of lead acid batteries as it has low maintenance and long life. But, its cost is more. Generally, for solar applications valve regulated lead acid batteries are used. It is low cost, maintenance free and most recyclable. To get long life of battery it should not be overcharged and deep discharged. In solar application battery life gets reduced when photo voltaic cell output is less. So converter requires maximum power point tracking control.

Maximum power tracking technique has advantage – it will increase solar cell efficiency, it will extract maximum power from p-v array, it will match source and load properly. Output of solar array is depends upon solar installation, cell temperature and load level. There are so many MPTT techniques. Trishan and Chapman in June 2007 gives, there were at least nineteen distinct methods. But the most commonly used methods are P&O, incremental conductance method, ripple correlation (RCC), constant voltage and constant current etc.

Cuk converter is responsible for maximum power. Cuk converter operates in both modes i.e. buck mode and boost mode. If input less then boost mode operation and if input is more buck mode operation. This will be controlled by duty cycle of pulses provided to switch. A SEPIC (Single Ended Primary Inductance Converter) DC-DC converter maintains output voltage constant for a input DC voltage that varies from above and below output voltage. This type of conversion is handy. SEPIC is able to function as both a buck a boost converter. A simple controller and clamped switching waveforms that provides low noise operation.

Conversion of AC-AC is very easy. i.e., by using transformer but conversion of DC-DC is not simple. By using diodes and voltage bridges, voltage can be reduced by a set amount i.e. output is less than input voltage. Voltage regulators are also used to provide a reference voltage. But these are not efficient methods. The most efficient method of regulating dc voltage is by using dc-dc converters. There are five main methods of dc-dc converters. Buck converter reduces voltage, boost converter which increases voltage and buck-boost, Cuk and SEPIC converters will increase or decrease the voltage. However in case of solar applications, solar output is varying hence it requires buck and boost operation. Buck-boost converters are cheaper because it requires only single inductor and capacitor. However these converters has drawback that output contains high amount of ripples. These ripples can create harmonics which will not be allowed in some applications. To improve harmonics, it requires large capacitor or LC filter, which will make circuit more expensive and inefficient. Another issue is that they invert the voltage. Cuk converter solves these problems by using extra capacitor and inductor. In case of Cuk and buck-boost converters operation causes large amount of electrical stress on the component. This can results in device failure or overheating. SEPIC converter solves both of these problems. For the solar applications Cuk converter and SEPIC converter are designed, its operation is checked in on simulation using MATLAB/SIMULINK. Their performance is compared on various parameters like changing voltage, current, output power and their efficiency.

II. BLOCK DIAGRAM

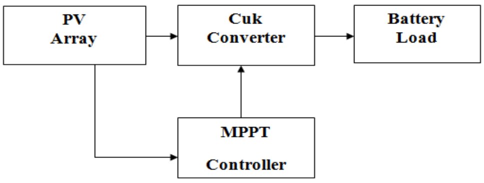

Figure 1: Block Diagram of Cuk Converter with MPPT

Output of the PV array is applied to load through Cuk converter which is shown in figure 1. Cuk converter will boost or buck the PV cell output voltage to the load. Cuk converter output will be controlled by MPPT controller. MPPT controller is used here as incremental conductance technique. If the input to the Cuk converter is less, i.e., Cuk converter operates in boost mode operation. For this MPPT controller output pulse duty cycle should be more than 50%. If the input to Cuk converter is more i.e., Cuk converter should be in buck mode operation. For this MPPT controller output pulse duty cycle should be less than 50%. Cuk converter and MPPT controller combined operate to extract maximum voltage from the PV cell to the battery.

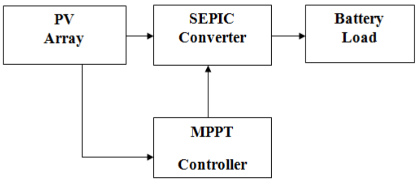

Figure 2: Block Diagram of SEPIC Converter with MPPT

Solar cell output voltage is not constant, it is variable and it will depends solar installation, cell temperature and load level. Output Voltage must be maximum to the load, i.e., to charge the battery. Output voltage of the solar cell should be more, but, if solar cell output is less then, it is necessary to increase the output voltage. The SEPIC converter is connected in between PV array and load as shown in above figure 2. The SEPIC converter can boost output voltage when input is low i.e. MPPT controller will increases the output pulse width i.e. nothing but duty cycle switch of SEPIC. SEPIC converter can operate in buck mode operation when input is less, i.e., controller will decrease duty cycle. MPPT controller uses incremental conductance technique (ICT). Here MPPT controller and SEPIC converter combined together to operate to extract maximum power from PV cell.

III. PHOTO-VOLTAIC ARRAY

Photovoltaic array is made up of combination of small single cells. Numbers of cells are connected in series to generate some useful voltage. A single cell cannot act as fixed current source or voltage source. But it is approximated as current source which is depends on voltage source. Solar cell is p-n semiconductor junction. A single cell generates about 0.6V when exposed to sunlight. Equivalent circuit of photovoltaic solar cell is shown in below figure 3-

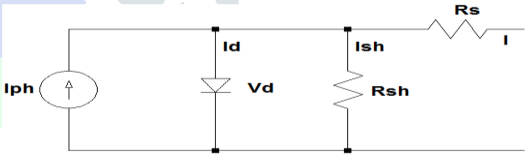

Figure 3: Equivalent Circuit of PV Solar Cell

Current generate by a solar cell is given by following equations which is dependent on solar radiation and temperature of cell-

$$I_L = I_{PH} - I_S[\exp(\frac{qV_d}{AK_BT}) - 1] - \frac{V_d}{R_{SH}} \qquad ....1$$

$$I_{PH} = [I_{SC} + K_1(T_C - T_{Ref})]G \qquad ....2$$

$$I_S = I_{RS}(\frac{T_C}{T_{Ref}})^3 \exp[qE_B(\frac{1}{T_{Ref}} - \frac{1}{T_C})/K_BA] \qquad ......3$$

$$I_L = N_P I_{PH} - N_P I_S[\exp(qV/N_S KT_C A) - 1] \qquad ......4$$

$$I_L = N_P I_{PH} - N_P I_S[\exp(qV/N_S KT_C A) - 1] \qquad .....5$$

Where,

I_L = Net Output Current

I_{PH} = Light Activated Current

I_S = Diode Saturation Current

q = Charge on Electron = $1.6 * 10^{-19}$ C

V_d = Voltage Across diode i.e. solar cell output voltage in volts

A = Diode Identity Factor

R_{SH} = Shunt Resistor of diode

R_S = Series Resistance

K_B = Boltzmann's Constants = $1.83 * 10^{-23}$ J/^{0}K

T_C = Cell Working Temperature

I_{SH} = Shunt Leakage Current

G = Solar Installation

I_{SC} = Short Circuit Current at Standard Test Condition i.e. 25^{0}C and 100 W/m2

K_1 = Cell short circuit temperature coefficient

T_{ref} = Reference Temperature of 25^{0}C

I_{RS} = Reverse Saturation Current

By using the equations 1 to 5 PV array can be modelled.

IV. DC-DC CONVERTERS

➢ Cuk converter

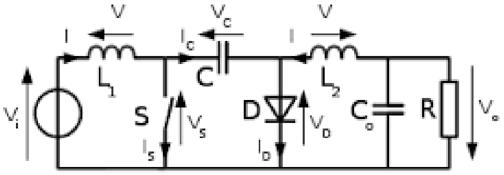

Figure 4: Circuit diagram of Cuk Converter

Above figure 4 shows the circuit diagram of Cuk converter. Cuk converter circuit is responsible for operating in both buck and boost mode. The switch 'S' is responsible for this. Duty cycle of this switch 'S' can control the buck and boost operations. Cuk converter operation is divided into two parts i.e. when switch 'S' is ON and when switch 'S' is OFF. When switch 'S' is ON, input voltage is given to the circuit via inductor L1. The current I1 develops the magnetic field of the inductor. The diode D1 gets reverse biased due to voltage capacitor C1. The current I2 flows through L2. Both current I1 and I2 flow through switch 'S'. The voltage on capacitor C1 gets decreased i.e. transferring energy to the L2 and output load and hence I2 goes on increases. The input energy feeds to L1 causing I1 to increases.

When switch 'S' is OFF inductor L1 tries to maintain the current through if reversing its polarity. L1 acts as current source and its magnetic field starts decreasing. This energy is transforming to next section via C1. Capacitor C1 is charged through diode by input and L1. As C1 voltage starts developing, the current I1 decreases. The energy stored into L2 is given to load and I2 also goes on decreasing. By using principles of energy conservation i.e. current through L1 and L2 i.e. I1 and I2, we can write, $\frac{Vo}{Vs} = \frac{Ds}{1-Ds}$ where Ds = Duty Cycle, $Ds = \frac{TON}{TON+TOFF}$.

A main advantage of this converter is that input and output currents are filtered. In case of buck, boost and buck boost converters have pulsating currents on input and output sides. This will cause increase in ripples and hence efficiency of battery gets reduced. By adjusting duty cycle of the switch 'S', output voltage can be controlled

➢ SEPIC Converter

The SEPIC converter can be used as step-up or step-down operations. High frequency pulse is applied to operate the switch. By changing the duty cycle of this high frequency pulse output can be controlled. The circuit diagram of the SEPIC converter is as shown in below figure 5.

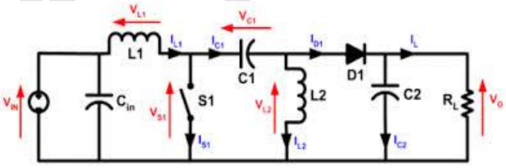

Figure 5: Circuit Diagram of SEPIC Converter

Operation of the SEPIC converter is also explained in two parts. i.e. when switch 'S1' is ON and when switch 'S1' is OFF. When switch 'S1' is ON, i.e. when pulse is high, inductor L1 is charged by the input voltage and inductor L2 is charged by capacitor C1, the diode gets reversed biased and output voltage is provided by the capacitor C2. Now pulse is made low i.e. switch 'S1' is OFF, the energy stored into the inductor is transferred to the output through diode. There are two current loops- first contains input, L1, C1, diode, C2 and load. Second loop contains – L1, diode, C2 and load. The capacitors C1, C2 and load is charged in this phase. If duty cycle is less output voltage will be more.

This type of converter has less active components, simple controller and clamped switching waveforms due to which it reduces noise. It reduces electrical stress on the components, it will results less failure of device and less overheating.

Output voltage of SEPIC converter will depends upon duty cycle and is given by $Vo = \frac{D*Vi}{1-D}$ where D = Duty Cycle. But the output voltage also depends upon the parasitic elements like diode. In this case, if we consider voltage drop across diode then output voltage is given by

$$Vo + Vd = \frac{D + Vi}{1-D} \quad \text{Hence,} \quad D = \frac{Vo+Vd}{Vi+Vo+Vd}$$

Where Vi = Input Voltage, Vo = Output Voltage and Vd = Voltage across diode.

V. MPPT CONTROLLER

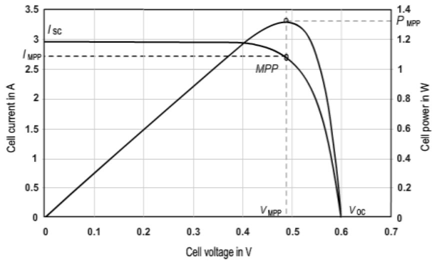

Figure 6: I-V and P-V Characteristics

Figure 6 shows I-V and P-V characteristics of solar panel. This curve is not stable; it will depend on insolation and temperature of weather. These two parameters are continuously changing throughout day. This will cause wide variations in produced energy from PV array. Observe I-V and P-V curve, there is a point on curve at the knee, where solar panel generates maximum energy. i. e. PV array operates with maximum efficiency. This point is nothing but maximum power point (MPP). For any atmospheric conditions if the maximum power point is tracked, it will maximum power. The Cuk and SEPIC converters are used as power conditioning units which are kept in between PV array and load. These units are controlled by MPPT controller. Input voltage to the power conditioning unit is variable and its output will be controlled such as it will extract maximum power.

There are so many MPPT algorithms. This controls output power by observing change in voltage, current and power. Some of the MPPT algorithms are as Perturb and Observe, Incremental Conductance Technique (ICT), constant voltage, constant current, ripple correlation control, fuzzy based control etc. out of these incremental conductance technique has some advantages like it has great accuracy in tracking MPP and it also has moderate complexity in implementation. Due to this advantage this technique is used for this project. In this technique to track MPP it will compare incremental conductance (ΔI/ΔV) with instantaneous conductance (I/V) of the PV array. The addition of these conductance is zero at MPP, it is less than zero on right side of MPP and it is more than zero on left side of MPP. This is shown in figure 7.

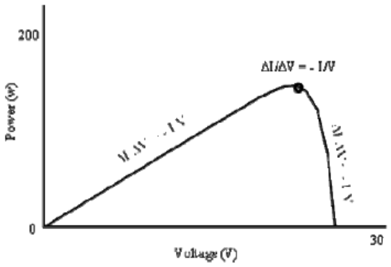

Figure 7: Incremental Conductance MPPT Techniques

VI.MATLAB SIMULINK ENVIRONMENT

➢ Cuk Converter without MPPT

Circuit diagram of Cuk converter without MPPT controller is shown in below figure 8. PV array output is applied to the battery through the Cuk converter. Here, pulse width of control signal applied to the MOSFET is fixed.

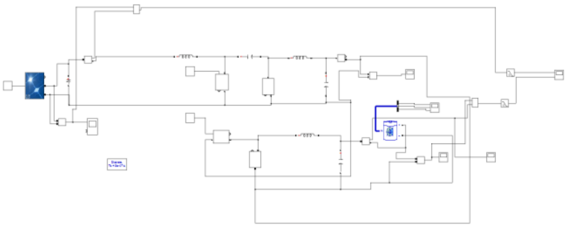

Figure 8: Circuit diagram of Cuk Converter without MPPT

➢ Cuk Converter with MPPT

Circuit diagram of Cuk converter with MPPT controller is shown in below figure 9. MPPT controller added here is an incremental conductance technique used to control duty cycle of control signal applied to the MOSFET.

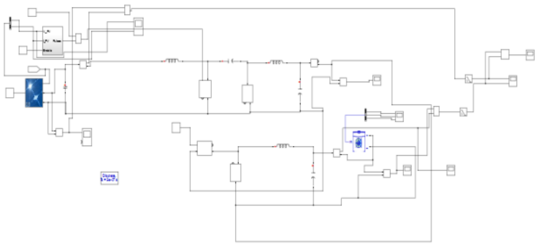

Figure 9: Circuit diagram of Cuk Converter with MPPT

➢ SEPIC Converter without MPPT

Circuit diagram of SEPIC converter without MPPT controller is shown in below figure 10. PV array output is applied to the battery through the SEPIC converter. Here, pulse width of control signal applied to the MOSFET is fixed.

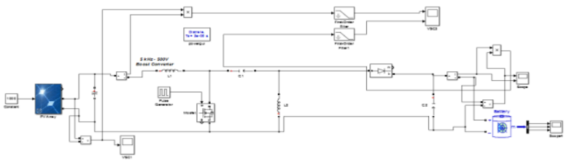

Figure 10: Circuit Diagram of SEPIC Converter without MPPT

➢ SEPIC Converter with MPPT

Circuit diagram of SEPIC converter with MPPT controller is shown in below figure 11. MPPT controller added here is an incremental conductance technique used to control duty cycle of control signal applied to the MOSFET.

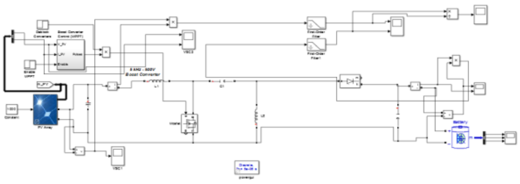

Figure 11: Circuit Diagram of SEPIC Converter with MPPT

VII. Comparison of Results

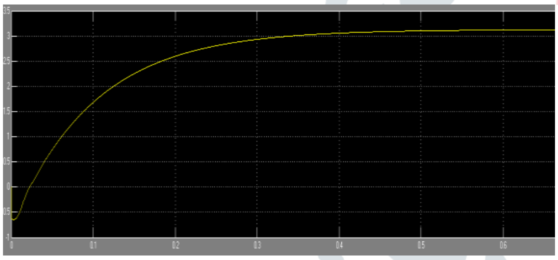

Figure 12: Graph of Output Power of Cuk without MPPT

Figure 12 showing output power (3W) of the Cuk converter without MPPT which is product of output voltage and current.

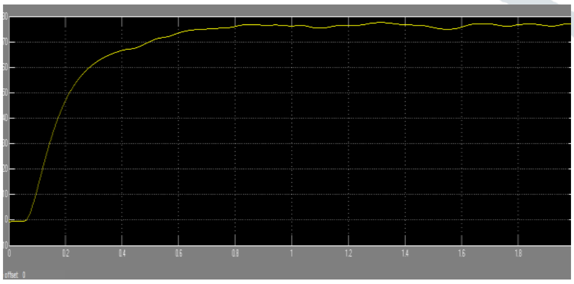

Figure 13: Graph of Output Power of Cuk with MPPT

Figure 13 showing output power (75W) of the Cuk converter with MPPT which is product of output voltage and current.

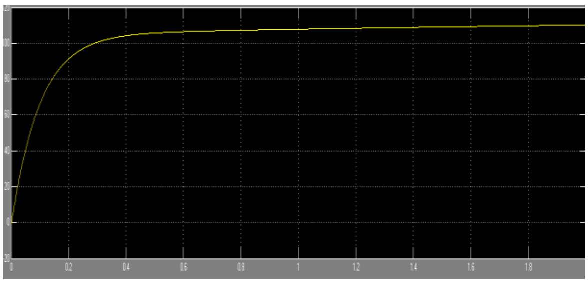

Figure 14: Graph of Output Power of SEPIC without MPPT

Figure 14 showing output power (110W) of the SEPIC converter without MPPT which is product of output voltage and current.

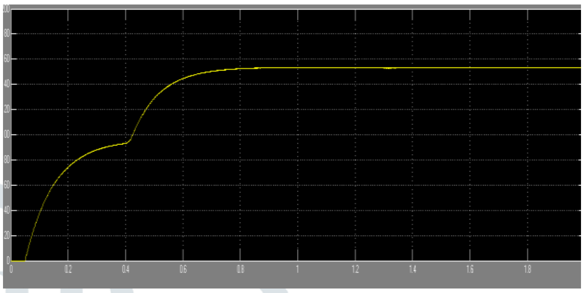

Figure 15: Graph of Output Power of SEPIC with MPPT

Figure 15 showing output power (150W) of the SEPIC converter with MPPT which is product of output voltage and current.

VIII. Discussion

From experimental results observed, the DC-DC converters without MPPT either Cuk or SEPIC, their output power is less as compared to the DC-DC converters with MPPT. Also it is observed SEPIC converter with MPPT output power is more as compared to Cuk converter output power for the same environmental conditions. In both cases there are less active components. MPPT controller used here is incremental conductance technique. And power conditioning unit having less active components and hence controller is simple. There output voltage and current waveforms are filtered one. Particularly SEPIC output has less noise, it reduces electrical stress, less overheating and hence circuit reliability will be more in SEPIC.

CONCLUSION

A DC-DC converter implemented with Cuk and SEPIC converter with MATLAB simulink for simulation. The MPPT method simulated in this project is incremental conductance method is able to extract maximum power even though fluctuation in output of PV array. When environmental conditions changes immediately, then system can track MPP quickly. Both Cuk and SEPIC converters are able to track MPP. They can work in both modes i.e. Buck and Boost modes. SEPIC converter output power is more than Cuk converter for same environmental conditions, and circuit reliability of SEPIC is more than other methods. Only one control signal can control output voltage and responsible for extracting maximum power. Proposed SEPIC converter based technique can be implemented using microcontroller to achieve maximum power in actual PV system.

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