

Simulation and Hardware Implementation of Incremental Conductance MPPT Using Self Lift Cuk Converter

M. Latha Devi¹, Mr. M. Chilambarasan, M.E.,²

PG Scholar, Dept. of EEE, St. Joseph's College of Engineering, Chennai, India¹

Assistant Professor, Dept. of EEE, St. Joseph's College of Engineering, Chennai, India²

Abstract— This paper presents design and simulation of incremental conductance (IncCond) Maximum Power Point Tracking (MPPT) using self lift cuk converter. The solar panel model is developed using the basic circuit equations of photo voltaic cell. The MPP of a solar panel varies with irradiation and temperature. The IncCond algorithm is used to track the maximum power from the solar panel. The unregulated voltage from the panel will be regulated by using the self lift cuk converter. It will reduce the voltage and current ripple. As for component stress the self lift cuk converter has a smaller voltage and current stresses than the original cuk converter. Matlab/Simulink was used for simulation studies.

Index Terms— Microcontroller, Incremental conductance (IncCond) maximum power point tracking (MPPT), self lift cuk converter, photovoltaic (PV) system.

I. INTRODUCTION

Global warming have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. Photo Voltaic (PV) power generation has an important role to play due to the fact that it is a renewable source.

The efficiency of a PV plant is affected by three factors: the efficiency of the PV panel, the efficiency of the converter and the efficiency of the maximum power point tracking (MPPT) algorithm.

Improving the efficiency of the photovoltaic panel and the converter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. Instead, improving the tracking of the Maximum Power Point with new control algorithms is easier, not expensive and it can be done even in plants which are already in use by

updating their control algorithms, which would lead to an immediate increase in photovoltaic power generation and consequently a reduction in its price.

II. PHOTOVOLTAIC MODELING

The simplest model of a photovoltaic cell consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons and its output is constant under constant temperature and constant incident radiation of light. A solar cell is the building block of a PV panel.. This model is known as a single diode model of aPV cell.

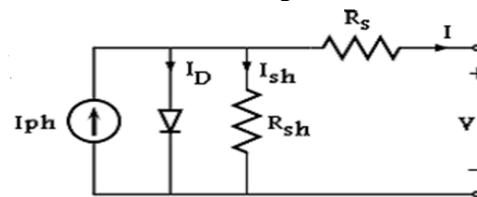


Fig. 1. Equivalent circuit of PV cell.

The output current from the PV cell is found by applying the Kirchoff's current law on the equivalent circuit.

$$I = I_{ph} - I_D \quad (1)$$

where I is the output current from PV cell, I_{ph} is the photon current, I_d is the diode current. The ideal diode equation is given as follows:

$$I_D = I_s (e^{qV_d/kT} - 1) \quad (2)$$

where I_D is the diode current, I_s is the saturation current, q is the electron charge, k is the Boltzmann constant and T is the actual temperature. By substituting Eq. 2 in Eq. 1, we can get the value of the photon current I_{ph} . The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = [I_{sc} + K_i(T-298)] \frac{\lambda}{1000} \quad (3)$$

where I_{ph} is the photon current, I_{sc} is the cell's short-circuit current, K_i is the cell's short-circuit current temperature coefficient, T is the solar cell's actual temperature, and λ is the solar insolation.

The reverse saturation current is expressed as

$$I_{rs} = I_{sc} / [\exp(qV_{oc}/N_s kAT) - 1] \quad (4)$$

where I_{rs} is the reverse saturation current, V_{oc} is the open circuit voltage, N_s is the number of cells connected in series, k is the Boltzmann constant, q is the electron charge, A is the ideality factor and T is the actual temperature.

The module saturation current I_s varies with the cell temperature, which is given by

$$I_s = I_{rs} [(T/T_r)^3 \exp\{qE_g/Ak\{(1/T_r)-(1/T)\}]} \quad (5)$$

where I_s is the saturation current, E_g is the band-gap energy of the semiconductor used in the cell, T_r is the reference temperature.

The current output of PV module is

$$I_{pv} = N_p I_{ph} - N_p I_s [\exp\{q(V_{pv} + I_{pv} R_s) / N_s A k T\} - 1] \quad (6)$$

where I_{pv} is the photovoltaic current and N_p is the number of cells connected in parallel. In fact, the PV efficiency is sensitive to small change in R_s but insensitive to variation in R_{sh} . For a PV module, the series resistance becomes apparently important and the shunt resistance approaches infinity which is assumed to be open, where $V_{pv} = V_{oc}$, $N_p = 1$ and $N_s = 36$.

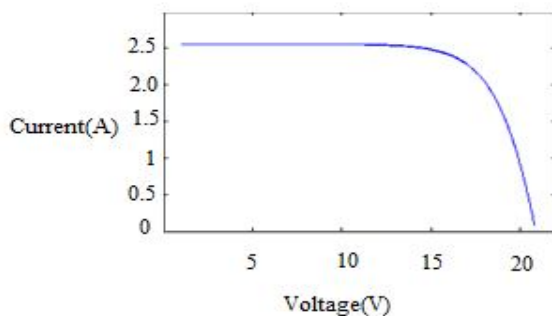


Fig. 2. I-V curve of a solar cell.

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values and

temperature. With increase in the solar irradiation the open circuit voltage increases. Increase in temperature is accompanied by a decrease in the open circuit voltage value.

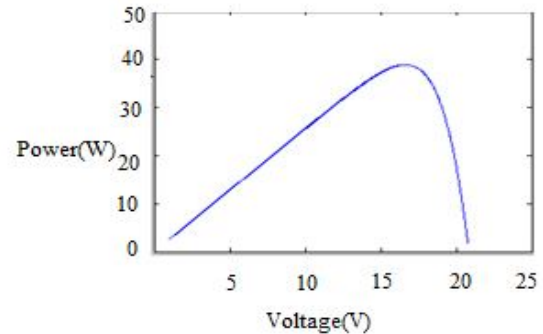


Fig. 3. P-V curve of a solar cell.

Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced.

III. MAXIMUM POWER POINT TRACKING

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel.

According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem.

In the source side we are using a self lift cuk converter connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load.

By changing the duty cycle of the self lift cuk converter appropriately we can match the source impedance with that of the load impedance.

A. Incremental Conductance Algorithm

Incremental conductance method uses voltage and current sensors to sense the output voltage and current of the PV array. At MPP the slope of the PV curve is 0.

$$\frac{dI}{dV} = -\frac{I}{V} \left(\frac{dP}{dV} = 0 \right) \quad (7)$$

The left hand side of the equation represents incremental conductance of the PV module, and the

right hand side of the equation represents the instantaneous conductance of the PV panel.

From the Equation 7, it is obvious that when the ratio of the change in the output conductance is equal to the negative output conductance, then maximum power point is reached.

$$\frac{dI}{dV} > -\frac{I}{V} \quad \left(\frac{dP}{dV} > 0\right) \quad (8)$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \left(\frac{dP}{dV} < 0\right) \quad (9)$$

Equation 8 and Equation 9 are used to determine the direction in which a perturbation must occur to move the operating point toward the maximum power point, and the perturbation is repeated until Equation 7 is satisfied.

Once the MPP is attained, the MPPT continues to operate at this point until a change in current is measured. The present value and the previous value of the PV voltage and current are used to calculate the values of dI and dV.

If $dV > 0$ and $dI > 0$, then the amount of sunlight has increased, by increasing the MPP voltage. The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values and temperature.

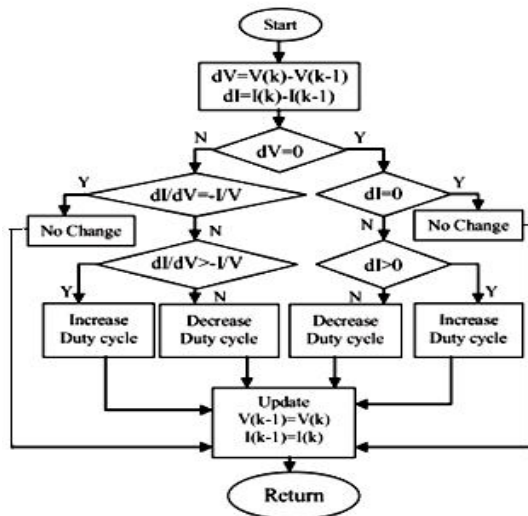


Fig. 4. Flowchart of the IncCond method.

Figure 4 shows a flowchart for the incremental conductance algorithm. Here we will measure both the voltage and current simultaneously. Hence the error due to change in insolation is eliminated. Incremental Conductance method is the best method because it does not produce steady state oscillations and it provides

precise control under rapidly varying atmospheric condition. It can track the maximum power from the sun.

IV. SELECTING PROPER CONVERTER

There are a number of different topologies for DC-DC converters. They are categorized into isolated or non-isolated topologies. These topologies are further classified into three types: buck, boost, and buck-boost. Then, there are topologies able to step up and down the voltage such as: buck-boost and cuk converter. Thus, the additional boost capability can slightly increase the overall efficiency. The cuk and the self lift cuk converter can be able to step up and step down the voltage.

A. Cuk Converter

The Cuk converter consist of two inductors, two capacitors, a switch and a diode. Its schematic can be seen in Figure 5. It is an inverting converter, so that the output voltage is negative with respect to the input voltage.

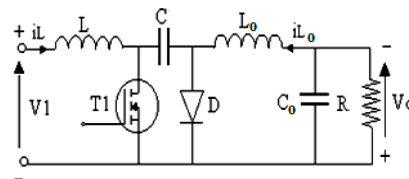


Fig. 5. Cuk converter.

The capacitor C is used to transfer the energy and it is connected alternately to the input and to the output of the converter via the commutation of the transistor and the diode. The two inductors L_1 and L_2 are used to convert the input voltage source V_1 and the output voltage source C_2 into current sources.

B. Self Lift Cuk Converter

The maximum voltage obtained from the panel is unregulated. The unregulated voltage can be converted to regulated voltage by using a self lift cuk converter. Self lift cuk converter is one of the type of voltage lift converters. It is the improved version of cuk converter. In this converter the input current and the output current is continuous.

The output voltage ripple produced in this converter is very less when compared to self lift cuk converter. As for component stress, it can be seen that the self lift cuk converter has smaller voltage and current stresses than the cuk converter. It has low switching losses and highest efficiency when compared to cuk converter.

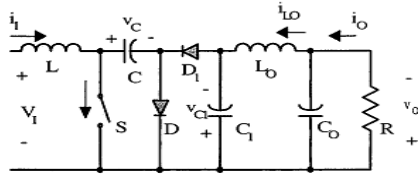


Fig. 6. Electrical circuit of self lift cuk converter.

Figure 6 shows the self lift cuk converter equivalent circuit and Figure 7 and Figure 8 shows its operating modes, which acts like an interface between PV panel and the resistive load.

C. Operating Modes of Self Lift Cuk Converter

This converter performs DC-DC voltage increasing conversion in simple structure. The self lift cuk converter has two modes of operation.

1) Mode 1:

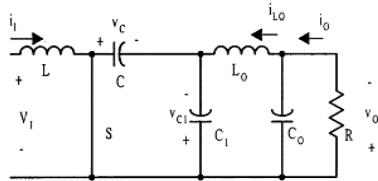


Fig. 7. Electrical circuit of self lift cuk converter during switch ON period.

During the first mode of operation the switch will be turned on. The switch S and diode D_1 are on. During switch-on period, the voltage across the capacitors C and C_1 are equal.

In this mode the capacitor C starts to discharge. It gives energy to the output. The equations for the switch conduction mode are as follows:

$$V_{c1} = V_{c0} = V_0 \quad (10)$$

The inductor current increases during switch on and it starts to decrease during switch off. The corresponding voltages across inductor L are input voltage V_1 and $-(V_c - V_1)$.

Therefore,

$$kTV_1 = (1-k)T(V_c - V_1) \quad (11)$$

$$\text{and hence } V_0 = V_c = V_{c1} = V_{c0} = \frac{V}{(1-k)} \quad (12)$$

Since all the components are ideal, the power loss associated with all the circuit elements is neglected. Therefore the output power P_o is considered to be equal to the input power P_{IN} :

$$V_o I_o = V_1 I_1 \quad (13)$$

$$\text{Thus, } I_L = I_1 = \frac{I_o}{(1-k)} \quad (14)$$

2) Mode 2:

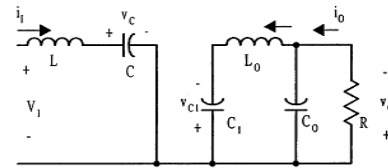


Fig. 8. Electrical circuit of self lift cuk converter during switch OFF period.

During the switch-off condition, diode D is on, switch S and diode D_1 are off. The inductor current decreases and diode D_1 is forward biased and the capacitor C is charged by using the input supply.

$$i_d = i_L \quad (15)$$

$$I_D = \frac{I_o}{1-k} \quad (16)$$

The capacitor C_o acts as a low pass filter so that

$$I_{L0} = I_o \quad (17)$$

The current i_L increases during switch-on. The voltage across it during switch-on is V_1 , therefore its peak to peak current variation is

$$\Delta i_L = \frac{kTV_1}{L} \quad (18)$$

During the steady state condition the average inductor voltage and the capacitive current waveforms are zero. The relationship between the output and input voltages and currents are given in the following:

$$\frac{V_o}{V} = \frac{1}{(1-k)} \quad (19)$$

$$\frac{I_1}{I_o} = \frac{1}{(1-k)} \quad (20)$$

The peak to peak variation of the voltage v_c is

$$\Delta v_c = \frac{I_o}{fC} \quad (21)$$

Assuming 5% of ripple in the capacitor voltage, we can find the value of capacitor C. The peak to peak variation of the voltage v_{c1} is

$$\Delta v_{c1} = \frac{I_o(1-k)}{f c_1} \quad (22)$$

Assuming 5% of ripple in capacitor voltage Δv_{c1} , we can find the value of C_1 . The peak to peak variation of the current i_{LO} is

$$\Delta i_{LO} = \frac{I_o(1-k)}{8f^2 L_o C_1} \quad (23)$$

Assuming 5% of ripple in the inductor current, we can find the value of i_{LO} . The peak to peak variation of voltage v_o and v_{CO} is

$$\Delta v_o = \Delta v_{CO} = \frac{I_o(1-k)}{64f^3 L_o C_1 C_o} \quad (24)$$

Assuming 5% of ripple in capacitor voltage Δv_{CO} , we can find the value of filter capacitor C_o .

TABLE I

COMPONENT VALUES USED IN SIMULATION

Components	Cuk Converter	Self Lift Cuk converter
L	3.59mH	2.7mH
L_o	3.59mH	0.136mH
C	13.3 μ F	29.45 μ F
C_o	0.25 μ F	0.184 μ F
C_1		14.7 μ F

V. SIMULATION RESULTS

The diagram of the open-loop system designed in MATLAB and Simulink is shown in Fig. 9, which includes the PV module electrical circuit, the self lift cuk converter and the MPPT algorithm.

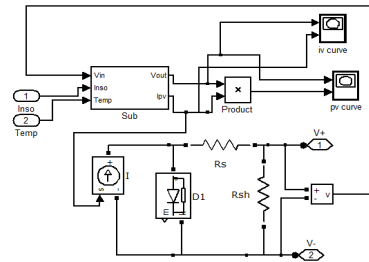


Fig. 9. Simulink model of the PV panel.

The PV module is modelled using electrical characteristics to provide the output current and voltage of the PV module. The duty cycle of the self lift cuk converter is adjusted directly in the algorithm.

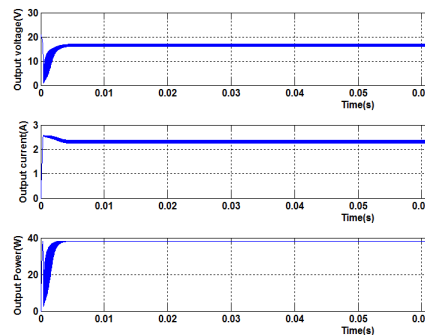


Fig. 10. Simulink results of the PV panel.

The output power obtained from the solar panel is unregulated and it contains more fluctuations. It can be regulated by connecting a proper DC-DC converter.

The flowchart of the incremental conductance MPPT algorithm has been implemented in Matlab/ Simulink. The Figure 11 illustrated the modeling diagram for the above algorithm.

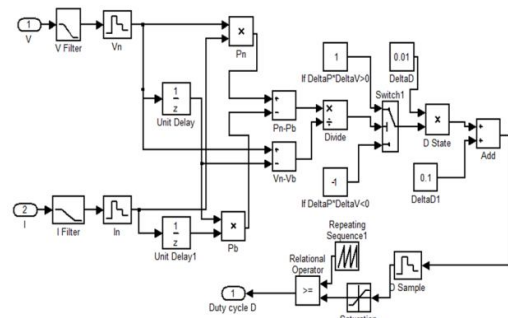


Fig. 11. Simulink model of the IncCond algorithm.

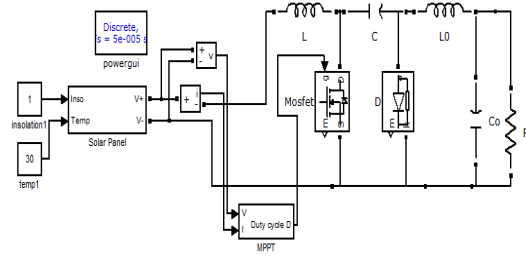


Fig. 12. Simulink model of the PV panel connected to the buck converter with MPPT.

Figure 12 represents the whole PV system with MPPT along with the buck converter has been implemented in the Matlab/ simulink. The duty cycle of the buck converter is directly adjusted using IncCond algorithm.

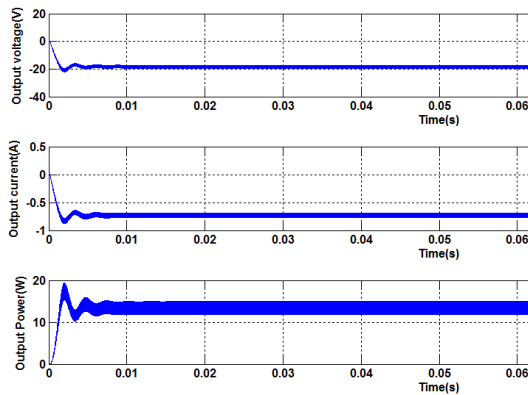


Fig. 13. Simulation results of PV panel connected to the buck converter with MPPT.

Figure 13 shows the output results while connecting buck converter with the solar panel. The buck converter regulates the power from the panel and boost up the voltage.

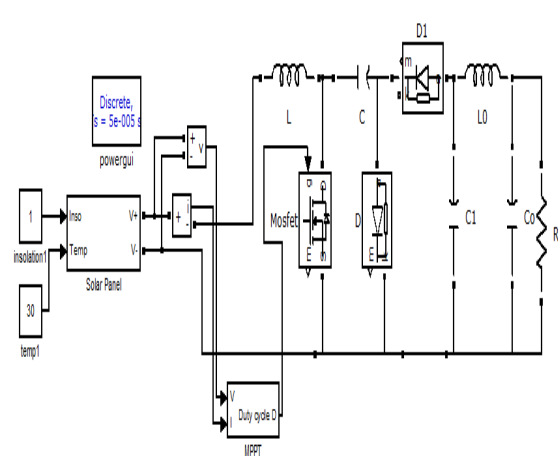


Fig. 14. Simulink model of the PV panel connected to the self lift buck converter with MPPT.

Figure 14 represents the whole PV system with MPPT along with the self lift buck converter has been implemented in the Matlab/ simulink. The self lift buck converter is selected to regulate the output obtained from the panel.

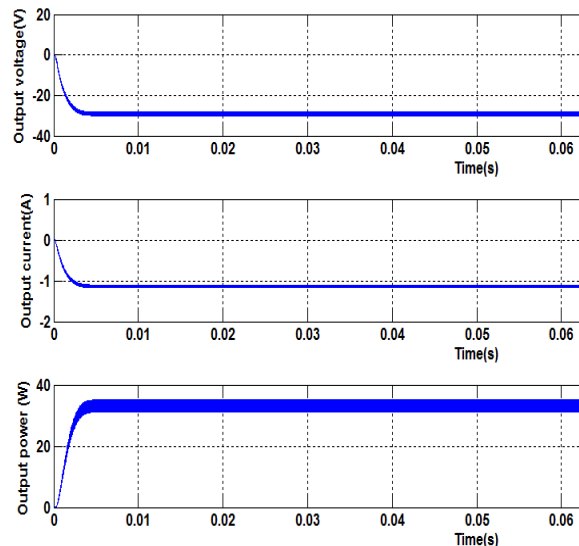


Fig. 15. Simulation results of PV panel connected to the self lift buck converter with MPPT.

Figure 15 shows the output results of the PV module connected with the MPPT. The comparison of buck and self lift buck converter is shown below:



TABLE II

COMPARISON OF CUK AND SELF LIFT CUK CONVERTER

Parameters	Cuk converter	Self lift cuk converter
Input voltage V_1	17V	17V
Output voltage V_0	-20V	-30V
Input current I_1	2.5A	2.5A
Output current I_0	-0.8A	-1.2A
Output power P	15W	38W
Resistive load R	25Ω	25Ω
Duty cycle D	0.5	0.5

The output results obtained from the self lift cuk converter connected to the PV panel is compared with the cuk converter. The output results obtained from the self lift cuk converter has more advantages when compared to the cuk converter. The output voltage of the self lift cuk converter is higher than the cuk converter.

VI. CONCLUSION

This paper proposes a simple MPPT method that requires only measurements of voltage and current. The proposed Incremental conductance MPPT algorithm increases the efficiency and it tracks the maximum power from the sun. This method computes the maximum power and controls directly the extracted power from the PV by changing the duty cycle in the self lift cuk converter. The proposed method offers different advantages which are: good tracking efficiency, response is high and well control for the extracted power.

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