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CONVERTER DESIGN USING MPPT TECHNIQUE

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ABSTRACT

In this paper Maximum Power Point Tracking (MPPT) control mechanism with cuk converter is presented. Main aim of the project is the use of cuk converter along with a Maximum Power Point Tracking control mechanism. The MPPT is responsible for extracting the maximum possible power from the photovoltaic and feed it to the load via the cuk converter which steps up the voltage to required magnitude. The main purpose will be to track the maximum power point of the photovoltaic module so that the maximum possible power can be extracted from the photovoltaic. The algorithms utilized for MPPT are generalized algorithms and are easy to model or use as a code. The algorithms are written in m files of MATLAB and utilized in simulation. The cuk converter is modeled using Sim Power Systems blocks.

KEYWORDS: MPPT, IC, Converter, Simulation.

INTRODUCTION

One of the major concerns in the power sector is the day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming.

Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever wherever necessary.

In order to tackle the present energy crisis one has to develop an efficient manner in which power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source. The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy [3], [8].

DIRECT CONTROL METHOD

In this paper, the IncCond method with direct control is selected. The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. The control loop is simplified, and the computational time for tuning controller gains is eliminated. To compensate the lack of PI controller in the proposed system, a small marginal error of 0.002

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was allowed. The objective of this paper is to eliminate the second control loop and to show that sophisticated MPPT methods do not necessarily obtain the best results, but employing them in a simple manner for complicated electronic subjects is considered necessary. The feasibility of the proposed system is investigated with a dc–dc converter configured as the MPPT. It was mentioned that the power extracted from PV modules with analog circuitry can only operate at the MPP in a predefined illumination level.

Therefore, control action is done using a TMS320F2812 digital signal processor (DSP), which is specially designed for control actions. It generates pulsewidth modulation (PWM) waveform to control the duty cycle of the converter switch according to the IncCond algorithm.

PV MODULE AND MPPT

Tracking of the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of PV systems. Many methods are used for maximum peak power for PV system. The problem considered by MPPT techniques is to automatically find the voltage VMPP or current IMPP at which a PV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array.

The main disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method . The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance condition s with higher accuracy than perturb and observe.

SELECTING PROPER CONVERTER

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. Among all the topologies available, both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. On the other hand, the Cuk converter has low switching losses and the highest efficiency among non isolated dc–dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus, the Cuk configuration is employed in designing the MPPT.

MODELLING OF SOLAR CELL

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered here [1], [2], [4], [7], [9] and [10].

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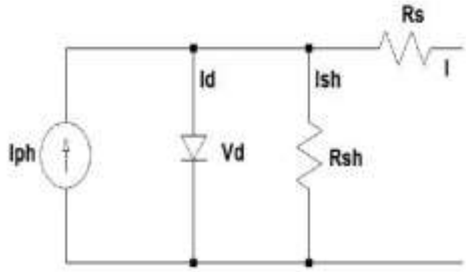

Figure 5.1: Single diode model of a solar cell
The characteristic equation for a photovoltaic cell is given by [1], [2], [4], [7], [9] and [10],

$$I = Ilg - Ios * \left[\exp\left\{q * \frac{V+I*Rs}{A*k*T}\right\} - 1\right] - \frac{V+I*Rs}{Rsh} \quad ....(1)$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr}\right)^3 * \left[\exp\left\{q * Ego * \frac{\frac{1}{Tr} - \frac{1}{T}}{A*k}\right\}\right] \quad ....(2)$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * lambda \quad ...(3)$$

I & V : Cell output current and voltage;

Ios : Cell reverse saturation current;

T : Cell temperature in Celsius;

k : Boltzmann's constant, $1.38 * 10^{-19}$ J/K;

q : Electron charge, $1.6*10^{-23}$ C;

Ki : Short circuit current temperature coefficient at Iscr;

lambda : Solar irradiation in W/m^2;

Iscr : Short circuit current at 25 degree Celsius;

Ilg : Light-generated current;

Ego : Band gap for silicon;

A : Ideality factor;

Tr : Reference temperature;

Ior : Cell saturation current at Tr;

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Rsh : Shunt resistance;

Rs : Series resistance;

The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance [7].

$$I = Np * Ilg - Np * Ios * \left[\exp\left\{q * \frac{\frac{V}{Ns} + I * \frac{Rs}{Np}}{A * k * T}\right\} - 1\right] - \frac{V * \left(\frac{Np}{Ns}\right) + I * Rs}{Rsh}$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

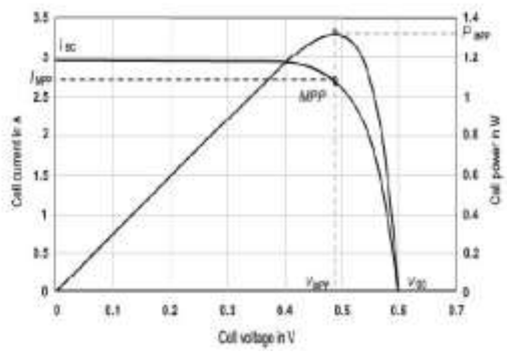

Figure 5.2: P-V I-V curve of a solar cell at given temperature and solar irradiation

EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated [7] and [10].

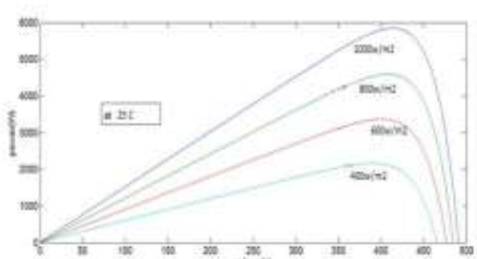

Figure 5.3: Variation of P-V curve with solar irradiation

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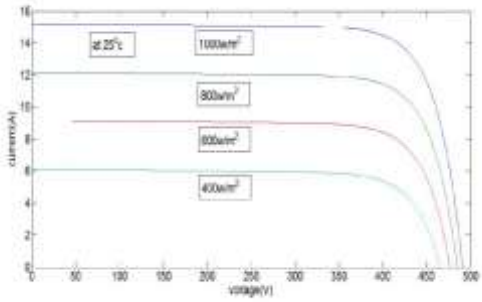

Figure 5.4: Variation of I-V curve with solar irradiation

EFFECT OF VARIATION OF TEMPERATURE

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. 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 [7] and [10].

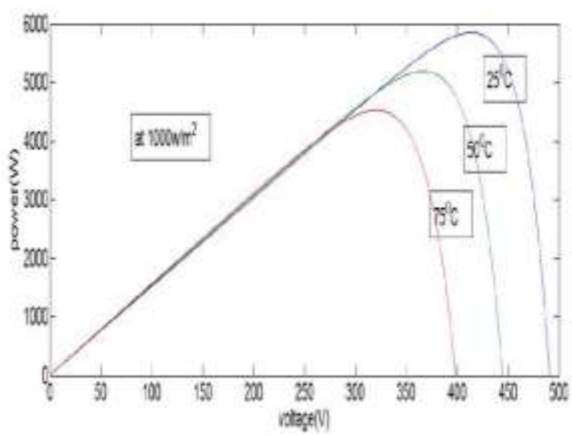

Figure 5.5: Variation of P-V curve with temperature

CUK CONVERTER

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. The efficiency of switch-mode dc–dc converters is widely discussed in [1]. Most switching-mode power supplies are well designed to function with high efficiency. Among all the topologies available, both Cuk and buck–Cuk converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–Cuk configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. On the other hand, the Cuk converter has low switching losses and the highest efficiency among non isolated dc–dc converters.

MODES OF OPERATION

Many years ago, Dr. Cuk invented the integrated magnetic concept called Dc-transformer, where the sum of Dc fluxes created by currents in the winding of the input inductor L1 and transformer T is equal to Dc flux created by the current in the output inductor L2 winding. Hence the Dc fluxes are opposingg each other and thus result in a mutual cancellation of the Dc fluxes. Cuk converter has several advantages over the buck con-verter. One of them cuk converter provide capacitive isola-tion which protects against switch failure (unlike the buck topology) [8]. Other

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advantage is, the input current of the Cúk is continuous, and they can draw a ripple free current from a PV array that is important for efficient Maximum power point tracking (MPPT)

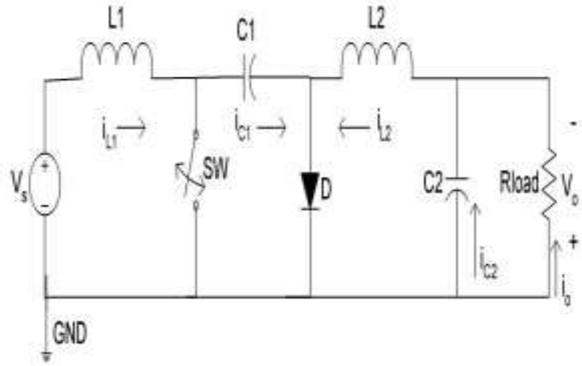

Figure 6.1:- Circuit Diagram of basic cuk converter

As shown in Fig.3.1, Cuk converter uses a capacitor as the main energy storage. As a result, the input current is conti-nuous. The circuits have low switching losses and high effi-ciency [9]. Due to the inductor on the output stage, the Cúk converter can provide a better output current characteristic.

The circuit arrangement of the Cuk converter using MOSFET switch is shown in Figure.2 in case of Cuk con-verter the output voltage is opposite to input voltage. When the input voltage turned on and MOSFET (SW) is switched off, diode D is forward biased and capacitor C1 is charged through L1–D. here the operation of converter divided into two modes.

Mode-1:- When MOSFET switch is turned on at t=0. The current through L1 rises. And at the same time the voltage of C1 reverse biases diode D and turn it off. The capacitor C1 discharges its energy to the circuit C1-C2-load-L2.

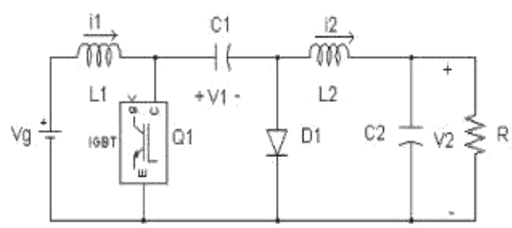

Figure 6.2:- Cuk converter with switch ON

Assuming that the capacitor (C1) is large enough and its voltage is ripple free even though it stores and transfer large amount of energy from input to output [10] (this requires a good low ESR capacitor [11]. The current through inductor i L1 rises linearly from L1 to L2 in time t1. Now voltage across inductor can be calculated by applying KVL.

Mode-2:- When MOSFET switch is turned off at t = t1. The capacitor will start to charge from input supply Vs and the energy stored in the inductor transferred to the load. The capacitor C1 is the medium for transferring energy from source to load.

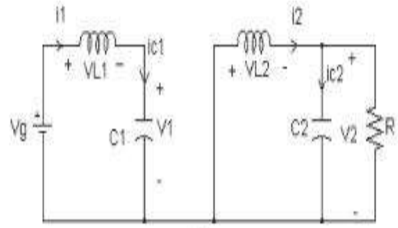

Figure6.3:- Cuk converter with switch OFF

MAXIMUM POWER POINT TRACKING

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a Cuk converter whose duty cycle is varied by using a mppt algorithm. Few of the many algorithms are listed below [3], [4], [5] and [8].

A Cuk converter is used on the load side and a solar panel is used to power this converter.

METHODS FOR MPPT

There are many methods used for maximum power point tracking a few are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

Perturb and Observe method

This method is the most common. In this method very less number of sensors are utilized [5] and [6]. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples . If is positive, then the algorithm increases the voltage value towards the MPP until is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP).

Incremental Conductance method

This method uses the PV array's incremental conductance to compute the sign of . When is equal and opposite to the value of I/V (where =0) the algorithm knows that the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. This method tracks rapidly changing irradiation conditions more accurately than P&O method. One complexity in this method is that it requires many sensors to operate and hence is economically less effective [5] and [6].

$$P = V * I$$

Differentiating w.r.t voltage yields;

$$\frac{dP}{dV} = \frac{d(V*I)}{dV}$$

$$\frac{dP}{dV} = I + V * \left(\frac{dI}{dV}\right)$$

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When the maximum power point is reached the slope $\frac{dp}{dv}$=0 . Thus the condition would be;

$$\frac{dP}{dV} = {}_{dv}\ I * \left(\frac{dV}{dV}\right) + V * \left(\frac{dI}{dV}\right)$$

$$\frac{dp}{dv} = 0$$

$$I + V * \left(\frac{dI}{dV}\right) = 0$$

$$\left(\frac{dI}{dV}\right) = -\frac{I}{V}$$

Parasitic Capacitance method
This method is an improved version of the incremental conductance method, with the improvement being that the effect of the PV cell's parasitic union capacitance is included into the voltage calculation [5] and [6].

Constant Voltage method
This method which is a not so widely used method because of the losses during operation is dependent on the relation between the open circuit voltage and the maximum power point voltage. The ratio of these two voltages is generally constant for a solar cell, roughly around 0.76. Thus the open circuit voltage is obtained experimentally and the operating voltage is adjusted to 76% of this value [8].

Constant Current method
Similar to the constant voltage method, this method is dependent on the relation between the open circuit current and the maximum power point current. The ratio of these two currents is generally constant for a solar cell, roughly around 0.95. Thus the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value [8].

The methods have certain advantages and certain disadvantages. Choice is to be made regarding which algorithm to be utilized looking at the need of the algorithm and the operating conditions. For example, if the required algorithm is to be simple and not much effort is given on the reduction of the voltage ripple then P&O is suitable. But if the algorithm is to give a definite operating point and the voltage fluctuation near the MPP is to be reduced then the IC method is suitable, but this would make the operation complex and more costly.

FLOW CHART OF MPPT ALGORITHMS
Two of the most widely used methods for maximum power point racking are studied here. The methods are

1. Perturb & Observe Method.
2. Incremental Conductance Method.

The flow charts for the two methods are shown below.

Flow chart for perturb & observe:

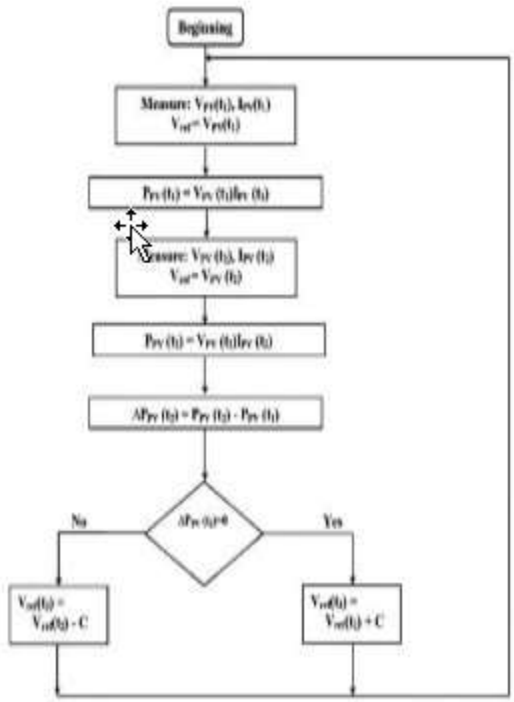

Figure 7.1: Flow chart of perturb & observe

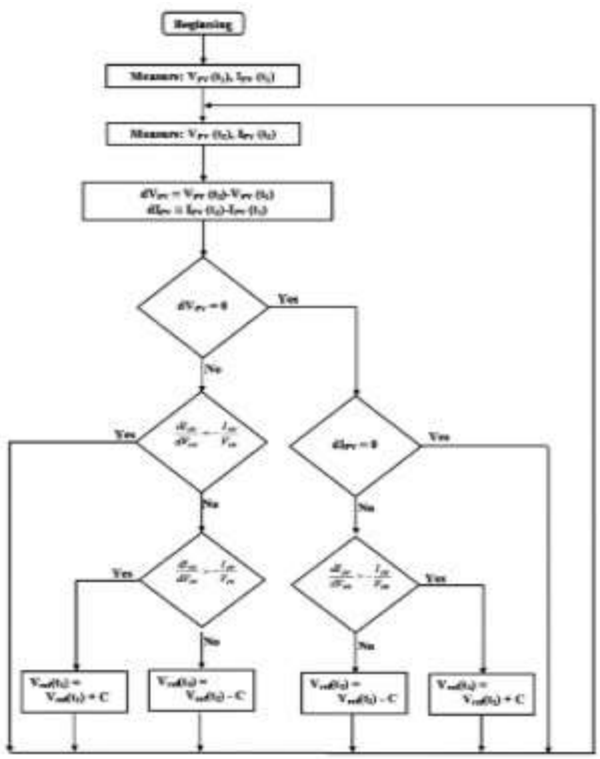

Figure 7.2: Flow chart of incremental conductance method

These two algorithms are implemented using the Embedded MATLAB function of Simulink, where the codes written inside the function block are utilized to vary certain signals with respect to the input signals.

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SIMULATION RESULTS OF THE CONVERTER MODEL

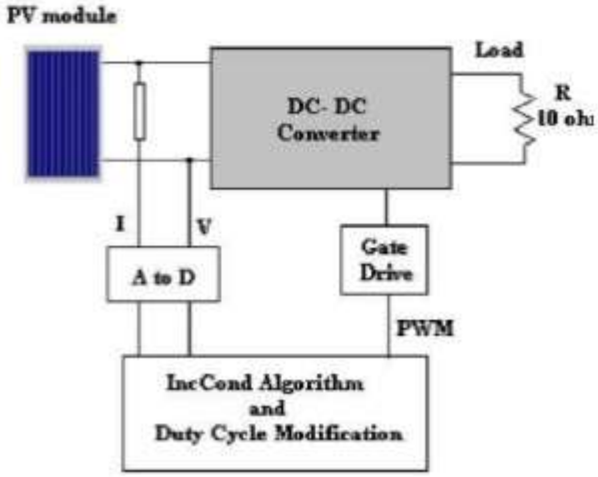

Figure 8.1 :- Blok diagram of cuk converter with MPPT

The proposed cuk converter is implemented in between a solar panel and load as shown in Fig.3 this system is able to deliver maximum output power.

The output voltage can be controlled by using the duty cycle variation. It is evident that the PWM signal is transmit-ted transmit-ted to a power MOSFET in power stage through a power MOSFET driver to perform on and off state. That means for a cuk converter.

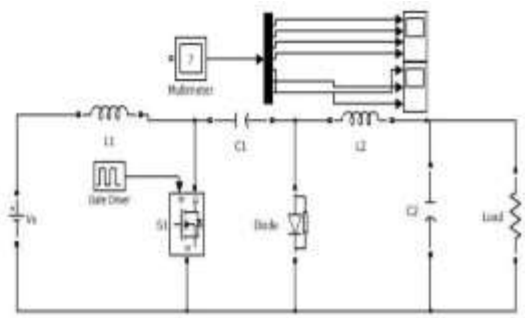

Figure 8.2:- Simulation model of cuk converter

The simulations were carried out in Simulink and the various voltages, currents and power plots were obtained.

Fig. 8.3 Output of cuk converter when duty cycle is 2

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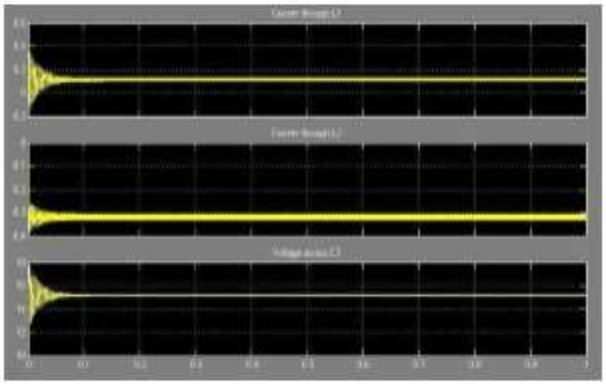

Fig. 8.4 Output of cuk converter when duty cycle is 25

Fig. 8.5 Output of cuk converter when duty cycle is 50%

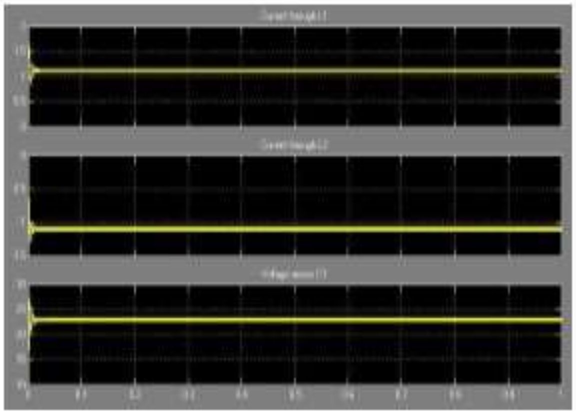

Fig. 8.6 Output of cuk converter when duty cycle is 50%

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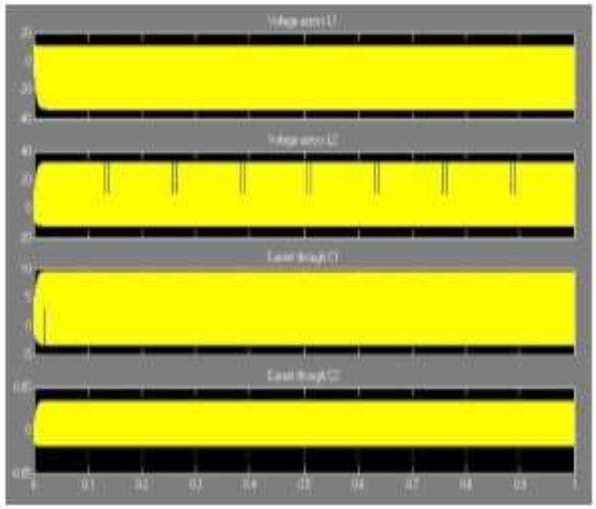

Fig. 8.7 Output of cuk converter when duty cycle is 75%

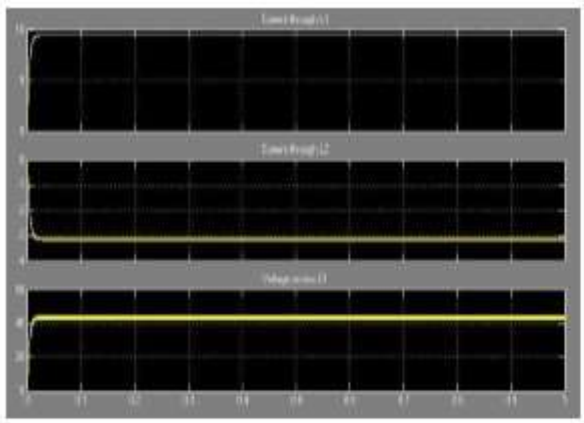

Fig. 8.8 Output of cuk converter when duty cycle is 75%

SOLAR CELL SIMULATION RESULTS

The simulation of a solar cell was done using MATLAB and SIMULINK. The PV and IV curves from the simulation are as shown.

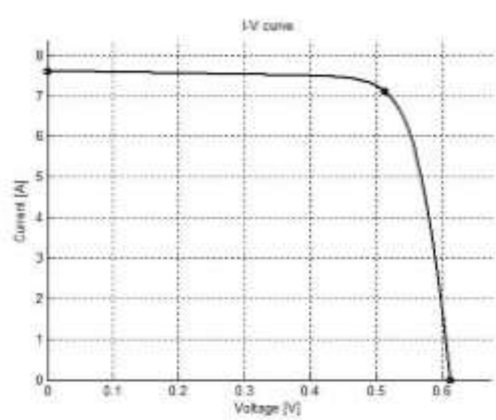

Figure 9.1: I-V characteristics of a solar cell

The parameters were obtained for a generalized solar cell. The plot is similar to the theoretically known plot of the solar cell voltage and current. The peak power is denoted by a circle in the plot. Since only one solar cell in series is considered, hence the solar output voltage is less (0.61V) in this case.

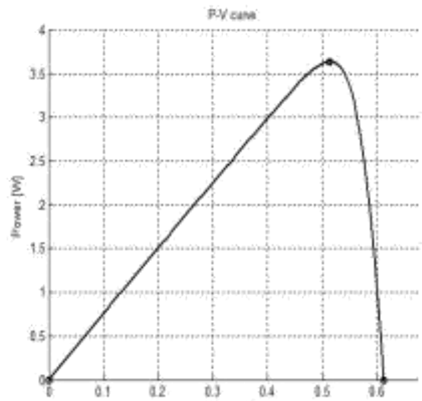

Figure 9.2: P-V characteristics of a solar cell

This plot gives the solar output power against the solar output voltage. This clearly abides by the theoretical plot that was shown previously. The maximum power point is marked with a small circle. The initial part of the plot from 0 V to the maximum power point voltage is a steady slope curve but after the maximum power point the curve is a steeply falling curve.

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