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Modelling and Simulation of Solar Panel

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ABSTRACT

This paper aims to model a solar photovoltaic system with built in MPPT(Maximum Power Point Tracker) for Photovoltaic (PV) system. It provides theoretical study of PV systems and modelling techniques using equivalent electric circuits. MATLAB simulations verify each individual block as well as combined simulation of model containing solar panel, MPPT and Cuk converter. The results validate that MPPT can significantly increase the efficiency and the performance of PV system.

Keywords: *MPPT (Maximum Power Point Tracker); PV (Photovoltaic).*

1.0 Introduction

Solar power has been playing an increasingly important role in fulfilling now a day's energy requirements. Solar power also finds use in sensitive applications like powering satellites and in providing power to off-grid installations in the telecom, oil, and defence industries. With ever increasing range of its applications, it is imperative that better design methodologies, such as more accurate models and simulation techniques, be developed for PV applications. As shown in section II that I-V and P-V curve is non linear and so for better efficiency we need to track the peak that will yield that maximum power point. In this paper we have explained the non linear characteristics of PV cell in section II and then we have done the modelling to simulate the MPP (Maximum Power Point) and finally we have modelled the complete circuit and had shown how the maximum power point is tracked by MPPT.

2.0 Literature Review

Recently, the needs of renewable energy resources increase due to the fuel energy crisis and the global warming issue. Solar energy is one of the most important renewable energy. Solar energy using photovoltaic (PV) offers several advantages such as clean, no noise, and free. The conversion efficiency of electric power generation is about 27% as reported in [1]. Naturally, the problem of PV is the electric power generated depends on the weather condition. To increase the reliability of the power generation, solar energy is combined with other renewable energy resources such as wind energy system [2]. The I-V characteristic of PV is expressed by using the standard model [3] with converter circuits as demonstrated in [4]. Based on these models, various computer simulations have been built using a number of powerful electronic component based software packages [5][6]. There are many Maximum Power Point Tracking techniques available in literature: Perturb and Observe (P & O) [7][8][9]; Incremental Conductance (IC) [10][11]; Fuzzy Logic [12]; and Artificial Neural Network [13]. The P&O method is widely used because of the simplicity and easy to be implemented, as shown in [14]. The common implementation of MPPT algorithm is by employing DC-DC converter between PV module and load/battery, and a MPPT controller to control the duty cycle of the converter. By varying the duty cycle of converter, the ratio of input and output voltage could be adjusted appropriately. Thus the input voltage of converter, i.e. output voltage of PV might be changed by changing the duty cycle. In other words, the control objective is to change the input of converter.

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This behaviour creates a problem when modeling the DC-DC converter using equation model approach, due to fact that in the equation modeling, the model is represented by the rule of "changing the input to change the output". Therefore, researchers prefer to employ circuit model for modeling the DC-DC converter modeling [15], which is done in our case too.

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3.0 Photovoltaic Module and Array Model

Solar cell is a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. PV system naturally exhibits a nonlinear I-V and P-V characteristics as shown in Fig.6 and Fig.7 which vary with the radiant intensity and cell temperature.

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. Fig.1 shows the equivalent circuit diagram of solar cell.

A. Solar Cell

The voltage–current characteristic curve for the *p–n* junction diode is described by the following Shockley diode equation:

$I = I_s[e(V_d/nV_T) – 1]$

Using kirchoff's current law, we get

$I = I_{sc} - I_0 (e^{qV_d/kT} – 1)$

voltage *VOC* when I = 0;

$V_{oc} = (kT/q)\ln(I_{sc}/I_0 + 1)$

At 25 degree C, equation becomes.

$I = I_{sc} – I_0(e^{38.9V}-1)$

$V_{oc} = (0.01257)\ln(I_{sc}/I_0 + 1)$

Where,

$V_t = kT/q$

Id is the diode current (A)

Vd is the voltage across the diode terminals (V)

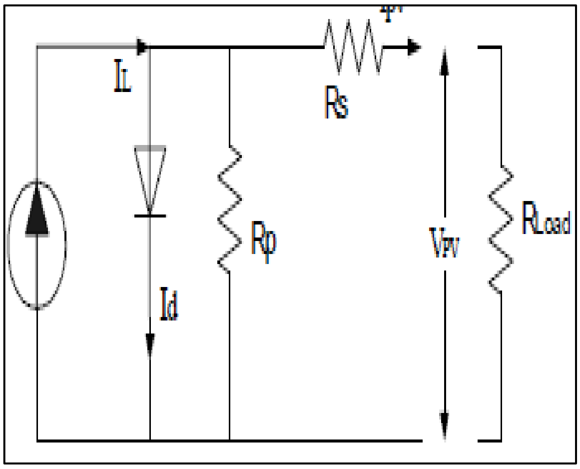
I0 is the reverse saturation current (A)

q is the electron charge (1.602×10^{-19} C)

k is Boltzmann's constant (1.381×10^{-23} J/K)

T is the junction temperature (K)

Fig 1: Equivalent Model of PV Cell



The characteristic equation for this PV model is given by

$I_{PV} = I_L - I_0(e^{(V_{PV}+R_SI_{PV})/V_T} – 1) – (V_{PV}+ R_S*I_{PV})/R_P$

where, *IPV* is output current and *VPV* output voltage respectively.

An ideal PV module is one for which *RS* is low and *RP* is very large. The output current and voltage are then as follows:

$I_{PV} = I_L - I_0(e^{(V_{PV}+R_SI_{PV})/V_T} – 1)$

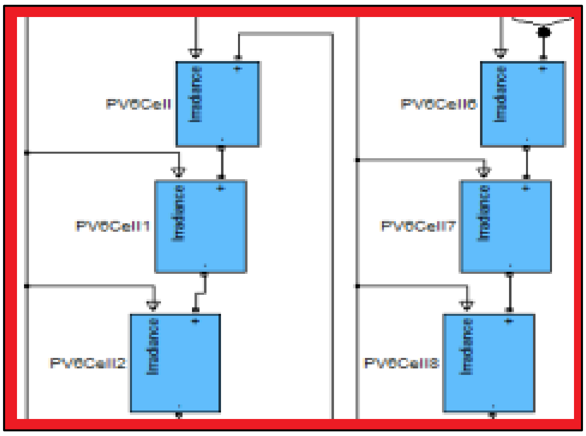
$V_{PV} = V_T \ln[(I_L-I_{PV})/I_0 + 1]$

B. PV Array

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. Fig. 2 depicts PV array.

Fig. 5 and Fig. 6 shows I-V and P-V graph obtained when a variable resistor is put across PV array.

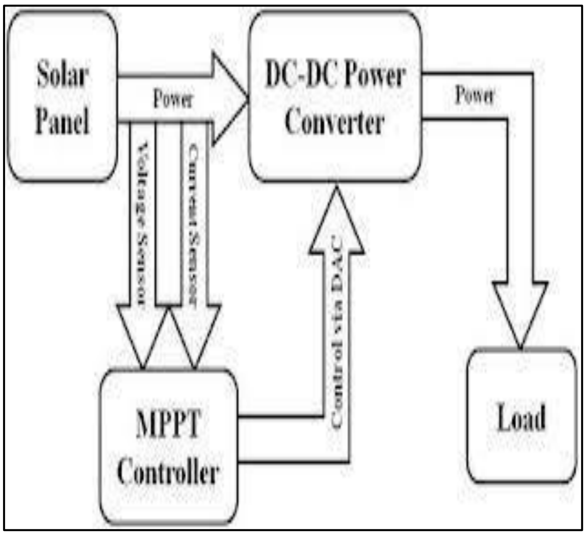
Fig 2: Portion of PV Cells Array



4.0 Components of Model

All the models are developed individually and then integrated together so that maximum power point of the PV array can be tracked. Fig.3 shows the net circuit diagram.

Fig 3: Net Circuit Diagram



A. Solar Cell Model

As it is stated that I-V characteristic of PV cell or array is nonlinear so their exist a maximum power point.

B. Solar Panel Model

The voltage across a single solar cell is very small so to get a particular amount of power we need to connect the solar cell in series and parallel connection. Fig.2 shows the PV array model.

C. Maximum Power Point Tracker

To make the efficiency better at different environmental conditions its necessary to track the MPP of PV curve as shown in Fig.5.

Fig 4: Power-Voltage Curve of PV Cell

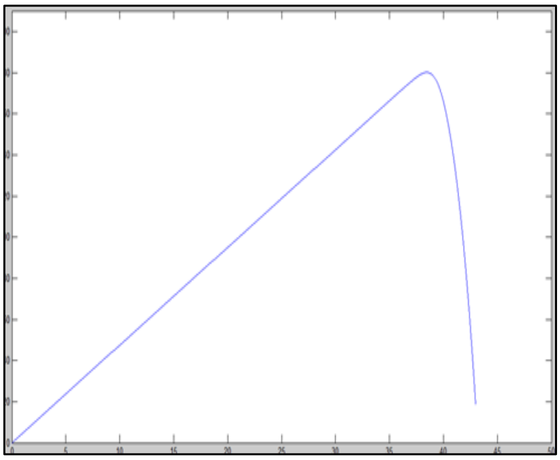
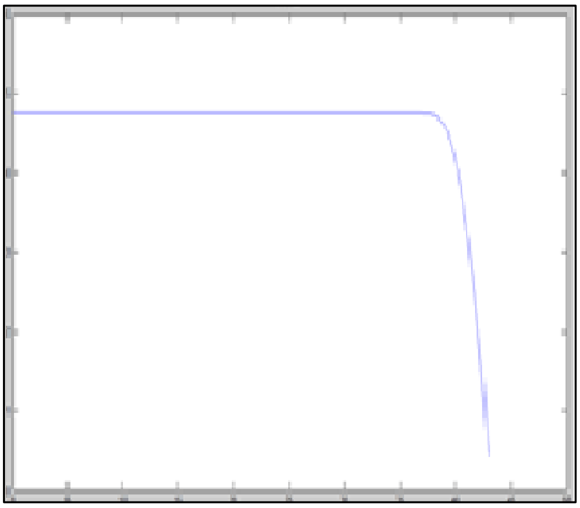


Fig 5: Shows the I-V Character of PV Cell

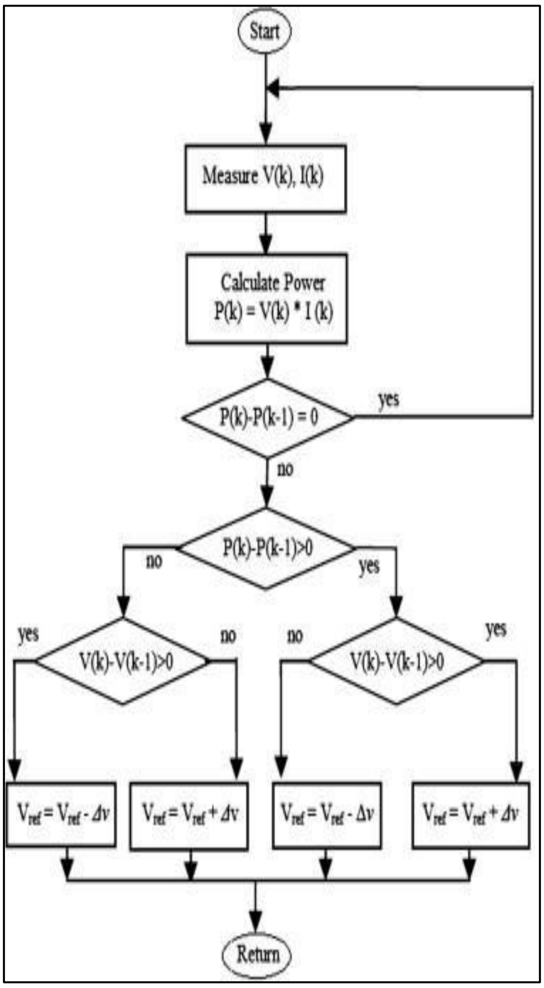


There are many techniques to track the maximum power point of PV curve. One of the most common and widely used algorithm is P&O algorithm, which we are explaining here and are using in our modelling.

1) P&O Algorithm: The Perturb and Observe (P&O) algorithm operates perturbs the PV voltage periodically by varying the duty cycle, and observes the PV power to increase or decrease PV voltage in the next cycle. If the perturbation voltage produces an increase of the power, then the direction or slope of perturbation voltage (duty cycle) is the same as the previous cycle. On the contrary, if the

perturbation voltage produces a decrease of the power, then the direction or slope of perturbation voltage (duty cycle) is the opposite from the previous cycle. Fig.7 depicts the flowchart of P&O algorithm.

Fig 7: Flowchart of Perturb and Observe (P&O) Algo



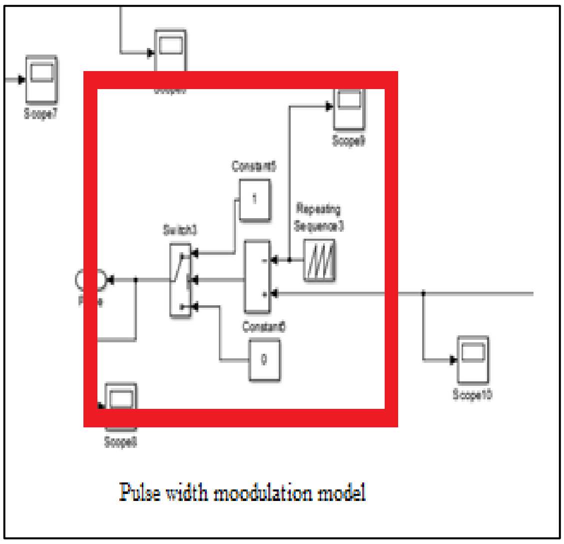
2) Tracking Model:

Here tracking is done by P&O algorithm. Fig. 8 shows the main tracking model.

3) Pulse Width Modulation Model:

It is the part of MPPT model. Once the maximum power point is tracked then the signal should be converted to pulses so that it can be fed into DC to DC converter. For that we compare the output signal with a triangular wave and thus convert it into pulses. Fig.9 shows the model.

Fig: 8 Model of PWM



4) Cuk Converter:

A convertor regulates the input voltage at the PV MPP and providing load matching for the Maximum power transfer. The output voltage magnitude can be same, larger or smaller than the input, depending *on* the duty cycle. In our paper we are using Cuk converter.

Its relationship to the duty cycle (D) is:

- If $0 < D < 0.5$ the output is smaller than the input.
- If $D = 0.5$ the output is the same as the input.
- If $0.5 < D < 1$ the output is larger than the input

Fig.10 depicts the Cuk converter.

For our design the value of C1, C2, L1, and L2 we have taken using the following formulas:

$L1(min) = ((1 - D)^2 R)/2Df$

$L2(min) = ((1 - D)R)/2f$

$C1(min) = (V0D)/(Rfdvc1)$

$C2(min) = (1- D)/((dv0/v0)8L2f^2)$

Where L1 and L2 are inductance,C1and C2 are capacitance and R is the load resistance as shown in the fig.10.

The values which we used in our model are as follows:

L1: 225uH
L2: 225uH
C1: 15uF
C2: 10uF

5) Results:

The full model, which was formed after integration of all the components right from PV solar cells (series and parallel connection), MPPT, Cuk converter and all other measuring equipment appears as follows:

Fig 9: Cuk Converter

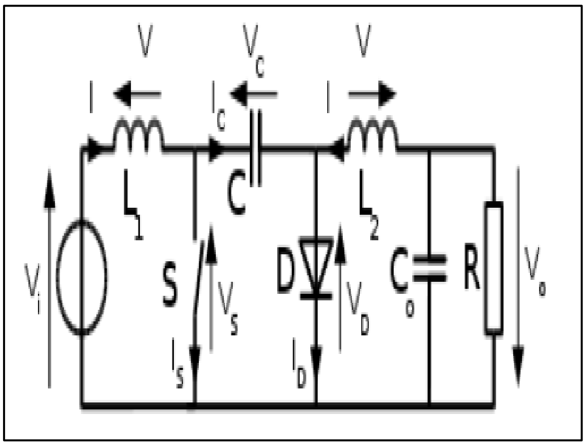
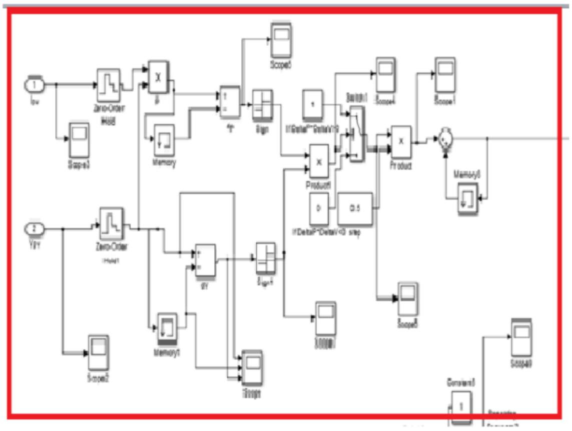
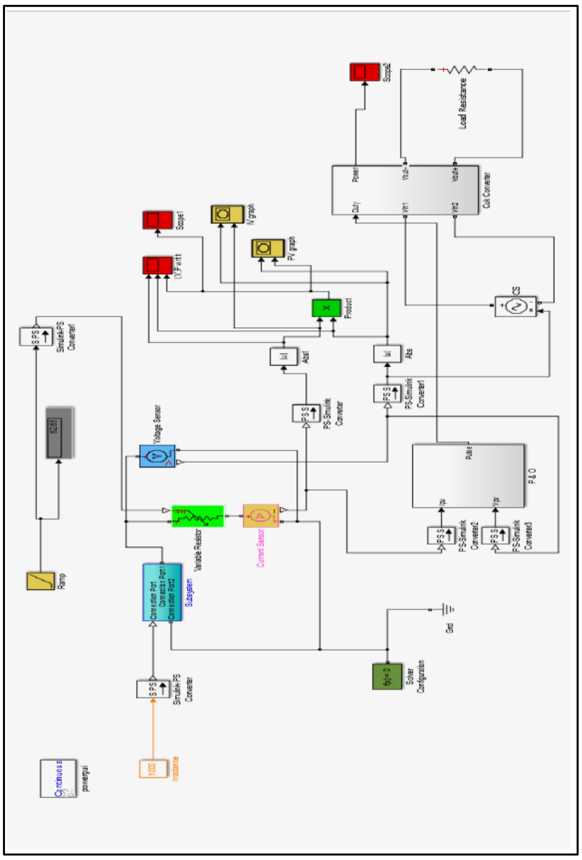


Fig 11: The Complete Model





The following graph were obtained during the simulation of the model:

Fig 12: The PV Curve Showing the MPP

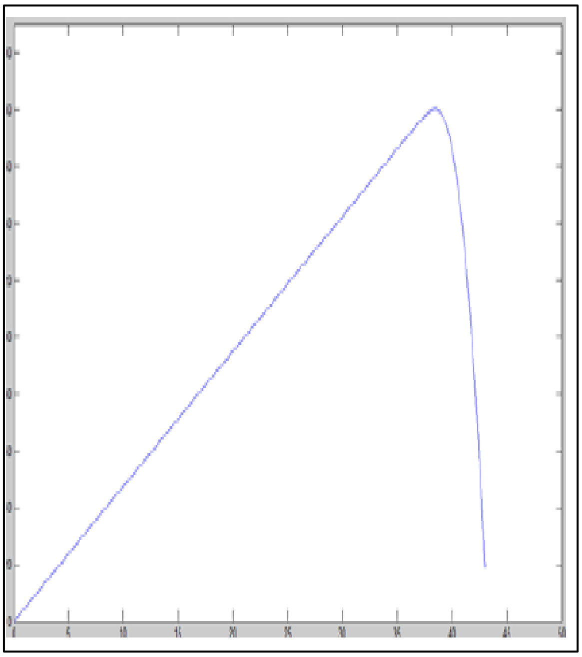


Fig 13: The IV Curve

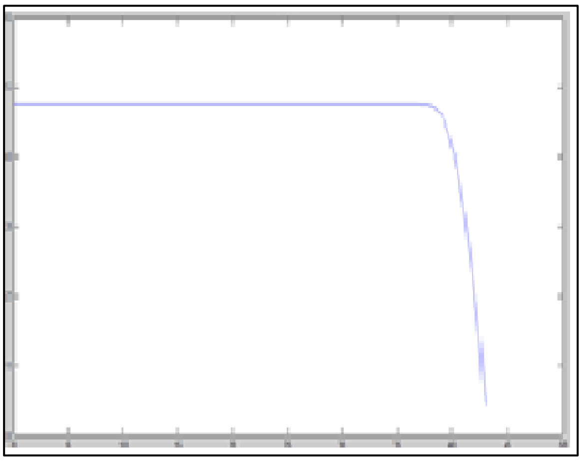
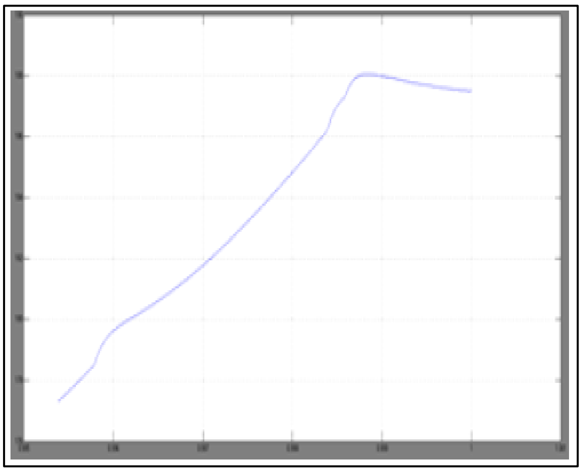


Fig 14: Finally Tracked Output Voltage



5.0 Conclusion

It is thus concluded that by the application of MPPT (P and O algorithm) and Cuk convertor, better efficiency and more power can be obtained from the same solar panel in different environmental conditions.

By tracking the maximum power point of the PV characteristics curve better efficiency is obtained due to the controllability of the operating point of the system.

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