Incremental Conductance MPPT Algorithm for Photovoltaic System

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***Abstract*—It is important to operate PV energy conversion system near the maximum power point to increase the output efficiency of PV arrays. The output power of PV array is always changes with weather condition such as solar irradiation and atmospheric temperature. The MPPT control to extract maximum power from the PV arrays at real time becomes indispensable in PV generation system. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and radiation conditions. The resulting system has high-efficiency: lower-cost this paper proposes a maximum power point tracking (MPPT) method with a simple algorithm for photovoltaic (PV) power generating systems. The method is based on use of a Incremental conductance of the PV to determine an optimum operating current for the maximum output power. This work proposes on investigation of Incremental conductance based maximum power point tracking for photovoltaic system.**

***Index Terms*—Photo voltaic model (PV), solar cell model, MPPT, Incremental conductance (INC) Algorithm.**

I. INTRODUCTION

The photovoltaic(PV) energy is the most important energy resources since it is clear, pollution free and inexhaustible. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). Maximum power point tracking (MPPT) is used in photovoltaic systems to maximize the photovoltaic array output power irrespective of the temperature and radiation condition [1]-[2].

At present, PV research use mathematical function models for the performance analysis of newly developed systems. These developed systems could not be readily adopted by the field professionals and hence the above difficulty raises hence the need for simplified Simulink modeling of PV module has been long felt. Simple circuit- based PV models have been proposed in literature [3]-[8].As known from P-V curve of a solar panel, there is an optimum operating point such that the PV delivers the maximum possible power to the load .The optimum operating point changes with solar irradiation and cell temperature .Therefore, maximum power point tracking is essential for PV panel. A variety of maximum point tracking (MPPT) methods is available. This paper deal with incremental conductance MPPT algorithm method as it is simple approach.

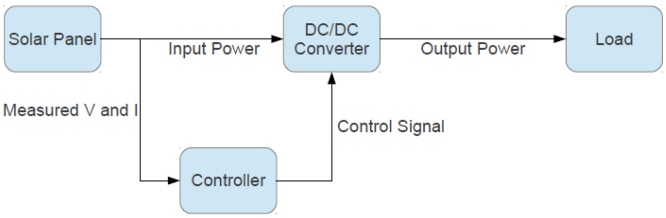


Figure.1. MPPT block scheme

However, despite all the fore mentioned advantages of solar power system, they do not present desirable efficiency. In addressing the poor efficiency of PV system, some methods is proposed, among which is a new concept called “maximum power point tracking (MPPT). Maximum power point tracking is a high efficiency DC-DC converter that presents an optimal electrical load to a solar panel or a array and produces a voltage Suitable for load. PV cells have a single operating point where the values of the current and voltage of the cell result in a maximum power point output. These values correspond to a particular load resistance, which is equal to V/I as specified by ohms law. In this paper, the design of PV system using simple circuit model with detailed circuit modeling of PV module is presented and matlab programming of the incremental conductance algorithm method.

II. MODELING OF THE PV CELL

The PV cell can be represented by the equivalent electric circuit shown in Figure 2.

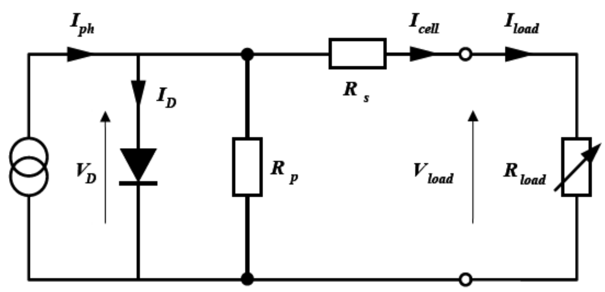
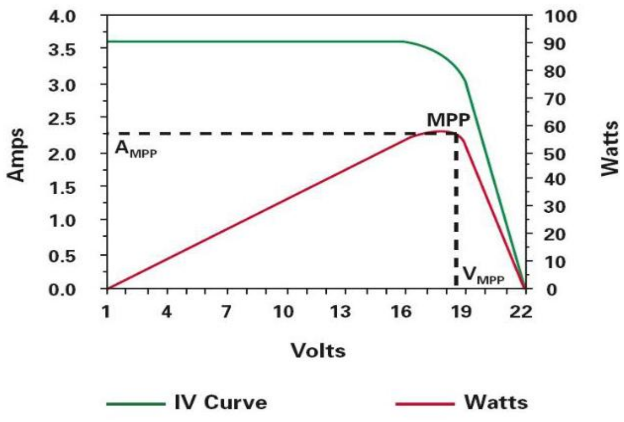


Figure 2: Equivalent electrical circuit of a PV cell connected to a load.

This circuit consists of a diode which represents the PN junction of the cell and a constant current source whose current amplitude depends on the intensity of the radiation. The parallel resistor Rp characterizes the leakage current on the surface of the cell due to the non-ideality of the PN junction an impurities near the junction. The series resistor Rs represents the various contact resistances and the resistance of the semi conductor. Current and voltages are:



Characteristics of Solar Cell

Solar cells naturally exhibit a non linear I-V and P-V characteristics which vary with solar irradiation and cell temperature. The fundamental parameters related to solar cell are short circuit current (Isc), open circuit voltage (Voc), maximum power point (MPP). The typical I-V and P-V characteristics of solar cell are shown in figure.

I_{ph} : photo current. Ip : current through the diode. I_{cell}: current delivered by the cell. V_{cell}: voltage across the cell. I_{load}: current through the load. V_{load}: voltage across the load.

A. Equation *of PV Model*

With such an equivalent electrical circuit, one can obtain the following mathematical model of a PV cell.

$$I = I_{ph} - I_s[(\exp(V_{cell} + I_{cell} R_s) / V_{th}) - 1] - (V_{cell} + I_{cell} R_s) / R_p \quad \text{--(1)}$$

Where $V_{th}= AKT_c/q$ is the thermal voltage
q: elementary electric charge ($1.6x10^{-19}$ C)
K: Boltzmann constant ($1.38x10^{-23}$ J/K)
T: absolute temperature of the cell (°K)
I_s : saturation current of the unlighted junction(A)
A: ideality factor of the junction.

III. PV DESIGN MODELING

A. *Photo Current*

The module photo current Iph of the photovoltaic module depends linearly on the irradiation and is also influenced by the temperature according to the following equation.

$$I_{ph} = (I_{SC} + K_I (T_C - T_{Ref}))*G \qquad \text{–(2)}$$

Where the I_{sc} is the cell short circuit current at 25°C and $1KW/m^2$, K_I is the cell's short-circuit current temperature coefficient. T_{ref} is the cells reference temperature and G is the solar insolation in $1000W/m^2$. Detailed Simulink model of equation (2) of photo current I_{ph} is shown in Figure 3.

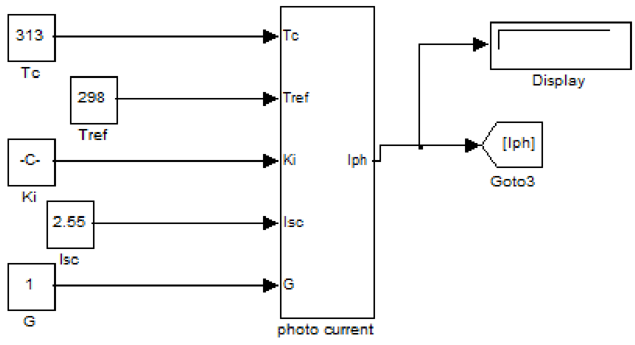


Figure3: Module Photo current

B. *Module Reverse Saturation Current*

Module reverse saturation current, I_{rs} is given by the equation (3) as follows

$$I_{rs} = I_{SC} / (\exp(qV_{OC}/N_S KAT_C) - 1) \qquad \text{-(3)}$$

Where
q: elementary electric charge ($1.6.1^{-10}$ C)

K: Boltzmann constant ($1.38.10^{-23}$ J/K)

A: ideality factor of the junction.

Voc: is the solar module open circuit voltage (21.64V)

Ns: is the number of cells connected in series.

Detailed Simulink model of equation (3) is developed in Figure-4

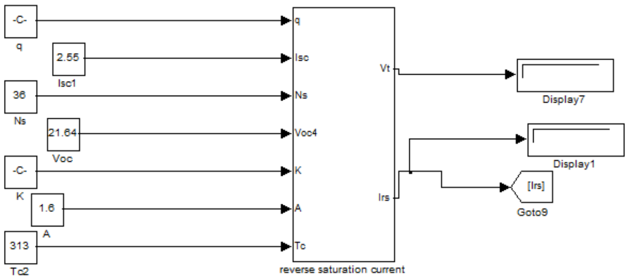


Figure 4: Module reverse saturation current

C. *Module Saturation Current*

The module saturation current Io that varies with the cell temperature is given by

$$Is = I_{rs}(T_c/T_{Ref})^3 \exp[qE_G(1/T_{Ref} - 1/T_c)/KA] \qquad \text{-(4)}$$

Where Irs is the cell's reverse saturation current at a reference temperature and a solar radiation,
E_G is Band-gap energy of the semiconductor used in the cell (E_G= 1.1EV for the polycrystalline Si at 250°C), T_{ref} is the cells reference temperature; T_c is the cells working temperature.
The equation is simulated with model shown in Figure-5.

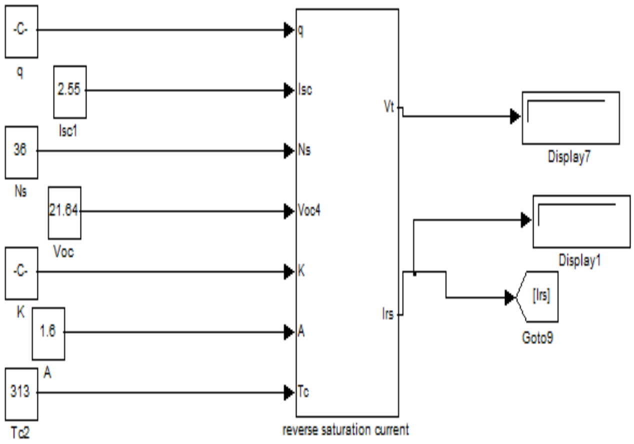


Figure 5: Module saturation current

D. Module Output Current

The basic equation that describe the current output of P_{pv} module I_{pv} of the single diode model presented in Figure-2 is given by

$$I_{pv} = N_p + I_{ph} - N_p * I_o \left[\exp\left\{q * \frac{Vpv+Ipv.Rs}{NsAKT}\right\} -1\right] - \quad (5)$$

Where N_p and N_s are number of parallel and series connections of cells, respectively in the given photovoltaic. Module (N_p=1 and N_s=36) V_{pv}=V_{oc}=21.08V, R_s is the equivalent series resistance of the module and R_{sh} is the equivalent parallel resistance. The current leakages, the tunnel effect, breakdown by micro plasmas, leaks along the surface channels, etc are modeled as a parallel resistance.

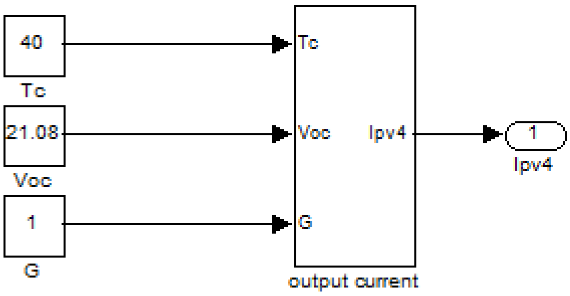


Figure 6: module output current

IV. MPPT Modeling

A. *Incremental Conductance MPPT*

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage.

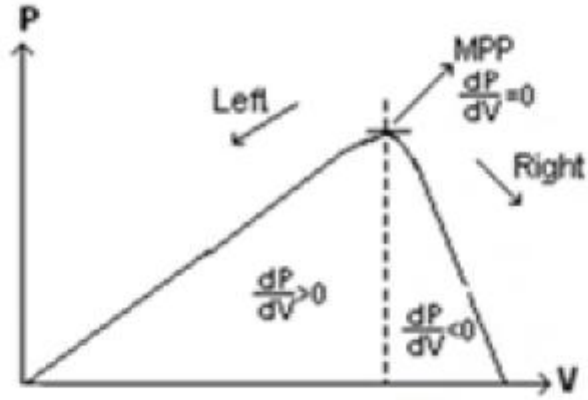


Figure 7: Basic Concept of Incremental Conductance on a PV Curve

This method is based on the fact that the slope of the power curve of the panel is zero at the MPP, positive to the left and negative to right [11, 12, 13].This method is based on the fact that the slope of the power curve of the panel is zero at the MPP, positive to the left and negative to right hand side of MPP[14].

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V}$$

Since

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V} \quad \text{At the MPP}$$

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V} \quad \text{Left of the MPP}$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V} \quad \text{Right of the MPP}$$

Where I and V are P-V array output current and voltage respectively.

B. *Incremental Conductance MPPT Algorithm*

This method exploits the assumption of the ratio of change in output conductance is equal to the negative output conductance instantaneous conductance. We have

$$P=V*I$$

Applying the chain rule for the derivative of products yields to

$$\partial P/\partial V=\partial (VI)/\partial V$$

At MPP $\qquad \partial P/\partial V=0$

The above equation could be terms of array voltage V and array current I as

$$\partial I/\partial V=-I/V$$

The MPPT regulates the PWM control signal until condition

$$(\partial I/\partial V) + (I/V) = 0$$

The MPP can be tracked by comparing the instantaneous conductance (G_{cl} = I/V) to the incremental conductance ($\partial G_{cl} = \partial I/\partial V$), as shown in the flow chart of figure 8.

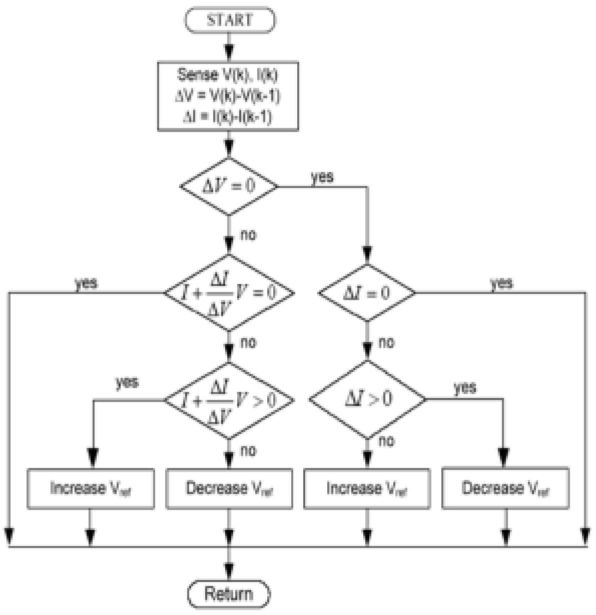


Figure 8: chart of the Incremental Conductance algorithm

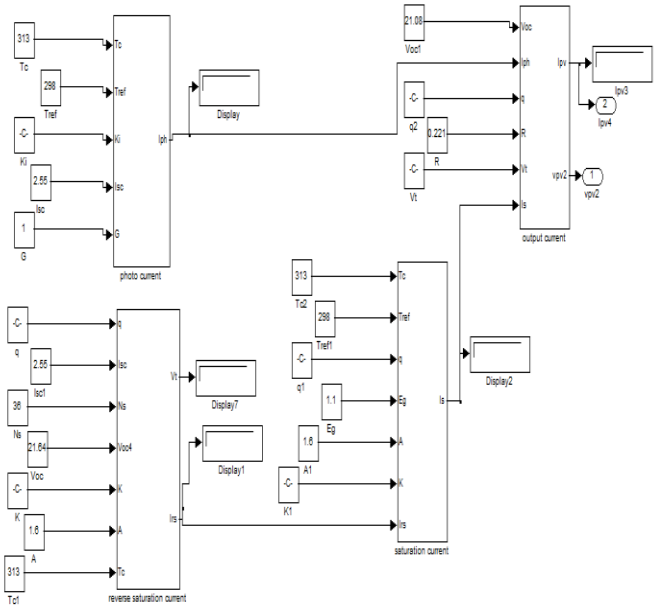


Figure 9: Details of all interconnection blocks

The output control signal of the INC method is used to adjust the voltage reference of PV array by increasing or decreasing a constant value ΔV to the previous reference voltage. We can understand to and fro of INC method from there advantages and disadvantages. The incremental conductance has certain advantages which are it has high efficiency of about 98%, it is highly reliable and accurate method when there is sudden changes of temperatures for example in London, Iceland etc, in can be automatically controllable, and it has good and automatically adjust for rapidly changing atmosphere but it has certain disadvantages which are it is more complexity and difficult when compared with other methods, it's realization is also more complex and its design cost is also high. So these are the advantages and disadvantages of INC method.

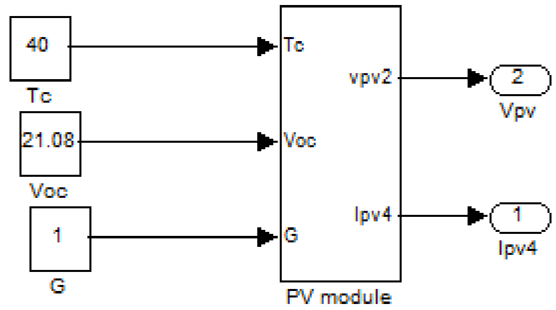


Figure 10: Simulink model

V.. MATLAB /SIMULINK MODEL

All figures from 4 to 7 inter connected to get I_{pv} simulink model of PV module. Ipv simulink model takes insolation, temperature and V_{pv} as inputs as calculates $I_{pv..}$The V_{pv} is varied from 0 to21.7 V I_{pv} simulink model is simulated with the step up shown in the Figure-9.The related simulink block diagrams of PV array for I-V and P-V are shown in figures 10 & 11.The MPPT module and related simulink blocks are shown in figures 12 & 13.

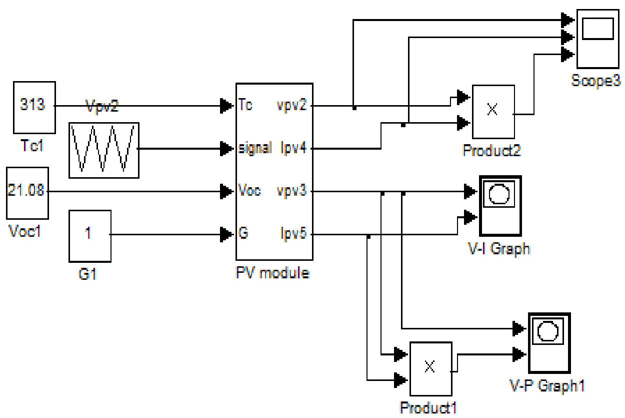


Figure 11: I-V and P-V characteristics setup of PV module

We have designed MPPT of incremental conductance in both matlab and simulink by using the algorithm shown in fig 8. In fig 12 we can see the programmable MPPT block in which the complete program is embedded in MATLAB function block. Similarly we have designed a simulink based

MPPT block which is shown in fig 14.

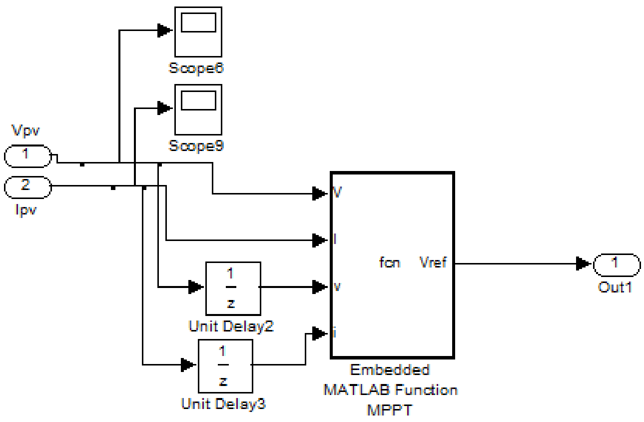


Figure 12: programming MPPT function Block

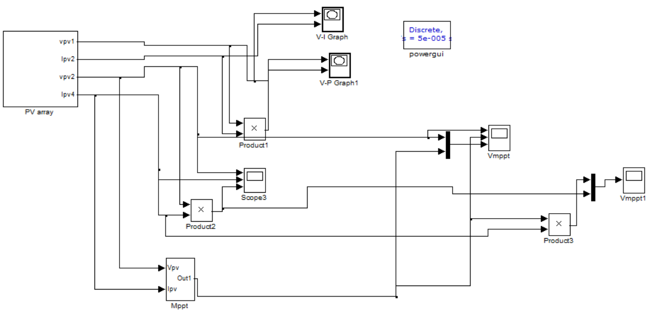


Figure 13: PV and MPPT block

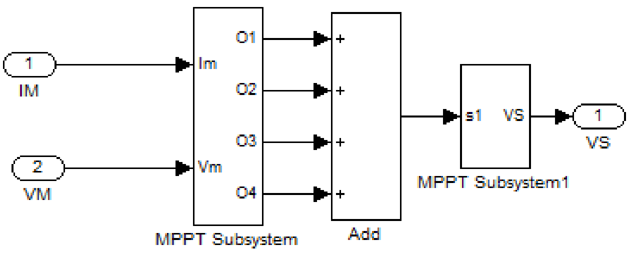


Figure 14: Simulink MPPT block

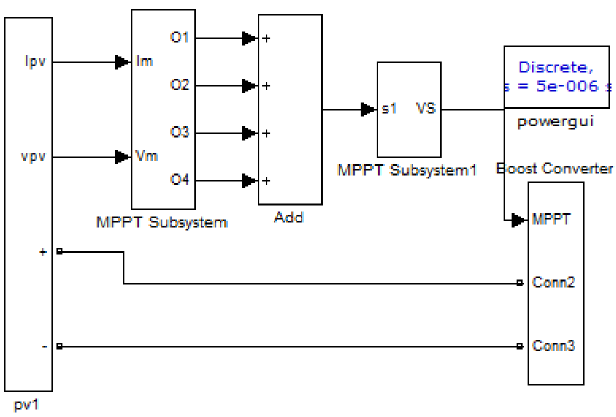


Figure 15: PV with Simulink MPPT block

Based on the application we can use these simulink and programmable MPPT blocks. For example in boosting converter we can go for simulink block which is shown in fig 15. Similarly in case of shoot through zero state conditions in z-source inverter we can go for programmable MPPT block.

VI. THE SIMULATION RESULTS

The model of the PV module and MPPT algorithm was implemented using a MATLAB/SIMULINK model. The model parameters are evaluated during execution using the equations listed as in the previous section the PV module chosen for this simulation. The model was built in stages as indicated above starting from stage to the final model. The sub system contains all the mathematical equations of every stage model block. Figure 16 & 17 shows the I-V & P-V output characteristics of PV module.

The flowchart of the incremental conductance MPPT algorithm has been implemented. The figure illustrated the modeling diagram for the above algorithm. The module of MPPT is shown above and the related graphs of MPPT with and without voltages and power are in figures 18-23.

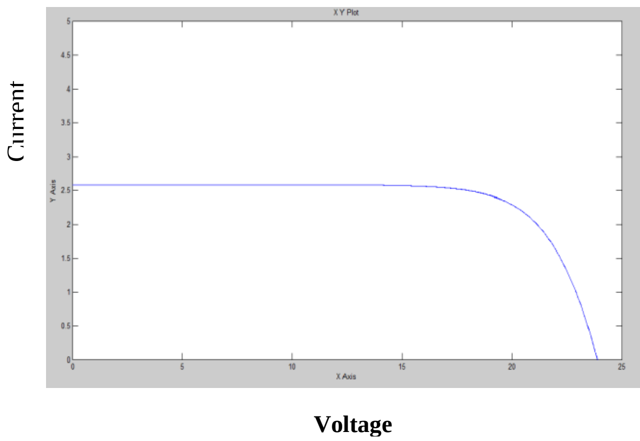


Figure 16:I-V curve

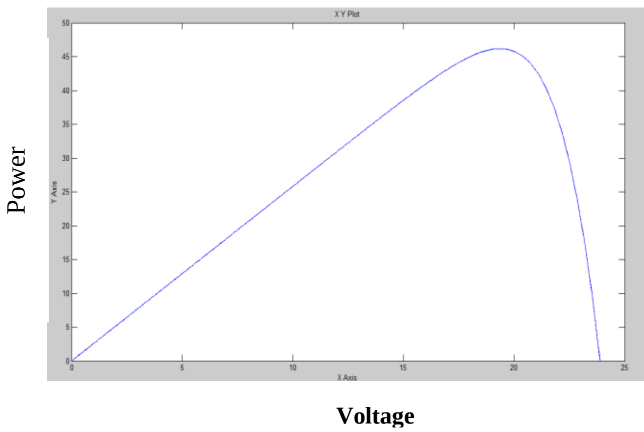


Figure 17: P-V curve

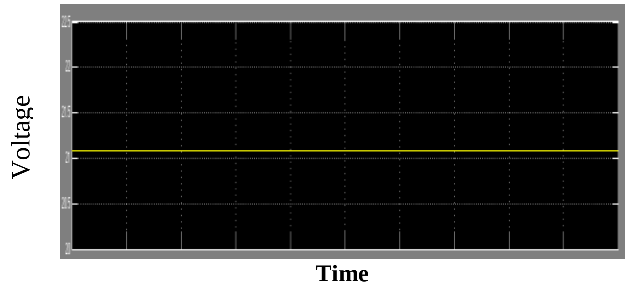


Figure 18: voltage without MPPT

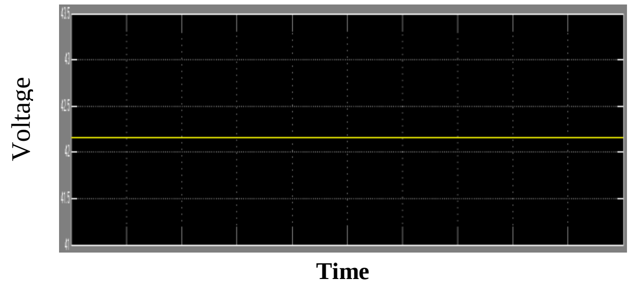


Figure 19: Voltage with MPPT

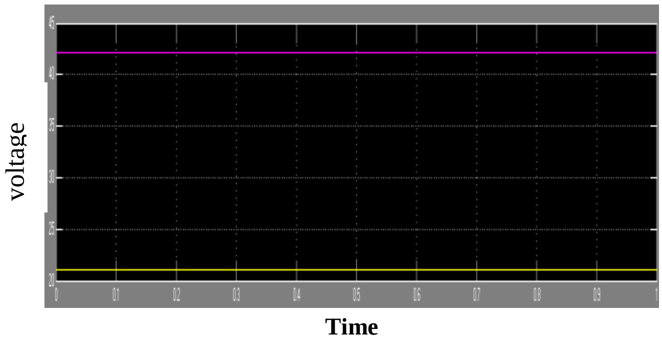


Figure 20: Voltages without and with MPPT

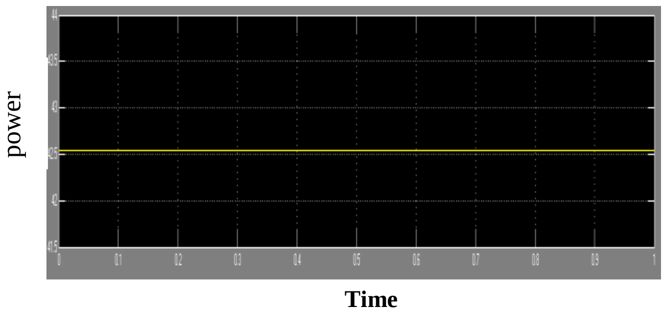


Figure 21: Power without MPPT

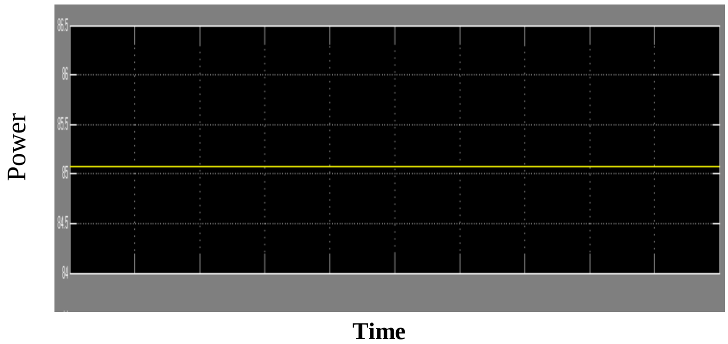


Figure 22: Power with MPPT

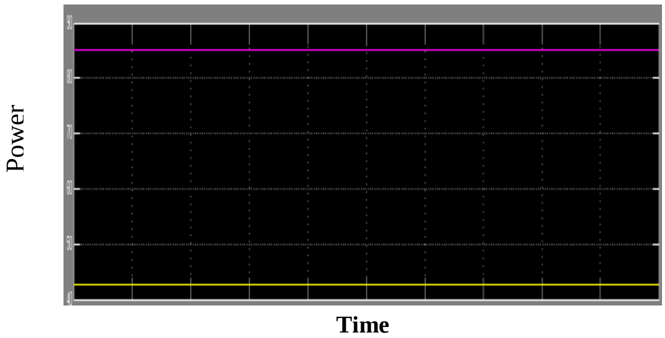


Figure 23: Power without and with MPPT controller

PV CELL & MPPT RESULTS

After mathematical circuit oriented modeling we have got following results

Photon current I_{ph}	: 2.581 A
Reverse saturation current I_{rs}	: 2.317*10-6 A
Saturation current I_s	: 0.552*10-6 A
Photovoltaic current I_{pv}	: 2.018 A
Photovoltaic voltage V_{pv}	: 21.08 V
Photovoltaic power P_{pv}	: 42.58 W
Voltage without MPPT	: 22.5 V
Voltage with MPPT	: 45V
Power without MPPT	: 42.5 W
Power with MPPT	: 85 W

VII. CONCLUSION

A MATLAB/SIMULINK model of the solar PV cell, module and array was developed and presented based on the mathematical equations in this paper. The paper also proposes a simple MPPT method that requires only measurement of Incremental conductance. The proposed MPPT algorithm is called Incremental Conductance Method. This method computes the maximum power and controls directly the extracted power from the PV. The method offers different advantages which are good tracking efficiency, response is high and well control for the extracted power.

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