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*Research Paper*

# ANALYSIS OF PHOTOVOLTAIC SYSTEMS TO ACHIEVE MAXIMUM POWER POINT TRACKING WITH VARIABLE INDUCTOR

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Photovoltaic (PV) system is the most promising source of energy and a new concept in use, which is obtaining popularity due to increasing importance to research for alternative sources of energy over exhaustion of customary fossil fuels worldwide. This systems are developed to draw energy from the sun, in the most competent manner. In this project Buck converter based PV system with resistive load is considered. The converter topology uses a variable inductor which provides adequate harmonic reduction. Employing the theorem that matching impedance yields maximum power transfer, a number of algorithms have been developed for Maximum Power Point Tracking (MPPT). In this paper Incremental Conductance with integral regulator MPPT algorithm has been used. The proposed system is simulated using Matlab/Simulink environment.

Keywords: PV, MPPT, Incremental Conductance (IC) algorithm

## INTRODUCTION

The demand for energy is increasing particularly worldwide. Although the unavailability of fossil fuels had pushed us to towards finding the alternative sources of energy. Solar energy is the most important and sustainable energy system. Solar energy systems has a major role in distributed generation network. There are many other renewable sources of energy such as wind, tidal, biomass, etc. But the solar energy is present everywhere which makes readily available than other renewable sources of energy that can be easily extracted and utilized. With the help of solar panel which is made up of silicon photovoltaic cells the solar energy can be converted into electrical energy. The efficiency of the solar systems depends on many factors such as insolation, temperature and spectral characteristics, dust, shading which results in poor performance. Currently more research has been focused on how to

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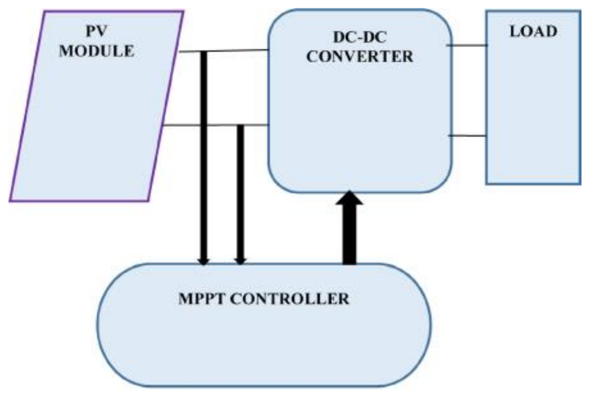
extract effective power form solar cells [1]. There are two ways such as MPPT and solar tracking systems. Literature survey shows that there will be a 30-40% increase in the percentage of energy as compared to PV systems with MPPT. Maximum Power Point tracking is the online control strategy to track the maximum output power point under different operation conditions such as insolation and Temperature. This MPPT is used to increase the efficiency Of PV systems. According to maximum power point theorem the output power can be maximized by adjusting the source impedance equal to the load impedance. Presently the most common algorithm used is the Perturbation and Observe (P&O) method, Incremental Conductance (IC) method and hill climbing. P&O and hill climbing are widely applied in MPPT controller due to their easy implementation and simplicity. Meanwhile in both methods the steady state oscillation appear due to perturbation, which may lead to increase in power loss. The MPPT algorithm used in this paper is Incremental Conductance (IC) algorithm. Incremental conductance method is based on the fact that under rapidly varying conditions the slope of the PV array power curve versus voltage curve is zero at maximum power point which in turn improves the tracking efficiency [2]. The block diagram of PV system with DC-DC converter and MPPT is shown in Figure 1.

The Simulink model of a PV system is simulated under different insolation. The Simulink model with PV system and MPPT with DC-DC converter will be implemented in Matlab/Simulink.

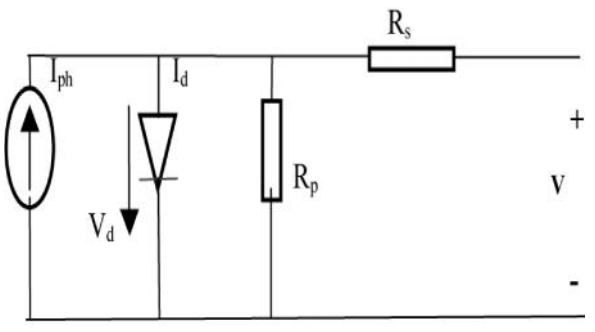
Figure 1: Block Diagram of Proposed Scheme




## MODELLING OF A PHOTOVOLTAIC SYSTEM

Photovoltaic cell generates electricity from the sun. PV panel works under the principle of Photoelectric effect which directly converts sunlight into electricity. The most common model used to foretell the energy production in modelling of a photovoltaic cell is the single diode circuit model. The ideal photovoltaic model consist of a single diode connected in parallel with the light generated current source. Solar cells are connected in series and parallel to set up a solar array. Figure 2 shows the equivalent model of a solar cell.

Figure 2: Equivalent Model of a Solar Cell




The use of the simplified circuit model in this work makes it suitable for power electronics designer to have a simple and effective model for the simulation of photovoltaic devices with power converters. The single diode model is used in this paper. In Figure 2 $I_{ph}$ refers to the photocurrent and $R_p$ and $R_s$ refers to the intrinsic parallel and series resistance. The photocurrent of the photovoltaic module depends linearly on the solar irradiation and t is also influenced by the temperature. It is given by

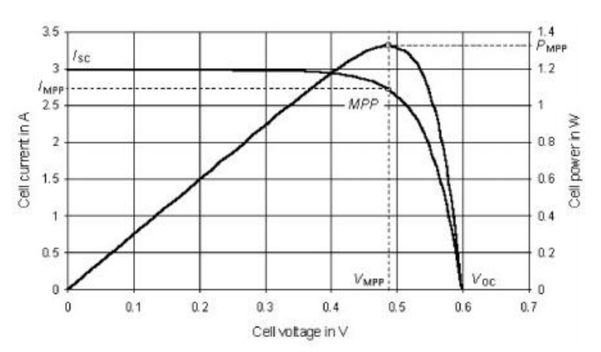
$$I_{ph} = (I_{sc} + k_i(T_k - T_{ref}))*a/1000 \quad ...(1)$$

where $I_{ph}$ is the photocurrent at nominal conditions (25 °C), $I_{sc}$ is the short circuit current, $k_i$ is the short circuit current temperature coefficient, and $T_{ref}$ and $T_k$ are the reference and actual temperatures in kelvin respectively. On the other hand cell's saturation current varies with the cell's temperature and is given by:

$$I_s = I_{rs}*(T_k/T_{ref})^3*exp(q*E_g(1/T_{ref} - 1/T_k)/K*A) \quad ...(2)$$

where $I_{rs}$ is the cell's reverse saturation current at a reference temperature and solar irradiation. $E_g$ is the band gap energy of the semiconductor used in the cell and A is the ideality factor. The reverse saturation current is given by:

Figure 3: I-V and P-V Characteristics of a Solar Cell




$$I_{rs} = I_{sc}/exp(q*V_{oc}/N_s*K*A*T_k)-1) \quad ...(3)$$

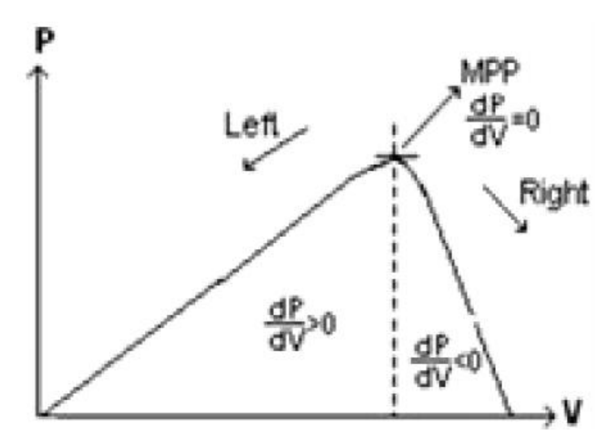
where $V_{oc}$ is the cell's open circuit voltage, $K$ is the Boltzmann's constant, $N_s$ is the no cell in series. The I-V and P-V characteristics of a solar cell is shown.

## INCREMENTAL CONDUCTANCE ALGORITHM

The output power of a PV module changes with the change in the solar insolation and temperature. In the PV characteristics there is a maximum power point for the PV module to operate, it is preferred that PV module operates close to this point. The voltage at which PV module produces maximum power is called maximum power point. The most common algorithm are P&O and Incremental conductance. The advantage of Incremental Conductance is that it provides high efficiency under rapidly changing atmospheric conditions. In this paper the maximum power point is achieved by Incremental Conductance algorithm with an integral regulator [3]. The theory of Incremental Conductance algorithm is determining the variation of terminal voltage of PV modules by comparing and measuring the incremental conductance and instantaneous conductance of PV module. The power will be maximum at a point when the value of incremental conductance is equal to that of instantaneous conductance. This maximum power point can be obtained from the voltage and current measurements, the algorithm calculates the duty cycle required to maximize the flow of power.

Figure 4 shows the basic concept of Incremental conductance on P-V curve of a solar module. In the above figure the slope of the P-V curve is zero. If the PV module

Figure 4: Basic Idea of Incremental Conductance on P-V Curve




operating to the left of the MPP on PV curve, the PV voltage must be increased in order to reach the MPP. If the PV module operating to the right of the MPP on P-V curve, the PV voltage must be reduced in order to reach the MPP. The basic equations of this method are as follows:

$$\frac{dI}{dV} = -\frac{I}{V} \text{ at MPP} \quad ...(4)$$

$$\frac{dI}{dV} > -\frac{I}{V} \text{ Left of MPP} \quad ...(5)$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ Right of MPP} \quad ...(6)$$

where I and V are the PV module output current and voltage respectively. By using the factor $\frac{\partial P}{\partial V}$ which is defined as the Maximum power point identifier factor, the IC method is recommended to efficiently track the MPP of PV array [7]. The right hand side of the equation represents the instantaneous conductance and left hand side of the equation represents the incremental conductance of the PV module. When the ratio of change in output conductance is equal to negative output conductance, the PV module will operate at maximum power point. In order to operate a PV system within its maximum power point and considering the temperature variation and irradiance a maximum power point tracking algorithm is needed to track and maintain the peak power. In this paper the algorithm is modified which includes integral regulator. This integral regulator minimizes the error where the output of the integral regulator will be equal to the duty cycle. This implementation can be done by adding a controller which improves the incremental conductance method by minimizing the error between the actual conductance and incremental conductance. This controller can reduce the ripple oscillations caused during steady states. We have,

$$P = V*I \quad ...(7)$$

Maximum power point is obtained when

$$\frac{\partial I}{\partial V} = 0 \quad ...(8)$$

Applying chain rule to the derivative of product yields to

$$\frac{\partial P}{\partial V} = \frac{\partial (V*I)}{\partial V} \quad ...(9)$$

The above equation can be written in terms of voltage and current as

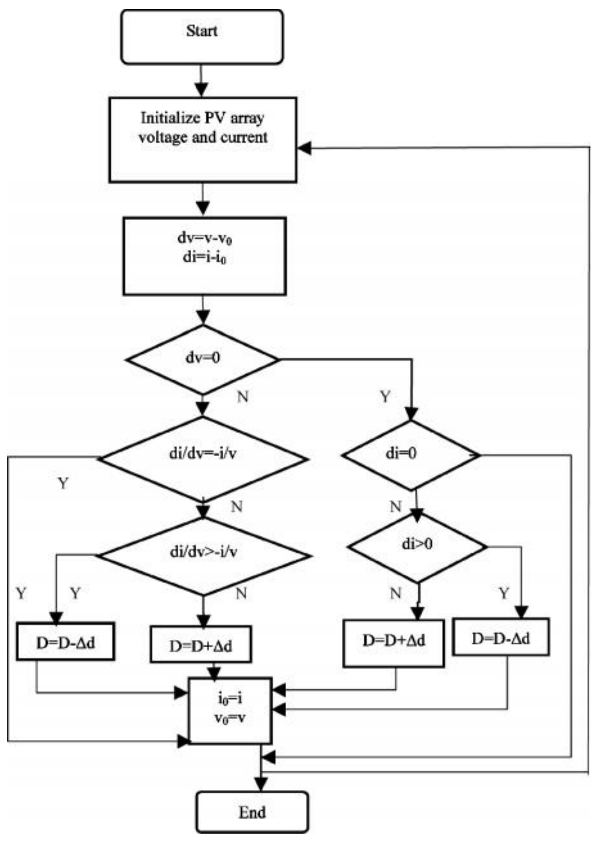
$$\frac{\partial I}{\partial V} = -\frac{I}{V} \quad ...(10)$$

The maximum power point tracking regulates the PWM output of the DC-DC converter until the condition: $\frac{\partial I}{\partial V} + \frac{I}{V} = 0$ is obtained. The flowchart of the incremental algorithm is shown in Figure 5.

## DC-DC CONVERTER WITH VARIABLE INDUCTOR

Dc-Dc converters can be used as switched mode regulators to convert an unregulated Dc voltage to a regulated Dc output voltage. In this

Figure 5: Flowchart of Incremental Conductance MPPT




paper the converter used is Buck converter. In buck converter, for a correct operation the output voltage must be less than the PV module voltage. The switch operates at high frequency to produce the chopped voltage. The power flow is controlled by adjusting the duty cycle. In this buck converter variable inductor has been introduced. This use of variable inductor has an advantage of increasing the load range [5]. The minimum inductance is given by:

$$L_{min} = \frac{D^2(1-D) * V_p}{2 * f_s * I_p} \quad ...(11)$$

where $D$ is the duty ratio, $V_p$ is the panel voltage, $I_p$ is the panel current, $f_s$ is the switching frequency.

## SIMULATION RESULTS AND DISCUSSION

The Simulation has been implemented in Matlab/Simulink. Simulation has been carried out for 10 W 18 V Solar panel with the switching frequency of 10 KHz. The insolation is varied from 200 W/m$^2$ to 800 W/m$^2$. The parameters of the PV module are obtained from the datasheet [4]. The Simulink model of PV module with MPPT of Buck converter is shown below.

Figure 6: Simulink Model of a PV Module with MPPT of Buck Converter

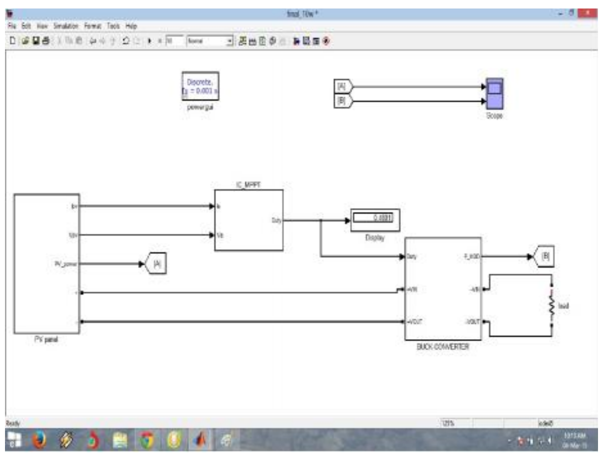


Figure 7: Simulink Model of a PV Module

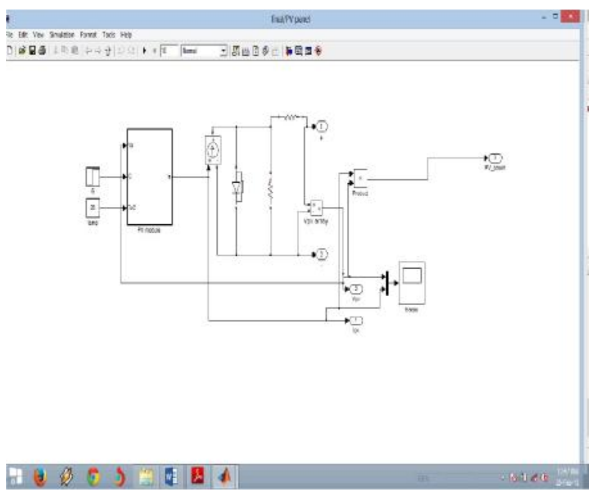
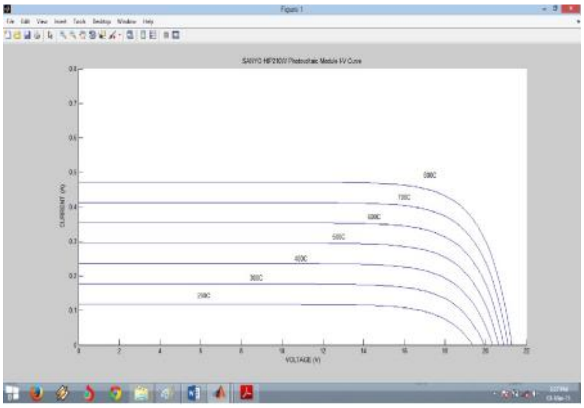


Figure 8: I-V Characteristics of a PV Module



The Simulink model of a PV module and I-V characteristics is shown below.

Table 1: Parameters Under Different Conditions

| Insolation (W/M²) | Voltage ($V_p$) | Current ($I_p$) | Duty Ratio (D) | $L_{min}$ (μH) |
|---|---|---|---|---|
| 800 | 14.1 | 0.47 | 0.480 | 179.7 |
| 700 | 12.4 | 0.41 | 0.487 | 184.1 |
| 600 | 10.6 | 0.35 | 0.490 | 185.4 |
| 500 | 8.85 | 0.29 | 0.490 | 186.8 |
| 400 | 7.08 | 0.23 | 0.491 | 188.4 |
| 300 | 5.3 | 0.17 | 0.491 | 190.8 |
| 200 | 3.5 | 0.12 | 0.491 | 178.5 |

Figure 9: Simulink Model of Incremental Conductance Algorithm with Integral Regulator

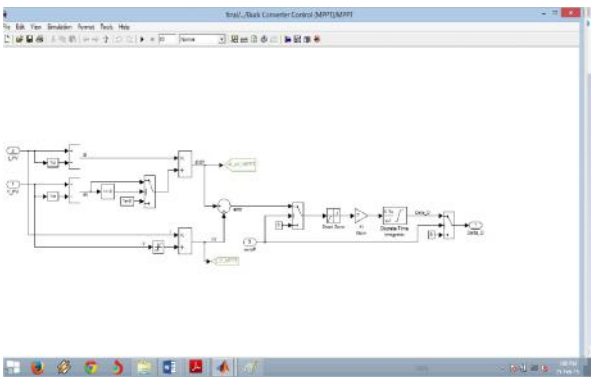


Figure 10: Waveform of Current After Switch with Harmonics for 800 W/m²

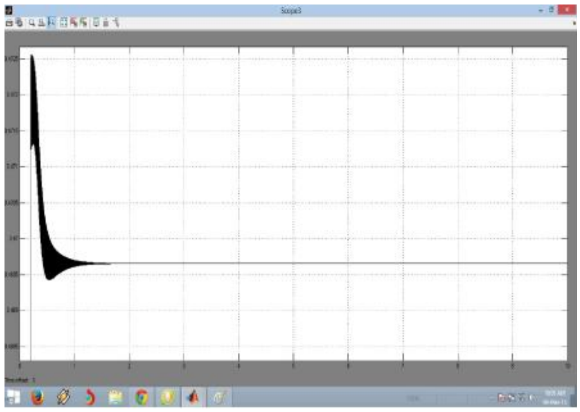


Figure 11: Waveform of Current After Variable Inductor for 800 W/m²

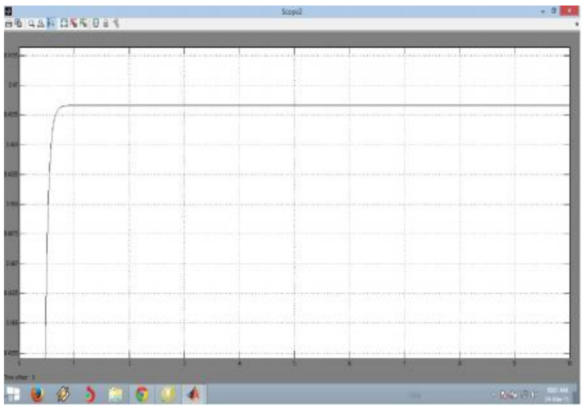
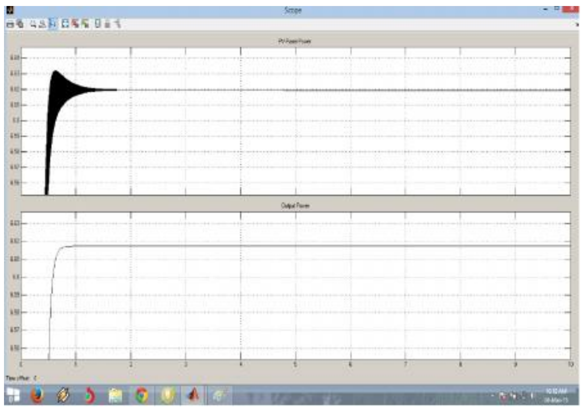


Figure 12: PV Module Power and Output Power at 800 W/m²



## CONCLUSION

The Simulation of PV module with MPPT has been successfully implemented in Matlab/Simulink. This paper intends a MPPT method with an integral regulator which requires only measurements of Incremental conductance method. The variable inductor provides good harmonic reduction. The proposed method has advantages like good tracking efficiency, high response.

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