



## Evaluation of Power Performance of a PV Module with MPPT Solution Using MATLAB Simulation

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### ABSTRACT

In the context of increasing emission of greenhouse gasses in the environment due to fossil fuel burning, this paper attempts to describe the significance of Maximum Power Point Tracking (MPPT) by investigating the power performance of photovoltaic modules with MATLAB simulation. MPPT algorithm was employed to secure maximum power from PV module. The boost converter whose pulse is linked to MPPT algorithm restricts the flow of load power and controls the current and voltage of PV panels. The whole design of the solar model, boost converter, and MPPT controlled algorithms was done in the SIMULINK to prioritize the system in simulation. The main concept employed in this paper was to develop a power generation process with MPPT algorithm and to provide information for future use. In this paper, all simulations along with the PV power generation process were done in MATLAB. This research could potentially play a vital role in mitigating the world fuel crisis.

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### 1. INTRODUCTION

The world remains challenged by the difficulties and constraints associated with energy generation. Societies are developing alongside new technology every day. New technology needs greater power which in turn increases the fuel cost of the power plant. Power generation and transmission cost are increasing day by day, which incurs a greater cost for customers [1]. Burning fossil fuel in every generating station produces a large amount of greenhouse gasses. Emission of CO<sub>2</sub> is increasing due to burning of fossil fuel which may increase the temperature of the environment by 20-60 Celsius up to the year 2100 [2]. The cost of electric power can be reduced using renewable energy sources like wind, solar, and hydropower nuclear reaction. Solar energy is considered a low-cost system with less maintenance and lower energy loss [3]. Photovoltaic systems play a vital role in ensuring a peaceful and clean environment because they do not contribute to global warming [4]. Moreover, a Photovoltaic (PV) power system represents a popular renewable energy system. Solar power demand increases day by day due to such advantages as (i) direct electric power access, (ii) little maintenance cost, and (iii) no noise [5]. The PV operation provides maximum power to its load. The output current and voltage depend on the radiation of the sunlight and the temperature of the solar cell [6]. Upon increase in sunlight radiation, the current of solar cell increases; in addition, when the temperature increases by the sunlight, the voltage of the solar cell increases. This paper runs

the power performance of PV module in MATLAB to prove the potentiality of solar cells in near future

### 2. SIMULATION OF PV MODULE

For simulation purposes, an equivalent circuit model of PV cell is required, as given in Figure 1.

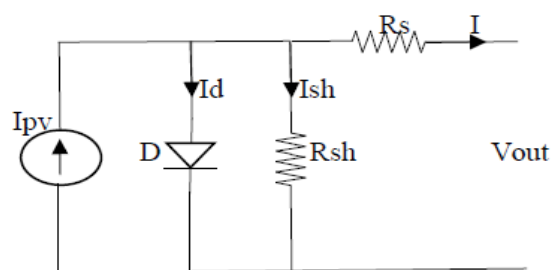


Figure 1. Single diode SIMULINK model of PV cells

Table 1 shows the PV module specifications. The simulation employed to determine the power performance of the PV module is carried out in MATLAB using the specifications provided in the table.

PV array is designed when modules with various arrangements are connected [7]. A significant amount of power can be retrieved by making connections among a series of PV modules in a PV array [8]. The connection among a fixed number of PV cells is known as PV module [9] and it provides

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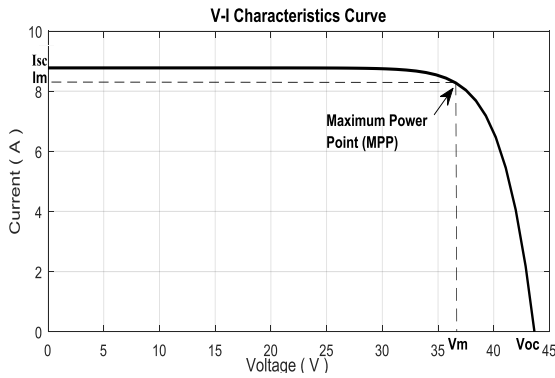


no current to the load in case of any disconnection from the load [10].

The V-I characteristics curve of the solar module is shown in Figure 2.

**Table 1.** Data sheet of JKM295P model

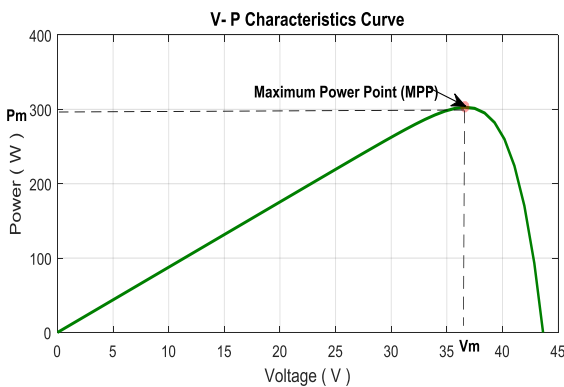
Parameters	Values
Maximum power ( $P_{max}$ )	295 W
Maximum power voltage ( $V_{mp}$ )	36.6 V
Maximum power current ( $I_{mp}$ )	8.15 A
Open-circuit voltage ( $V_{op}$ )	45.1 V
Short-circuit current ( $I_{sc}$ )	8.76 A
Number of series cells ( $N_s$ )	72
Number of parallel cells ( $N_p$ )	1
Energy band gap (A)	1.1 eV



**Figure 2.** V-I characteristics curve of PV module

The V-I characteristics curve is obtained for the solar model JKM295P. Here, the main parameters include maximum short-circuit current and maximum open-circuit voltage. On the maximum power point with high output efficiency, the fill factor should be 0.5-0.82 [11].

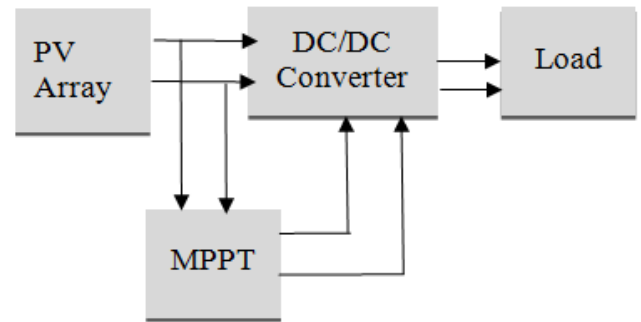
The V-P characteristics curve is shown in Figure 3. Based on the power curve, it is seen that the power reaches around 300 W with the maximum power point voltage  $V_m$ . The maximum power  $P$  relies on the PV module voltage  $V$ , which is the terminal voltage of the PV module [12]. The maximum power point voltage provides maximum power from the module.



**Figure 3.** V-P characteristics curve of PV module

The MPPT algorithm plays a vital role in obtaining maximum power despite possible variations in instant radiation. MPPT selects the duty cycle that determines the boost converter

switching using MOSFET [13]. Weather changes continuously upon every changes in radiation caused by earth rotation, which in turn induces changes in the PV current, voltage, and power. Incremental Conductance (IC) algorithm makes the array voltage suitable for obtaining maximum power from PV array [14]. PV module current and voltage are unstable if the MPPT algorithm is not applied. Increasing the module current can damage load electrical devices [15]. Installing solar power modules with a proper series-parallel combination can protect the connected electrical device. An alternating and convenient way of obtaining maximum power from solar array is to connect boost converter to the load. The block diagram for the whole project is shown in Figure 4.



**Figure 4.** Block diagram of solar MPPT

The PV array generates the voltage and current using the radiation from sunlight. The unstable PV module voltage and current can damage the load electrical device. Therefore, the incremental conductance algorithm can increase the generated power by selecting a proper duty cycle that provides the required power to the electrical device.

### 3. MATHEMATICAL MODEL OF PV MODULE

The developed equation from the equivalent circuit is as follows:

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

where  $I$  is the photovoltaic current. The photon current and the diode current are denoted by  $I_{ph}$  and  $I_d$ , respectively. The shunt resistor current is  $I_{sh}$ .

The following equation can be considered for PV module:

$$I = I_{ph} - I_s \left\{ \exp \frac{q(V+IR_s)}{kT_c * A} - 1 \right\} - I_{sh} \quad (2)$$

where  $I_{ph}$  is the photon current which is generated by the sunlight radiation,  $q$  is the electric charge ( $1.60 \times 10^{-19}$  C), and the Boltzmann's constant  $k$  is ( $1.38 \times 10^{-23}$  J/K).  $T_c$  is the cell's temperature,  $A$  defines ideality factor, and  $R_s$ ,  $I_{sh}$  are series and shunt resistors, respectively.

Photon current of the PV module is developed from sunlight irradiation and the mathematical equation of the photon current is expressed as follows:

$$I_{ph} = I_{sc} + K_i * \{T_c - T_{ref}\} * \frac{G}{G_n} \quad (3)$$

Here, the symbols are short-circuit current ( $I_{sc}$ ), short-circuit current temperature coefficient ( $K_i$ ), cell temperature ( $T_c$ ), and Cell's reference temperature ( $T_{ref}$ ). ( $G$ ) and ( $G_n$ ) are the solar irradiation and nominal solar irradiation, respectively, in Standard Test Condition (STC). Figure 5 shows the MATLAB

SIMULINK model employed in illustrating the photon current characteristics. The saturation current ( $I_s$ ) of PV cells varies with respect to the temperature of the solar cell. The mathematical equation of solar cell saturation current is as follows:

$$I_s = I_{rs} * \left(\frac{T_c}{T_{ref}}\right)^3 * \exp * \{q * E_g * \left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)\} \quad (4)$$

Figure 6 shows the MATLAB SIMULINK model for saturation current.  $I_{rs}$  is the reverse saturation current of the PV solar cell. Energy bandgap ( $E_g$ ) depends on the materials used in semiconductor. The solar cell is made of silicon and the bandgap for silicon is 1.2 eV.

$$I_{rs} = \frac{I_{sc}}{\exp * \frac{q * V_{oc}}{k * T_c * A} - 1} \quad (5)$$

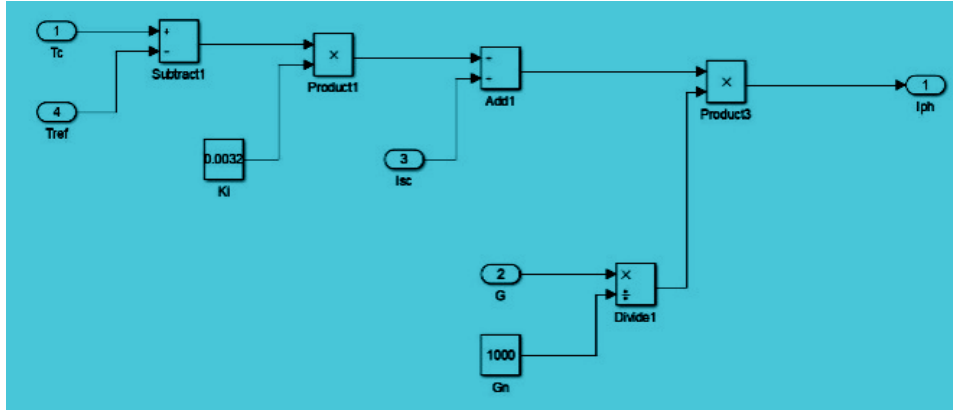


Figure 5. SIMULINK diagram for equation of photon current in PV module

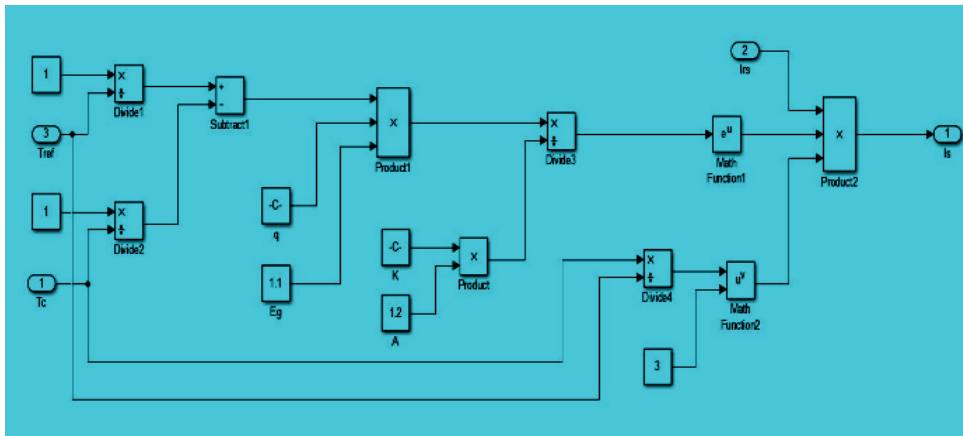


Figure 6. SIMULINK diagram for equation of saturation current for PV module

In the equation, the symbols are short-circuit current ( $I_{sc}$ ), diode ideality factor ( $A$ ), and the open-circuit voltage ( $V_{oc}$ ). The output current and short-circuit current of PV cell result from sunlight radiation and cell temperature. This is developed by the MATLAB SIMULINK model. The PV module is made using the series-parallel combination. Thus, the developed mathematical equation for the array is given by Equation (6).

$$I_{pv} = N_p * I_{ph} - N_{pls} \left\{ \exp \frac{q \left( \frac{V}{N_s} + \frac{I_{rs}}{N_p} \right)}{k * T_c * A} - 1 \right\} - \left\{ \frac{N_p V + I_{rs}}{R_{sh}} \right\} \quad (6)$$

For characterizing the output current of the PV module, the SIMULINK model is established in Figure 7. The equation also defines V-I and V-P curves that find the Maximum Power Point (MPP) of the PV module. The whole equation is developed by the MATLAB SIMULINK model in Figure 8.

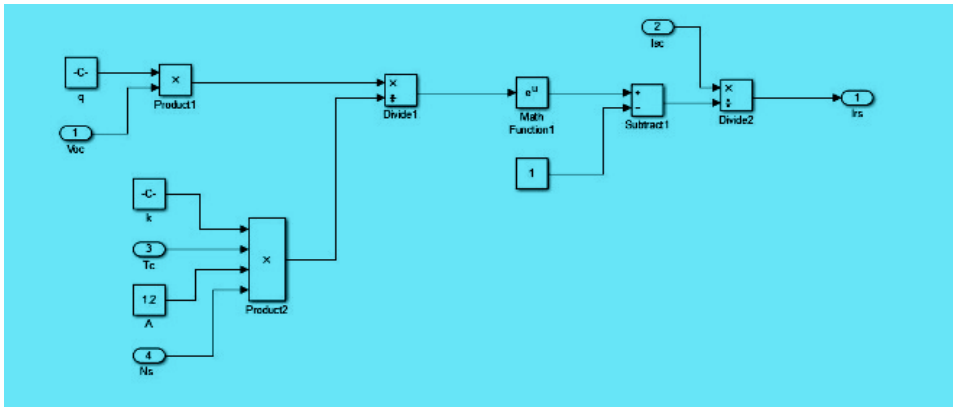


Figure 7. SIMULINK diagram for equation of reverse saturation current for PV module

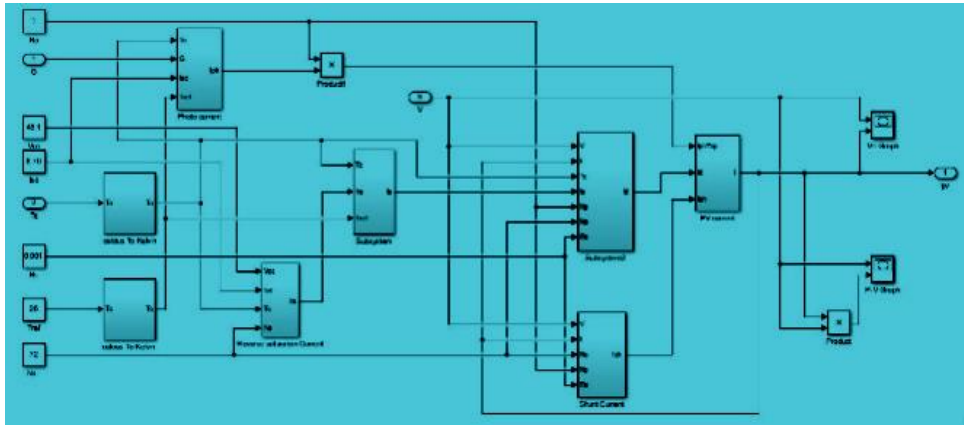


Figure 8. SIMULINK model for equation of PV load current

**4. INCREMENTAL CONDUCTANCE AS AN MPPT SOLUTION**

The output current and the voltage of the PV module vary with respect to the continuous change of the solar radiation and temperature. To stabilize the output voltage and to obtain the maximum power from the PV module, an MPPT algorithm is required to transfer maximum power to the load. The unwanted duty cycle is modified so that the MPP can be implemented

fully. To meet the MPP condition, the duty cycle needs to be adjusted for obtaining the fixed position, because rapid variation of duty cycle may hamper the function of the device connected to load. The SIMULINK model together with the MATLAB function of MPPT algorithm is shown in Figure 9.

Incremental Conductance (IC) of MPPT algorithm is designed to achieve maximum power in different weather conditions. The block diagram of Incremental Conductance is shown in Figure 10.

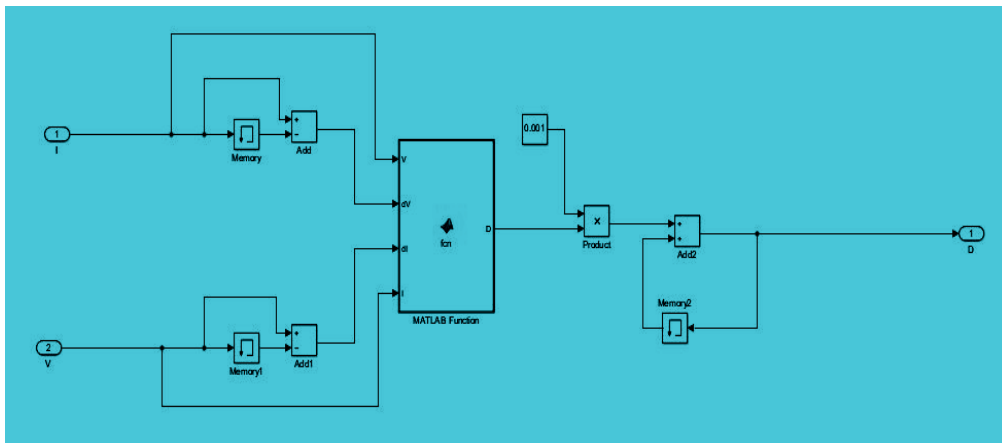


Figure 9. MPPT SIMULINK model with MATLAB function

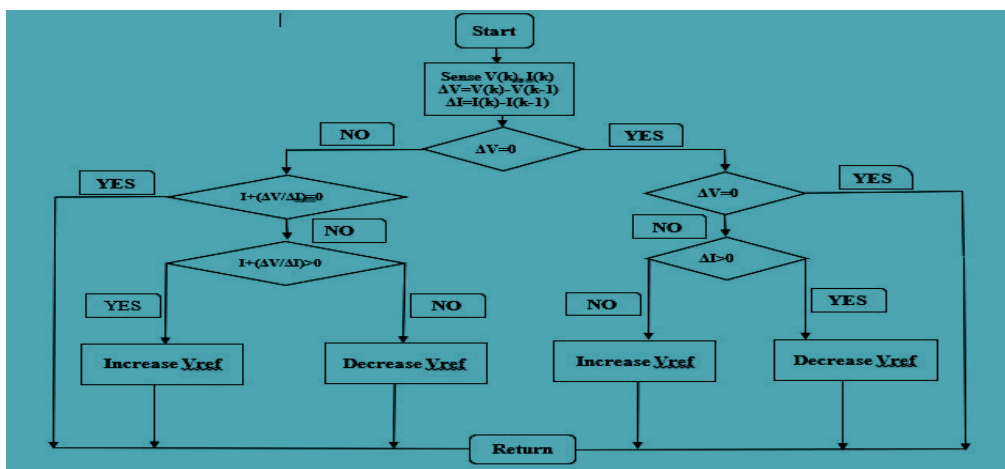


Figure 10. Incremental Conductance MPPT algorithm

The incremental conductance algorithm can fix the output more rapidly than the Perturb and Observe (P & O) algorithm method [16]. This model is used to ensure the Incremental

Conductance ( $dI/dV$ ) of PV array to measure the power changes with respect to the change in voltage ( $dP/dV$ ), where ( $I/V$ ) is the array conductance or instantaneous conductance

[17]. MPPT is designed with the boost converter. Boost converter boosts the input voltage to make it equal to the load voltage. The buck converter decreases the output voltage to increase the output current [18].

## 5. BOOST CONVERTER FOR PV MODULE

The MOSFET works like a switch, as shown in Figure 11. When the switch is turned off, diode works as reverse bias resisting current flow. However, when the switch is turned on, diode is in forward bias which results the current to the load. Inductor and capacitor values are constant for measuring the duty cycle.

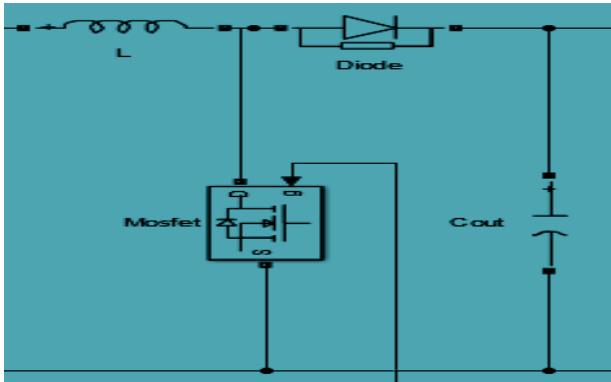


Figure 11. Boost converter of PV module

Duty cycle  $D$  can be measured through the following equation:

$$\text{Duty cycle, } D = 1 - \frac{V_{\text{out}}}{V_{\text{in}}} * \eta \quad (7)$$

Output voltage is  $V_{\text{out}}$ , Input voltage is  $V_{\text{in}}$ , and  $\eta$  is the efficiency of the boost converter.

Capacitor value can be determined using the following equation:

$$C = \frac{I_o(\text{max}) * D}{F_s * \Delta V_c} \quad (8)$$

$I_o(\text{max})$  is the maximum output current,  $F_s$  is the frequency, and  $\Delta V_c$  is the capacitor ripple voltage ranging from 1 % to 5 % of output voltage.

$$\text{Inductor, } L = \frac{V_{\text{min}} * D}{F_s * \Delta I_L} \quad (9)$$

$V_{\text{min}}$  is the minimum voltage and  $\Delta I_L$  is the ripple inductor current. The ripple current value varies from 20 % to 40 % of inductor current based on the rule of Thumb.

## 6. SIMULATION RESULT FOR PV MODULE WITH MPPT SOLUTION

Figure 12 shows simulation for output duty cycle. As mentioned earlier, IC reaches the MPP very faster than Perturb and Observe (P & O) algorithm method.

Here, Figure 13 defines the maximum current characteristics due to the Incremental Conductance (IC) algorithm in MPPT.

Similarly, Figure 14 shows the output power characteristics obtained in the load depending on the output current and voltage of the solar cell.

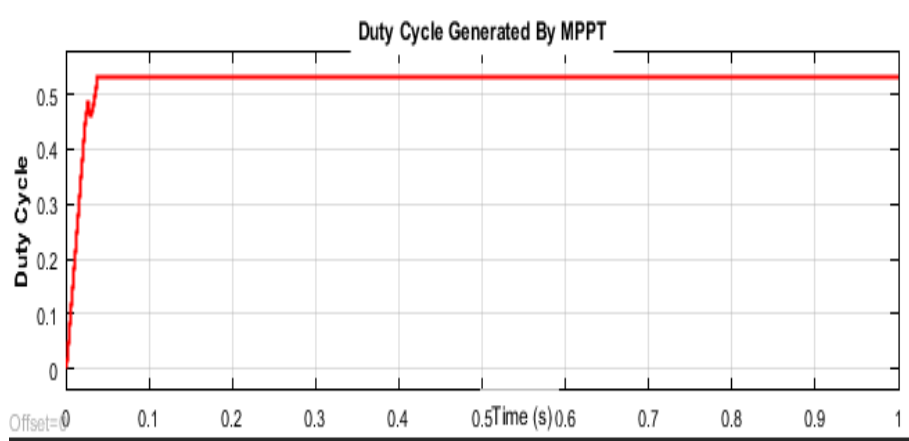


Figure 12. Duty cycle

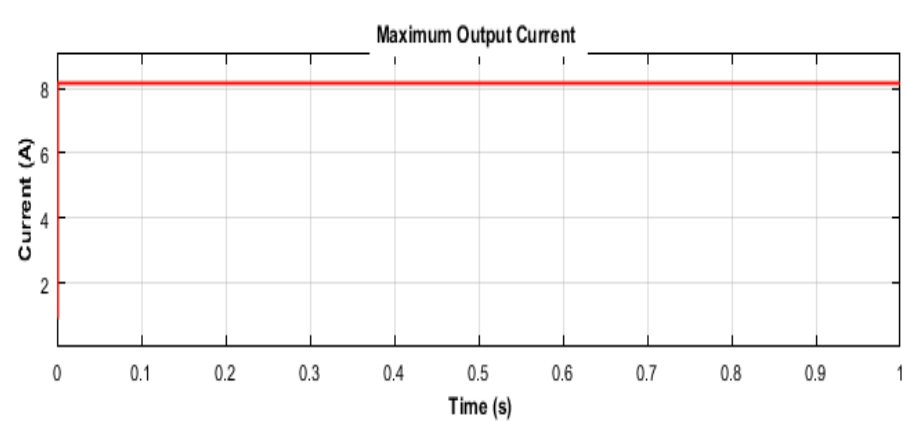


Figure 13. Maximum output current characteristics

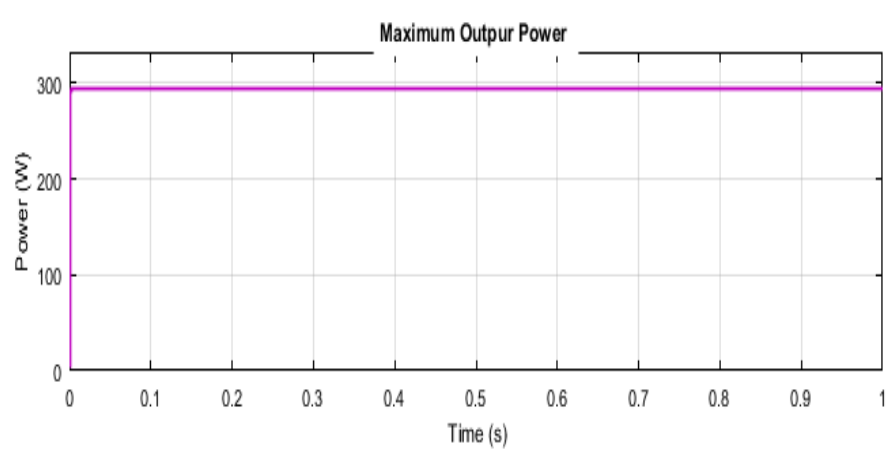


Figure 14. Maximum output power characteristics

## 7. CONCLUSIONS

The aim of every resource is to generate more power in a cost-effective manner without damaging the environment and to improve PV module to distribute a significant generation of electric power. Incremental Conductance (IC) provides maximum power with different weather conditions in different critical places. This study investigated whether the incremental conductance would work faster and provide maximum power with different radiation degrees of sunlight. The boost converter provided maximum efficiency and reliability in reducing the ripple current and voltage. Load-connected electrical device was saved by boost converter and load resistor was added to deliver limited power. Overall observation of this SIMULINK investigation indicated that some factors like low power generation cost, low maintenance cost, immunity against climatic variations were helpful in developing economic changes.

## 8. ACKNOWLEDGEMENT

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## REFERENCES

- Bhagwat, P.C., Richstein, J.C., Chappin, E.J.L. and De Vries, L.J., "The effectiveness of a strategic reserve in the presence of a high portfolio share of renewable energy sources", *Utilities Policy*, Vol. 39, (2016), 13-28. (<https://doi.org/10.1016/j.jup.2016.01.006>).
- Singh, B.R. and Singh, O., "Global trends of fossil fuel reserves and climate change in the 21<sup>st</sup> century", In: Khan, Sh. (Ed.), *Fossil fuel and environment*, Chapter 8, InTech, India, (2012), 167-192. (<https://doi.org/10.13140/2.1.1079.8084>).
- Sheik Mohammed, S. and Devaraj, D., "Simulation of incremental conductance MPPT based two phase interleaved boost converter using MATLAB/SIMULINK", *Proceedings of 2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, Coimbatore, India, (2015), 1-6. (<https://doi.org/10.1109/ICECCT.2015.7225987>).
- Chandwani, A. and Kothari, A., "Design, simulation and implementation of Maximum Power Point Tracking (MPPT) for solar based renewable systems", *Proceedings of 2016 International Conference on Electrical Power and Energy Systems (ICEPES)*, Bhopal, India, (2016). (<https://doi.org/10.1109/ICEPES.2016.7915987>).
- Chiu, C.-S., "T-S fuzzy Maximum Power Point Tracking control of solar power generation systems", *IEEE Transactions on Energy Conversion*, Vol. 25, No. 4, (2011), 1123-1132. (<https://doi.org/10.1109/TEC.2010.2041551>).
- Carrasco, J.A., de Quiros, F.G., Alaves, H. and Navalon, M., "An analog Maximum Power Point Tracker with pulswidth modulator multiplication for a solar array regulator", *IEEE Transactions on Power Electronics*, Vol. 34, No. 9, (2019), 8808-8815. (<https://doi.org/10.1109/TPEL.2018.2886887>).
- Atiq, J. and Kumar Soori, P., "Modelling of a grid connected solar PV system using MATLAB/SIMULINK", *International Journal of Simulation: Systems, Science and Technology*, Vol. 17, No. 41, (2017), 45.1-45.7. (<https://doi.org/10.5013/IJSSST.a.17.41.45>).
- Said, S., Massoud, A.M., Benammar, M. and Ahmed, Sh., "A MATLAB/SIMULINK-based photovoltaic array model employing SimPowerSystems toolbox", *Journal of Energy and Power Engineering*, Vol. 6, (2012), 1965-1975. ([https://www.academia.edu/2887497/A\\_Matlab\\_Simulink\\_Based\\_Photo\\_voltaic\\_Array\\_Model\\_Employing\\_SimPowerSystems\\_Toolbox?auto=download](https://www.academia.edu/2887497/A_Matlab_Simulink_Based_Photo_voltaic_Array_Model_Employing_SimPowerSystems_Toolbox?auto=download)).
- Said, S., Massoud, A.M., Benammar, M. and Ahmed, Sh., "Development of generalized photovoltaic model using MATLAB/SIMULINK", *Proceedings of the World Congress on Engineering and Computer Science*, San Francisco, USA, (2008). (<http://s2i.bordeaux.free.fr/Espace%20Terminale/Ressources/Projet/ProjetASI/2.%20Development%20of%20Generalized%20Photovoltaic%20Model%20using%20Matlab.pdf>).
- Murshed, N., Khan Tushar, Md.S. and Chowdhury, S., "Power performance analysis of PV module with dc to dc buck converter", *Advanced Journal of Graduate Research*, Vol. 1, No. 9, (2019), 27-39. (<https://doi.org/10.21467/ajgr.8.1.27-39>).
- Sheik Mohammed, S., "Modeling and simulation of photovoltaic module using MATLAB/SIMULINK", *International Journal of Chemical and Environmental Engineering*, Vol. 2, No. 5, (2013), 24-32. ([https://www.researchgate.net/publication/301602460\\_Mathematical\\_Modeling\\_and\\_Digital\\_Simulation\\_of\\_PV\\_Solar\\_Panel\\_using\\_MATLAB\\_Software](https://www.researchgate.net/publication/301602460_Mathematical_Modeling_and_Digital_Simulation_of_PV_Solar_Panel_using_MATLAB_Software)).
- Surya Suresh, K. and Vishnu Prasad, M., "PV cell based five level inverter using multicarrier PWM", *International Journal of Modern Engineering Research (IJMER)*, Vol. 1, No. 2, 545-551. (chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=http%3A%2F%2Fwww.ijmer.com%2Fpapers%2Fvol%25201%2520issue%25202%2FAP012545551.pdf&clen=701280&chunk=true).
- Ilyas, A., Ayyub, M., Rizwan Khan, M., Jain, A. and Aslam Husain, M., "Realisation of incremental conductance MPPT algorithm for solar photovoltaic system", *International Journal of Ambient Energy*, Vol. 39, No. 8, (2018), 873-884. (<https://doi.org/10.1080/01430750.2017.1354322>).
- Sarathi Maji, P., Dikshit, S. and Mohapatra, S., "Modelling and simulation of photovoltaic model using incremental conductance algorithm", *International Journal of Engineering and Management Research*, Vol. 4, No. 2, (2012), 205-211. ([https://www.ijemr.net/DOC/ModellingAndSimulationOfPhotovoltaicModelUsingIncrementalConductanceAlgorithm\(205-211\)626d1cf0-bc09-476b-a1fe-205846b3a526.pdf](https://www.ijemr.net/DOC/ModellingAndSimulationOfPhotovoltaicModelUsingIncrementalConductanceAlgorithm(205-211)626d1cf0-bc09-476b-a1fe-205846b3a526.pdf)).
- Ritu, Verma, N., Mishra, Sh. and Shukla, S., "Implementation of solar based PWM fed two phase interleaved boost converter", *Proceedings of International Conference on Communication, Control and Intelligent*

- Systems (CCIS)*, (2015), 470-476. (<https://doi.org/10.1109/CCIntelS.2015.7437962>).
16. Sreenivasa Rao, K. and Mahesh, M., "ARM based solar tracking system", *International Journal of Modern Engineering Research (IJMER)*, Vol. 2, No. 4, (2012), 2504-2507. ([chromeextension://efaidnbmnnnibpcjpcglclefindmkaj/viewer.html?pdfurl=http%3A%2F%2Fwww.ijmer.com%2Fpapers%2FVol2\\_Issue4%2FDA2425042507.pdf&clen=492184&chunk=true](chromeextension://efaidnbmnnnibpcjpcglclefindmkaj/viewer.html?pdfurl=http%3A%2F%2Fwww.ijmer.com%2Fpapers%2FVol2_Issue4%2FDA2425042507.pdf&clen=492184&chunk=true)).
17. Chandwani, A. and Kothari, A., "Comparative study of Maximum Power Point Tracking algorithms", *Progress in Photovoltaics: Research and Applications*, Vol. 11, (2003), 47-62. (<https://doi.org/10.1002/pip.459>).
18. Glasner, I. and Appelbaum, J., "Advantage of boost vs. buck topology for Maximum Power Point Tracker in photovoltaic systems", *Proceedings of 19<sup>th</sup> Convention of Electrical and Electronics Engineers in Israel*, Jerusalem, Israel, (1996), 355-358. (<https://doi.org/10.1109/EEIS.1996.566988>).