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Optimization of the Power Output of the Photovoltaic System through MPPT Algorithm

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تحسين إنتاج الطاقة لنظام الطاقة الكهروضوئية من خلال خوارزمية MPPT

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Abstract:
Renewable energy from the sun is the energy that the sun radiates as light, which is subsequently used by people in a variety of ways, including photovoltaic cells. An endless supply of energy, like solar energy, is free since it is not owned by anyone. Under certain conditions, Maximum Power Point Tracking (MPPT) can be utilized to extract the maximum output that can be obtained from solar cells while also being linked into charge control systems. The specific input used in photovoltaic modules that has the capacity to produce the highest output power is known as the maximum power point, or highest voltage. Maximum power varies with the solar energy parameter that determines the photovoltaic (PV) module's necessary temperature.
MATLAB/SIMULINK is utilized to develop a Maximum Power Point Tracking (MPPT) strategy based on perturb and observe (P&O) method, which allows for the efficient operation of the photovoltaic system while accounting for the swift fluctuations in climatic circumstances. Based on simulation results, it was found that the point of operation oscillates around the maximum power point, as well as these oscillations are proportional to changes in incident illumination.
Keywords: MATLAB, P&O Maximum Power Point Tracking (MPPT), Photovoltaic..

الملخص:
الطاقة المتجددة من الشمس هي الطاقة التي تشعها الشمس كضوء، والتي يستخدمها الناس بطرق متنوعة، بما في ذلك الخلايا الكهروضوئية. مصدر الطاقة اللامحدود، مثل الطاقة الشمسية، مجاني لأنه غير مملوك لأحد. في ظل ظروف معينة، يمكن استخدام تقنية تتبع نقطة القدرة القصوى (MPPT) لاستخراج أقصى خرج يمكن الحصول عليه من الخلايا الشمسية، مع ربطها أيضًا بأنظمة التحكم في الشحن. تُعرف نقطة القدرة القصوى، أو أعلى جهد، كمدخل محدد في الوحدات الكهروضوئية القادرة على إنتاج أعلى طاقة خرج. تتغير الطاقة القصوى باختلاف معامل الطاقة الشمسية الذي يحدد درجة الحرارة اللازمة للوحدة الكهروضوئية.
يُستخدم MATLAB/SIMULINK لتطوير استراتيجية تتبع نقطة القدرة القصوى (MPPT) القائمة على طريقة الاضطراب والمراقبة (P&O)، والتي تتيح التشغيل الفعال للنظام الكهروضوئي مع مراعاة التقلبات السريعة في الظروف المناخية. بناءً على نتائج المحاكاة، وُجد أن نقطة التشغيل تتذبذب حول نقطة القدرة القصوى، وأن هذه التذبذبات تتناسب طرديًا مع تغيرات الإضاءة الساقطة.
الكلمات المفتاحية: P&O تتبع نقطة القدرة القصوى (MPPT)، MATLAB، الطاقة الكهروضوئية

I. INTRODUCTION

One of the initiatives being researched at the moment is using solar energy as a fuel source to generate electricity. Turkey has substantial resources to advance solar power generation technology. Turkey benefits greatly from abundant sunshine throughout the year due to its equatorial location.

In Turkey, the average daily solar radiation ranges from 4.50 to 4.80 KWh/m2/day [1]. The most effective renewable energy option to progressively replace fossil fuels is to use solar energy. As solar energy is easily obtained and used, it is a renewable resource that minimizes harmful effects on the environment due to its low pollution level when compared to fossil fuels [2]. In Turkey, An electricity-generating facility that runs on solar energy is known as a solar power plant.

Photovoltaic (PV) technology is a crucial part of solar power plants that produces electricity by converting solar radiation [3]. One of the many benefits of photovoltaic energy is that, in contrast to conventional generators, it emits no pollution and makes no noise, making it a very reliable and environmentally friendly alternative. Nonetheless, the ambient temperature of the module and the irradiation factor have a significant impact on how much electricity the PV system produces [4]. Variations in these two parameters result in less-than-ideal PV system output power. As a result, we require a solution that enable the PV system to function at its best under all lighting circumstances and temperature variations within the module. Using Maximum Power Point Tracker (MPPT) is the solution. With the help of MPPT, PV can always operate at its best at the maximum power point. The point that occurs when the power produced by the photovoltaic cell achieves its greatest power is known as the maximum power point [5]. With the MPPT, it is intended that the PV system will be able to operate to generate its maximum output power under various lighting and temperature scenarios [6]. The purpose of this study is to use Simulink Matlab software to create and simulate the MPPT algorithm in order to maximize and optimize the PV output power.

II. PHOTOVOLTAIC SYSTEM MODELLING

One of the finest methods for producing electrical power for extended periods of time is the use of photovoltaic (PV) cells in PV panels to convert the sun into electrical energy. Solar radiation to electrical power conversion is highly dependent on a number of variables, including cell efficiency as well as insolation level. For a specific operational voltage and output power, photovoltaic generators typically consist of many modules connected in series and parallel [7]. The photovoltaic cell is composed of semiconductor materials with the help of name aspect positive, which represents the sun before aspect negative. When sunlight strikes the PV cell, electrons are produced that flow through the external circuit in a manner known as photocurrent current[8]. The modelling of photovoltaic generators may thus be inferred from that of solar cells; numerous research have previously been suggested that use one-diode or, more accurately, two-diode models. We employ the traditional single diode model shown in (figure 1) in this work.

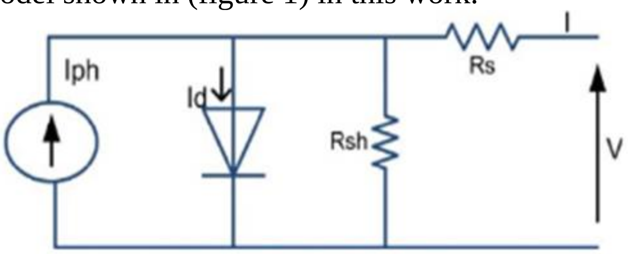


Fig. 1. Traditional single-diode configuration.

Id is the current flowing through the diode; Rsh and Rs are the series and shunt resistances, respectively; and Iph is the photo generated current associated with the illumination level [9]. Drawing from Figure 1, the output voltage and current reliance can be expressed as follows:

$$I=I_{ph}-I_o(e^{((V+R_s I)/V_i)}-1)-(V+R_s I)/R_{sh} \qquad (1)$$

The formula for calculating thermal voltage is

$$V_t= (A*K*T)/q,$$

Where A denotes ideality factor, K is the Boltzmann constant, T is the cell temperature, and q is the elementary charge.

Dark current is denoted by Io.

The photocurrent at alternative operating circumstances can be represented as follows in comparison to the measured photocurrent Iph_ref at standard testing conditions (STC: Gref = 1000W/m2, Tref = 25°C):

Iph=G/G_REF [I_(PH,_REF)+ 〖(T- T〗 _REF] (2)

α is the temperature coefficient of the short circuit current, and G is the sun irradiation.

A solar module manufacturer will often provide Icc_ref and α. Iph_ref can be assumed to be the short current at STC (Icc_ref) [10]. Should a temperature sensor be used to directly ascertain the cell temperature Tambnot, the following relationship can be used to infer it:

T=Tamb+[(N_oct- 20)/800]G (3)

While Noct is typically the usual operating cell temperature provided by the manufacturer, Tamb is the ambient temperature. For the dark current Io, we can write:

Io=I0,REF(〖T/T_REF)〗 ^(1/A) 〖exp〗 ^((qE_g)/AK(1/T_REF - 1/T)) (4)

Eg is the energy of the restricted band, and I0,ref is the dark current at STC. We considered Rsh to be infinite in the single diode model; the series resistance can be obtained as follows:

Rs=-dV/ 〖dI〗 _((Voc)) -(AKT/q)/ 〖Io exp〗 ^((qVoc/AKT)) (5)

A numerical approach such as Newton-Raphsons can be used to solve equation (1) [5].

X_(n+1)=X_n-(f(X_n))/(f^' (X_n)) (6)

DC-DC Boost converter

The main goal of a boost converter's design is to increase the DC system's output voltage. The gate pulse, or switching frequency, has a significant impact on the converter's output [11]. The boost converter is shown in Figure 2, and the converter's output can be described by the following equation.

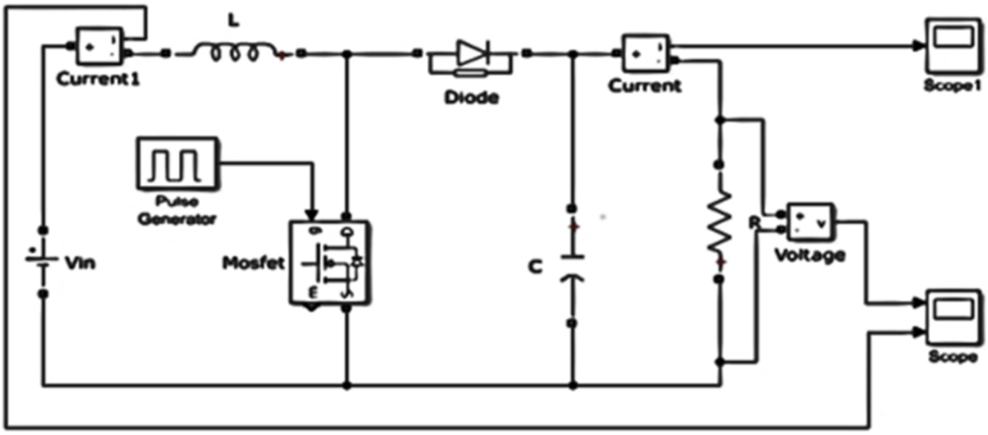


Fig. 2. Boost converter

An optimal boost converter has the following average output, input, and current values:

Vo = Vg/(1 – D)

Io = Ig (1 – D)

The load resistance R' on the input side can be written as:

R’ = R (1 – D)2

Only by changing D such that 0 < D < 1 can the load as perceived by the source be reduced. As a result, the maximum power from a PV module can only be extracted when its maximum power point current Imp is greater than the initial load [12].

Table I: Boost converter

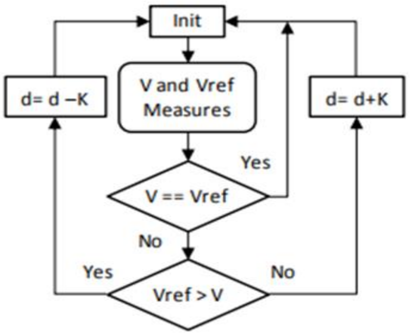
Model components	Parameters
Inductance, L	5Mh
Capacitance, C	100µF
Load, R	10Ώ
DC voltage, Vdc	595.3V
Switching frequency	50Hz

IV. REVIEW OF MPPT TECHNIQUES

The following techniques are used to enhance the performance of solar system output.

A.Constant voltage method

A constant voltage is used to supply the PV, according to the straightforward Constant Voltage (CV) Method's idea. Neglected are the effects of temperature and solar irradiance. The MPP of the P(i) characteristic directly yields the reference voltage. In this case, the examined PV's MPP voltage is roughly 16.3V. The CV algorithm is displayed in Figure 3:




```
function y=CV(u)
  global Kcv d_cv
  Kcv=0.01;
% u(1) is the constant PV voltage reference
% u(2) is the measure PV voltage
  If (u(1)==u(2))
    C = d_cv;
  else if (u(1)>u(2))
    C = d_cv –Kcv;
  else
    C = d_cv +Kcv;
  end
end
d_cv = C;
y = d_cv;
```

Fig. 3. Constant voltage method and Matlab code

The photovoltaic (PV) voltage measurement is all that is needed for the CV approach. The frequency at which the Matlab embedded function is evaluated is 1 kHz. Regarding the effect of solar irradiance and most definitely not the effect of temperature, this constant voltage method cannot be very effective [13]. So, there are certain improvements to the CV methods:

Although it is based on the CV approach, the Open Voltage (OV) approach assumes that the MPP voltage is always approximately 75% of the open-circuit voltage VOC [14]. Thus, as seen in Fig. 3, this technique primarily considers temperature. However, it calls for a unique process to assess the open-circuit voltage and to periodically disconnect the PV. Furthermore, the aging of the cell can be somewhat taken into account with this technique.

The Temperatures Technique is an enhancement of the OV Method as well; it now regards the open-circuit voltage as having a linear relationship with temperature. The open-voltage measurement is then no longer required when using a temperature sensor, as its value may be determined straight from the temperature value [15].

B.Incremental conductance methods

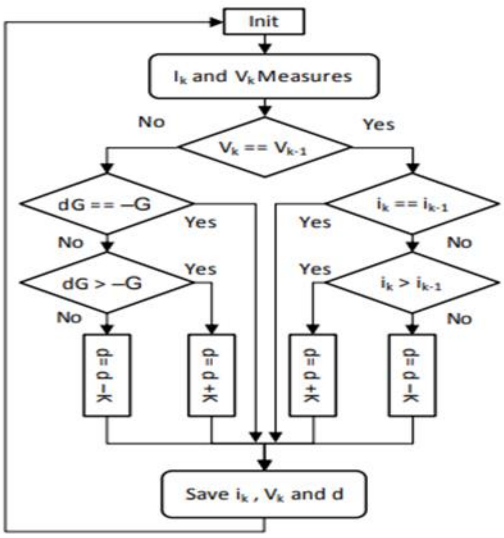
Equation 5 illustrates the fundamental idea behind the Incremental Conductance (IC) Method, which is the MPP's property that the derivative of the power is null [16]. Equation 6 illustrates the iterative procedure that the IC technique employs, which is based on the evolution of the derivative of conductance G. as the I/V ratio represents the conductance.

$dP/dV=0, with P=V.I$ (7)

$dP/dV = V . dI/dV + I\, dV/dV = 0,$

Thus: $dI/dV + I/V = 0 \rightarrow dG + G = 0$ (8)

Since dG is not defined when the voltage is constant, this approach (ICa) has been improved. Combining the IC and CV methods is therefore one way to find a solution. It's called the ICb, or Two Method MPPT Control [17]. The code for the Matlab embedded function and the Two-Method MPPT Control algorithm are displayed in Figure 4:



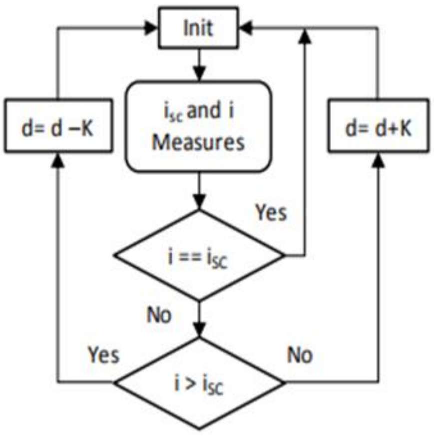

```
function y=IC(u)
  global i v Kic d_ic
  Kic=0.01;
% u(1) is the measure PV current
% u(2) is the measure PV voltage
G=u(1) / u(2); %G is the conductance
dv = u(2) – v;
di  = u(1) – i;
if (dv==0)  %equivalent to the CV method
  if (di==0)            C = d_ic;
    else if (di > 0)  C = d_ic + Kic;
    else                   C = d_ic – Kic;
    end
  end
else
  dG = di / dv; % here start the IC method
  if (dG==–G)          C = d_ic;
    else if (dG > –G) C = d_ic – Kic;
    else                    C = d_ic + Kic;
    end
  end
end
i= u(1); %save old current value
v=u(2); %save old voltage value
d_ic=C; %save old conductance value
y=d_ic;
```

Fig. 4. Two-Method Matlab Embedded Function Control technique and its code

The measurements of PV current as well as voltage are necessary for the Two-technique MPPT Control technique. A frequency of 1 kHz is used to test the Matlab embedded function [18].

C. Short current pulse method

The fundamental idea behind the Short-Current Pulse (SC) Method is a straightforward relationship [19]: under certain temperature and solar irradiation circumstances, the MPP current is proportionate to the Short-circuit current (i_{SC}). Even though the temperature fluctuates between 0 and 60°C, the i_{SC} estimation is frequently treated as constant in order to simplify calculations [20]. Actually, the calculation of the short-circuit current (i_{SC}) occurs right before the PV systems are connected to the grid




```
function y=SC(u)
  global iref Ksc d_sc
  Ksc=0.01;
%u(1) is the measure PV short-circuit current
%u(2) is the measure PV current
  if (u(2)>1e-2)
    if (abs(iref – 0.92*u(2))>1e-2)
      iref = 0.92*u(2);
    end
  end
  if (u(1)< Iref)        d_sc = d_sc + Ksc;
  else if (u(1)> iref)  d_sc = d_sc – Ksc;
    end
  end
y=d_sc;
```

Fig. 5. The SC algorithm as well as the integrated function code in Matlab

Only the measurement of the PV current is needed for the SC approach. One kHz frequency is used to assess the Matlab embedded function [21].

D. Artificial neural network methods

These algorithms are a useful tool for keeping an eye on PV systems' maximum power point [22]. The building blocks of these algorithms are biological neural networks, which mimic the information processing mechanisms of the human brain. The ANN is a great option for working with non-linear systems since it can be trained to solve issues and is extremely skilled at performing complicated computations [23]. An input layer, a hidden layer, as well as an output layer make up the typical design of an artificial neural network (ANN), as shown in Figure 6. ANN uses a variety of input parameters in MPPT applications, including temperature, irradiance, and the open- along with short-circuit currents of the solar module [24]. Any combination of these variables may be used as an input for the ANN. Usually the device's current, voltage or duty cycle, the converter's output parameter

serves as a reference signal to calculate the MPP. When an ANN is first being trained, the weight values of the connections between the neurons are arbitrarily selected [25]. These weight values are fixed once the ANN has undergone considerable training, enabling it to accurately monitor the MPP of the PV system. An ANN's training period might be anything from a few days to several months or even years. In order to increase the neural network's efficiency, trends are observed in both its inputs and outputs over this period. The fact that different solar power modules may have different properties necessitates that the ANN be specially trained for each module, which is a significant disadvantage of utilizing ANN for MPPT [26]. Furthermore, weather conditions might change a PV module's properties over time, requiring regular neural network retraining to ensure accurate MPPT.
The hidden layer uses an algorithm to estimate tracking accuracy. While adding more nodes to the hidden layer can boost tracking accuracy, in some cases it can also slow down tracking and increase computing time [27]. On the other side, lowering the overall number of nodes might expedite calculations, but accuracy may suffer.

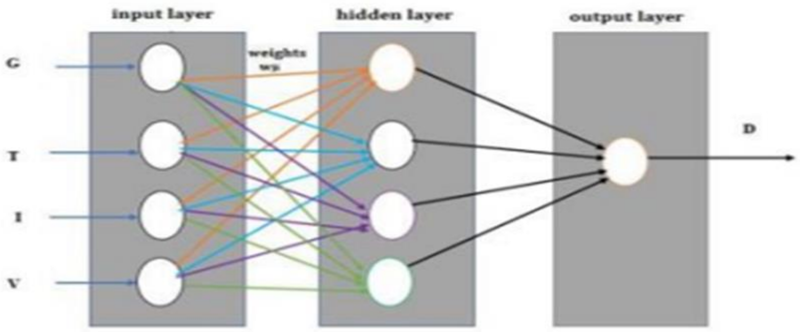


Fig. 6. Artificial neural network with three layers

V. METHODOLOGY

Perturbation and observation MPPT
The MPPT technique for observation and perturbation P&O is predicated on the fact that, according to figure 7, the derivative of the power-voltage characteristic of the solar module or cell is zero at the maximum power point, negative on the right side, and positive on the left [28]. Ppv and Vpv stand for the PV module or cell's output power and voltage, respectively.

$$\frac{\partial Ppv}{\partial Vpv}=0 \qquad (9)$$

In order to determine the associated output power and subsequently its derivative with regard to voltage, the solar module or cell's output current and voltage are measured frequently in sequential steps during the P&O MPPT procedure [29].
Equation 10 describes how a PWM controller of the power converter modifies the reference signal Vref Figure 1 based on the sign of $\frac{\partial Ppv}{\partial Vpv}$ during the MPPT process.

$$Vref(k)=Vref(k-1)+\alpha \mathrm{sign}\left(\frac{\partial Ppv}{\partial Vpv}(k)\right) \qquad (10)$$

Time steps k, k-1 at instants t and t-1
A constant, $\alpha > 0$, controls the rate of convergence to the maximum power point.
When in a steady state, the PV module or cell's operating point oscillates about the MPP, and the magnitude of this oscillation is governed by the numerical value of the constant α in equation 10 [30]. Under situations of climatic change, solar radiation and/or ambient temperature, an increase in the disturbance step converges the operating point more quickly towards the maximum point power and heightens the oscillations associated with the MPP [31]. Energy is lost as a result. Equation 10 can be used to create an MPPT system based on the P&O technique [32]. A microcontroller or a digital signal processing unit (DSP) can carry out this algorithm. An algorithm for the MPPT P&O approach is shown in Figure 7. The perturbation and observation P&O technique can also be implemented using mixed signal circuits [33].

Once the value of the derivative $\frac{\partial Ppv}{\partial Vpv}$ is less than a predetermined threshold value, indicating that the operating point converges to the MPP with the appropriate accuracy, the process shown in Figure 7 is executed iteratively [34]. In order for the P&O MPPT approach to operate with the ideal values for the step size and perturbation period, the control unit must be designed accordingly [35].

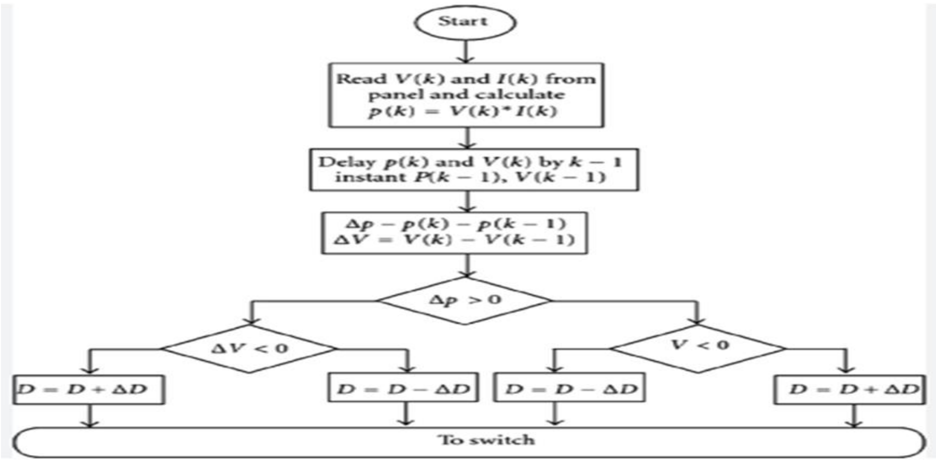


Fig. 7. Flow chart of P & O MPPT algorithm

One potential technique to consider is the Perturb and Observe (P&O) tracking algorithm, which involves adding a minor perturbation to the current set-point and monitoring the resulting changes in output power [36]. Based on whether the disturbance tends to raise or lower the output power, the current set point is adjusted correspondingly [37].

Put otherwise, the current set point is increased further if a tiny ΔI is added to it, as this would increase the output power [38]. In a reciprocal relationship, if ΔI is positive and tends to decrease output power, then ΔI will also decrease the subsequent current reference.

Due to the Perturb and Observe algorithm's fully empirical methodology, it is necessary that:

- The intended setpoint is appropriately observed, which implies that before the outcome is assessed, the current control, if any, can attain steady state and not become saturated [39].
- The maximal power point in the world is unique [40].

VI. SIMULATION RESULT

The PV system is modelled with MPPT controller in SIMULINK environment. For PV array, temperature used is 25^0C while the radiation is 1000W/m^2, figure 8. The output voltage and output current of the PV array are fed into MPPT controller. To maximize power at the load's output, an MPPT controller as well as a boost converter are utilized. The boost converter is employed to have a change in the output voltage and reduce current. When a load demands a greater input voltage, the boost converter is utilized to raise it to that level. By holding energy in an inductor and delivering it to the load at a higher voltage, this special capability is accomplished. This short note identifies a few of the more typical mishaps that occur when utilizing enhance regulators.

The primary function of boost converters is to increase the input voltage to the necessary levels. They work in switching mode to convert DC to DC, ensuring that the output voltage is always higher than the input voltage. Another name for it is a step-up converter. This name comes from the step-up transformer process, which increases input to the desired level. According to the rule of energy conversion, input power and output power should be equal when there are no losses.

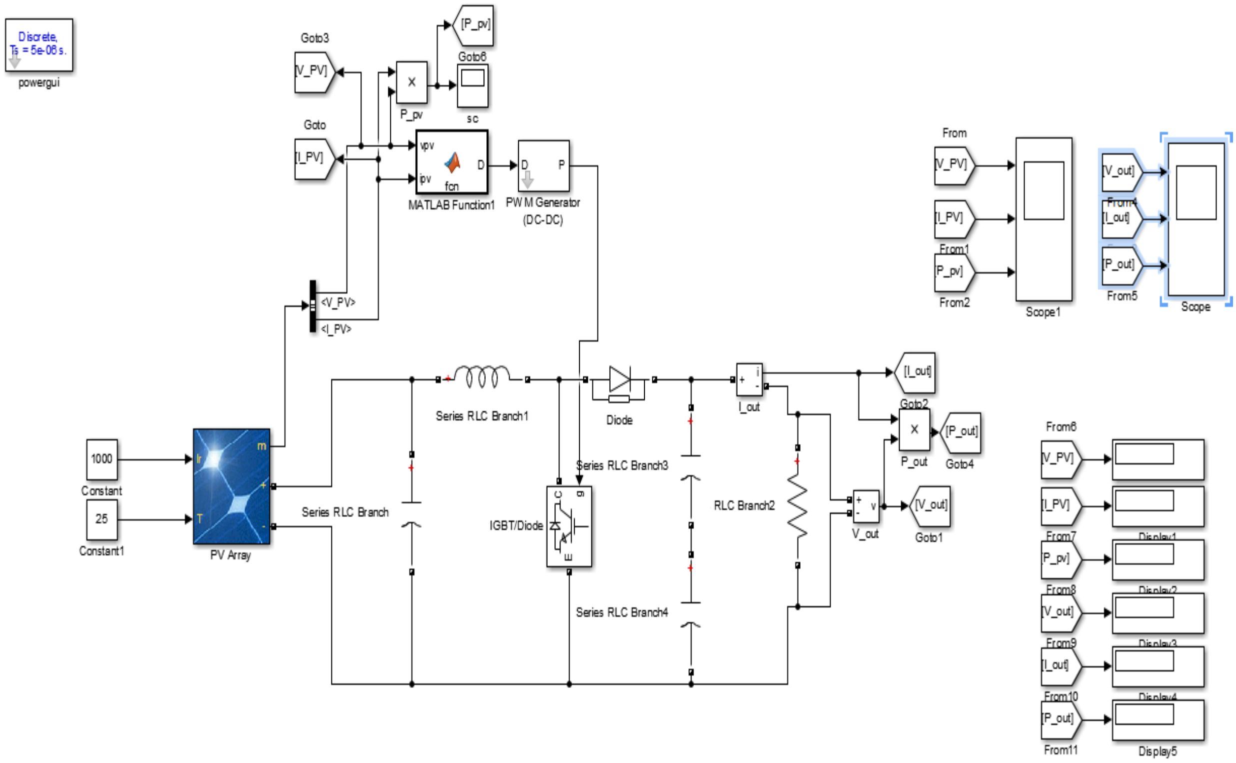


Fig. 8. Model of PV system with MPPT controller

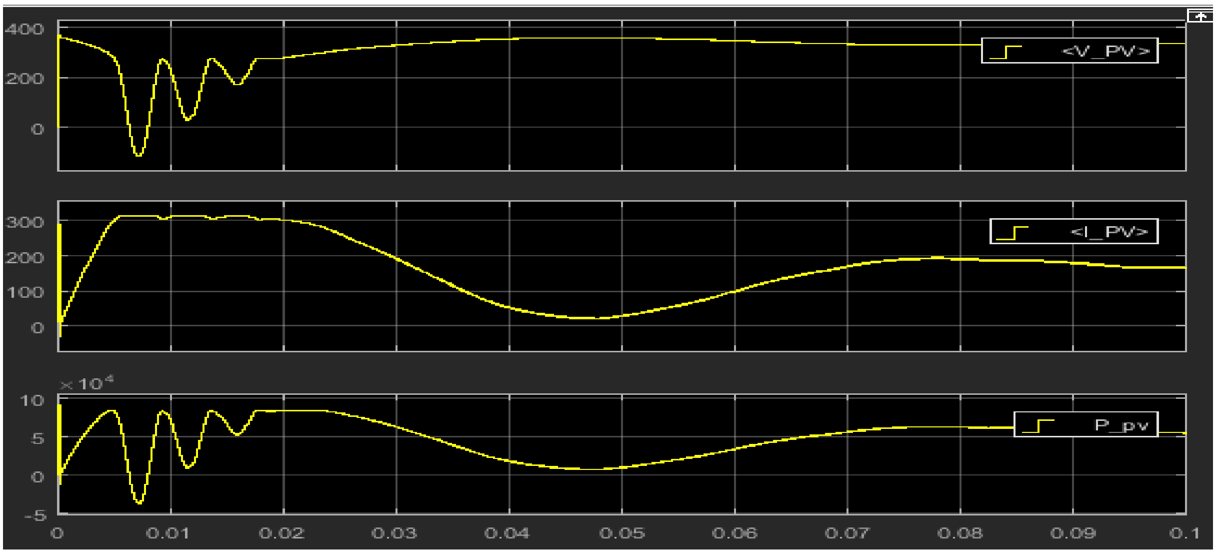


Fig. 9. Simulation results of both PV output

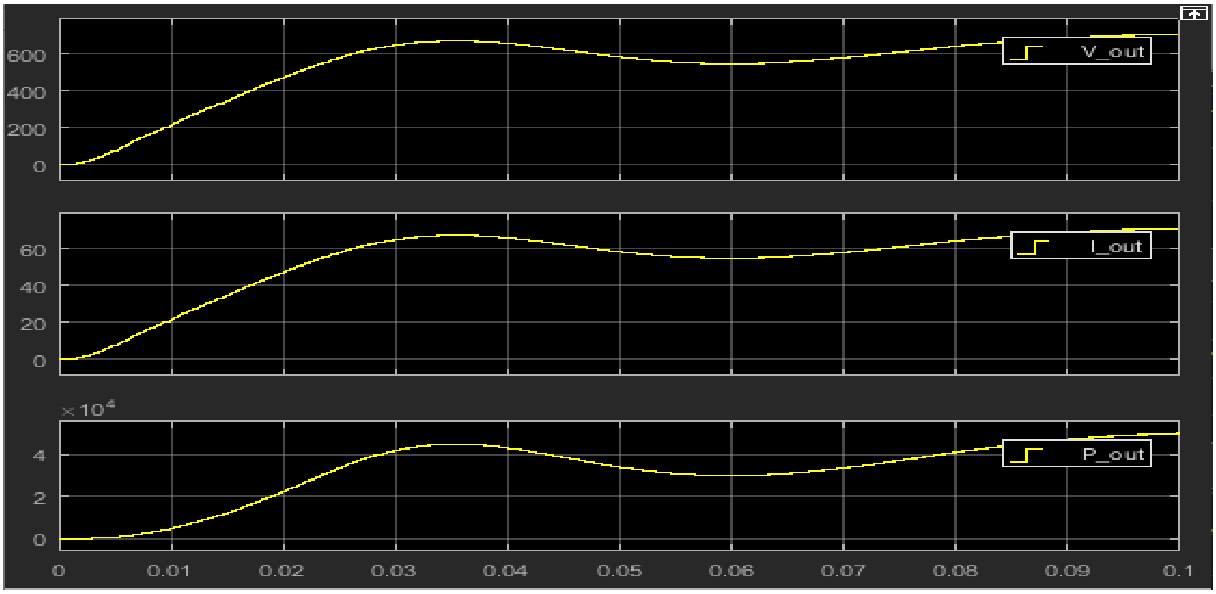


Fig. 10. Simulation results of Load output

The previously described computational equations of solar cells are used to construct a solar photovoltaic (PV) module model in the Matlab/Simulink environment. With respect to the input parameters of radiation as well as temperature, the completed Solar PV model, as shown in Figure 8, is simulated and produces output results including current, voltage, and power at PV output and Load output Figure 9 and 10.

VII. CONCLUSION

MPPT, which is based on a modified P&O algorithm, is used to extract the most power possible from a PV module. The PV system is composed of an MPPT controller with microcontroller based technology and a high efficiency DC/DC boost converter. It demonstrates how, in the face of abrupt changes in temperature and irradiance, the improved P&O algorithm offers an effective and dependable maximum power tracking performance.

Maximizing power extraction from solar photovoltaic systems to increase their efficiency is currently one of the main research problems in the renewable energy field. In this regard, it is determined that the MPPT controller concept is beneficial since it maximizes the output power supplied by the photovoltaic (PV) module.

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