Control and Modeling of PSO-PID based MPPT

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ABSTRACT
This paper proposes a design and modeling of the control system for a photovoltaic (PV) generator, which depends on solar radiation and ambient temperature, for this reason, the use of the Maximum Power Point Tracking (MPPT) controller is a necessity to obtain the maximum power required for the (PV) system despite the variance in climatic conditions. The most common method used to control MPPT is the perturb and observe (P&O) algorithm, despite the simplicity of this method, it suffers from many problems including oscillation around the (MPPT), and the maximum overshoot, especially when the perturbation step size is very large. For these reasons, the improved MPPT algorithm becomes an important goal for many researchers. This paper introduces Particle Swarm Optimization (PSO), which enhancesthe (PID) controller to make it more accurate and faster to reach the target,despite the difference in temperature and sun irradiance directed at the solar panels. Both of them (PSO-PID)are based on MPPT control. MATLAB Simulink programs were used for modeling of PV array to provide the load of thePower Engineering Department for the Electrical Technical College with 5 kW. In addition to (DC to DC) boost converter was designed and modeled. The performance of the proposed (PSO-PID) controller was compared with the simulation result of the P&O method, and Fuzzy logic controllers (FLC). The simulation results illustrate an enhanced performance of the proposed (PSO-PID) control system of oscillation, response time, maximum harvesting power, ripple, and maximum overshoot.

General Term
Modeling, solar Photovoltaic voltage controller, grid-tied Inverter, Perturb and Observe (P&O) MPPT.

Keywords
Modeling, Sun Irradiance, Ambient Temperature, Photovoltaic (PV), P&O, PSO-PID Controller, Fuzzy logic Controller, MPPT, Boost Converter.

1. INTRODUCTION
One of the most important control methods in the photovoltaic array systems is the maximum power point tracking (MPPT). The maximum power can be extracted from PV panels under different environmental conditions, such as solar radiation, ambient temperature, and loads [1]. Photovoltaic panels can operate at a voltage called the "maximum power voltage" (Vmp). In a PV panels system, MPPT requiresto measure the PV panels outputs (output voltage, output current, and maximum power) [2, 3]. There are many MPPT algorithms for PV systems, such as Perturb and Observe (P&O), and (INC) method,which are classic and simple in implementation, but suffers from many problems under sudden changes that occur in the system, which are large oscillations, ripples, slow response time, and power loss. Because of these reasons, it led to the use of innovative, advanced, and appropriate intelligent control methods to solve the problems, such as the fuzzy controller method (FLC), the artificial neural networks (ANN), the particle optimization algorithms (PSO), as well as hybrid controllers such as the particle optimization algorithm using PID control where the last methods provide fast control for the systems under sudden changes of conditions with reliable results and more Accuracy.

2. MATHEMATICAL MODEL OF THE SOLAR ARRAY
A principal Solar PV cell model includes a perfect current source in parallel through a perfect diode. The basic building that prevents PV arrays is the solar cell, which is principally a p-n semiconductor junction, as shown in Figure 1.

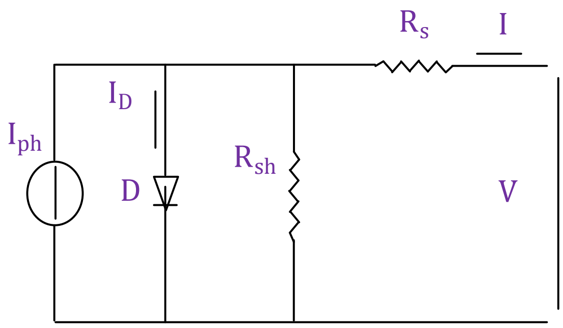


Fig1. Equivalent circuit of PV cell

The following equations explain the classic of a PV panel:

$$I_{ph} = \frac{G}{GT}\left[(T_c - T_{ref})K_i + I_{sc}\right] \quad (1)$$

$$I_d = \left(e^{\frac{q(V+I*R_S)}{K*T_c*N_s*A}} - 1\right) \times I_s \times N_p \quad (2)$$

$$I_{rs} = \frac{I_{sc}}{\frac{q*V_{oc}}{(e^{N_s*K*A*T_c}-1)}} \quad (3)$$

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

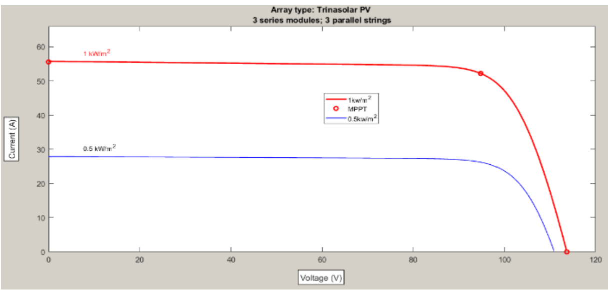
$$I_{sh} = \frac{V+I*R_s}{R_p} \quad (5)$$

$$I = I_{PV} - I_d - I_{sh} \quad (6)$$

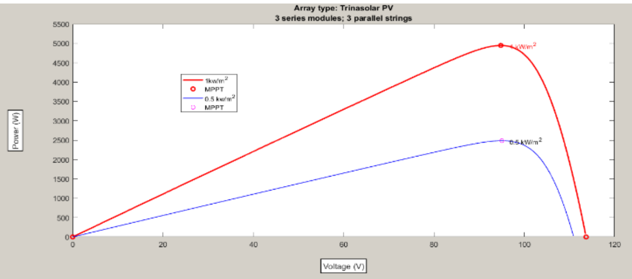
Everywhere, the cell photocurrent (Iph), the cell saturation current (Is), the cell opposite saturation current (Irs), the PV panel output current (I), the diode current (Id), the silicon diode ideality factor (A), the number of parallels joined panels (Np), the number of series joined cells inside a PV panel (Ns), the energy band gap of a semiconductor data of the solar cells (Eg), the open-circuit voltage (Voc), the short circuit current (Isc) [4, 5]. The Trinasolar PV panel is chosen for modeling and simulation in this work. Table 1 shows the typical electrical characteristics of this panel, it consists of 96 monocrystalline silicon solar cells andits dimensions are (2.38 m* 1.09 m) and it has an efficiency of 21%. The (I-V) and (P-V) characteristics curves of the selected panel obtained from the simulation for Trinasolar PV panel by Simulink Program at Tc=25°C (298°K) and Gr=1000W/m2, Ns=3, Np=3, Rsh=75.12Ω Rs=0.1214 Ω, Tref=298°K (25°C), as shown in Figure 2.

Table 1 Electrical characteristics of (PV) panels

Parameter Type	Value
Peak Power	549.93 W
Open Circuit Voltage (VOC)	37.9 V
Short Circuit Current (ISC)	18.52 A
The voltage at Maximum Power Point (Vmp)	31 V
Current Maximum Power Point(imp)	17.4 A
Temperature Coefficient of Current	0.04
Temperature Coefficient of Voltage	-0.25
Cells Per Module (N cell)	96
Shunt Resistance (ohms)	75.12
Series Resistance(ohms)	0.1214



(a)



(b)

Fig 2 a, b current-voltage characteristics (a) and power-voltage characteristics (b) of the implemented PV array

2.1 Perturb and Observe (P&O)

The flowchart shows the P&O algorithm as shown in Figure 3. If the power of the (PV) system increases, the direction of the maximum voltage of the power of the (PV) system is on the same path to achieving MPP if there is a decrease in the output power of the (PV) array, the direction of the maximum voltage of the power of the (PV) system is in the opposite path to achieve MPP. Therefore, the signs of disturbance vary under different conditions [5, 6, and 7]. The P&O method is considered one of the most widely used methods for its ease of use, but it suffers from the problem of its slow response to sudden rapid changes in the system [7]. Other drawbacks are fluctuations around MPP, slow response time, and power loss.

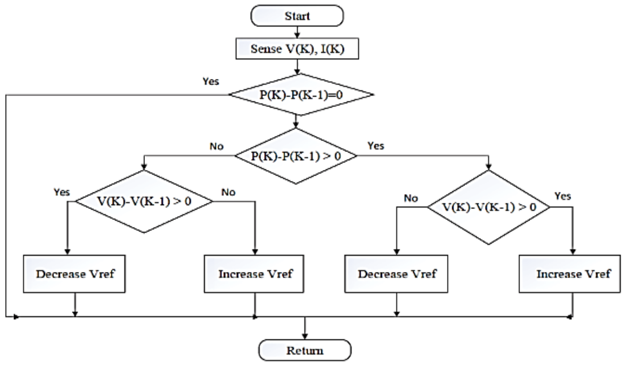


Fig 3. Flowchart of the Perturb & observe algorithm

2.2 Fuzzy Logic Controller (FLC)

It is an artificial intelligence method used in MPPT. FLC method is based next on three essential stages: Fuzzification period, inference engine period, and rule base period, then defuzzification period, as given away in the block diagram in Figure 4. Inside the fuzzification period, numeric input variables are changed into linguistic variables. The input variables of the controller are chosen to be the change in the voltage (DV(k)) and change in power (DP(k)) [8],calculated according to equations (7, 8) respectively, and k is the sampling instant.

$$Dv(k) = V_{PV}(k) - V_{PV}(k-1) \quad (7)$$

$$Dp(k) = P_{PV}(k) - P_{PV}(k-1) \quad (8)$$

The change is carried outby applying membership functions, set for different ranges of input variables, and its value varies between zero and one [10]. These functions may vary in number to increase accuracy, but generally are as follows: generally are as follows: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) [9].

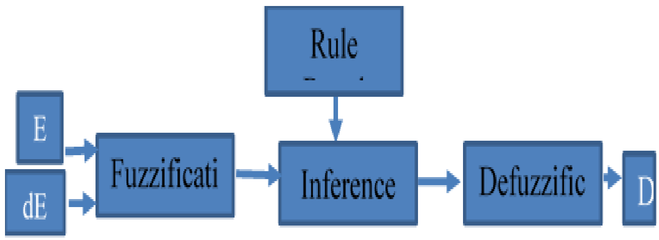


Fig 4. FLC

The inference period, whose entries are the linguistic variables of the error and change of error, is responsible for implementing the rule-based table that defines the behavior of the controller [10]. The controller output will be a linguistic variable that defines the duty ratio of the converter, and iteratively, make the error tend to zero. Control rules can be seen in Fig. 4. Finally, in the defuzzificationperiod, as in the first period, the membership functions are applied to obtain a numerical output value.

2.3 Particle Swarm Optimization (PSO)

It is one of the powerful optimization techniques that simulate the behavior and behavior of organisms that live in the form of colonies such as bees, ants, birds, and fish. It is based on evolutionary computation and solves and improves all system problems. It also searches for the fastest and shortest way to reach the goal. PSO maintains a swarm of individuals, which consists of several particles that make up a group, and one particle moves into the search space to find the best location and the best solution. As for the rest of the particles, they will go to the search space to find the best solution, as well as for each body when it moves, it will be at the best speed, due to the ability to converge any non-linear behavior [11, 12]. When using this method to improve the controller used to extract the maximum possible power from the arrays of solar panels, where the mathematical complexities are not used, so the optimization process is done initially by calculating the output of the array (current, voltage, and power), where the controller will give an increase or a decrease in the value of the duty cycle(D), and so on for the rest of the times to come. The (PSO) method aims to make the controller faster to respond to any sudden changes and disturbances that occur in the system to reach asteady with minimal error. The cost function indicated the error of the output power [13, 14, and 15]. The (PSO) algorithm is based on only three phases as shown in Figure 5.

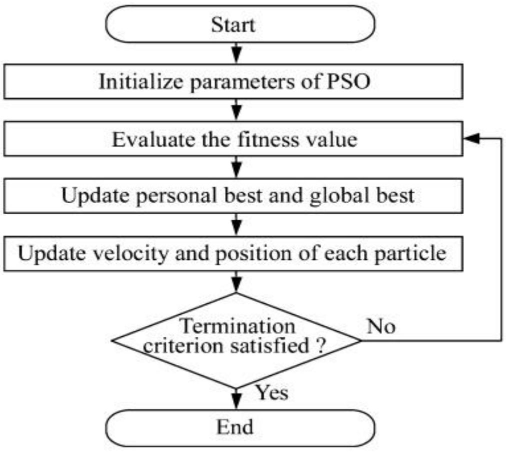
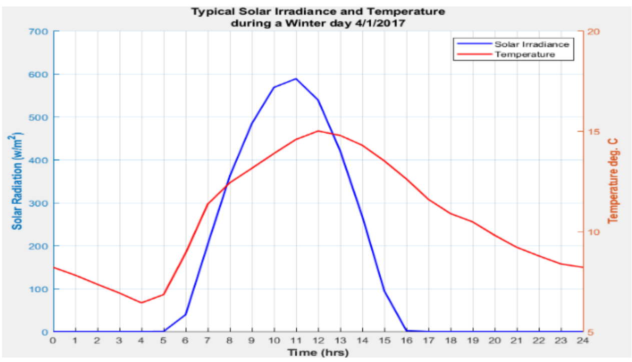


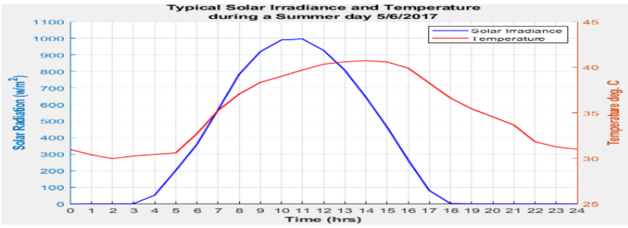
Fig 5. PSO Flow Chart

3. DESIGN OF THE (PV) POWER SYSTEM

Designing a PV system for a specific application requires an accurate estimation of the daily load for that application, only an estimate of the daily load is required for the application under study (Power Engineering Department for the Electrical Technical College with 5 kW). The study of the Climatic Conditions of Place can be seen in Figures6 a, b. The Global Positioning System (GPS) gives the latitudinal and longitudinal coordinates of the collage at 33.31° and 44.33° respectively. The available governmental data about the annual solar irradiance and temperature was acquired from the Iraqi Weather Forecast / The Center of Renewable Energy Technology.



(a) Solar radiation and temperature during a winter day



(b) Solar radiation and temperature during a summer day

Fig 6 a, b Study of the Climatic Conditions of Electrical engineering technical college

The total load power during sun hours was calculated (5kW) with the addition of system losses. The total number of solar panels is designed to provide the required load, 3 panels are connected in series to form 3 strings of panels.

3.1 Design of DC to DC Boost Converter

A DC to DC boost converter is used to boost and regulated the output voltage of the PV arrays and to implement (MPPT). The circuit is given away in Figure 7.

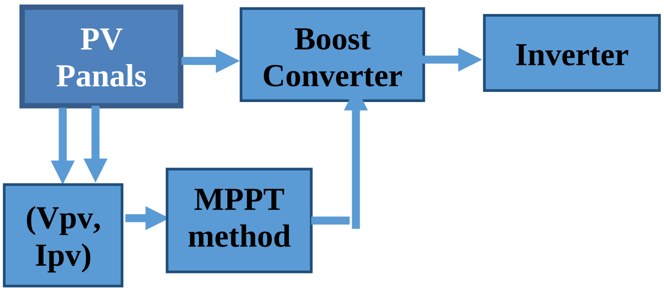


Fig 7 MPPT Controller with Boost Converter

Pulse Width Modulation (PWM) signal is typically used to control the converter's output voltage. The largeness of the output voltage Vo is controlled through the duty cycle of the PWM. The PV power system terminal voltage is 118.6 V as calculated before. The required batteries or inverter voltage is 100 V. At Standard Test Conditions (STC) and the predefined switching frequency, fsw=1000 Hz, the inductor ripple current then ripple voltage at the PV link would be stated by the peak-to-peak values, ΔIL and ΔVPV, separately. The duty cycle at the nominal load operational situation can be determined by steady-state analysis. At STC, the PV source circuit is likely to output VMPP and IMPP, which characterize the MPP organization. The duty cycle can be calculated;

$$= 1 - \frac{V_{MPP}}{Vo} \quad (9)$$

The value of the inductance, L, can be calculated as:

$$L = \frac{V_{MPP}\ D}{\Delta I_L f_{SW}} \quad (10)$$

And the value of the capacitance, C, can be calculated as:

$$C = \frac{V_o D}{f \Delta V_o R_L} \quad (11)$$

Where RL is the load resistance=100 Ω.

The particular and calculated values for the DC to DC boost converter circuit constituents and parameters are organized in Table 2.

Table 2 list of parameters with specifications used for the design

Parameters	Value	Unit
Output voltage	330	V
Input voltage	118.5	V
Duty cycle	0.64	
Switching frequency	1	kHz
Inductance (L)	1.43	µH
Capacitor (C)	300	µF

3.2 Design and simulation of the FLC of MPPT controller

This is one of the methods of artificial intelligence used by MPPT. The FLC advance is based next on three basic phases: the fuzzification period, the inference engine the rule base period, then the stage of defuzzification. Numeric input variables are changed intothe linguistic. The user has the flexibility to choose how to compute, then the (FLC) model is created to complete the needed presentation prerequisites on a trial-and-error basis. The controller's input variables are chosen to be located in the voltage change (Dv(k)) and the power change (Dp(k)).

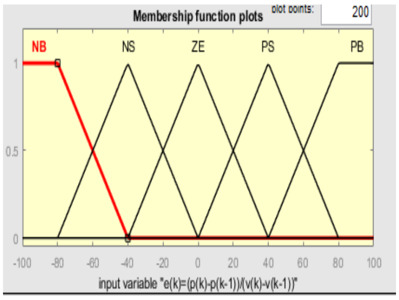
The change is complete by relating membership elements, which are set for several input variable ranges, and their value changes between zero and one, using five fuzzy sets. Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) are usually as follows, as displayed in Figure 10. The rule-based table that requires the behavior of the controller is the accountability of the inference stage, whose entrances are the linguistic variables of voltage shift and power change, to submit. The development in task ratio is the realization of this regulation table. Allowing the preceding summary, the fuzzy rule table is broken up into seven areas. The controller presentation would be a linguistic vector that requires the job ratio of the converter, which, iteratively, varieties the error look to be negligible. In Table 3, it is possible to see the control rules. Finally, in the defuzzification phase, as in the first step, the membership functions are implemented to produce a numerical performance value. The input variable range is [-100 100], and the output variable range dD is [-1e-10 – 1e -10], as can be seen in Figure 8, using the input scaling factors K1 and K2 and the output scaling factor K3.

Mamdani's fuzzy inference approach was used in the inference engine. It's in Table 3. The basis of 25 rules used to evaluate the relationship between the inputs and the MPPT controller output, the (FLC) tracks the maximum power depending on the code-base, the suffuse of the code; if the power has been changed from the last shift in the service cycle, the reference voltage tends to change in the same direction. Otherwise, if the power has diminished, transfer it in the opposite direction. The methodology of Inference specifies the yield of the fuzzy controller.

The inference method of Mamdani is used alongside the max-min development technique within the known context. This is because this method is more computationally capable and has preferable interpolator properties to techniques relying on other capacities for a recommendation. The PWM generator that outputs the reference voltage to the boost converter is supplied with the fuzzy output. The operating theory of the PWM generator is based on a two-signal analogy. A triangular waveform is one of the impulses, and the other is a fixed linear pulse, which is the time equivalent of the initiating voltage. The Simulink models for the FLC can be seen in Figure.9, and the simulation diagram of FLC Based MPPT controller for the PV power system using MATLAB is shown in Figure 10. The fuzzy control alone was a solution because of the problems in the P&O method in terms of oscillation, accuracy, and error rate to reach the maximum power of the solar panel system. This method is quick and easy to implement, but it lacks high precision accuracy, for any sudden change in the system parameters and weather conditions, the error rate in the decision is large in the fuzzy logic, so using the PSO-PID has a higher tracking efficiency than the fuzzy.

Table 3 Design of Membership Function.

E / ΔE	PB	PS	Z	NS	NP
PB	PB	PB	PB	PS	Z
PS	PB	PB	PS	Z	NS
Z	PB	PS	Z	NS	NB
NS	PS	Z	NS	NB	NB
NP	Z	NS	NB	NB	NB



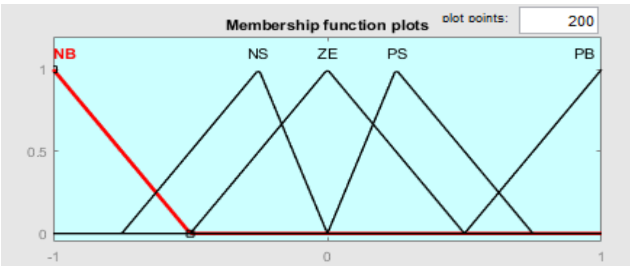


Fig 8. Membership Function Plots of The Input and The Output of FLC.

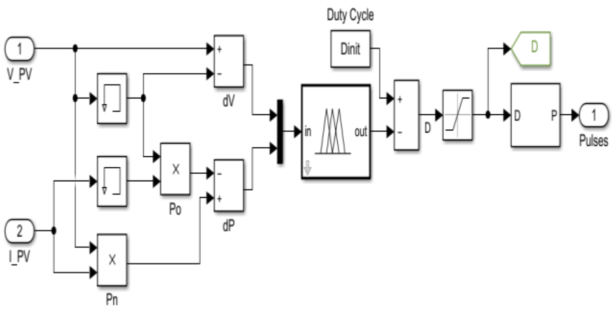


Fig 9. Simulation of a fuzzy-based of MPPT Controller.

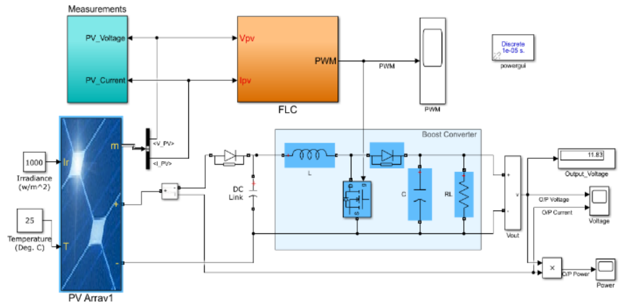


Fig 10 The simulation diagram of FLC-based MPPT controller for PV power system Using MATLAB.

3.3 Design and Simulation of a PSO-PID based on MPPT Controller

The change in the duty cycle (D) of a DC to DC converter to make MPPT effective. In this work, the PSO feedback is based ona PID controller to enhance the (MPPT). Particle Swarm Optimization (PSO) was chosen due to its relative simplicity and superior performance. Furthermore, (PSO) is a parameter less algorithm which means that it does not have any tuning parameters specific to the algorithm, unlike the rest of the algorithms which have certain parameters. In this work, (PSO) algorithm was chosen to improve the PID controller to achieve the aim of obtaining the maximum power from the solar panels.

This algorithm initially adjusts the solution based on the best solution obtained, i.e. the current fitness, that is, the approach helps to increase the average fitness of all solutions and avoid local minimum solutions. After this stage, the solutions obtained are modified based on the relative suitability, which leads to moving the solutions towards the appropriate solutions for implementation. The PID controller settings are set using (PSO). Integral Time Absolute Error (ITAE) was selected as the Fitness Value. It is worth noting, that ITAE was chosen because it greatly reduces errors, which may appear when running the simulation, and speeds up the system to a stable state. Because it is better to track the MPPT for a certain time. The main benefit of it is the minimum error between the setpoint and the actual value.

MPP can be found from solar arrays, (Dp/Dv) must be zero. In this work, Figure 11, illustrates how to track MPP continuously by calculating the (Dp/Dv) of the PV system and comparing it with the reference value (zero). The resulting error value e(t) enters into the (fitness function), PSO optimization algorithm, to be processed and made small, and then compare the new error value (e(t) new) with the previous value oferror (e(t) old), the lowest error value is taken into account, and then the parameters of the PID controller are updated to generate pulses to the DC to DC converter.

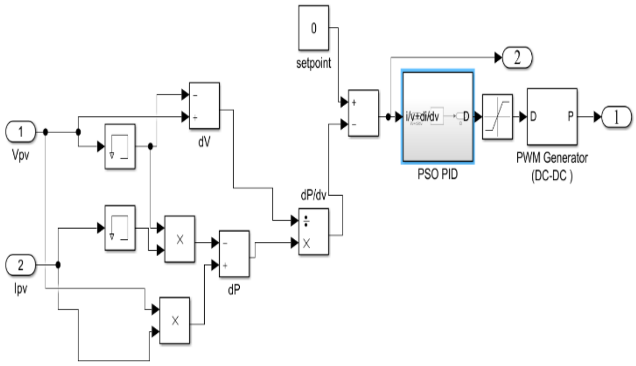
here fitness function= value$\int_0^t t * |e(t)|\ dt$

e(t)=0-(Dp/Dv) (12)

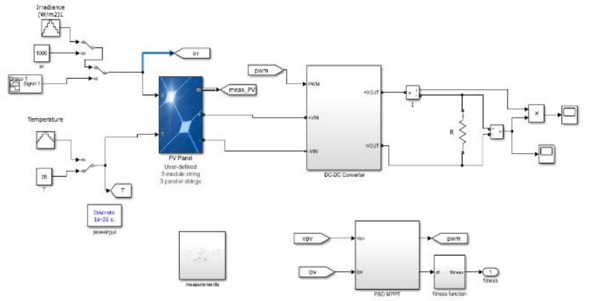
Where U(t) is the PID controller output, and according to the equation shown

$$U(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \quad (13)$$

Where U(t), is the controller output, e(t) is the error, and (KP, KI, and KD) are the gains of the PID controller. The Simulink models for the PSO-based PID controller for MPPT can be seen in Figure 11.



(A)



(B)

Fig 11 a, b, Complete Simulation with Details of the PSO-PID based on the MPPT controller

4. RESULT AND DISCUSSION

The simulation results, the utilization of (the PSO-PID controller), improves the system performance. The response time is reduced; the proposed algorithm gives better stability and accuracy to the system. And a few oscillations and reach a higher final value. The variation of the (D) With the proposed, the system has a better stability. The variation of instantaneous power. The proposed (PSO-PID controller) allows for increasing the final value and minimizing the oscillations and time response. With the variation of PV output voltage, the proposed algorithm drives the system to a higher final value a few times and without oscillations. The proposed algorithm displays a faster response time compared to FLC and MPPT-based P&O, given the sudden changes that occur to the system. As for the fuzzy logic controller, the ripples around (MPP) and response time are less compared to the P&O algorithm. The results of the fuzzy controller in terms of (maximum power, duty cycle), as well as the results of the PSO-based PID controller in terms of (voltage, current, power) shown in the following figures(12, 13, 14, 15, and 16).

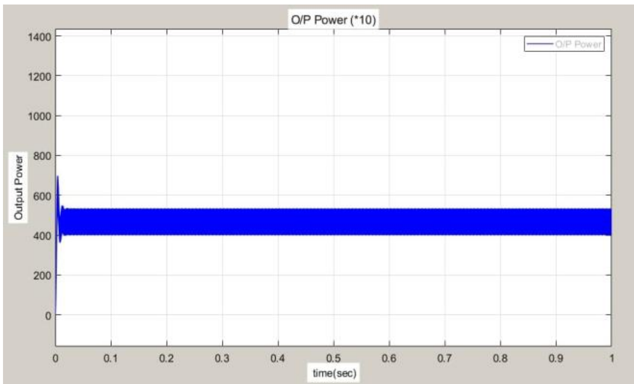


Fig 12. Output power by using FLC at G =1000 W /m

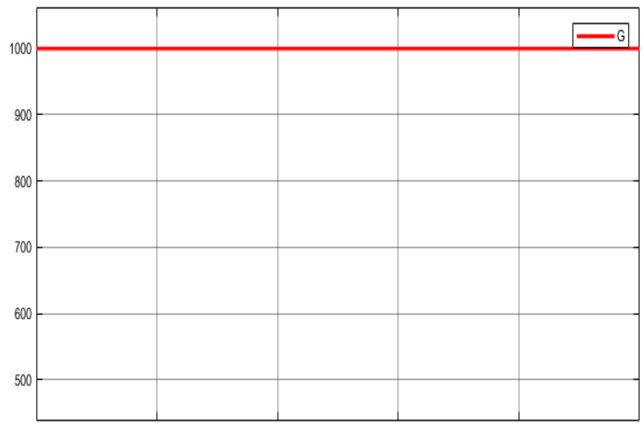


Fig 13. Solar Irradiance (1000)W/m^2

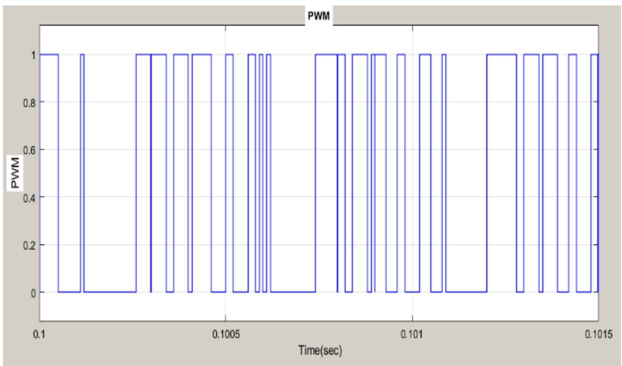
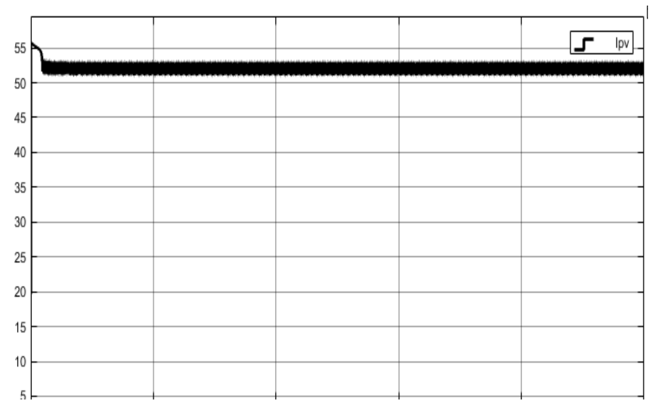
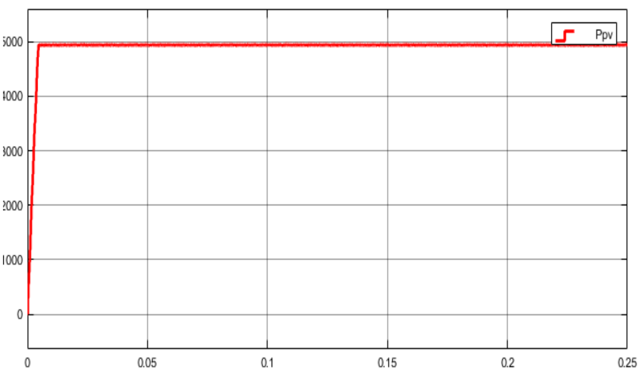


Fig 14. PWM of the (DC to DC) Boost Converter.



(a)



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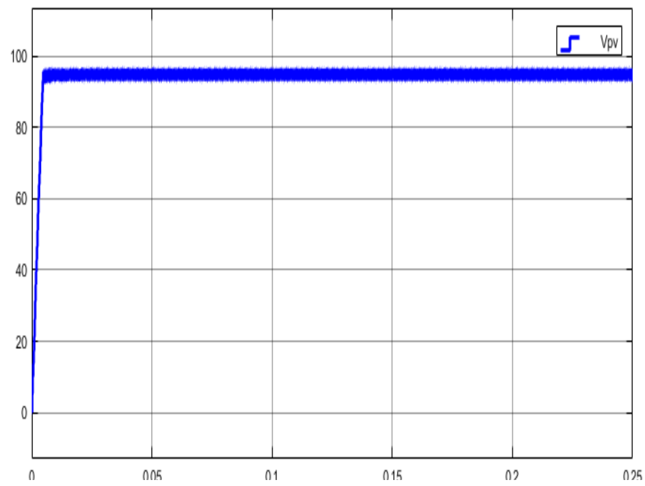

(c)

Fig 15 a, b, andc (Current, Voltage, and Power) by using PSO-PID at G =1000 W /m^2

Different values the output current , voltage, and powerfor different solar radiations (400-700-1000) W/m2 and for 25°C temperatures as shown in Figure.17.

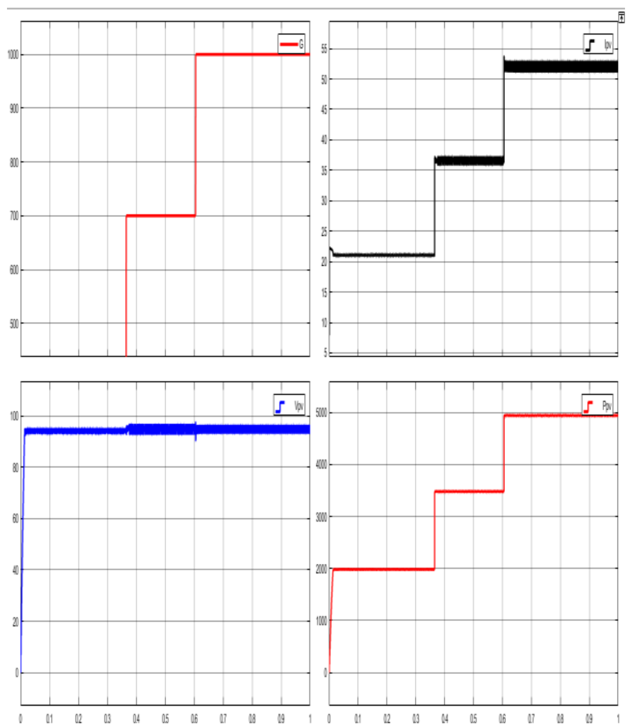

Fig 16. Solar radiations (400-700-1000) W/m^2, (Output Current, Output Voltage, And Output Power) of PV power system by using PSO-PID controller

5. MATLAB Program codes

```
%% PSO Parameters
w = 0.4;
c1 = 1.5;
c2 = 1.5;
Dim = 3;
SwarmSize = 4;
%% Problem Definition
ObjFun = @PSO_fitness;
```

```
        MaxIter = 2;
        MinFit = 0.001;
        Vmax = 1;
        Vmin = -1;
        Ub = [10  0.09 0.002];
        Lb = [7 0.04 0];
%% Velocity Limits &  Initialization
            Range = ones(SwarmSize,1)*(Ub-Lb);
          Swarm = rand(SwarmSize,Dim).*Range
      + ones(SwarmSize,1)*Lb ;
        VStep = rand(SwarmSize,Dim)*(Vmax-
      Vmin) + Vmin ;
        fSwarm = zeros(SwarmSize,1);
        for i=1:SwarmSize
        fSwarm(i,:) = feval(ObjFun,Swarm(i,:));
        end
        [bestfbestindex]=min(fSwarm);
        zbest=Swarm(bestindex,:);
        gbest=Swarm;
        fgbest=fSwarm;
        fzbest=bestf;
       %% PSO Main Loop
        iter = 0;
        y_fitness = zeros(1,MaxIter);
        fSwarm(j,:) = feval(ObjFun,Swa
        if fSwarm(j) <fgbest(j)
        gbest(j,:) = Swarm(j,:);
        fgbest(j) = fSwarm(j);
              end
              if fSwarm(j) <fzbest
        zbest = Swarm(j,:);
        fzbest = fSwarm(j);
              end
          end
        iter = iter+1;
        y_fitness(1,iter) = fzbest;
        disp(['Iteration ' num2str(iter,iter) ': Best
      Cost = ' num2str(y_fitness(1,iter))])
        end
```

6. CONCLUSION

In this paper, the controller (PSO-PID) was designed for a solar power system, simulating and comparing it to an (FLC) and a (P&O) controller. The suggested controller (PSO-PID), illustrates how to track MPP continuously by calculating the (Dp/Dv) of the PV system and comparing it with the reference value (zero). The resulting error value e(t) enters into the (fitness function), PSO optimization algorithm, to be processed and made small, and then compare the new error value (e(t) new) with the Previous value (e(t) old), the lowest error value is taken into account, and then the parameters of the PID controller are updated to generate pulses to the DC to DC converter. The proposed (PSO-PID), FLC, and P&O algorithms were simulated using MATLAB / Simulink software.

The simulation results showed an improved performance of the proposed controller in terms of a quick response in a short time whatever the surrounding conditions, better optimum stability, less fluctuation around MPP, getting the highest possible power from solar panels in addition to reaching better and faster MPP compared to FLC controllers, and P&O. A comparative test was conducted between the proposed algorithm and other algorithms (P&O, FLC) under actual radiation and weather conditions with temperatures

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