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Comparison between the Conventional Methods and PSO Based MPPT Algorithm for Photovoltaic Systems

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***Abstract*—**Since the output characteristics of photovoltaic (PV) system depends on the ambient temperature, solar radiation and load impedance, its maximum power point (MPP) is not constant. Under each condition PV module has a point at which it can produce its MPP. Therefore, a maximum power point tracking (MPPT) method is needed to uphold the PV panel operating at its MPP. This paper presents comparative study between the conventional MPPT methods used in (PV) system: Perturb and Observe (P&O), Incremental Conductance (IncCond), and Particle Swarm Optimization (PSO) algorithm for (MPPT) of (PV) system. To evaluate the study, the proposed PSO MPPT is implemented on a DC-DC cuk converter and has been compared with P&O and INcond methods in terms of their tracking speed, accuracy and performance by using the Matlab tool Simulink. The simulation result shows that the proposed algorithm is simple, and is superior to the P&O and IncCond methods.

***Keywords*—**Incremental Conductance (IncCond) Method, Perturb and Observe (P&O) Method, Photovoltaic Systems (PV) and Practical Swarm Optimization Algorithm (PSO).

I. Introduction

RENEWABLE energy sources have many advantages over conventional energy sources, as they are green, do not emit carbon dioxide and in many cases are sustainable. Consequently, there is much interest in using renewable energy as a solution of the problems created by burning finite fossil fuels. However, the use of renewable energy still has a number of limitations, as most renewable energy sources depend on the weather conditions, such as wind in wind power generation, rain in hydropower and clear skies in photovoltaic (PV) systems. Furthermore, the cost of renewable energy sources is higher than the conventional energy sources when generating large volumes of energy. Therefore, the main issue in renewable energy research is to reduce the cost and increase the efficiency of production. In recent years, wind power and PV energy have been the two main areas of the research and development. However, much work needs to be done in this field in order to make renewables as efficient and reliable as possible [1], [2]. Nevertheless, the PV system has become an important source for generating electricity due in part to the development that has occurred in the semiconductor field, which has made it possible to increase the energy output to meet the required load power. Thus PV systems can replace conventional energy sources in the future as a result of its inexhaustible source. Furthermore, it is clean without pollution and has no moving parts which reduce the cost of maintenance [2]. Since the output characteristics of the PV system depends on the ambient temperature, solar radiation and load impedance, it is important to operate the PV panel at its maximum power point (MPP) which as explained is not constant as it varies with the weather conditions [3].

Several MPPT methods have been developed in relation to PV systems in order to reach the MPP. These range from using simple methods to more complex analysis depending on the weather conditions and the application [7]-[9]. The main aim of the MPPT is to extract maximum output power from the PV module under different sunlight radiation and temperatures. In this survey, the Perturb and Observe (P&O), the Incremental Conductance (IncCond) and Practical Swarm Optimization (PSO) MPPT algorithms are presented and compared under different atmospheric conditions.

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II. The Terminal Characteristics of PV Cells

Fig. 1 shows the equivalent-circuit diagram of PV cell that consist of a source current (I_{ph}), a diode (D), and series and parallel resistances (Rs, Rp).

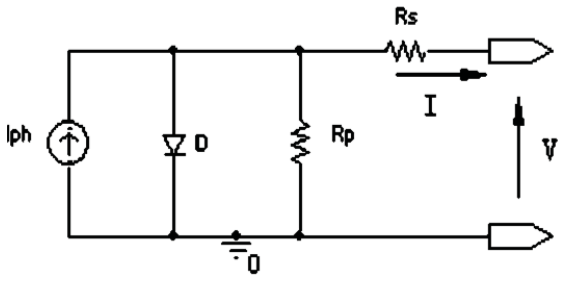


Fig. 1 The equivalent-circuit of PV cell model [4].

The output current-voltage (I-V) characteristics can be calculated by using the following equation:

$$I = I_{ph} - I_{01}\left(e^{(V+I.R_{s/AKT_c})} - 1\right) - \left(V + I.\frac{Rs}{Rp}\right) \quad (1)$$

where, I , V - the PV cell output current and voltage respectively, I_{ph} is the photon generated current, and Io is the diode reverse saturation currents. A is the ideality factors, T is the cell temperature in Kelvin, k is the Boltzmann's constant (K=1.380 x 10^{-23} J/K) and q is the Electronic charge =1.6×10−19C). The selected PV module for this study is BP Solar BP SX 150S PV module, and it is able to generate an

output power of 60 watt. Its electrical specifications are shown in (see Table I).

TABLE I
ELECTRICAL SPECIFICATIONS OF THE SIMULATED PV MODULE

Maximum Power (*Pmax*)	60 W
Voltage @ *Pmax* (*Vmp*)	17.1 V
Current @ *Pmax* (*Imp*)	3.5 A
Open-circuit voltage (*Voc*)	21.1 V
Short-circuit current (*Isc*)	3.8 A
Temperature coefficient of *Short-circuit current (Isc)*	.(0.065±0.015)%/°C
Temperature coefficient of *Open-circuit voltage (Voc)*	–(80±10)mV/°C
Temperature coefficient of power	–(0.5±0.05)%/°C

III. THE PV MODULE PERFORMANCE

By using (1), and the electrical specifications of the PV module, the current-voltage (I-V) characteristics at different environmental conditions, temperature and irradiance are displayed in Figs. 2 and 3.

From the figures, it is clear that the PV module has a non-linear characteristic which differs according to solar radiation, temperature and the load condition. Each curve has a different point at which the module can produce its maximum power. Hence, in order to overcome this problem, a MPPT controller is required. The major job in an MPPT system is to choose and design a high efficiency DC-DC converter that can operate the PV module at its MPP.

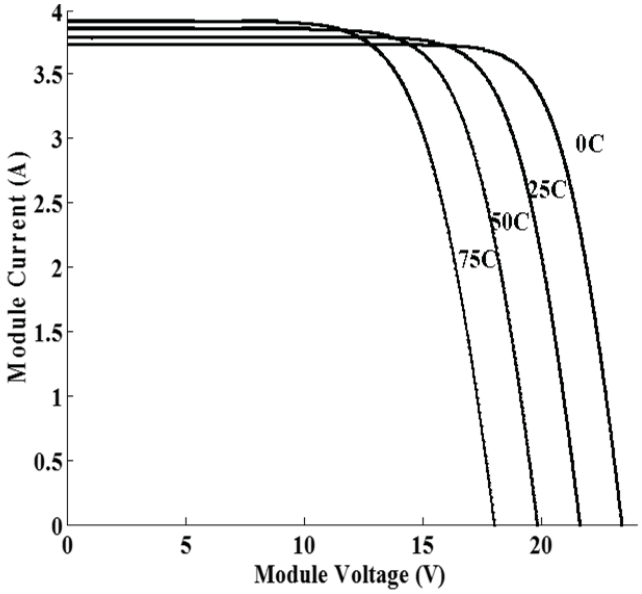


Fig. 2 I-V Characteristics with variable temperatures and constant irradiance (1KW/m2)

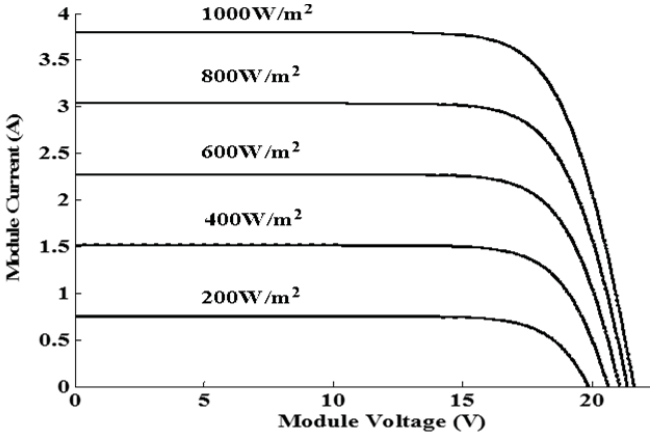


Fig. 3 I-V Characteristics with different irradiance values and a constant temperature (25°C)

IV. CUK CONVERTER

Fig. 5 illustrates the Cùk converter circuit diagram which was designed according to the electric specification is shown in Table II.

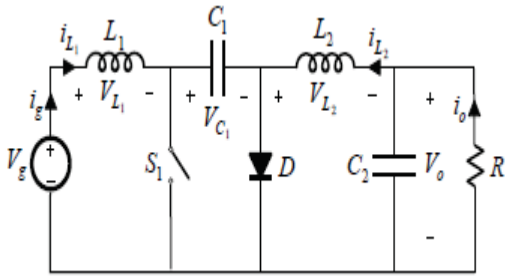


Fig. 4 Basic electrical circuit of DC-DC cùkconverter [4]

The voltage transfer function can be written as following;

$$\frac{V_{out}}{V_S} = \frac{D}{1-D} \quad (2)$$

TABLE II
THE ELECTRIC SPECIFICATION OF CUK CONVERTER

Specification	
Input Voltage (V_s)	12-18V
Input Current (I_s)	0-5A(<5% ripple)
Output Voltage (V_{out})	40V(<5% ripple)
Output Current (I_o)	0-5A(<5% ripple)
Maximum Output Power (P_{max})	60W
Switching Frequency (f)	10KHz
Duty Cycle (D)	0.6≤D≤1

V. TECHNIQUES OF MAXIMUM POWER POINT TRACKING

A. Perturbation and Observation Algorithm (P&O)

This technique is based on the relationship between the PV module output power and the its output voltage, and the MPP is obtained by adjusting the switching mood of the converter (duty ratio) until d_p/d_v is equal to zero, The drawback of P&O methods are that it produces osculation around the MPP in the steady state. Reference [5] shows that a continuous oscillation

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in P&O methods in the steady statecauses a reduction in the PV module output power. In addition it cannot operate the module at its maximum output power in rapidly changing of weather conditions, the flowchart of the P&O algorithm is depicted in Fig. 8 [6]-[8].

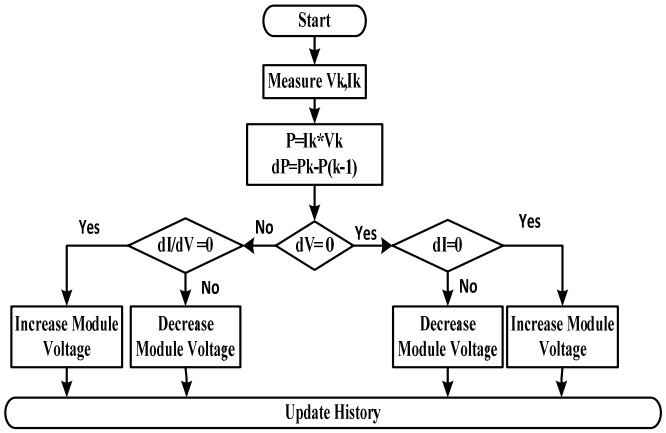


Fig. 5 Flowchart of P&O algorithm

B. Incremental Conductance (IncCond) Algorithm

The Incremental Conductance (IncCond) algorithm was developed to overcome the drawback of the P&O method under rapidly changing weather conditions. The relationship between the voltage and power can be expressed as follows;

$$\frac{\mathrm{dP}}{\mathrm{dV}} = 0 \quad at\ MPP \tag{3}$$

$$\frac{\mathrm{dP}}{\mathrm{dV}} > 0 \quad on\ the\ left\ side\ of\ MPP \tag{4}$$

$$\frac{\mathrm{dP}}{\mathrm{dV}} < 0 \quad on\ the\ right\ side\ of\ MPP \tag{5}$$

The P-V characteristic slope (dP/dV) can be calculated using the PV module output voltage and its output current as follows:

$$\frac{\mathrm{dP}}{\mathrm{dV}} = I \times \frac{\mathrm{dV}}{dV} = I \times \frac{\mathrm{dV}}{\mathrm{dV}} + V \times \frac{\mathrm{dI}}{\mathrm{dV}} = I + V\,\frac{\mathrm{dV}}{dI} \tag{6}$$

Hence, the PV module operating point at its maximum output power can be calculated based on (16) as follows;

$$\frac{\mathrm{dI}}{\mathrm{dV}} = -\frac{\mathrm{I}}{\mathrm{V}} \quad at\ MPP \tag{7}$$

$$\frac{\mathrm{dI}}{\mathrm{dV}} > -\frac{\mathrm{I}}{\mathrm{V}} \quad on\ the\ left\ side\ of\ MPP \tag{8}$$

$$\frac{\mathrm{dI}}{\mathrm{dV}} < -\frac{I}{\mathrm{V}} \quad on\ the\ right\ side\ of\ MPP \tag{9}$$

These equations show that the PV module operates at its MPP when the IncCond dI/dV is equal to its direct conductance -I/V. while if the PV module IncCond dI/dV is greater than the its conductance -I/V, then the controller would increase the PV module voltage by adjusting the duty ratio of a DC –DC converter, otherwise, the perturbation would be in the opposite direction or to increase the duty ratio of the converter in order to reduce the voltage and shift the operating point back to the MPP [8], [9]. Fig. 8 shows the flowchart of the IncCond algorithm.

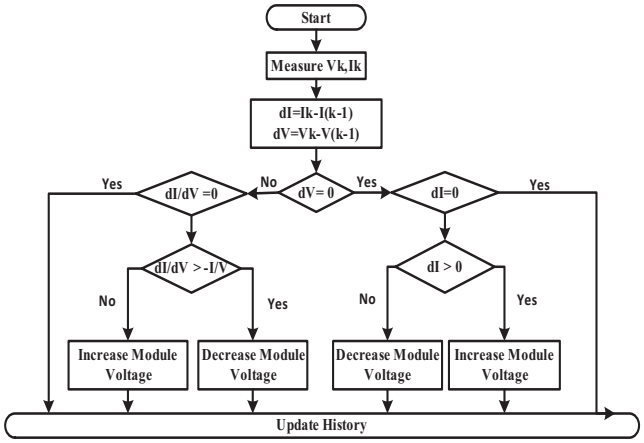


Fig. 6 Flowchart of the IncCond algorithm

C. Over View of the Particle Swarm Optimization Algorithm

Particle swarm optimization (PSO) is an intelligence optimization theory was developed by Eberhart and Kennedy in 1995. The principle of this algorithm was inspired from the foraging behavior of birds and fish schooling, and the two scholars were applied this phenomenon to overcome the problems associated with search and optimization. In this algorithm, several cooperative birds are used, and each bird, referred to as a particle, each particle flying in the space has its own fitness value that mapped by an objective function and velocity which uses to decide the direction and distance of their movement. Each particle exchanges information obtained in its respective search process. The typical process of optimization the particles are shown in Fig. 1 [10]-[12].

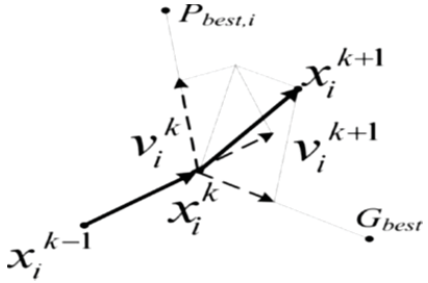


Fig. 7 Movement of a PSO particle

The movement of particles impact by two variables; the P_{best} that used to store the best position of each particle as an individual best position, and the G_{best} that found by comparing individual positions of the particle swarm and store it as best position of the swarm. The particle swarm uses this process to move towards the best position and continuously it revise its direction and velocity, by this way, each particle quickly converge to an optimal or close to a global optimum. The

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standard PSO method can be defined by the following equations;

$$v_i(k+1) = wv_i(k) + c_1 r_1.\left(P_{best} - x_i(k)\right) + c_2 r_2.\left(g_{best} - x_i(k)\right) \quad (10)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (11)$$

i=1, 2…, N

where xi and vi are the velocity and position of particle i, ; k represents the iteration number; w is the inertia weight; $r1$,$r2$ are random variables and their values are uniformly distributed between [0,1]; $c1$, $c2$ represents the cognitive and social coefficient respectively. $p_{\text{best},i}$ is the individual best position of particle i, and g_{best} is the swarm best position of all the particles. If the condition (14) of initialization was satisfied, the method updated like (13)

$$p_{\text{best}i} = x_{i\text{k}} \quad (13)$$

$$f(x_{i\text{k}}) > f(p_{\text{best}i}) \quad (14)$$

where f represents the objective function that should be maximized.

The basic operating principle of this method can be explained as follows;

Step 1. (PSO Initialization): Particles are usually initialized randomly following a uniform distribution over the search space, or are initialized on grid nodes that cover the search space with equidistant points. Initial velocities are taken randomly.

Step 2. (Fitness Evaluation): Evaluate the fitness value of each particle. Fitness evaluation is conducted by supplying the candidate solution to the objective function.

Step 3. (Update Individual and Global Best Data):Individual and global best fitness values (pbest,i and gbest) and positions are updated by comparing the newly calculated fitness values against the previous ones, and replacing the pbest,i and gbest as well as their corresponding positions as necessary.

Step 4. (Update Velocity and Position of Each Particle): The velocity and position of each particle in the swarm is updated using (10) and (11).

Step 5. (Convergence Determination): Check the convergence criterion. If the convergence criterion is met, the process can be terminated; otherwise, the iteration number will increase by 1 and go to step 2.

D.Application of PSO to MPPT

This section describes the implementation of PSO method in solving the problem involved to MPPT controller in PV system. The flowchart of the proposed PSO-based MPPT algorithm is illustrated in Fig. 2, and the main blocks of the proposed algorithm can be described as following;

Step 1. Parameter Selection:

For the proposed MPPT algorithm, the duty cycle of the converter was defined as the particle position, and the generated output power was chosen to be the fitness value evaluation function, the position and initial velocity of each particle was randomly initialized in a uniform distribution over the search space.

Step 2. Fitness Evaluation:

The fitness value of particle i, is computed after the controller sent the duty cycle command which represents the position of particle i.

Step 3. (Update Individual and Global Best Data):

Update the fitness values, individual best positions (Pbest) and global best fitness values (gbest) of each particle by comparing the new calculated fitness values against the previous ones and replacing the pbest, and gbest corresponding to their positions as necessary.

Step 4. (Update Velocity and Position of Each Particle):

After evaluating all particles, update the velocities and positions of each particle in the swarm by using the PSO formulas (1) and (2).

Step 5. (Convergence Determination):

The converge criterion are either locating to optimal solution or reaching the maximum number of iterations. If the convergence criterion is met, the process would terminate; otherwise, rerun Steps 2 through 5.

Step 6. (Reinitialization):

In standard PSO method the converge criterion are either locating to optimal solution or reaching the maximum number of iterations. However in PV systems the fitness value is not constant as it changes with the weather condition and load. Therefore, the PSO must be reinitialized and search again for a new to search the new MPP when the PV module output changed .for this application the proposed PSO algorithm is reinitialized whenever the following functions are satisfied;

$$\frac{p_i(k+1) - p_i(k)}{p_i(k)} > \Delta p \quad (15)$$

VI. Design and Simulation of MPPT Algorithm

Fig. 7 illustrates the Simulink module of the proposed system that was simulated in Matlab, in which the terminal voltages of the PV module was controlled by the DC-DC cuk converter and its output was coupled to the load. The switch of the converter was controlled by different MPPT algorithms and their tracking efficiency were analyzed and compared under various conditions.

Firstly the proposed MPPT system was simulated with the MATLAB model at (1000w/m^2, 25°C), and then simulated at rapidly atmospheric conditions. The performance of each MPPT technique was evaluated when the steady state condition is reached.

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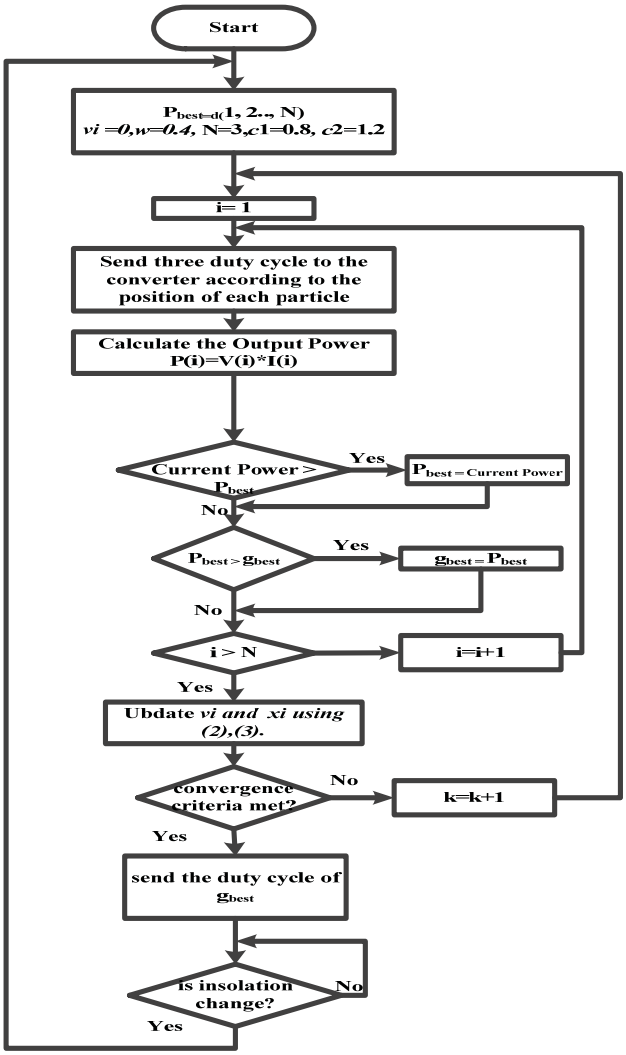


Fig. 8 PSO method flowchart

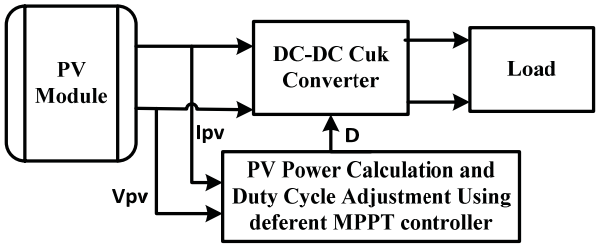


Fig. 9 Simulink module of the MPPT system

Fig. 10 shows the simulation result for the response of the three methods in the first stage at (1000kw/m^2, 25°C). While Fig. 10 shows the output power of the PV module under low solar radiation (G=200w/m2, T=25°C).

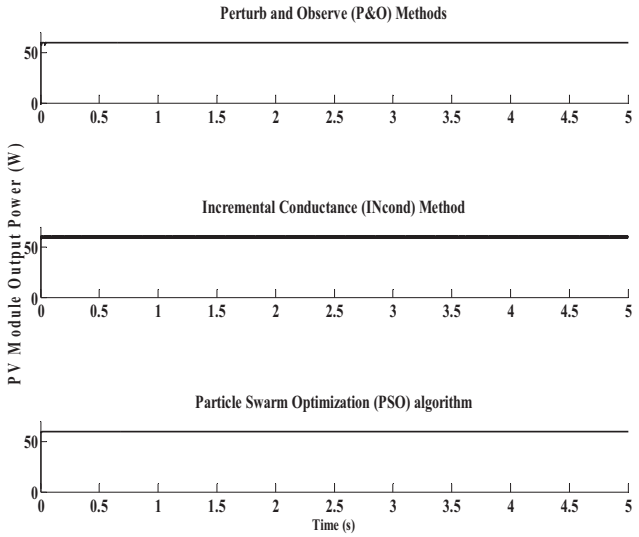


Fig. 10 11The PV module output power (w) simulated with the MATLAB model at 1000kw/m^2, 25°C

From Fig. 10 it can be seen that the theoretical maximum power value is 60 W, and it is 60.7 W, by the PSO MPPT control algorithm. In addition, the optimization time of PSO is 0.059 s and has a very fast convergence speed which proves the accuracy of the proposed PSO-MPPT. While the tracking efficiency of the P&O method was the lowest 59.7 W comparing to PSO and IncCond. methods. The IncCond method tracking efficiency was higher than P&O method 59.89 W, as a result of its independent to the solar radiation level. Thus, this algorithm is usually used at high and fast radiance variations.

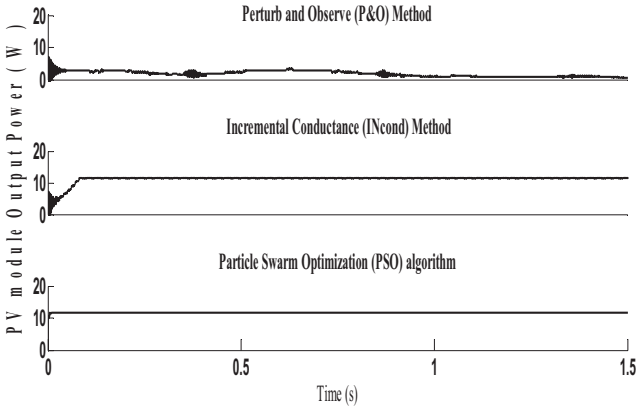


Fig. 12 The PV module output power (w) simulated with the MATLAB model at 200kw/m^2, 25°C

From the result in condition 2 Fig. 11 under low solar radiation (G=200w/m^2, T=25°C), the P&O efficiency is lower than PSO and IncCond methods and it was not able to converge to the MPP. In that time, the IncCond method was able to open the PV module near to the MPP, and its efficiency is higher than P&O. However, PSO algorithm was the best control method throughout the simulation results, as it

was quickly and successfully tracked the MPP of the module in both conditions.

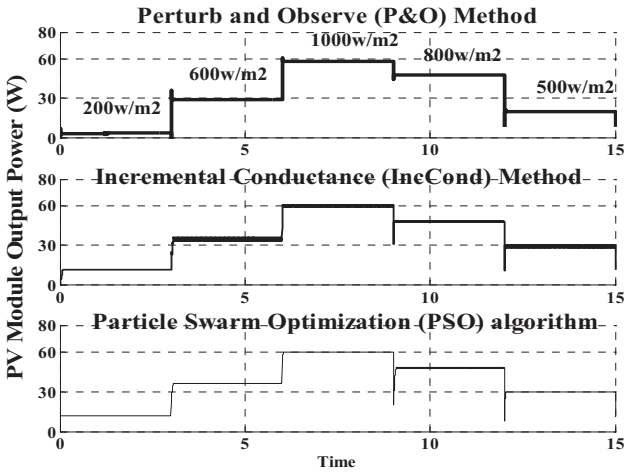


Fig. 13 The PV module output Power (w) simulated with the MATLAB model at rapidly changing solar radiation, 25°C

Fig. 12 shows output power of the PV module under rapidly changing atmospheric conditions. The results highlight that the tracking efficiencies of the systems with PSO in all conditions was higher than 99.8%. The P&O method had large amount of power losses and causes an oscillation around the MPP, while the tracking efficiencies of the systems with the IncCond method was better than the P&O performances. However, the IncCond method is more complicated than the P&O method as it requires a fast controller speed and more sensor devices that leading to increase the system cost.

VII. Conclusion

This study presents the simulation of MPPT of PV system using P&O, IncCond and PSO techniques in terms of their tracking efficiency, convergence speed, cost and performance. According to the simulation results, the PSO method was able to track the MPP correctly in all conditions, and it has advantages over other techniques such as a very high tracking efficiency, simple structure, easy implementation, and has a very fast convergence speed to the desired solution .however, the choice of its parameters has some impacts on the optimization performance.

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