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A GWO-P&O Algorithm MPPT for PV Systems Under UIC and PSC

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A B S T R A C T

The operation of PV systems can experience uniform (UIC) and partial insolation (PSC) that depends on its environment. Many MPPT algorithm has been proposed in literature such as P&O, and many metaheuristics algorithm such as PSO and GWO. Those algorithm only work at a certain environmental condition. The P&O algorithm only work at UIC but fail to track maximum power at PSC hence reducing efficiency of MPPT system when it is experiencing UIC and PSC. The GWO algorithm can track maximum power at PSC but when the change of insolation to UIC can shift power output below maximum power hence reducing efficiency of MPPT system. In this paper another method is proposed by implementing the result of GWO to the input of the P&O algorithm subsequently the GWO is reset periodically to search a new maximum power point to anticipate any environmental changes. This new method is called a GWO-P&O algorithm. Simulation results show that the GWO-P&O algorithm yields better efficiency compared to the GWO or the P&O algorithm in case the modules of PV array experiencing UIC and PSCs. Simulation is done using MATLAB/SIMULINK software.

INTRODUCTION

Solar power is gaining momentum recently due to advances in solar panel manufacturing and efficiency that makes photovoltaics at the forefront of clean renewable energy[1]. The performance of photovoltaics (PV) systems depends on many factors. Solar irradiation and temperature is the most affecting factors of PV generation systems. There are two conditions of irradiation that needs to be considered when employing a maximum power point tracker (MPPT) of a PV systems. The first condition is when PV modules receive the same irradiation or under uniform irradiation condition (UIC). The second condition is when a certain modules of PV array are shaded by passing clouds, trees, poles, buildings and many other objects. This condition is called non uniform irradiation condition or partial shading condition (PSC)[2]. Moving clouds can cause great inefficiency in large photovoltaics power plant due to PSC[3]. The conventional P&O (Perturb and Observe) algorithm can only track maximum power when the operation of MPPT is under UIC [4]. But when an MPPT operates under PSCs the P&O algorithm fails to track the maximum power [5]. Another MPPT techniques such as incremental conductance (INC) and hill climbing (HC) also fails to track global MPPT under PSC[6]. PSC causes multiple peaks at power-voltage curve (P-V curve). Multiple peaks is the biggest challenge to MPPT because the objective function of the MPPT algorithm becomes more complex and inability to discriminate between global and local peaks [7]. To overcome the condition of PSCs many metaheuristics algorithm has been proposed. Almost all metaheuristics algorithm are inspired directly from the behaviors of the organisms such as searching and hunting [8]. Some metaheuristics algorithm in literature are implemented in MPPT such as PSO in [9] and GWO in [5]. GWO has shown better performance than PSO with efficiency 99.92% [5]. The performance of PV array strongly depends on operating environmental conditions[10]. In nature environmental conditions is unpredictable and becoming worse due to the effect of climate change. Therefore, PV array operations can experience from PSCs to UIC and vice versa. The efficiency of PV array in [5] only discuss the operation from one PSC to another PSC. The GWO algorithm proposed by Mirjalili in [11] bases on iteration process for searching the optimal solution. This iteration needs a lot computation and repeated periodically to handle any environmental changes conditions of the PV systems. Moreover, exploration phase of the GWO algorithm creates fluctuation at output power and hence reducing efficiency. This research proposes combination of GWO and P&O algorithm to reduce the number of fluctuation at output power and hence increasing efficiency of the PV systems under uniform and partial insolation conditions. The simulation of the proposed GWO-P&O algorithm is carried out with MATLAB/SIMULINK software.

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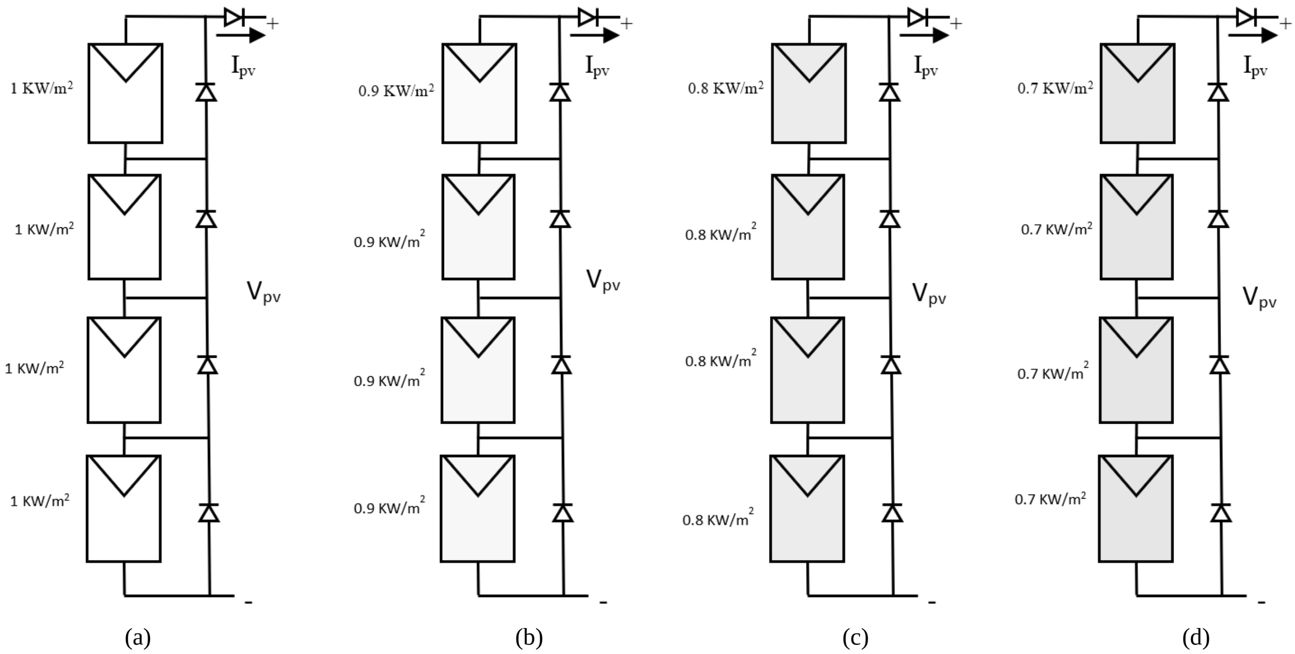

Figure 1. PV array under UIC (a). 1000 W/m^2 (b). 900 W/m^2 (c). 800 W/m^2 (d). 700 W/m^2

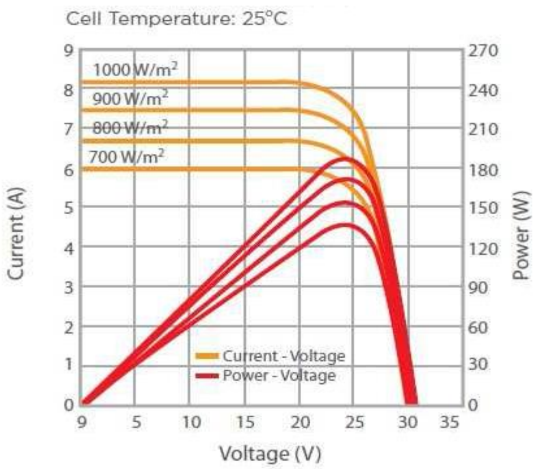

Figure 2. Current-Voltage and Power-Voltage curve of PV array under UIC [13].

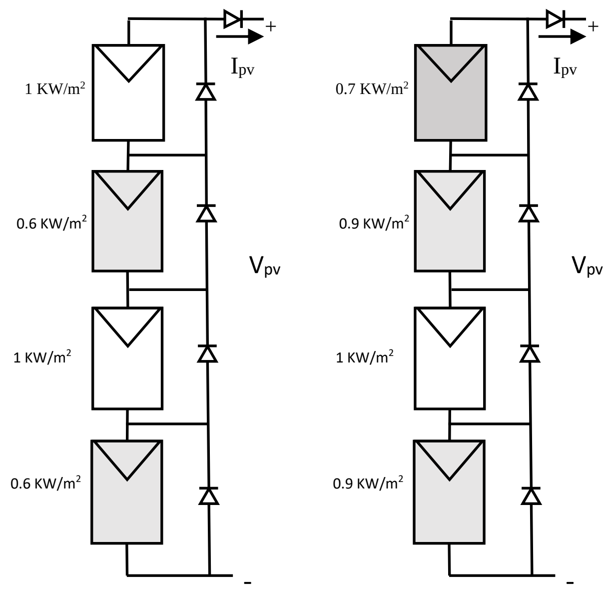

Figure 3. PV array under PSC.

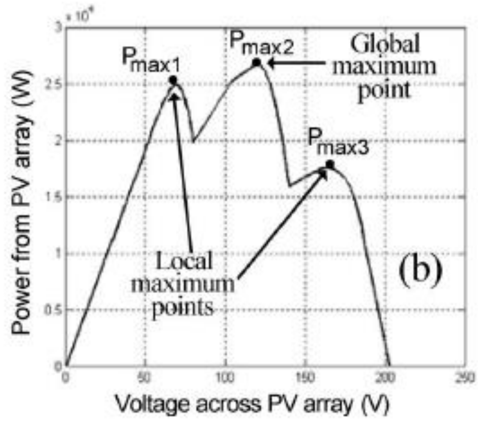

Figure 4. Power-Voltage curve of PV array under PSC [7]

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Partial Shading Condition (PSC)

Often PV array gets shadowed completely or partially by passing clouds, building, tower, and trees. Under partially shaded condition (PSC) the PV characteristics (power-voltage and current-voltage curve) get more complex with multiple peaks. Partial shading is also known as non uniform insolation condition. Figure 3 shows PV array in partially shaded condition. Blocking diodes is used in the array in order to protect the PV module from hotspot [7] . In PSC several modules receive less irradiance than the other modules. Figure 4 shows the power-voltage curve of PV array under PSC. Power losses during partial shading is more compared to other losses in photovoltaics system [14]. From figure 4 we can see that there are several peaks appear in power-voltage curve. Several of the peaks are local maximum power point (P_{max1},P_{max3}) and one global maximum power point (P_{max2}). In order to achieve maximum efficiency of PV system any MPPT algorithm should be able track this global maximum power point. Conventional algorithm such as P&O could not be able to track this global maximum power point at PSC and frequently is trapped in local maximum power point. However many metaheuristics algorithm such as GWO has been reported able to track this global maximum power point at PSC [5].

called alpha (α), the second leader is called beta (β, the third leader is called delta (δ). The other wolves are subordinate wolves and are called omegas. Grey wolves encircling behaviour during the hunt process is modelled mathematically by the following equations :

$$\vec{D} = |\vec{C} \cdot \overrightarrow{X_p}(t) - \vec{X}(t)| \quad (1)$$

$$\vec{X}(t+1) = \overrightarrow{X_p}(t) - \vec{A} \cdot \vec{D} \quad (2)$$

t is the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\overrightarrow{X_p}$ is the position vector of the prey, and $\vec{X}$ indicates the position vector of a grey wolf. The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows :

$$\vec{A} = 2\vec{a} \cdot \overrightarrow{r_1} - \vec{a} \quad (3)$$

$$\vec{C} = 2 \cdot \overrightarrow{r_2} \quad (4)$$

Where components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and $\overrightarrow{r_1}$ and $\overrightarrow{r_2}$ are random vectors in [0,1]. In the hunt process alpha, beta and delta have better knowledge about the potential location of the prey.

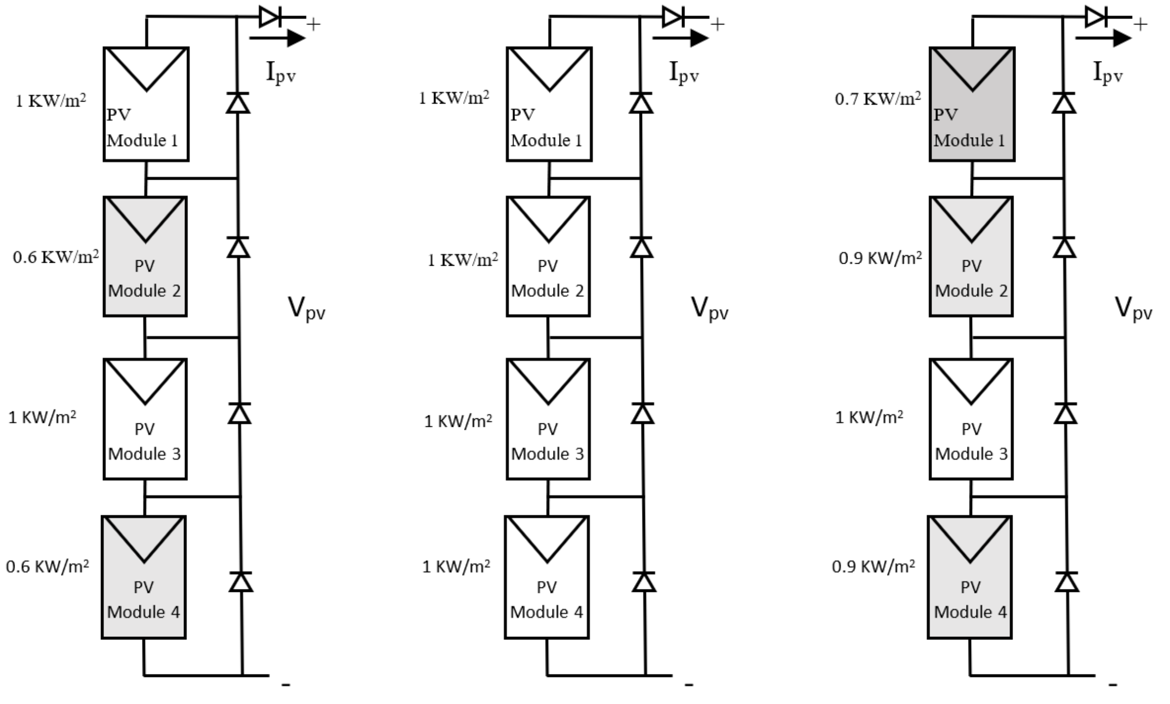

Figure 5. Simulation of insolation of PV array (a). PSC pattern 1 (b). uniform insolation (UIC) (c). PSC pattern 2

Insolation is adjusted to mimic partial shading (PSC) and uniform insolation (UIC). First PV arrays are subjected to PSC pattern 1 for 4 seconds in figure 5a. During PSC pattern 1 multiple peaks occurs and global peak power is 640 Watt as shown in figure 6. After 4 seconds insolation changes to UIC with irradiation 1000 W/m^2 in as shown in figure 5b. During PSC pattern 2 multiple peaks occurs and global peak power is 760 Watt as shown in figure 6.

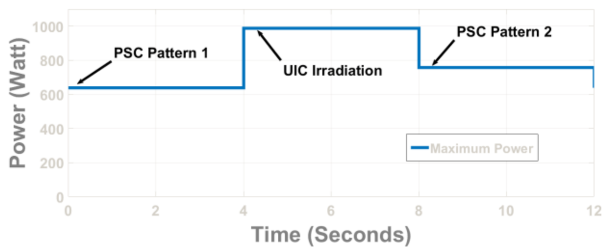

Figure 6. Maximum power during PSC and UIC.

Design of GWO-P&O Algorithm

Grey wolves are the top predators who live in a pack of 5-12 on average and have their own social hierarchy. The top leader is

Therefore, the other search agents (omegas) update their positions according to these three best agents. Below are the formulas to model this mathematically.

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{X_\alpha} - \vec{X}\right| \tag{5}$$

$$\overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{X_\beta} - \vec{X}\right| \tag{6}$$

$$\overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{X_\delta} - \vec{X}\right| \tag{7}$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1}.(D_\alpha) \tag{8}$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2}.(D_\beta) \tag{9}$$

$$\overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_3}.(D_\delta) \tag{10}$$

$$\vec{X}(t+1) = \frac{\overrightarrow{X_1} + \overrightarrow{X_2} + \overrightarrow{X_3}}{3} \tag{11}$$

From the equation (11), the updating position of each grey wolf depends on the position of the three best agents alpha (α), beta (β), and delta (δ) by averaging or assigning the same weight 1/3 of each three agents[11]. The flowchart of GWO algorithm is depicted in figure 7.

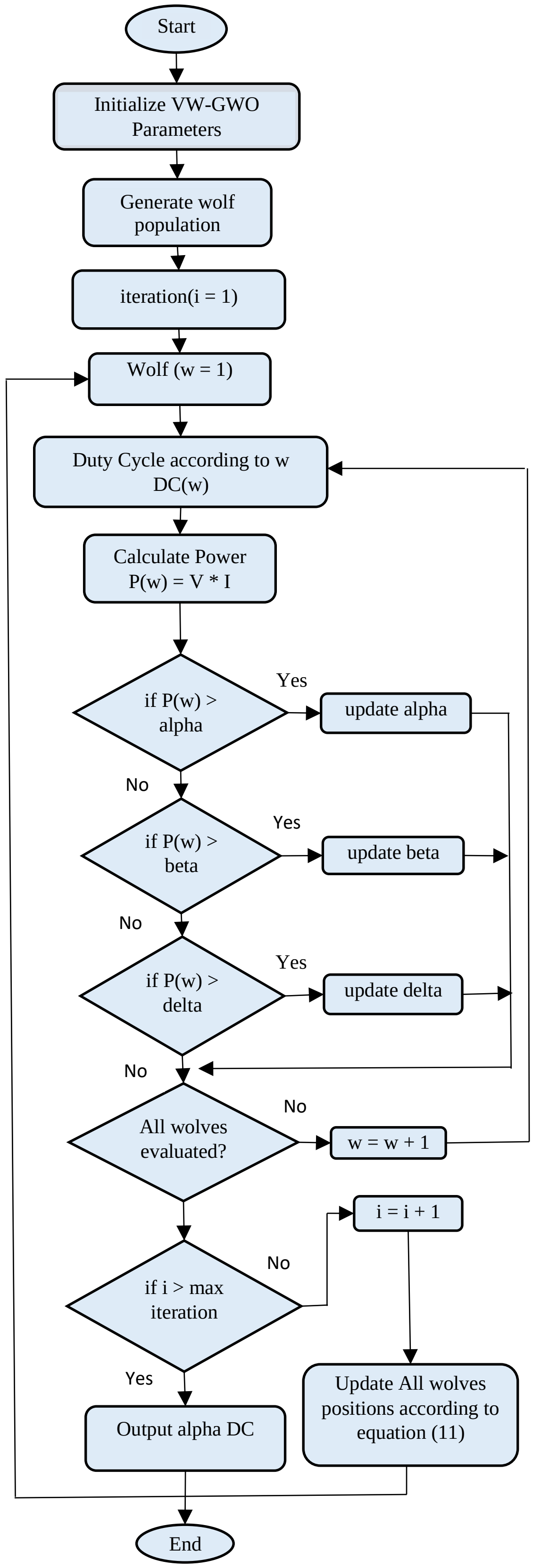

Figure 7. Flowchart of GWO algorithm.

The most widely known MPPT algorithm is pertubation and observation method or P&O which is very easy to implement [15]. The P&O algorithm is also called “hill-climbing” method. On V-P characteristics curve, at the left of MPP point the variation of power against voltage dP/dV > 0 where at the right

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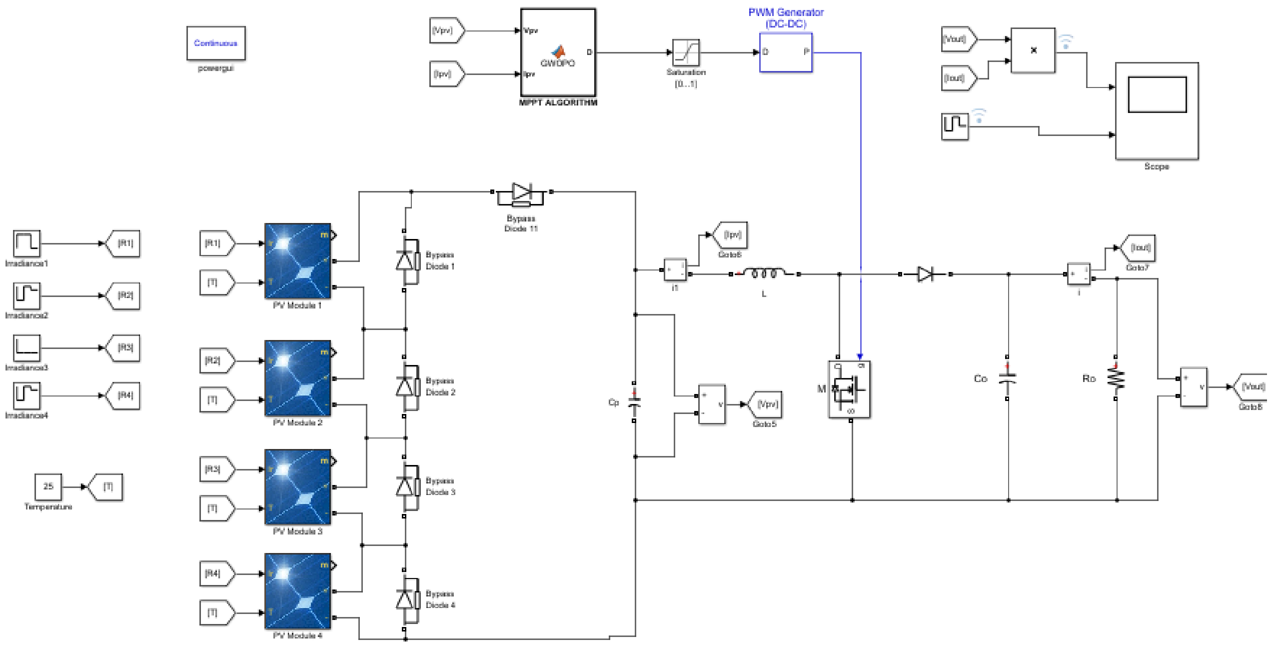


Figure 10. Simulation of MPPT system with SIMULINK/MATLAB.

of MPP the dP/dV < 0. The operating voltage of PV array is perturbed in a given direction.

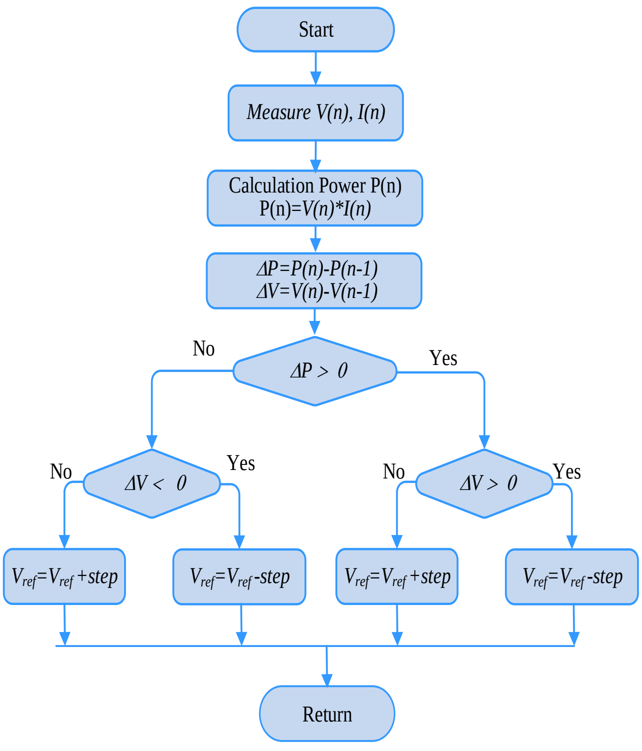


Figure 8. Flowchart of P&O algorithm[16].

If dP/dV > 0 then the pertubation moves the operating point toward the MPP. The P&O algorithm would then continue to perturb the PV array voltage in the same direction. If dP/dV < 0 then the pertubation moves the operating point away from the MPP. The P&O algorithm should then reverse the direction of the pertubation. The main advantage of P&O method is that it is easy to implement and low computational demand. However it has some drawbacks like oscillations around MPP at steady state operation, slow response speed, and trapped in local peak during PSC conditions[17].

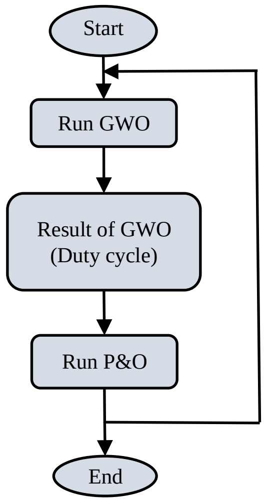


Figure 9. Flowchart of GWO-P&O algorithm.

The P&O algorithm first calculates the power (P) by sensing the voltage and current. A pertubation in duty (D) of the DC-DC converter is then provided based on the change of power according to the equations below. Where ΔD is the perturbed duty cycle [18]. The flowchart of P&O algorithm is depicted in figure 8.

$$D_{new} = D_{old} + \Delta D \ \ (if\ P > \ P_{old}) \qquad (12)$$

$$D_{new} = \ D_{old} - \Delta D\ (if\ P < P_{old}) \qquad (13)$$

Combination of GWO and P&O method is implemented by first running the GWO algorithm and its result is given as the initial value of P&O algorithm. The flowchart of combination of GWO and P&O is shown in figure 9.

Design and Simulation of MPPT Systems

Maximum Power Point Tracking or MPPT is a concept in order to address the poor efficiency of photovoltaics systems [19]. DC-DC boost converter is applied to MPPT system to vary the load resistance seen by the source and matched with the internal resistance of the PV module at maximum power point hence to transfer the maximum power to the load [20]. Simulation of the proposed MPPT systems is conducted with MATLAB/SIMULINK software. The block diagrams of the proposed MPPT systems is shown in figure 10. To mimic insolation changes of figure 5, repeating sequence stair block is used as input to irradiance to the PV modules. Vector of output values and sample time of this block is shown in table 1.

Table 1. Input irradiance parameters

Photovoltaics Modules	Irradiance Vector (W/m^2)	Sample time (seconds)
Module 1	1000 1000 700	4
Module 2	600 1000 900	4
Module 3	1000 1000 1000	4
Module 4	600 1000 900	4

PV modules are connected in 4S configuration with a blocking diode for each module. Blocking diode is used to protect the modules from hotspot. The input temperature to each module is a constant 25 degrees celcius. The parameters of the PV module is shown in table 2.

Table 2. PV module parameters

Parameters	Values
Module	Tata Power Solar System TP250MBZ
Max Power	249 Watt
Open Circuit Voltage	36.8 Volt
Short Circuit Current	8.83 A
Voltage at Max Power	30 Volt
Current at Max Power	8.3 A

Inductor L and Capacitor C for boost converter design is calculated according to equations in [21]:

$$L = \frac{D(1-D)R}{f_s} \quad (14)$$

$$C = \frac{D}{2f_sR} \quad (15)$$

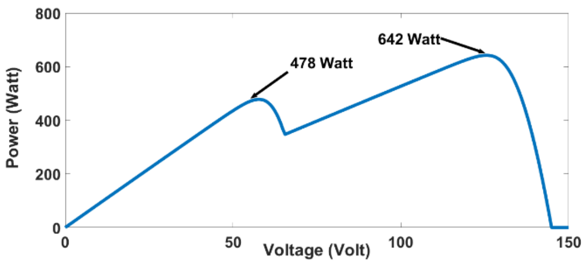
Where :
D = Duty cycle of PWM signal
f_s = Switching frequency (Hz)
R = Resistive load (Ohm)
Parameter values for boost converter design is shown in table 3.

Table 3. Parameters of boost converter design

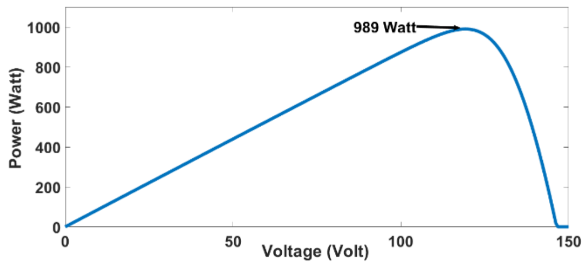
Parameters	**Values**
Inductor L	1.15 mH
Capacitor C	467.6 µF
Resistive Load R	53 Ohm

RESULTS AND DISCUSSION

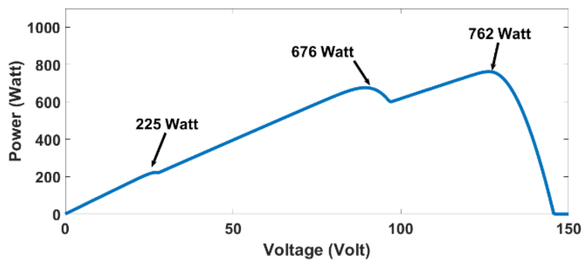
To know the efficiency of the MPPT algorithm we need to plot power-voltage curve of the PV array. Figure 11 shows the power-voltage curve of the PV array configured in figure 5. Figure 11a shows power-voltage curve for PSC pattern 1.



(a)



(b)



(c)

Figure 11. power-voltage curve of PV array (a). PSC pattern 1 (b). UIC 1000 W/m^2 (c). PSC pattern 2

There are two peaks for PSC pattern 1, one local peak at 478 watt and one global peak which is the global maximum power point at 642 watt. Figure 11b shows power-voltage curve for UIC at 1000 W/m^2. There are only one peak for UIC which is the global maximum power point at 989 watt. Figure 11c shows power-voltage curve for PSC pattern 2. There are three peaks for PSC pattern 2, two local peaks at 225 watt and 676 watt and one global peak which the global maximum power point at 762 watt.

After knowing the power-voltage curve of the PV array at PSC and UIC, a GWO-P&O based MPPT is run and comparison with conventional P&O and GWO is conducted.
Figure 12,13 and 14 shows the power curve of each algorithm. Figure 12 is the power curve of GWO algorithm. At PSC pattern 1 GWO is able to track global power point at 642 watt. Exploration time of GWO is around 1 second.

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After 4 seconds insolation changes to UIC but GWO only generates power 734 watt which is below global maximum power 989 watt. After 8 seconds insolation changes to PSC pattern 2 and GWO is able to track global maximum power at 762 watt. Neglecting fluctuation during exploration phase of GWO, efficiency during 12 seconds is calculated as below.

$$GWO\ eff = \frac{eff_{PSC\ pattern1} + eff_{UIC} + eff_{PSC\ pattern2}}{3}$$

$$= \frac{\frac{642}{642} x\ 100\% + \frac{734}{989} x\ 100\% + \frac{762}{762} x\ 100\%}{3}$$

$$= 91.4\ \%$$

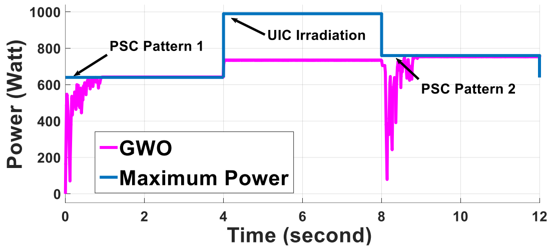

Figure 12. Simulation result of GWO algorithm.

Figure 13 is the power curve of P&O algorithm. At PSC pattern 1, P&O is trapped in local power point which is at 478 watt. But global maximum power is at 642 watt. After 4 seconds, insolation changes to UIC and P&O is able to track maximum power at 989 watt. After 8 seconds, insolation changes to PSC pattern 2 and P&O is able to track global maximum power 762 watt. Efficiency of P&O during 12 seconds is calculated as below.

$$P\&O\ eff = \frac{eff_{PSC\ pattern1} + eff_{UIC} + eff_{PSC\ pattern2}}{3}$$

$$= \frac{\frac{478}{642} x\ 100\% + \frac{989}{989} x\ 100\% + \frac{762}{762} x\ 100\%}{3}$$

$$= 91.5\ \%$$

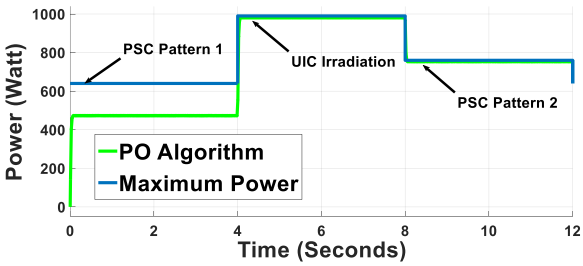

Figure 13. Simulation result of P&O algorithm.

Figure 14 is the power curve of GWO-P&O algorithm. At PSC pattern 1, GWO-P&O algorithm is able to track global maximum power at 642 watt. After 4 seconds, insolation changes to UIC and GWO-P&O is able to track new global maximum power point at 989 watt. Then after 8 seconds insolation changes to PSC pattern 2 and GWO-P&O is able to track global maximum power at 762 watt. Neglecting exploration fluctuation of GWO-P&O, efficiency during 12 seconds is calculated as below.

$$GWO - P\&O\ eff$$

$$= \frac{eff_{PSC\ pattern1} + eff_{UIC} + eff_{PSC\ pattern2}}{3}$$

$$= \frac{\frac{642}{642} x\ 100\% + \frac{989}{989} x\ 100\% + \frac{762}{762} x\ 100\%}{3}$$

$$= 100\ \%$$

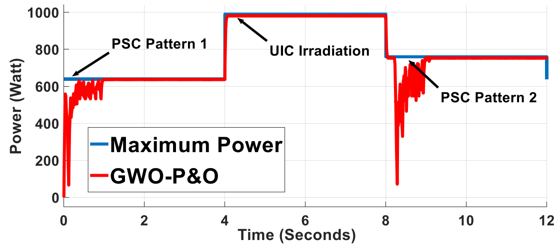

Figure 14. Simulation result of GWO-P&O algorithm.

CONCLUSIONS

The operation of MPPT PV systems can experience PSC and UIC insolations at anytime. GWO algorithm is very good in tracking maximum power in partial shading conditions. Meanwhile P&O algorithm in very popular because it is easy to implement but would not be able to track maximum power in case of partial shading conditions. In its operation PV systems can experience PSCs and uniform irradiation condition (UIC) that depends on the irradiation of sunlight. An MPPT system should be able to track maximum power in any of irradiation conditions including PSC and UIC. In this paper a combination of GWO and P&O algorithm called GWO-P&O algorithm is implemented to make MPPT system able to track maximum power at PSC and UIC. Simulation with MATLAB/SIMULINK shows that this proposed algorithm is better in tracking maximum power at PSC and UIC than conventional P&O and GWO algorithm.

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