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A hybrid method based MPP tracking strategy for solar power systems

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***Abstract*—One of the key factors used to measure the efficiency of a solar power system is the convergence time during the MPP tracking. In other words, the number of duty ratio samples should be as low as possible. In particular, the MPP tracking takes a long time and easily falls into the local MPP when the PV system is partially shaded, which reduces the operational efficiency of the PV system. The incremental conductance (In-Cond) algorithm and the improved grey wolf optimization (GWO) method have been combined to provide a novel approach for a standalone PV power system to overcome this drawback. In the proposed methodology, the global MPP is searched using the hybrid method, which is integrated the improved GWO with the In-Cond algorithm. To demonstrate the feasibility of the proposed method, MATLAB simulations the PV system are provided. The global MPP is not only obtained under uniform irradiance, but also under partial shading influences.**

***Index Terms*—Partial shading influence, photovoltaic (PV), maximum power point (MPP), boost converter, direct current (DC), grey wolf optimization (GWO), incremental conductance (In-Cond) algorithm.**

I. Introduction

Renewable energy sources including solar energy, wind energy, tidal energy, and hydrogen energy are considered clean energy sources. Among them, the solar energy is not only universal but also non-polluting and inexhaustible, it is one of the most popular energy sources. To enhance the solar energy conversion efficiency, many authors have proposed solutions to find the global MPP by using the perturbation and observation (P&O) method [1], the In-Cond algorithm [2], etc. The P&O and In-Cond algorithms are most commonly used in MPP tracking because they are easy to program, simple, and quickly reach the MPP. But the demerit of the P&O method is easy to oscillate around the MPP which reduces the performance of the PV system. Furthermore, under partial shading influences, these traditional methods are easily fallen into the local MPPs. To overcome these failures, researchers have addressed them through a number of innovative modifications [3]. However, an optimal solution for the PV system to operate in the real environment has not to be found, if these innovative solutions operate well in a homogeneous environment, they will be difficult with complex environmental events, and vice versa. Some solutions have performed relatively well, but design constraints and the computational complexity are large when the implemented processors are cheap and have low reliability.

The P-V curve has only one peak under the uniform distribution of PV irradiance, the above methods can easily catch this peak. However, when PV power panels are affected by environmental factors (e.g. clouds and obstacles), they produce not only global MPP but also many local MPPs. In these situations, the above traditional methods cannot find the global MPP of the entire operating area. Therefore, an innovative method is needed to track the global maximum power area under all environmental conditions. Many improved methods have been listed [4, 5], which can be classified into two kinds: hardware based maximum power tracking methods and soft computing based maximum power tracking methods. The MPP tracking methods based on soft computing included metaheuristic methods [6], improved metaheuristic methods [7], and hybrid methods [8-10]. On the contrast, hardware based methods included PV power system reconfigurations [11], etc. However, each method has its advantages. The general goal of these methods is to search the global MPP quickly, the output power of the PV system has low oscillation and simple calculations.

Based on the results of the above studies, this paper has designed a PV maximum power controller and achieved the expected results. Inspired by the grey wolf optimization [12] and the hybrid method combining the GWO and P&O methods [13], a new hybrid method is proposed to effectively search the global MPP. In this hybrid method, the improved GWO method is applied to search the global region quickly, and move to the In-Cond algorithm to find the MPP in this global area. This solution not only reduces the calculation time and calculation manipulation but also reduces the ripple amplitude of the output power. A stand-alone PV power conversion system including an MPP tracking controller, a DC boost converter [14], and a load has implemented [15]. With different duty ratio values, the system will receive different power values from the PV power panels. Improved GWO method uses these duty ratio values to find the global power area even considering partial shading influences as well as uniform irradiances.

II. Standalone solar power system

A. Model of the solar power panel

The PV cells are connected in series and parallel to form the PV power array ($N_s * N_p$) as seen in [16]. The output current I_{pv} and output power P_{pv} of the PV panels are calculated using the following equations:

$$I_{pv} = I_{ph} * N_p - I_{sa} * N_p * (e^{\frac{k_o * V_{pv}}{N_s}} - 1) \quad (1)$$

$$P_{pv} = V_{pv} * I_{pv} = V_{pv} * I_{ph} * N_p - V_{pv} * I_{sa} * N_p * (e^{\frac{k_o * V_{pv}}{N_s}} - 1) \quad (2)$$

where I_{sa} is a reverse saturation current, $k_o = q / (n * k * T)$, q is the amount of charge of a single electron ($1.6 * 10^{-19} c$), k is Boltzmann constant ($1.38 * 10^{-23} J / {}^oK$), T is the operating temperature of the PV power panel (${}^oK$), n is a factor of PV cell, V_{pv} is the output voltage of the PV power array. The current source I_{ph} effected by the PV irradiance intensity is calculated as follows:

$$I_{ph} = (I_{sc} + K_{sc} * (T - T_{ref})) * \lambda / 100 \quad (3)$$

where I_{sc} is the short-circuit current at the reference temperature $T_{ref}({}^oK)$ and PV irradiance condition 100 mW / cm^2, K_{sc} is the temperature coefficient ($mA / {}^oC$) of the short-circuit current, λ is the PV irradiance intensity (mW / cm^2). Different environmental conditions will produce different P-V curves. When the same PV irradiance intensity, the output power of the PV system decreases if ambient temperature increases. Conversely, when considered at the same ambient temperature, the output power of the PV panel will increase if the PV irradiance intensity increases. In real-world environments, panels can be affected by both different irradiance intensity and temperature, and finding the MPP is more complicated.

B. *Partial shading influences*

In order to increase the output voltage, the PV power panels are connected in series. A diode is connected in parallel to the PV panel to isolate this panel in the worst situation. Fig. 1 shows an example of three-series PV power panels. When the irradiance intensity of each PV power panel is the same, they will generate the same current values. If one PV power panel is shaded by clouding etc., the output current and voltage of the shaded PV power panel will decrease. In the worst situation, the shaded PV power panel generated the current is equal to zero, the parallel diode with this PV power panel will turn on and the shaded PV power panel is isolated to avoid the minimum output current. For example, the PV power panels are set the PV irradiance intensities as shown in Fig. 1 (from top to bottom). Allow us denote I_1, I_2 and I_3 as the short-circuit currents for the three PV irradiance intensities, respectively (i.e., $I_1 > I_2 > I_3$). if the output current of the measured PV array is $I_{pv} < I_3$, this current is limited by PV panels with the smallest PV irradiance intensity, which means these PV panels are working normally. The output voltage of the PV array is $V_{pv} = v_{pv1} + v_{pv2} + v_{pv3}$. When the output current of the PV array is limited by $I_2 < I_{pv} < I_1$, the third PV power panel has a current equal to zero, and the diode D_3 conducts the current of the PV array. That means the third PV power panel is isolated, i.e., $I_{pv} = i_{pv1} = i_{pv2}$, $i_{pv3} = 0$, the output voltage of the PV array is $V_{pv} = v_{pv1} + v_{pv2}$. From (1), the output voltage of the PV power panel is calculated as follows:

$$v_{pv(j)} = \frac{N_s}{k_o} \ln\left(\frac{I_{sa} * N_p + I_{ph(j)} * N_p - i_{pv(j)}}{I_{sa} * N_p} \right); j = 1, 2, ..., n \quad (4)$$

where $v_{pv(j)}$ and $i_{pv(j)}$ are the output voltage and output current of the j^{th} PV power panel. $I_{ph(j)}$ depends on the PV irradiance intensity.

In addition, to illustrate the partial shading influences, the PV irradiance intensities have been set to get the P-V curves as seen in Fig. 2. When the PV system under partial shading influences, three power peaks are generated, one peak has the highest power, the remaining two peaks have the lower power. More PV irradiance intensity changes will create more local peaks. Because many power peaks are generated, the traditional method easily falls into the local MPP area. A new MPP search method is needed to effectively tracking the global MPP of the PV array.

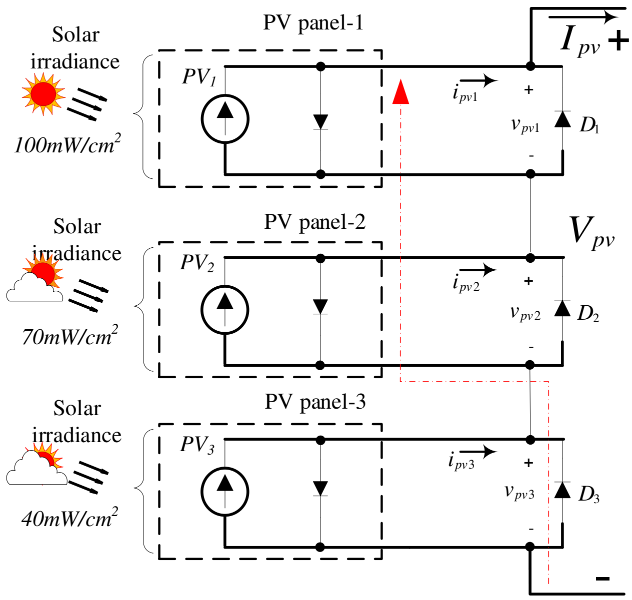

Fig. 1.Model of one partial shading situation of the PV string.

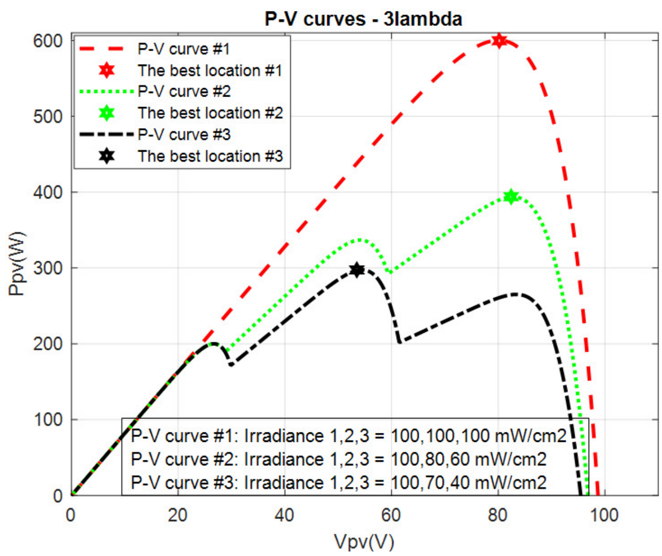

Fig. 2. P-V curves under partial shading influences.

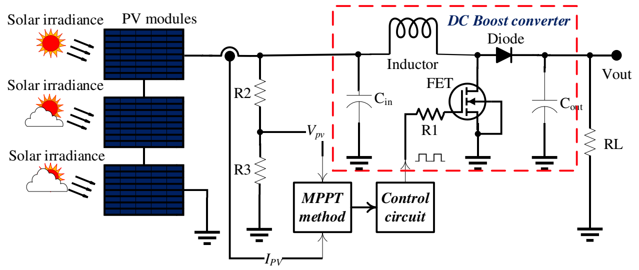

Fig. 3.Basic controller and boost converter for the PV panels.

III. MPP TRACKING STRATEGY OF THE SOLAR POWER SYSTEM

A. *Circuit design for the stand-alone solar power system*

For efficient use of PV panels, a stand-alone PV energy conversion system is illustrated in Fig. 3. This system includes PV power panels, the MPPT method, a control circuit, a DC boost converter, and a DC load. When the PV power panels receive solar irradiance energy, they will generate the current and voltage. The proposed hybrid method is used to track the global MPP. From the searched result, the control circuit is applied to control the duty ratio of the boost converter, and this boost converter is used to transfer the global maximum power value into the load. When the system operates, the initial duty ratio (D) value is chosen based on the assumption that the working power is greater than or equal to 80% of the maximum PV power. The solar irradiance intensity on the PV power panels is assessed by both the measured voltage and current. The measured current after processing is connected to the control circuit. The measured voltage value after using a voltage divider with a resistor bridge to get the appropriate voltage value is also connected to the control circuit for processing. The control circuit uses these two signals with the proposed hybrid method to find the best MPP. In this proposed method, the location of the grey wolf has replaced by the duty ratio and the fitness F_i has also replaced by the output power (P_{pv}) of the PV panels.

B. *Proposed MPP tracking method for solar power systems*

As mentioned above, when PV power panels are shaded by the environment conditions, many power peaks are generated, the conventional MPP search methods will be easy to fall into the local MPP. The power conversion efficiency of the PV energy array will reduce. Therefore, this paper was proposed a combined solution, which is a hybrid method between the improved GWO method and the traditional In-Cond method. The improved GWO method is used not only to avoid local areas but also to quickly find the global maximum energy area. When the global area is found, it will be switched to the In-Cond algorithm to achieve the global MPP. This hybrid method can effectively prevent the local trapped area, and it is classified into two stages:

1) *Phase 1. Grey wolf optimization method*

The grey wolf optimization (GWO) method is used to solve optimization problems in the global area search. The GWO method is known as one of the most modern heuristic optimization algorithms that first introduced in [17]. This algorithm is inspired by the lifestyle of the grey wolves in the process of living and hunting prey in wildlife. Mostly, the grey wolves like to live in a group 5 to 10 on average. The social dominance hierarchy of the grey wolves is very strict, their leadership is *classified* into four levels with ascending dominance from top to bottom [18]. The behavior of grey wolves has been mimicked in the optimization field with the grey wolf algorithm. The leadership hierarchy of the grey wolves is done by assuming the leader levels as follows: the leading wolves are called the level 1 ($L1$), subleaders are called the level 2 ($L2$), the lower rank wolves are called the level 3 ($L3$), and the lowest rank wolves are called the leader level 4 ($L4$). When the grey wolves hunt prey, they encircle prey during the hunt. The behavior of encircling prey is modeled with mathematical equations [19]. In the first phase of the hybrid method, the improved GWO method was proposed for a new approach by dividing N areas with incremental values from $D_{\min}$ to $D_{\max}$, and each wolf will randomly work within its range. In this way, the improved GWO method found the global area more quickly than the solution using random wolves without arrangement. Each grey wolf will randomly move within its area as follows:

$$D_n = \left[(D_{\min} + (n-1) * \Delta D) \quad (D_{\min} + n * \Delta D) \right] \tag{5}$$

where $\Delta D = (\mathrm{D}_{\max} - \mathrm{D}_{\min}) / N)$, N is the number of grey wolves in the herd; $D_{\min}$ and $D_{\max}$ are the minimum, maximum values of duty ratio. Each D_n location will have a corresponding fitness value ($P_n = P(D_n)$). Among these N locations, the best fitness location is called D_{best} (or D_{L1}) corresponding to the wolf $L1$, one location is called D_{L2} which the fitness is smaller the fitness of wolf $L1$, and one location is called D_{L3} which the fitness is smaller the fitness of wolf $L2$. After selecting the three best grey wolves, the three grey wolves will continue to prey in their areas. The new location of these grey wolves are updated according to the following equations:

$$D_{Ln\_update} = D_{Ln} \pm \Delta D / k; n = 1,2,3 \tag{6}$$

where k is the number of iterations. Since the three best values are used to update the new locations, this solution significantly reduces the number of test samples in unnecessary locations. Therefore, this new approach greatly reduces the time to find the global area. The grey wolves will finish the hunt when (7) is satisfied. This means that the global area is found.

$$\left| D_{best} - D_{Ln-update} \right| \le \varepsilon \cdot \Delta D \tag{7}$$

where ε is a custom number, it has a value less than 1. Depending on the number of grey wolves, this value decreases as the number of grey wolves increases and vice versa.

2) *Phase 2. Incremental conductance algorithm*

When the distance between the grey wolves and the prey is satisfied (7), this means that the grey wolves hunted or approached the prey, phase 1 with the improved GWO method will finish. In other words, the improved GWO method has reached global maximum power value or was close to it. To get the perfect solution, the global maximum power value is always achieved in all situations, the In-Cond algorithm is included to find this global maximum power value is always achieved in all situations, the In-Cond algorithm is included to find this global maximum power value. The In-Cond algorithm uses the dP_{pv} / dV_{pv} slope to determine the direction of voltage regulation. The condition to obtain the MPP must be satisfied by the following equation:

$$\frac{dP_{pv}}{dV_{pv}} = \frac{d(V_{pv} * I_{pv})}{dV_{pv}} = I_{pv} + V_{pv} * \frac{dI_{pv}}{dV_{pv}} = 0 \quad (8)$$

The equation above is completed to yield the following equation:

$$\frac{dI_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}} \quad (9)$$

where dV_{pv} , dI_{pv} are the value differences of the voltage and current measured before and after the increase. By comparing the instantaneous conductivity value (I_{pv} / V_{pv}) with the incremental conductivity value dI_{pv} / dV_{pv}), this method will find the operating point with the maximum power. When the condition (9) is satisfied, the In-Cond algorithm will skip the adjustment process of the duty ratio. The flow chart of the proposed hybrid method is seen in Fig. 4, which outlines each step in the process of finding and achieving a global MPP.

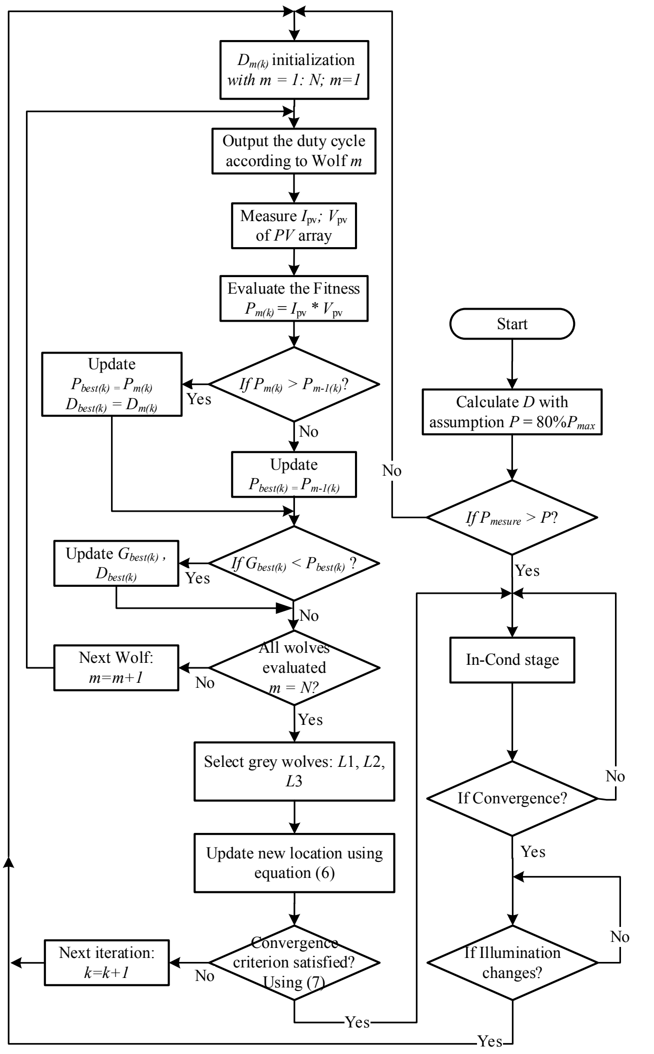

Fig. 4. Flow chart of the proposed hybrid method.

When the system begins to operate, the initial D value is set based on the assumption that operating power = 80% of the maximum power value. This condition is satisfied when the irradiance intensity on the panels is uniform and maximum. The In-Cond algorithm is applied to minimize the MPP tracking time without performing the sequence from stage 1 to stage 2. This initial D value selection is based on the simulated P-V output curve of the PV power system.

IV. Simulation results

A. Setup

MATLAB simulations have displayed the results of the different methods. The specifications of the PV power panel are P_{max}=200W, N_s=54pcs, N_p=1, V_{oc}=32.9V, V_{max}=26.3V, I_{sc}=8.21A, I_{max}=7.61A. For the improved GWO method, the number of grey wolves is 8. The hybrid method is switched to the In-Cond algorithm after satisfying the condition (7).

The differences among the In-Cond algorithm, the conventional GWO method, the PSO, and the proposed method were simulated for considering the partial shading influences as shown in Fig. 2. The GWO method named "conventional GWO" used the equation in [19] to update the locations of the wolves. The methods were simulated in all 3 situations, and each situation was simulated in 6.0 seconds.

B. Simulation results

The PV power system is connected as shown in Figure 1(b). This case is also established for the three situations with the irradiance intensities of 100, 100, 100 mW/cm^2; 100, 80, 60 mW/cm^2; and 100, 70, 40 mW/cm^2, respectively (see Fig. 2). The simulation results are displayed in Fig. 5 to Fig. 8.

In circumstances of the partial shading influence, the In-Cond algorithm also falls into the local MPP (situations 2 and 3). Similarly, The PSO method takes a longer time than the hybrid method to get the global MPP [6]. The conventional GWO method not only takes a long time to find the global MPP but also sometimes fails to reach this global MPP. With the combination of the improved GWO method and the In-Cond algorithm, the global MPP is easy achieved. In this paper, the improved GWO method has found the

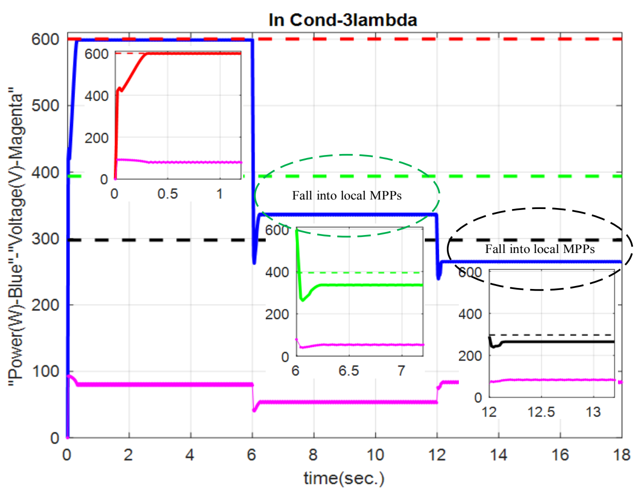

Fig. 5. In-Cond algorithm under partial shading influences.

global area quickly. As a result, the proposed hybrid method is successful in searching and tracking the global MPP in all 3 situations.

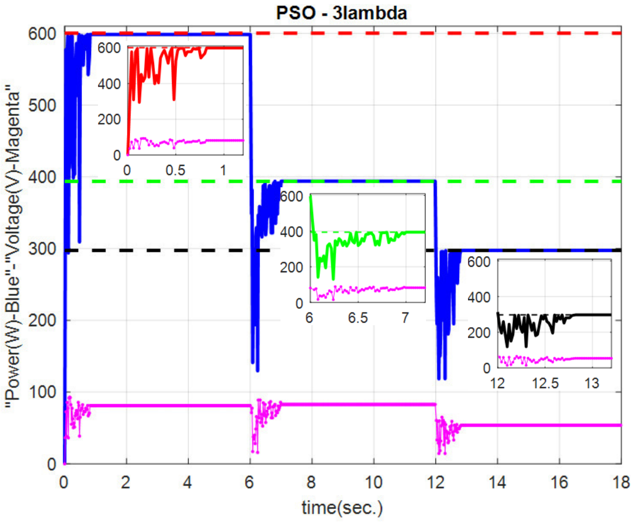

Fig. 6. PSO method under partial shading influences.

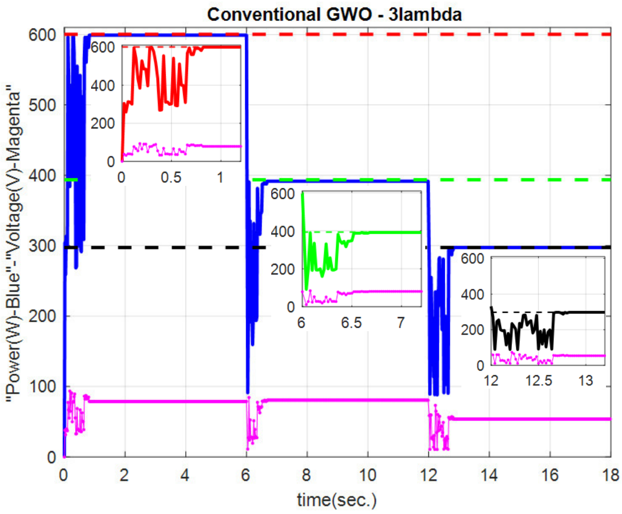

Fig. 7. Conventional GWO method under partial shading influences.

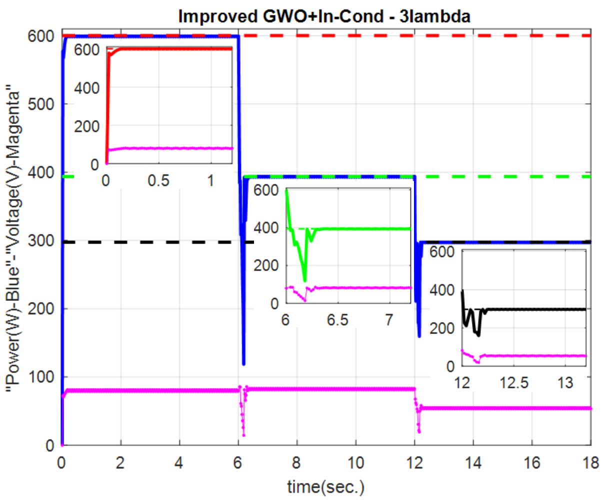

Fig. 8. Proposed hybrid method under partial shading influences.

Since the three best grey wolves were selected to update the new locations, the proposed hybrid method is reduced the execution time as mentioned above. Besides, the convergence of this method is faster than the conventional GWO method [13, 18]. The power values tend to gradually approach the maximum power value as shown in Fig. 8.

V. Conclusion

This paper was used a stand-alone PV power system with the proposed method. With the arrangement of the initial duty ratio values combined with the update of the selected duty ratio values, the proposed hybrid method has achieved the expected results. This proposed method has improved the disadvantages of conventional MPP tracking methods under partial shading influences. The proposed method is effective not only to avoid the local MPP but also to quickly achieve the best PV power of the energy conversion process. Besides, the ability to quickly converge, the simple way of updating values are also the highlights of this paper compared to the conventional GWO, PSO methods, and In-Cond algorithm.

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