# Global Power Extraction of the Time Variant Partially Shaded PV System using Improved PSO Technique

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## ABSTRACT

Global peak (GP) of the generated power of photovoltaic (PV) systems changes its location in P-V curve upon shading pattern variation from time to time. Although, the conventional Particle Swarm Optimization (PSO) technique can catch the GP easily under the same shading pattern (SP), once it changes its location, the conventional PSO may not be able to catch the new GP due to the particles search around the first GP caught. This means that, the conventional PSO is time invariant maximum power tracker (MPPT) technique that cannot track the dynamic GP under time variant SP. The novelty in this paper is the modification of the conventional PSO technique to become a time variant GP tracking technique through dispersing the particles based on two new methodologies for searching the new time variant GP. The first methodology depends on dispersing the particles every certain time in order to look for the new GP. The second one depends on continually monitoring any changes in the SP to disperse the particles. A detailed comparison between these two techniques and standalone without re-initialization technique is introduced. The proposed techniques show a significant increase in the generated power and tracking efficiency. In addition, the new proposed techniques do not need any hardware modification in the existing system, which can make it an excellent option to improve the running and the new installed PV systems as well.

### Introduction

In recent years, renewable energy systems have attracted the attention of the world, especially solar energy systems because there is no pollution, less maintenance, and it has many other benefits compared to conventional sources of energy. With recent advances, the generated energy cost has become lower and the PV arrays efficiency has improved through tracking the maximum power, which is the main focus of this paper. Doubtless, increasing the generated energy from PV systems will reduce the cost of energy and improve the system performance considerably. This can be achieved by imposing modern, effective and smart maximum power point tracking (MPPT) techniques to the PV systems.

Under uniform conditions, P-V characteristics contain a unique peak and conventional MPPT techniques are efficient in tracking this unique peak [1-3]. Whereas, P-V characteristics contain multiple peaks (one global peak; GP; and many local peaks; LPs) under non-uniform or partial shading conditions (PSCs), which cannot be tracked by conventional MPPT techniques [4, 5]. As a result, numerous modern, efficient and accurate MPPT techniques based on bio-inspired are proposed to track the GP instead of LPs. For example, Jubaer *et al.* [6] discovered that both Cuckoo Search Optimization (CSO) and PSO are efficient to track the GP under PSC but CSO performs well compared to PSO in both GP convergence speed and tracking speed terms [6]. The PSO modifications implemented in [7, 8] improved the PSO performance to be in the same ranking with Firefly Algorithm (FA) and CSO in terms of GP convergence speed and tracking speed [7, 8]. Fathy *et al.* [9] proposed a modified Ant Bee Colony (ABC) to alleviate the partial shading effect and proved that a modified ABC has the best performance in tracking the GP compared to GA, PSO and ABC. Finally, Prasanth *et al.* [10] proved the superior performance of Flower Pollination Algorithm (FPA) in GP tracking technique in terms of tracking speed and GP convergence compared to PSO and P&O [10].

In the case of the shading pattern (SP) changes, the GP will change its value and position. The MPPT technique should be able to catch the GP with time variation. Many research papers [2, 6-16] claimed that, particle swarm optimization (PSO) technique can track the GP in general. Nevertheless, this is not true because it catches the GP and all particles will be concentrated at this peak and cannot follow the new GP in case of changing its position with time. In addition, the GP value and region is always changing under time variant SP of the PV system. All these researches [2, 6-16]; did not point out to the problem of changing the GP position with time and the performance of PSO particles in case of time variant GP. PSO can track the GP under time invariant SP efficiently and accurately. Once the GP changes due to time variant SP; PSO sticks to the first GP and cannot follow the dynamic GP under time variant SP without certain initialization or particles dispersion. Therefore, certain modification on PSO is compulsory to deal with the time variant SP and track the time variant GP. On the other hand, numerous research papers [7, 10, 17-23] are modified PSO and some MPPT techniques based on bio-inspired techniques such as FPA, FA and ABC to track the variant GP under time variant SPs. Different methodologies are introduced to detect whether the SP or radiation is changed or not. Ram and Rajasekar in [7, 10] detected the SPs or radiations changes by checking the variation of the PV voltage and current. Whereas, Jiang *et al.* [17] detected the radiations change by checking the PV current change between two subsequence iterations [17]. In addition, the research studies in [18-21] considered that the radiations are changed if the PV output power is changed. Also,

Sundareswaran *et al.* in [22] detected the radiations change based on the two previous conditions mentioned in [7, 10] and [18-21] to re-initialize the PSO or ABC to track the dynamic GP efficiently. Also, Mirhassan *et al.* in [23] detected the radiations change based on two conditions together; first, the change between current duty cycle and the GP of PSO, $G_{best}$ is less than the minimum change in duty ratio, $\Delta D_{min}$; second, the change between the current and global power is greater than ($P_G$* $\Delta P$) to re-initialize the improved PSO. These detection methodologies in [7, 10, 15, 17-23] do not guarantee that the SP has changed, where, it may happen due to load or/and normal radiation changes even without changes in SP. In addition, although the radiation may change, the searching region may not; hence, there is no need for PSO re-initialization, which may make undesirable disturbances in the PV system.

To date, this problem has not been overcome, but it will be solved in this paper, which proposes two new methodologies to disperse the PSO particles to track the dynamic GP under time variant SP. The two new proposed methodologies for initialization of the PSO depend on predefined time and detection of SP changes. A detailed description, simulation, and comparison between these two new methodologies and the state of the art methodology [2, 6-16] that uses PSO without dispersing particles will be introduced, discussed and analyzed. In the literature, to the best knowledge of the authors of this paper, this research study is counted as the first study which discusses in details the PSO with dispersing the particles to track the variant GP cases continuously under time variant SPs.

This paper is organized as follows; Section 2 describes the PV system modelling. Section 3 and 4 introduce the GP extraction based on PSO techniques with new and different methodologies of re-initialization. Section 5 presents and discusses the simulation results. Finally, Section 6 introduces the conclusions and recommendations.

## 2. Description of the Partially Shaded Photovoltaic System

Figure 1 shows the PV energy system where the PV array is interfaced to the utility grid through boost converter and three-phase inverter. The inputs to the PV array are sun irradiance (W/m$^2$) and cell temperature ($^o$C). Three PV arrays with three different radiations are used for representing the PSCs. As a result of PSCs, multiple peaks are generated for each shading pattern; three peaks (one GP and two LPs); and the occurrence of the GP at different places of the P-V curve is achieved under time variant radiations or SPs. Time variant radiations will make the GP change its position along with the voltage from time to time. Three different shading patterns are applied continuously with three different GP cases (case 1; GP at the beginning, case 2; GP at the middle, case 3; GP at the end) as shown in Figure 2. Time variant radiations are applied to generate GPs in different positions to see the PSO response to follow the GP if it changes its position with and without initialization (particle dispersing). Co-simulation between Matlab (M-file) and Simulink is used to handle the simulation of the PV system. M-file includes the Improved PSO (IPSO) algorithm; while, Simulink includes the grid-connected PV system as shown in Figure 1. In addition, IPSO in M-file receives the PV voltage, current and power at each duty cycle sent to the boost converter in Simulink.

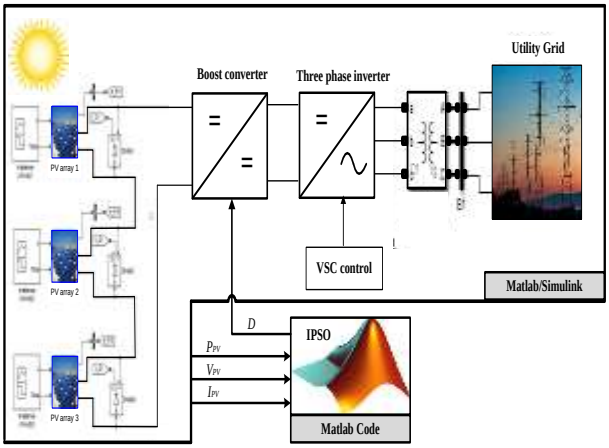



**Figure 1.** Simulation of the partially shaded PV grid-connected system.

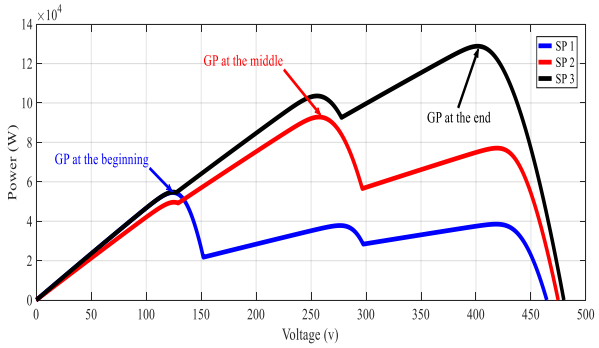



**Figure 2.** Three different global peak (GP) Cases applied sequentially in this study.

## 3. Global Peak Extraction based Particle Swarm Optimization Technique

PSO based MPPT technique represents one of the most efficient soft computing techniques based on bio-inspiration. It can track the GP under the same SP accurately [2, 6-16]. Whereas, it cannot track the variant GP under time variant radiation or SP without re-initialization of the PSO searching process [7, 10, 17-23]. Tracking the GP depends on the particle's speed and position, which are renewed and updated to track the GP instead of LPs through sending the duty cycle to the boost converter [8, 24-26]. Each particle in the swarm has mainly two variables; the position vector $x_i^k$ and the velocity vector $v_i^k$. The new position can be calculated as shown in the following equation [8]:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (1)$$

Where, *i* represents the particle number and *k* represents the iteration number.

The new position of the particle is determined by calculating the velocity through using current position $x_i^k$, the particle velocity $v_i^k$, and the global best position $G_{best}$ as follows:

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 \left(P_{best\ i} - x_i^k\right) + c_2 r_2 \left(G_{best} - x_i^k\right) \quad (2)$$

Where, $\omega$ is the inertia weight that determines the search area. It can be constant value (0.5) or variable to accelerate the GP tracking [25].

Some researches [8, 26, 27] modified the conventional PSO to improve the tracking speed during the steady state oscillations. A modified PSO based MPPT was proposed in [8] to reduce the steady state oscillations through the accurate initialization of the duty ratios. This had been achieved through two phases which are decreasing or increasing the previous duty ratios linearly (according to the change in PV power); or the perturbation of two far duty ratios ($d_1$ and $d_3$) in positive and negative trends with a constant value. Also, a deterministic PSO (DPSO) was proposed in [26] to improve the tracking capability of the conventional PSO, where the random number in the velocity equation is removed as follows [26]:

$$v_i^{k+1} = \omega v_i^k + \left(P_{best\ i} - x_i^k\right) + \left(G_{best} - x_i^k\right) \quad (3)$$

$$v_i^{k+1} = \omega v_i^k + \left(P_{best\ i} + G_{best} - 2x_i^k\right) \quad (4)$$

The random numbers ($r_1$ and $r_2$) in the velocity equation in (2) is removed to reduce the steady state oscillation. Therefore, the velocity of the particle can be calculated as follows:

$$v_i^{k+1} = \omega v_i^k + c_1 * P_{best\ i} + c_2 * G_{best} - c_3 x_i^k \quad (5)$$

## 4. Proposed Particle Swarm Optimization Techniques

### *4.1. State of the Art IPSO Methodology without re-initialization (Case-1)*

As discussed in the introduction section, the IPSO technique will track the first GP and the particles will be concentrated at this GP. Once, the SP is changed the GP may change its value and position and the particles will not see this new GP due to their position around the previous GP. The algorithm logic sequence used in the simulation is shown in the following points [4]:

- **Step-1:** Initialize the IPSO parameters ($\omega$, $c_1$, $c_2$, and $c_3$) and send the initial duty cycles sequentially to the partially shaded PV system (objective function) and gather the corresponding powers values.
- **Step-2:** Update the particles' position and velocity ( $x_i^{k+1}$ and $v_i^{k+1}$ ) using Equations (1), and (5), respectively, then obtain the new duty cycles of the DC-DC converter.
- **Step-3:** Send the new duty cycles (particles' position) to the partially shaded PV system and gather the associated powers values.
- Step-4: Evaluate $P_{best,i}$, $G_{best}$ and their related particle's position (duty cycles ), then; go back to Step 2.

### *4.2. IPSO Initialization upon Predefined Time (Case-2)*

Due to the variation of SP, the GP may change its value and position and the particles will not catch the new GP. For this reason, the first proposed methodology has been done by dispersing the IPSO particles (re-initialization) after certain predefined time (PDT) to let the particles look for the new GP in the whole searching space. The PDT for re-initialization can be set depending on the SP frequency in the installation site. In this paper, the PDT is set to be 25 Sec. where the PDT equals to 100 iterations number and each iteration takes 0.25 Sec. The flowchart of the IPSO initialization upon PDT is shown in Figure 3 and the algorithm logic sequence used in this simulation is shown in the following points:

- **Step-1:** Initialize the IPSO parameters ($\omega$, $c_1$, $c_2$, and $c_3$) and send the initial duty cycles sequentially to the partially shaded PV system (objective function) and gather the associated powers values.
- **Step-2:** Update the particles' position and velocity ( $x_i^{k+1}$ and $v_i^{k+1}$ ) using Equations (1), and (5), respectively, then obtain the new duty cycles of the DC-DC converter.
- **Step-3:** Send the new duty cycles (particles' position) to the partially shaded PV system and gather the associated powers values.
- **Step-4:** Evaluate $P_{best,i}$, $G_{best}$ and their related particle's position (duty cycles ), then if the time is less than PDT (iteration <100), go back to Step 2 otherwise go to Step 1.

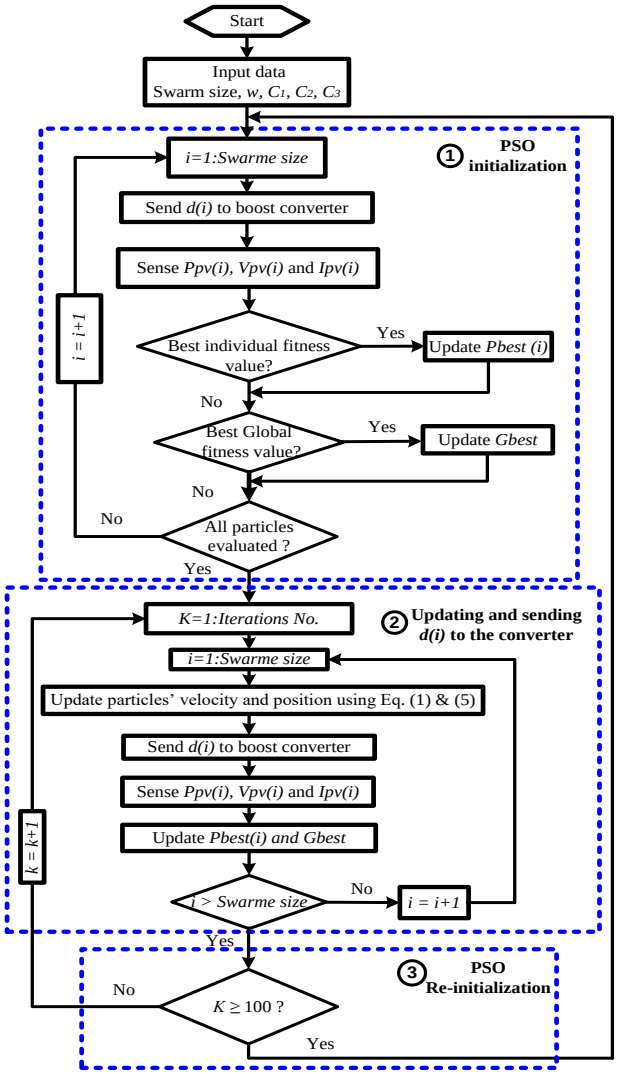



**Figure 3.** Flowchart of the IPSO re-initialization upon PDT.

### *4.3. IPSO Initialization upon Shading Pattern Change (Case-3)*

The second proposed methodology for tracking the time variant GP has been done by checking the SP variations. If the SP changes, the methodology will re-initialize the IPSO parameters otherwise it will continue looking for GP near the current peak. This technique is better than the previous one in terms of the generated energy captured due to it will not randomly initialize the duty ratio with/without the need for that. However, the main problem associated with this technique is the need for sensors to detect the variation of radiation. The flowchart of IPSO initialization upon SP change is shown in Figure 4 and the algorithm logic sequence used in this simulation is shown in the following points:

- **Step-1:** Initialize the IPSO parameters ($\omega$, $c_1$, $c_2$, and $c_3$) and send the initial duty cycles sequentially to the partially shaded PV system (objective function) and gather the associated powers values.
- **Step-2:** Update the particles' position and velocity ( $x_i^{k+1}$ and $v_i^{k+1}$ ) using Equations (1), and (5), respectively, then obtain the new duty cycles of the DC-DC converter.
- **Step-3:** Send the new duty cycles (particles' position) to the partially shaded PV system and gather the associated powers values.
- **Step-4:** Evaluate $P_{best,i}$, $G_{best}$ and their related particle's position (duty cycles ), then if the SP of the PV system is not changed, go again to Step 2 otherwise go to Step 1.

The condition that has been used to check if the SP changed or not is shown as follows:

$$Ir_{new} - Ir_{old} \geq \varepsilon \tag{6}$$

Where, $Ir_{new}$ and $Ir_{old}$ are the average radiation collected from all sensors in the new and previous iteration, respectively. $\varepsilon$ is the allowable limit of radiation change that has been taken as 5% in this study.

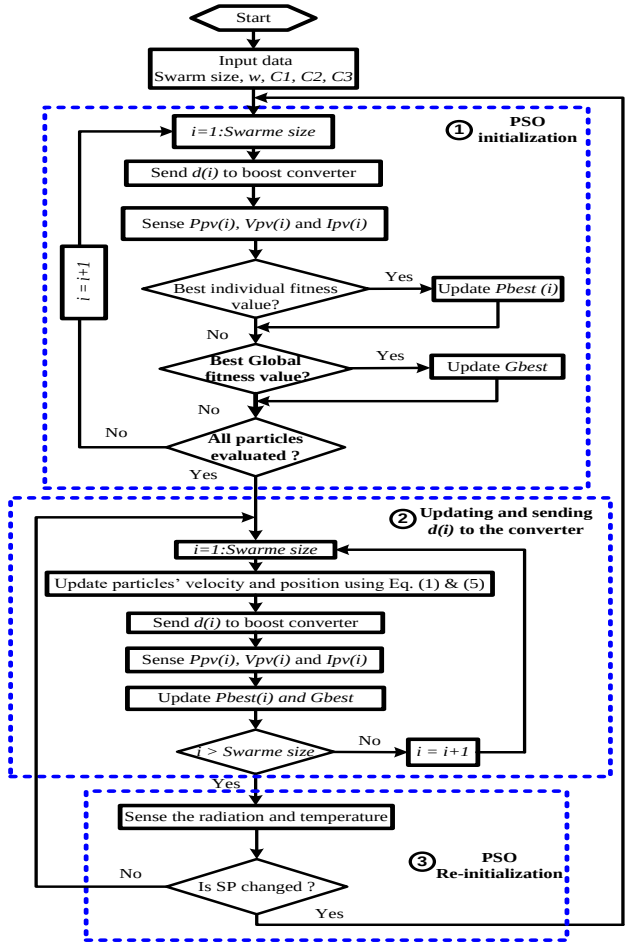



**Figure 4.** Flowchart of IPSO initialization upon SP variation.

## 5. Simulation Results and Discussion

In order to show the effective performance obtained through the proposed IPSO technique, numerical simulations (Co-simulation between M-file and Simulink) have been implemented. Simulink contains the PV array with three different radiations interfaced to the utility grid through boost converter and three-phase inverter while M-file contains the IPSO algorithm. Time variant radiations will cause the GP to change from time to another. Three time variant SPs are applied continuously as shown in Figure 5. The purpose of this arrangement is to guarantee that the occurrence of the GP at different places of the P-V curve (GP at the beginning, GP at the middle, GP at the end) as shown in Table 1 to analyze and evaluate the proposed IPSO performance in time variant SPs. The three different SPs are applied to simulation program, where, SP1 is applied for the first 40 Sec, followed by SP2 for the next 40 Sec, and SP3 for the last 40 Sec, where the total simulation time is about 120 Sec.

**Table 1.** Three shading patterns with three different cases of the GP.

| Cases \ SP No. | | SP#1 | SP#2 | SP#3 |
|---|---|---|---|---|
| | Irradiance ($W/m^2$) | (1000, 300, 200) | (800, 400, 900) | (1000,700, 900) |
| | GP value (kW) | 54.6 | 92.8 | 128.8 |
| | GP Position | 1st Peak | 2nd Peak | 3rd Peak |
| | $V_{PV}$ at GP (V) | 124 | 257 | 402 |
| PSO without re-initialization | $P_{PV}$ (kW) | 54.6 | 49.6 | 54.8 |
| | $V_{PV}$ (V) | 124 | 124 | 124 |
| | Efficiency % | 100% | 53.4% | 42.6% |
| IPSO re-initialization upon PDT | $P_{PV}$ (kW) | 54.6 | 49.6-92.8 | 54.8-128.8 |
| | $V_{PV}$ (V) | 124 | 124-257 | 257- 402 |
| | Efficiency % | 100% | 53.4% -100% | 42.6%-100% |
| IPSO re-initialization upon SP change | $P_{PV}$ (kW) | 54.6 | 92.8 | 128.8 |
| | $V_{PV}$ (V) | 124 | 257 | 402 |
| | Efficiency % | 100% | 100% | 100% |

Time variant radiations are applied in this study to show that, the conventional PSO will not follow the variant GP unless the IPSO disperses the particles as done in the two new proposed methodologies. A detailed comparison between these two new methodologies with dispersing the particles and the conventional methodology without dispersing the particles has been introduced in the following sections:

### *5.1. PSO without re-initialization (Case-1)*

The PSO initialization is carried out one time only at the beginning and the output response of the new proposed system with time is discussed in the following points:

- **From 0-40 Sec.:** PSO search for the first GP in a certain searching area and it successfully caught the first GP (54.6 kW) for SP1 as shown in Figure 5.
- **From 40-80 Sec.:** The SP is changed (SP2); hence, the GP value (92.8 kW) and position (GP at the middle) also changed. Nevertheless, PSO cannot catch the new GP and stick to the first GP (54.6 kW) and its $G_{best}$ ($d$=0.785); however, the current GP is 92.8 kW for SP2. The reason behind this is that, the PSO re-initialization is not executed upon the SP changes.
- **From 80-120 Sec.:** Similarly, the SP is changed (SP3); hence, the GP value (128.8 kW) and position (GP at the end) also changes. Nevertheless, PSO cannot catch the new GP and stick to the first GP (54.6 Kw) and its $G_{best}$ ($d$=0.785); however, the current GP is 128.8 kW for SP3. The reason behind this is that, the PSO re-initialization is not executed upon the SP change.

Therefore, conventional PSO re-initialization must be modified and carried out to disperse the PSO particles to search for GP all over the searching space. If re-initialization of PSO has not been carried out, the PSO particles will stick to the first GP. Therefore, the PV system will stick to the duty ratio of the first GP and generates output power that is not GP, but the value that corresponds to the duty ratio of the first GP. As a result, PSO re-initialization must be carried out upon one of the two new proposed methodologies of the IPSO re-initialization that will be shown in the next sections.

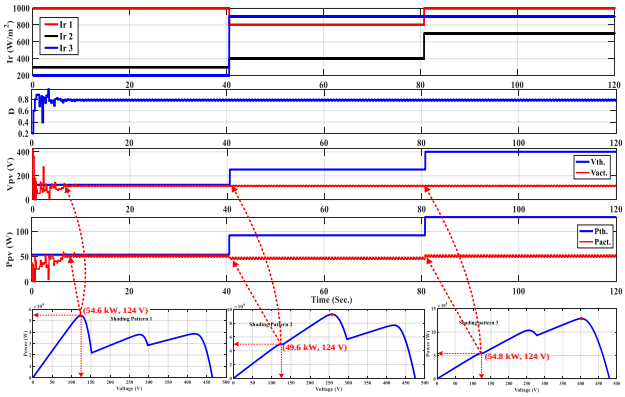



**Figure 5.** PV output power, output voltage and duty cycle for time variant SPs based on PSO without re-initialization.

### *5.2. IPSO re-initialization upon predefined time (Case-2)*

As discussed above in the simulation results of Case-1, the particles stick to the first GP and if the SP changed, the particles cannot catch the new GP. With the PDT for IPSO re-initialization (Case-2), the IPSO is initialized every PDT (24 Sec.) to search for the new GP. The output response of the new proposed system versus time is shown in the following points:

- **From 0-24 Sec.:** The IPSO caught the first GP (54.6 kW and 124 V) for SP1 as shown in Figure 6.
- **From 24-40 Sec.:** The IPSO initialization is executed; but the SP has not been changed, that is why the system works again after initialization at the same situation (54.6 kW and 124 V).
- **From 40-48 Sec.:** The SP is changed (SP2); hence, the GP value and position also changes, but the IPSO will not catch it until IPSO initialization is executed.
- **From 48-72 Sec.:** The particles are dispersed at the beginning of this period and the particles will catch the new GP (92.8 kW and 257V) at $d$=0.43.
- **From 72-80 Sec.:** The IPSO is initialized at the beginning of this period, but the SP has not been changed; hence, the system will go again to the same operating point (92.8 kW and 257V).
- **From 80-96 Sec.:** The SP is changed (SP3); hence, the GP value and position is changed, but the IPSO will not catch it until the IPSO initialization is executed.
- **From 96 to 120 Sec.:** The IPSO is initialized at the beginning of this period and the particles caught the new GP (129 kW at 402V) for SP3.

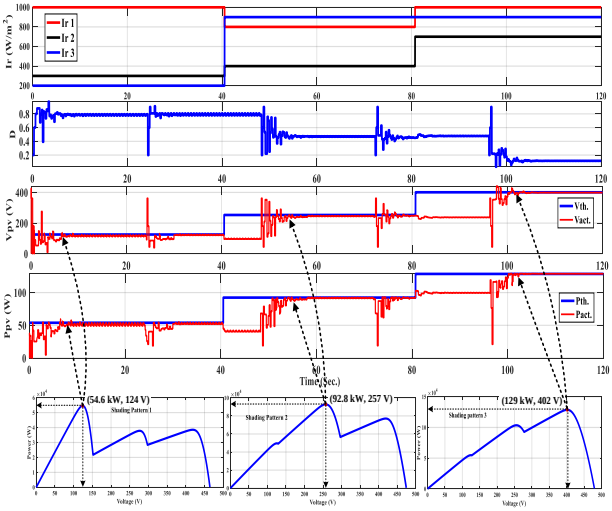



**Figure 6.** PV output power, output voltage and duty cycle for time variant SPs based on IPSO re-initialization upon PDT

IPSO re-initialization upon PDT will save the sensors cost. In addition, the performance and efficiency of the PV system is improved with IPSO re-initialization upon PDT compared to the state of the art IPSO technique without re-initialization. The question here is that, the time interval between re-initialization is preferred to be short or long. IPSO re-initialization every short time will increase the disturbances of the system. In addition, the generated output power will be decreased without need. Meanwhile, the long-time of IPSO re-initialization can cause the IPSO to be unable to see the atmospheric variation and stick at the last GP as shown in Figure 6. In addition, inaccurate response with the radiation change and high power losses is observed. Finally, dispersing the IPSO particles upon PDT depends on the SP frequency change in the installation site.

### *5.3. IPSO re-initialization upon the SP change (Case-3)*

As discussed in Case-1, conventional PSO cannot follow the dynamic GP under time variant SP. In Case-2, a new methodology is proposed to initialize the IPSO to search for a new GP at certain PDT. This technique is a really simple technique, but it may have initialization without need or it may stay unchanged for certain time less than the PDT, where, the SP changed and IPSO cannot catch the new GP until IPSO re-initialization is executed. In the second new initialization methodology (Case-3), the radiation sensors will get their values and send it to the control system to check whether the SP has changed or not. In the case when the SP changes, the system will order IPSO to reinitialize in order to look for the new position of the GP and catch it. Actually, this new method will omit the two drawbacks of the previous technique, but it will increase the system's cost due to the need for radiation sensors. The output response of the new proposed system with time is shown in the following points:

- **From 0-40 Sec.:** IPSO has successfully caught the first GP (54.6 kW and 124V) for SP1 as shown in Figure 7.
- **From 40-80 Sec.:** The SP is changed (SP2), both the GP value (92.8 kW) and its position are changed (GP at the middle). IPSO re-initialization is executed upon the SP change at $t$=40 Sec. IPSO has successfully caught the second GP (92.8 kW) as shown in Figure 7.
- **From 80-120 Sec.:** Similarly, the SP is changed (SP3). IPSO re-initialization is executed upon the SP change at $t$=80 Sec. IPSO successfully caught the third GP (128.8 kW) as shown in Figure 7. The performance efficiency for this PV system is 100% as shown in Table 1, which reflects the effective performance of IPSO re-initialization upon the SP change.

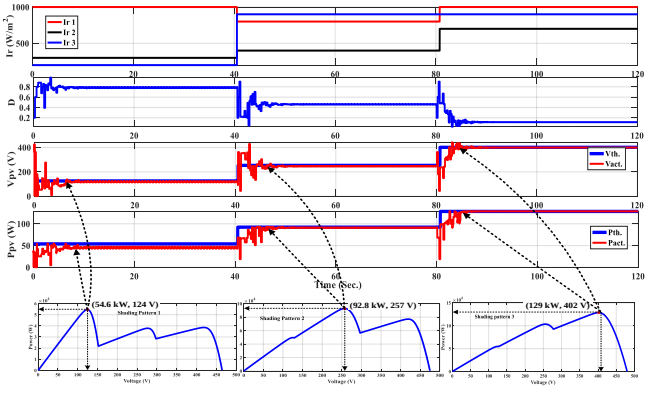


**Figure 7.** PV output power, output voltage and duty cycle for time variant SPs based on IPSO re-initialization upon the radiation change.

According to the above discussions, IPSO re-initialization upon the SP change is the best methodology to restart the searching process to extract the variant GP quickly under time variant SP compared to other dispersing methodologies of particles. Although, radiation and temperature sensors can sense any variation of the radiation and temperature to re-initialize the IPSO quickly and effectively, IPSO re-initialization upon the SP change has some demerits. For example; the radiation and temperature sensors on each PV module will increase the total cost of the PV system. In addition, it will add a computational time, which will reduce the tracking speed of the GP.

## 6. Conclusions

Conventional PSO based on MPPT technique can track the global peak (GP) under time invariant shading pattern (SP) efficiently and accurately. Once the radiation or SP changes, the value and position of GP change whereas PSO sticks to the first GP and cannot follow the new GP. This means that, the conventional PSO is a time invariant optimization technique. Therefore, certain modifications on PSO (IPSO) is compulsory to deal with the time variant SP and track the variant GP. This target has been achieved by dispersing the conventional PSO particles using two new proposed methodologies for searching the new time variant GP of the PV energy system. The first methodology of dispersing the IPSO particles is proposed at certain predefined time. Whereas, the second methodology of dispersing the IPSO particles is upon SP change. Although, both these new methodologies proved the superior performance in dynamic GP tracking, the second methodology shows higher generated-power captured and efficiency than the first one. Each methodology has its own merits and demerits. Although, the second methodology has higher efficiency and faster than the first one, it needs radiation sensors to continually track any changes in SP. On the other hand, dispersing the IPSO particles upon predefined time depends on the SP frequency in the installation site.

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