

Unified MPPT Controller for Partially Shaded Panels in a Photovoltaic Array

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Abstract: The power output of the photovoltaic (PV) system having multiple arrays gets reduced to a great extent when it is partially shaded due to environmental hindrances. The maximum power trackers which are conventionally used may not be competent enough to find the maximum power point (MPP) during partially shaded conditions. The sensible reason for the failure of conventional trackers is during partial shaded conditions the PV arrays exhibit multi peak power curves, thereby making simple maximum power point tracking (MPPT) algorithms like perturb and observe (P&O) to get stuck with local maxima instead of capturing global maxima. Therefore, global search MPPT aided by evolutionary and swarm intelligence algorithms will be conducive to find global power point during partially shaded conditions. This work suggests a unified controller which feeds control signal to its power electronic conditioner placed at each module. The evolutionary algorithm which is taken into consideration in this work is differential evolution (DE). The performance of the proposed method is compared to the classical un-dimensional search controller and it is evident from the Matlab/Simulink results that the unified controller prevails over the distributed counterpart.

Keywords: Maximum power point tracking (MPPT), solar energy, photovoltaic (PV), differential evolution (DE), solar power generation, evolutionary algorithm, soft computing.

1 Introduction

The power demand in the whole world is increasing day by day and serious efforts have been made to meet the demand by increasing the power production^[1]. The depleting nature of the conventional sources and the polluting contents in them is a great concern to deal with. In recent past, much emphasis has been given to use renewable sources like wind, solar, biomass etc., for power production. Among these renewable sources, solar photo voltaic system is the most promising one. Though there are many advantages in photovoltaic (PV), there are few potential barriers that hinder its growth. The two main barriers are low conversion efficiency and its inconsistent nature of power output^[2-4]. Maximum power point tracking (MPPT) is a technique which is adopted to improve the conversion efficiency by making the PV system to operate at its maximum power^[5-7]. When the PV panels are exposed to uniform insolation, it is rather easy for the MPPT tracker to find the peak power in non linear P-V curve as there will be a single peak power. There are numerous MPPT techniques available in market among them all the perturb and observe, incremental conductance etc., methods are quite familiar^[8-12]. But these MPPT techniques bound to struggle when the panels are exposed to sun's irradiation inhomogeneously.

Several research articles have been archived on the impact of partial shading on PV panels and the failure of the conventional MPPT techniques during partial shading^[13-15]. The core reason for the failure of mundane MPPT algorithms is during partial shading, PV array exhibits P-V curves having multiple power peaks. Researches expressed their innovativeness by suggesting soft

computing techniques based global search algorithm to find global maxima during partially shaded conditions. Among all the soft computing based global search algorithm, particle swarm optimization (PSO) has been dealt elaborately^[16-21]. Another meta-heuristic algorithm differential evolution has also rendered its part in global maximum power point (GMPP) tracking^[22-25]. Several other soft computing techniques like genetic algorithm (GA) and ant colony algorithm (ACO) have also been considered^[23-25]. The conventional controllers are either distributed controllers or uni-dimensional type controllers which result in poor performance and more complex. To overcome the drawbacks of existing controllers, a unified MPPT controller which adopts multi dimensional differential evolution (DE) algorithm is proposed. The whole setup is realized in Matlab/Simulink environment.

The paper has been arranged in the following manner, Section 2 gives analysis of PV system modeling and Section 3 deals with multidimensional DE MPPT. Results are analyzed in Section 4 and the conclusive part of the work is dealt in Section 5.

2 Characteristics of photovoltaic array

2.1 Uniform or homogenous insolation

The circuit of a photovoltaic cell is represented in Fig. 1. The output PV current depends on the ambient temperature and solar irradiation.

PV's output current is represented as:

$$I_{pv} = I_{ph} - I_{o1} \left[e^{\frac{q(V_{pv} + I_{pv}R_s)}{AK_bT_k}} - 1 \right] - \frac{(V_{pv} + I_{pv}R_s)}{R_p} \quad (1)$$

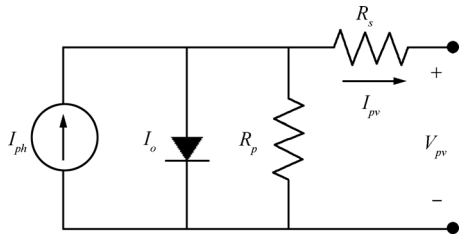


Fig. 1 Electrical circuit model of a PV cell

$$F(I_{pv}, V_{pv}, T_k, G) = I_{ph} - I_{pv} - I_{o1} \left[e^{\frac{q(V_{pv} + I_{pv}R_s)}{N_s A K T_k}} - 1 \right] - \frac{(V_{pv} + I_{pv}R_s N_s)}{R_p N_s} = 0 \quad (2)$$

where I_{pv} is output current, I_{ph} denotes the generated PV current, I_{o1} is the reverse saturation current, A is ideality factor, R_s is the series resistance and R_p is the parallel resistance, T_k is the temperature constant.

Equation (1) indicates the output PV current for a single array. In order to have higher capacity, several PV arrays are to be connected in series or in parallel. Thus, the output of the entire module can be represented as shown in (2), where N_s is the number of series connected cells and N_p is the number of parallel connected cells.

The I-V & P-V characteristics of a PV array are shown in Fig. 2, where three individual panels are connected to form an array and the first three panels show the respective

panel's characteristics whereas the fourth panel shows the array characteristics. The characteristics are simulated in Matlab/Simulink GUI environment assuming that the PV system is exposed to uniform irradiation.

2.2 Under partially shaded conditions

The PV array is normally shaded by disturbances like branches of trees, passing clouds, poles and buildings, etc., which result in partial shading of PV systems as shown in Fig. 3. In a PV array, the cells configured in series will render constant current whereas the shaded cells will operate with a reverse bias resulting reverse power polarity leading to net power drop and thereby reducing the net power conversion efficiency^[26].

Partially shaded module is shown in Fig. 4. The bypass diode paves the way for current when it is partially shaded and the shaded region will act as a reverse biasing circuit^[26]. The modeling equations of partially shaded panel are given as [3-6].

$$I_{pv} > I_{ph2} \quad (3)$$

$$N_{s1} = sN_{s1}, \quad N_{s2} = (r - s)N_{s2}. \quad (4)$$

Here, the subscripts 1 and 2 refer to the cells receiving irradiance of G_1 and G_2 , respectively.

$$I_{pv} = \min(I_{pv1}, I_{pv2}) \quad (5)$$

$$V_{pv} = \sum V_{pv(i)}. \quad (6)$$

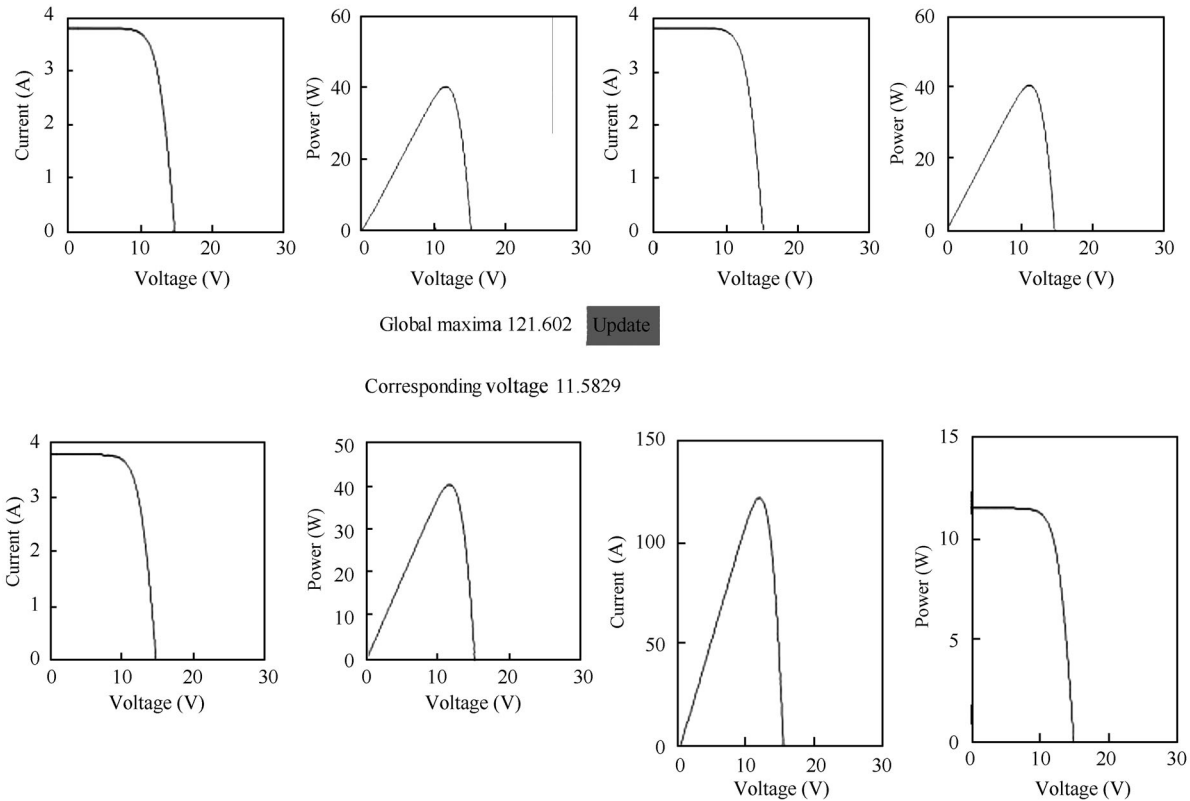


Fig. 2 PV array I-V and P-V characteristics

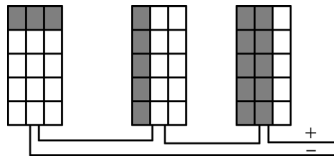


Fig. 3 PV system under partially shaded condition

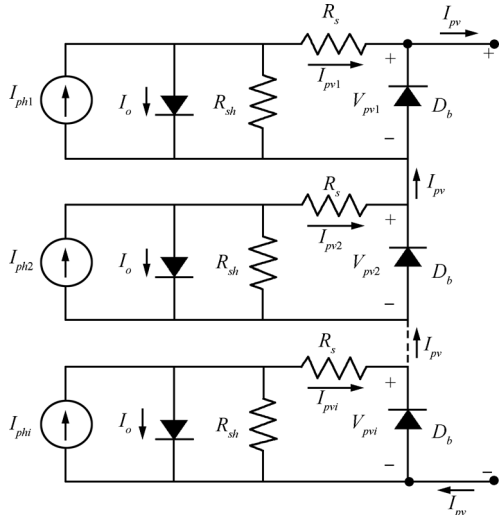


Fig. 4 Circuit model of an array consisting of n series connected array

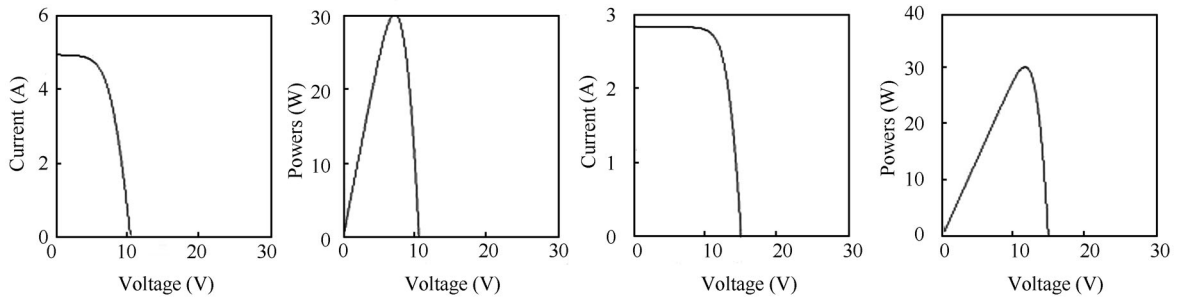
During partial shading, each panel gets exposed to different irradiation and therefore each panel has its own peak power. Fig. 5 shows the output (I-V & P-V) curves of the partially shaded PV system, the last panel shows the array characteristics exhibiting multiple power peaks, say 17 W, 42 W, 62.2 W. The characteristic curves are simulated in Matlab/Simulink GUI environment.

The 3D view of the P-V curve under partial shaded condition is represented in Fig. 6. The inference is the power has different peak value for different operating voltages. The conclusion of the analysis is a reliable MPPT algorithm should be followed when PV array receives in-homogenous insolation.

3 Proposed unified MPPT system

The proposed system depicted in Fig. 7 consists of a unified MPPT controller which controls three DC-DC converters to make operate each panel at its peak power. The output power is a function of temperature (T_1, T_2, T_3) and irradiation (S_1, S_2, S_3). The functional equation is given in (7).

$$\begin{aligned} \text{Global fitness} = & \\ & \text{current}_1 \times \text{Panel voltage (current}_1, S_1, T_1) + \\ & \text{current}_2 \times \text{Panel voltage (current}_2, S_2, T_2) + \text{current}_3 \times \\ & \text{Panel voltage (current}_3, S_3, T_3). \end{aligned} \tag{7}$$



Global maxima 62.2005 Update
Corresponding voltage 8.13759

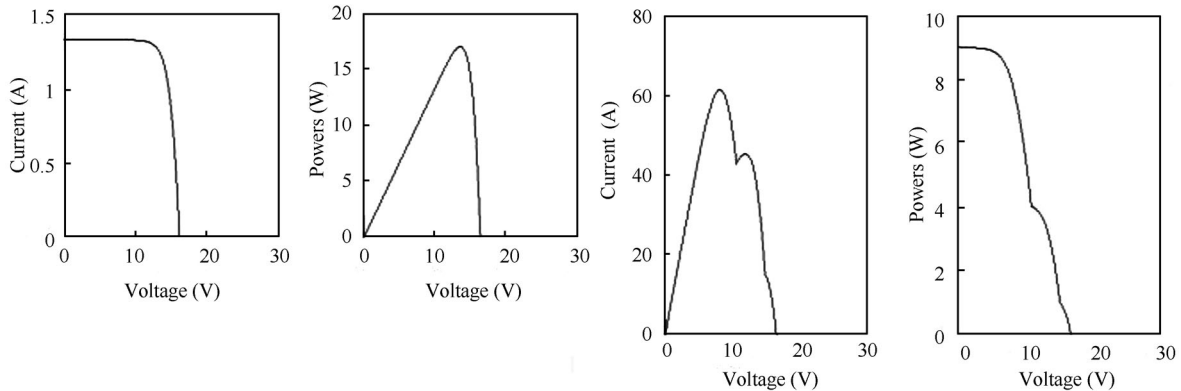


Fig. 5 I-V and P-V curves of a partially shaded PV system

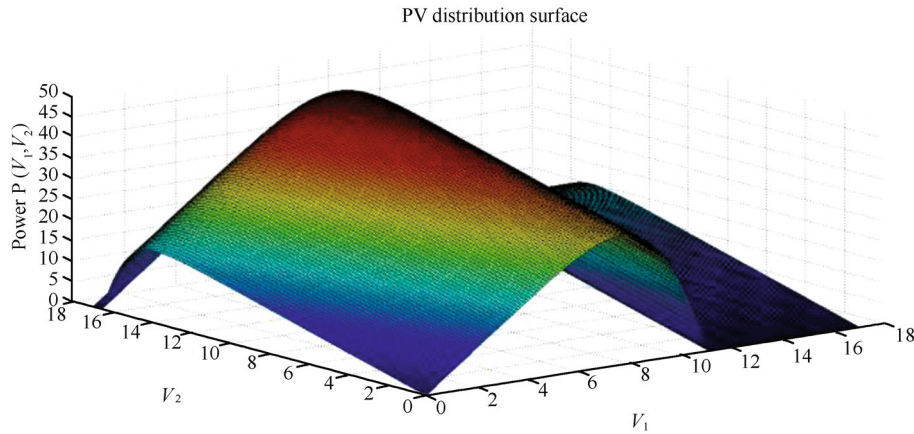


Fig. 6 3-D P-V curve

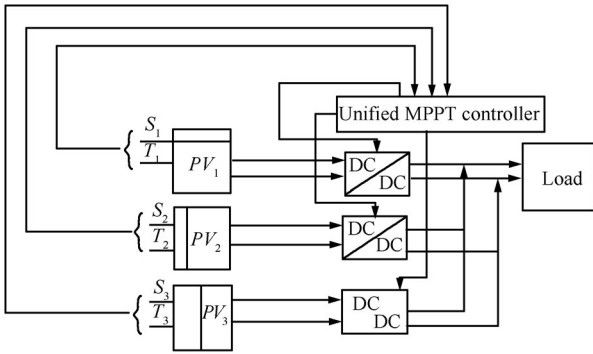


Fig. 7 Proposed Unified MPPT System

The conventional controllers will have a distributed MPPT controller that is employed in each panel resulting in a complex power tracking methodology. Also it requires sensors in each panel in an array. The number of sensors is reduced in the proposed method by having only one sensor set up for the whole PV system. The shading pattern (variation in irradiation and temperature) on the PV panels varies the output voltage where the output voltage is a function of irradiation and temperature. Therefore it is imperative that a voltage sensor is good enough to estimate shading effect.

3.1 Unified DE MPPT

In this work, a unified controller employing differential evolution algorithm is used to track the peak power and to enhance the performance of a PV array when it subjected to partially shaded conditions. The algorithm necessarily consists of four stages in its search mechanism namely initialization, selection, mutation and crossover. A flow chart depicting all the four stages is shown in Fig. 8.

3.1.1 Initialization

An initial population of particles (NP) is initialized in the search space. In this particular problem, each of the particles is initialized with a random voltage. The search space has a lower and upper boundary limit, say open circuit voltage (21 V) and short circuit current (0 V). The expression

for initialization is given as

$$X_{1,i,G} = [x_{1,i,G}, x_{2,i,G}, x_{3,i,G}, \dots, x_{D,i,G}]. \quad (8)$$

3.1.2 Mutation

In this process, a donor vector is created for each i -th target vector by taking random samples from the population. The expression for donor vector is given by

$$V_{i,G} = X_{1,G} + f(X_{2,G} - X_{3,G}) \quad (9)$$

where f is the scaling factor between $[0, 1]$.

3.1.3 Cross over

Trial vector creation is the outcome of the cross over process. The donor vector and target vector are crossed over to create trial vector

$$U_{j,i,G} = \begin{cases} V_{j,i,G} \text{ (donor vector),} & \text{if rand} \leq \text{cross over rate} \\ X_{j,i,G} \text{ (trial vector),} & \text{otherwise.} \end{cases} \quad (10)$$

3.1.4 Evaluation and selection

The expression for this stage is given by

$$X_{i,G+1} = \begin{cases} U_{i,G+1}, & \text{if } J(U_{i,G}) < J(X_{i,G}) \\ X_{i,G}, & \text{otherwise.} \end{cases} \quad (11)$$

If the new trial vector reaches a new max value then it swaps the target vector and if it does not reach, then it is retained. Therefore, the search algorithm either converges to max value or remain in same fitness states.

Therefore, DE MPPT process starts with initializing the population vector say reference voltage. Then the fitness of the vectors is calculated by the fitness equation given in (7). For each target vector in the population, its own mutant vector is created and by crossover operation trial vector is created, refer (8)–(10). Only a vector with good fitness or same fitness as before will survive for next iteration. This process will continue till it achieves GMPP. Table 1 represents the DE parameters chosen for this application.

Table 1 DE parameters

Cross over rate (CR)	Scaling factor or mutation factor (f)	Population size (NP)	Maximum iteration
0.6	07–0.8	05	100

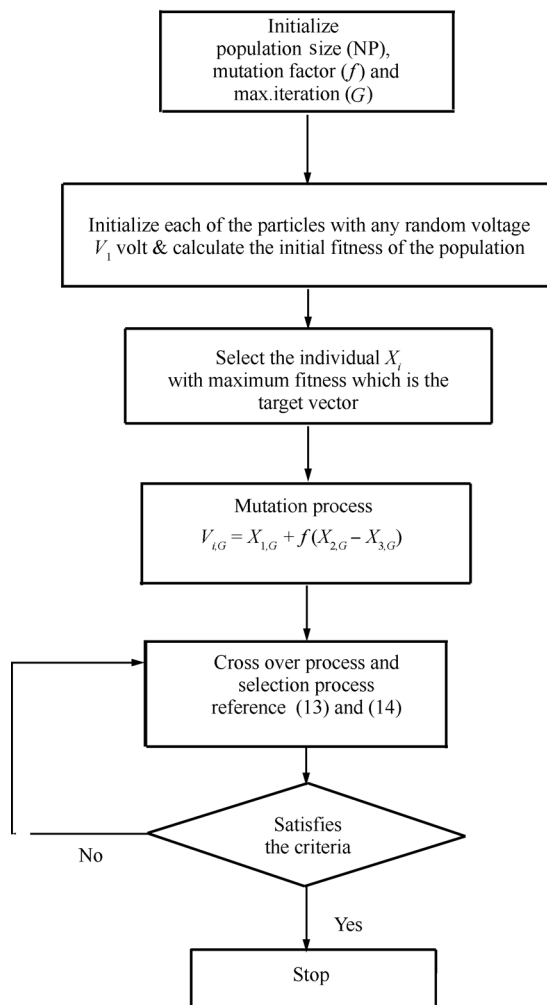


Fig. 8 Flow chart of DE algorithm

4 Results and discussions

This section presents the simulation results of the proposed unified DE MPPT and the uni-dimensional MPPT. The MPPT controller feeds the duty cycle to boost converter. The boost converter will match the source impedance with that of the load to see that maximum power is transferred for the given ambient temperature and solar irradiation. Fig. 9 shows the power output of the controller which adopts uni-dimensional search, and its peak power is 62.23 W. But when the proposed unified DE controller is employed, it makes each panel to operate at its maximum power. Each shaded panel has its own peak power and the proposed controller is competent enough to make each shaded panel to operate at its peak power and thereby increasing the overall power extraction to 77.01 W (Panel₁ 30 W + Panel₂ 30 W + Panel₃ 17.01 W = 77.01 W, refer Fig. 5). Fig. 10 shows the output power curve for the enhanced power.

A comprehensive comparison of the proposed and prevailing techniques is carried out and it is tabulated in Table 2. Here in this study a PV array of 3 panels (MSX-60) are exposed to non-homogenous irradiation resulting in a multi-peak power curve. When a conventional MPPT tech-

nique like perturb and observe is applied it gets stuck to a local maxima and it ends up in extracting a meek power of 17.01 W only. But the Uni-dimensional DE MPPT controller is capable of attaining global peak power of 62.23 W. The power extraction capability of DE MPPT is further enhanced to 77.01 W when a multi dimensional search embedded unified controller is employed.

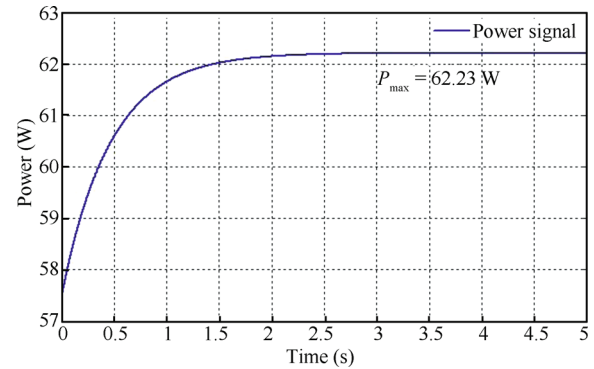


Fig. 9 Uni-dimensional MPPT controller output power curve

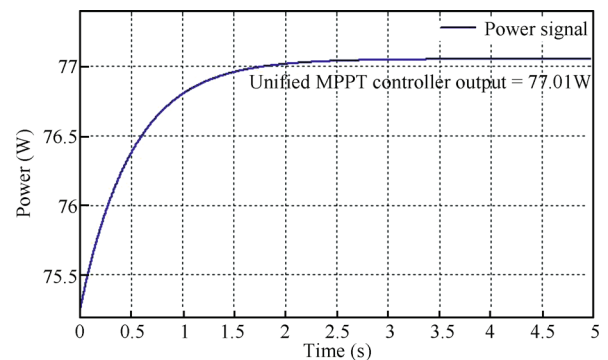


Fig. 10 Unified MPPT controller output power curve

Table 2 Simulation results

Scheme	Power delivered	Time taken to reach MPP
Without MPPT	12.05 W	NA
With P&O MPPT	17.0 W	0.02 s
Uni-dimensional controller	62.23 W	0.076 s
Proposed multi-dimensional DE	77.01 W	0.091 s

5 Conclusions

In this particular work, a unified differential evolution (DE) aided MPPT controller is proposed which is capable of yielding maximum available power even when the PV system is under shaded conditions. The uni-dimensional DE MPPT is only capable of extracting the global power (62 W) but the suggested unified controller will make each panel to operate at its maximum power and thereby making the total power extraction to 77.01 W. The simulation results indicate that the suggested unified MPPT technique has a clear edge over the other available MPPT systems as it has secured nearly 25% of more power than that of uni-dimensional counterpart. This work can be extended

by implementing this simulation work on hardware environment. Though it is little difficult to develop an MPPT controller which addresses partially shaded conditions, it is worth creating it as shading issues on PV panel will become a greater concern in near future.

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