AN IMPERIALIST COMPETITIVE ALGORITHM MAXIMUM POWER POINT TRACKER FOR PHOTOVOLTAIC STRING OPERATING UNDER PARTIALLY SHADED CONDITIONS

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Abstract: *Maximum Power Point Tracking (MPPT) in Partial Shading Condition (PSC) is challenging due to multiple peaks on power-voltage (P-V) curve. PV string configuration due to some specific output requirements uses in different household or commercial application. Accuracy and quickness of MPPT algorithm in PV string system should be considered thoroughly because of several reasons; the algorithm need to scan wide area from nearly zero to open circuit voltage, also due to series connection of PV modules and presence of bypass diodes, maximum power points increase dramatically. In this study Imperialistic Competitive Algorithm (ICA)-based MPPT algorithm was presented to find Global Maximum Power Point (GMPP) of PV string under PSC rapidly and precisely.*

Keywords: Imperialist competitive algorithm, maximum power point tracking, partial shading condition, photovoltaic systems

1. INTRODUCTION

Many researchers are used different search algorithms and technical software for solving power system problems [1-9]. Renewable energy attracts more attention due to energy crisis recently. Environmental issues and depletion of fossil fuels force us to consider green energy as the best alternative for conventional sources. Photovoltaic (PV) power generation because of several reasons such as being maintenance free, having no moving part and high accessibility have bright prospect. The main obstacle for PV systems to being used widely is a higher cost in the same output energy [10], [11], [12]. Although governments' policies like subsidy on solar energy or tax on pollutant such as CO_2 causes growing use of PV systems, these policies may not last longer [13]. Recent trends focus on catching more energy out of PV modules by maximum power point tracker.

Maximum Power Point Tracking (MPPT) is a challenging task because of weather dependent PV characteristic curves. Tracking becomes more complicated if the entire array does not receive uniform irradiance, this phenomenon known as Partial Shading Condition (PSC). Conventional MPPT techniques such as perturbation and observation (P&O) and incremental conductance (INC) are the best choice for tracking maximum power point (MPP) in uniform irradiance as the ease and cost effectiveness in implementation; however, they don't have suitable performance during PSC. These gradient based algorithms cannot differ between Local Peaks (LPs) and Global Peak (GP), so there is possibility to trap in LPs [14].

The basic form of P&O fluctuate around MPP, in addition in lower irradiance this algorithm cannot find the right direction of tracking. Researchers presented improved version of P&O, however inability for tracking in PSC still remains [15]. INC does not have P&O problems, but have the same problem with PSC [16]. To handle tracking during PSC various techniques have been presented by researchers, some of them are hardware-based; modular and cascaded configurations eliminate the impact of PSC, however these methods are inflexible and complex [14]. Parallel connection of PV modules is not applicable in household application or large scale systems due to output voltage limitation [17]. Also PV system reconfiguration moderate the impact of PSC and elevate extracted output energy, such methods increase system cost and circuitry [18]. Another category of the MPPT technique is algorithm-based one; [19] proposed DIRECT algorithm search, the technique does not guarantee to find GP under all conditions, also the algorithm is quite complex. Algorithm-based maximum power point trackers are more likely to be used due to fewer components and more flexibility. Because of complicated and unknown nature of MPPT, using artificial intelligence seems logical [20]. Although fuzzy logic control in MPPT is effective, it brings additional parts to system. Neural network (NN) is another approach, it handle tracking during PSC with a satisfactory performance. Negative aspect of NN-based tracker is training process. It requires information for network training, information size depends on the size of PV array, and then for large PV arrays it may need several months or even a year. In addition expansion of PV array is not possible, because NN system is structure dependent [14]. An evolutionary algorithm (EA) is an alternative approach for MPPT, unlike NN and fuzzy logic control it doesn't need extra components. In [14], [21], various kind of EA-based tracker with different control strategy has been proposed. In all of the aforementioned EA approaches, PV system consists of several PV panels connected in serial without bypass diodes. Bypass diodes prevent hot spots on shaded cells; also by short circuiting the shaded cells it stop power dissipation. Using bypass diodes in PV modules increase recently due to aforementioned reasons. Maximum numbers of MPPs directly depend on bypass diodes. Using more bypass diodes is challenging in

MPPT, consequently it is more likely for algorithm to converge in LPs.

In this investigation imperialist competitive algorithm (ICA) is utilized as a search algorithm to find GMPP. PV string was chosen as a PV configuration, MPPT become harder in this topology due to increase in searching space. Furthermore, new generation of PV systems, building integrated photovoltaic (BIPV) systems commonly use string configuration [20]. Introducing fast and accurate maximum power point tracker for PV string systems is the main purpose of this paper.

2. MODELLING PV SYSTEM

The single diode model presented by Villalva et al. [22] has been used for modeling the PV modules characteristic. The model is based on commonly used one diode model shown in Fig. 1.

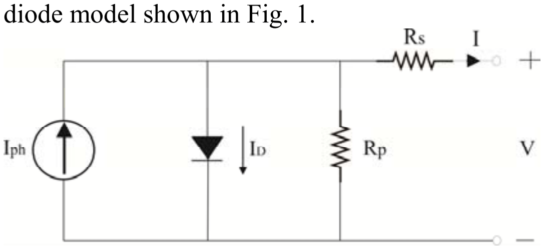


Figure. 1. Single diode model of PV module.

The validity of this model has been proved due to usage of several authors, besides the model is simple and accurate. Current-Voltage relation can be stated by

$$I = I_{Ph} - I_0\left[\exp\left(\frac{U + R_S I}{U_t A}\right) - 1\right] - \frac{U + R_S I}{R_P} \qquad (1)$$

Where I_{Ph} is the light-generated current, I_0 is the diode saturation current, R_s and R_p are the series and parallel resistance, A is the ideality factor, and thermal voltage of PV cell is represented by U_t. Diode current is depicted by the second term in right-hand side of (1) and the last term represents parallel resistant current.

In (1) the thermal voltage of PV modules is given by $N_S kT / q$, Where N_s is the number of cells in the module, k is the Boltzmann constant, T is the temperature of the module, and q is the electron charge. The description which has been presented for thermal voltage is just applicable for PV module without bypass diode. It should be refined by dividing N_s by the numbers of bypass diodes on each module. New U_t is the thermal voltage of a cell string, numbers of cells in a PV module which are paralleled with a bypass diode consist a cell string.

According to Fig.1, light-generated current is approximately equal to short circuit current. The assumption is true by some facts; Series resistance is low and parallel resistance is high, furthermore diode current is negligible. Such simplifications are quite necessary through limited information which is provided by manufacturer. Impact of solar irradiation and temperature on light-generated current is considered by the following equation:

$$I_{Ph} = (I_{Sc,STC} + k_I \Delta_T)\frac{G}{G_n} \qquad (2)$$

Where $I_{Sc,STC}$ is the short circuit current in standard test conditions(STC), k_I is the current coefficient, $\Delta_T = T - T_{STC}$ (T and T_{STC} are the actual and STC temperature), and G is the solar irradiance. Saturation current can be calculated by solving (1) in open circuit condition, and also by considering current and voltage coefficient to model the effect of temperature on saturation current. The dark saturation current is given by:

$$I_0 = \frac{I_{Sc,STC} + k_I \Delta_T}{\exp\left(\frac{U_{oc,STC} + k_U \Delta_T}{A U_T}\right) - 1} \qquad (3)$$

Where $U_{oc,STC}$ is the open circuit voltage in STC and k_U is the voltage coefficient. Diode ideality factor has been chosen in the range between 1 and 2, however typically this parameter in the normal condition set 1.3 [23].

Iterative method has been used to find optimum values of R_s and R_p, as both parameters are related to each other. The key idea is that there is only one value for R_s and R_p that experimental maximum power (maximum power of datasheet) and calculated maximum power are equal. $P_{max,c}$ can be obtained by finding I_{mpp} from (1) and $I_{mpp} \times U_{mpp}$ as follows:

$$P_{max,c} = U_{mpp} I_{Ph} - U_{mpp} I_0 \left\{\exp\left(\frac{U_{mpp} + R_s I_{mpp}}{A U_t}\right) - 1\right\} - U_{mpp}\left(\frac{U_{mpp} + R_s I_{mpp}}{R_P}\right) = P_{max,e} \qquad (4)$$

Where $P_{max,e}$ is the power at the MPP, and I_{mpp} and U_{mpp} are the current and voltage at the MPP which is provided by manufacturer. By extracting R_p from (4) the equation for calculating R_s and R_p is given by:

$$R_p = \frac{(U_{mpp} + I_{mpp} R_s)}{I_{Ph} - I_0 \exp\left[\frac{\left(U_{mpp} + I_{mpp} R_s\right)}{U_t A}\right] + I_0 - \frac{P_{max,e}}{U_{mpp}}} \qquad (5)$$

In the iterative process R_s will receive the initial value (R_s=0) and in each step R_p will be calculated until $P_{max,e} - P_{max,c} \approx 0$. Solarex MSX 60 PV module with two by pass diodes for each module is used in this paper, the module specifications are listed in Table 1.

TABLE 1.
PV MODULE SPECIFICATION

Electrical parameters	MSX 60
Maximum power	60 W
Maximum power voltage	17.1 V
Maximum power current	3.5 A
Open circuit voltage	21.1 V
Short circuit current	3.8 A
Voltage coefficient	-80 mV/C^o
Current coefficient	0.003 A/C^o

3. IMPERIALISTIC COMPETITIVE ALGORITHM

Imperialistic Competitive Algorithm applied as a MPPT algorithm in this paper, the algorithm introduced by Atashpaz Gargari and Lucas [24] which is inspired by a social event. In the MPPT application ICA is triggered by variation in irradiance. Differences in irradiance can be measured by variation in output current or power. Like other EA algorithms, ICA starts by the initial countries as the initial population, duty cycles of converter are countries. Countries vector define by Country= $[x_i^1, x_i^2, \ldots, x_i^N]$, i=1,2,…,N_{cnt} where N_{cnt} is the total number of countries. The Cost function of the countries can be found by estimating the function f at the variables. Output power of each duty cycles consider as its cost. The cost of each country is as follows

$$\mathrm{Cost}_i = f\,(Country_i) = f\,(x_i^1, x_i^2, \ldots, x_i^N) \qquad (6)$$

Countries divide in two groups, some of the stronger countries based on their cost function is called imperialist and the rest of them are categorized as colonies. In the next step, colonies must be divided among the imperialists based on their power. Imperialists power are proportional to their cost function, consequently stronger imperialists poses more colonies. Power of each imperialist is given by:

$$IP = \frac{\exp(-IC_n\alpha)}{\sum_{i=1}^{N_{imp}} \exp(-IC_n\alpha)} \qquad (7)$$

Where IP is the normalized power of each imperialist, IC_n is the normalized cost, and α is the selection pressure, high value for this parameter mean stronger imperialists have a better chance to possess a colony. Then Roulette Wheel selection applies to define which imperialist is going to take the colony. At the end each imperialist and its relevant colonies make an empire.

First operator in the ICA is assimilation, in this stage colonies move toward imperialist in their own empire. Positions of colonies are updated according the following equation:

$$Col_n^i = Col_n^i + rand \times \beta\left(I_n - Col_n^i\right) \qquad (8)$$

Where Col_n^i is the position of the *i*th colony of the *n*th empire, rand is the random number (0-1), β is the assimilation coefficient, and I_n is the position of the *n*th imperialist. In order to search different points around the imperialist random amount of deviation is added to the direct movement. During assimilation a colony may reach to a position with lower cost than that of imperialist. In this situation, imperialist position and colony position must be exchanged; Afterward the rest of colonies of this empire move toward the new position of imperialist.

Random search play an urgent role in the EAs, by this feature trapping in LPs will be reduced. In ICA revolution act as mutation in GA, this operator is defined as following:

$$Col_n^i = Col_n^i + rand \times \sigma\left(V_{Size}\right) \qquad (9)$$

Where Col_n^i is the position of the *i*th colony of the *n*th empire, rand is the random number (0-1), σ is the revolution coefficient, and V_{size} is the variable size. Applying revolution on colonies depend on revolution probability, higher value causes more colonies revolve.

Last operator is Imperialistic competition. In the imperialistic competition stage the algorithm pick some (one) of the weakest colonies of the weakest empire and through a competition, colonies (colony) will be given to winner empire. According to total power of empires, all of them have a chance to possess the mentioned colonies; consequently the most powerful empire has the biggest chance. Total power of an empire is proportionate to imperialist power and colonies power. Total power of an empire defines as:

$$TP_n = \mathrm{Cost}\left(Imperialist\right) + \xi \times mean\left(Colonies\ of\ \ empire\right) \qquad (10)$$

Where TP_n is the total power of *n*th empire and ξ is the colonies mean cost coefficient, importance of colonies in the total power of empire is defined by this parameter.

Winner Empire is selected by the Roulette Wheel selection.

In the imperialistic competition weak empires will collapse, different criteria can be defined for collapse mechanism, but in the most cases an empire is considered collapsed when it losses all of its colonies. During several iteration all empires will collapsed except the most powerful one, in this situation all colonies belong to this empire and colonies and imperialist converge to one position. Performance description of the proposed MPPT algorithm described briefly in the flowchart of Fig. 2.

4. DEFINING OPTIMUM VALUE OF PARAMETERS

4.1. Initial Countries and Stop Condition

Defining optimum numbers of initial population always is a challenging task. Large initial population lead into better searching of solution and more accurate result, however tracking time will be longer, in this situation power loss is inevitable due to changes in PV curves. On the other hand, small initial population shorten tracking time but there is no guaranty that algorithm won't trap in LPs. There should be a compromise between accuracy and tracking time. Some authors consider numbers of series connected panels (or cell strings) as a population number, this idea is based on the fact that in PV system with *m* series connected PV panels (or cell strings) exist at the most *m* MPPs in P-V curve [25], [26]. In small scale PV system the idea for initial population works properly, in the PV system with several series connected PV panels (or cell strings) this method is not applicable by considering tracking time.

Based on the Patel et al. observation in P-V curve all peaks occurs around $(n \times 0.8 \times U_{oc})$ where n is an integer number which vary between one and maximum number of panels (or cell strings), also minimum displacement between two consecutive peaks is $(0.8 \times U_{oc})$. PV string with 2 cell strings was simulated under various values of shading. Irradiation values started with the uniform irradiation and was decreased by $10W/m^2$ in each step. Fig. 3 depicts maximum power and maximum power voltage in each state, based on the figure most of the MPPs are around the 8.44V $(1\times0.8\times10.55)$ and 16.88V $(2\times0.8\times10.55)$. MPPs on the upper voltage have higher values than lower ones.

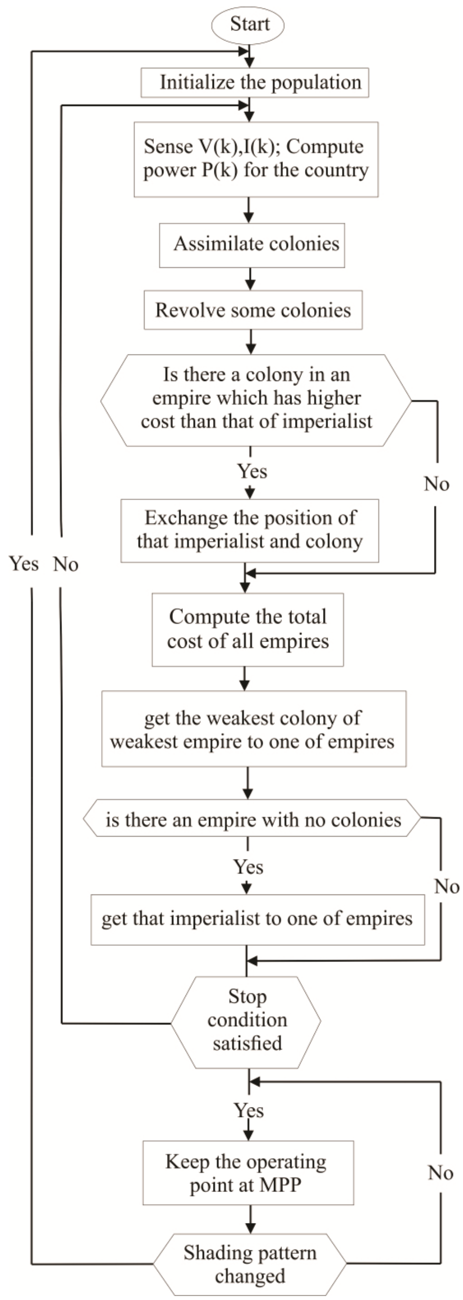


Figure. 2. Flowchart of ICA based MPPT control algorithm.

Same experiment was conducted for PV system with four and eight cell strings. Irradiation steps were 50 W/m^2 and 110 W/m^2 respectively, results reported on Fig. 4 and Fig. 5 Based on figures MPPs do not cover the whole P-V curve space, then initiating population in the specific position make the tracking faster. MPPs percentage around each peaks depict on table 2, first peak has the highest voltage value and last one has the least voltage value. Upper voltages have higher values of maximum power; consequently false tracking on higher voltages causes more power loss. Also, diversity of MPPs on higher voltages is more than lower ones. In 4 cell string model 96.4% of MPPs are on the first three peaks, and in 8 cell string model 93.5% of MPPs are on the first five peaks. According to what was mentioned initial population vector for PV string in the last section with 12 cell string is Country= [$n\times0.8\times U_{oc}$], n=5, 6… 12.

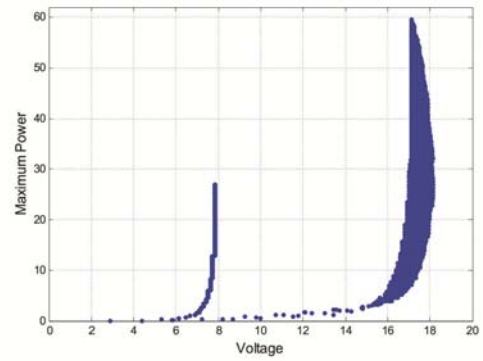


Figure. 3. Maximum power vs. its related voltage of two series connected cell string in different irradiation.

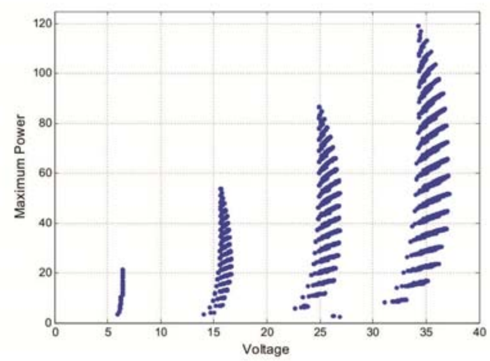


Figure. 4. Maximum power vs. its related voltage of four series connected cell string in different irradiation.

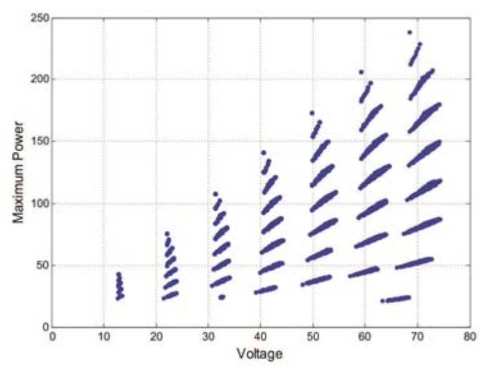


Figure. 5. Maximum power vs. its related voltage of eight series connected cell string in different irradiation.

In some versions of ICA, whenever all empires collapsed and only one of them remains algorithm stops. However

in MPPT application due to fewer number of initial countries
searching process will be limited by applying this setting. The proposed algorithm run in 100 different shading pattern cases, the algorithm stops when it reaches maximum iteration of 30. In Fig. 6 differences between the iteration that algorithm find the best answer and the last iteration reveals. According to the figure most of cases are in the iterations between 20 and 25, this means that algorithm is capable of finding the best solution in 5 to 10 iterations most of the time. Therefore two mechanism consider for stop condition either algorithm reaches the maximum iteration or following equation satisfied.

$$|P_{PV}^{n} - P_{PV}^{n+10}| \leq 0.05 \quad (11)$$

In eq. (11) P_{PV}^{n} is the tracking power in n^{th} iteration and P_{PV}^{n+10} is the tracking power in $(n+10)^{th}$ iteration. If output power variation is less than 0.05 in 10 consecutive iteration then algorithm stop searching.

TABLE 2.
PEAK POSITION PERCENTAGE OF 1, 2, AND 4 SERIES PV MODULES ON DIFFERENT IRRADIATION

N_{module}	1^{st} peak	2^{nd} peak	3^{rd} peak	4^{th} peak	5^{th} peak	6^{th} peak	7^{th} peak	8^{th} peak
1	55.96	44.04						
2	22.58	42.15	28.4					
3	15.85	17.67	24.29	21.58	14.8	5.74	0.76	0

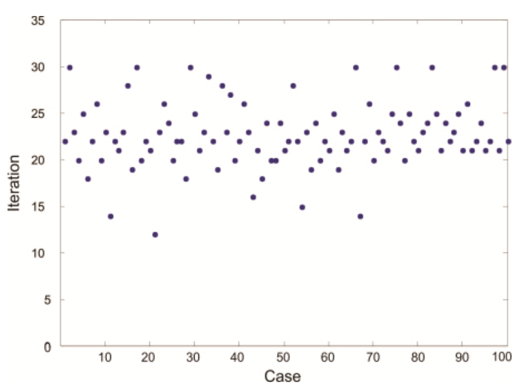


Figure. 6. Iteration differences between the last iteration and iteration of best solution in 100 different cases.

4.2. ICA Parameters

Following fitness function used in order to evaluate optimum values of ICA parameters

$$16e^{-\frac{(x+19)^2}{0.25}} - 16e^{-\frac{(x+18)^2}{0.25}} + 4e^{-\frac{(x+17)^2}{0.25}} - 4e^{-\frac{(x+16)^2}{0.25}} + 6e^{-\frac{(x+15)^2}{0.25}} - 6e^{-\frac{(x+14)^2}{0.25}} + 8e^{-\frac{(x+13)^2}{0.25}} - 8e^{-\frac{(x+12)^2}{0.25}} + 18e^{-\frac{(x+11)^2}{0.25}} + 20e^{-\frac{(x-19)^2}{0.25}} \quad (12)$$

Based on Fig. 7 the function has several local optimum peaks on one side and one global optimum at the other side. In this experiment initial population distributed randomly on searching space and maximum iteration was 100 in all cases. Fig. 8 illustrates relationship between mean optimization solution and execution number of algorithm, variation in the solutions among all cases are less than 0.2. Results for 20 and 40 run are quite inconsistent, answer diversity for 120 execution seems satisfying, in order to reach valid and reliable values of ICA parameters every cases in all experiments run 120 times. Number of empires in ICA has been varied in the experiment for the aforementioned function and optimization solution has been plotted in Y-axis against number of empires in the X-axis, details illustrates in Fig. 9. Three initial empires reach the best solution, it's clear that performance of algorithm for 3 to 6 empires is satisfying. Meanwhile algorithm come up with poor results in the first and last case.

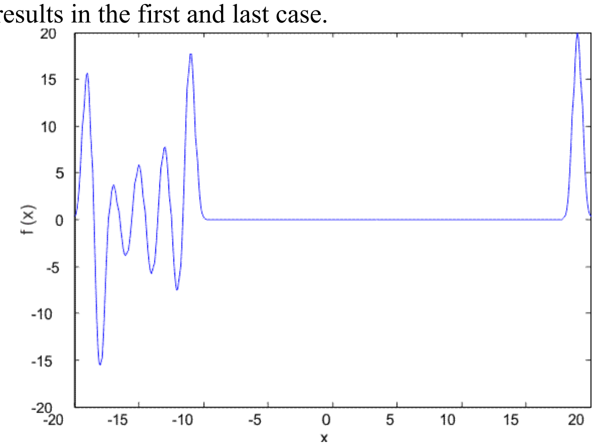


Figure. 7. The function used in the experiments.

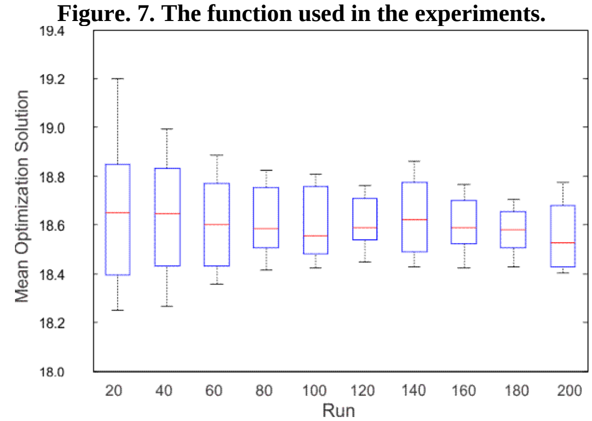


Figure. 8. Box-plot of the relationship between the mean optimization solution and execution number of algorithm; the edges of the box are the *25th* and *75th* percentiles of optimization solution, and the red line inside the box depicts the average value of optimization solution.

Fig.10 and Fig.11 illustrate optimization solution for aforementioned fitness function in case of variation in P_{rev} (revolution probability) and ζ, accordingly. Theoretically higher values of P_{rev} causes better optimization due to more variation in colonies position, however voltage and power oscillation increase dramatically. Middle values of ζ brings satisfying performance, this means both colonies and imperialist have to have same power in total cost to have desirable performance. Optimum values for all parameters illustrate in red.

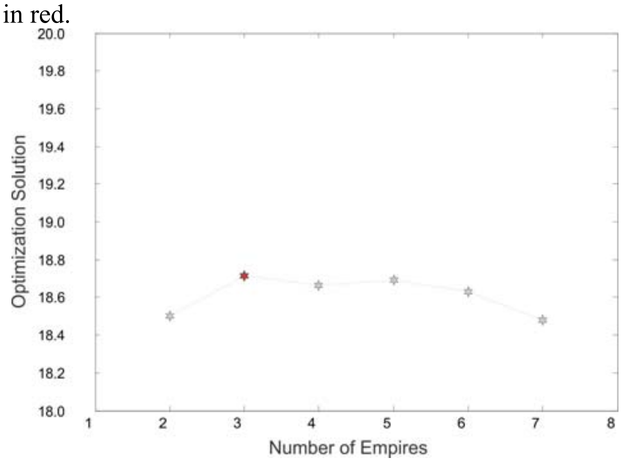


Figure. 9. Mean optimization solution in terms of variation in number of empires.

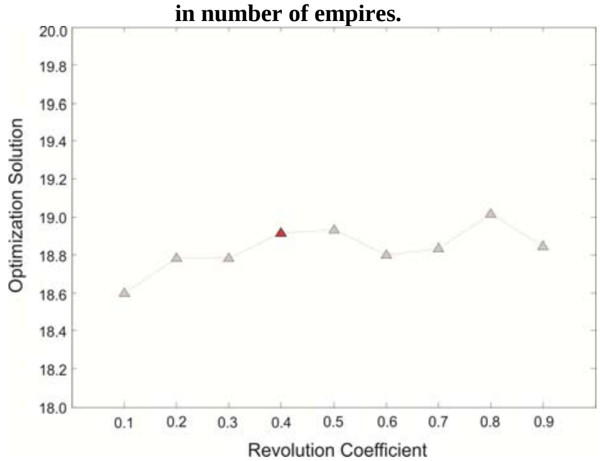


Figure. 10. Algorithm solutions versus revolution factor.

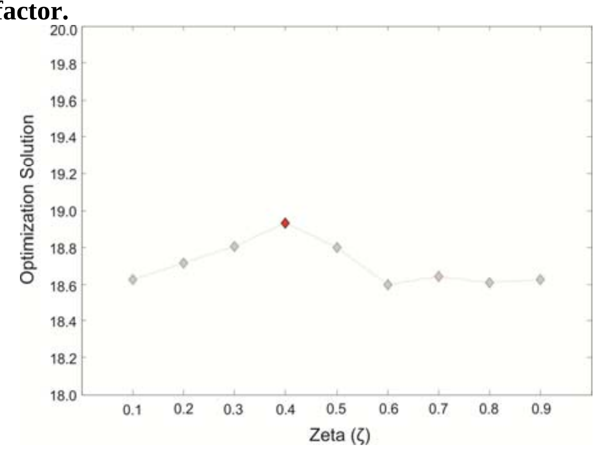


Figure. 11. Algorithm solutions versus zeta parameter.

Parameters of β and α have been varied in the different sets of experiments, optimization solution for each case illustrate in Fig.12 and Fig.13. According to the Fig.12 and equation (8) lower values of β causes colonies stay on their own position which lead into poor searching for optimum solution. Based on the figure overall performance of β is more suitable around 1, where colonies move to the vicinity of imperialist. It should be mentioned that higher values of β causes voltage and power oscillation.

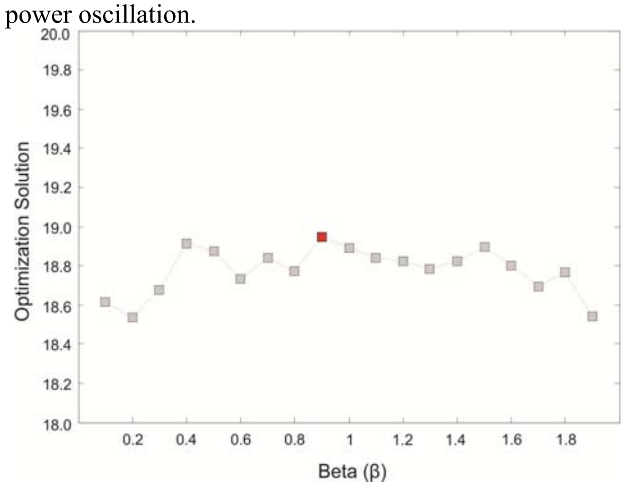


Figure. 12. Algorithm solutions versus beta parameter.

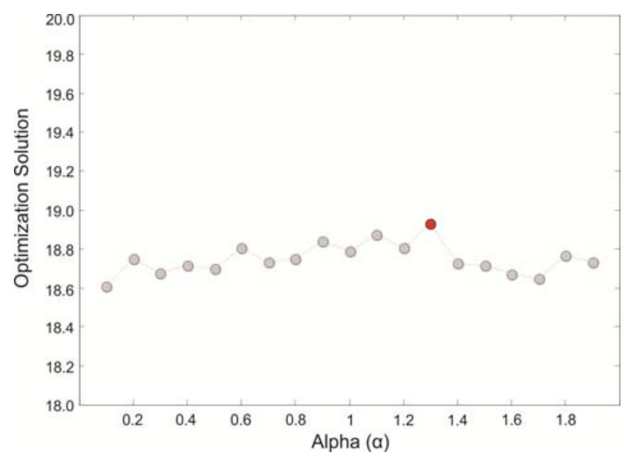


Figure. 13. Algorithm solutions versus alpha parameter.

In the proposed algorithm both colonies and imperialist revolve based on eq. (9), imperialists' revolution are conditional, if by applying revolution imperialists reach better position it apply otherwise imperialists position remain unchanged. Imperialists possess better position in comparison with colonies position so two parameters for revolution coefficient were considered. σ_1 and σ_2 are revolution coefficient for imperialists and colonies respectively. The 3-D plot for the relationship between optimization solution and revolution coefficients is shown in Fig.14. From the figure, we can see lower values of σ_1 achieved better solution, on the other hand with higher values of σ_2 better optimization solution is reached. It can be concluded that due to better imperialists position they need to move less and colonies move more for optimum solution.

The parameters of the proposed MPPT method in the following simulation are set as shown in table 3.

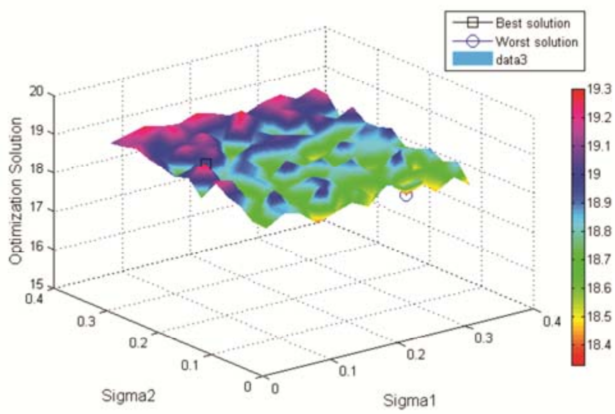


Figure. 14. 3-D image of optimization solution versus revolution coefficients.

TABLE 3.
PARAMETERS SPECIFICATION OF ICA

Number of countries	8	α	1.3
Number of empires	3	β	0.9
Number of colonies	5	ζ	0.4
Maximum iteration	30	σ_1	0.05
P_{rev}	0.4	σ_2	0.175

5. EXPERIMENTAL RESULTS

In this section, the simulations of three cases under different partial shading patterns are executed in MATLAB software in order to examine the performance of the proposed method. PV modules specifications are listed in table I. A PV string with 6 series connected PV modules (12 cell string) was used. System configuration of proposed maximum power point tracker is shown in Fig. 15, Buck-boost converter is selected as a Dc/Dc converter because of its tracking ability under every atmospheric condition [27]. The switching frequency and sampling time are set to 20 kHz and 0.2S, converter parameters are considered as: C1:500µF, C2:200µF, L=800µH. The algorithm parameters are shown in table III. Experiments are simulated under constant temperature of 25°C.

5.1. First Experiment

In the first experiment performance of proposed algorithm compare with PSO method. The PV string consists of 6 series PV modules, each of them is composed of two cell strings (CS1 and CS2) paralleled by a bypass diode. Four PV modules receive uniform irradiance and two others receive irradiance of 700W/m^2 and 600W/m^2 as shown in Fig. 16(a). Particles and countries position are illustrated by $P_1,\ldots,P_{12}$ and $C_1,\ldots,C_8$ respectively on P-V characteristic curve. Specifications of PSO algorithm are tuned based on [25] as shown in Table IV. Variation in tracking voltage for ICA and PSO methods are depicted in Fig. 17 and Fig. 18 accordingly, the proposed algorithm converged on thirteenth iteration due to unchanged best solution in 10 consecutive iterations.

Performance comparison of ICA and PSO algorithm in terms of tracking voltage and convergence speed in 50 runs is reported in Fig. 19. Although both methods have satisfying performance in tracking optimum voltage, it seems ICA is a little bit accurate. From the Fig. 19(b), convergence speed of ICA method by far is faster than PSO algorithm. It should be noted that due to fewer initial population, ICA is capable of finding optimum voltage faster.

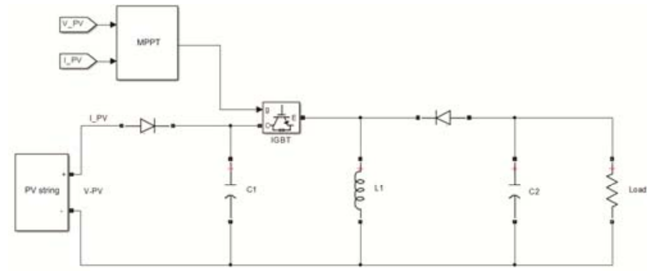


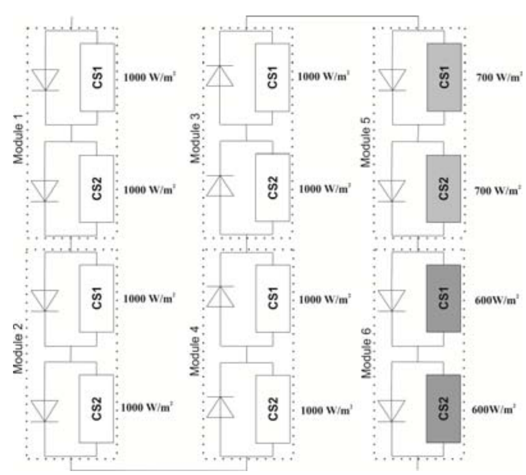
Figure. 15. Simulink model of MPPT control structure.

5.2. Second Experiment

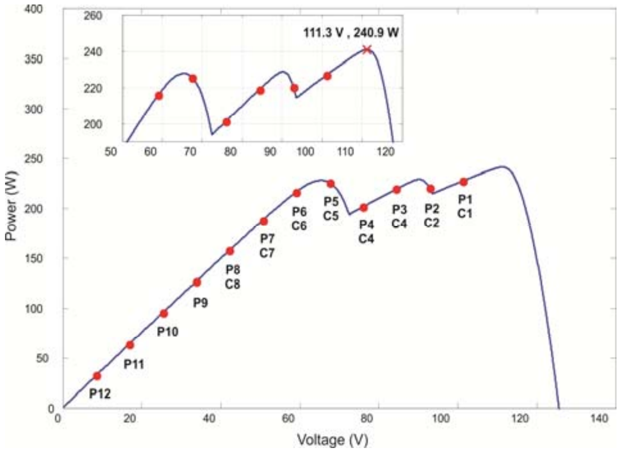
This case was simulated to investigate the capability of the proposed algorithm in GMPPT on the lower voltages, where there is no agent to facilitate searching process. Like previous case PV string is formed with 12 series cell strings, first PV module receive uniform irradiance and rest of PV modules are under serious shading condition as shown in Fig. 20 (a). Distribution of initial countries on P-V curve is illustrated in Fig. 20(b). Tracking voltage for this experiment is depicted in Fig. 21. Tracking voltage and iterations of 40 trails are shown in Fig. 22, tracking voltage in all cases are located around optimum voltage (V_{opt}) of 9.706V. Number of iterations to converge in this experiment in comparison with the last case increases due to longer searching process which is caused by considerable voltage differences between GP and C8.

TABLE 4.
DESCRIPTION OF PSO PARAMETERS

Number of Particles	**12**	**Maximum iteration**	**30**
$\mathbf{W_{max}}$	1	W_{min}	0.1
$\mathbf{C_{1,max}}$	2	$C_{1,min}$	1
$\mathbf{C_{2,max}}$	2	$C_{2,min}$	1
$\mathbf{Vel_{max}}$	$0.1I_{Sc\text{-}STC}$	Vel_{min}	$-Vel_{max}$



(a)



(b)

Figuer. 16. PV string details for the first experiment. (a). shading pattern and (b).P-V curve.

5.3. Third Experiment

The objective behind the last case is to examine the algorithm accuracy when LPs and GP approximately have similar values. Shading pattern alongside P-V curve details is depicted in Fig. 23, MPPs values is illustrated in zoomed view of the figure. An example of tracking voltage of this experiment is shown in. Fig. 24 illustrates tracking voltage and iterations of the PV string in 40 execution, minimum tracking efficiency has been reached by tracking voltage of 112.3 V which is 99.82%. On average, the ICA maximum power point tracker converge on fifteenth iterations. According to Fig. 25. it can be seen that during the latest iterations algorithm started to converge, however stop condition of eq.(11) was satisfied and ICA has been blocked

6. CONCLUSION

In this study imperialist competitive algorithm was modified and adjusted to track the global maximum power point of photovoltaic string under partially shaded condition. The proposed method was simulated under three different partial shading patterns in order to examine the performance of the algorithm. The first simulation reveals that the proposed algorithm is quite faster than PSO algorithm, meanwhile ICA is more accurate. The second and last case approve the tracking ability and accuracy of the ICA maximum power point tracker regardless to where the global maximum power point is.

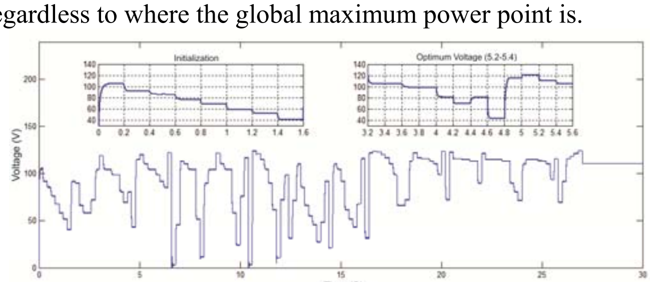


Figure. 17. Variation of tracking voltage of proposed algorithm in the first case.

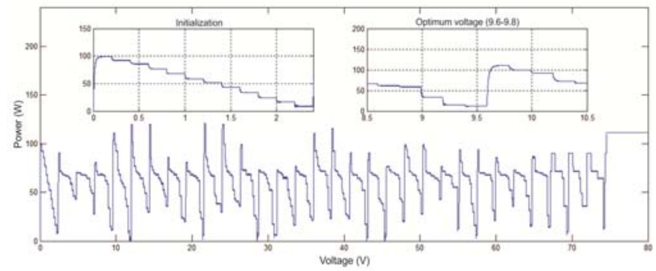
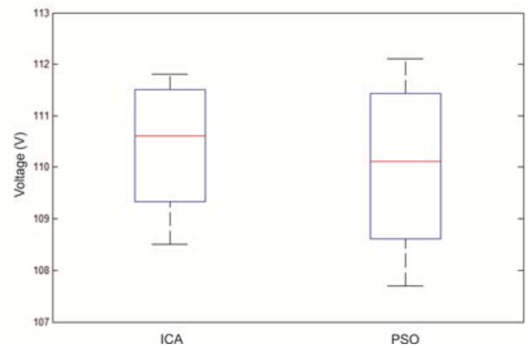
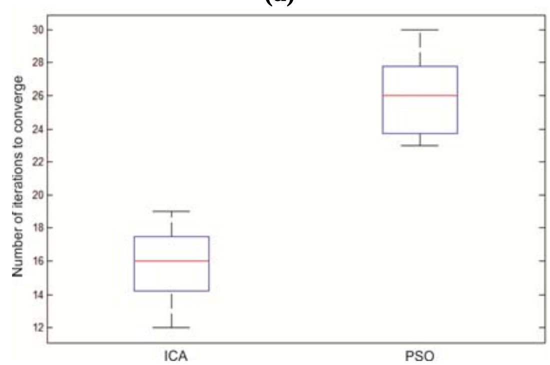


Figure. 18. Variation of tracking voltage of PSO algorithm in the first case.

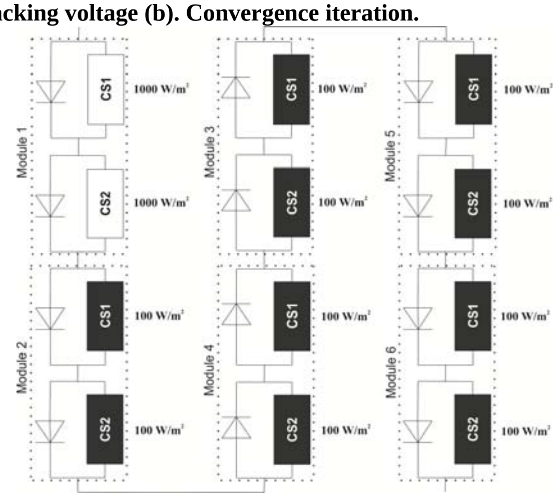


(a)

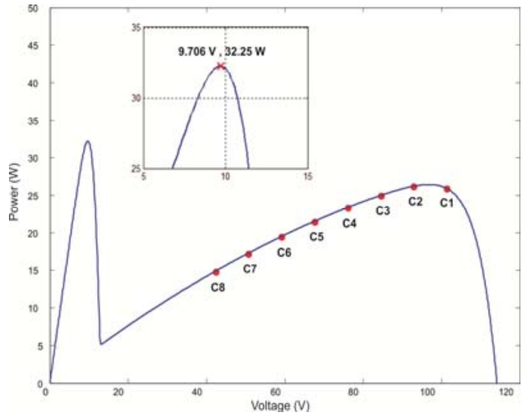


(b)

FIG. 19. Performance comparison of ICA and PSO. (a). tracking voltage (b). Convergence iteration.



(a)



(b)

Figure. 20. PV string details for the second experiment. (a). shading pattern and (b).P-V curve.

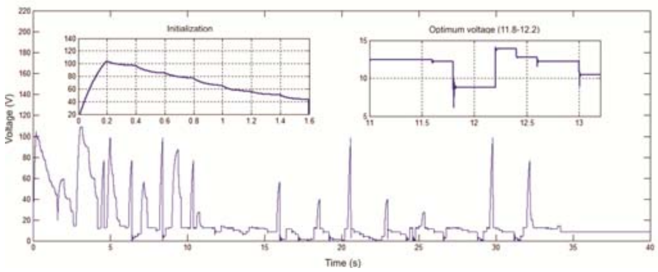
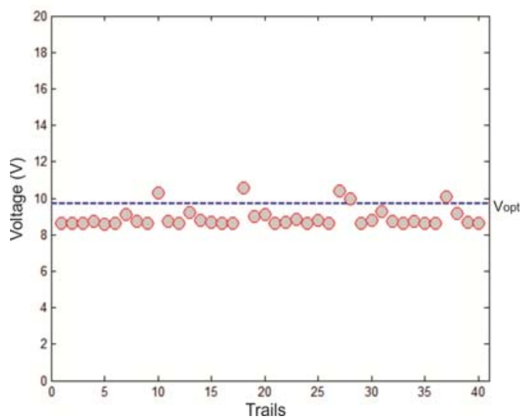
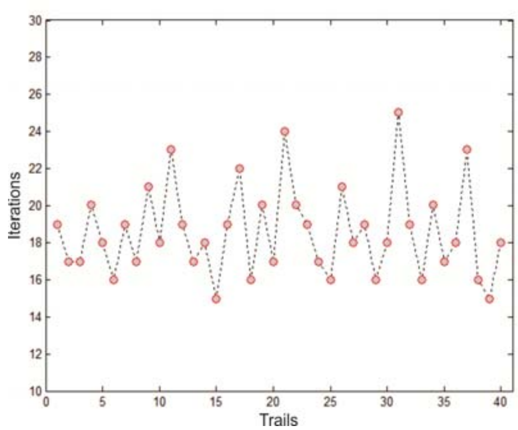


Figure. 21. Variation of tracking voltage of proposed algorithm in the second case.

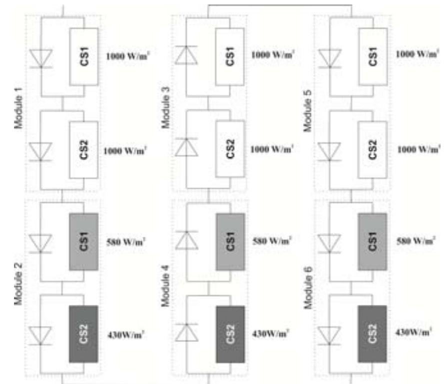


(a)

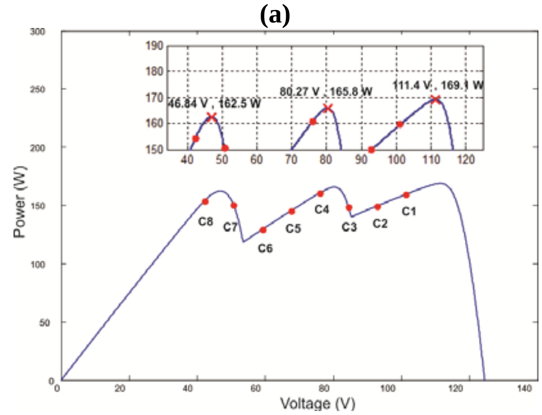


(b)

Figure. 22. Performance description of proposed method in second case.(a) Tracking voltage.(b)Convergence iteration.

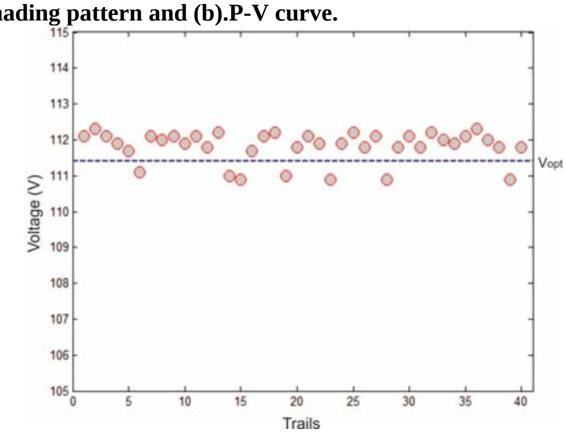


(a)

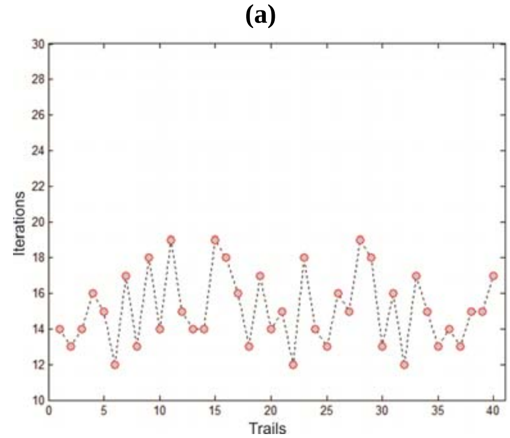


(b)

Figure. 23. PV string details for the third experiment. (a). shading pattern and (b).P-V curve.



(a)



(b)

Fgure. 24. Performance description of proposed method in second case.(a) Tracking voltage.(b)Convergence iteration.

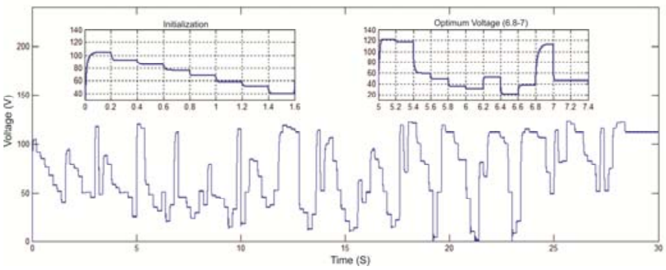


Figure. 25. Variation of tracking voltage of proposed algorithm in the third case.

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