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A Novel MPPT algorithm for PV systems under variable Shading Conditions using Horse Herd Optimization

Photovoltaic cell or PV cell effectively acts as a current source, primarily dependent on the incident solar irradiation. Due to the non-linear current-voltage (I-V) & power-voltage (P-V) characteristics of PV cells, power will be transferred depending upon the load voltage. So, the operating point or the load voltage should be monitored continuously and placed in such a manner so that maximum power can be extracted from the PV system. Perturb & Observe (P&O) method is one of the popular and commonly used methods used to track the maximum Power Point or MPP under uniform insolation. During partial shading conditions, it is observed that multiple peaks exist in the case of a large PV system, one of which is only a global peak (GP) and the rest are local peaks (LP). This paper investigates the failure of the P&O method and proposes a new optimization technique namely Horse Herd (HH) optimization to find the global peak during partial shading. This paper also compares the result with other optimization techniques in terms of efficacy. A simulation model of PV array is developed in MATLAB software, and I-V and P-V characteristics are studied during partial shading conditions. Further studies were conducted to overcome the problem and track the global peak successfully during various shading patterns using Horse Herd optimization technique.

Keywords: Maximum Power Point Tracking (MPPT); Partial Shading; Local peak; Global peak; Irradiation; Duty Cycle; Horse Herd Optimization;

1. Introduction

Maximum Power Point Tracking (MPPT) is a very important phenomenon in case of solar or photo voltaic (PV) system. It is basically the operating point that gives the maximum power that can be delivered to the load. The Maximum Power Point (MPP) of a PV cell is not universally constant; rather it varies depending on several conditions including weather, load impedances and so many other factors. MPPT is essential to achieve the efficient operation of the PV panels [1]. If PV systems operate under uniform solar irradiation then the maximum power point can be easily detected using conventional methods like P&O method, Incremental Conductance method, etc. Especially, the problem occurs during partial shading condition or when the irradiance value differs in the modules of a PV array. The composite P-V characteristics show a set of local maxima and global maxima. Conventional methods often detect local maxima in the P-V curve rather than global maxima point [2]. Thus, these kinds of approaches fail to detect maximum power point of the P-V panel. Consequently, the researchers have started using optimization techniques to find the MPPT in case of partial shading conditions instead of conventional methods.

A lot of algorithms have been attempted in the past to solve the problem of MPPT tracking. Each method is having its advantages and disadvantages. Initially, to optimize the P&O MPPT parameters, a converter-specific methodology is proposed in [3]. Addressing

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the issues with the conventional tracking techniques, a Particle Swarm Optimization (PSO) based technique and an Overall Distribution PSO (OD-PSO) based techniques are suggested to identify global MPP, in [4, 5]. But, the response is found to be relatively slow. Paper [6] has applied an Improved PSO (IPSO) for MPPT. But, this approach has resulted in a huge power loss. Papers [7, 9] described a method that uses perturbation in the duty cycle of power converter. But, these methods yield oscillations at maximum power point. Considering the local minima obtained from the PSO, a methodology combining the benefits of P&O with PSO (P&O-PSO) to reduce the search space and to reach the global maxima, another work is presented in [8]. Later in [10, 11], a Modified Firefly (M-FF) is applied to identify the MPP. Ref. [12] shows MPPT using Grey Wolf Optimization (GWO) technique. However, these methods give a problem during random patterns. Ref. [13] uses an MPPT tracking methodology using Lagrangian interpolation and particle swarm optimization (PSO). But, this method is taking the extra iterations to converge which could have been reduced. Soon after, an improved Grey Wolf Optimization is suggested to reduce the tracking time of Global maxima point, in [14]. Considering the abrupt change in the shade pattern, a technique based on Fractional chaotic Flower Pollination Algorithm (FC-FPA) is recommended in [15, 16]. Recently, considering the change in current as additional input, a modified P&O (AM-PSO) technique is suggested in [17]. Later, considering the voltage as reference, an algorithm which is adaptive to the weather conditions is suggested [18]. Then, to track MPPT without large oscillations and with reduced settling time, variable step size PO is proposed in [19] considering different wind speed conditions. Very recently, in [20], a Slap Swarm Optimization (SSO) based algorithm is suggested for MPPT tracking considering partial shading conditions. Though these all approaches are good in the global search of the MPPT, there are unavoidable changes in the voltage.

In this work, we suggest a novel approach for finding a global peak using Horse-herd optimization technique. This technique is new and capable of finding the global peak of MPPT in a very efficient manner without disturbing the stability of the system. The efficacy of the proposed algorithm has also been compared with various recent approaches that have been applied in this work so far.

2. Mathematical Model of PV Module

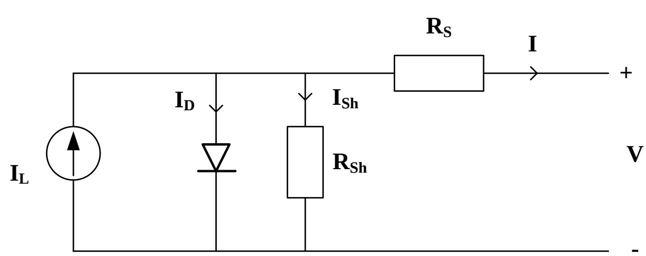

Fig. 1. Equivalent Circuit of PV module

As shown in Fig. 1, the PV module is basically a diode-connected current source having a load connected through a series resistor and a shunt resistor. For, this module, the current voltage characteristics will be,

$$I = I_{sh} - I_0[\{\exp(\frac{q(V + IR_S)}{AKT}) - 1\}] - \frac{V + IR_s}{R_{sh}} \tag{1}$$

$$\frac{V_{load}}{V_{pv}} = \frac{D}{1-D} \quad (2)$$

Here, D is the duty cycle of the converter.

PV Cells will be connected in series or parallel to form a module to generate a desired voltage and current level. The PV cell output voltage depends on the generated current value which again depends on the solar irradiance. If any system is connected with different modules of PV cell, two conditions may arise. In first case, if all the modules are getting similar irradiance, finding of MPPT is easy through conventional methods. But, if the modules are getting different irradiances due to shadow or cloudy conditions, the composite PV characteristics contains more than one peak. Conventional methods often find local maxima instead of global maxima. The entire analysis is done using MATLAB R2018a package.

a) Under uniform solar irradiation:

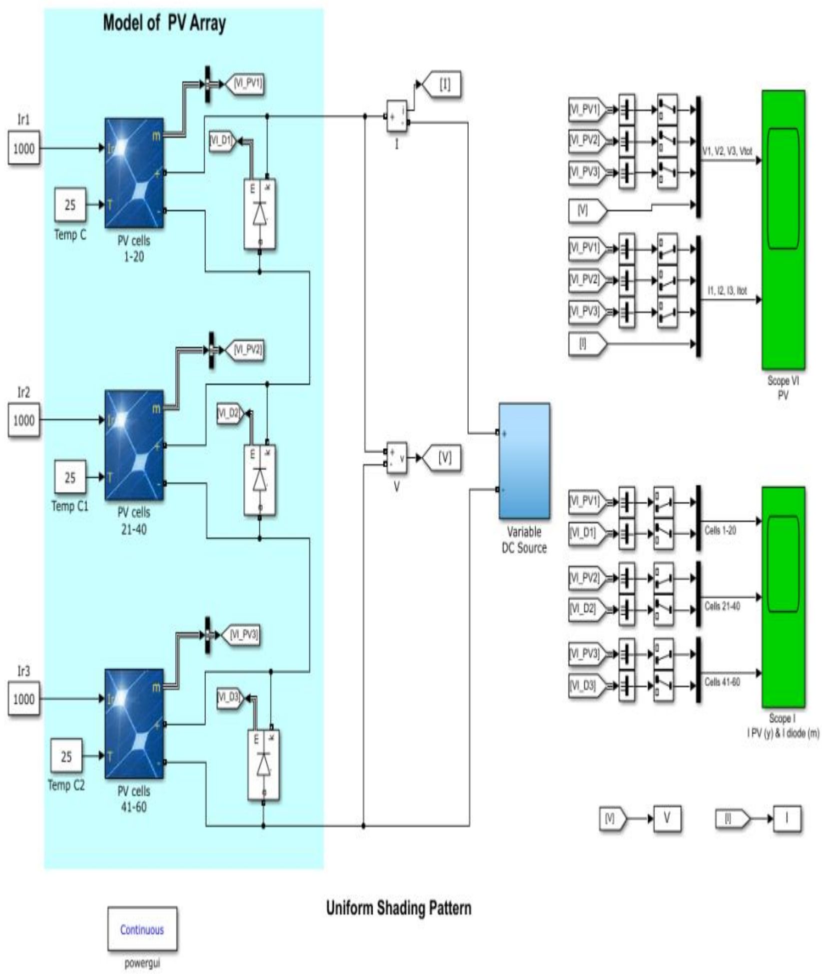

Fig. 2. PV Cell with 3 modules in SIMULINK with uniform shading

As shown in Fig. 2, there are three modules being considered. As shown in Fig. 3(a), with uniform solar irradiation of 1000 watt/m^2, Maximum power is observed nearly at 3997 (3x1332.5) Watts. As there are three modules connected in series, the voltage at MPP is observed at 247.6 (3x82.53) Volts. Similarly, as shown in Fig. 3(b), when uniform solar irradiation is 500 watt/m^2, the MPP is observed nearly at 2008 (3x669.3) Watts. In both cases it is observed that the open circuit voltages will be more or less similar but short circuit current is nearly half in 500 watt/m^2 case compared to 1000 watt/m^2 case. The reason is that the PV system acts as a current source that depends on the incident solar irradiation. An important point to be understood is that the MPP lies towards right half of the P-V curve i.e. near the open circuit voltage (approximately 81.7% of the open circuit voltage in our case). After that, the output power falls sharply and eventually becomes zero at V_{oc}. The various parameters of each module for the given uniform irradiation are listed in the Table-1.

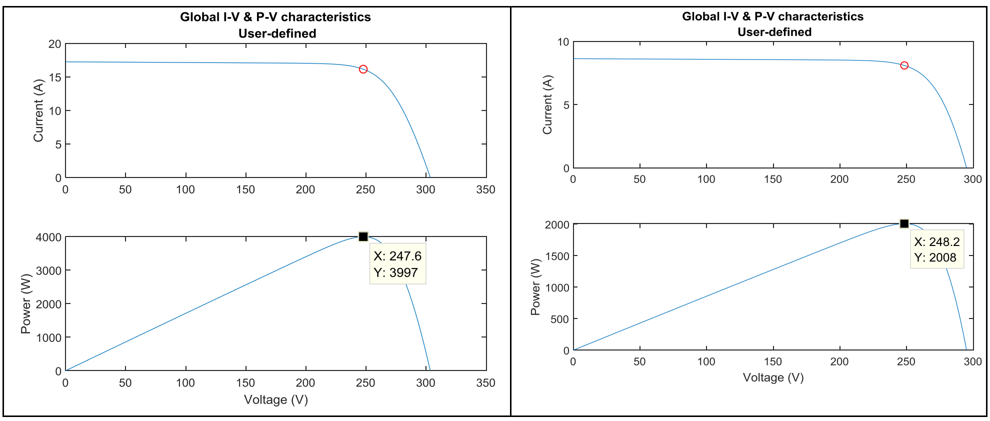

Fig 3: I-V and P-V characteristics with (a) solar irradiation 1000 watt/m^2, (b) solar irradiation 500 watt/m^2

Table 1: Parameters of the each simulated solar module (solar)

Parameter	Numerical values	
	irradiation of 1000, watt/meter^2	irradiation is 500, watt/meter^2
Open circuit voltage (V_{oc})	101.12 Volts	101.12 Volts
Short-circuit current (I_{oc})	17.24 Amps	17.24 Amps
Voltage at MPP (V_{mp})	82.53 Volts	82.73 Volts
Current at MPP (I_{mp})	16.14 Amps	8.09 Amps
Maximum Power (P_m)	1332.5 watts	669.3 watts

b) Under partial shading condition:

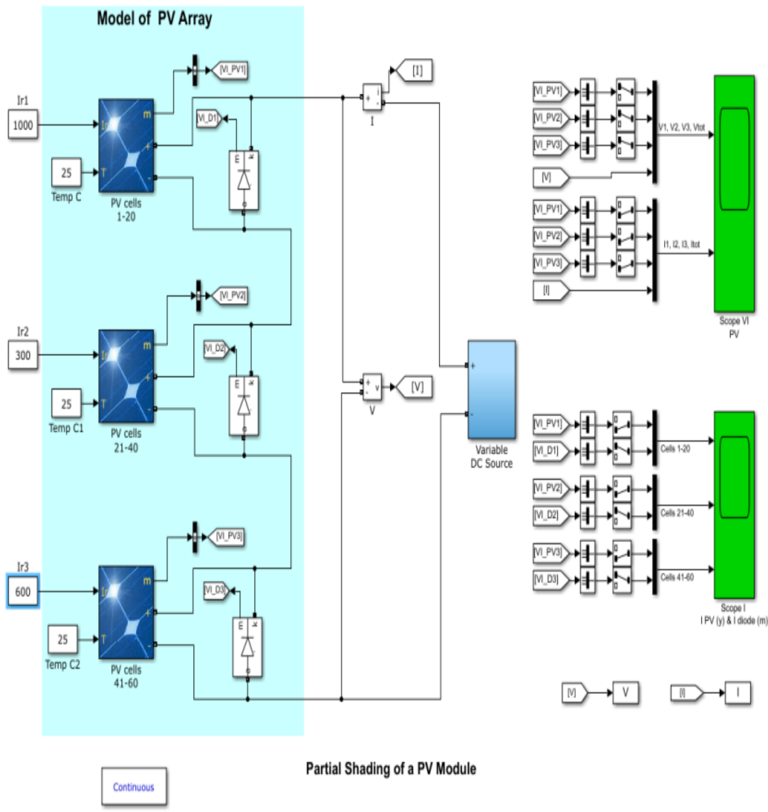

Fig. 4. PV Cell with 3 modules in SIMULINK with partial shading

As the Fig. 4, shows, if we consider three modules with the solar irradiations at 1000 Watt/meter^2, 300 Watt/meter^2 and 600 Watt/meter^2 respectively, the three modules will generate different currents as well as powers proportional to irradiations. As shaded panels are incapable of producing power compared to un-shaded panels, the heating effect may occur due to the formation of hot-spot which could damage the entire PV system. To overcome this issue, the bypass diodes are connected with each of the PV modules. The shaded panels thus bypassed and protected would result in multiple peaks in the P-V curve, under partial shading condition. The various parameters of each module for the given partial shading are listed in the Table-2.

As the Fig. 5 shows, the I-V and P-V composite characteristics of the PV array when three identical PV modules are getting three different irradiations show three different peaks where one is a global peak and the remaining two are local peaks. The conventional techniques like Incremental Conductance, Perturb and Observe method, Constant Voltage techniques fail to detect the global peak. So, various optimization techniques like Particle Swarm, Grey Wolf, Cuckoo search, flower pollination, Genetic Algorithms have been used by various researchers to find the global peak. Each of the algorithms has unique characteristics to find out the desired

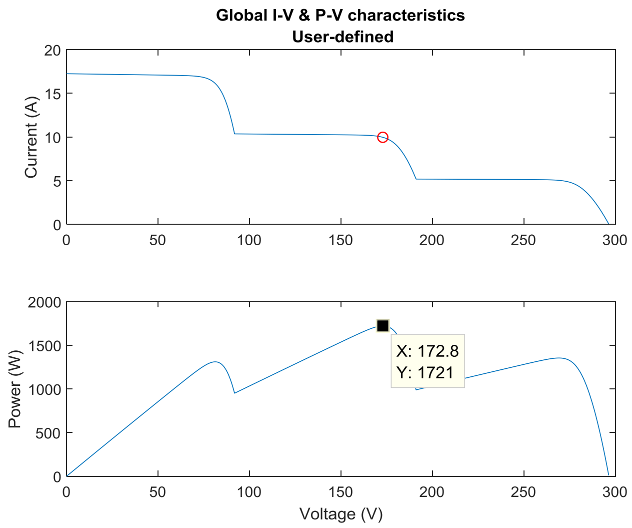

Fig 5: I-V and P-V characteristics of PV array under partial shading condition

result. In this paper, we use new meta-heuristic optimization named as Horse-herd algorithm that works based on the behavior of horse herding.

Table 2. Parameters of the simulated PV array under partial shading condition

Parameter	Numerical values
Global Peak Power	1721 Watts
Voltage at Global peak (V_{gp})	172.8 Volts
Current at Global Peak (I_{gp})	9.96 Amps

3. Horse Herd Optimization Algorithm

Horse herd Optimization Algorithm (HOA) is a new meta-heuristic algorithm that mimics the behavioral pattern of horses in the living environment [21]. The behavioral pattern of horses is having six characteristics such as Grazing (G), Hierarchy (H), Sociability (S), Imitation (I), Defense mechanism (D) and Roam (R) [22-24]. The movement of horse at different age can be described by the following equation:

$$X_m^{Iter,A} = V_m^{Iter,A} + X_m^{(Iter-1),A},\ A=\alpha,\beta,\gamma,\delta \tag{3}$$

Where, $X_m^{Iter,A}$ = Position of m^{th} horse,

$A =$ Age range of the horses,

$V_m^{Iter,A}$ = Velocity vector of the horse

In general, as the maximum life span of a horse is 25-30 years [25]. So, *A* is chosen in such a way that *δ, γ, β* and *α* indicate the horses whose age range is 0-5, 5-10, 10-15 and above 15 years respectively. The motion vector of horses can be written as follows in the equation:

$$V_m^{iter,\alpha} = G_m^{iter,\alpha} + D_m^{iter,\alpha} \tag{4}$$

$$V_m^{iter,\beta} = G_m^{iter,\beta} + H_m^{iter,\beta} + S_m^{iter,\beta} + D_m^{iter,\beta} \tag{5}$$

$$V_m^{iter,\gamma} = G_m^{iter,\gamma} + H_m^{iter,\gamma} + S_m^{iter,\gamma} + I_m^{iter,\gamma} + D_m^{iter,\gamma} + R_m^{iter,\gamma} \tag{6}$$

$$V_m^{iter,\delta} = G_m^{iter,\delta} + I_m^{iter,\delta} + R_m^{iter,\delta} \tag{7}$$

The main steps involved in horse herd algorithm are as follows.

a. Gazing

Horses gaze on a pasture 16-20 h in a day. The mathematical interpretation of gazing can be done as follows.

$$G_m^{iter,A} = g_{iter}(\mu + \rho l)[X_m^{iter-1}], \qquad A = \alpha, \beta, \delta, \gamma \tag{8}$$

$$g_m^{iter,A} = g_m^{(iter-1),A} \times \omega_g \tag{9}$$

Where $G_m^{iter,A}$ indicates the motion parameter of i[th] horse. The value of l can be taken as 0.95 and μ can be taken as 1.05. g, the coefficient, can be taken as 1.5 for horses of all ages.

b. Hierarchy

Horses pass their life following a leader. From the law of hierarchy, in the herds of wild horses, an adult stallion or a mare is also responsible for [26]. In this case, the coefficient *h* is the tendency of herd of horses to follow the most experienced and strongest horse. Studies have shown that the horses follow the law of hierarchy at the middle the ages, β and γ. The Hierarchy layer can be defined by following equations:

$$H_m^{iter,A} = h_m^{iter,A}[X_*^{iter-1} - X_m^{iter-1}], \qquad A = \alpha, \beta, \gamma \tag{10}$$

$$h_m^{iter,A} = h_m^{(iter-1),A} \times \omega_h \tag{11}$$

Here, $H_m^{iter,A}$ indicates the effects of the best horse location, on velocity parameter, and $X_*^{(iter-1)}$ indicates the location of the best horse.

c. Sociability

As horses are social animals, sometimes they live with other animals also. Living in a herd is better for security of the horse. Horses do not like loneliness. Sometimes they are happy to be around other animals like cattle and sheep also. This behavior indicates the movement towards an average position of other horses and is shown by a factor *s*. The sociability feature of horses is indicated by following equation.

$$S_m^{iter,A} = s_m^{iter,A}[(\frac{1}{N}\sum_{j=1}^{N} X_j^{iter-1}) - X_m^{iter-1}], \qquad A = \beta, \gamma \tag{12}$$

$$s_m^{iter,A} = s_m^{(iter-1),A} \times \omega_S \tag{13}$$

Here, $S_m^{iter,A}$ is Social motion vector of i[th] horse, $s_m^{iter,A}$ is concerned horses orientation towards the herd in iter[th] iteration, and N is the total number of horses.

d. Imitation

Horses imitate each other. They learn each other's good and bad habits and find proper location in a pasture. The imitation behavior is indicated by factor *i* in this algorithm. Young horses try to mimic each other. They do it till they attain full maturity.

$$I_m^{iter,A} = i_m^{iter,A}[(\frac{1}{\rho N}\sum_{j=1}^{\rho N} X_j^{iter-1}) - X^{iter-1}], \qquad A = \gamma \tag{14}$$

$$i_m^{iter,A} = i_m^{(iter-1),A} \times \omega_i \tag{15}$$

Here, $I_m^{iter,A}$ is the motion vector of i[th] horse towards the average best horse with *X* location, ρN is the number of horses with best locations, ρ is, usually, 10% of the horses, ω_i is the reduction factor per cycle.

e. Defense Mechanism

It is known that the Horses defend themselves by fight or fight response. They first try to escape and they buck in case of trapping. Horses fight for food and water with the rivals. They also fight with unfriendly or hazardous environment. Horses' defense mechanism in Horse-herd algorithm includes running away from the horses showing inappropriate response. The defense mechanism works throughout the life of the horse. The defense mechanism of horses is indicating by following equations.

$$D_m^{iter,A} = -d_m^{iter,A}[(\frac{1}{qN}\sum_{j=1}^{qN} X_j^{(iter-1)}) - X^{(iter-1)}], \quad A = \alpha, \beta, \gamma \tag{16}$$

$$d_m^{iter,A} = d_m^{(iter-1),A} \times \omega_d \tag{17}$$

Where, $D_m^{iter,A}$ is the escape vector of i[th] horse from the average of some horses with worst locations which are shown by X vector, qN is the Number of horses with worst location, q is 20% of the total horses, ω_d is the reduction factor per cycle for d_{iter} .

f. Roam

It is fact that the horses roam outside in search of food. A horse may suddenly go somewhere to graze. Horses are usually very curious and visit new places to discover new pasture or to know their neighborhood well. The roaming in horse is usually found in young ages and gradually disappears with attaining maturity. The equations describing this stage are as follows.

$$R_m^{iter,A} = r_m^{iter,A}\rho X^{(iter-1)}, \quad A = \gamma, \delta \tag{18}$$

$$r_m^{iter,A} = r_m^{(iter-1),A} \times \omega_r \tag{19}$$

Here, $R_m^{iter,A}$ is the random velocity vector of i[th] horse for a local search and escape for local minima, ω_r is the reduction factor of $r_m^{iter,A}$ per cycle. Equations (20)-(23) give the velocities of the horses under δ, γ, β and α categories respectively.

$$V_m^{iter,\delta} = \left[g_m^{(iter-1),\delta}\omega_g(\mu+\rho l)X_m^{(iter-1)}\right] + \left[i_m^{(iter-1),\delta}\omega_i\left[\frac{1}{\rho N}\sum_{j=1}^{\rho N} X^{(iter-1)}\right]\right] + \left[r_m^{(iter-1),\delta}\omega_r\rho X^{(iter-1)}\right] \tag{20}$$

$$V_m^{iter,\gamma} = \left[g_m^{(iter-1),\gamma}\omega_g(\mu+\rho l)X_m^{(iter-1)}\right] + \left[h_m^{(iter-1),\gamma}\omega_h\left[X_*^{(iter-1)} - X_m^{(iter-1)}\right]\right] + \left[s_m^{(iter-1),\gamma}\omega_s\left[\frac{1}{N}\sum_{j=1}^{N} X_j^{(iter-1)} - X_m^{(iter-1)}\right]\right] + \left[i_m^{(iter-1),\gamma}\omega_i\left[\frac{1}{\rho N}\sum_{j=1}^{\rho N} X_j^{(iter-1)} - X^{(iter-1)}\right]\right] - \left[d_m^{(iter-1),\gamma}\omega_d\left[\frac{1}{qN}\sum_{j=1}^{qN} X_j^{(iter-1)} - X^{(iter-1)}\right]\right] + \left[r_m^{(iter-1),A}\omega_r\rho X^{(iter-1)}\right] \tag{21}$$

$$V_m^{iter,\beta} = [g_m^{(iter-1),\beta}\omega_g(\mu+\rho l)[X_m^{(iter-1)}]] + [h_m^{(iter-1),\beta}\omega_h[X_*^{(iter-1)} - X_m^{(iter-1)}]] + [s_m^{(iter-1),\beta}\omega_s[(\frac{1}{N}\sum_{j=1}^{N} X_j^{(iter-1)}) - X_m^{(iter-1)}]] - [d_m^{(iter-1)}\omega_d[(\frac{1}{qN}\sum_{j=1}^{qN} X_j^{(iter-1)}) - X^{(iter-1)}]] \tag{22}$$

$$[s_m^{(iter-1),\beta}\omega_s[(\frac{1}{N}\sum_{j=1}^{N} X_j^{(iter-1)}) - X_m^{(iter-1)}]] - [d_m^{(iter-1)}\omega_d[(\frac{1}{qN}\sum_{j=1}^{qN} X_j^{(iter-1)}) - X^{(iter-1)}]] \tag{23}$$

g. Effect of Various Parameters of Horse Herd Optimization Algorithm

The HOA increases the speed of searching and avoids the local maxima trapping by using sorting mechanism from a global matrix. HOA algorithm employs 6 factors of horse movement and keeps a good balance between exploration and exploitation phases and thus reduces the complexity in the problem solving process. The various parameters that affect HOA algorithm are as follows.

The Hierarchy factor (h_β and h_γ) for β and γ horses are equal to 0.9 and 0.5 respectively for best convergence. The Sociability factors s_β and s_γ are 0.2 and 0.1 respectively. The limiting factor i_γ is 0.3. The Defense factors ($d_\alpha, d_\beta, d_\gamma$) for α, β, γ horses are 0.5, 0.2 and 0.1 respectively. And, the Roam factor r_δ and r_γ are equal to 0.1 and 0.05 respectively. The flow chart given in the Fig. 8 will completely infer the HO algorithm.

4. Results and Discussions

The Horse-herd algorithm is implemented using MATLAB R2018a environment.

Case-1: For partial shading condition.

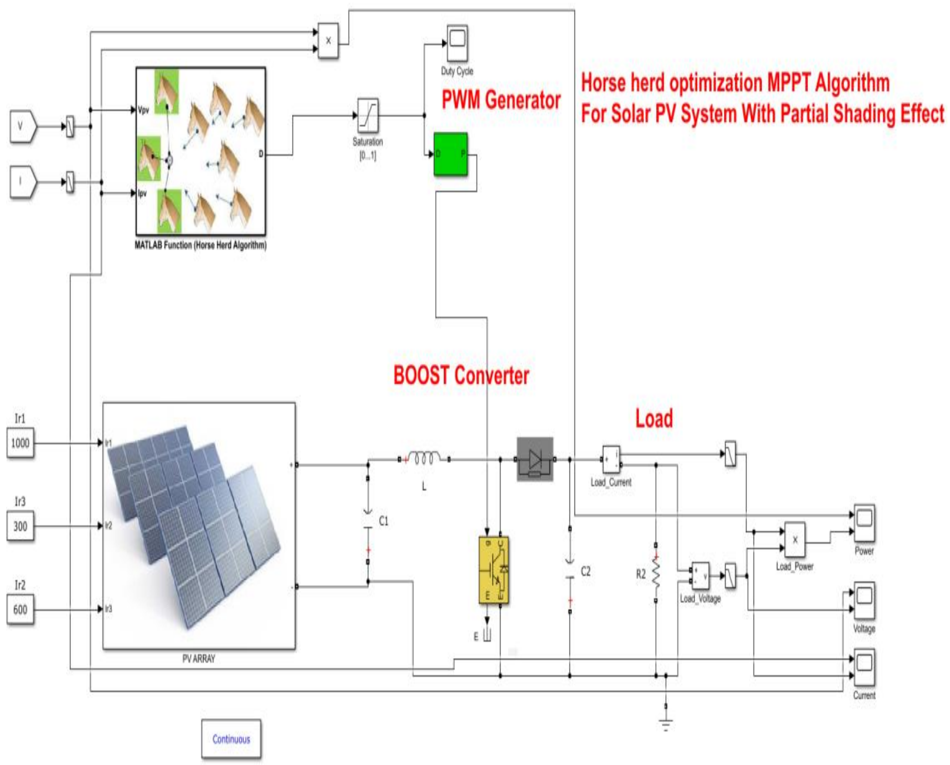

Fig. 6: Arrangements for tracking global peak using Horse-herd algorithm under partial shading condition

Here the same system as shown in Fig. 6 has been simulated and duty cycle (best position of horse) of the converter is being controlled via Horse-herd algorithm. Here we considered resistive load of 10 Ω. The output power, voltage and current of PV array and the same across the resistive load were measured with respect to time, as shown in Fig. 7. It is to be noted that the blue line represents PV array output parameters and red line indicates the same parameters across the resistive load.

The value of load power is little less than output power due to loss in the system. The various parameters of each module for the given partial shading are listed in the Table-3.

Duty cycle (D) of the boost converter is obtained by the Horse herd optimization algorithm.

$$D = \frac{T_{on}}{T_{on} + T_{off}} \tag{24}$$

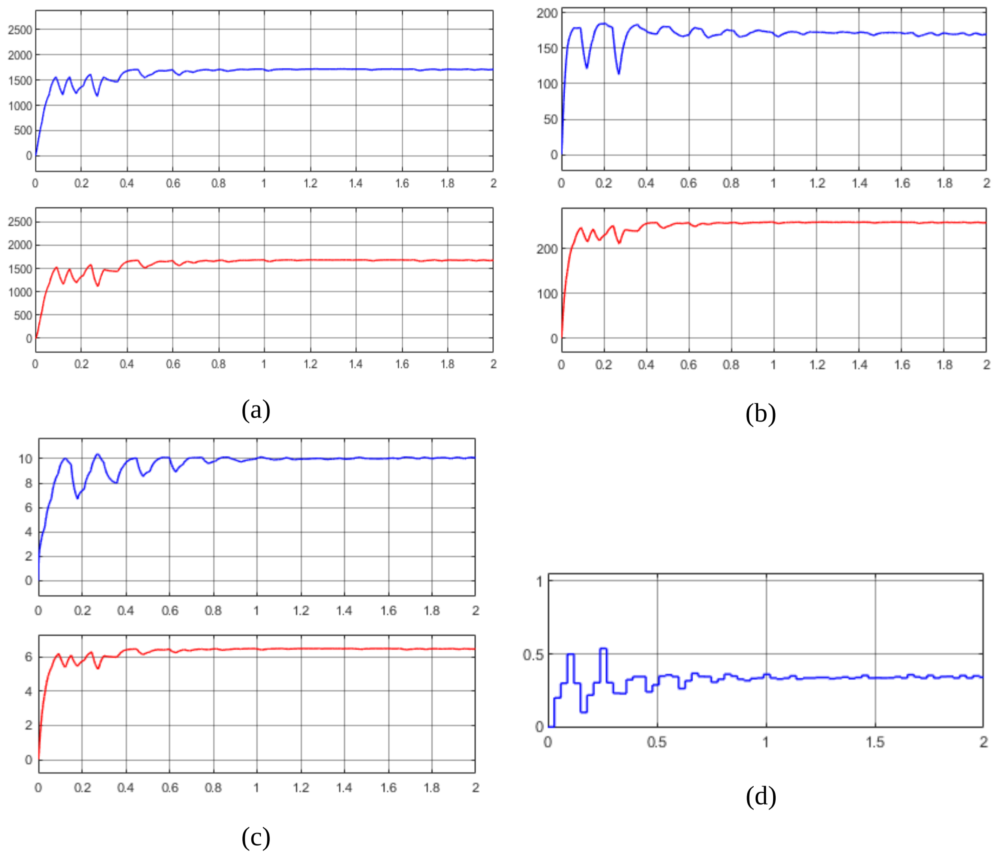

Fig. 7. Variations in Power (a), Voltage (b), and Current (c) across PV array (Blue) and Resistive Load (Red) with respect to time, for the selected Duty cycle (d).

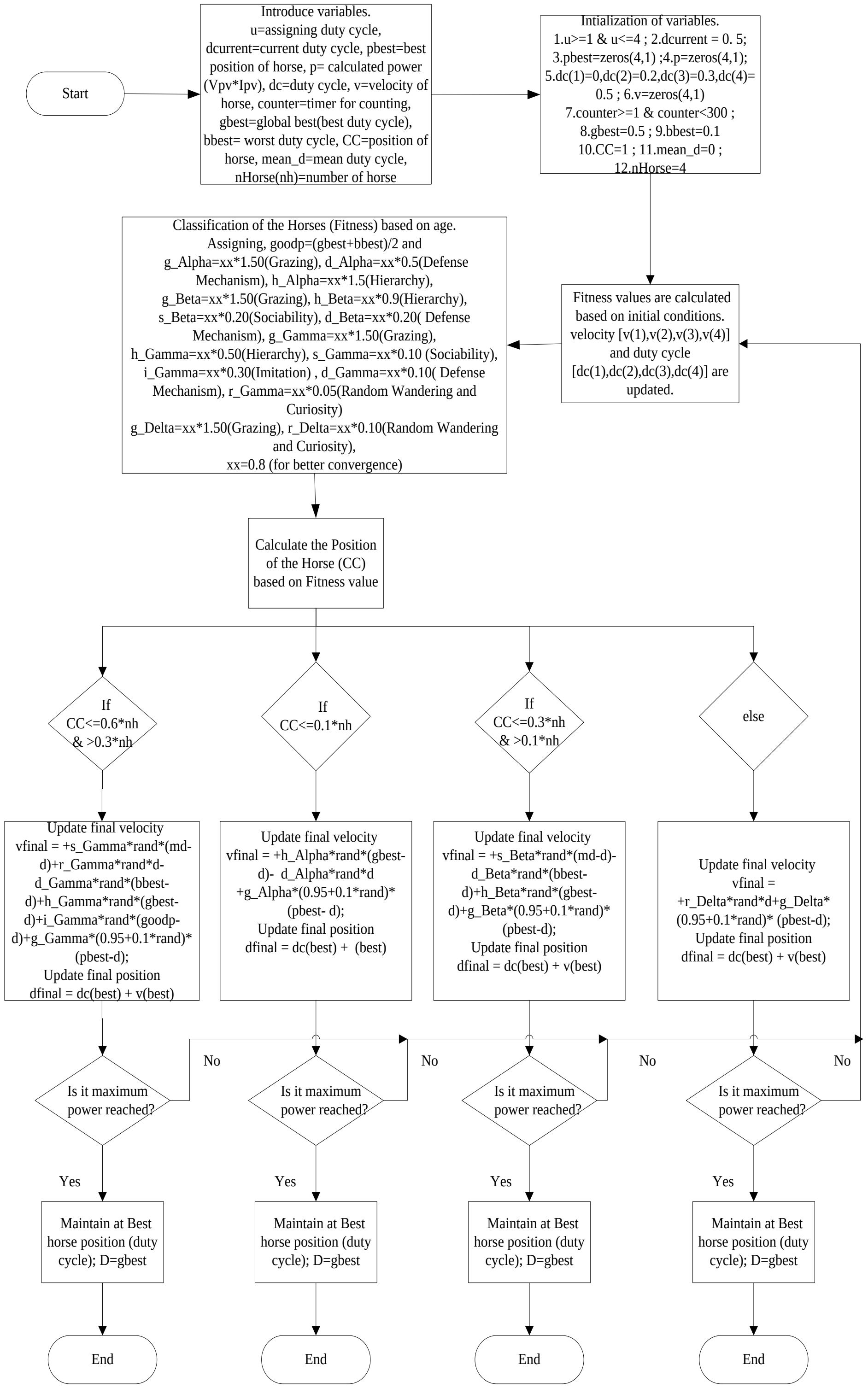

Fig. 8. Flow-chart for the Horse herd algorithm

Table 3: Result of the simulated PV array connected to resistive load using horse-herd algorithm under partial shading Condition

Parameter	Theoretical values	PV array output (Simulated)	Converter output at load terminal (Simulated)	Converter steady state duty cycle	Tracking time (sec)	Tracking efficiency
Global Peak Power	1721 Watts	1720 Watts	1684 Watts	0.3356	0.985	99.94%
Voltage at Global peak (V_{gp})	172.8 Volts	172.7 Volts	259.6 Volts			
Current at Global Peak (I_{gp})	9.96 Amps	9.96 Amps	6.49 Amps			

Case-2: Initially partial shading but after that uniform solar irradiation happens

As shown in Fig. 9, two modules of PV array get fixed irradiation of 1000 Watt/m2 and one module receives varying irradiation with respect to time. Figure 10 shows shading pattern of the varying irradiation.

From Fig. 11, it is to be followed that during 0-2 seconds, two modules receive fixed irradiation of 1000 Watt/m^2 and one module getting 300 Watt/m^2. During 2-4 seconds, two modules get same irradiation (1000 Watt/m^2) but the third module receives the irradiation with a slope of 350 Watt/m^2. And, after 4 seconds, all three modules get same irradiation of 1000 Watt/m^2. The various parameters of each module for the given partial shading considered under case-3 are listed in the Table-4.

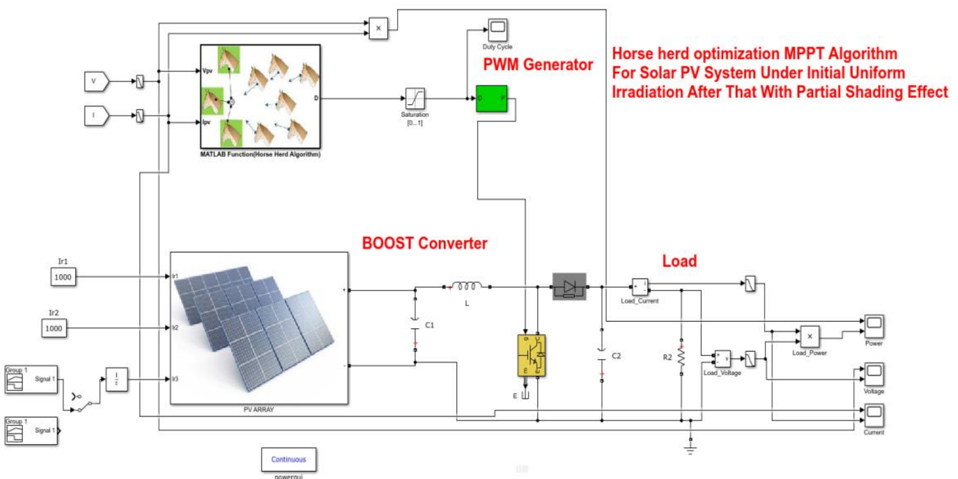

Fig. 9. Arrangements of PV panel for initially uniform solar irradiation and then partial shading

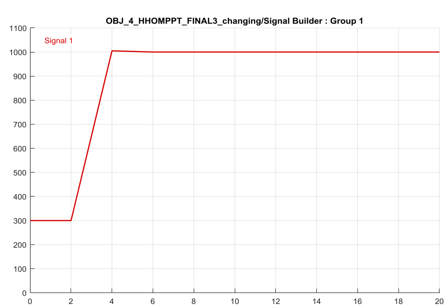

Fig. 10. Shading pattern of third module of PV array for case 3

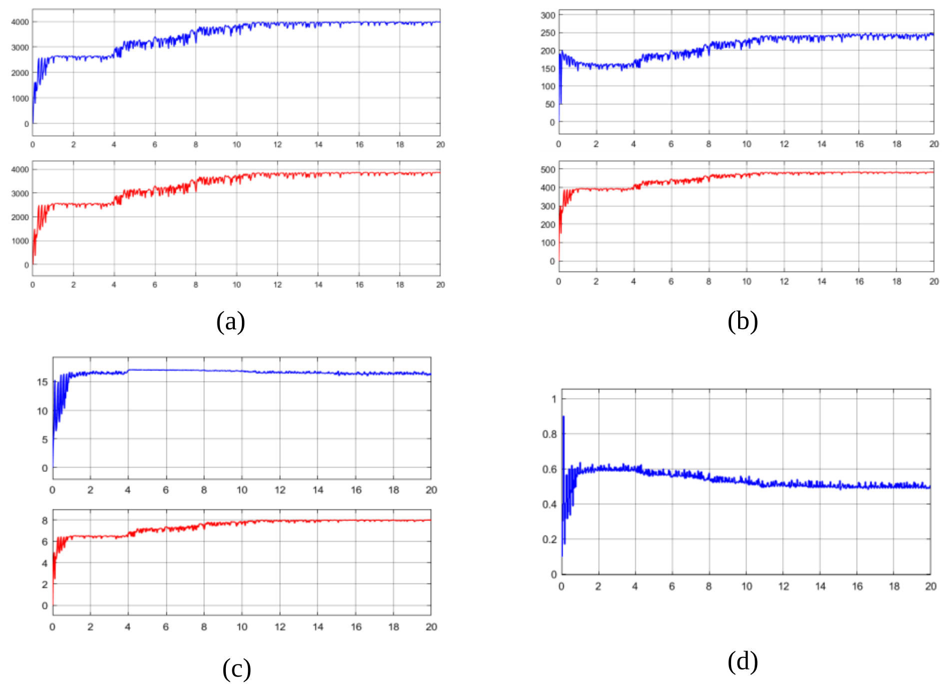

Fig. 11. Variations in Power (a), Voltage (b), and Current (c) across PV array (Blue) and Resistive Load (Red) with respect to time, for the selected Duty cycle (d), considering partial shading

Table 4. Result of the simulated PV array connected to resistive load using horse-herd algorithm under initially partial shading condition after that uniform irradiation occurred

<table>
<tr><th>Parameter</th><th>Theoretical values</th><th>Experimental simulated values (PV array output)</th><th>Experimental simulated values (Converter output at load terminal)</th><th colspan="2">Converter steady state duty cycle</th><th colspan="2">Tracking time (in sec)</th><th colspan="2">Tracking efficiency</th></tr>
<tr><td>Global Peak Power (For 0-2sec)</td><td>2653 Watt</td><td>2651 Watt</td><td>2566 Watt</td><td rowspan="6">Initially 0.58</td><td rowspan="6">After 4 sec 0.49</td><td rowspan="6">Initially under uniform irradiation it took 1.22 sec to track Peak</td><td rowspan="6">After 4sec at new condition, it took 7 sec to track GP</td><td rowspan="6">Initially 99.92%</td><td rowspan="6">After 4 sec 99.89 %</td></tr>
<tr><td>Global Peak Power (For 4 sec onward)</td><td>3997 Watt</td><td>3993 Watt</td><td>3865 Watt</td></tr>
<tr><td>Voltage at Global peak (V_{gp}) (For 0-2sec)</td><td>165 Volts</td><td>164.7 Volts</td><td>393.5 Volts</td></tr>
<tr><td>Voltage at Global peak (V_{gp}) (For 4 sec onward)</td><td>247.6 Volts</td><td>247.2 Volts</td><td>483 Volts</td></tr>
<tr><td>Current at Global Peak (I_{gp}) (For 0-2sec)</td><td>16.08 Amps</td><td>16.09 Amps</td><td>6.52 Amps</td></tr>
<tr><td>Current at Global Peak (I_{gp}) (For 4 sec onward)</td><td>16.14 Amps</td><td>16.15 Amps</td><td>8.02 Amps</td></tr>
</table>

To proove the efficacy of the proposed method we have compared the results with various algorithms applied so far for finding MPPT, and is tabulated in Table 5.

Table 5. Comparison of the proposed method with other methods

Optimization Algorithm	*MPPT efficiency*
OD-PSO [5]	99.83%
M-FF [10]	99.73%
P&O-PSO [8]	99.82%
P&O [9]	31.30%
IPSO [6]	99.75%
GWO [12]	99.81%
AM P&O [17]	95%
SSO [20]	99.87%
FC-FPA [15]	99.8976%
Horse-Herd Optimization	99.94%

The comparison shows the Horse-Herd algorithm produces highest efficiency regarding MPPT than contemporary other techniques.

5. Conclusion

In this paper Horse-herd algorithm, a new meta heuristic algorithm, is suggested for solving Maximum Power Point Tracking problem under partial shading conditions for PV cells. The methodology is tested with various conditions and changing shading patterns. Then, the results are compared with contemporary algorithms that have been implemented so far. The result analysis show that the efficiency of the proposed algorithm is higher compared to other algorithms though the tracking time is little higher. The proposed method also works in efficient manner when tested in different shading patterns. Hence, it can be concluded that the Horse-herd algorithm would be a best technique for solving Maximum Power Point Tracking (MPPT) problem where efficiency is the key criteria.

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