Prediction of the optimum surface orientation angles to achieve maximum solar radiation using Particle Swarm Optimization in Sabha City Libya

F A Mansour¹, M Nizam², M Anwar³
¹ Student, Mechanical Engineering Department, Sebelas Maret University, Surakarta
² Professor, Electrical Engineering Department, Sebelas Maret University, Surakarta
³ Lecturer, Electrical Engineering Department, Sebelas Maret University, Surakarta
E-mail: fathifg@yahoo.co.uk

Abstract. This research aims to predict the optimum surface orientation angles in solar panel installation to achieve maximum solar radiation. Incident solar radiation is calculated using koronakis mathematical model. Particle Swarm Optimization (PSO) is used as computational method to find optimum angle orientation for solar panel installation in order to get maximum solar radiation. A series of simulation has been carried out to calculate solar radiation based on monthly, seasonally, semi-yearly and yearly period. South-facing was calculated also as comparison of proposed method. South-facing considers azimuth of 0°. Proposed method attains higher incident predictions than South-facing that recorded 2511.03 kWh/m² for monthly. It were about 2486.49 kWh/m², 2482.13 kWh/m² and 2367.68 kWh/m² for seasonally, semi-yearly and yearly period. South-facing was calculated also as comparison of proposed method. South-facing considers azimuth of 0°. South-facing predicted approximately 2496.89 kWh/m², 2472.40 kWh/m², 2468.96 kWh/m² and 2356.09 kWh/m² for monthly, seasonally, semi-yearly and yearly periods respectively. Semi-yearly is the best choice because it needs twice adjustments of solar panel in a year. Yet it considers inefficient to adjust solar panel position in every season or monthly with no significant solar radiation increase than semi-yearly and solar tracking device still considers costly in solar energy system. PSO was able to predict accurately with simple concept, easy and computationally efficient. It has been proven by finding the best fitness faster.

1. Introduction
Utilization of the solar energy depends on solar radiation that striking the surface. Solar radiation on the surface information is important to engineer for designing solar collector device installations in order to maximize solar radiation. Solar radiation on inclined surface information is needed to enrich the accurate information of solar radiations beside solar radiation in horizontal surface. It purposed to determine the optimum orientation of the solar collector device in receiving maximum solar radiation to generate maximum energy. The optimum orientation angles depend on radiation area characteristics, climate, latitude and also period utilizations during a year [1, 2, 3, 4]. However comprehensive solar radiations data is not widely available on the developing countries. Therefore, it is necessary to develop methods to predict the solar radiations [5].
Global solar radiations depend on beam and diffuse solar radiation components. Some research have been carried out to develop mathematical relations in assessing solar radiation of inclined surface gain such as Liu and Jordan, Klein, Klutcher, Hay, Riendl, Koronokis and soon. The models categorized into two, which are isotopic model and anisotropic model due to different deal about sky diffuse component. Isotropic assumes that the intensity of diffuse radiation is uniform over entire the skies, while anisotropic assumes circumsolar diffuse, horizontal brightening or both [3].

Particle Swarm Optimization (PSO) is an evolutionary computation technique that is developed to optimize continuous non-linear, constrained and unconstrained, non-differentiable multi-modal function [6]. The concept based on the behavior of organism such as bird flocking or fish schooling. This optimization has been tested as simple concept, computationally efficient, easy to implement and accurate result as well. It maintains several candidate solutions on the search space. The algorithm remembers the global best fitness and the candidate solutions. Every iteration either local or global best are updated in order to achieve better fitness value.

This study is proposed to measure the incident solar radiation on an arbitrary surface and to predict the monthly, seasonally, semi-yearly and annually optimum orientation angles in order to achieve maximum solar radiations in Sabha city, Libya. Koronakis method which is an isotropic model will be applied to predict global solar radiations on inclined surface in various angles. Further PSO will be employed to analyze and determine the best solution for optimum orientation angles.

1.1. Principle of Solar Radiation

Global horizontal solar radiation (G) is the total of solar radiation that reach the horizontal on earth surface. The power that produced by solar collectors will depends on the radiations reaching the solar panel surface which generally is not horizontal. So in each time, it must be calculated the global solar radiation incident on the surface of the panel [7]. Figure 1 illustrates beam radiation direction, which are angle of incidence (θ), zenith angle (θz), solar altitude angle (αa), tilt angle (β), surface azimuth angle (γ) and solar azimuth angle (γs).

\[
\delta = 23.45^\circ \sin \left[360^\circ \left(\frac{284 + n}{365}\right)\right] \tag{1}
\]

Solar hour angle can be calculated thorough following equation:

\[
\omega = (t_c - 12hr) \cdot 15'/hr \tag{2}
\]

Where \(t_c\) is the civil time in respect to the midpoint of time step (hour), \(\lambda\) is local longitude, \(Z_c\) is time zone in hours, east of GMT, and \(E\) is equation time. Time equation accounts due to obliquity effect, which means tilt of earth axis rotation relative to the ecliptic plane and the earth eccentricity orbit is derived as following calculation:
And B here is given by:

\[ B = 360^\circ \left( \frac{n-1}{365} \right) \] 

(4)

\( n \) is the day of the year, starting with 1 for January 1st.

Incidence Solar Radiation Angle is the angle between beam radiations and the normal on a surface for any orientation. It derives from following equation:

\[
\cos \theta = \sin \delta \sin \phi \cos \beta - \sin \delta \cos \phi \sin \gamma + \cos \delta \cos \phi \cos \beta \cos \omega + \sin \delta \sin \beta \sin y \sin \omega
\]

(5)

Where \( \theta \) is the angle of incidence, \( \beta \) is the slope of the surface, \( \gamma \) is the azimuth of the surface, \( \phi \) is the latitude, \( \delta \) is the solar declination, \( \omega \) is the hour angle. Zenith angle is the angle between vertical and line to the sun, which is the angle of incidence of beam radiation on a horizontal surface. It is zero when the sun is on overhead position and 90°. Zenith angle derived be setting the \( \beta = 0 \) in previous equation, which is:

\[
\cos \theta_z = \cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta
\]

(6)

The sunset hour angle derived from the following equation:

\[
\omega_s = \pm \cos^{-1}(\text{tang} . \text{tan} \delta)
\]

(7)

Where the sign (+) is for the sunrise and (-) is for the sunset hour angles. \( \phi \) is the latitude of location and \( \delta \) is the declination angle.

\[ G_{on} = G_{sc} \left[ 1 + 0.033 \cos \left( \frac{360n}{365} \right) \right] \] 

(8)

\( G_{sc} \) is the solar constant (1.367 kW/m²), and \( n \) is the day of the year (a number between 1 and 365).

Extraterrestrial horizontal radiation \( (G_o) \) is solar radiation that striking a horizontal surface at the top atmosphere. Its amount can be calculated as follows:

\[ G_o = G_{on} \cos \theta_z \]

(9)

Those calculations simulate on a time step by step basis, equation 10 integrated over the time step to determine the average extraterrestrial horizontal radiation over the time step as follow:

\[
\bar{G}_o = \frac{12}{\pi} G_{on} \left[ \cos \phi \cos \delta \cdot (\sin \omega_2 - \sin \omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin \phi \sin \delta \right]
\]

(10)

Where \( \bar{G}_o \) is the extraterrestrial horizontal radiation averaged over the time step (kW/m²), \( \omega_1 \) is the hour angle at the beginning of the time step and \( \omega_2 \) is the hour angle at the end of the time step. Furthermore, it can be revealed monthly average daily for extraterrestrial horizontal radiation \( (H_o) \) and global horizontal radiation \( (H) \). \( H_o \) and \( H \) for day derived from hourly of \( G_o, \bar{G} \) respectively can be found the monthly average as follows:

\[ H_{o,ave} = \frac{\sum_{i=1}^{N} H_o}{N} \]

(11)

\[ H_{ave} = \frac{\sum_{i=1}^{N} H}{N} \]

(12)

\( N \) is the number of days in the month.
1.2. Solar Radiation of Surface
Enumeration of both beam and diffuse radiation defines as global solar radiation which is expressed as following equation:

\[ \bar{G} = \bar{G}_b + \bar{G}_d \]  \hspace{1cm} (13)

Where \( \bar{G}_b \) is the beam radiation (kW/m\(^2\)) and \( \bar{G}_d \) is the diffuse radiation (kW/m\(^2\)). Beam and diffuse classification become main role in calculation of solar radiation on inclined surface. The surface orientation has an effect on the beam radiation which comes from one part of the sky, while diffuse radiation can comes from all over sky dome. It means the calculation must solve the global horizontal radiation in every step into the beam and diffuse radiation to find radiation incident on the surface. It uses correlation which introduced by Erbs for this purpose. It gives diffuse fraction as a clearness index function as follows:

\[ \frac{G_d}{G} = \begin{cases} 1.0 - 0.09, & K_T \\ 0.9511 - 0.1604.K_T + 4.380.K_T^2 - 16.638.K_T^3 + 12.336.K_T^4 & \text{for } K_T \leq 0.22 \\ 0.165 & \text{for } 0.22 < K_T \leq 0.80 \\ & \text{for } K_T > 0.80 \end{cases} \]  \hspace{1cm} (14)

Global horizontal radiation average can be used to calculate clearness index, further the diffuse radiation. It calculates beam radiation through retrieving the diffuse radiation from the global horizontal radiation.

1.3. Total Incident Radiation on Inclined Surface based Koronokis Model
Global solar radiation on the inclined consists of three components; beam, diffuse, and reflected component. So that total radiation incident can be calculated:

\[ G_T = G_{bT} + G_{dT} + G_{gr} \]  \hspace{1cm} (15)

\( G_T \) defines as hourly total radiation on a tilted surface (KW/m\(^2\)) and \( G_{bT} \) is hourly beam radiation on a tilted surface (KW/m\(^2\)).

\[ G_{bT} = (G - G_d) \times R_b \]  \hspace{1cm} (16)

\( R_b \) is the ratio of beam radiation on inclined surface with the beam radiation in horizontal surface. It can be calculated as following equation:

\[ R_b = \frac{\cos \theta}{\cos \theta_s} \]  \hspace{1cm} (17)

Koronokis expressed diffuse solar radiation as isotropic component which comes from all over sky dome \( G_{dT} \) is hourly diffuse radiation on a tilted surface (KW/m\(^2\)) expressed by [5]:

\[ G_{dT} = \left( \frac{2 + \cos \theta}{3} \right) \]  \hspace{1cm} (18)

Hourly ground-reflected solar radiation expressed as follows:

\[ G_{gr} = \bar{G} \times \rho_g \times \left( \frac{1 - \cos \theta}{2} \right) \]  \hspace{1cm} (19)

Total incident solar radiation on inclined surface can be derived from substitution of equation (18), (19), (21) and (22) as follows:

\[ G_T = (G - G_d) \times R_b + \left( \frac{2 + \cos \theta}{3} \right) + \bar{G} \times \rho_g \times \left( \frac{1 - \cos \theta}{2} \right) \]  \hspace{1cm} (20)

\( \rho_g \) is the ground reflectance, which is also called the albedo.

1.4. Particle Swarm Optimization (PSO)
Kennedy and Eberhart (1995) introduced Particle Swarm Optimization (PSO) as a result of motivation by the behavior of bird flocking or fish schooling. The concept consists of a number of particles omitting their position in given search space. Each particle characterized by its position and become a candidate solution towards the problem [9]. The particles change the position in a multidimensional search space exploring better fitness positions.

PSO starts with initial random population of particles where each particle is a candidate solution. The particles’ velocity and position are initialized at random. During the optimization process, each particle memorizes its own best position encountered so far which is called the local best. On the other hand, the population memorizes the best position among all individual best positions obtained so far which is called the global best. To balance between the global and local exploration capabilities of the particles, inertia weight is introduced. The inertia weight is linearly decreased through the optimization process to emphasize the search globally at initial iterations and locally at final iterations. PSO has several advantages over other optimization techniques including: simple in concept, easy to implement, and computationally efficient.

2. Experimental

This study proposed to predicts the solar radiation on inclined surface for Sabha city, Libya. It is located on the latitude of 27°2.77'N and longitude of 14° 25.25'E, at elevation of 420 m. Available solar energy data is global horizontal radiation. The data of this study were hourly global horizontal radiation, and ground reflection. The data simulated using MATLAB. The range of tilt and azimuth were -90° to +90° and -180° to +180° respectively. Population of particles was 20, inertial weight was 0.9 to attempt the balance between exploitation and exploration. Iteration number was chosen 50. C1 and c2 were 1.49 where c1 is to control the step towards local best position and c2 is to control the step towards global best position.

Procedure of the present study simulation began by creating Matlab programs to calculate solar radiation components, programs of PSO and South-facing simulation based on monthly, seasonally, semi-yearly and yearly periods. Second step was calculating parameters and component for hourly radiation components, programs of PSO and South-facing simulation based on monthly, seasonally, semi-yearly and yearly periods. Third step was simulating hourly, monthly and yearly incident solar radiation on the inclined surface with the Koronokis model (equation 23) as an objective function. It calculated at the range of tilt and azimuth angles. Further, applying PSO by creating certain sub-programs with tilt and azimuth angle as the constrain variables (equation 23) as an objective function. It calculated at the range of tilt and azimuth angles. Further, applying PSO by creating certain sub-programs with tilt and azimuth angle as the constrain variables to find optimum orientation angle and maximum incident solar radiation. The next was analyzing the simulation results to get conclusion.

The PSO algorithm can be described in the following steps:

1. **Initialization**: Initialize randomly n position vectors \(X_k(0), k = 1, 2, \ldots, n\). The elements of \(X_k\) are uniformly distributed in a suitable range. Subsequently, initialize randomly n velocity vectors \(V_k(0), k = 1, 2, \ldots, n\). The fitness of each particle is evaluated by using an objective function. Initialize the local best of each particle to its initial position and the global best to the best fitness among the best locals. Finally, initialize the range of the inertia weights \(\nu(0)\).

2. **Update velocity**: Each element \(j\) of the velocity vector of the \(k\)th particle can be updated as follows:

\[
u_{k,j}(t) = w(t)\nu_{k,j}(t-1) + C_1n_1 \left(x_{k,j}(t-1) - x_{k,j}(t-1)\right) + C_2n_2 \left(x_{k,j}(t-1) - x_{k,j}(t-1)\right)
\]

(21)

Where \(t\) is the iteration number, \(C_1\) is a positive constant called the cognitive parameter and controls the step size towards the particle’s local best position. \(C_2\) is a positive constant called the social parameter, and it controls the step size towards the global best position found by the entire swarm. \(n_1\) and \(n_2\) are uniformly distributed random numbers in \([0, 1]\) to add randomness to the
velocity updates, $x_{k,j}(t)$ represents the current position of the particle, $x^E_{k,j}$ is the particle’s best position, and $x^G_{k,j}$ is the global best position, $w(t)$ is the inertia weight to control the acceleration of the particle in its original direction. Lower values of $w$ speed up the convergence to the optima and higher values of $w$ encourage exploration of the entire search space. The first term of the velocity update $w(t)v_{k,j}(t-1)$ is the inertia component to keep the particle moving in the same direction as in the previous iteration. The second term $(c_1\tau_1(x^E_{k,j}(t-1) - x_{k,j}(t-1))$ is called the cognitive component and acts as a memory of the particle causing it to return to its local best that it has encountered so far. The third term $(c_2\tau_2(x^G_{k,j}(t-1) - x_{k,j}(t-1))$ is called the social component as it causes the particle to move towards the global best.

3. **Update position**: After updating the velocity of each particle, the particle position is updated using the lately updated velocity as:

$$x_{k,j}(t) = v_{k,j}(t) + x_{k,j}(t-1) \quad (22)$$

4. **Update bests**: The fitness of each particle is evaluated according to the new updated position. If the updated position leads to a better objective function value, the local best and the global best are updated.

5. **Stopping criteria**: The process is repeated until the number of iterations since the last change of the best solution is greater than a pre-specified number, or the number of iterations reaches a maximum allowable number or the desired value of the objective function is reached.

3. **Result and Discussion**

3.1. **Prediction of Monthly Incident Solar Radiation**

Detailed results of monthly incident solar radiation can be seen on table 1. Incident solar radiation of all scenarios seems attaining almost same amount on May, June, July and August. However apart from those months, PSO attained much higher than South-facing. The highest solar radiation happened on July which is in the middle of summer season. Others results show monthly optimum orientation angle which consist of tilt and azimuth angle for PSO and South-facing since this method considers azimuth at 0°. Tilt angle of PSO and South-facing recorded similar trend. Optimum tilt angle turned to similar angle on August to December. Azimuth angle of PSO has been described on table 1 during a year. The tilt angle or slopes seemed to close to horizontal surface on May to August.

Table 1 shows total monthly incident solar radiation for PSO, South-facing and Horizontal surface. PSO recorded the highest total monthly incident solar radiation which was 2511.03 KWh/m$^2$ due to the optimal tilt and azimuth angle while South-facing recorded 2496.89 KWh/m$^2$. PSO gave more accurate orientation in collecting incident solar radiation compared with other scenarios because it didn’t adjust tilt angle only but also the azimuth. The monthly optimization worked greatly on December and January since the incident solar radiation increased significantly than the horizontal surface compare with other months.

| Month | Horizontal Surface | PSO | South Facing |
|-------|-------------------|-----|-------------|
|       | ISR (KWh/m$^2$)  | ISR (KWh/m$^2$) | Optimum Angles | ISR (KWh/m$^2$) | Optimum Tilt (°) |
|       |                   |                 | Tilt (°) | Azimuth (°) |                       |                   |
| Jan   | 130.92            | 198.23          | 55.6503 | -9.3163    | 196.25               | 55.5938           |
| Feb   | 137.90            | 177.49          | 46.3746 | -7.3090    | 176.96               | 46.1815           |
| Mar   | 181.01            | 204.70          | 34.4587 | -23.7343   | 202.14               | 32.2312           |
| Apr   | 201.69            | 207.46          | 18.5012 | -39.7678   | 205.55               | 14.1388           |
3.2. Prediction of Seasonally Incident Solar Radiation

The result of simulation was illustrated on the figure 2. It can be seen that similar trend happened on seasonally prediction where PSO attained the highest incident solar radiation in all season during a year. It was 569.99 on winter where falling at optimum tilt angle of 53.93° and azimuth of -7.65°. Further it attained 613.22 KWh/m² on spring where falling at optimum tilt angle of 20.09° and azimuth of -39.10°. Simulation predicted 673.17 KWh/m² and 630.11 KWh/m² for fall and summer respectively. Those was retrieved at the optimum tilt angle of 8.79° and azimuth of -96.30° on fall season, meanwhile optimum tilt angle of 41.52° and azimuth of -5.57° were determined during summer season.

![Figure 2. Comparison of Seasonally incident solar radiation and Optimum Orientation Angles](image)

South-facing simulation calculated incident solar radiation approximately 567.40, 606.80, 669.07 and 629.13 KWh/m² on winter, spring, fall, and summer respectively during a year. Those fallen at optimum tilt angle of 53.66° along winter, 15.94° along spring, -1.85° along fall, and 40.96° along summer. South-facing considers 0 azimuth angle. Seasonally horizontal result shows incident solar radiations were 392.92, 592.91, 668.84 and 513.42 KWh/m² for winter, spring, fall, and summer season. Based on the figure 2, it can be figured out the highest incident solar radiation happened on summer season during a year, either conducted by PSO, South-facing and Horizontal surface. It also can be seen the optimum tilt angle of PSO and South-facing predicted at closed value and indicates similar trend as on the monthly prediction. Further the azimuth angle seems at same trend also with the monthly predictions. The optimization attained the best result on winter season where it increased the solar radiation better than other seasons comparing to horizontal surface.

3.3. Prediction of Semi-yearly Incident Solar Radiation

Semi-yearly simulation was conducted to determine the semi-yearly of optimum orientation angles and its maximum incident solar radiations. Semi-yearly was calculated based on first six month which
starts from October to March and second six month which starts from April to September. The result illustrated on figure 4.6. PSO predicted 1192.16 KWh/m² for October to March which fallen at optimum tilt angle of 48.70° and azimuth of -7.50°. It was 1289.97 KWh/m² during April to September where fallen at optimum tilt angle of 10.87° and azimuth of -56.63°.

| Period     | Horizontal Surface Solar radiation | South Facing Solar radiation | PSO Solar radiation |
|------------|------------------------------------|-------------------------------|--------------------|
| Oct-Mar    | 890.90                             | 1187.79                       | 1192.16            |
| Apr-Sep    | 1277.20                            | 1280.96                       | 1289.97            |
| Total      | 2168.10                            | 2468.75                       | 2482.13            |

South-facing predicted maximum incident solar radiation of 1187.79 during October to March where fallen at optimum tilt angle of 48.42° and it was 1280.96 KWh/m² during April to September where it fallen at tilt angle of 5.47°. Meanwhile horizontal surface predicted about 890 KWh/m during first six month of October to March and 1277.20 KWh/m for the rest months. Solar radiation was higher during April to September where the summer season happens on this period. The semi-yearly optimization recorded the best result during October-March because solar radiation increased better than on April-September period compare to horizontal surface.

3.4. Prediction of Yearly Incident Solar Radiation
Prediction of optimum orientation angle to collect maximum solar radiation on yearly basis can be seen on table 2. It shows that proposed method was able to find better solution for yearly optimum orientation angle. It can be seen that the total incident radiation of a year recorded better than South-facing. PSO calculated 11.6 KWh/m2 higher than South-facing which was approximately 2367.68 KWh/m2. This value falls at slope of 29.50° and azimuth of -18.29°. Meanwhile South-facing recorded 2356.09 KWh/m2 which fallen at slope of 28.27° where the azimuth considered at 0°.

Based on the orientation angle results, PSO determined the accurate orientation considering the higher solar radiation attained. The best solar panel installation of PSO inclined about 29.5° and rotating to face the east about 18.28°.

4. Conclusion
Incident solar radiation on inclined surface has been predicted which calculated using Koronakis mathematical model were. Total incident solar radiation has been calculated based on monthly, seasonally, semi-yearly and yearly which were simulated using PSO and South-facing. Total incident solar radiation of horizontal surface was 2168.10 KWh/m² for all periods. South-facing attained 2496.89, 2472.40, 2468.96 and 2356.09 KWh/m² for monthly, seasonally, semi-yearly and yearly respectively. PSO recorded 2356.80, 2486.49, 2482.13, and 2367.68 KWh/m² for monthly, seasonally, semi-yearly and yearly respectively. The best result by PSO rather than South-facing for all bases which were monthly, seasonally, semi-yearly and yearly. Monthly optimization recorded significant result in increasing solar radiation on December and January. Seasonally based optimization increased
solar radiation significantly on winter season, meanwhile October-March period increased better than another period for semi-yearly based optimization.

Monthly of PSO orientation angles tended to rotate the east due to the negative value of azimuth for all months, moreover it rotated to the east on May and to the north-east for June to July. South-facing result indicated that the slopes were closed to horizontal line due to small degrees which was in the range of -1° to +7° on May, June, July and August. Seasonally orientation angle of proposed method tended to rotate to the east because of negative value of azimuth with the range of -5° to -96° and it was closed to the horizontal surface on summer season. South-facing was also recorded to close to horizontal surface on summer season, where the slopes were on the range of +15° to +54° on fall, winter and spring. Semi-yearly azimuth angle of proposed method tended to rotate to the east which was -7.50° on October to March period and -56.63° for another period. The optimum slopes were at 48.70° for the first period and 10.87° for another one. South-facing result determined the optimum slopes were at 48.42° and 5.47° for first and second period respectively. The second period angles which were April to September indicated to close to horizontal surface. Meanwhile, yearly optimum orientation angles of proposed method determined at 29.5° slope and -18.29° azimuth angle. Yearly slope of south-facing was at 28.27°.

Semi-yearly based optimization determined as the best optimization although there were higher solar radiations for seasonally and daily bases because it would only need twice adjustments of the solar panel in a year. Yet it considers inefficient to adjust solar panel position in every season or even daily with no significant solar radiation increase than semi-yearly and solar tracking device still considers costly in solar energy system. PSO was able to predict accurately with simple concept, easy and computationally efficient. It has been proven by finding the best fitness faster.

References
[1] Darhmaoui H and Lahjouji D 2013 E. Procedia 42 426-435
[2] Khorasanizadeh H, Mohammadi K, Mostafaeipour A 2014 E. Conv. and Manage. 78 805-814
[3] Ng K M, Adam N M, Inayatullah O, Kadir M Z A A 2014 Inter. Journal of En. and Env. Engin. 5 011-13
[4] Noorian A M, Moradi I, Kamali G A 2008 Renewable Energy 33 61406-1412
[5] Shukla K, Rangnekar S, Sudhakar K 2015 Energy Reports 1 96-103
[6] Khare A and Rangnekar S 2013 Applied Soft Computing 13 52997-3006
[7] Duffie J A and Beckman W A 2013 Solar Engineering of Thermal Processes (New Jersey: Wiley)
[8] Kalogirou S A 2013 Solar Energy Engineering: Processes and Systems (California: Academic Press)
[9] Mohandes M A 2012 Solar Energy 86 113137-3145