# An Innovative Optimization Algorithm for Precis Estimation of the Optical Efficiency of Heliostat Fields

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*Received: 25.02.2016 Accepted:28.06.2016*

**Abstract-** Shading and blocking are one of the main causes that result in the drop of the optical performance of the heliostat fields. In this paper, we suggest through the simulation, an accurate and fast framework to enhance the optical performance of the solar field with the existence of the shading and blocking. By practicing the new style, running down the implementation time and keeping off unnecessary computations, our framework increases the speed of the computations through parallel computing architectures, then using the Artificial Neural Network (ANN) to investigate the efficiency of our proposed system. The results indicate the matching with the previous studies and satisfy the correspondence gain.The results also indicate the optimization of heliostat field layout for 2650 Sener heliostat, which considered as a reference in this work, by using the scarce open literature data on GEMASOLAR (Seville-Spain).Annual efficiency to transform sun's energy to thereceiver has been chosen as the target work. Each mirror position specified using an optimization algorithm, by utilizing the layouts of the MIT team model while two parameters of this model settle down the layout outline of the reflectors.

**Keywords:** central receiver system; heliostat field; parallel computing; artificial neural networks; shadowing and blocking; phyllotaxis

## 1. Introduction

The growth in energy demand, the depletion of fossil fuels, and the awareness of the public opinion of environmental problems motivatethe production of electrical energy from renewable sources.Sunshine is the most plentiful source of energy on Earth, and every year,the sun delivers more than 10,000 times the quantity of energy that humans currently use[1].Of all of the technologies for concentrated solar power (CSP), the solar power tower plant(SPTP) technologyis viewed as mostworthwhilebecauseits high working temperaturesincreasethe efficiency of the power cycle. With this great featureand the recentfocus ondecreasing the price and increasing the efficiency of (SPTP), most researchershave been inspired to workon(SPTP) technology.The primary function is performed by a large number ofjoined reflectors thatare called the heliostat field,which reflectand condense the rays of the sun toward a main receiver. A computer controls the rotation of each reflector around two axes to ensure a continuous, accurate orientation, with a tracking error of less than a fraction of a degree. By this orientation,the intensified sunlightis focused directlyon the tower receiver,where an absorberis heated to temperatures of approximately 1000 ℃ or more[2]. Heat transfer fluid(HTF) then transfers the absorbed energy to a heat exchanger connected to a gas or steam turbine, which is in its turn coupled to an electricgenerator. The capital importance and the topic of many studiesare the ideallayouts of the reflector field,mainlybecause theapproach requires 50% of the full price of the scheme, and the annual energy loss is approximately 47%[3]. Several codes have been produced for this purposedating from the 1970s,and most of thosecodes are

recorded in Ref.[4]. At the same time, the most recent codes[5], [6], [7], [1]mostly use various forms ofaccessforincreasing the global efficiency,which isgiven as:

$$\eta = \eta_{cos} \times \eta_{at} \times \eta_{in} \times \eta_{s\&b} \times \eta_{ref} \quad (1)$$

Wheretheparameters are the cosine effect efficiency($\boldsymbol{\eta_{cos}}$),the atmospheric attenuation efficiency($\boldsymbol{\eta_{at}}$),theinterception efficiency($\boldsymbol{\eta_{in}}$),theshading and blocking efficiency($\boldsymbol{\eta_{s\&b}}$), and thereflectivity of the heliostats$\left(\boldsymbol{\eta_{ref}}\right)$.The mean yearly heliostat field efficiency orthe insolation weighted efficiency$\left(\eta_{year,Eb}\right)$is calculated[5] and defined as:

$$\eta_{year,Eb} = \frac{\sum_{day=1}^{365} \int_{sunrise}^{sunset} E_b(t)\eta(t)dt}{\sum_{day=1}^{365} \int_{sunrise}^{sunset} E_b(t)dt} \quad (2)$$

because any (SPTP) optimization operation should depend on the annual energy estimation of the different layouts studied.The annual energy is the integrated sum of the instantaneous energy transformed byall reflectors, over the moments of time[8].

The demand for working out $(\boldsymbol{\eta_{s\&b}})$with high precision, as time, is high as a rule because the result depends on different factors such as the position of the sun, theposition of the reflector, and placement of the neighboring reflectors.At the same time, one of the main ingredients that result in the decline of the optical performance of the heliostat fields must be considered. Thus, during the optimization,all neighbors causing shading or blocking the analyzed reflector should be evaluated individually, to estimate the $(\boldsymbol{\eta_{s\&b}})$ exactly.

Shading often takes place when a heliostat is shaded from the sunlight by an adjoining heliostat or a tower, and blockingsimilarly occurs if a heliostat blocks the rays of the sun being reflected from an adjoining receiver. Theoretically, high-density heliostat layouts would result in serious shading and blocking and reduce the optical efficiency. Nevertheless, the placement of the mirrors should be equidistant from the tower as much as possible to obtain a high intercept factor. Thus, to optimize the heliostat field layout, the effects of shading and blocking should be computed accurately.

M.Chiesi et al.[1]cut down the computational time through algorithms that utilizea new parallel calculatingframeworkdepending on the general objective graphic processing units and carried out on desktop workstations, developed with multiple graphics processing units (GPUs) using the data parallel programming pattern provided by the CUDA C implementation.In addition, the algorithmsfor computingthe shading and blocking effect based on projection coordinates of the affected heliostats onto the plane are called mirrorprojection.The main heliostatis then discretized into a matrix of square sub-mirrors.A sub-mirroris counted in the shadow area if the projection of the neighboringmirror falls on it.Similarlyto blocking,the only difference is in the observation position, which, in this case,corresponds to the receiver.The model is consideredaccurateif it has a high number of sub-elements,but this condition also results in slow speed[9], soparallel computing architectures wereused in their estimates. Nevertheless, the hurdle of this model is implemented in the normal hardware computing system.

Saeb et al. [7]built on the layout of the MIT team proposed by Noone et al. [5]while at the same timedeveloping the optimization by using genetic algorithm (GA) to find the best value for two parameters,which are considered responsible for the final layout of the field.However,thefixednecessary heliostats (594 of 3000)depend oncollected power after consideringglobal efficiencywithout calculation($\boldsymbol{\eta_{s\&b}}$).Further,estimation of theannual energy occurred after determining the number of fixed heliostatsbecausethe heliostats neededwere estimatedat noon, March 21st.

In this paper,the central ray tracing and discretization techniquewasadapted to calculate $(\boldsymbol{\eta_{s\&b}})$with small subdivisions and high accuracy.However,at the same time, the computational period was ameliorated, and superfluous computations for heliostats that werenot causing shading or blockingwere blocked, and the process could handle the overlapping problem created by multiple heliostats through using logical parameters.Development of this technique occurredwith theuse ofparallel computing architectures based on the MATLAB Parallel Computing Toolbox, andlater by using neural algorithmthatclarify in detail. The outcomesare consistent with those of other studies and good improvement in the result is obtained.Then, an optimization studywas performedwith a new methodology to find the best layout of the field for a GEMASOLAR(SPTP) (Seville –Spain), as a reference used in this work and as a case study[6],utilizing genetic algorithm (GA) and depending on the prophylaxis pattern proposed by Noone[5].

## 2. Simulation Tools

### *2.1 The location of the sun*

To interpret how to gather energy from the sun, one must first be able to predict the positionof the sun with respect

to the heliostats. In this paper, four main necessary solar angle equations have been applied to calculate annual efficiency.
Solar declination($\delta$): the angle between the earth/sun line and the equatorial plane[10].

$$\delta = 23.45 sin\left(360^o \frac{n_d + 284}{365}\right)(degree) \quad (3)$$

Hour angle ($\omega$)[5]for sunrise and sunset estimated from the equation:

$$\omega_{sunrise} = cos^{-1}(tan\,\phi\, tan\,\delta) - \pi = -\omega_{sunset}(rad) \quad (4)$$

Solar altitude angle($\alpha$): the angle between the horizontal plane and light waves coming from the sun[10].

$$\alpha = sin^{-1}(sin\delta\, sin\emptyset + cos\delta cos\omega cos\emptyset)\ \ (rad) \quad (5)$$

Solar azimuth angle($A$): the angular displacement that is measured from due north in a clockwise direction to the earth-sun line projection[11].

$$A = cos^{-1}\left(\frac{sin\delta\, cos\emptyset - cos\delta\, cos\omega\, sin\emptyset}{cos\alpha}\right)(rad) \quad (6)$$

Where:$if sin\,\omega > 0, \quad then\ A = 2\pi - A$

As noted before, the annual energy reaching the receiver is the total of the instantaneous energy produced by the solid field of heliostats. After transforming the energy from the solar radiation, the moments of time sampled are atypical of the ASHRAE Clear-sky Radiation Model [10], which was utilized to evaluate the solar radiation or beam normal irradiance $\boldsymbol{E_b}(\boldsymbol{t})$for (Seville –Spain), as clarified in the ASHRAE Handbook[10].

*2.2.Sener heliostats, specifications*

GEMASOLAR[12], [6]a power tower plant in (Seville, –Spain), is the plant used as a reference in this work,furthermore, the total dimensions of Sener heliostat and other parameters utilized in GEMASOLAR have been tabulated in Ref [12], [6].Thepresentstudy used field parameters are presented in Table 1.

**Table1**. Gemasolar fields parameters**[12]**, **[6]**

| **Heliostats** | |
|---|---|
| Width $\boldsymbol{W_h}$ | 12.305 m |
| Height $\boldsymbol{H_h}$ | 9.752 m |
| Heliostat total diagonal, $\boldsymbol{d_h}$ | 15.7 m |
| Heliostat total area, $\boldsymbol{A_h}$ | $120m^2$ |
| Heliostat mirror area, $\boldsymbol{A_m}$ | 115.7 $m^2$ |
| Effective reflectivity, $\boldsymbol{\eta_{ref}}$ | 0.88×0.95 |
| Heliostat numbers | 2650 |
| **Receiver** | |
| Tower optical height $\boldsymbol{h_t}$ | 140m |
| Receiver radius$\boldsymbol{R_r}$ | 4m |
| Receiver height $\boldsymbol{H_r}$ | 9m |
| Latitude location, $\boldsymbol{\phi}$ | 37.46 $N$°(Seville) |

*2.3.Coordinate transformation of heliostat and discretized heliostat surface*

In the selection coordinate system (referred to in the following text as "tower system of coordinates"), east is inthe positive$(y)$ direction, and north is in the positive $(z)$direction, while the zenith is in the $(x)$direction, as Fig (1) shows.

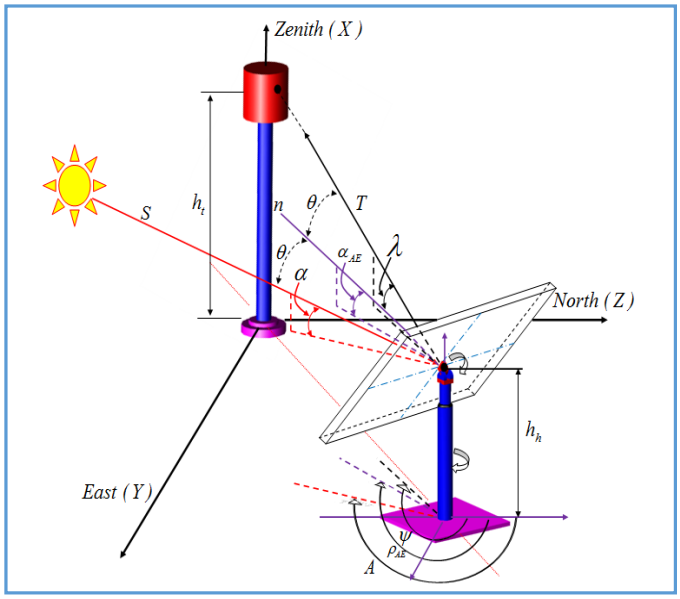



**Fig. (1).** Coordinate system for heliostat fields attached to the earth-surface reference frame

Given that the sun is a moving object while the receiver is a fixed object, the normal $(\vec{\boldsymbol{n}})$of the heliostat has toadjust when the sun position changes with time, to ensure that theheliostatis oriented at the necessary angles. To determine$(\boldsymbol{\eta_{s\&b}})$of the heliostat, the heliostat position frame

shouldbe estimated. The altered orientation of the frame during the sun tracking period in three-dimensional space can modelled by applying the coordinate transformation. For the convenience of the three-dimensional coordinate transformation, an additional dimension of spaceis added to make all of the transformations linear.The rest position or the initial coordinate of the frame is first defined in a fixed coordinate system. Whenthe plane of the heliostatis parallel to the x-y plane, the normal to its surface($\vec{n}$)is directed to the north direction,wherethe center point of the heliostat surface is given by $P_C$ with coordinating (0, 0, 0). In this analysis, the total heliostat surface elements in our research will be 100because the error reduces to less than $10^{-4}$ using a grid of 100 points[5],which are assigned for the gridfixed on the moving frame to study the shadow and block effect,as we will see in the following section. The coordinates of the pointsare treated as a vector in the coordinate space and arewritten as:

$$P_{i,j} = \begin{bmatrix} P_{i,j,x} \\ P_{i,j,y} \\ P_{i,j,z} \\ 1 \end{bmatrix} \tag{7}$$

In addition, the surface of the heliostat is partitioned into $(H_e)$ number for height$(H_h)$ and $(w_e)$ number for width$(W_h)$, and the diagonal diameter of the element $(d_e)$ which equals$d_e = \sqrt{(W_e^2 + H_e^2)}$, is calculated.
To convert from $(P_C)$ to the center of the discretization area $(P_{i,j})$, we should use translational transformation $[\boldsymbol{T_r}, \boldsymbol{c}]$**,**whichis written as

$$[T_r, c] = \begin{bmatrix} 1 & 0 & 0 & (H_h/2 - ((2 \times i) - 1/2) \times H_e) \\ 0 & 1 & 0 & \left((-W_h/2) - ((2 \times j) - 1/2) \times W_e\right) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

Then, the coordinates of the center of the discretization area relative to the center of the heliostatis calculated as follows:

$$P_{i,j} = \begin{bmatrix} P_{i,j,x} \\ P_{i,j,y} \\ P_{i,j,z} \\ 1 \end{bmatrix} = [T_r, c] \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{9}$$

The reflector is oriented using an actuator for rotation in the coordinate transformation for the Azimuth-Elevation ***(AE)*** sun-tracking method[11]. The first rotation transformation by the angle $(\alpha_{AE})$about the Y-axis will transform the point from the fixed coordinate system to an elevation-movement coordinate system. The second rotation transformation for the rotational movement by the angle $(\rho_{AE})$ about the X-axis will transform the point of the elevation-movement coordinate system to the azimuth-movement coordinate system, as shown by the following two rotation matrices, as follows:

$$[\alpha_{AE}] = \begin{bmatrix} \cos(\alpha_{AE}) & 0 & \sin(\alpha_{AE}) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\alpha_{AE}) & 0 & \cos(\alpha_{AE}) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

$$[\rho_{AE}] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\rho_{AE}) & \sin(\rho_{AE}) & 0 \\ 0 & -\sin(\rho_{AE}) & \cos(\rho_{AE}) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

After all of the rotational transformations, the points are transformed from the heliostat coordinate system to the real coordinate system in the heliostat field under a translational transformation $[\boldsymbol{T_r}, \boldsymbol{p}]$which is written as:

$$[T_r, p] = \begin{bmatrix} 1 & 0 & 0 & h_h \\ 0 & 1 & 0 & E_h \\ 0 & 0 & 1 & N_h \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

The final three transformation matrices for the heliostat $[G]$are presented as:

$$[G] = [T_r, p]([\rho_{AE}][\alpha_{AE}]) \tag{13}$$

Finally, the coordinates of the center of the discretization area after finishing the orientation and relative to the coordinate system in the heliostat field, after the transformation $(P'_{i,j})$ are written as:

$$P'_{i,j} = \begin{bmatrix} P'_{i,j,x} \\ P'_{i,j,y} \\ P'_{i,j,z} \\ 1 \end{bmatrix} = [G] \begin{bmatrix} P_{i,j,x} \\ P_{i,j,y} \\ P_{i,j,z} \\ 1 \end{bmatrix} \tag{14}$$

The final matrices are stored in the cells that had previously been set.

**3. Methodology and Mathematical Model.**

The procedure of an algorithm to estimate the annual optıcal efficıency of the heliostat field is presented in the flowchart as sketched in Fig. (2). the main step in forming of heliostat field, that

Define field layout, which are based on the pattern of the MIT model[5], which is inspired by the spiral patterns of the phyllotaxis disc. The disc shown increases the overall efficiency of the proposed model. The equations needed for this layout are presentedas [5]:

$$\theta_p = 2\pi\varphi^{-2}n_h \quad (15)$$

$$r_p = an_h^b \quad (16)$$

where$(\boldsymbol{\theta_p})$ is the polar position angle for heliostat in field, $(\boldsymbol{r_p})$ is the radius position for the heliostat, and$(a)$, and $(b)$ are the layout constants estimated precisely by applying an optimization algorithm later.Further,$(\boldsymbol{\eta_{year,Eb}})$ was considered as the objective function, and all optical efficiency factors were considered, is Estimated according to the Eq. (2). All of the days of the year (1→365) should be considered as shown in Fig. (2). or for comparison with the literature study, specify the 21st of each month during the year, and carry out the discretization model to estimate$(\boldsymbol{\eta_{s\&b}})$with all computations that are related to the other parameters of optical efficiency, that is clarified in Ref. [6] and [13], during the period from sunrise to sunset.

The shading and blocking function $(sbf)$ calculations are estimated after preparing the final three transformation $[G]$ matrices for the heliostat.

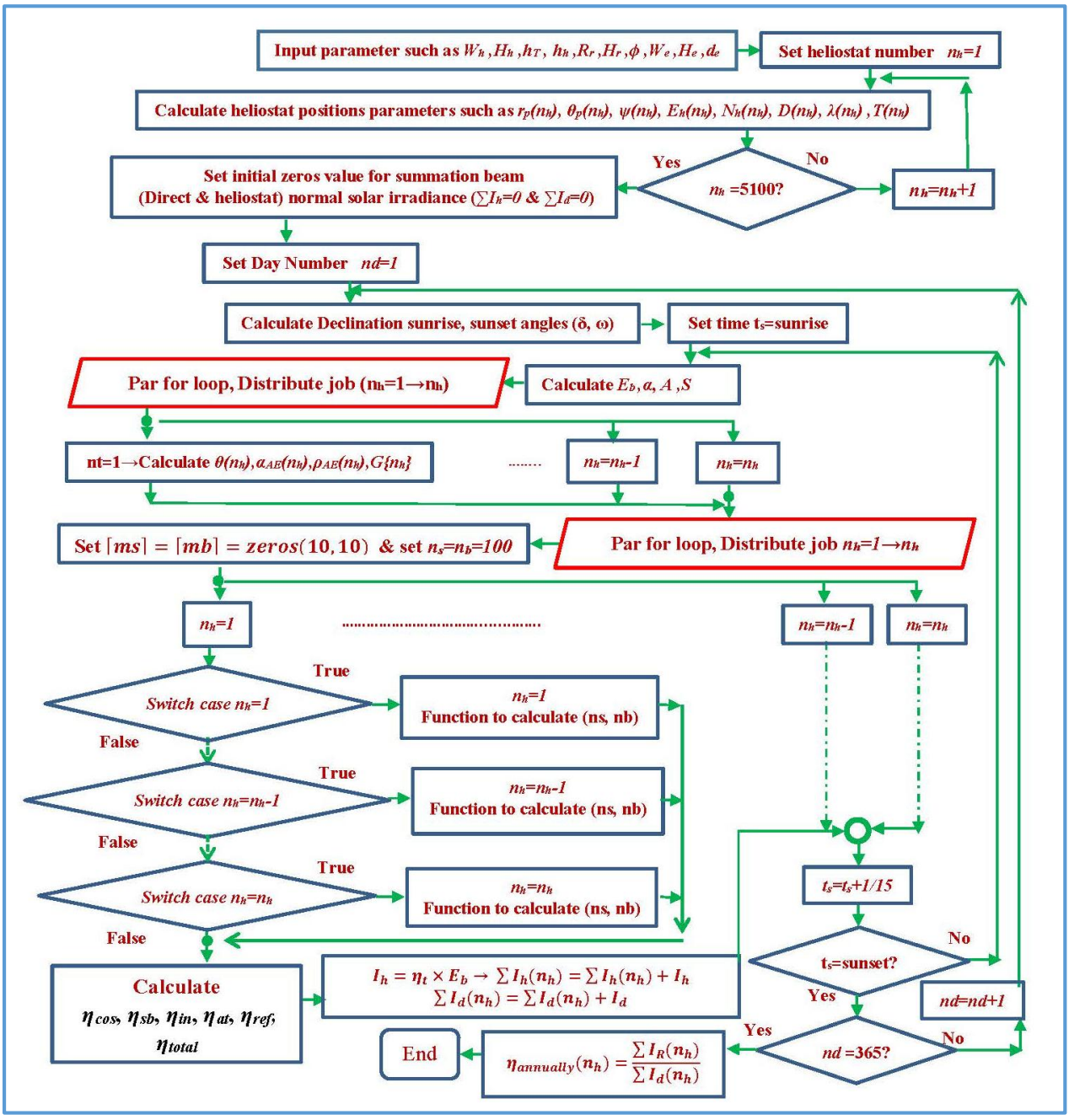



**Fig. (2).** The flow chart to show the algorithm to estimate the$(\eta_{year,Eb})$

The first step in afunctionthat setszero matrices as the value ofthe logic parameters in the shadow and blocking estimate for each number of the heliostatis seen in the following form.

$$[ms]=[mb]=zeros(10,10)=\begin{bmatrix}0 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & 0\end{bmatrix} \quad (17)$$

This matrixis imposed to prevent recalculation of the discretization area that occurswhenshadow or block conditions take place withoverlapping produced by multiple heliostats. At the same time,the set initialvalue for the number of discretization areas for calculating shading and blocking is$(ns=nb=100)$.In the beginning, the numbers of the heliostats causing$(n_{sb})$have been fixed, which probably causes shadowing and blocking, and named(heliostat causes) for shadowing and blocking, then finding polar coordinates $(r_{sb}\&\theta_{sb})$of each relative to the main heliostat and studyingthe

effect of each reflector on the main heliostat separately.As an example, we have a heliostat number (571), which is seen inFig. (3). This method may lead tothe selectionof heliostats that is more than factual.Study heliostats alsomight not have an impact on the shading and blocking effect at the specified time.So,the next steps will include estimation of the possibility for each heliostat, whetherthe shading or blocking is affected or not beforethe calculation of $(\boldsymbol{\eta_{s\&b}})$.If the shading or blocking has not been impacted, the heliostat shouldbe passed and another heliostat studied.In this way, we can decrease the time for computationby decreasing a number ofheliostats that will require implementation$(\boldsymbol{\eta_{s\&b}})$computations.Then,prevent any overlapping produced by multiple heliostats in the calculations, and the computation canbe done with tests, which are summarized in the next points.

1- Testing between the heliostat main and the heliostat causes if the intersection between the horizontal circles of the movement exists, and it canbe done, by a comparison between diagonal diameters.

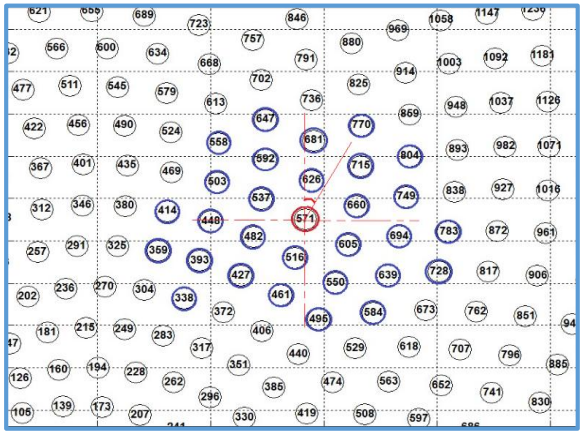


**Fig. (3).** Fixed heliostat numbers that cause shadowing and blocking for heliostat (571), with the polar coordinates($r_{sb}$ and $\theta_{sb}$)

2-Shadowing and blocking aperture:

The shadowing aperture is a window that allows the sunshine to fall on the main heliostat through it.Any obstacle (heliostat) inthe place ofthe directionof the rays of the sun will causeshadeto occur on the main heliostat.The shadowing aperture canbe seen as a thick red line in Fig.(4). The chance of an event should be checked in this case, depending on the solar azimuth angle$A$,when the $(\theta_{sb})$valueis within the possible range of angle$A$,$(\pm 90)$. The blocking aperture isa window that passessunshine through, from the main heliostattoward the tower.Any obstacle (heliostat) in the direction of the rays of the sun will cause blocking to occur on the main heliostat.Check the chance of an event in this case, dependingon the heliostat polar angle or facing angle $\psi(n_h)$ which is seen in Fig.(1), when the$\theta_{sb}$ value has been within the possible range of angle$\psi(n_h)$,$(\pm 90)$.

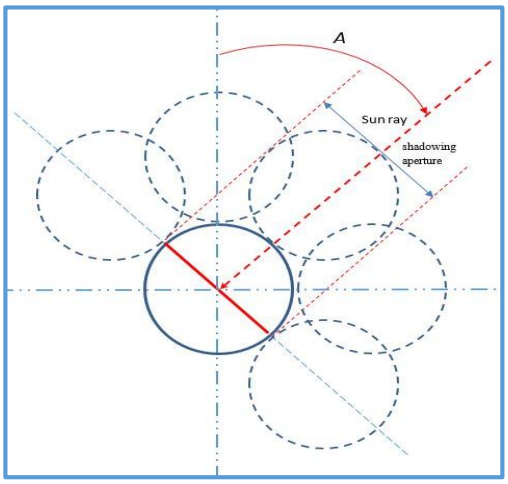



**Fig. (4).** Shadowing aperture

3- Normal distance between the two centers of the circles of movement of the heliostats (main heliostat and heliostat causes), which is presented here as$(P_1, P_2)$. For shadowing, the normal distance $(d_{s1})$betweenthe center of the circle of movementfor each heliostatcause and the vector of the sun that passes through the center circleof movementof the main heliostat shouldbe calculated[14] from the following equation.

$$d_{s1} = \frac{\left\|\overrightarrow{P_1P_2} \times \vec{S}\right\|}{\left\|\vec{S}\right\|} \tag{18}$$

Then,a comparison is made between distance $(d_{s1})$and diameter of movement $(d_h)$for each heliostat.Ifthe distance falls within the circle of movement of the heliostat causes, shadowsoccur.For blocking; the normal distance $(d_{b1})$betweenthe center of the circleof movement for each heliostat and the vector of the tower that passes through the center of the circle of movement of themain heliostat shouldbe calculated[14] from the following equation.

$$d_{b1} = \frac{\left\|\overrightarrow{P_1P_2} \times \vec{T}\right\|}{\left\|\vec{T}\right\|} \tag{19}$$

Then, a comparison is made between distance $(d_{b1})$and diameter of movement$(d_h)$ for each heliostat as the shadow case. After passing the likelihood test for shadowing and blockingthose havebeen set for heliostat causes and having confirmed that heliostat causes have animpact by shadowing

and blocking,then divide the heliostat causes and main surfaces into 100 elements, as shown in Fig. (5).

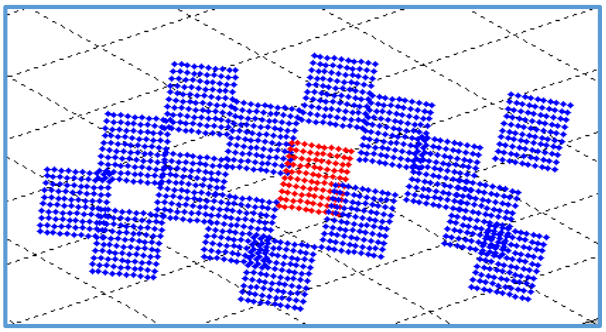
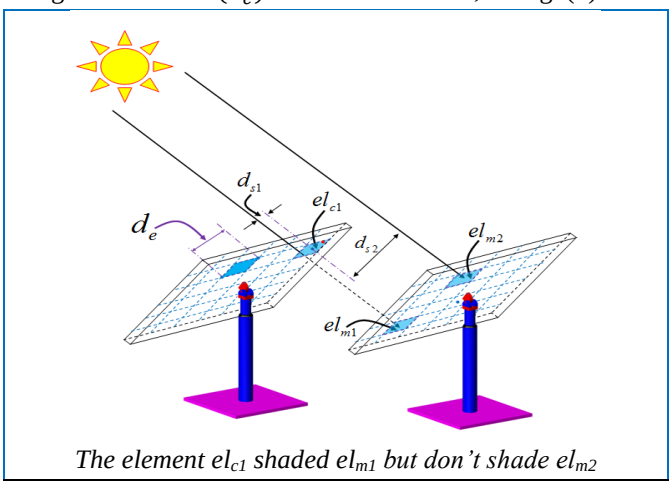
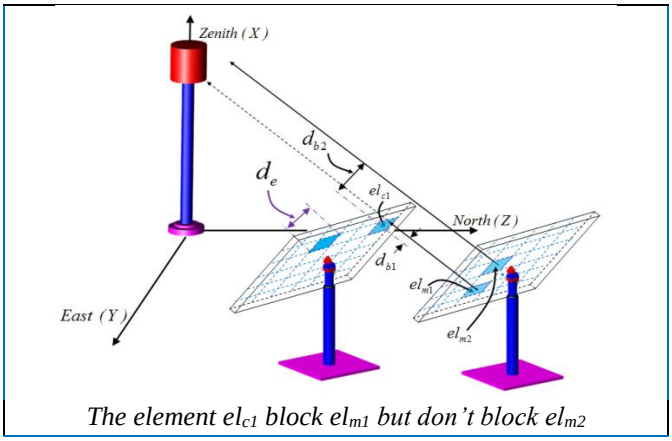


**Fig. (5).** Discretization area of heliostats

Then, find the coordinates of the center of the discretization($P'_{i,j}$)of the heliostats (causes and main)relative to the coordinate system in the heliostat field after the transformation by using Eq. (14).Afterthat, by using the same Eq. (18) forshadowing.The normal distance ($d_{s2}$)is found between the center of the subdivisions ($P'_{i,j,sb}$) of each heliostat cause and the center of the subdivisions($P'_{i,j,h}$)ofthe main heliostat thatthe vector of the sun passes through.Later,a comparisonis made between the distance ($d_{s2}$)and the diagonal diameter($d_e$) of the subdivisions.If the distance falls within the diagonal diameter, shadowingoccurs. Then by using the same Eq. (19),for blocking,the normal distance ($d_{b2}$)is found between the center of the subdivisions ($P'_{i,j,sb}$) of each heliostat cause and the center of the subdivisions($P'_{i,j,h}$)ofthe main heliostat that the vector of the tower passes through. Then, same comparison is made between the distance ($d_{b2}$)andthe diagonal diameter ($d_e$) of the subdivisions; as Fig. (6) shows.




*The element $el_{c1}$ shaded $el_{m1}$ but don't shade $el_{m2}$*




*The element $el_{c1}$ block $el_{m1}$ but don't block $el_{m2}$*

**Fig. (6).**Normal distance between two centers of subdivisions

At the same time, after confirmationthat the subdivision of the main heliostat is affected by shadowing or blocking.The value of the number of discretization areas ($ns$or $nb$) is decreased one unit, and the value of the element in the zero matrices, from imposing Eq. (17) as a logic parameter (in the case of shadowing$(ms(i,j))$and case blocking $(mb(i,j))$that have the same position($P'_{i,j,h}$)inthe arrangement subdivision of the main heliostat is changed to one.Finally, to calculate ($\boldsymbol{\eta_{s\&b}}$),we should estimate the area that is not effected by shadowing and blocking, and we can do that by multiplying$(ns, nb)$ by the area of an element asfollows:

$$A_s = n_s * A_e \tag{20}$$

$$A_b = n_b * A_e \tag{21}$$

Then, the shadowing efficiency is calculated as follows:

$$\eta_{shadow} = \frac{A_s}{A_t} \tag{22}$$

Then, the blocking efficiency as follows:

$$\eta_{block} = \frac{A_b}{A_t} \tag{23}$$

This technique is characterized as an accurate model but at the same time, the slowest model, so one of the targets of this study is how to use this technique, or its accuracy calculation, with less implementation time.

The first solution to decreasing processing time is that for each step of time, parallel computing is carried out to perform all computation that is related to factors of annual efficiency.

As scientific/engineering problems grow in complexity and the need for computational and storage resources grows,

MATLAB can solve "embarrassing parallel" parallel problems with minimum modification to the existing MATLAB code.
Dramatic changes have been made in hardware, and parallelism has become mainstream. We now have clusters of machines (since the late 1990's) and multi-core processors on new machines (more recently), so The Parallel Computing Toolbox (PCT) in MATLAB is available. The PCT, which is explained in details in Ref[15],lets you solve any data-intensive problems computationally using multi-core CPUs, GPUs (graphics processing units), and computer clusters. Thus, running a loop that occurs in the series change to parallel as we see in Fig. (2). Through change (for loop) to (parfor loop) and by developing the program on a multi-core desktop computer utilizing the PCT, we can then scale up to many computers by running program on a MATLAB Distributed Computing Server. The server supports batch jobs, parallel computations, and shared large data sets, and the percentage decrease in time depends on the specification of the computers, as shown in the same reference. Parallel computingis prompted by the need to have a precise and fast simulation environment for estimating and maximizing The optical efficiency of heliostat field. The algorithm is carried out to run on desktop workstations equipped with 6/12 CPU cores, 15 M Cache, up to 3.50 GHz (Intel®I7-3970X CPU @3.5GHz), which means the computations of all numbers of heliostats$(n_h)$, distributed on 12 working units to decrease the running time. This technique is employed in our code twice as we see from Fig (2). The first instance gives out computing final three transformations $[G]$ for the heliostat with other boundaries that are needed in efficiency computing. The second instance gives out the computations carried for the shading and blocking algorithm that is based on the MATLAB type cell data framework, as shown in Fig. (2).

## 4. Optimization of the Field Layout

Any ideal layout evaluation should depend on the annual energythat reaches the receiver.Thus, evaluations of the different layouts are checked byforming multiple distribution layouts from Eqs.(15)and(16), by changing the $(a, b)$parameters, which, depending on a Noone et al. model.[5],therefore have$(□, □)$ considered as design variables of field layouts, where the best value of $(□, □)$ must beestimated by using an optimization algorithm. The limits of $(□, □)$assume [2,8] and [0.4,0.7], respectively. A feature of the created heliostat field, which is larger thanthe reflector numberfor the needed rangeusesEqs. (15) and (16). Everyoptimization starts with 5000 heliostats. Thus, the specific trimming of the field applies to find the best layout of 2650.

The layout isthe conclusion of the needed collector field size to achieve the dedicated plant design power at the design point time.However, this code, for comparison with the case study model,selected the best 2650.The main conditions, the distance between the heliostat and its neighbors,needto be specified and be addressed before optimizing the field, to prevent overlap from occurring between the close circle of movement for the heliostats.Thus, a programwas written such that each step found itand layouts were not consideredthatlead to interference between the circle movements for the heliostats. Further, the diagonal of the total reflector area$(□_h)$equals (15.7m for senior heliostats, see Table (1))anddoes not consider any extra separation distance (dsep=0) in this code. An optimizationis produced, dependingon genetic algorithm (GA) to manage the needed optimization duty which is utilized in the present study.
Today, GA is one of themost efficient methods for optimization. The first step in GA is constructing the population based on the chromosomes, a good result obtained with a large number of chromosomes as well as 100 chromosomes used to preventincreasing the execution time. Each chromosome consists of two variables, and each execution time is evaluated according to the values of these variables. The population in each generationis represented by 100 x 3 matrix, where each row represents the variable values, and the last column (column three) represents the fitness values (F) which represent$(□_{□□□□,□□})$.

$$\begin{bmatrix} □_1 & □_1 & □_{□□□□,□□_1} \\ □_2 & □_2 & □_{□□□□,□□_2} \\ & & \\ □_□ & □_□ & □_{□□□□,□□_□} \end{bmatrix} \begin{matrix} □h□□□□□□□□ \ 1 \\ □h□□□□□□□□ \ 2 \\ \\ □h□□□□□□□□ \ □ \end{matrix} \quad (24)$$

Based on the options of the MATLAB toolbox, the roulette wheel method is used for selection techniques, arithmetic crossover is usedfor crossover operation, and mutation isimplemented with a mutation likelihoodof approximately 0.2 percent.Random values of the design variablesare createdand go on until the highest value of $(□_{□□□□,□□})$ is recorded using (GA) optimization, and the optimal field layout is shown in Fig. (10),where the corresponding a and b parameters are 3.55 and 0.675, respectively, demonstrating 2650 heliostats in this layout.

## 5. Artificial Neural Networks (ANNs)

The present code is based on a discretization model to estimatethe $(□_{□\&□})$,which is consideredan accurate model butat the same time,the slowest model, and impossible to implemented by normal computers with high precision.

Therefore,The second step to speed up operations while keeping high accuracy in calculations is the use offast algorithms,theANNs used.ANNs feature a relative simplification of a simulation methodology description.Neural netsare employed to find out the manner of the system and then to simulate and anticipate its manner.ANNs,although carried out on computers,are not programmed to do specific jobs. Instead, the ANNs are trained on data sets until they learn the patterns used as inputs. Once the ANNsare trained, new patterns may be delivered to them for prediction or classification. ANNs can automatically learn to spot patterns in data from real systems or physical examples, computer programs, or other authors. They can handle many inputs and obtain results in a shape suited for architects.A training set is a group of matched input and output patterns used for training the network, usually by suitable adjustment of the synaptic weights. The outputs are the dependent variables that the network produces for the corresponding input. It is important that all the information the network needs to learn besupplied to the network as a data set. When each pattern is read, the network uses the input data to produce an output, which is then compared to the training pattern, i.e., the correct or desired output. If there is a difference, the connection weights (usually, but not always)are altered in such a direction that the erroris decreased. In this paper, the task of the ANNsis to estimate(□□&□),whichdependson thelocation of the sun and the heliostat location, after fixingthe location of the neighboring heliostat when the (GA) finds the best layout from the previous step.Therefore, inour code, the input and output variables for ANNsare presented in Table (2).

**Table 2.**Input and output variables for ANNs

| | |
|---|---|
| **Input variables** | |
| **1** | Solar declination □ |
| **2** | Solar altitude angle □ |
| **3** | Solar azimuth angle □ |
| **4** | Polar angle for heliostat axis position |
| **5** | □□<br>Radius position for heliostat □□ |
| **Output variables** | |
| **1** | Shadowing efficiency □□ |
| **2** | Blocking efficiency □□ |

In addition, the training set is prepared during runs of the code for each fixed time step (specific period of days during the yearand specific period of minutes during the day), which will be presented in the next section.By recording the input and output variables, which are used for training the network, and detecting suitable adjustments of the synaptic weights, we will identify the network type thatwas used:generalized regression with one hidden layer and one output layeras shown in Fig. (7).Then,after preparing the network of ANNs, theANNs are joined with the main codeinstead of the shading and blocking function(□□□) and transformation matrices(G), to use the ANNs in computations of efficiency.

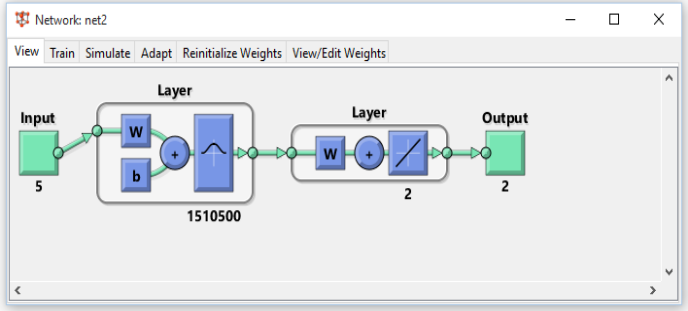



**Fig. (7).**Properties of the network, which is used in ANNs

## 6. Computational Benchmarking

The first comparison targets the performance of computing(□□&□)by ANNs, and compares results with a discretization model with parallel computing.

First, it is necessary to adjust fixed time steps to ensure the validity of the results at the lowest errors and high resolution, which is used to prepare a training set, found during the runs of the code for each fixed time step.

As Table (3) shows, errors occur in the calculation of (□□&□) whenmulti-values of the time step are used. Increases in the steps or decrease in the duration time during training leads to higher accuracy in evaluating the(□□&□). An acceptable error is therefore imposed at $10^{-2}$ when used (15 days and 20 minutes).

**Table 3.** Calculation error in the (□□&□) as a function of fixed time step

| Minute / day | 30 | 15 | 5 |
|---|---|---|---|
| 32 | $10^{-1}$ | $10^{-1}$ | $10^{-1}$ |
| 20 | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ |
| 10 | $10^{-1}$ | $10^{-3}$ | $10^{-4}$ |

The performance of the network and the instantaneous error (that is, single time step) in calculating (□□&□) by ANNs can be seen in Fig. (8), when several days are studied randomly during the year. Then, one day is chosen randomly, its sequence equal to 180, not within the days on which the network was trained to present the result that is based on computing (□□&□) duringthe day, from sunrise to sunset and

every four minutes. A period is selected, different from the period fixed when the network was trained. The convergence noted between the results is shown in Figure Fig. (8).

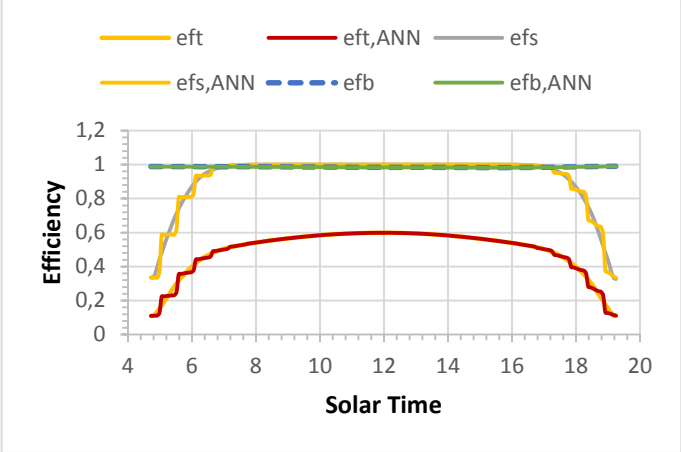



**Fig. (8).** Deferent between ANNs and the discretization model, for computing the field efficiency (eft) and shadow efficiency (efs)and block efficiency (efb), for day 180 and every 4 minutes

Further, Table (4) shows the total values of efficiencies and for all field, for ANNs and the discretization model, throughout the day.

**Table 4.** The values of efficiencies during the day

| | **Field Efficiency** | **Shadow Efficiency** | **Block Efficiency** |
|---|---|---|---|
| ANNs | 0.539321 | 0.97353 | 0.984169 |
| Discretization Model with Parallel | 0.539909 | 0.97457 | 0.984228 |

Two heliostats from the field (2640, 3006) are chosen and used to study ANNs performance, as seen in Fig. (9), which presents their position as a red circle inside the figures

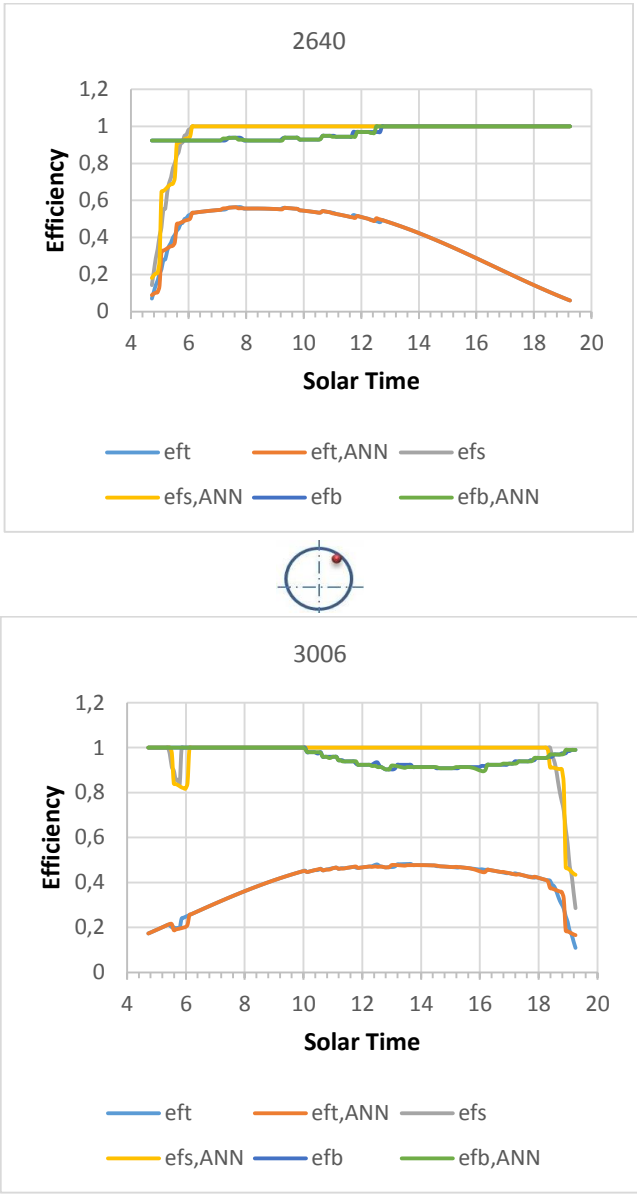



**Fig. (9).** Deferent between ANNs and discretization model for computing efficiencies for heliostats (2640,3006)

Additionally, the implementation time for one- step has been reduced to 191.79 sec as shown in Table (5).

**Table 5.** The values of the implementation time (sec) for one-step for the deferent technique

| Discretization Model without Parallel | **Discretization Model with Parallel** | **ANNs without Parallel** | **ANNs with Parallel** |
|---|---|---|---|
| 16750.045 | 2640.2844 | 573.909 | 191.79 |

The second comparison is targeted by computing the value of the field efficiency in GEMASOLAR by the modeling results of Ref. [6], depending on the same reference data and considering the same model of solar radiation and same duration of simulation in Ref. [6]. The comparison shows that the result (57.3693%) is very close to the published data of Ref. [6], which is (57.232%).

In order to increase the reliability, implement the same value of the parameters of Ref. [**5**], with same number of heliostats and locations. The results of unweighted heliostat field efficiency are obtained with the same Eq. (2), but without considering $\square_{\square}(\square)$ in the computation; the result obtained in Ref . [5] is 64.3% and that obtained in the present study is 65.173%.

Finally, the new value of $(\square_{\square\square\square\square,\square\square})$ ,(52.8589%)is recorded, and the layout of the fieldis presented in Fig. (10). where the corresponding $(\square, \square)$ parameters are 3.55 and 0.675, respectively,whichis explored with the design variables thatare recordedby Ref.[7]and[5]andcompared to the layout suggestion in this study, as presented in theTable (6).

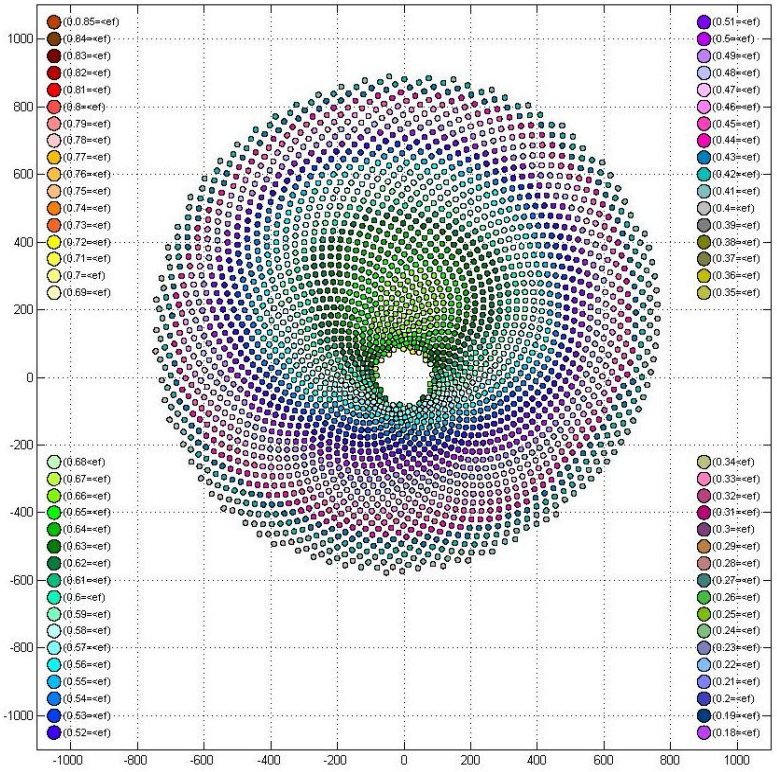



Fig. (10). Layout of the field and $(\square_{\square\square\square\square,\square\square})$ for each heliostat

**Table 6.** Yearly weighted efficiency for different design variables

| | $\square = \square.\square\square\ \square\square\square\ \square = \square.\square\square\square$ **present model** | $\square = \square.\square\ \square\square\square\ \square = \square.\square\square$ **[5]** | $\square = \square.\square\square\square\ \square\square\square\ \square = \square.\square$ **[7]** |
|---|---|---|---|
| $\square_{\square\square\square\square}$ | 52.8589% | 51.7604% | 48.563% |

**7. Summary and Conclusion**s

In this paper, an accurate modelofcomputing $(\square_{\square\&\square})$was firstdeveloped,known as "the discretization model."At the same time,using this model, we cut outsuperfluouscomputations for heliostats thatare not consideredin shading or blocking causesand thatlead to improving the computational time.However,the model is still considered the slowest model.Therefore,the operations have been speeded up bymaintainingahigh accuracy in calculations on three levels.First, by using the parallel computing with a workstation computer;second, by using the artificial neural networks;third,by using the artificial neural networks with parallel computing with a workstation computer.This schemeleads to reduced implementation time on the same workstation computer.With this methodology and accuracy,processing times for this estimate that usually take several hours can bereduced to a matter of minutes by using this technique (from 4.6528 hours to 3.197 minutes).Two

factorsareresponsiblefor the schemeof the layout of the field,and these factors are handledas the formingvariables,where the best valuesare estimatedby using an optimization algorithmwhileimproving theannual efficiency(□□□□□,□□)whenchosenasa target.Benchmarking with the previous study,a clarifiedhigher efficiency than that estimated by others, and displayingthe new modelcanestimate the (□□&□)precisely with a low implementation time

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