



Maximization of Solar Radiation on PV Panels With Optimal Intervals and Tilt Angle: Case Study of Yanbu, Saudi Arabia

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A key factor in the performance of PV panels is the tilt angle, adjustable via various tracking systems. Fixed tilt angle PV panels miss out on most of the solar radiation each day whereas continuous tracking systems are not always cost-efficient, rather impractical in some cases. Therefore, adjusting the tilt angle using a limited number of periods per year can be a good, compromised solution. In this paper, a new approach is proposed to maximize the impact of solar radiation on PV panels by adjusting their tilt angles. Based on a limited number of periods or intervals per year, the optimal duration (number of days) of each period or interval along with the optimum tilt angle corresponding to each interval are determined by solving two interlinked optimization problems. These two problems are solved using the Most Valuable Player Algorithm (MVPA) combined with the Particle Swarm Optimization (PSO) algorithm. The case study for Yanbu, a western coastal city of Saudi Arabia has been investigated. The obtained results show that the enhanced solar power generation can be achieved by using optimal intervals and optimum tilt angle and provide a suitable benchmark for similar techniques to be used in the future to solve the problem of tilt angle adjustment for maximizing PV panels output.

Keywords: optimal intervals, optimum tilt angle, solar panel, solar radiation, most valuable player algorithm, particle swarm optimization

INTRODUCTION

The world is leaning towards the use of renewable energy sources to fulfill the ever-increasing demand for electrical power. Among the green energy sources, solar energy is the most popular choice, due to its widely abundant and environment-friendly nature (Awasthi et al., 2020; Dey and Subudhi, 2020). Therefore, the countries around the globe are working to increase the amount of solar energy generation. Due to high solar radiation potential, Saudi Arabia has achieved significant advancement in exploiting the solar energy in recent past. Moreover, Saudi Arabia's government has set a target to support around 5% of the national demand with solar energy (Alyahya and Irfan, 2016; G Khalil, 2021).

Optimization of various solar parameters is considered indispensable in the process of solar energy exploitation. One of these parameters is the global solar radiation and the appropriate selection of it may result in increased efficiency of solar system technologies like solar PV panels and

solar collectors. The amount of incident radiation depends upon the orientation and tilt angle of the panel and collectors (El-Sebaï et al., 2010; Demain et al., 2013; Mawloud et al., 2020). The general practice is to install these facing the equator so that the orientation is towards South and North, in the northern and southern hemispheres, respectively. However, it is needed to find out the optimal tilt angle of the solar panel as it changes with the movement of the Sun, daily, weekly, and yearly. The optimization of the tilt angle is an effective approach to find the specific angle of the solar panel that ensures the maximum solar radiation of a location, for a particular period (Hafez et al., 2017). A solar tracker can be used to accomplish the task. However, using such a mechanical tool with separate energy support requirements is not suitable, practically and economically. Therefore, finding the optimal tilt angle for different time intervals of the year and orient the solar panels manually is a practical and energy-efficient solution to this problem. Factors like cloudiness (Armstrong and Hurley, 2010), flatness of the collector plate (Kern and Harris, 1975), location and clearness index (Elsayed, 1989), radioactive transfer properties (Smith et al., 2016) etc. are needed to be considered in the tilt angle calculation process since they affect the optimization of tilt angle and intervals directly.

- A healthy number of technical and academic works of literature are found on the topic of tilt angle optimization. The case studies are noted from different countries of the world. European solar radiation data is used to estimate the optimal tilt angle in (Calabrò, 2013). Research on Basrah city of Iraq concluded that the hectic daily adjustment of tilt angle can generate equal energy when compared to the yearly adjustment of 8 times (Hamad, n.d.). The article (Khahro et al., 2015) summarized that the energy can be saved up to 8% by adjusting the tilt angles monthly, instead of the yearly adjustment, where the experiment has been conducted in Sindh, Pakistan. Another tilt angle analysis was conducted in Spain (Navntoft et al., 2012) with the data of summer and winter seasons for four consecutive years. A similar study in Germany (Beringer et al., 2011) presented the variation of tilt angles in different months of a year. An empirical method-based approach was used on a dataset of Abu Dhabi, to study the effect of solar panel tilt angles (Jafarkazemi and Saadabadi, 2013) and suggested to adjust the tilt angles at least twice a year. Chang (Chang, 2010) presented the optimal results for seven cities of Taiwan whereas article (Nfaoui and El-Hami, 2020) discusses the case study of Morocco. Similar studies have been conducted on the cities of Saudi Arabia, too. Benghanem worked with the case study of Madinah city in (Benghanem, 2011). Dhahran, a city of the eastern province was presented in (Ramli and Bouchekara, 2018) whereas Tarek et al. analyzed the solar radiation data of some selected cities including Riyadh, Jeddah, Abha, and Al-Jouf (Kaddoura et al., 2016). Researchers gathered all such references in a review article (Yadav and Chandel, 2013) and documented a well-structured comparative analysis on the subject matter. In a recent study, various

transposition models of PV tilted surface was investigated to increase the estimation accuracy of the global solar radiation in Palestine. It is found that the analysis of the measured data based on annual and monthly period could be represented by the transposition models (Nassar et al., 2020). Real time data acquisition system has been used to determine the optimal tilt angle in (Sharma et al., 2020).

- Although there are some complex and expensive instrumentations used in the measurement and parameterization of solar data, some direct and inexpensive methods based on prediction and diagnoses are also possible. One of such methods of determining the solar radiation is the prediction by artificial intelligence techniques. Nonlinear time-varying PSO (Chang, 2010), slope and orientation-based optimization (Despotovic and Nedec, 2015), Bee algorithm (Sarailoo et al., 2018), mathematical method (Tang and Wu, 2004), empirical corrections (El-Sebaï et al., 2010), vortex search algorithm (Ramli and Bouchekara, 2018) are documented in the literature as the searching tools of optimal tilt angle of the solar panel.

All the above-mentioned articles optimized the tilt angle of the solar panel only, considering that the panel will be equipped with the tracking system. However, a more practical solution is to find the optimal number of time intervals in a year to adjust the angles manually. This approach will save the cost of maintaining the tracking system and therefore, will be more suitable to be used in the domestic loads. A little has been reported in this field and the researchers have proposed a different number of yearly intervals to change the tilt angle. Reference (Saraf and Hamad, 1988) suggested that the number of intervals should be eight for Iraq whereas (Skeiker, 2009) proposed it to be 12 for Syria, in order to ensure the maximum utilization of solar radiation. With the data of nine different locations of the United States, (Akhlaghi et al., 2017; Sarailoo et al., 2018) comes with the conclusion that the solar output of daily intervals can almost be achieved by taking four intervals in a year. However, in most of the tilt angle optimization studies, methodology of the year division is not described that ensures the maximum solar radiation.

The purpose of this research is to simultaneously optimize the tilt angle of the solar panel and the number of days per period or interval of panel adjustment. It will analyze and predict solar radiation and tilt angle using the Most Valuable Player algorithm (MVPA), combined with the Particle Swarm Optimization (PSO) algorithm. MVPA was first proposed in 2017 (Bouchekara, 2020) as a novel algorithm with some excellent features of searching the global solution. However, as a new approach, it has not been implemented in the field of power and energy. On the other hand, PSO is one of the mostly used heuristic approaches in the field of power systems and energy conversions (Alrashidi et al., 2010; Zhou et al., 2016). The area of the investigation is Yanbu, a port city on the Red Sea coast of western region in Saudi Arabia.

The reminder of this paper is structured as follows. In *Solar Radiation Model*, the solar radiation model is described. In *Proposed Approach* the proposed approach is explained and detailed. The simulation results are discussed in *Application*

and Results. Finally, the most important conclusions are drawn in Conclusions.

SOLAR RADIATION MODEL

PV module's output power is a function of solar radiation density and the angle between the Sun and the module itself (Ramli et al., 2015). Thus, the power obtained when solar radiation is normal to the PV surface would be different from the case when solar radiation falls with an angle onto the surface.

The total radiation I_T received by a tilted module can be calculated as:

$$I_T = I_B + I_D + I_R \tag{1}$$

where: I_T is the total radiation, I_D is the diffuse radiation and I_R is the reflected radiation.

The reflected radiation I_R can be found using the following equation (Shukla et al., 2015):

$$I_R = I_g \rho_g \left(\frac{1 - \cos \beta}{2} \right) \tag{2}$$

where: β is the tilt angle, I_g is the horizontal global radiation and ρ_g denotes the ground albedo and it is assumed to be 0.2 as in (Benghanem, 2011).

The direct beam radiation I_B is an important component of total radiation given by:

$$I_B = (I_g - I_d) R_b \tag{3}$$

where: I_d is the diffuse radiation and R_b is the ratio between the tilted beam and horizontal beam radiation given by:

$$R_b = \frac{\cos \theta}{\cos \theta_z} \tag{4}$$

where θ is the incident angle at noon and its cosine is given by:

$$\begin{aligned} \cos \theta &= \cos \delta \cos \varphi \cos \beta + \cos \delta \sin \varphi \sin \beta \cos \gamma \\ &+ \sin \delta \sin \varphi \cos \beta - \sin \delta \cos \varphi \sin \beta \cos \gamma \end{aligned} \tag{5}$$

and θ_z , the zenith angle at solar noon, and its cosine is defined as:

$$\cos \theta_z = \sin \varphi \sin \delta + \cos \varphi \cos \delta \tag{6}$$

where γ represents surface azimuth, φ is the latitude and δ is the declination.

The declination angle is given as:

$$\delta = 23.45^\circ \sin \left[\frac{360}{365} (284 + d) \right] \tag{7}$$

where: d represents a day in the year. It is to be noted that $(284 + d)$ and $(d-81)$ are mathematically equivalent, for a non-leap-year.

Finally, the diffuse radiation on a tilted surface I_D is given by:

$$I_D = I_d R_d \tag{8}$$

where R_d is the ratio between tilted diffuse and horizontal diffuse radiation and can be found by (Nfaoui and El-Hami, 2018):

$$R_d = \left(\frac{1 + \cos \beta}{2} \right) \tag{9}$$

Thus Eq. 1 becomes

$$I_T = (I_g - I_d) R_b + I_g \rho_g \left(\frac{1 - \cos \beta}{2} \right) + I_d R_d \tag{10}$$

According to Eq. 10, the direct and diffuse components of global radiation are needed for estimating global solar radiation on tilted surfaces.

PROPOSED APPROACH

Models Definition

It is obvious that the ideal adjustment interval of the tilt angle is 1 day; however, this is impractical. To solve this problem, the tilt angle is adjusted in a limited number of times per year (i.e., a certain Number of Periods (NP) or intervals per year). Here, two models can be defined and applied.

In the first model, NP is specified. Then the number of days per period is calculated by dividing the total number of days in a year (365) over NP. Therefore, the number of days is same for all periods (more accurately it is almost the same since 365 can sometimes be not a multiple of NP). For instance, if NP = 3, we will have three periods of 122, 122, and 121 days to adjust the tilt angle. It is assumed in this paper that the year starts on the 1st of January and ends on the 31st of December. Having said that, this partition is not mandatory, i.e., the studied period can be extended to more than 1 year. Generally, the starting and ending days can be predefined by the user or the engineer in charge of the investigation. This first model is the mostly used one in the literature to optimize the tilt angle of a solar panel.

In the second model, the Number of Days per each Period (NDP) is not fixed and it is different from one period to another. For instance, if NP = 3, we might have three periods with different NDPs; for example, $NDP_1 = 100$, $NDP_2 = 120$, and $NDP_3 = 145$ days to adjust the tilt angle. This model has not been used in any other study to the best of our knowledge.

In this paper, a novel approach based on the second model is proposed for adjusting the tilt angle. The developed algorithm can run both methodologies to draw comparisons and ascertain the superiority of one method over the other one. Based on a given NP, the proposed approach can solve two interlinked optimization problems simultaneously. The objective of the first problem is to determine the NDPs whilst the objective of the second problem is to determine the best tilt angle which provides the maximum total solar radiation at the surface of a solar panel over a given NDP.

Optimization Problem Formulation

For both models, the treated problem in this paper can be formulated as follows:

$$\text{Maximize } f(\mathbf{x}) \tag{11}$$

$$\text{Subject to } g(\mathbf{x}) = 0 \tag{12}$$

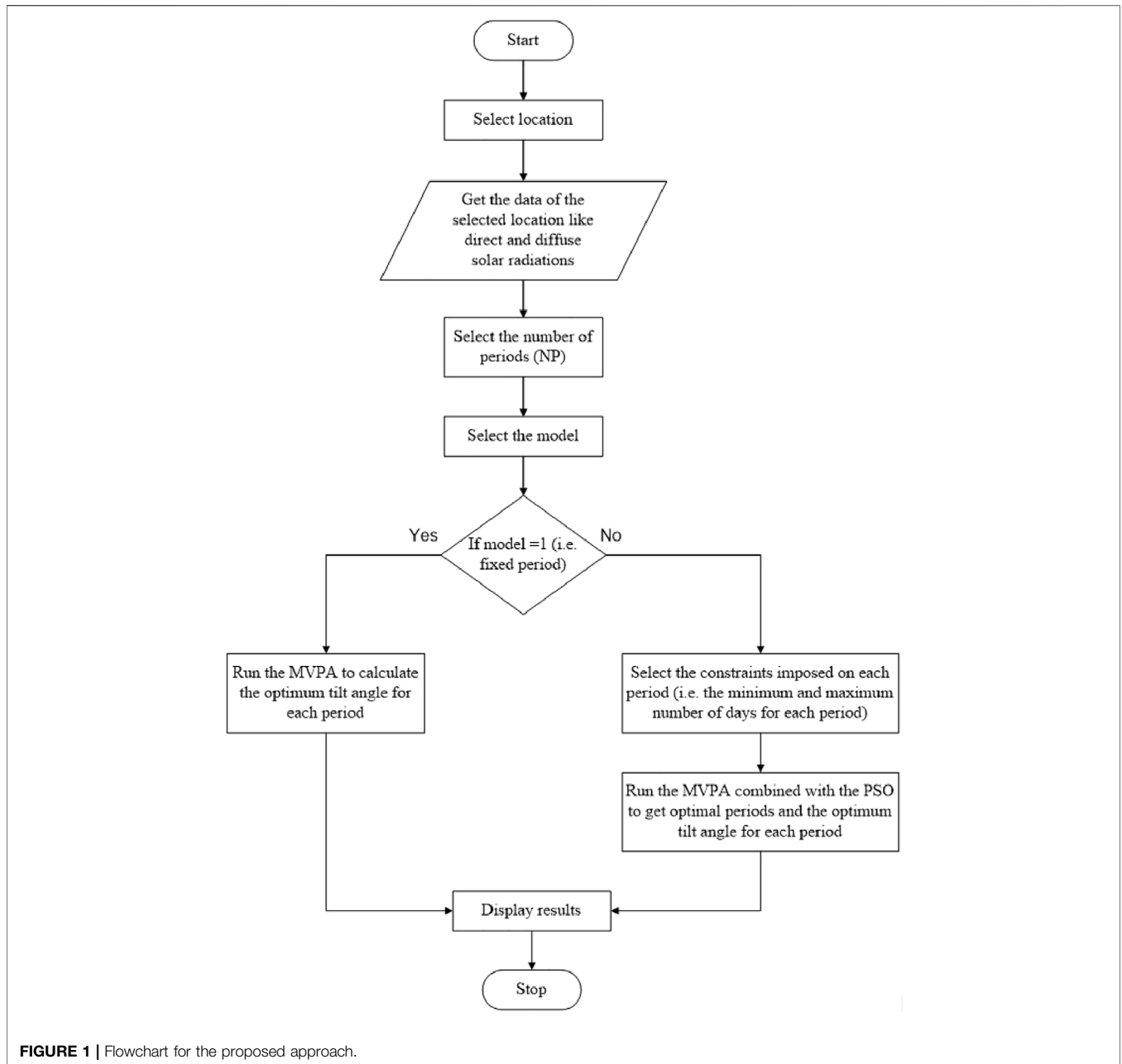


FIGURE 1 | Flowchart for the proposed approach.

$$\text{and } h(\mathbf{x}) \leq 0 \quad (13)$$

where: $f(\mathbf{x})$ is the objective function. \mathbf{x} is the vector of design variables. $g(\mathbf{x})$ is the set of equality constraints. $h(\mathbf{x})$ is the set of inequality constraints.

The aim of the optimization process treated in this paper is to maximize the total radiation. Therefore, the objective function is defined by:

$$f(\mathbf{x}) = I_T$$

The vector of design variables depends on the model chosen. For model = 1:

$$\mathbf{x} = [\beta] \quad (15)$$

For model = 2:

$$\mathbf{x} = [\beta, NDP_1, NDP_2, \dots, NDP_{NP}] \quad (16)$$

where: NDP_i is the number of days per period i .

The constraints imposed on the problem are:

$$NDP_1 + NDP_2 + \dots + NDP_{NP} = 365 \quad (17)$$

In other words, the sum of the number of days for all periods must be equal to the number of days per year (i.e., 365 days).

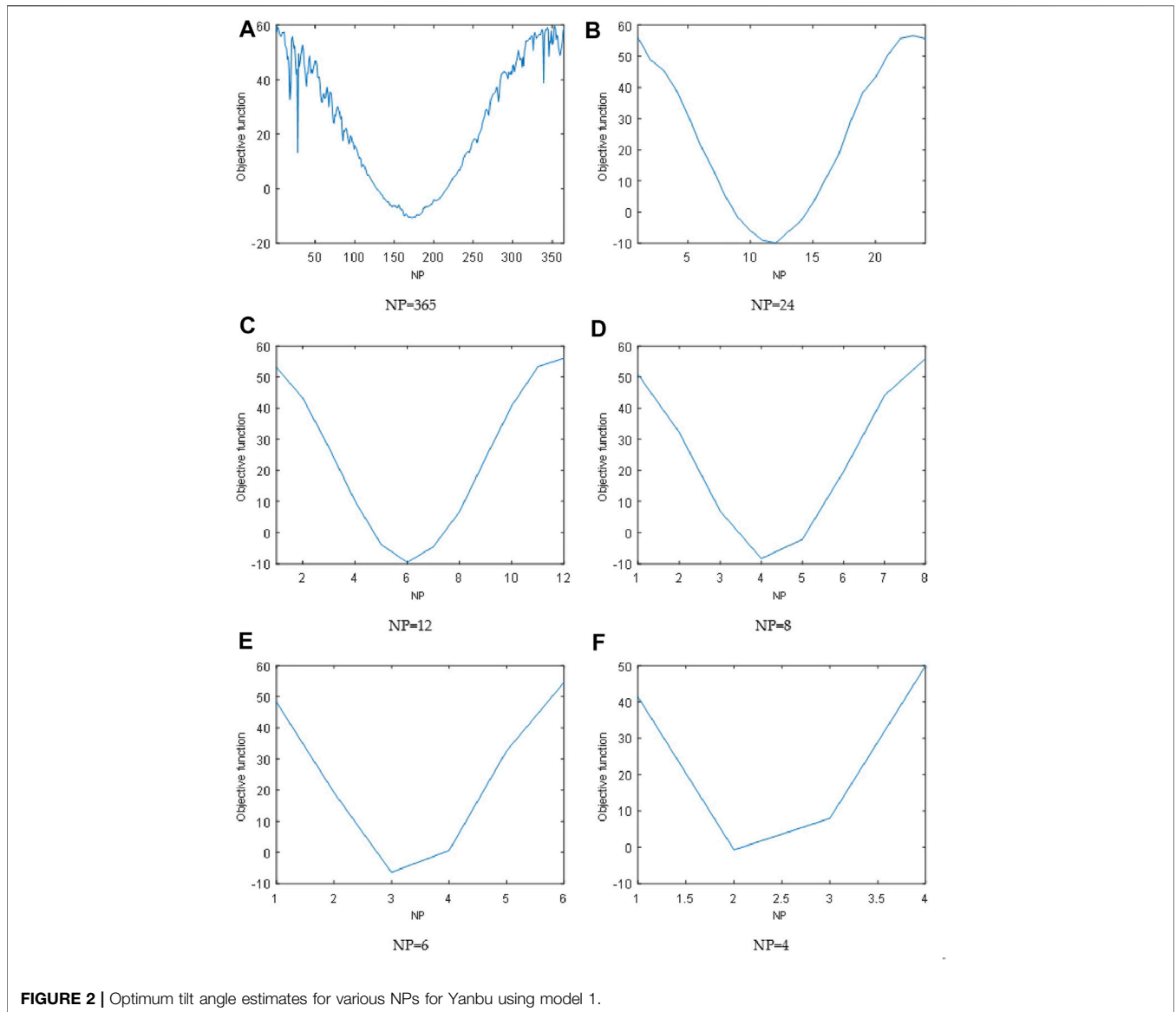


FIGURE 2 | Optimum tilt angle estimates for various NPs for Yanbu using model 1.

Optimization Algorithms

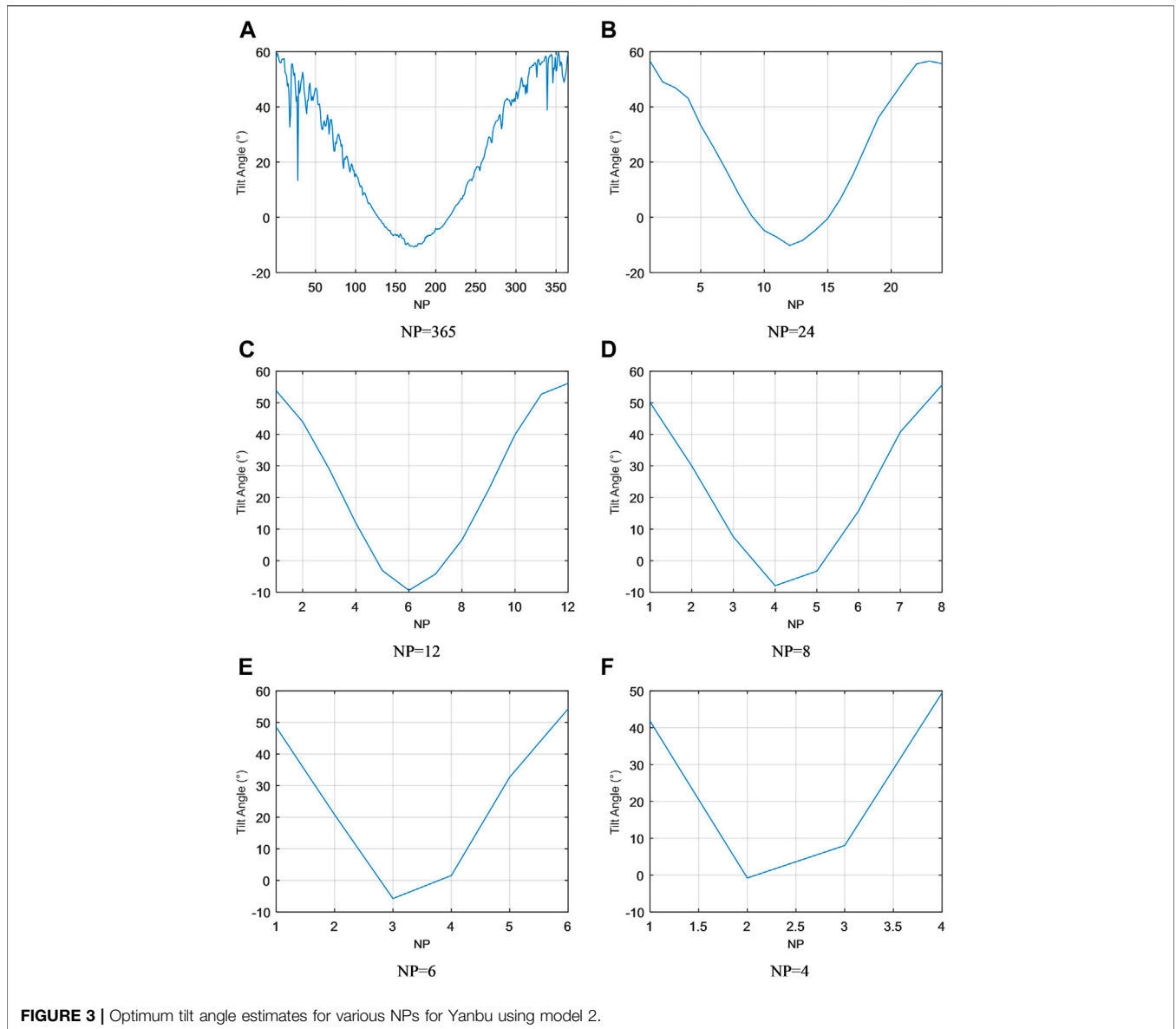
In the proposed approach two algorithms are interlinked to solve the formulated problem based on the model chosen which are the MVPA and the PSO.

The MVPA is a new optimization algorithm developed in (Boucekara, 2020). Like other population-based algorithms it starts by defining a population of players in each region (i.e., the search space) then these players will evolve during games and practices to improve their skills through individual and collective competitions phases. Such process will analogically improve the quality of the solutions to the optimization problem in hand. The MVPA has been used in many studies with successful and efficient results like in (Liu et al., 2018; Alatas, 2019; Korashy et al., 2019; Ouili et al., 2019; Ramli and Boucekara, 2019; Ramli and Boucekara, 2020; Srilakshmi et al., 2020). Therefore, it has been selected for this study.

The second algorithm selected in this paper is the PSO. This algorithm with the Genetic Algorithm (GA) is the most well-known and widely used optimization metaheuristic algorithm. Using simple displacement rules a population of particles evolve to better locations (in the search space) and consequently the solutions converge toward the global minimum.

Implementation of the Proposed Approach

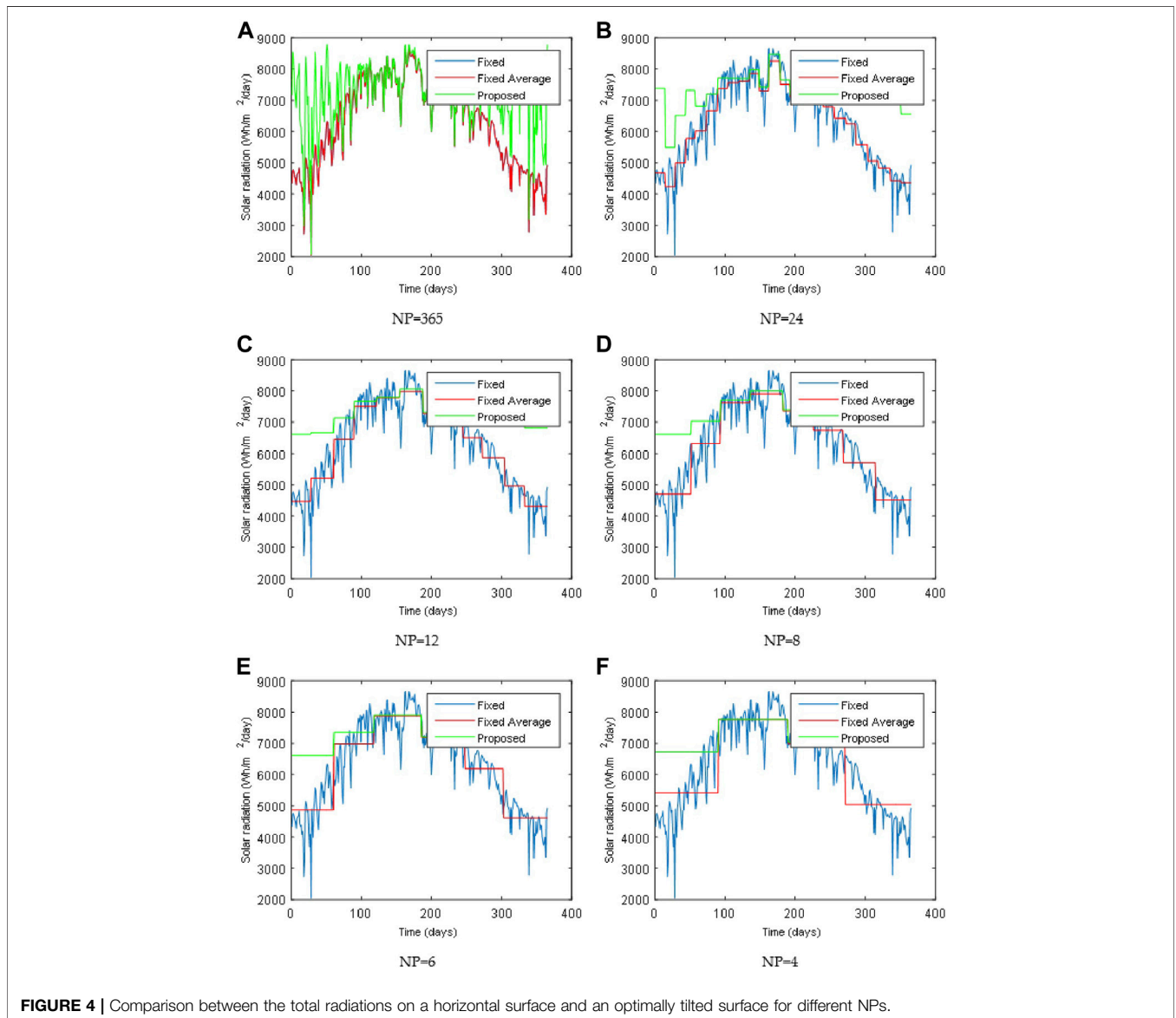
The flowchart of the proposed approach is given in Figure 1. A MATLAB-based program has been developed to implement this approach. This approach starts with a given location where the investigation is aimed to take place. Once the location is specified, the data of the selected location such as direct and diffuse solar radiations (needed for Eq. 10) is obtained (i.e., measured). Then two important parameters are defined:



the number of periods or intervals (i.e., NP) and the model number (i.e., model 1 or model 2). If the first model of fixed period is chosen, the MVPA will run to calculate the optimum tilt angle for each period. For this model, the *NDP* is same and is calculated by NP. Now, if the second model is selected, the *NDP* does not remain the same and becomes a design variable of the first optimization problem. Therefore, the constraints imposed on each period i.e., the minimum and the maximum number of days for each period, are calculated. Then the MVPA combined with PSO is run to solve the two interlinked optimization problems to get the optimal number of days and tilt angle for each period. In this interlinked problem the MVPA is used to determine the optimum *NDPs* whilst the PSO is used to determine the optimal β for each *NDP*. Finally, the obtained results are displayed and exploited by the engineer who's in charge of the study.

APPLICATION AND RESULTS

The proposed approach has been applied to estimate the optimum tilt angle for the city of Yanbu in Saudi Arabia. Six different NPs, $NP = \{365, 24, 12, 8, 6, 4\}$, are tested. The optimal angles found using model 1 for all the tested NPs are sketched in **Figure 2**. In **Figure 2A**, the optimum angle is obtained for $NP = 365$ (daily adjustment of the tilt angle). It varies between -10.72° corresponding to day number 173 and 59.88° corresponding to day number 353. In **Figure 2B**, the optimum angle is obtained for $NP = 24$. It varies between -10.20° corresponding to period number 12 and 56.58° corresponding to period number 1. In **Figure 2C**, the optimum angle is obtained for $NP = 12$. It varies between -9.41° corresponding to period number 6 and 56.15° corresponding to period number 12. In **Figure 2D**, the optimum angle is obtained



for NP = 8. It varies between -7.94° corresponding to period number 4 and 55.64° corresponding to period number 8. In **Figure 2E**, the optimum angle is obtained for NP = 6. It varies between -5.75° corresponding to period number 3 and 54.27° corresponding to period number 6. In **Figure 2F**, the optimum angle is obtained for four periods. It varies between -0.78° corresponding to period number 2 and 49.43° corresponding to period number 4.

The optimal angles found using model 2 for all the tested NPs are illustrated in **Figure 3**. The same analysis presented for fixed periods or intervals can also be made on the results shown on this **Figure 3**.

The total radiations on a horizontal surface and the one on the optimum tilt angle found using model 2 are sketched in **Figure 4**. It can be seen from this figure that the proposed approach is

much better than the one with fixed panels in the horizontal position in terms of receiving effective solar radiation.

The optimal results found when NP = 24 are tabulated in **Table 1**. The first four columns correspond to model 1 while the remaining four columns correspond to model 2. In the first column of this table the number of days per period is given, in the second column the optimum tilt angle found is given, whereas, in the third and fourth column I_T and I_d are given, respectively. The same results are given for model 1 in the same order starting from column five to column 8. Some comments can be made from this table. For model 1, the number of days per period is either 15 or 16, as explained before. However, for model 2 the number of days per period can be 14, 15, 16, or 17.

For model 2, the total radiation received per day on the adjusted surface is $7239.58 \text{ Wh/m}^2/\text{d}$, which is slightly higher

TABLE 1 | Optimal results for Yanbu when NP = 24.

Model 1				Model 2			
Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)
16	55.88	7138.63	4506.06	14	56.58	7388.03	4674.28
16	48.79	5641.52	4182.13	14	49.03	5496.41	4223.48
16	45.68	6750.41	5165.19	15	46.89	6516.21	5000.51
16	39.55	6996.31	5764.00	14	43.14	7,330.27	5779.81
16	31.02	7223.60	6436.19	16	33.28	6825.50	6016.24
15	21.41	7273.94	6867.51	16	25.42	7210.95	6668.24
15	13.63	7823.40	7570.45	14	17.09	7711.35	7374.01
15	4.91	7693.13	7586.76	16	8.32	7698.23	7559.66
15	-1.85	7813.42	7716.26	15	0.60	7691.97	7604.88
15	-6.08	7731.05	7613.20	14	-4.80	7972.28	7841.94
15	-9.14	7983.22	7808.70	14	-7.21	7423.10	7311.74
15	-9.95	8304.04	8088.01	16	-10.20	8471.07	8244.66
15	-6.39	7055.04	6981.01	14	-8.41	7648.64	7504.28
15	-2.93	7600.38	7512.51	16	-4.79	7187.18	7119.13
15	2.99	7321.39	7251.01	14	-0.45	7540.88	7458.21
15	10.71	7015.77	6889.45	17	6.70	7103.47	7068.82
15	18.03	6728.42	6485.95	16	15.50	7010.61	6797.13
15	29.09	7241.68	6529.63	17	25.84	6940.37	6432.41
15	38.54	7494.06	6188.76	14	36.16	7375.40	6252.34
15	43.32	6779.64	5406.45	17	42.75	7064.64	5578.35
15	50.55	7104.92	5057.63	15	49.39	6932.06	5053.88
15	55.71	7694.97	4886.57	17	55.57	7740.82	4829.94
15	56.56	6907.04	4420.32	15	56.56	6907.04	4420.32
15	55.63	6562.31	4361.76	15	55.63	6562.31	4361.76

TABLE 2 | Optimal results found for Yanbu city for NP = 12.

Model 1				Model 2			
Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)
31	53.06	6367.64	4325.10	27	53.83	6601.11	4468.51
31	43.30	6874.13	5418.71	33	43.94	6650.21	5205.03
31	27.44	7168.98	6568.10	29	28.97	7128.66	6457.04
31	10.24	7741.09	7648.19	32	11.96	7665.59	7,503.16
31	-3.75	7761.70	7749.84	33	-3.12	7792.58	7784.27
30	-9.56	8143.47	8001.42	33	-9.41	8058.53	7977.39
30	-4.51	7325.41	7277.20	28	-4.27	7321.78	7273.01
30	6.75	7156.91	7094.97	29	6.56	7,186.72	7,124.54
30	24.01	6961.43	6514.39	28	22.37	6883.02	6503.11
30	40.77	7131.95	5781.30	32	39.89	7177.65	5868.19
30	53.30	7393.64	4929.17	28	52.75	7359.08	4964.56
30	56.11	6734.49	4329.36	33	56.15	6808.83	4299.18

than the one obtained using model 1 (7238.15 Wh/m²/d). Both quantities are notably higher than the radiation to be received by a fixed horizontal surface i.e., 6320.41 Wh/m²/d.

Accumulating the radiations over a year to see the advantage of model 2 over model 1, it is noted that the total radiation received per year on the adjusted surface using model 2 is 2642447.88 Wh/m², which is higher than the yearly accumulated radiation obtained using model 1 i.e., 2641924.86 Wh/m². It is pertinent that the radiation that could have been received by a fixed horizontal surface would be the least. In this case, its amount is 2306951.15 Wh/m².

The optimal results found when NP = 12 are tabulated in **Table 2**. Similar observations can be made from this table. For model 1, the number of days per period is either 30 or 31 (since the number of days

per period is fixed). However, for model 2 the number of days per period can be either 27, 28, 29, 32, or 33. Here also, the radiation received by model 2 is higher than that of using model 1. The yearly accumulation of solar radiation for model 2 is 2639382.81 Wh/m², whereas, for model 1, this quantity amounts to 2638738.91 Wh/m². Since the radiation received by a fixed horizontal surface does not depend upon NP, it would remain the same 2306951.15 Wh/m² for all cases discussed here. The comparison of yearly radiation among different NPs is provided in **Table 6**.

Similarly, for NP = 8, the optimal results are tabulated in **Table 3**. Here again, model 1 would restrict the number of days per period to 45 and 46, whereas model 2 would allow a flexible number of days per period, allowing it to be either 42, 43, 46, 47, or 51. Using model 1, annual radiation received is found to be 2633900.88 Wh/m². For

TABLE 3 | Optimal results found for Yanbu city for NP = 8.

Model 1				Model 2			
Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)
46	50.79	6482.51	4585.13	51	50.14	6602.89	4704.94
46	32.26	7092.22	6264.35	42	30.02	7027.94	6326.05
46	6.89	7708.76	7667.37	42	7.51	7705.87	7625.24
46	-8.31	7998.32	7936.43	47	-7.94	8002.82	7911.98
46	-2.12	7327.46	7323.93	43	-3.32	7394.17	7360.82
45	19.63	6949.46	6649.44	43	15.74	6930.98	6735.41
45	44.10	7104.24	5518.24	46	40.72	7037.76	5708.90
45	55.96	7054.62	4480.26	51	55.64	7141.88	4515.33

TABLE 4 | Optimal results found for Yanbu city for NP = 6.

Model 1				Model 2			
Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)
61	48.28	6608.29	4859.30	60	48.49	6608.70	4866.95
61	19.21	7367.04	7060.66	57	20.82	7348.58	6977.69
61	-6.40	7934.16	7897.85	68	-5.75	7908.16	7878.90
61	0.60	7255.79	7255.51	62	1.54	7198.47	7182.46
61	32.57	6974.67	6143.74	55	32.70	7033.47	6187.65
60	54.63	7062.29	4601.82	63	54.27	7038.78	4621.96

TABLE 5 | Optimal results found for Yanbu city for NP = 4.

Model 1				Model 2			
Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	Number of days per period	Tilt angle (°)	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)
92	41.34	6718.74	5424.74	90	41.83	6716.69	5401.06
91	-0.73	7800.57	7783.84	99	-0.78	7761.21	7760.68
91	7.93	7058.62	7003.10	82	8.04	7044.59	6987.21
91	49.98	7051.43	5000.90	94	49.43	7060.00	5050.70

TABLE 6 | Results comparison.

NP	Model = 1		Model = 2	
	I _T (Wh/m ² /d)	I _g (Wh/m ² /d)	I _T (Wh/m ² /year)	I _g (Wh/m ² /year)
365	7245.98	7245.98	2644781.56	2644781.56
24	7238.15	7239.58	2641924.86	2642447.88
12	7229.42	7231.19	2638738.91	2639382.81
8	7216.17	7220.97	2633900.88	2635653.91
6	7200.75	7204.75	2628274.55	2629734.57
4	7156.14	7162.08	2611990.74	2614158.12

model 2, this quantity is found to be 2635653.91 Wh/m² which is 1753.03 Wh/m² greater than that of model 1.

For NP = 6, the optimal results are tabulated in **Table 4**. In congruence with previous cases, model 1 allows days per period to be either 60 or 61, whereas, days per period in model 2 can be either 55, 57, 60, 62, 63, or 68. Likewise, the annual radiation received by model 2

is higher than that of model 1 by 1460.02 Wh/m² — 2628274.55 Wh/m² (model 1) subtracted from 2629734.57 Wh/m² (model 2).

Finally, at NP = 4, the obtained optimal results are tabulated in **Table 5**. In continuation with the previous discussion, model 1 gives two options for days per period i.e., 45 or 46. For model 2, the number of days per period could take either 82, 90, 94, or 99. For model 2, the received annual radiation is 2614158.12 Wh/m² which is 2167.38 Wh/m² greater than that of model 1 (2611990.74 Wh/m²).

Based on the results of **Table 6** it can be concluded that, when NP = 24, NP = 12, NP = 8, NP = 6, and NP = 4 the I_g increases by around 523, 644, 1753, 1,460, and 2,167 Wh/m²/year, respectively, if compared with the horizontal surface's solar radiation. However, 6423.12 Wh/m²/d of solar radiation can be achieved by the panel if the required adjustments are made in daily basis. It is worth to mention that I_g and I_T presented in this table are calculating by getting the average daily values by dividing the yearly values by 365 i.e., the number of days per year.

CONCLUSION

In this paper, two models of ascertaining PV panels tilt angles have been presented. Their results are compared with one another and with the base case of the fixed horizontal PV panel. The PV panel with the tendency to change its tilt angle every single day would capture maximum radiation but is economically infeasible. This fact has been used as a vantage point to figure out the number of days in one complete year after which the tilt angle can be manually changed. The geographical data of Saudi Arabian western coastal city, Yanbu, has been used to quantify the proposed hypothesis and associated benefits. An approach based on MVPA and PSO has been developed with two separate stipulations; named as models. In the first model, a year must be divided into periods comprising of a fixed number of days, whereas the second model is flexible with assigning the number of days to each period and thus provides an opportunity to receive maximum solar radiation at a certain tilt angle. Analysis of results reveals that with an increased number of adjustments in a year, better proficiency is achieved. Between the first and second models, the later one outperforms the former one for being more adaptive to the receiving radiations. For example, for NP = 4, using model 1 the tilt angles are 41.34°, -0.73°, 7.93°, and 49.98° while using model 2 the optimal tilt angles found are 41.83°, -0.78°, 8.04°, and 49.43° which has improved the I_g by 2167 Wh/m²/year.

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DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HB and MR conceived the conceptualization and methodology. HB and MS conducted the normal analysis and writing. AM and MR conducted the data curation and visualization. MR, MS, and AM conducted the review and editing. MR managed funding acquisition. MR managed project administration. All authors have agreed to the submitted version of the article.

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