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Novel Approach to Investigate the Influence of Optimum Tilt Angle on Minimum Cost of Energy-Based Maximum Power Generation and Sizing of PV Systems: A Case Study of Diverse Climatic Zones in India

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ABSTRACT Optimum Photovoltaic (PV) system integration in power grid depend upon the total of power accessible from the PV. To figure the PV systems highest power yield, PV panels must be positioned at an optimal tilt angle (OPTA) to absorb maximum solar radiation (SR). This OPTA is a function of the latitude, clearness index, diffuse SR, global SR, direct SR and optimum PV size. Therefore OPTA has an impact on maximum power generation and optimal PV system sizing. The PV is not installed at OPTA for most of the sites in India which is important for maximum power generation and optimum sizing of standalone PV systems. This results in variation of OPTA from site to site and its effect on PV sizing needs to be investigated. The innovative aspect of this work is the calculation of OPTA, which are employed as sensitive factors in Hybrid Optimization of Multiple Energy Resources (HOMER), to determine their impact on maximum optimum sizing and power generation for 26 cities in India's various climate zones. This methodology can be applied all over the world to determine the impact of OPTA on maximum power generation and size. It is found that OPTA varies from 63° to 0° throughout year in India and it is maximum for December in India. The results indicates that Net Present Cost varies from $1105 to $1280 and Cost of Energy (COE) variation is 0.041 to 0.048 $/kWh throughout India cities and low temperature sites are good for photovoltaic (PV) power generation. Two axis tracking system produces more power in comparison to other tracking systems. This research is beneficial for researcher and industry to install PV system in different climatic zones of India to generate maximum power at minimum cost of energy.

INDEX TERMS Power generation, optimum tilt angle, optimum sizing, solar photovoltaic system, cost of energy, India.

I. INTRODUCTION

Over the previous several years, the installation of photovoltaic (PV) systems has resulted in a rising growth mark. In order to reduce carbon emissions in the world by the end of the century, growth must accelerate in the next decades, eventually leading to several connected Terawatts of PV capacity. 2019 records the third year with around 100 GWp of recent set up PV size, leading the additive installed capacity close to Terawatt globally by end of this

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decade [74] and installation location also affect lifetime of PV inverter [79]. For this geographically location of country play an important role for maximum power generation. India is situated between the tropic of cancer and the equator, with a variety of climatic zones and a large solar potential [1]. PV systems convert solar energy into electricity. Photovoltaic (PV) energy is obtained by absorbing photons in a PV cell connected in parallel and series. The output of PV systems is required for hybrid system design [77], power flow analysis and it is influenced by tilt angle with horizontal and orientation. These factors changes incident SR on PV surface. Due to variable solar radiation, electricity output varies from site to site, necessitating a cost-benefit analysis of PV systems in India's diverse climate zones. In this regard, Soni and Gakkhar [2] examined the viability of implementing PV technologies in India and discovered that economic metrics are critical for PV installation. To accelerate solar project funding regulations are required [78]. In this aspect Jawaharlal Nehru National Solar Mission (JNNSM) was initiated by the government with target 175 GW by 2022. JNNSM is being rolled out in three stages. The deadlines for completing phases 1, 2, and 3 are 2013, 2017, and 2022, respectively. During phase 1 (2010-2013), the PV installed capacity plants of various states total 2208.36 MW as of 31 January 2014, with Rajasthan and Gujarat having the most installed PV systems [3], [4]. In India, there are significant issues with PV power generation, including a lack of consistent SR at multiple sites and optimum PV size [5], [6]. The design process necessitates the estimation of SR on a tilted surface. The tilt angle (TA) has an impact on dust deposition on PVs, and the TA and tracking system work together to maximize incidence SR on PV surfaces [7], [8]. In the literature, incident SR on a horizontal surface for Indian cities is presented [9], [10] however, it is restricted to inclined surfaces [11]–[14]. Under various tracking settings, Ulgen [15] calculated OPTA for Bangalore as 12.96 for Bangalore, India. The results reveal that solar energy tracking by dual and single axis improved by up to 35 percent. Sinha and Chandel [16] investigated various types of tracking systems for PV-based hybrid power generation. When a two-axis tracking system is used instead of a fixed tilt, power is enhanced by 4.88–26.29 percent. Bahrami *et al.* [17] discussed effect of latitude and solar trackers on the energy performance for Africa and Europe. It has been demonstrated that tracking performance is significantly reliant on latitude and consequently fluctuates with latitude. For determining SR, Stanciu and Stanciu [18] used the Hottel and Woertz models. The difference between declination angle and latitude is used to calculate OPTA. Nijegorodov *et al.* [19] suggested that optimum tilt angle (OPTA) is dependent on day of year, latitude, surface ground albedo, azimuth angle, diffuse fraction, anisotropy index and phase shift. For thin film, polycrystalline, and monocrystalline PV technologies, Ayaz *et al.* [20] estimated OPTA. OPTA ranges from 12 to 25 degrees for thin films, 5 to 13 degrees for monocrystalline, and 11 to 15 degrees for polycrystalline. Nicolás *et al.* [21] developed OPTA equation as an objective of albedo, diffuse fraction and latitude. Root mean square error in estimation is found to be 2%. Ullah *et al.* [22] developed an OPTA for Lahore and other Pakistani cities. It was discovered that adjusting the tilt angle four times in a year boosted annual energy generation by 6.6 percent.

A number of studies have been provided for OPTA computation based on maximizing incident SR on PV systems [21], [23]–[49], load demand [50], [51], and optimum PV system sizing [52]–[54].

The breakdown of the paper's structure are: research gap in section 2, methodology is presented in section 3. The results and discussion are given in section 4 and conclusion in section 5.

II. RESEARCH GAP

From preceding mentioned study it was found that OTA varies for different site due to change in climatic condition. Moreover in a detailed review analysis by Yadav and Chandel [55], the OPTA computation has been found as a crucial research area for optimum sizing of PV system and maximum power generation. However, studies regarding effect of tilt angle on optimum sizing and maximum power generation are not done for India which is important for industry from economic point of views.

The goal of this research is to look at the impact of OPTA on optimum sizing and maximum power generation with the lowest energy cost of a SAPV system for 26 distinct cities in India's various climate zones. In this study monthly and yearly OPTA are calculated to maximize incident SR on PV system and these optimum tilt angles are used as sensitive variables in HOMER to determine the impact on maximum power generation and sizing.

III. METHODOLOGY

The proposed approach for novel analysis of the effect of OPTA on minimum cost of energy based maximum power generation and sizing of stand-alone photovoltaic systems is presented in Figure 2(a), which is comprises in to two main parts (i.e., PART-A and PART-B). PART-A analysis belongs to the effect of OPTA analysis on cost of energy and maximum power generation, whereas PART-B analysis related to effect of tracking system analysis on PV power generation. In this part, five different tracking system have been analyzed to evaluate the maximum PV power. The detailed information of the proposed approach implementation is presented in subsequence sections along with implementation of HOMER in Figure 2(b).

A. SELECTED INDIAN CITIES

India, which covers 3.287 million square kilometres, is a big country with distinct climate. As per Koeppen's classification [76] the country is divided into six different zones of climate: Arid, Semi-arid, Tropical Wet and Dry, Humid Subtropical, Tropical Wet, Montane. The six climate zones are depicted in Figure 1 and their coordinate data is presented in Table 1.

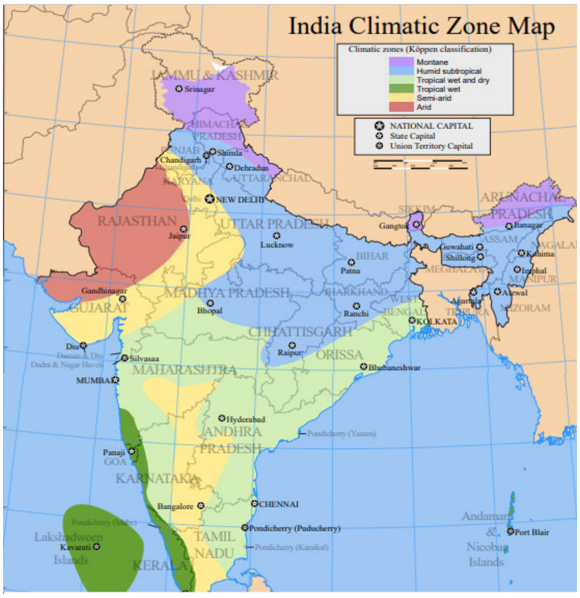

FIGURE 1. India climatic zone map [75].

TABLE 1. Selected 26 cities in different climatic zones.

S.No.	Cities	Lat (^{o} N)	Long (^{o} E)	Climatic Zone
1	Srinagar	34.08	74.79	Montane
2	Hamirpur	31.68	76.52	
3	Dehradun	30.19	78.02	
4	New Delhi	28.35	77.12	
5	Lucknow	26.45	80.53	
6	Varanasi	25.45	82.85	
7	Patna	25.61	85.13	Humid Sub tropical
8	Shillong	25.34	91.53	
9	Bhopal	23.25	77.42	
10	Ranchi	23.35	85.33	
11	Port Blair	11.61	92.72	
12	Nagpur	21.09	79.07	
13	Mumbai	19.07	72.51	
14	Pune	18.52	73.84	
15	Hyderabad	17.36	78.46	
16	Vishakapatnam	17.43	83.14	Tropical wet and dry
17	Chennai	13.081	80.27	
18	Kolkatta	22.39	88.27	
19	Panjim	15.49	73.81	
20	Minicoy	8.28	73.03	Tropical wet
21	Thiruvanathpuram	8.5	76.9	
22	Bhavnagar	21.77	72.15	
23	Ahmedabad	23.04	72.38	
24	Bangalore	12.57	77.38	Semi-Arid
25	Jodhpur	26.18	73.01	
26	Jaipur	26.92	75.82	Arid

B. DETERMINATION OF THE BEST TILT ANGLE

Extraterrestrial radiation (H_{ER}) is SR that occurs outside of the earth's atmosphere, and its average value is solar constant $S_c = 1367\text{W/m}^2$. It is given for N^{th} day of the year as.

$$H_{ER} = \frac{24}{\pi} S_c \left(1 + 0.033 \frac{360N}{365}\right) \tag{1}$$

The SR incident on earth surface dependent on sun's position in sky, orientation, location and inclination angle to the surface. As a result, it's critical to pay attention to the fluctuation in incident SR on a tilted surface. The declination angle (D_A) is given by Cooper and is as follows [56]:

$$D_A = 23.45 \times \sin\left(\frac{2\pi\,(284 + N)}{365}\right) \tag{2}$$

The hour angle (H_A) refers to the sun's angular displacement from the local meridian to the west or east. It is a formulation describing the deviation between and solar noon and local solar time. After solar noon, H_A estimate time in span of 1° for each 15° per hour or 4 minutes. After solar noon H_A is positive after solar noon and before solar noon it is negative. The H_A is stated as follows.

$$H_A = \cos^{-1}(-\tan\phi \tan D_A) \tag{3}$$

Beam radiation refers to incident SR that falls on the earth's without being scattered or absorbed on the surface, while diffuse radiation (H_{DR}) refers to SR that is scattered. The H_{DR} is stated by equations 4 and 5. The average monthly clearness index ($C_I = \frac{H_G}{H_{ER}}$)

$$H_{DR} = H_G\left(1.391 - 3.560C_I + 4.189\,(C_I)^2 - 2.137\,(C_I)^3\right) \quad if\ H_A < 81.4° \tag{4}$$

$$H_{DR} = H_G\left(1.311 - 3.022C_I + 3.427\,(C_I)^2 - 1.821\,(C_I)^3\right) \quad if\ H_A > 81.4° \tag{5}$$

The reflected component of SR by ground surface is called reflected radiation (H_R). The total of H_{DR}, H_R is called global SR (H_G). To utilize maximum SR, PV tilt angle (β) is used which vary between $O^0 - 90°$ [57]. For a titled surface β, incident total SR (H_{TR}) including isotropic model [58] is specified by the equation:

$$H_{TR} = (H_G - H_{DR})\,R_B + H_G\rho\frac{(1 - \cos\beta)}{2} + H_{DR}\frac{(1 + \cos\beta)}{2} \tag{6}$$

Liu and Jordan [59] is used to compute R_B when PV is in northern hemisphere and is sloped towards equator is stated by bellow expression.

$$R_B = \frac{\cos(\phi - \beta)\cos D_A \sin SH_A + SH_A \sin(\phi - \beta)\sin D_A}{\cos\phi \cos D_A \sin SH_A + SH_A \sin\phi \sin D_A} \tag{7}$$

where SH_A is sunset hour angle at tilted surface and is shown by following relation

$$SH_A = \min\left[\cos^{-1}(-\tan\phi \tan D_A),\ \cos^{-1}(-\tan(\phi + \beta)\tan D_A)\right] \tag{8}$$

The OPTA (β_{opt}) for incident maximum SR on PV surface is evaluated by varying β from 0°-90° at difference of 1°.

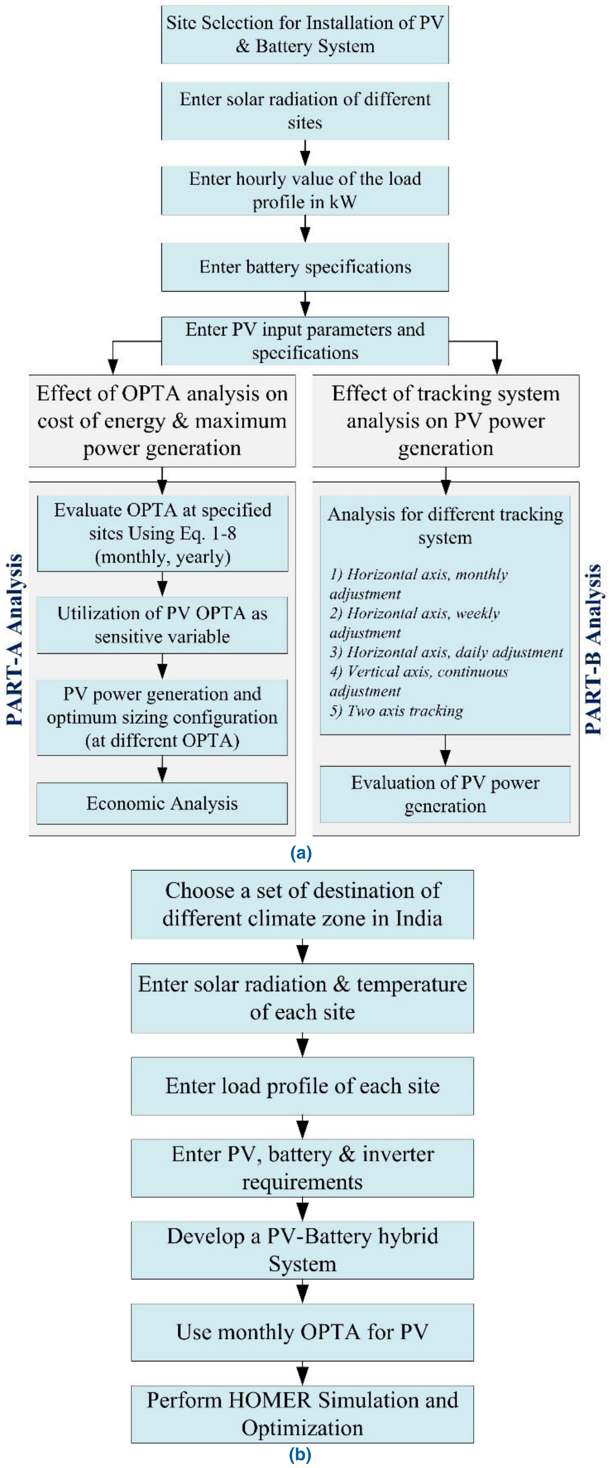

FIGURE 2. **(a). Proposed method for calculating optimum SAPV sizing and power generation at different optimum tilt angles (β_{opt}) and different tracking systems. (b). Procedure for HOMER implementation and optimization.**

The OPTA maximize PV array capacity (PV_{AC}) in PV system as indicated below [60].

$$PV_{AC} = \frac{E_{PV} A H_{TR}}{L_d} \tag{9}$$

TABLE 2. **Data for cost analysis and sizing of standalone photovoltaic system.**

Description	Details
Type of Solar Module	Multi crystalline
PV lifetime (N) is the number of years that a PV lasts.	25 years
Battery life time	5 years
PV module costs [64]	US $ 0.19-0.24/Wp
Efficiency of Cells	13 %
Efficiency of Modules	> 11 %
Efficiency of Power Conversion	90 %
Correction Factor of Temperature	0.9
Battery Depth of Discharge	80 %
Inverter Rating	4 kW
Inverter Efficiency	90 %
Real Interest Rate	2.5 %
PV Array Derating Factor	0.77

where L_d is daily load consumption, A is PV array area (m^2), E_{PV} is efficiency of PV array. The PV_{AC} is depending on H_{TR} and hence on (β_{opt}) i.e.

$$\text{Maximize } PV_{AC} = f\left(\beta_{opt}\right). \tag{10}$$

C. OPTIMUM SIZING OF STANDALONE SOLAR PV SYSTEM

HOMER develop by NREL U.S.A and is freely downloadable software [61], [62]. It is used for designing of micro power system, evaluation of different power generation technologies, life cycle cost (LCC) analysis (installation and system operation cost) and modeling of different design systems based on economic analysis [63]. It operates on three main parameters: optimization, simulation and sensitivity analysis. LCC is determined by simulation and technical feasibility of standalone PV (SAPV) system. The simulation of different system configurations is performed by optimization in the search space that meet specified constraints at least LCC. In sensitivity analysis, it executes multiple optimizations using a range of input variables for calculating output. For the analysis SAPV system to meet a load demand of 3.75 kWh/day is considered.

The monthly OPTA is calculated using Eqs. (1) - (8). The annual OPTA is derived by averaging the results of monthly OPTA. The monthly and annually calculated value of β_{opt} and latitude are used as sensitive variable for calculating optimum sized configuration, maximum power generation, LCC and COE. The different tracking systems is used for calculating PV generation and optimum sizing. The proposed process followed in this study using HOMER for finding optimum sizing of SAPV system at β_{opt} is given in Figure 2.

D. MODELLING OF STANDALONE PV SYSTEM

In simulating SAPV system at OPTA, 3.75 kWh/day of fixed load demand is used. There is no scarcity of capacity. Table 2 lists the components of the SAPV system that were used in the simulation.

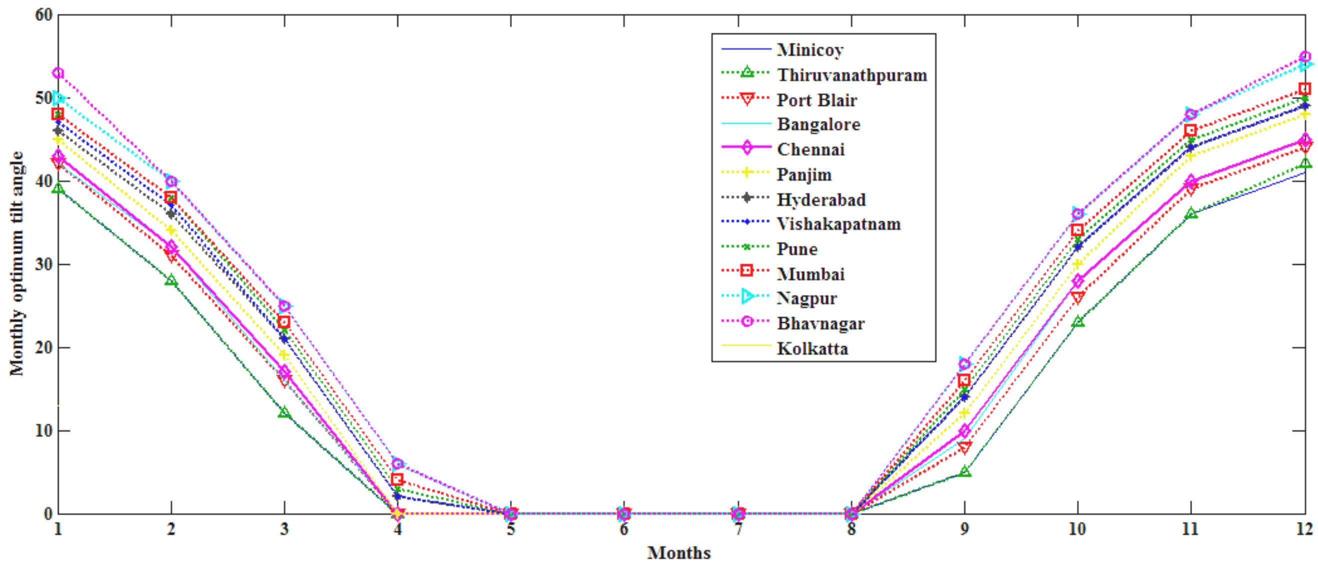

FIGURE 3. Monthly OPTA for 13 cities in India.

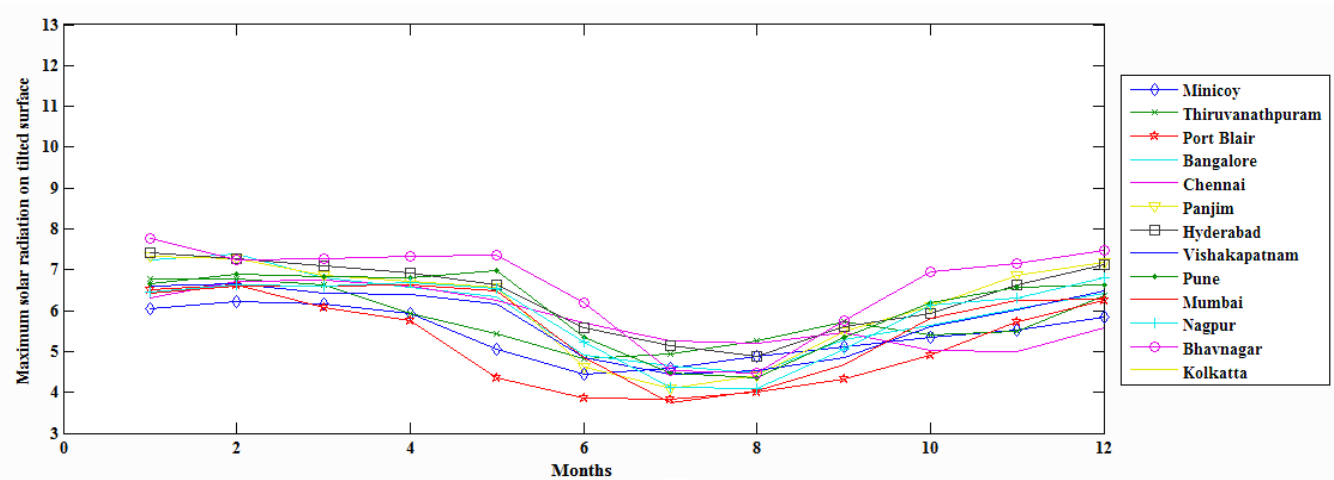

FIGURE 4. Maximum SR on monthly OPTA for 13 cities in India.

E. SOLAR RESOURCE ANALYSIS

The solar resource used in HOMER simulation for Hamirpur (latitude 31.68° N and longitude 76.56° E) are taken from pyranometer installed at rooftop of CEEE at National Institute of Technology Hamirpur, Himachal Pradesh. The average SR and clearness index are found to be 4.312 kWh/m^2/day and 0.501. The measured SR data for another 25 Indian cities are taken from reference [65]. The thermoelectric pyranometer has been used for measuring solar radiation in the range 300-4000 nm by IMD.

The ambient temperature of sites affects PV power generation, so it has to be used in designing a SAPV system [66]. The annual average ambient temperature of different cities is taken from NASA database [67].

F. SAPV SYSTEM COMPONENT ANALYSIS

SAPV system generate, convert, store and transfer energy. For storing and converting electricity batteries and converters are used. It contain 1000Wp PV array and its capital cost (CC) is $350 The PV module cost is $0.35/Wp and cost of replacement is $ 35 which is 10 % of CC [68], [69]. The lifetime of converter is 20 year and nominal operating cell temperature, ground reflectance, derating factor, temperature coefficient of power, standard test condition efficiency are 20%, 77%, −0.48 (% / °C) 47 °C and 10 % respectively. To maintain constant voltage during power shortage Hoppecke 24 OpzS 3000 battery is used. The rating of nominal voltage, nominal capacity, lifetime are 2V, 3000 Ah (6 kWh), 10196 kWh. The replacement and capital cost are $5 and $50 respectively [70].

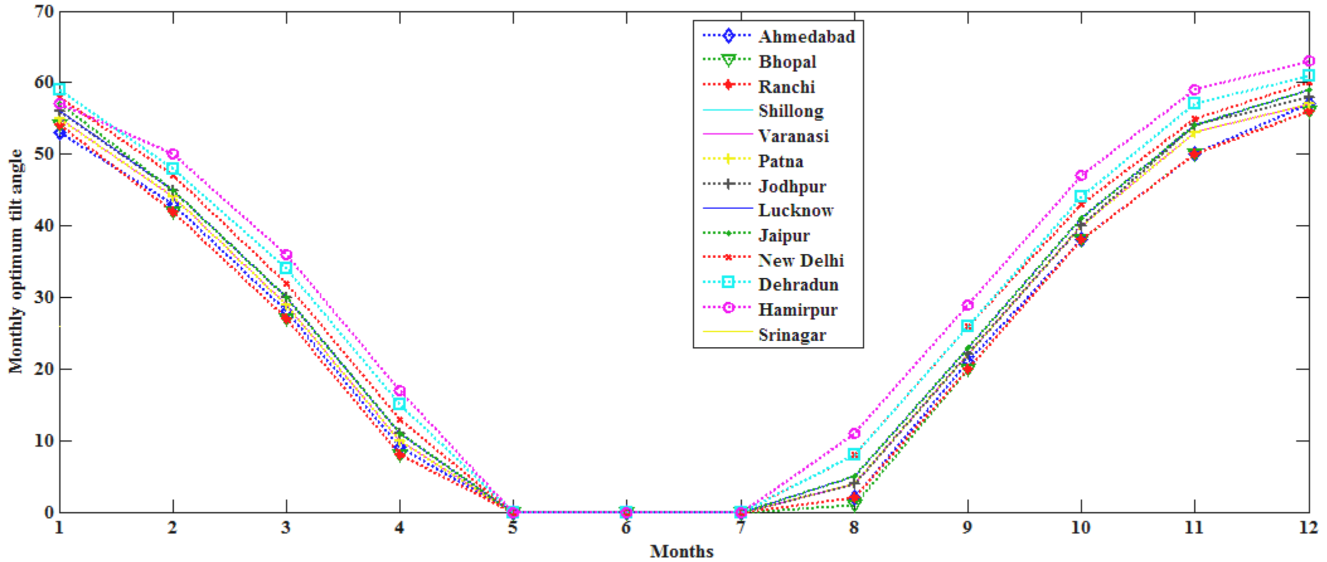

FIGURE 5. Monthly OPTA for other 13 cities in India.

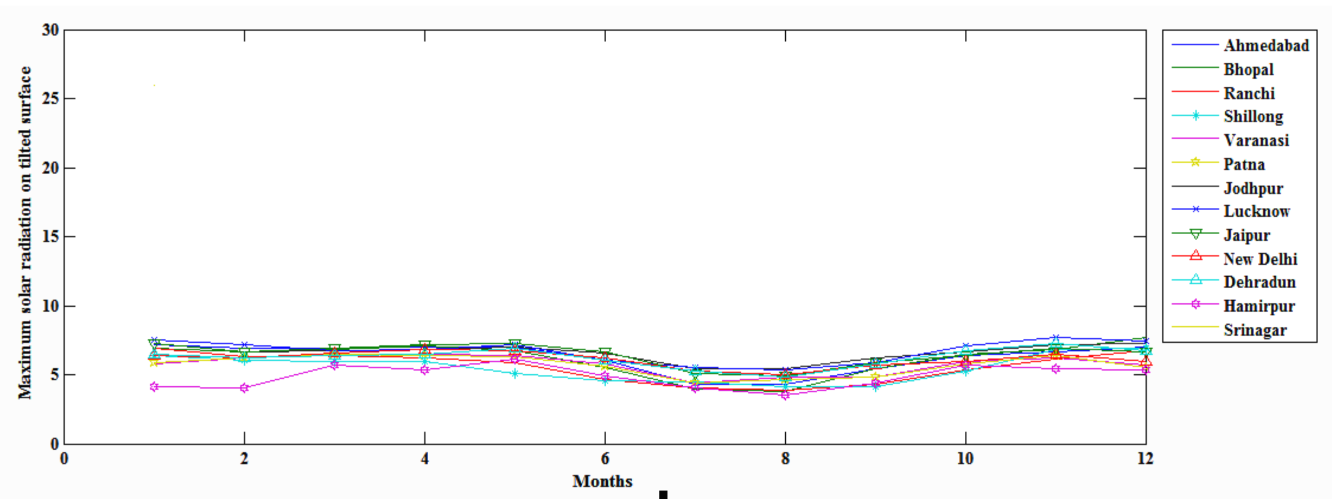

FIGURE 6. Maximum SR on monthly OPTA for remaining 13 cities in India.

The efficiency of rectifier, inverter are 85 %, 90 % and converter lifetime is 15 years.

G. ANALYSIS OF SENSITIVITY

It stands for the effect of input on output, and it's employed in the HOMER simulation. Monthly, yearly OPTA, and latitude of different sites are used in this work, and their impacts on the economic analysis of the SAPV system are also noticed.

H. PV ARRAY

The output power of a PV array (P) is directly proportional to incident SR in HOMER and is provided by the equation below.

$$P = F_{PV} N_{PV} \frac{H_{TR}}{H_{RSR}} \tag{11}$$

where F_{PV} is PV array derating factor, which shows a reduction in PV power owing to increased temperature, dust, and wire loss. N_{PV} is capacity of solar panels, H_R as a reference SR (1kW/m^2). As illustrated in the diagram, the incident SR is turned into power with efficiency (η).

$$\eta = \frac{P_N}{H_{TR} \times A_R} \tag{12}$$

where P_N is solar cell output power at its maximum power point and A_R is surface area of solar cells.

I. ECONOMIC ANALYSIS

The major goal is to reduce NPC by determining the best combination of PV, battery, and converter to maximise the value of SR resources. All costs are included in the NPC.

TABLE 3. Variation of clearness index, OPTA, maximum SR at monthly OPTA, latitude and yearly OPTA in different climatic zones of India.

S.No.	Cities	Clearness index	OPTA	Maximum SR	HL	HY	Climatic Zone
1	Srinagar	0.17-0.83	0-61	1.67-6.18	1.64-5.67	1.62-5.68	Montane
2	Hamirpur	0.3-0.73	0-63	3.52-6.14	3.33-5.65	3.38-5.64	
3	Dehradun	0.42-0.82	0-61	4.84-7.29	4.58-6.57	4.66-6.47	
4	New Delhi	0.38-0.78	0-60	4.96-6.81	4.63-6.62	4.72-6.67	
5	Lucknow	0.48-0.8	0-59	5.34-7.72	4.82-6.9	4.9-6.82	
6	Varanasi	0.38-0.71	0-57	4.35-6.49	3.82-6.47	3.88-6.46	
7	Patna	0.37-0.70	0-57	4.36-6.5	3.83-6.48	3.89-6.47	Humid Sub tropical
8	Shillong	0.42-0.65	0-57	4.13-6.91	3.91-6.09	3.96-5.99	
9	Bhopal	0.4-0.77	0-56	3.8-7.67	3.53-6.89	3.57-6.9	
10	Ranchi	0.41-0.67	0-56	3.85-6.89	3.55-6.34	3.59-6.33	
11	Port Blair	0.39-0.6	0-44	3.82-6.63	3.53-6.32	3.43-6.41	
12	Nagpur	0.43-0.71	0-54	4.1-6.8	3.65-6.58	3.66-6.57	
13	Mumbai	0.39-0.70	0-51	3.73-6.62	3.34-6.59	3.33-6.59	
14	Pune	0.45-0.74	0-50	4.35-6.99	4-6.82	3.99-6.82	
15	Hyderabad	0.5-0.72	0-49	4.87-7.41	4.61-7.09	4.59-7.1	
16	Vishakapatnam	0.46-0.67	0-49	4.45-6.65	3.99-6.4	3.97-6.41	Tropical wet and dry
17	Chennai	0.4-0.68	0-45	4.99-6.75	4.53-6.73	4.61-6.74	
18	Kolkatta	0.38-0.63	0-54	4.19-5.88	3.7-5.75	3.72-5.75	
19	Panjim	0.42-0.7	0-48	4.1-7.32	3.71-6.9	3.67-6.99	
20	Minicoy	0.46-0.6	0-41	4.44-6.21	4.15-6.15	3.95-6.16	Tropical wet
21	Thiruvanathpuram	0.45-0.62	0-42	4.82-6.78	4.5-6.61	4.29-6.62	
22	Bhavnagar	0.47-0.8	0-55	4.48-7.76	4-7.26	4.03-7.25	
23	Ahmedabad	0.45-0.76	0-57	4.3-7.19	3.8-6.93	3.82-6.93	
24	Bangalore	0.44-0.67	0-45	4.48-7.38	4.26-7.05	4.15-7.14	Semi-Arid
25	Jodhpur	0.47-0.8	0-58	5.43-7.27	4.79-6.76	4.88-6.74	
26	Jaipur	0.43-0.82	0-59	4.9-7.25	4.49-6.98	4.59-7.04	Arid

TABLE 4. RMSE and MBE evaluation.

Cities	RMSE (°)	MBE (°)
Minicoy	5.33	3.36
Thiruvanathpuram	5.35	3.32
Port Blair	5.19	3.07
Bangalore	5.17	2.93
Chennai	5.03	2.84
Panjim	5.29	2.40
Hyderabad	5.03	2.08
Vishakapatnam	5.24	2.19
Pune	5.27	2.04
Mumbai	5.30	2.11
Nagpur	5.68	1.84
Bhavnagar	6.02	1.56
Kolkatta	5.69	1.84
Ahmedabad	6.12	2.05
Bhopal	6.13	1.44
Ranchi	5.99	1.43
Shillong	6.12	0.85
Varanasi	6.11	0.74
Patna	6.09	0.58
Jodhpur	6.40	0.51
Lucknow	6.42	0.58
Jaipur	6.51	0.19
New Delhi	6.59	0.18
Dehradun	7.08	-0.82
Hamirpur	7.37	-0.9
Srinagar	7.15	-2.8

Levelized cost of energy (COE), capital recovery factor (CRF), and total net present cost (C_{NPC}) are three essential economics parameters.

TABLE 5. Effect of OPTA on optimum configuration and PV generation.

(β_{opt})	PV (kWp)	Converter (kW)	Number of Batteries	PV Production kWh/year
31.68^0	1	1	30	1524
30.75^0	1	1	30	1523
57^0	**1.5**	**1**	**10**	**2,137**
50^0	1	1	40	1,472
36^0	1	1	30	1,521
17^0	1	1	30	1,489
0^0	1.5	1	10	2,030
0^0	1.5	1	10	2,030
0^0	1.5	1	10	2,030
11^0	1	1	30	1,453
29^0	1	1	30	1,522
47^0	1	1	30	1,488
59^0	1.5	1	10	2,112
63^0	1	1	60	1,371

$$COE = \frac{C_{TAC}}{L_p + L_d + E_{gs}} \tag{13}$$

$$C_{RF(i,n)} = \frac{(i+1)^n i}{(i+1)^n - 1} \tag{14}$$

$$C_{NPC} = \frac{C_{TAC}}{CRF(i, P_L)} \tag{15}$$

TABLE 6. Calculation of optimum configuration of SAPV systems at β_{opt} for 26 Indian cities.

Cities	β_{opt} (°)	PV (kW)	No. of Batteries	Converter (kW)	Climatic Zones
Srinagar	31	1	30	1	Montane
Hamirpur	57	1.5	10	1	
Dehradun	34	1	10	1	
New Delhi	32, 28.4	1	30	1	
Lucknow	56	1.5	10	1	
Varanasi	57	1.5	10	1	
Patna	57	1.5	10	1	
Shillong	53	1.5	10	1	Humid Sub tropical
Bhopal	27	1	30	1	
Ranchi	27	1	30	1	
Port Blair	16	1.5	10	1	
Nagpur	25	1	30	1	
Pune	45	1.5	10	1	
Mumbai	23	1	30	1	Tropical wet and dry
Hyderabad	44	1.5	10	1	
Vishakapatnam	44	1.5	10	1	
Chennai	40	1.5	10	1	
Kolkatta	49	1.5	10	1	
Panjim	19	1	30	1	Tropical wet
Minicoy	28	1.5	10	1	
Thiruvanathpuram	28	1.5	10	1	
Bangalore	40	1.5	10	1	Semi-Arid
Bhavnagar	48	1.5	10	1	
Ahmedabad	50	1.5	10	1	
Jodhpur	58	1.5	10	1	
Jaipur	59	1.5	10	1	Arid

where P_L project lifespan, L_d defferable load, C_{TAC} total annualised cost, L_p primary load, n number of years, and i yearly real interest are all factors.

J. INPUT VARIABLES

The annual real interest and project lifetime are 2.5 % and 25 years [71]. The system fixed operation, maintenance cost and whole project are $12.55/year and fixed capital cost is $ 62.75. The labor wages, construction and other costs are in system fixed capital costs.

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K. ANALYSIS

HOMER simulate different configuration as per load demand and remove infeasible configuration (load demand does not meet). Feasible configuration is ranked as per NPC and lowest total NPC is considered as optimum. Converter size, PV array, tilt angle and number of batteries are taken as decision variable in optimization.

IV. RESULTS AND DISCUSSIONS

First monthly OPTA is calculated using Eqs. (1) - (9) using by initializing β from 0° to 90° at interval of 1°. These monthly and annual values of OPTA for all cities have been used as sensitive variable in HOMER is being studied to see how it affects optimum sizing and maximum power generation with 0 % capacity shortage with minimum COE which is presented in subsequent sections. The monthly β_{opt} and its corresponding H_T for Minicoy, Thiruvanathpuram, Port Blair, Chennai, Bangalore, Panjim, Hyderabad, Vishakapatnam, Pune, Nagpur, Mumbai, Kolkatta and Bhavnagar are in Figures 3 and 4 demonstrate the results, respectively. For Ahmedabad, Ranchi, Bhopal, Shillong, Varanasi, Jodhpur, Patna, Lucknow, New Delhi, Jaipur, Dehradun, Srinagar and Hamirpur monthly β_{opt} and its corresponding H_T are depicted in Figures. 5 and 6, respectively. The variation of clearness index, OPTA, Maximum SR at monthly OPTA, latitude and yearly OPTA in India's several climate zones is shown in Table 3. These angles increases from June to December and decreases from January to June as suggested by Tripathy *et al.* [72].

For validation of results the root mean square error (RMSE) and mean bias error (MBE) are two types of errors for calculated OPTA of 26 cities in India is compared with estimated OPTA given by Soulayman and Sabbagh [73] i.e. φ-δ is shown in Table 4. The RMSE varies from 5.03° to 7.37° and MBE varies from −2.8° to 3.36°

A. EFFECT OF β_{opt} MAXIMIZING ELECTRICITY GENERATION AND SCALING THE SAPV SYSTEM

Monthly OPTA and latitude are used as sensitive variable with 0% capacity shortage for Hamirpur city is shown

TABLE 7. Calculation of maximum power production of SAPV systems at β_{opt} for 26 Indian cities.

Cities	β_{opt} (°)	Energy Production kWh/year	Total NPC ($)	COE ($/kWh)	Climate Zone
Srinagar	31	1621	1207	0.045	Montane
New Delhi	32, 28.4	1648	1207	0.045	Humid Sub tropical
Dehradun	34	1797	1105	0.041	
Hamirpur	57	2137	1280	0.048	
Lucknow	56	2311	1280	0.048	
Varanasi	57	2152	1280	0.048	
Patna	57	2158	1280	0.048	
Shillong	53	2231	1280	0.048	
Bhopal	27	1609	1207	0.045	
Ranchi	27	1571	1207	0.045	
Port Blair	16	2203	1280	0.048	
Mumbai	23	1545	1207	0.045	Tropical wet and dry
Nagpur	25	1567	1207	0.045	
Pune	45	2213	1280	0.048	
Hyderabad	44	2192	1280	0.048	
Vishakapatnam	44	2174	1280	0.048	
Chennai	40	2084	1280	0.048	
Kolkatta	49	2130	1280	0.048	
Panjim	19	1544	1207	0.045	Tropical wet
Minicoy	28	2142	1280	0.048	
Thiruvanathpuram	28	2159	1280	0.048	
Bangalore	40	2169	1280	0.048	Semi-Arid
Bhavnagar	48	2292	1280	0.048	
Ahmedabad	50	2242	1280	0.048	
Jodhpur	58	2229	1280	0.048	
Jaipur	59	2222	1280	0.048	Arid

in Table 5. It is found that yearly production by PV and number of PV, batteries are affected by β_{opt}. For Hamirpur site at OPTA of at 57°, the optimum configuration of SAPV systems are 10 numbers of Hoppecke 24 OpzS 3000 batteries with Net Present Cost of 1280 $, 1 kW converter. With a COE of 0.048 $/kWh and 1.5 kWp PV, the maximum annual power production is 2137 kWh/year.

The same approach as Hamirpur city is used to select β_{opt} of different cities for optimum configuration of SAPV system [Table 6] and maximum power generation with minimum COE in India as shown in Table 7.

The COE of standalone solar PV system for 26 cities of India varies from 0.041 to 0.048 $/kWh with 0 % capacity shortage proving PV installation as a good option for electrification in India.

B. POWER PRODUCTION BY SUN TRACKING SYSTEMS

The and power production and optimum configuration of tracking systems (two Axis, Horizontal axis weekly adjustment, Horizontal axis monthly adjustment, horizontal axis daily adjustment, continuous adjustment and vertical axis) are searched for CEEE NIT Hamirpur in SAPV system. In comparison to horizontal and vertical axis tracking systems, the two axis tracking system produces greater power. The PV generation (kWh/year) by two axis tracking systems with 1 kW PV, 1kW converter and 10 numbers of batteries for 26 cities in India are 2247 for Srinagar, 2213 for New Delhi, 2176 for Jodhpur, 2190 for Jaipur, 2116 for Varanasi, 2117 for Patna, 2104 for Shillong, 2133 for Bhopal, 2085 for Ranchi, 2134 for Bhavnagar, 2074 for Nagpur, 2046 for Mumbai, 2064 for Pune, 2033 for Hyderabad, 2027 for Vishakapatnam, 2013 for Panjim, 1967 for Chennai, 1941 for Port Blair, 1953 for Minicoy, 1943 for Thiruvanathpuram, 2414 for Dehradun, 2203 for Lucknow, 2068 for Hamirpur, 2105 for Ahmedabad, 2011 for Bangalore and 2012 for Kolkatta. Therefore it is found that on two axis tracking system Port Blair has minimum production of PV energy and Dehradun has maximum production of PV energy throughout the year.

V. CONCLUSION

The OPTA of 26 cities in India for various climatic zones is determined in this study by varying the tilt angle from zero to ninety degrees at a difference of one degrees. These OPTA are used to determine their impact on optimum sizing with a minimum COE, 0% capacity shortage, and maximum power. The following conclusions are reached based on the computed findings:

(i) OPTA in India varies between 63° (December) to 0° (July, June, May) throughout the year with December being the highest month for all cities. For different cities the months in which OPTA is 0° are June and July ($\phi = 34°N$), July and June ($22.3°N \leq \phi \leq 31.6°N$) August, July, June and

May ($17.3°N \leq \phi \leq 21.7°N$), August, July, June, May, April ($8.28°N \leq \phi \leq 15.4°N$) which is closed to OPTA calculated by Soulayman and Sabbagh [73].

(ii) OPTA variation for selected sites of montane (0°-61°), humid subtropical (0°-63°), tropical wet and dry (0°-54°), tropical wet (0°-48°), semi-arid (0°-58°) and arid (0°-59°). Converter size is independent of OPTA.

(iii) The monthly OPTA of PV surface has an average SR of 4.77 to 6.7 kWh/m^2/day.

(iv) The OPTA has an impact on PV system energy costs, maximum power generation, and optimal sizing, hence it is important for PV installation from an economic standpoint.

(v) Because a two-axis tracking system with optimal SAPV system configuration produces more PV power than other tracking systems, it is recommended for PV systems.

(vi) The COE varies from 0.041 to 0.048 $/kWh throughout Indian cities. COE for arid and semi-arid zone is same i.e. 0.048 $/kWh. The low temperature sites, i.e. mountainous regions like Hamirpur, Srinagar and Dehradun shows COE variation from 0.041 to 0.048 $/kWh, proving hilly region has good option for PV system installation.

The focus of future research will be on calculation of optimum tilt angle with non-zero surface azimuth angle experimentally.

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REFERENCES

[1] T. V. Ramachandra, R. Jain, and G. Krishnadas, "Hotspots of solar potential in India," *Renew. Sustain. Energy Rev.*, vol. 15, pp. 3178–3186, Aug. 2011.

[2] M. S. Soni and N. Gakkhar, "Techno-economic parametric assessment of solar power in India: A survey," *Renew. Sustain. Energy Rev.* vol. 40, pp. 326–334, Dec. 2014.

[3] V. Khare, S. Nema, and P. Baredar, "Status of solar wind renewable energy in India," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 1–10, Nov. 2013.

[4] Press Information Bureau, Government of India. (2012). *Progress Under Jawaharlal Nehru National Solar Mission*. Accessed: Jan. 17, 2014. [Online]. Available: http://pib.nic.in/newsite/erelease.aspx?relid=83632

[5] M. F. Ansari, R. K. Kharb, S. Luthra, S. S. L. Shimmi, and S. Chatterji, "Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 163–174, Nov. 2013.

[6] T. Khatib, A. Mohamed, and K. Sopian, "A review of photovoltaic systems size optimization techniques," *Renew. Sustain. Energy Rev.*, vol. 22, pp. 454–465, Jan. 2013.

[7] H. Lu and W. Zhao, "Effects of particle sizes and tilt angles on dust deposition characteristics of a ground-mounted solar photovoltaic system," *Appl. Energy*, vol. 220, pp. 514–526, Jun. 2018.

[8] P. Sawicka-Chudy, M. Sibiński, M. Cholewa, and R. Pawełek, "Comparison of solar tracking and fixed-tilt photovoltaic modules in Lodz," *J. Sol. Energy Eng.*, vol. 140, no. 2, pp. 1–6, Apr. 2018.

[9] A. K. Yadav, H. Malik, and S. S. Chandel, "Selection of most relevant input parameters using WEKA for artificial neural network based solar radiation prediction models," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 509–519, Mar. 2014.

[10] A. K. Yadav and S. S. Chandel, "Solar energy potential assessment of western Himalayan Indian state of Himachal Pradesh using J48 algorithm of WEKA in ANN based prediction model," *Renew. Energy*, vol. 75, pp. 675–693, Mar. 2015.

[11] V. Thakur and S. S. Chandel, "Maximizing the solar gain of a grid-interactive solar photovoltaic power plant," *Energy Technol.*, vol. 1, pp. 661–667, Nov. 2013.

[12] P. Yadav and S. S. Chandel, "Comparative analysis of diffused solar radiation models for optimum tilt angle determination for Indian locations," *Appl. Sol. Energy*, vol. 50, no. 1, pp. 53–59, Jan. 2014.

[13] A. K. Yadav and S. S. Chandel, "Formulation of new correlations in terms of extraterrestrial radiation by optimization of tilt angle for installation of solar photovoltaic systems for maximum power generation: Case study of 26 cities in India," *Sādhanā*, vol. 43, no. 6, pp. 1–15, Jun. 2018.

[14] A. Agarwal, "Comparative approach for the optimization of tilt angle to receive maximum radiation," *Int. J. Eng. Res. Technol.*, vol. 1, no. 5, pp. 1–9, 2012.

[15] K. Ulgen, "Optimum tilt angle for solar collectors," *Energy Sour., A*, vol. 28, pp. 1171–1180, Sep. 2006.

[16] S. Sinha and S. Chandel, "Analysis of fixed tilt and sun tracking photovoltaic–micro wind based hybrid power systems," *Energy Convers. Manage.* vol. 97, pp. 121–131, Mar. 2016.

[17] A. Bahrami, C. O. Okoye, and U. Atikol, "The effect of latitude on the performance of different solar trackers in Europe and Africa," *Appl. Energy*, vol. 177, pp. 896–906, Sep. 2016.

[18] C. Stanciu and D. Stanciu, "Optimum tilt angle for flat plate collectors all over the World—A declination dependence formula and comparisons of three solar radiation models," *Energy Convers. Manage.*, vol. 81, pp. 133–143, May 2014.

[19] N. Nijegorodov, K. R. S. Devan, P. K. Jain, and S. Carlsson, "Atmospheric transmittance models and an analytical method to predict the optimum slope of an absorber plate, variously oriented at any latitude," *Renew. Energy*, vol. 4, no. 5, pp. 529–543, Jul. 1994.

[20] R. Ayaz, A. Durusu, and H. Akca, "Determination of optimum tilt angle for different photovoltaic technologies considering ambient conditions: A case study for burdur, Turkey," *J. Sol. Energy Eng.*, vol. 139, no. 4, pp. 1–6, Aug. 2017.

[21] C. Nicolás-Martín, D. Santos-Martín, M. Chinchilla-Sánchez, and S. Lemon, "A global annual optimum tilt angle model for photovoltaic generation to use in the absence of local meteorological data," *Renew. Energy*, vol. 161, pp. 722–735, Dec. 2020, doi: 10.1016/j.renene.2020.07.098.

[22] A. Ullah, H. Imran, Z. Maqsood, and N. Z. Butt, "Investigation of optimal tilt angles and effects of soiling on PV energy production in Pakistan," *Renew. Energy*, vol. 139, pp. 830–843, Aug. 2019.

[23] P. Talebizadeh, M. A. Mehrabian, and M. Abdolzadeh, "Prediction of the optimum slope and surface azimuth angles using the genetic algorithm," *Energy Buildings*, vol. 43, no. 11, pp. 2998–3005, Nov. 2011.

[24] H. S. S. Pour, H. K. Beheshti, and M. Rahnama, "The gain of the energy under the optimum angles of solar panels during a year in Isfahan, Iran," *Energy Sour., A*, vol. 33, pp. 1281–1290, Apr. 2011.

[25] M. Kacira, M. Simsek, Y. Babur, and S. Demirkol, "Determining optimum tilt angles and orientations of photovoltaic panels in Sanliurfa, Turkey," *Renew. Energy*, vol. 29, pp. 1265–1275, Jul. 2004.

[26] L. E. Hartley, J. A. Martínez-Lozano, M. P. Utrillas, F. Tena, and R. Pedrós, "The optimisation of the angle of inclination of a solar collector to maximise the incident solar radiation," *Renew. Energy*, vol. 17, no. 3, pp. 291–309, Jul. 1999.

[27] E. D. Mehleri, P. L. Zervas, H. Sarimveis, J. A. Palyvos, and N. C. Markatos, "Determination of the optimal tilt angle and orientation for solar photovoltaic arrays," *Renew. Energy*, vol. 35, pp. 2468–2475, Nov. 2010.

[28] A. G. Siraki and P. Pillay, "Study of optimum tilt angles for solar panels in different latitudes for urban applications," *Sol. Energy*, vol. 86, pp. 1920–1928, Jul. 2012.

[29] Y. P. Chang, "Optimal the tilt angles for photovoltaic modules in Taiwan," *Elect. Power Energy Syst.*, vol. 32, pp. 956–964, Nov. 2010.

[30] A. Chatterjee and A. Keyhani, "Neural network estimation of micro-grid maximum solar power," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1860–1866, Dec. 2012.

[31] H. Khorasanizadeh, K. Mohammadi, and A. Mostafaeipour, "Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in tabass, Iran," *Energy Convers. Manage.*, vol. 78, pp. 805–814, Feb. 2014.

[32] K. Bakirci, "General models for optimum tilt angles of solar panels: Turkey case study," *Renew. Sustain. Energy Rev.*, vol. 16, pp. 6149–6159, Oct. 2012.

[33] P. Fahl, "Tracking benefits for solar collectors installed in Bangalore," *J. Renew. Sustain. Energy*, vol. 3, Mar. 2011, Art. no. 023103.

[34] S. Abdallah, "The effect of using sun tracking systems on the voltage-current characteristics and power generation of flat plate photovoltaics," *Energy Convers. Manage.*, vol. 45, pp. 1671–1679, Jul. 2004.

[35] S. Beringer, H. Schilke, I. Lohse, and G. Seckmeyer, "Case study showing that the tilt angle of photovoltaic plants is nearly irrelevant," *Solar Energy* vol. 85, pp. 470–476, Mar. 2011.

[36] M. Bojić, D. Bigot, F. Miranville, and A. Parvedy-Patou, "Optimizing performances of photovoltaics in Reunion Island—Tilt angle," *Prog. Photovolt., Res. Appl.*, vol. 20, pp. 923–935, Dec. 2012.

[37] Y. P. Chang, "Optimal design of discrete-value tilt angle of PV using sequential neural-network approximation and orthogonal array," *Expert Syst. Appl.*, vol. 36, pp. 6010–6018, Apr. 2009.

[38] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*. New York, NY, USA: Wiley, 1980.

[39] H. Heywood, "Operating experience with solar water heating," *IHVE J.*, vol. 39, p. 63, Jun. 1971.

[40] P. Lunde, *Solar Thermal Engineering: Space Heating and Hot Water Systems*. New York, NY, USA: Wiley, 1980.

[41] D. Chinnery, "Solar water heating in South Africa," *CSIR Rep.*, vol. 248, p. 44, Jun. 1971.

[42] J. Kern and I. Harris, "On the optimum tilt of a solar collector," *Sol. Energy*, vol. 17, no. 2, pp. 97–102, May 1975.

[43] H. Yellott, "Utilization of sun and sky radiation for heating cooling of buildings," *ASHRAE J.* vol. 15, pp. 31–42, Oct. 1973.

[44] H. K. Elminir, A. E. Ghitas, F. El-Hussainy, R. Hamid, M. M. Beheary, and K. M. Abdel-Moneim, "Optimum solar flat-plate collector slope: Case study for Helwan, Egypt," *Energy Convers. Manage.*, vol. 47, pp. 624–637, Mar. 2006.

[45] B. Meng, R. C. G. M. Loonen, and J. L. M. Hensen, "Data-driven inference of unknown tilt and azimuth of distributed PV systems," *Sol. Energy*, vol. 211, pp. 418–432, Nov. 2020.

[46] M. Despotovic and V. Nedic, "Comparison of optimum tilt angles of solar collectors determined at yearly, seasonal and monthly levels," *Energy Convers. Manage.*, vol. 97, pp. 121–131, Jun. 2015.

[47] W. G. Le Roux, "Optimum tilt and azimuth angles for fixed solar collectors in south Africa using measured data," *Renew. Energy*, vol. 96, pp. 603–612, Oct. 2016.

[48] J. V. Herrera-Romero, D. Colorado-Garrido, M. A. E. Soberanis, and M. Flota-Bañuelos, "RETRACTED: Estimation of the optimum tilt angle of solar collectors in coatzacoalcos, veracruz," *Renew. Energy*, vol. 153, pp. 615–623, Jun. 2020, doi: 10.1016/j.renene.2020.02.045.

[49] C. S. Schuster, "The quest for the optimum angular-tilt of terrestrial solar panels or their angle-resolved annual insolation," *Renew. Energy* vol. 152, pp. 1186–1191, Jun. 2020.

[50] K. R. Agha and M. N. Sbita, "On the sizing parameters for stand-alone solar-energy systems," *Appl. Energy*, vol. 65, nos. 1–4, pp. 73–84, Apr. 2000.

[51] S. Armstrong and W. G. Hurley, "A new methodology to optimize solar energy extraction under cloudy conditions," *Renew. Energy*, vol. 35, pp. 780–787, Apr. 2010.

[52] H. Ge, L. Ni, and S. Asgarpoor, "Reliability-based stand-alone photovoltaic system sizing design-a case study," in *Proc. 10th Int. Conf. Probabilistic Methods Appl. Power Syst.*, 2018, pp. 1–8.

[53] M. M. H. Bhuiyan and M. A. Asgar, "Sizing of a stand-alone photovoltaic power system at Dhaka," *Renew. Energy*, vol. 28, pp. 929–938, May 2003.

[54] A. K. Yadav, H. Malik, S. M. S. Hussain, and T. S. Ustun, "Case study of grid-connected photovoltaic power system installed at monthly optimum tilt angles for different climatic zones in India," *IEEE Access*, vol. 9, pp. 60077–60088, 2021.

[55] A. K. Yadav and S. S. Chandel, "Tilt angle optimization to maximize incident solar radiation: A review," *Renew. Sustain. Energy Rev.*, vol. 23, pp. 503–513, Jul. 2013.

[56] P. I. Cooper, "The absorption of radiation in solar stills," *Sol. Energy*, vol. 12, no. 3, pp. 333–346, 1969.

[57] M. Benghanem, "Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia," *Appl. Energy*, vol. 88, pp. 1427–1433, Apr. 2011.

[58] B. Liu, "Daily insolation on surfaces tilted toward the equator," *ASHRAE Trans.*, vol. 67, pp. 526–541, Oct. 1967.

[59] R. Jordan, "The long-term average performance of flat-plate solar energy collectors," *Solar Energy* vol. 7, p. 53, Mar. 1963.

[60] M. Egido and E. Lorenzo, "The sizing of stand alone PV-system: A review and a proposed new method," *Sol. Energy Mater. Sol. Cells*, vol. 26, nos. 1–2, pp. 51–69, Mar. 1992.

[61] *HOMER Energy*. Accessed: Jan. 17, 2014. [Online]. Available: http://www.homerenergy.com/login.asp?redirect=/download.asp

[62] HOMER Energy. *HOMER User Manual*. Accessed: Feb. 14, 2021. [Online]. Available: http://www.homerenergy.com/pdf/HOMERGettingStarted210.pdf

[63] Y. V. Pavan Kumar and R. Bhimasingu, "Renewable energy based microgrid system sizing and energy management for green buildings," *J. Modern Power Syst. Clean Energy*, vol. 3, no. 1, pp. 1–13, Mar. 2015.

[64] *Solar Panel Cost, Alibaba.com*. Accessed: Jan. 17, 2014. [Online]. Available: http://www.alibaba.com/product-gs/1228055774/top_quality_most_popular_polycrystalline_silicon.html

[65] Solar Radiation Handbook. (2008). *A Joint Project of Solar Energy Centre, MNRE, Indian Metrological Department*. Accessed: Jan. 17, 2014. [Online]. Available: http://Indiaenvironmentportal.org.in/files/srd-sec.pdf

[66] G. K. Singh, "Solar power generation by PV (photovoltaic) technology: A review," *Energy*, vol. 53, pp. 1–13, May 2013.

[67] NASA. *Surface Meteorology and Solar Energy: Accuracy*. Accessed: Feb. 10, 2014. [Online]. Available: https://eosweb.larc.nasa.gov/cgi-bin/sse/print.cgi?accuracy.txt

[68] *Alibaba.com—Solar Products Price List*. Accessed: Feb. 10, 2014. [Online]. Available: http://www.alibaba.com/showroom/polycrystalline-silicon-solar-cell-price.html

[69] *Solar Photovoltaic, International Renewable Energy Agency (IREA)*. Accessed: Feb. 10, 2014. [Online]. Available: http://www.irena.org/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf

[70] *Alibaba.com—Lead Acid Battery*. Accessed: Feb. 10, 2014. [Online]. Available: http://www.alibaba.com/productgs/1322294960/Maintennance_Free_hoppecke_lead_acid_battery.html

[71] R. Sen and S. C. Bhattacharyya, "Off-grid electricity generation with renewable energy technologies in India: An application of HOMER," *Renew. Energy*, vol. 62, pp. 388–398, Feb. 2014.

[72] M. Tripathy, S. Yadav, P. K. Sadhu, and S. K. Panda, "Determination of optimum tilt angle and accurate insolation of BIPV panel influenced by adverse effect of shadow," *Renew. Energy*, vol. 104, pp. 211–223, Apr. 2017, doi: 10.1016/j.renene.2016.12.034.

[73] S. Soulayman and W. Sabbagh, "Comment on 'Optimum tilt angle and orientation for solar collectors in Syria'by Skeiker, K," *Energy Convers. Manage.*, vol. 89, pp. 1001–1002, Jan. 2015.

[74] *Annual Report—2019, International Energy Agency, Photovoltaic Power System Programme, International Energy Agency*. Accessed: Dec. 20, 2021. [Online]. Available: https://iea-pvps.org/wp-content/uploads/2020/05/IEA-PVPS-AR-2019-1.pdf

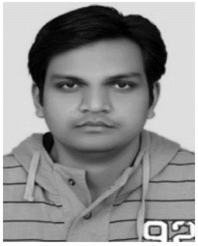
[75] *India Climatic Zone Map*. Accessed: Dec. 20, 2021. [Online]. Available: https://upload.wikimedia.org/wikipedia/commons/8/88/India_climatic_zone_map_en.svg

[76] *Stamp's & Koeppen's Classification of Climatic Regions of India*. Accessed: Dec. 20, 2021. [Online]. Available: https://www.pmfias.com/climatic-regions-of-india-stamps-koeppens-classification/#Koeppen%E2%80%99s_Classification_of_Climatic_Regions_of_India

[77] K. Y. Yap, C. R. Sarimuthu, and J. M.-Y. Lim, "Grid integration of solar photovoltaic system using machine learning-based virtual inertia synthetization in synchronverter," *IEEE Access*, vol. 8, pp. 49961–49976, 2020, doi: 10.1109/ACCESS.2020.2980187.

[78] A. S. Al-Sumaiti, M. M. A. Salama, S. R. Konda, and A. Kavousi-Fard, "A guided procedure for governance institutions to regulate funding requirements of solar PV projects," *IEEE Access*, vol. 7, pp. 54203–54217, 2019, doi: 10.1109/ACCESS.2019.2912274.

[79] U.-M. Choi, "Study on effect of installation location on lifetime of PV inverter and DC-to-AC ratio," *IEEE Access*, vol. 8, pp. 86003–86011, 2020, doi: 10.1109/ACCESS.2020.2993283.



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