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Estimation of optimal tilt angle for solar photovoltaic installations in India

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Abstract -*Solar panels are one of the important and most promising renewable energy technologies in India for energizing solar based application such as heating, desalination, cooking, cooling and power generation system. As there is tremendous availability of sunshine throughout the year. For ambitious, smart urban cities program solar PV based technology is prime, an ideal choice for power generation. In all these solar based application, the amount of solar radiation plays an important role which is mainly affected by tilt and azimuth angle of location. So in order to have maximizedannual average incident solar energy on the surface of PV system, it is required to determine optimal tilt angle. Optimization of tilt angle ensures the maximum energy generation, thereby reducing the cost of power generation. This paper attempts to estimate the optimal tilt angle of PV for six different locations of India using various simulation software like RETSCREEN, PVSYST and NREL SAM. The simulated result shows that the majority of average solar radiation is above 5kWh/m²/d and falls in the range of 5-6.5kWh/m²/d. The yearly optimal angle obtained are having variation of +2° to +3° from the latitude of the location.*

Key Words:**Tilt angle, PV system, Solar Photovoltaic, Solar radiation.**

1. INTRODUCTION

Environmental concerns as well as rise in demand for cleaner energy are the main motives for research in various renewable resources like wind, tidal, geothermal and solar. Solar is an ancient source of energy among all these resources of energy which is the origin of all fossil fuel and renewable energy like biomass, wind, etc. High density energy consumption urban areas are considered to be one of the most reasonable locations for installation of renewable energy technologies due to the recent shortage of fossil fuel [1]. The quantity of solar radiation captured by a solar collector is mainly affected by the orientation and tilt angles of PV panel. This is because both of these factors influences the angle of incidence of the solar radiation upon the solar panel and can change the amount of solar radiation arriving at the earth's surface. Explicit data of solar radiation reception by a solar surface at different tilt angles along with cognizance of the optimum tilt angle are of great importance for experts and designers related to solar energy field [2]. Generally speaking, the optimal orientation is due south for the India as it lays in the northern hemisphere. It is also immensely important to calculate the optimum tilt angle for each particular location because it depends upon climatic condition, latitude, solar system utilization span as well as solar radiation characteristics of that particular spot [3].

In current scenario, the solar energy based power generating systems can play an important part in fulfilment of the energy requirements of the industrial sector [4]. India most importantly needs to meet its energy demands in a sustainable, responsible and eco-friendly manner, in the right way and at the right time. Due to all these aspects, it is required to replace non-renewable sources with renewable ones, especially solar energy, for fulfilling the electricity or power needs. In India about 5×10^9 GWh solar radiation energy is incident per year with most parts receiving solar irradiance of 4-7 kWh/m²/d (see Fig. 1) [4, 5]. Hence, solar energy has a vast potential to satisfy the increased demands of energy.

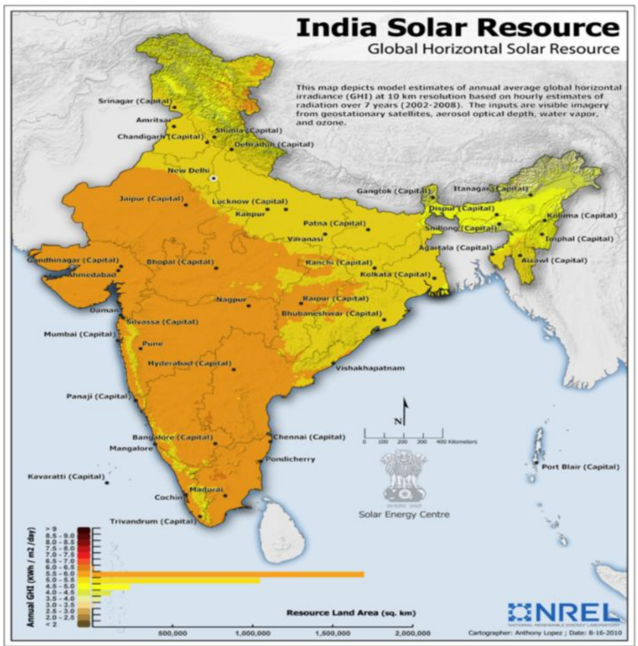

Fig -1: Solar radiation energy (kWh/m²/d) in India

In all the solar PV technology, the most significant parameter is input, which is solar radiation. Solar radiation input is required for performance evaluation of

PV as well as for optimization of solar thermal and solar PV. While having maximized incident solar radiation, we require optimal tilt inclination of PV module [6]. Photovoltaic (PV) panels convert solar energy into electrical energy with the peak efficiencies in the range of 5–20%, depending on the type of PV cells [7]. The National Action Plan on Climate Change (NAPCC) is the main key plan for the development of solar energy technologies in India. The Government of India approved "Jawaharlal Nehru National Solar Mission" (JNNSM), in November 2009. The Mission mainly focuses on deployment and development of solar energy technologies in the country to achieve parity with grid power tariff by 2022 [8].

On the optimum tilt angle of the solar system, several studies have come into the field of vision in the literature. Milan Despotovic and Vladimir Nedic [9] examined the optimum tilt angle of solar collectors for Belgrade, which is situated at the latitude of 44°47'N. They found yearly, biannual, seasonal, monthly, fortnightly, and daily optimum tilt angles by looking for the values for which the solar radiation on the collector surface is maximized. They observed that, by installing the PV panels at yearly, seasonal and monthly optimum tilt angles, yield increases amount of collected solar energy by a factor of 5.98%, 13.55%, and 15.42% respectively compared to PV panels at current roofs' surface angles. Hamid Moghadam and Saeed Moghadam Deymeh [10] determined the optimum location and optimum tilt angle of solar collectors placed on the roof, in respect of the shadow of adjacent buildings. Their result suggests that for northern hemisphere of the earth solar collectors should be installed on the southern verge of the roof as far as possible away from the bigger adjacent building. They found that optimum location direct solar radiation collected energy could be increased furthermore the 15%. In addition to this, shade has little effects on the optimum tilt angle for the parts of the roof near to the taller adjacent building.

Hamdy K. Elminir, et al [11], examines the theoretical features of tilt angle selection for the solar flat-plate collectors used in Egypt. They performed a statistical comparison of three specific anisotropic models (Tamps–Coulson, Perez and Bugler) to get the most accurate solar radiation estimating model. That most accurate model used to determine optimum collector slope. Their study showed that the Perez's model is the best one, followed by the Tamps-Coulson then Bugler models in respect of overall calculated performance of all these three models. Adnan Shariah, et al [12], used the annual solar fraction of the system as an indicator to obtain optimum tilt angles for a thermosyphon solar water heater installed in northern and southern parts of Jordan. The powerful computer program TRNSYS (Transient System Simulation) used by them for calculation of the system operated with a daily hot water load of 150 l at 55°C flowing during the day as per the widely used Rand consumption profile. The results reveal that the optimum tilt angle for the maximum solar fraction is about ϕ + (0→10°) for the northern region and about ϕ + (0→20°) for the southern region. These values are about 5 to 8° more than those for maximum solar radiation.

Lave and Kleissl [13] calculated the optimal tilt and azimuth angles of solar PV panels in the continental United States. They compared the annual global radiation incident on a panel at various optimum orientations with that of a flat horizontal panel and a 2-axis tracking panel. They found that solar irradiation at optimum fixed tilted PV panel increases from 10% to 25% with increment in latitude. Also, solar irradiation reception on a 2-axis tracking panel was between 25% and 45% more than irradiation on the panel at optimum fixed orientation. Ekadewi A. Handoyo, et al [14], done the research to find the optimal angle of installing a solar collector for helping the farmers. They used mathematical equation and done experiments to determine the optimum tilt angle for Surabaya location of Indonesia. The result shows that for a collector installed in Surabaya, the optimal tilt angle during March 12 – September 30 is varied between 0 – 40° (face to the North) and during October 1 – March 11 is between 0 – 30o (face to the South). Another option is installing two collectors with one facing to the East to be used in the morning session and one to the West in the afternoon session of the day. The optimal tilt angle obtained for these orientations is 36 – 39.4°.

Although the optimum inclination angle is normally close to the latitude of the location, but definite value can rarely be on optimum tilt angles. There are different optimization techniques to obtain optimal tilt angle such as using experimental analysis, solar tracking method and simulation or modelling. In spite of many practical and modelling based investigations on optimization of solar systems inclination, there are several inconsistencies in the presented results. In Indian scenario where solar radiation intensity is 1000kW/m^2 ,the optimal tilt angle variation from latitude of the location is not much and has good opportunity to collect maximum solar radiation.. In this study, PV simulation software RETSCREEN, PVSYST and NREL SAM are used to determine the optimal tilt angle for six different Smart cities of India lying in different regions (northern, southern, eastern, western and central region) i.e., Ahmedabad(Latitude23.0300° N, 72.5800° E), Delhi(Latitude 28.6139° N, 77.2090° E), Kolkata(Latitude 22.5667° N, 88.3667° E), Bhopal(Latitude 23.2500° N, 77.4167° E), Mumbai(Latitude 18.9750° N, 72.8258° E) and Chennai(Latitude 13.0827° N, 80.2707° E). These six cities comes under Smart cities programme running by Indian Government. Determination of optimal tilt for PV installation will be useful aspect for Smart cities programme.

2. Methodology

Solar energy incident on solar PV surface is sum of beam and diffuse radiation. For maximized output from a PV system, it is necessary to understand the nature of dependence of solar radiation and inclination angle of PV system [15]. Over the past few years, many simulation, modelling and experiment have been done to estimate the solar radiation on inclined surface. All these investigation and experiment have specific technique and measurement. Some of these are limited in their scope for determining the optimal tilt angle. In this study, PV simulation software are used to determine annual average solar radiation on various tilt. Finally maximum annual average solar radiation on different tilted surfaces was obtained to estimate optimum tilt angle.

2.1 Global solar radiation

Sun's radiation passing through the earth's atmosphere and because of scattering and absorption by atoms and ions of gases present in the atmosphere (oxygen, hydrogen, nitrogen, ozone, carbon dioxide, etc.), the intensity of solar radiation reduces to 25% – 30%. Solar radiation that comes to thus reaches to earth surface is known as solar radiation on a horizontal surface or global solar radiation [16]. The solar radiation that reaches the earth's surface is 0.5 milliard part of emitted solar energy, and that corresponds to the solar power of 175 × 109 MW. This solar power is having more strength than the power of all power plants on the earth when it work in full energy.

Two components of solar radiation come to ground surface. One component comes directly from the Sun (beam solar radiation) without any dispersion and the other originates from scattering of direct solar radiation from the atmospheric obstacles (diffuse solar radiation). Global solar radiation consists of beam and diffuse solar radiation which is given by:

$$H_g = H_b + H_d \qquad (1)$$

2.1.1. BeamSolar Radiation

The beam solar radiation represents a component of global solar radiation that comes directly to the earth's surface in a bright and clear sky day. The direction of the beam solar radiation is normal to earth's surface. When the sky is clear and the sun is normal to the ground surface in the sky, beam solar radiation is around 85% of the total solar insolation reaching the earth's surface.

2.1.2. Diffuse Solar Radiation

Except, of the beam solar radiation every point of earth's surface receives a part of solar radiation that comes to it indirectly. It is called the diffuse solar radiation. Even on a brightest clear day, with minimal amount of water steam, about 8% of the whole energy of solar radiation that comes to the ground surface originates from diffuse radiation. As the effect of air pollution and ground configuration, the diffuse radiation comes even to 22% of the complete solar radiation [16].

2.2 Solar radiation on inclined surface

The incident solar energy on a PV module depends not only on the incident sunlight, but also on the angle formed between the module and the sun. When the absorbing surface of the PV system and the incident sunlight are perpendicular to each other, then the PV surface obtains maximum solar energy. However, as the angle formed between the sun and a fixed horizontal surface is changed continuously throughout the day, the incident solar energy also varies with the orientation of the sun. The component of incident global solar radiation on a tilted surface (H_T) at tilt angle (β) can be expressed by:

$$H_T = (H_g - H_d)R_b + H_g\left(\frac{1-\cos\beta}{2}\right) + H_d\left(\frac{1-\cos\beta}{2}\right) \qquad (2)$$

Primarily, R_b is a function of transmittance of atmosphere, which is determined by the following expression for the inclined surfaces that are sloped due south the in the northern hemisphere.

$$R_b = \frac{\cos(\emptyset-\beta)\cos\delta\sin W_{ss} + W_{ss}\sin(\emptyset-\beta)\sin\delta}{\cos\emptyset\cos\delta\sin W_{ss} + W_{ss}\sin\emptyset\sin\delta}$$

The numerator part of eq. (3) represents the amount of extra-terrestrial solar radiation on inclined surface and the denominator part is that on horizontal surface [16], [17]. Where, ϕ is the latitude (in degree) of the location and W_{ss} is the sunset hour angle for inclined surfaces for the month under consideration, which is expressed as:

$$W_{ss} = min\left\{\begin{array}{c}\cos^{-1}(-\tan\emptyset\tan\delta) \\ or \\ \cos^{-1}(-\tan(\emptyset+\beta)\tan\delta)\end{array}\right\} \qquad (4)$$

The declination angle (δ) is the angular point of the solar noon with respect to the plane of the equator, and was calculated by the formula proposed by Cooper (1669) as follows:

$$\delta = 23.45 \times \sin\left(\frac{2\pi(284+n)}{365}\right) \qquad (5)$$

2.3. Optimum tilt angle

Optimization of tilt angle of PV panel provide optimal angle for PV system of particular location where optimal angle is the angle of inclination of PV panel to harness the maximum solar radiation throughout the year for large PV power production. The optimum tilt angle calculations are based on maximizing the solar radiation falling on a tilted surface [19]. In order to find the optimum angle of installation for determining the optimal tilt angle for particular location, different PV simulation software are used having following steps to determine the optimal tilt angle:

(i) Six locations in different regions of India have been chosen for investigating optimal tilts. Then, for every chosen location, all solar radiation geometry data like latitude, longitude and the meteorological data at horizontal surface are obtained using different PV simulation software.

(ii) Then, PV simulation software are used to vary the tilt angle ±5° to the latitude of every location. Then it gives all the meteorological data for every tilt angle of PV system.

(iii) The tilt where the maximum solar radiation is obtained is considered as the optimal tilt angle for that particular location.

2.4. Simulation software

2.4.1. RETScreen (Renewable Energy Technologies Screen)

RETSCREEN is a clean energy management software technology for energy efficiency analysis. It designed with the contribution of numerous experts from government, industry, and academia[18]. This software has an entry of monthly global solar radiation on horizontal surface, ambient temperature and wind speed. The latest version of RETScreen is version 4. It consist of two separate program one is RETScreen 4 and another one is RETScreen plus. RETScreen 4 is excel based software tool that can be utilized in the area of technical as well as financial visibility of renewable potential, energy efficiency analysis and cogeneration energy projects. Here, RETScreen 4 has been utilized to simulate optimal tilt angle (see Table 1). This software can be used worldwide to evaluate the energy generation and savings, total installation and operation and maintenance costs, CO2 emission reductions, economical viability and risk analysis for various types of Renewable-energy and Energy-efficient Technologies (RETs)[20],[21].

2.4.2. PVsyst (PhotoVoltaic systems)

PVsyst is a suitable software tool for grid-connected, stand-alone, pumping and DC-grid systems. It is a windows based software package and has similar meteorological data requirements as RETSCREEN [18]. This can be used for PV system analysis of any location that has long term measured meteonorm solar radiation data to calculate all the PV parameters [22]. The latest version of PVsyst is 6.4.3 (April, 2016), which facilitates a multi-language interface (English, German, French, Italian and Spanish). In this study the PVsyst 6.3.9 is used (see Table 1). PVsyst gives several choices to the PV system designer for project design as it has three different steps. These are Preliminary design; Project design and Tools [21].

(National Renewable Energy Laboratory Solar Advisor Model)

The System Advisor Model (SAM) is a free simulation software developed by the US department of the National Renewable Energy Laboratory that prognosticates hourly energy production for renewable energy systems. It is a performance and the financial model software tool. The purpose of this model is to make a quick decision for people related to various areas of renewable energy. It is a software for planning, monitoring and visualizing energy systems. For all this purpose NREL SAM provides state-of-the-art functions in the form of blocks that can be linked to a concrete solution, for e.g. in simulating meteorological data, electrical and thermal energy components, etc. SAM utilizes a system-driven approach (SDA) and Solar Energy Technologies Program (SETP) [22].Latest version of SAM is 2015.6.30 (see Table 1).

Table -1: Simulation software

Simulation Software	Manufacturer	Cost	Website/Link	Version Utilized
RETScreen	Natural Resources Canada	Free of Charge	www.retscreen.net	4
PVsyst	Institute of Environmental Sciences (ISE), University of Geneva, Switzerland	900 CHF for one machine license ; 150 CHF for additional machines	http://www.pvsyst.com /5.2/index.php	6.3.9
NREL SAM	National Renewable Energy Laboratory, Washington	Free	https://www.nrel.gov/analysis/sam/background.html	2015.6 .30

3. Result and discussion

PV simulation software RETSCREEN, PVSYST AND NREL SAM were used to determine the optimal tilt angle for six smart cities i.e. Ahmedabad, Delhi, Kolkata, Bhopal, Chennai and. Then optimal angles for these locations are determined to know how they vary from one location to other across different regions of India. Steps involved are:

(a). Firstly the locations which reside in different regions i.e. central, north, south, east and west are chosen which include *Ahmedabad, Delhi, Kolkata, Bhopal, Chennai and Mumbai*. The software gives all related meteorological data for horizontal surface of the chosen cities.

(b). Solar radiation energy for PV system placed at horizontal surface for all these six locations are simulated using three different simulation software (see Table 2-4). All these locations of India receive maximum solar radiation on horizontal surface from the month of March to June which ranges from 6 to 7 kWh/m^2/. While during the rest of the month the solar radiation ranges between 4 and 6 kWh/m^2/d. Annual average solar radiation is more than 5 kWh/m^2/d for each of these cities except Kolkata. Ahmedabad city which is located on western part of India receives more solar radiation as compared to other cities. All these three software are showing approximately same simulation result of solar radiation energy (see Table 2-4).

Table -2: Solar radiation energy (kWh/m^2/d) simulation at horizontal surface using RETScreen

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	4.70	3.74	3.97	4.50	4.99	4.70
FEB	5.56	4.76	4.89	5.25	6.06	5.51
MAR	6.49	5.89	5.53	6.07	6.61	6.27
APR	7.09	6.79	6.22	6.59	6.64	6.73
MAY	7.25	6.96	6.42	6.52	6.39	6.76
JUN	6.11	6.30	4.92	5.46	5.73	4.87
JUL	4.53	5.27	4.64	4.11	5.35	3.79
AUG	4.33	5.10	4.47	3.70	5.40	3.93
SEPT	5.39	5.46	4.64	4.77	5.48	4.75
OCT	5.50	5.04	4.53	5.15	4.67	5.11
NOV	4.77	4.13	4.28	4.64	4.12	4.69
DEC	4.37	3.55	3.83	4.20	4.18	4.36
AVG	**5.50**	**5.25**	**4.86**	**5.08**	**5.46**	**5.12**

Where, M/C = Month/City, ADI = Ahmedabad, DEL = Delhi, KOL = Kolkata, BPL = Bhopal, CHN = Chennai, MUM = Mumbai.

Table -3: Solar radiation energy (kWh/m^2/d) simulation at horizontal surface using PVsyst

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	4.56	3.81	4.14	4.61	4.8	4.58
FEB	5.43	4.89	4.97	5.43	5.93	5.4
MAR	6.3	6.07	5.32	6.19	6.35	6.19
APR	6.9	6.88	6.67	6.6	6.51	6.6
MAY	6.99	7.16	6.44	6.52	6.21	6.5
JUN	5.98	6.55	4.85	4.9	5.6	4.87
JUL	4.31	5.37	4.31	3.87	5.23	3.84
AUG	4.17	5.16	4.41	3.94	5.27	3.9
SEPT	5.23	5.69	4.32	4.73	5.31	4.7
OCT	5.3	5.31	4.8	5.09	4.57	5.06
NOV	4.65	4.28	4.55	4.63	4.04	4.63
DEC	4.24	3.71	3.9	4.26	4.09	4.25
AVG	**5.34**	**5.4**	**4.89**	**5.064**	**5.32**	**5.043**

Table -4: Solar radiation energy (kWh/m^2/d) simulation at horizontal surface using NREL SAM

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	4.65	3.84	3.93	4.57	4.95	4.53
FEB	5.41	4.56	4.65	5.75	5.88	5.32
MAR	6.46	5.77	5.54	6.76	6.45	6.19
APR	7.19	6.81	6.06	7.14	6.80	6.86
MAY	7.28	7.31	5.89	7.21	6.42	6.56
JUN	6.29	6.98	4.91	6.16	5.69	4.84
JUL	4.94	5.69	4.25	4.35	4.94	3.77
AU	4.52	5.33	4.41	3.94	5.03	3.84
SEPT	5.36	5.38	4.23	5.46	5.39	4.19
OCT	5.49	4.97	4.39	5.74	4.86	5.10
NOV	4.75	4.08	3.86	4.93	4.2	4.73
DEC	4.23	3.70	3.73	4.56	4.19	4.27
AVG	**5.55**	**5.37**	**4.65**	**5.55**	**5.40**	**5.02**

(c). Now by varying the tilt angle of PV panel through simulation software ±5° from latitude of location of these cities, solar radiation for these tilt angles are obtained. Wherever the enormous solar radiation is harvested by PV module, it is concluded as the optimal tilt angle of the location. The optimal tilt angles for six locations of India varying between 10° to 30° (see Table 5). Optimal tilt obtained is close to the latitude of the location.

Table -5: Optimum tilt for six cities in India

S/N	City	LATITUDE(in degree)	OPTIMAL TILT ANGLE(in dgree)		
			RETScreen	PVsyst	NREL SAM
1.	ADI	23.0300	25	26	26
2.	DEL	28.6139	28	30	30
3.	KOL	22.5667	21	21	23
4.	BPL	23.2500	25	26	25
5.	CHN	13.0827	10	10	12
6.	MUM	18.9750	20	19	22

(d). Now, solar radiation energy for all the six locations is simulated for the above obtained optimum tilt (see Table 6-8). Solar radiation reception at optimal tilt is increases beyond 7kWh/m^2/d and even falls in the range of 6 to 7kWh/m^2/d for almost all the months of the year except July and august. As July and august are months of rainy season with no clear sky, hence reduction in the reception of solar radiation is observed.

Each of these cities has annual average solar radiation above 5kWh/m^2/d at optimal tilt. But, for Kolkata city, the annual average solar radiation is below 5kWh/m^2/d as per the simulation result of NREL SAM. Delhi city is having maximum annual average solar radiation as compared to other cities, which is about 6kWh/m^2/d as per the PVsyst and NREL SAM software. Ahmedabad city is second most maximum solar radiation energy reception city, which is close to 6kWh/m^2/d. Bhopal and Chennai cities are having annual average solar radiation energy about 5.5kWh/m^2/d. While Mumbai city is having solar radiation energy near to 5.4kWh/m^2/d. Kolkata city is receiving annual average solar radiation energy about 5.1kWh/m^2/d.Every city has solar radiation energy receptionincrement in the range from +0.08kWh/m^2/d to 0.7kWh/m^2/d at optimal tilt as compared to PV system placed at zero tilt. This increment in solar energy leads to MW to rise in power generation for big solar farms.

Table -6: Solar radiation energy (kWh/m2/d) simulation at horizontal surface using RETScreen

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	6.11	5.16	4.85	5.82	5.43	5.59
FEB	6.67	5.99	5.63	6.25	6.44	6.25
MAR	7.04	6.60	5.89	6.55	6.77	6.61
APR	6.95	6.80	6.16	6.46	6.56	6.59
MAY	6.61	6.42	6.01	5.98	6.15	6.26
JUN	5.45	5.64	4.56	4.92	5.47	4.49
JUL	4.17	4.83	4.35	3.80	5.14	3.57
AUG	4.14	4.93	4.34	3.55	5.29	3.79
SEPT	5.54	5.79	4.75	4.88	5.52	4.81
OCT	6.32	6.09	5.02	5.88	4.85	5.60
NOV	5.96	5.61	5.11	5.79	4.39	5.53
DEC	5.80	5.08	4.79	5.55	4.53	5.25
AVG	**5.89**	**5.74**	**5.12**	**5.45**	**5.54**	**5.36**

Table -7: Solar radiation energy (kWh/m2/d) simulation at horizontal surface using PVsyst

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	6.31	5.72	5.25	6.18	5.3	5.7
FEB	6.81	6.6	5.92	6.71	6.41	6.28
MAR	7.07	7.17	5.81	6.92	6.58	6.69
APR	6.87	7.04	6.7	6.58	6.47	6.56
MAY	6.37	6.6	6.05	5.95	5.98	6.08
JUN	5.29	5.78	4.45	4.36	5.32	4.46
JUL	3.9	4.85	4.02	3.51	5	3.58
AUG	3.97	4.95	4.28	3.75	5.16	3.77
SEPT	5.49	6.21	4.46	4.96	5.4	4.84
OCT	6.31	6.77	5.47	5.99	4.8	5.67
NOV	6.17	6.28	5.74	6.02	4.39	5.62
DEC	6	5.88	5.06	5.03	4.53	5.37
AVG	**5.88**	**6.15**	**5.26**	**5.5**	**5.45**	**5.38**

Table -8: Solar radiation energy (kWh/m2/d) simulation at horizontal surface using NREL SAM

M/C	ADI	DEL	KOL	BPL	CHN	MUM
JAN	6.26	5.61	4.87	5.94	5.51	5.52
FEB	6.66	5.94	5.43	7.08	6.37	6.16
MAR	7.16	6.66	6.00	7.47	6.68	6.63
APR	7.19	6.98	6.08	7.09	6.73	6.78
MAY	6.71	6.86	5.56	6.65	6.15	6.10
JUN	5.66	6.28	4.55	5.53	5.39	4.44
JUL	4.53	5.24	3.99	4.01	4.74	3.52
AUG	4.33	5.22	4.26	3.73	4.93	3.67
SEPT	5.66	5.89	4.31	5.74	5.46	4.17
OCT	6.48	6.19	4.89	6.77	5.07	5.71
NOV	6.16	5.79	4.71	6.37	4.52	5.73
DEC	5.82	5.62	4.73	6.23	4.62	5.33
AVG	**6.05**	**6.02**	**4.95**	**6.05**	**5.51**	**5.31**

4. CONCLUSIONS

Energy generation using solar PV technologies can be enhanced by setting the PV system inclination to the optimum tilt angle for the entire year. In this study, we have preferred the PV simulation software to calculate optimal tilt angle. Optimum tilt angle of Solar PV system for six different sites (Ahmedabad, Delhi, Kolkata, Bhopal, Chennai and Mumbai) in India are determined by varying the tilt angle from ±5° from its latitude. The conclusions obtained are summarised as follows:

(i) This study reveals that the annual optimal tilt is close to value of the location latitude in most cases.

(ii) For some locations, the optimal tilt angles obtained were varied +1°to +3° from their latitudes.

(iii) We observed that annual average solar radiation for all these cities are more than 5kWh/m^2/d at optimal tilt angle. While Kolkata city have minimum annual average solar radiation compared to other cities.

(iv) There is solar radiation energy increment of +0.08kWh/m^2/d to 0.7kWh/m^2/d at optimal tilt compared to solar radiation energy at zero tilt or horizontal surface of PV.

This simulation result can be taken as reference for researchers, PV installer and designers interested in installing photovoltaic arrays to install it at an optimal tilt to get the maximised solar energy which resulted in maximum PV power output. The use of solar energy as an alternative energy source in rural and remote areas within different region of India could aid the growth of livelihood populations resides within these areas [23].

Nomenclature

H_g	Global solar radiation energy(in kWh/m^2/d)
H_b	Beam solar radiation energy(in kWh/m^2/d)
H_d	Diffuse solar radiation energy (in kWh/m^2/d)
H_T	Solar radiation energy on inclined surface (in kWh/m^2/d)
β	Tilt angle(in degree)
R_b	Function of transmittance, dimensionless
ϕ	Latitude of location(in degree)
W_{ss}	Sunset hour angle(in degree)
δ	Declination angle(in degree)
n	Total number of days, starting from January 1st

REFERENCES

[1]. Arbi Gharakhani Siraki, Pragasen Pillay, Study of optimum tilt angles for solar panels in different latitudes for urban applications, Solar Energy 86 (2012) 1920-1928.
[2]. H. Khorasanizadeh, et al., Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabass, Iran, Energy Conversion and Management 78 (2014) 805–814.
[3]. Shahnawaz Farhan Khahro, et al., Evaluation of solar energy resources by establishing empirical models for diffuse solar radiation on tilted surface and analysis for optimum tilt angle for a prospective location in southern region of Sindh, Pakistan, Electrical Power and Energy Systems 64 (2015) 1073–1080.
[4]. Naveen Kumar Sharma, et al., Solar energy in India: Strategies, policies, perspectives and future potential, Renewable and Sustainable Energy Reviews 16 (2012) 933– 941.
[5]. Vikrant Sharma, S.S. Chandel, Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India, Energy 55 (2013) 476-485.
[6]. Milan Despotovic, Vladimir Nedic, Comparison of optimum tilt angles of solar collectors determined at yearly, seasonal and monthly levels, Energy Conversion and Management 97 (2015) 121–131.
[7]. Soteris A. Kalogirou, Use of TRNSYS for modelling and simulation of a hybrid pv–thermal solar system for Cyprus, Renewable Energy 23 (2001) 247–260.
[8]. Government of India. Annual Report 2009–10. New Delhi, India: Ministry of New and Renewable Energy, Government of India; 2010 [online].
[10]. Hamid Moghadam, et al., Optimization of solar flat collector inclination, Desalination 265 (2011) 107–111.
[11]. Hamdy K. Elminir, et al., Optimum solar flat-plate collector slope: Case study for Helwan, Egypt, Energy Conversion and Management 47 (2006) 624–637.
[12]. Adnan Shariah, et al., Optimizing the tilt angle of solar collectors, Renewable Energy 26 (2002) 587–598.
[13]. Lave M, Kleissl J., Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States. Renew Energy 2011; 36:1145–52.
[14]. Ekadewi A. Handoyo, et al., The optimal tilt angle of a solar collector, Energy Procedia 32 (2013) 166 – 175.
[15]. Murat Kacira, et al., Determining optimum tilt angles and orientations of photovoltaic panels in Sanliurfa, Turkey, Renewable Energy 29 (2004) 1265–1275.
[16]. Jasmina Radosavljević, Amelija Đorđević, Defining of the intensity of solar radiation on horizontal and oblique surfaces on Earth, Working and Living Environmental Protection Vol. 2, No 1, 2001, pp. 77 – 86.
[17]. Abdul Qayoom Jakhrani, et al., Estimations of incident solar radiation on tilted surface by different empirical models, International Journal of Scientific and Research Publications, Vol. 2, Issue 12, December 2012, ISSN 2250-3153.
[18]. Dinesh Kumar Sharma, et al., Review and Analysis of Solar Photovoltaic Softwares, International Journal of Current Engineering and Technology, Vol.4, No.2 (April 2014), E-ISSN 2277 – 4106, P-ISSN 2347 – 5161.
[19]. Qais Azzam Khasawneh, et al., Determining the Optimum Tilt Angle for Solar Applications in Northern Jordan, JJMIE, Vol. 9, No. 3, June.2015, ISSN 1995-6665,Pages 187 – 193.
[20]. Vijaya Lalita. P et al. Energy and Comfort Management in Energy Efficient Buildings Using RETSCREEN Software-A Case Study Analysis, Int. Journal of Engineering Research and Applications, ISSN : 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.378-381.
[21]. Creating Low-Cost Energy-Management Systems for Homes Using Non-Intrusive Energy Monitoring Devices, Rebecca L. Sawyer, Jason M. Anderson, Edward Lane Foulks, John O. Troxler, and Robert W. Cox 978-1-4244-2893-9/09/ 2009 IEEE.
[22]. Mahendra Lalwani, et al., Investigation of Solar Photovoltaic Simulation Softwares, IJAER Volume 1, No 3, 2010, ISSN - 0976-4259.
[23]. Nwokocha CO, et al., Estimation of solar radiation in South eastern Nigeria. International Journal of Natural and Applied Sciences 2009; 5 (3):223-8.