A Review on Optimal Inclination Angles for Solar Arrays

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Received: 21.12.2016 Accepted:01.03.2017

Abstract- The knowledge of solar radiation falling on horizontal surface is the fundamental requirement for installing and monitoring the solar technologies. Due to variable nature of sun radiation, the power production of solar photovoltaic is fluctuating as compare to conventional power plant that's why the cost of power is increase. During the many decades, in order to estimate the horizontal components of solar radiation on hourly, daily and monthly mean basis have been estimated by different empirical models. There is one possible solution to improve the power production cost by changing the tilt angle and orientation angle on the basis of different factors such as time, season and location. To capture the maximum solar radiation inclination angle play an important role.

The purpose of this study is to provide a review of different diffuse models proposed in past and provides the optimal tilt angle for different locations around the world on the basis of monthly, seasonally, bi-annually and yearly. This review would be beneficial for the further research in solar energy in term of, to identify the optimal tilt angle and collection of radiation for different location in the globe. Additionally, to get the proper accuracy and reliability of orientation angle and tilt angle to get the strong correlation with solar radiation for different time periods such as monthly, seasonally, half yearly and yearly at desired location.

Keywords Solar energy, tilt angle, solar radiation, inclination angle, solar photovoltaic.

1. Introduction

With the gradual increasing the demand of solar energy in our planet, the solar energy become popular. To remove the dependency on fossil fuel, new options are investigated to develop the clean and sustainable energy for world. Solar energy is clean natural resource which is directly utilized by photovoltaic module and thermal collector around the world. The performance of photovoltaic module or thermal collector is depending on the amount of solar radiation that reaches on it. The solar radiation depends upon the time, location and position of the panel *w.r.t.* to sun.

To capturing the solar radiation is mainly affected by collector's tilt angle and orientation angle. Generally the collector oriented toward the south side in northern hemisphere and north side in southern hemisphere. Then, the incident of solar radiation mainly depends on the tilt angle of collector. It is critical issue to select the both angle to improve the efficiency of a collector [1-5].

This study provides the status of tilt angle of different location around the world. In section 2, provides the expression of different component of solar radiation on inclined surface. Section 3 describes the tilt angle of different location calculated by different researcher followed by conclusion in section 4.

2. Expression for Different Component of Solar Radiation

The global solar irradiance on tilted plane based on three components namely beam irradiance, reflection irradiance, and diffusion irradiance. The beam irradiance on tilted plane depends upon the zenith angle and incident angle of solar radiation. The reflection and diffusion components on tilted plane are based upon the tilt angle of plane [1, 4].

The beam component on inclined plane is calculated by:

$$I_{tb} = I_b.(\cos\theta_i / \cos\theta_z) \quad (1)$$

$$\cos\theta_z = \sin\varphi.\sin\delta.\cos\varphi.\cos\delta.\cos\omega \quad (2)$$

$$\begin{aligned}\cos\theta_i &= \sin\delta.\sin\varphi.\cos\beta - \sin\delta.\cos\varphi.\sin\beta.\cos\gamma \\ &+ \cos\delta.\cos\varphi\cos\beta.\cos\omega + \cos\delta.\sin\beta.\sin\gamma.\sin\omega \\ &+ \cos\delta.\sin\varphi.\sin\beta.\cos\gamma.\cos\omega\end{aligned} \quad (3)$$

$$\delta = 23.45 * \sin[2\pi(284+n)/365] \quad (4)$$

$$\omega = [\text{solar time -12:00}](\text{in hours})*15 \text{ degrees} \quad (5)$$

Solar time is calculated by using following expression:

$$\text{solar time} = \text{standard time} \pm 4(L_{st} - L_{loc}) + E \quad (6)$$

$$\text{where } E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B \text{ (in minutes)} \quad (7)$$

$$B = (360/364)*(n-81) \quad (8)$$

The reflection component on inclined plane is evaluated by using following expression:

$$I_{tr} = 1/2 * r_g * I * (1-\cos\beta) \quad (9)$$

The diffusion component is estimated by different isotropic and anisotropic model:

Liu and Jordan model [6]:

$$I_{td} = I_d * (1+\cos\beta/2) \quad (10)$$

Tian Model [7]:

$$I_{td} = I_d\left(1 - \frac{\beta}{180}\right) \quad (11)$$

Badescu Model [8]:

$$I_{td} = I_d\left[(3+\cos 2\beta)/4\right] \quad (12)$$

Koronaski model [9]:

$$I_{td} = \frac{1}{3} I_d * (2+\cos\beta) \quad (13)$$

Jimenez and Castro model [10]:

$$I_{td} = \frac{1}{2} * 0.2 I_d * (1+\cos\beta) \quad (14)$$

Ma and Iqbal Model [11]:

$$I_{td} = I_d\left[\frac{I}{I_{ext}}.\frac{\cos\theta_i}{\cos\theta_z} + \left[\left(1 - \frac{I}{I_{ext}}\right).\left(\cos^2\frac{\beta}{2}\right)\right]\right] \quad (15)$$

Bugler Model [12]:

$$I_{td} = \left[\left(I_d - 0.05 * \frac{I_{tb}}{\cos\theta_z}\right) * \frac{1}{2}(1+\cos\beta)\right] + 0.05 I_{tb}\cos\theta \quad (16)$$

Steven et al. [13]:

$$I_{td} = I_d\left[\left(\frac{I_b}{I_{ext}} R_b\right) + \left(1 - \frac{I_b}{I_{ext}}\right)\left(\frac{1+\cos\beta}{2}\right)\left(1 + \sqrt{\frac{I_b}{I_g}}\sin^3\left(\frac{\beta}{2}\right)\right)\right] \quad (17)$$

Klucher Model [14]:

$$I_{td} = 0.5 I_d (1+\cos\beta)\left(1 + F\sin^3(\beta/2)\right)\left(1 + F\cos^2\theta_i.\sin^3\theta_z\right) \quad (18)$$

$$\text{where} \quad F = 1 - \left(I_d / I\right)^2$$

Perez et al. Model [15]:

$$I_{td} = I_d\left[(1-F_1)\left(\frac{1+\cos\beta}{2}\right)\right]\left(F_1 * \frac{a}{b}\right)\left(F_2\sin\beta\right) \quad (19)$$

a, b = solid angle occupied by circumsolar and horizontal

F_1, F_2 = circumsolar and horizon brightness coefficient

Muneer Model [16]:

$$I_{td} = I_d\left[\cos^2(\beta/2) + \frac{2b}{\pi}(3+2b)\left(\sin\beta - \cos\beta - \pi\sin^2\left(\frac{\beta}{2}\right)\right)\right] \quad (20)$$

b = Radiance distribution index

Hay Model [17]:

$$I_{td} = I_d\left[\frac{I - I_d}{I_{ext}}\frac{\cos\theta_i}{\cos\theta_z} + \left(\frac{1+\cos\beta}{2}\right)\left(1 - \frac{I - I_d}{I_{ext}}\right)\right] \quad (21)$$

Reindel Model [18]:

$$I_{td} = I_d\left[(1 - \frac{I_b}{I_{ext}})\left(\frac{1+\cos\beta}{2}\right) + \left(1 + \sqrt{\frac{I_b}{I}}.\sin^3\left(\frac{\beta}{2}\right)\right) + \frac{I_b}{I_{ext}} R_b\right] \quad (22)$$

$$\text{where } R_b = \frac{\cos(\varphi-\beta)\cos\delta\sin\omega_{ss} + \omega_{ss}\sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\sin\omega_{ss} + \omega_{ss}\sin\varphi\sin\delta} \quad (23)$$

$$\omega_{ss} = \min[\cos^{-1}(-\tan\varphi\tan\delta),\ \cos^{-1}(-\tan(\varphi-\beta)\tan\delta)] \quad (24)$$

The hourly total solar irradiance on tilted plane is

$$I_{tg,i} = I_{tb,i} + I_{td,i} + I_{tr,i} \quad (25)$$

where $I_{tg,i}$, $I_{tb,i}$, $I_{td,i}$ and $I_{tr,i}$ are estimated by Equations (1-24) respectively for i = 1, 2, 3,…8760 (for a calendar year).

3. Overview of Optimal Tilt Angle for Different Location

The annual incident solar radiation depends upon the surface tilt angle and orientation angle. An optimal angle of collector obtained the more radiation as compare to horizontal surface radiation [19]. In northern hemisphere, the south face collector obtain more energy as compere to other orientation [20]. The performance deviation of solar panel directly affected by the time period of examination, tilt angle, surface orientation factor and location. The size of solar array and proper use of battery are essential to save the energy. The power production is directly proportional to performance of solar panel [21-23]. The tilt angle play an important role to improve the performance of the panel. The optimal tilt angle is depends upon the location latitude, weather condition and surrounding obstacles. If the clearness index is almost same during the year then the tilt angle should be equal to the latitude the location otherwise not [24].

The year fixed tilted surface capture around 7% more energy as compare to horizontal surface. In similar manner the seasonal and monthly tilted surface received approximately 14% and 16% respectively more radiation as compared to horizontal surface [25-26]. The collection of radiation can be improve by implementation of the tracing system. With the help of single axis tracking system capturing approximately 29% more radiation. In same way the by using two axis tracking system the level of capturing 45% more radiation as compere to horizontal incident radiation [3, 27]. The year fixed tilt angle of solar panel is change 3 times *w.r.t.* vertical axis eastward, southward and westward direction in morning noon and afternoon respectively (3A), then annual collectible radiation is around 92-93% of two axis tracing system. In same way, with the seasonal fixed tilt angle adjusted in this manner, capture up to 95% energy of two axis tracing system [2].

In northern hemisphere, to capture the maximum solar radiation for building integrated solar photovoltaic panels are installed at southern edge from taller building with optimal tilt angle. In case of two taller building cover the roof, then collector installed on centred of the southern edge with optimal tilt angle [28-29]. As the share of photovoltaic module is increase in electricity power production, the overall cost of electricity production is decrease and also reduced the emission of carbon-dioxide (CO_2) in the atmosphere [26, 30]. The tilt angle plays important role in other application. By using optimal tilt angle of solar panel is used in solar cooling application in summer season, solar heating in winter season throughout the world [31]. Unlike the photovoltaic module the T-type glass evacuated tube is tilted 10˚ less than the site latitude and H-type glass evacuated tube is tilted 20˚ less than the latitude to capture the maximum solar radiation [32].

Some study shows the tilt angle $\beta=\varphi-\delta$ with $\gamma=0˚$ (September-March) and $\gamma=180˚$ (April-August) is proved the more energy as compare to the tilt angle is $\beta=0˚$ and $\beta=\varphi$ [33]. For some cases the tilt angle are lower (0˚-30˚) in summer seasons and higher (50˚-70˚) in winter season [34]. The target of maximum power can be achieve by incident the maximum radiation on panel and reduce the variance power production with optimal tilt angle of solar panel [35]. Y.P. Chang [36-38] used the PSO-NVTE, ADHDEOA and SNAOA techniques to determine the tilt angle of photovoltaic to capture the maximum radiation, which is depend on the sun position at any time and location to predict by mathematical procedure of Julian dating. Many new software are available to evaluate the performance of different solar application. These softwares have the characteristics to improve the quality of solar photovoltaic applications [39].

Baringer *et al.* investigated the optimal tilt angle for mid latitude location. The tilt angle varies from 0˚-30˚ in summer season and 50˚-70˚ for winter season. The largest energy difference is 6% for tilt angle 0˚ and 70˚ [40]. The maximum value of '$\cos\theta$' shows the maximum collection of solar radiation. To obtain the value of tilt angle first derivative and second derivative of '$\cos\theta$' is evaluated. On the basis of this study the tilt angle of Surabaya, Indonesia is varied between (0˚-30˚) (from 12 march to 30 September) with northern orientation and 0˚-40˚ (from 1 October to 11 March) with southern orientation. In this also calculated the tilt angle for every day vary 36˚-39.4˚ with east facing in morning and west facing evening [41].

For Hong Kong, they said that the yearly optimal tilt angle 20˚ with south facing azimuth angle. In winter season the tilt angle value reach up to 41˚ and in summer season its value in minus. The monthly optimal tilt angle is maximum 46˚ in December and negative in May and June [42]. For Isfahan, the yearly optimal tilt angle is 28.84˚ and the monthly optimal tilt angle is varies from 0.15˚ to 57.74˚. To get the maximum solar radiation (yearly fixed angle) $\beta=\varphi-10˚$ at $\gamma=0˚$. In monthly cases, in January $\beta=\varphi+20˚$ at $\gamma<50˚$ and $\beta=\varphi-10˚$ at $\gamma>50˚$, in similar manner $\beta=\varphi-10˚$ at $\gamma=0˚$ for July month [43].

The tilt angle is very effective to collect the solar radiation, if tilt angle change seasonally or four times in year as compare to annually fix tilt angle [44]. The yearly fixed tilt angle is calculated for eight different locations in India by mathematical model in MATLAB [45]. Twenty different models are applied to evaluated diffuse radiation in different atmospheric conditions for location in Brazil [46].

The materials of solar panel also play an important role to produce power. The single crystalline silicon, multi crystalline silicon, amorphous silicon, compound thin film and spherical type PV module are applied at two different locations in Japan and USA to evaluate the performance ration and degradation rates [47]. The different type MPPT algorithms are applied in MATLAB environment and hardware. The results are found better with MPPT technique as compare to without MPPT technique implementation [48-50]. The recurrent scan and track MPPT algorithm is applied in dynamic partial shading for moving application [51]. The optimal tilt angles of different locations are shown in Tables 1 and 2.

4. Conclusions

In this paper, the optimum tilt angle of solar panel for different location are reviewed, based upon the yearly, half yearly, seasonally and monthly as shown in Table 1 and 2. On the basis of this study the conclusions are following:

- The proper inclinations of solar panel capture the maximum solar radiation.
- According to location, time and surrounding obstacles the optimal value of tilt angle may be varied from 0˚ to 90˚.
- The year fixed tilt angle is equal to the location latitude, but it is not suitable for some location.
- On the basis of manpower and cost, the half yearly arrangement is much suitable than other.

- On the basis of energy gain, the monthly optimal angle arrangement is best as compare to the other arrangements.
- For better performance, the optimal tilt angle is to be evaluated by different isotropic and anisotropic model for any location.

Nomenclature

L_{st} = standard longitude
L_{loc} = location longitude
θ_z = zenith angle
θ_i = Incident angle
δ = declination angle
ω = hour angle
β = tilt angle
γ = Orientation angle
φ = location latitude
n = day of the year, starting from 1^{st} January
I_b = beam solar irradiance on horizontal surface
I = global solar irradiance on horizontal surface
I_d = diffuse solar irradiance on horizontal surface
I_b = beam solar irradiance on horizontal surface
I_{tg} = total solar irradiance on tilted surface
I_{td} = diffuse solar irradiance on tilted surface
I_{tb} = beam solar irradiance on tilted surface
I_{tr} = reflected solar irradiance on tilted surface
$I_{tr,i}$ = reflected solar irradiance on tilted surface for i_{th} hour
$I_{td,i}$ = diffusion solar irradiance on tilted surface for i_{th} hour
$I_{tb,i}$ = beam solar irradiance on tilted surface for i_{th} hour
$I_{tg,i}$ = global solar irradiance on tilted surface for i_{th} hour

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Table 1. Tilt angle are calculated for solar PV for different locations in world (except Bharat) (in degree)

Ref.	Location	Latitude (Degree)	Year (Degree)	Half yearly (Degree)	Seasonal (Degree)	Monthly (Degree)	Remarks
[52]	Ifrance	33.50˚N	34	9, 59	14, 5, 47, 71	0 to 75	
[53]	Tabass	33.36˚N	32	10, 55	19, 1, 47, 60	0 to 64	the optimum tilt angle for summer=φ-10˚, winter=φ+10˚
[54]	Sindh	25.12˚N	23	1, 38	21, 0, 18, 46	0 to 49	twice tilt angles are more benefit in term of manpower and cost
[55]	Jeddah		19.28		7.27, -8.73, 32.76, 46.56	-14.63 to 50.9	PV panel tilt adjusted six times in a year
[56]	Abu dhabi	24.4˚N	22	42, 2	39, -1, 6, 45	-9 to 52	The optimum azimuth angle 50 is better the south facing
[57]	Izmir	38.46˚N	35.8			0 to 67.4	summer β=φ+15˚,winter β=φ-15˚
[58]	Izmir		30.3		55.7, 18.3, 4.3, 43	0 to 61	
[59]	Zahedan	29.49˚N	27.9	5, 50.3		-8.1 to 59.2	The annual optimum tilt angle is β=0.197φ+0.321, two change tilt angle produce 8% more as compere to yearly tilt angle
	Bandar Abbass	27.18˚N	25.7	2.7, 48.2		-9.9 to 57.2	

[60]	Brunei	4.9˚N	3.3		29.4, 6.3, -22.6, 0.1	1.6 to 32.3	daily tilt angle 1˚ (in march) - 37˚ (December), Monthly tilt angle is suggested
[61]	Bandar Abbas	27.18˚N	22.3		35.5, 2.3, 7.9, 43.4	-4.2 to 49.4	Surface azimuth angle is equal to zero and results show that monthly tilt angle set is better to collect the more radiation.
	Bushehr	28.99˚N	23.6		35.3, 2.6, 10.2, 46.4	-5.3 to 49.1	
	Zahedan	29.49˚N	26.7		42.7, 3.5, 10.6, 50.0	-5.2 to 56.6	
	Shiraz	29.62˚N	25.9		40.4, 3.1, 10.5, 49.3	-5.2 to 57.5	
	Kerman	30.29˚N	27		41.0, 3.8, 11.5, 51.6	-4.8 to 58.6	
	Yasoj	30.67˚N	27.6		42.3, 4.2, 11.8, 52.1	-4.5 to 58.7	
	Ahvaz	31.33˚N	28.4		43.9, 4.8, 12.5, 52.3	-4.2 to 58.8	
	Yazd	31.9˚N	29		45.6, 5.2, 12.9, 52.5	-3.9 to 58.8	
	Shahrekord	32.33˚N	29.4		46.0, 5.6, 13.1, 52.8	-3.6 to 59.4	
	Isfahan	32.63˚N	26.9		42.0, 5.9, 12.4, 47.5	-1.3 to 54.9	
	Birjand	32.87˚N	29.9		46.4, 6.1, 13.7, 53.5	-2.8 to 60.9	
	Khoramabad	33.49˚N	28.3		43.3, 5.8, 13.2, 50.9	-2.5 to 58.9	
	Ilam	33.64˚N	27.7		42.7, 5.6, 13.1, 49.3	-2.8 to 57.5	
	Arak	34.09˚N	26.9		40.5, 6.5, 12.7, 47.7	-0.3 to 54.3	
	Kermanshah	34.35˚N	27		39.9, 6.5, 13.1, 48.5	0 to 56.4	
	Ghom	34.64˚N	29.1		44.1, 7.0, 14.3, 51.0	-0.4 to 57.9	
	Hamedan	34.87˚N	31.1		47.7, 7.4, 15.7, 53.5	-0.7 to 60.1	
	Sanandaj	35.31˚N	30.5		46.8, 7.2, 14.7, 53.3	-1.1 to 60	
	Semnan	35.58˚N	30.1		46.1, 6.8, 14.1, 53.4	-1.9 to 60.1	
	Tehran	35.69˚N	33.4		50.5, 9.0, 16.9, 57.3	-0.8 to 63.3	
	Karaj	35.8˚N	32		47.0, 8.3, 16.3, 56.1	0.5 to 63.3	
	Qazvin	36.26˚N	31		45.4, 7.9, 16.1, 54.6	0.8 to 61.2	
	Mashhad	36.3˚N	29.9		43.1, 7.8, 16.1, 52.7	1.2 to 59.2	
	Sari	36.56˚N	29.3		43.0, 7.7, 15.9, 50.5	1.3 to 57.7	
	Zanjan	36.68˚N	28.5		42.5, 8.0, 15.1, 48.4	1.6 to 56.2	
	Gorgan	36.84˚N	30.2		45.2, 8.5, 15.4, 51.6	1.9 to 60.1	
	Ramsar	37.28˚N	28.4		42.0, 8.0, 11.6, 52.0	3.6 to 63.2	
	Bojnord	37.47˚N	32.9		47.8, 9.4, 16.8, 57.5	2.1 to 64.4	
	Urmia	37.55˚N	31.3		46.4, 9.2, 15.9, 53.6	2 to 63	
	Tabriz	37.07˚N	26		32.4, 8.2, 16.4, 47.2	2.2 to 53.1	
	Ardabil	38.25˚N	25.1		31.3, 7.9, 15.8, 45.6	2.3 to 52	
[62]	Sanliurfa					13 to 61	by two axis tracing daily average gain 29.3% in total solar radiation result in 34.6% gain generated power
[63]	Ottawa	45˚N	36-38				the azimuth angle varied between 4˚W-6˚E
	Toronto	44˚N	32-35				the azimuth angle varied between 1˚W-2˚E
[64]	Athens	37.96˚N	15				15˚±2.5˚ for summer
[65]	USA and Europe		φ-27±1				Semi-fixed panel installed to change tilt angle
[66]	Tripoli		30	50, 20		20 to 60	Monthly tilt angle more gain as compare to other
[67]	Wuhan	29.96˚N	20	20, 45			Year fixed angle has low power as compare to half year angles
[68]	Ifrance	33.32˚N	36.6	62.8, 0.6			Monthly energy gain is more as compare to other
[69]	Sabha city	27.03˚N	30.4			8.86 to 58.95	monthly azimuth angle change (-8.82˚ to -142.73˚) and yearly azimuth angle is -19˚
[70]	Madinah	24.5˚N	23.5	37, 12			at year optimal tilt angle 8% losses as compare to monthly optimal tilt angle
[71]	Kitak-yushu	33.87˚N	25 to 32				Direct and diffuse solar radiation have the strong relation with radiation rate, Monthly tilted surface capture more radiation as compare to other
[72]	Bet Dagan		22	42,1			Tilt angle is equal to the location latitude. Two angle setting reduce the percentage up to 1%.
	Gavdos		24	44, 5			
	Kythnos		26	46, 7			
	Portland		28	50, 13			

[73]	Izmir	38.46˚N	37.43	φ-24.1˚, 0.873φ +24.65		0 to 67.5	tilt angle change twice in year: one is 22 march and other on 22 September
	Itarian Station	32.5˚N	33.04			0 to 63.5	
	Abu dhabi	24.4˚N	26.2	47.9, 5.7	41.7, 2.9, 8.4, 48.5	0 to 55.3	
	Hamirpur	31.59˚N	32.32		59.3, 33.7, 0.5, 27.97	0 to 61.6	
	Tabass	33.6˚N	33.9	53.2, 10.3		0 to 63.2	
[74]	Adana		31.2		19.67, 4.33, 44.67, 56	0 to 60	Monthly optimum angles gets maximum radiation as compare to year and seasonal tilt angle
	Ankara		32.7		21.33, 6, 46.67, 56.67	0 to 60	
	Diyarbakir		32.6		21, 5, 47.33, 57	0 to 61	
	Erzurum		34.3		22, 6, 48, 61.33	0 to 65	
	Istanbul		32.6		22, 6.33, 46.33, 55.67	0 to 59	
	Izmir		32.8		21.33, 5.33, 47, 57.33	0 to 61	
	Samsun		33.2		21.67, 6.67, 46.67, 57.67	0 to 62	
	Trabzon		31.8		20.33, 5.67, 44.33, 56.67	0 to 61	
[75]	Ankara	39.95˚N	24	21, 28	41, 11, 18, 48	5 to 53	More adjustment in tilt angle produce better energy gain
	Antalya	36.88˚N	24	20, 27	40, 9, 15, 47	2 to 55	
	Cannakal	40.13˚N	24	20, 27	40, 11, 17, 47	6 to 53	
	Hakkari	37.57˚N	22	18, 26	39, 9, 16, 47	3 to 54	
	Istanbul	40.97˚N	23	20, 27	39, 11, 18, 47	3 to 54	
	Izamir	38.5˚N	23	19, 26	39, 9, 15, 46	6 to 52	
	Konya	38.97˚N	25	21, 28	41, 10, 17, 49	4 to 56	
	Mugla	37.2˚N	23	20, 26	41, 9, 16, 47	2 to 52	
	Trabzon	41˚N	25	22, 28	43, 9, 15, 48	5 to 57	
[76]	Zahedan	29.28˚N	26.7		42.72, 3.46, 10.6, 50	-5.28 to 56.62	The energy gains of daily and monthly optimum tilt angle are almost same.
	Birjand	32.52˚N	29.93		46.42, 6.11, 13.69, 53.51	-2.8 to 60.94	
	Shraz	29.32˚N	25.88		40.45, 3.14, 10.56, 49.36	-2.07 to 57.5	
	Tabass	33.36˚N	30.16		46.19, 6.87, 14.11, 53.48	-1.94 to 60.15	
	Yazd	31.54˚N	29.05		45.6, 5.24, 12.85, 52.52	-3.91 to 58.8	
	Kerman	30.15˚N	23.95		40.99, 3.81,-0.69, 51.68	-4.89 to 58.62	
[77]	London	51.51˚N	45.5				Optimal tilt angle = 0.8818*$\beta_{pan\ globe}$ + 0.132
	Colchester	51.89˚N	45.8				
	Dundee	56.46˚N	49.9				
	New York	53.96˚N	47.7				
	Tripoli	32.90˚N	29.1				
	Misratah	32.38˚N	28.6				
	Benghazi	32.12˚N	28.4				
	Ajdabiya	30.76˚N	27.2				
	Akita	39.72˚N	35.1				
	Gifu-shi	35.42˚N	31.3				
	Yamagatashi	38.24˚N	33.8				
	Niigatashi	37.90˚N	33.5				
	Jilin	43.70˚N	38.6				
	Lima	12.04˚N	10.7				
	Johan-nesburg	26.20˚N	23.2				
	Sydney	33.87˚N	29.9				
	Christchurch	43.53˚N	38.5				
	Dunedin	45.87˚N	40.5				

Table 2. Optimum tilt angle are calculated for solar PV for different locations in Bharat (in degree)

Ref.	Location	Latitude (Degree)	Seasonal (Degree)	Monthly (Degree)	Remarks
[78]	Roorkee	29.87˚N		0-40	optimal tilt angle get more as compare tilt angle equal to 0˚ or latitude
[79]	Aligarh	27.62˚N	0, 24.29, 56, 30.19	0-58.33	monthly angles more beneficial as compare to seasonal and year fixed tilt angle
[80]	New Delhi		0, 24, 56, 30	0-58	Optimum monthly tilt angle is more power capture
[81]	Chennai			0-48	By using Reindl model yearly angle for Chennai 20.20˚ and for Nagpur 24.29˚
	Nagpur			0-55	
[82]	Minicoy			0-41	Two correlation equations are develop between the tilt angle declination angle: β=17.69-1.055 δ β=12.44+0.0197δ^2-1.0581δ
	Thiruvananthapuram			0-42	
	Port Blair			0-44	
	Bangalore			0-45	
	Chennai			0-45	

	Panjim			0-48	
[83]	Chennai	13.08˚N	0, 0, 22, 30		The life cycle cost is more effective as compare to the stand alone PV system or Diesel generator. ANN and ANFIS are used to find size of arrays and tilt angle of any location.
	Thiruvananthapuram	8.48˚N	0, 0, 21, 27		
	Bangalore	12.96˚N	0, 0, 24, 31		
	Goa	15.49˚N	0, 0, 31, 36		
	Mumbai	18.97˚N	0, 0, 35, 40		
	Bhubaneswar	20.27˚N	0, 0, 33, 38		
	Hyderabad	17.36˚N	0, 0, 31, 36		
	Raipur		1, 0, 38, 42		
	Bhopal		1, 0, 38, 42		
	Ghandhinagar		1, 0, 38, 42		
	Ranchi		1, 0, 37, 42		
	Jaipur		3, 0, 41, 45		
	Lucknow		4, 0, 42, 44		
	Calcutta		1, 0, 36, 40		
	Patna		3, 0, 42, 45		
	Delhi		5, 0, 44, 47		
	Chandigarh		7, 2, 48, 50		
	Dehradun		7, 1, 48, 50		
	Shimla		7, 2, 49,51		
	Srinagar		7, 5, 49, 50		
	Gangtok		3, 0, 42, 46		
	Guwahati		4, 0, 43, 46		
	Shilong		4, 0, 41, 45		
	Imphal		3, 0, 40, 45		
	Itanagar		2, 0, 40, 43		
	Agartala		2, 0, 38, 43		
	Kohima		3, 0, 41, 46		
	Aizawal		2, 0, 38, 43		