Assessment of Solar Potential for Solar PV Applications in Vijaypur, Karnataka, India

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***Abstract*—Planning and performance of solar PV system depends on meteorological conditions at the project location. The purpose of this study is to create data base which is essential for designing a PV system for stand-alone application near Vijaypur, Karnataka, India. It is based on three years meteorological data, which is parameterized through analytical methods. The assessment realizes the solar potential on horizontal and tilted surface, clearness index, optimum tilt angles and electricity generation capacity of a PV technology. It is found that the characteristic of solar potential almost maps with stand-alone power demands in the region and south facing PV module at tilt angle 22^o can generate 234kWh/m^2/year. A solar PV application is technical viable over 310-330 days year around.**

Keywords—solar radiation; diffuse radiation; clearness index; tilt angle; PV module.

I. INTRODUCTION

Rural electrification is often considered to be the backbone of the India's economy. It brings tangible social and economic benefits to rural public who contribute 68% of the India's population. However, in India about 32,227 villages yet have no access to electricity and those have electricity often struggling to access basic needs [1]. It is due to environment impacts, terrain difficulties and supply shortage as well as ageing transmission and distribution systems. These challenges are motivating applications of decentralized renewable technologies to serve dispersed and remote rural electricity needs. In this context, solar PV energy systems play a crucial role. It is due to availability and topological advantages solar energy in local power generation [2].

Therefore, in view to establish a renewable based power solution for stand-alone rural applications near Vijayapur, the present study is conducted on local solar resource. A solar PV system which uses solar energy is constantly substituted in nature and its performance is directly affected by the solar radiation as well as its characteristics [3, 4]. Therefore, to realize the maximum benefits of the solar energy, it is essential to have an adequate knowledge of resource and load demand for designing and understanding the performance of PV system at the time of inception [5, 6].

Many researchers have conducted study on solar potential and its characteristics at various locations in and around the country. Accordingly, the present study is based on10-min interval meteorological solar radiation data collected over period of three years from Agricultural Research Station Vijayapur. It is processed through analytical methods proposed in [7-11], to illustrate directional and variability nature of solar potential. The various characteristic parameters such as solar radiation on horizontal and inclined surfaces, sunshine hours, sky status, diffuse and direct radiations and optimum tilt angle for solar PV array are estimated to realize the solar potential at the project location. Further, the technical viability of the location is parameterized by estimating energy yield from a PV technology.

The overall analysis depicts that the solar potential and climatic situation is ideally suited for solar PV applications for 310-330 days year around. The energy yield from PV technology at the location is appreciable quantity for local power applications. The investigation results can provide useful information and guidance on solar potential characteristics for researchers, agriculturist, architects, engineers and investors to speed up the activities in solar energy in and around Vijaypur.

II. METHODOLOGY

The quantity and quality of solar radiation reaches a PV array depends on the latitude, altitude, climatic and cloud condition including daily as well as yearly apparent motion of the sun at project location. The local meteorological time-series solar radiation and sunshine hour data measured over three years are used to assess the solar potential, potential characteristics and electricity generation capacity. Analysis is performed using analytical methods. The following subsections detail the analytical methods used in the problem formulation and solution.

A. Total horizontal radiation

It is a global solar radiation incident on a horizontal surface. It includes; direct (beam), diffuse and ground reflected radiations. The monthly average daily and hourly total

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horizontal radiation (THR) is processed according to the meteorological data for the past three years and it is shown in Figs 1 and 2. Similarly the variations of total sunshine duration in months are shown in Fig. 3.

B. Clearness Index

Clearness index (CI) is significant in characterization of cloud condition. The cloud status is the main factor that causes the difference between solar radiation measured outside the atmosphere and incident on earthly surface. CI is evaluated using total radiation and extraterrestrial radiation through the following equations [7].

$$K_t = \frac{H_t}{H_o} \tag{1}$$

where

$$H_o = \frac{12*60}{\pi} G_{sc} E_o \left\{ cos\emptyset \, cos\delta \, (sin\omega_2 - sin\omega_1) + \frac{\pi}{180}(\omega_2 - \omega_1)\, sin\emptyset \, sin\delta \right\} \tag{2}$$

where G_{sc} is the solar constant (1367 W/m^2), E_o is the correction factor for varying earth-sun distance, $\emptyset$ is the altitude, δ is the declination angle, ω_1 and ω_2 solar time angle at sunrise and sunset respectively. The E_o and δ are computed using Eqs. (3 & 4):

$$E_o = 1 + 0.33\, cos\, \frac{360n}{365} \tag{3}$$

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) \tag{4}$$

where n is the Julian day of the year (1-365 day). The daily variation of clearness index is shown in Fig. 4. The sky status or CI (K_t) at the project location over the year is categorised based on contribution of diffusion radiation as; overcast sky (K_{t1}): $0 \leq K_t < 0.35$ (diffuse radiation ≥40% of total radiation), clear sky (K_{t2}): $0.35 \leq K_t < 0.65$ (diffuse radiation 15 to 40%) and most clear sky (K_{t3}): $K_t \geq 0.65$ (diffuse radiation <15 %). Based upon the implied values of K_t the frequency distribution of daily variation of CI is computed using equation (5).

$$\%f_{Kt} == \frac{number\ of\ days\ with\ K_{ti}}{365} \tag{5}$$

where f_{Kt} is the percentage frequency of occurrence of CI for i=1, 2, 3.

C. Solar Radiation on inclined PV module

The amount of radiation incidences on PV array surface depends on tilt angle. Tilt angle is site specific and depends on the geographical latitude, climate conditions, time of a day and utilization time period [8]. The tilt radiations are essential for designing and assessing the performance of a solar PV system are simulated using empirical models proposed by [9-11]. The total radiation incident on tilted surface ($H_{\beta t}$) is assessed using equation (6).

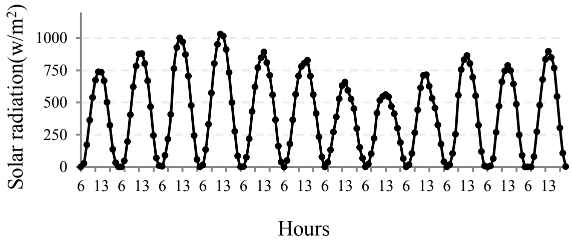

Fig. 1. Monthly average daily hourly variation of solar radiation profile over year.

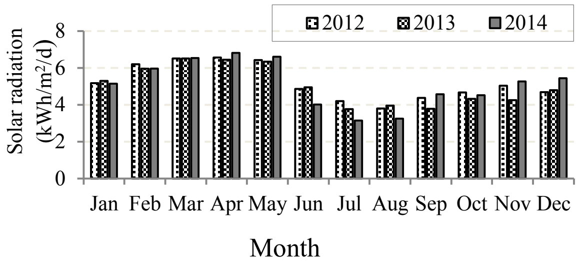

Fig. 2. Monthly average daily solar radiations.

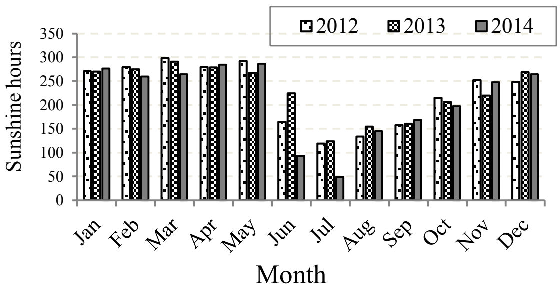

Fig. 3. Monthly total sunshine hours

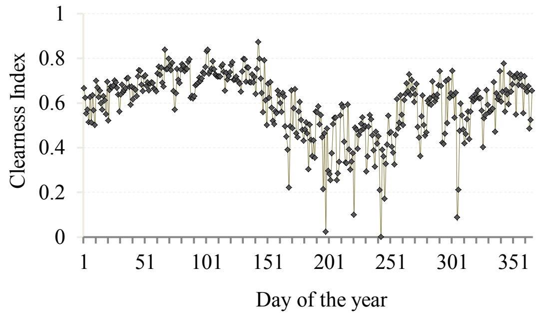

Fig. 4. Daily variation of CI

$$H_{\beta t} = H_b R_b + H_d R_d + H_t R_r \qquad (6)$$

where R_b, R_d, and R_r are the tilt factors for beam (H_b), diffuse (H_d) and ground reflected radiations respectively and are computed using equations (7-15). Beam tilt factor is evaluated using equation (7).

$$R_b == \frac{cos\theta}{cos\theta_z} \qquad (7)$$

where θ is the incidence angle and θ_z is the zenith angle. Incidence angle is calculated using following equations.

$$R_b = cos\theta = cos\delta\ cos\omega_s\ (sin\emptyset sin\beta cos\gamma + cos\gamma sin\beta) + sin\delta(sin\emptyset cos\beta - cos\gamma\ sin\beta cos\emptyset) + cos\delta\ sin\gamma\ sin\beta\ sin\omega_s \qquad (8)$$

where $\emptyset$ is the latitude, β is tilt angle γ is the azimuth angle. ω_s is the solar hour angle refers to sunrise (negative) or sunset (positive). It is evaluated using equation (9).

$$\omega_s = cos^{-}(-tan\emptyset\ tan\delta\ ) \qquad (9)$$

In northern hemisphere and for the surface facing due south: $\gamma = 0$. Then, θ can be evaluated using equation (10).

$$cos\theta = sin\delta\ (\sin\emptyset + cos\delta\ cos\omega_s \cos(\emptyset - \beta)) \qquad (10)$$

The azimuth angle is given by equation (11) for horizontal surface. It is obtained by equating $\beta\ and\ \gamma$ to zero in equation (8).

$$cos\theta_z = cos\delta\ cos\emptyset\ cos\omega + sin\delta\ sin\emptyset \qquad (11)$$

Similarly the diffuse tilt factor (R_d) for a surface having inclination angle of β is obtained by considering sky dome as an isotropic source of diffuse radiation. It is evaluated using equation (12).

$$R_d = \frac{1 + cos\beta}{2} \qquad (12)$$

Then the tilt factor for ground reflected radiation is given by equation (13).

$$R_r = \frac{(1 - cos\beta\ )\rho}{2} \qquad (13)$$

Liu and Jordan have suggested ρ=0.7 for snow covered surfaces and 0.2 for snow free surfaces. The project location is free from snow, ρ=0.2 is considered in the present assessment.

The beam (direct) and diffuse radiation components on horizontal surface used to assess the tilt radiations. Intensity and direction of the diffuse radiation depends on geography, sky status and atmospheric constituents. It is simulated using empirical model (14) proposed by [11].

$$\frac{H_d}{H_t} = c + d\ K_t \qquad (14)$$

The site specific regression constants $c = 1.165$ and $d = 1.668$ computed for H_d/H_t and K_t through regressions method. The beam radiation is evaluated by subtracting diffuse radiation from the total radiation.

$$H_b = H_t - H_d \qquad (15)$$

The total tilt radiations are computed at tilt angles from 0^0 to 90^0 in a step of 1^0. The optimum tilt angle (β_{opt}) for each month is determined by looking for the values at which the total radiation is larger for a particular day of the month.

III. ELECTRICITY GENERATION

The power output of PV module is estimate according to equation (16) using solar radiation on tilted surface, ambient temperature and technical parameters of PV module. A conversion efficiency of PV modules is considered to be 12%, reference PV cell temperature 25°C, NOCT =45°C [4].

$$P_e = \eta_g A_t H_{\beta t} \qquad (16)$$

where, A_t is the area (m^2) of a single module and η_g is the PV generator efficiency and it is given by equation (17).

$$\eta_g = \eta_r \eta_{pt} \eta_d \left[1 - \beta_t (T_c - T_r) - \beta_t H_{\beta t} \left(\frac{NOCT - 20}{800}\right)(1 - \eta_r \eta_{pt} \eta_d)\right] \qquad (17)$$

where, η_r is the PV module reference efficiency, η_{pt} maximum power point tracking efficiency, η_d is derating factor for dirt /soiling, T_c is the PV cell temperature(°C), T_r is the PV cell reference temperature(°C), and β_t is the temperature coefficient of efficiency [4].

IV. RESULTS AND DISCUSSION

The local meteorological data for past three years (2012-15) is employed in the present analysis. Fig.1 shows the monthly average daily solar radiations available in the region. It is observed that the solar radiations for three years are almost same with small variation of ± 2.5% during summer and winter seasons, whereas variation is more during winter. Seasonal variability of radiations is presented in Table-1. It reveals that, the highest radiations observed during April of all three years and lowest during July-August. The monthly assessment on solar potential depicts that, reach solar energy is available for about 10.5 months.

TABLE 1. THE SEASONAL VARIABILITY OF SOLAR RADIATIONS.

Sl. No.	Season	Solar radiation in kWh/m²/day		
		2012	*2013*	*2014*
1	Summer (Mar-June)	6.32	6.37	5.85
2	Monsoon (July-Oct)	4.25	3.9	2.6
3	Winter (Nov-Feb)	5.20	5.13	4.77

The region has good number of sunshine hours during summer and winter months and it is between 220 to 300 hr. However, during monsoon, day length is attenuated by overcast skies; thus, it is shorter (0-4 hr.). Monthly variation of total bright sunshine duration is shown in Fig.2. The study on sunshine duration reveals that, the region bears: + 250 hours during summer, +210 hours during winter and 50-200 hours in monsoon. During rainy season solar energy is uncertain and difficult to predict.

The estimated CI figures the sky status at the project location over three years. The annual pattern of daily variation of CI and its frequency of occurrence is shown in Figs. (5) and (6). This indicates that, during summer and winters, the sky condition is clear for most days of the seasons. The frequency of occurrence of daily CI, sky status, sunshine duration is presented in the Table-2. Overall observation highlights that, the overcast skies appear for about 10% of the time all the year around.

The total solar radiations include the beam and diffuse radiation components. The monthly average daily diffusion, beam and total radiation are shown in Fig. 7. The beam component is high (5.8kWh/m²/day) during March. Though, the April (5.75 kWh/m²/day) and May (5.56 kWh/m²/day) receive quite good amount of beam radiation, but it is comparatively less than March. It is mainly because; during extreme summer, the atmosphere will be loaded more with dust particles which attenuate beam radiation.

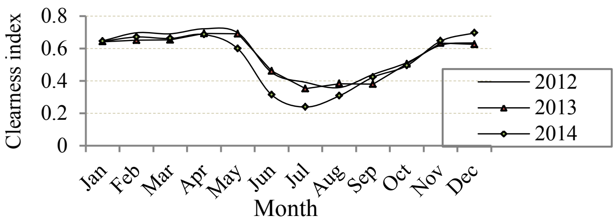

Fig.5: Monthly average daily clearness index.

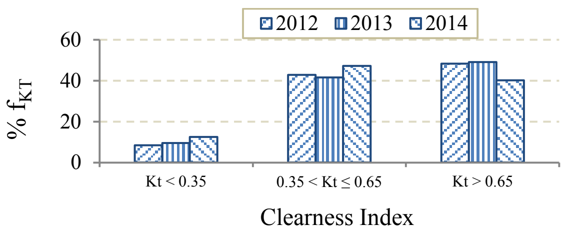

Fig.6: Frequency distribution of daily clearness index.

TABLE II. THE FREQUENCY OF OCCURRENCE OF CI, SKY STATUS AND SUNSHINE DURATION (SD).

K_t/ (SD)	$\%f_{Kt}$			Sky status (days/year)
	2012	*2013*	*2014*	
0-0.35/ (0- 4 hr.)	9	7.9	10.9	Cloudy (27-40)
0.36-0.65/ (5-7 hr.)	42.5	40.6	42	Clear (147-153)
0.66-0.87/ (8-11 hr.)	48.5	51.5	47.1	Most clear (175 – 195)

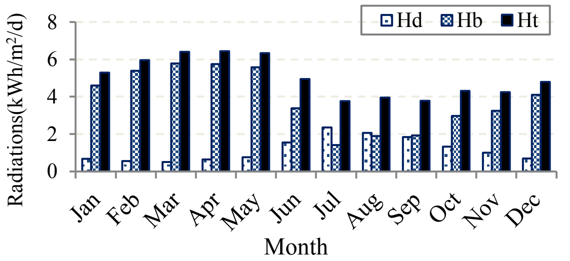

Fig. 7: Monthly average daily diffuse, beam and total radiation.

The optimum tilt angles and corresponding tilt radiations as well as radiations on horizontal surface are presented in Table-3. The optimum angle of tilt for a solar PV array during January is 47^0 subsequently, the value of optimum tilt angle is decreasing and it goes to minimum value of 2^0 in August. On contrary, it is increases during the winter months and reaches a maximum value of 49^o in December. The solar energy captured by south facing PV array can be enhanced by placing it at proper inclination. It can be depicted by comparing the horizontal radiations with radiation incident on tilted surface presented in Table-3. The percentage increase in solar potential from horizontal radiation to tilt radiation is about 7% during summer and winters. However, it is 2.5-3.6% in monsoon season.

At Vijayapur, occurrence of annual solar potential would be 2000kWh/m² at annual average tilt angle of 22^0. At this potential an expected annual electricity generating capacity of the PV technology is around 234kWh/m². The monthly average daily energy demand (kWh/day) in the typical farmhouse located near Vijayapur is shown in Fig.8 along with solar potential. The present analysis demonstrates that the characteristic of solar potential almost maps with the stand-alone demand at the region. It is evident from Fig.8.

TABLE-III. OPTIMUM TILT ANGLE AND SOLAR RADIATIONS.

Months	β_{opt} (degree)	$H_{\beta t}$ (kwh/m²/d)	H_t (kwh/m²/d)
Jan	47	6.3	5.29
Feb	38	6.81	5.95
Mar	22	6.59	6.51
Apr	5	6.44	6.44
May	3	6.34	6.26
Jun	6	4.94	4.74
Jul	4	3.86	3.76
Aug	2	3.98	3.96
Sept	13	3.82	3.78
Oct	32	5.49	4.69
Nov	40	5.29	4.34
Dec	49	5.81	4.79
Average	**21.75**	**5.47**	**5.04**

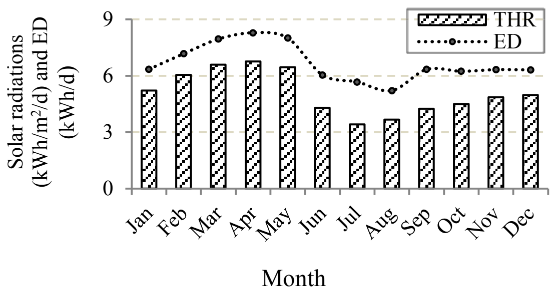

Fig.8: Solar potential and Energy demand (ED) in typical farmhouse near Vijayapur.

V. Conclusion

In this paper, solar potential and its characteristics essential to design and analyse the performance of PV system is studied thoroughly. It depicts that Vijayapur being located in solar belt receives total horizontal radiation in the range between 3.5 to 7.3kWh/m^2/day. The continuous non-sunny days observed are 1.5-2 days, the total overcast skies in year around are 27- 45 days (July-August) and monsoon season i.e July -September designates the lean period for solar application. The optimum value of tilt angle for south facing PV array are between 47^0 (Jan) to 2^0 (Aug) to 49^0 (Dec), while annually average tilt angle: 22^0 ($\text{i.e } \emptyset + 6^0$) is optimum to enhance the utility of PV technology year around. The characteristic of local solar potential supports the PV technology to generate electricity about 222 kWh/m^2/year and potential characteristics almost maps with seasonal variations of small scale stand-alone demands in the region.

Acknowledgment

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