International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 23 Issue 6 –OCTOBER 2016 (SPECIAL ISSUE).

Reliability Analysis of Solar Photovoltaic Systems for Maximum Power Tracking

Kandagal S. S[#1] and G. Suchitra[*2]

[#]*B.E., M. Tech, Assistant Professor, Department of Electrical and Electronics,*
Tontadarya College of Engineering, Gadag, Karnataka, India
[*]*PhD, Associate Professor, Department of Electrical and Electronics,*
Basaveshwar Engineering College (A), Bagalkot, Karnataka, India

***Abstract*— This paper introduces a detailed methodology for evaluation of reliability of SPV systems of different company to extract maximum power and it is successfully modeled in the MATLAB/Simulink. The output power of the SPV panel depends on the solar radiation data and panel tilt angle. For this, solar radiation data is considered for every hour of the day for one year. For a given load characteristics and a given solar panel, an algorithm is developed to evaluate the total solar radiation with the tilt angle and incident angle for maximum power tracking from SPV systems. Maximum power generated to meet the load is calculated by taking hourly average and monthly average values of power generated by each panel and respective tilt angle at that hour.**

***Index Terms*— Direct beam radiation, diffuse radiation, tilt angle, load curve and reliability.**

I. Introduction

Solar Photovoltaic electricity generation offers the benefits of clean, non-polluting energy generation, which has very less maintenance requirement, and of having a very long lifetime. Due to these advantages, today, the photovoltaic is one of the fastest growing markets in the world. However, PV power is still considered to be expensive, and the cost reduction of PV systems is subject to extensive research.

With the penetration of renewable energies into the conventional energy fields, there are growing concerns of the reliability and stability of these systems. Previous researches are available on how to construct alternative energy systems, combine them into the traditional power grid, and how to size the storage volume or the energy source capacity to meet the loads' needs. The impact of the alternative energy on the traditional power grid is also examined in order to improve systems' stability.

But most of the design rules are based on "meeting the need" strategy, not based on the reliability. This paper inspires its motivation from the fact that the keen study of these existing techniques reveals that there is still quite a need for optimal sizing design of a standalone solar PV system to extract maximum power. Variation in solar radiation and the tilt angles gives the more generation of power from each panel. Increase in the power per panel gives the reliability to meet the load demand [1].

II. Solar Photovoltaic System

A. Direct Beam Radiation

The relationship of solar panels and solar positions is illustrated in Fig.1; 'α' is the elevation angle between sunray and horizontal plane. The following factors represent the failure rate of the systems.

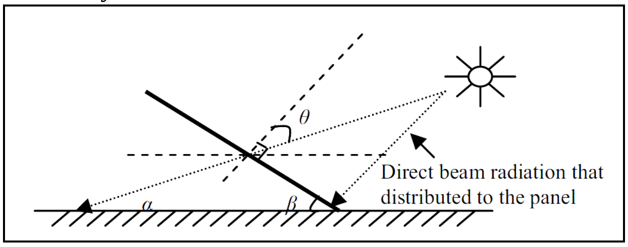

Fig. 1: Direct Beam Insolation on the Solar PV Panel [1]

i) Tilt angle β

Initially, the tilt angle is calculated to maximize the direct beam radiation, at worst solar insolation conditions, which are usually around Feb.14[th]. The tilt angle will be changed slightly later, to find the optimum value. The definition of tilt angle is shown in Fig.2.

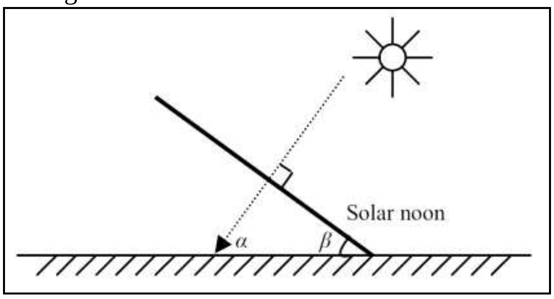

Fig. 2: The tilt angle to maximize the direct normal radiation in mid of Feb [1]

The Declination Angle (δ): Angle made between the line drawn joining the centre of the earth and the sun and the earth's equatorial plane. It is zero at the autumnal and vernal equinoxes.

The range of declination angle is given by $-23.45^0 \leq \delta \leq +23.45^0$ as shown in Fig. 3.

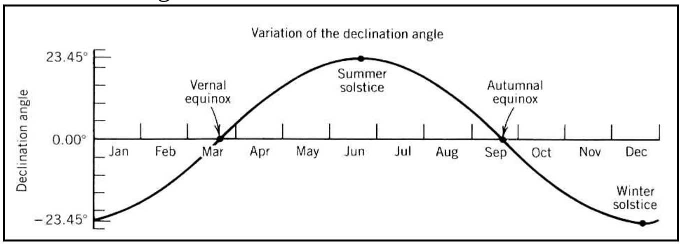

Fig.3: Variation of Declination Angle [8]

δ is the declination angle in degrees given as,

$$\delta = 23.45^0\, sin[\tfrac{360}{365}.(d-81)] \quad (2)$$

d is the day of the year from Jan 1st.

Case 1: At the time of solar noon tilt angle can be obtained as,

$$\beta = 90^0 - \alpha \quad (3)$$

$$\alpha = 90^0 - |\emptyset| + sign(\emptyset).\,\delta \quad (4)$$

α is elevation angle,

$\emptyset$ is the latitude of a site

"sign" is the symbolic function: if $\emptyset > 0$, **sign** $(\emptyset) = 1$, otherwise -1;

Case 2: When it is not the solar noon, α can be calculated by,

$$\alpha = sin^{-1}(sin\delta.\,sin\emptyset + cos\delta.\,cos\emptyset.\,cosHRA) \quad (5)$$

Where,

HRA is the hour angle, used to convert the local solar time into the number of degrees,

$$HRA = 15^0(LST - 12) \quad (6)$$

$$LST = LT + TC \quad (7)$$

$$TC = 4(-\Delta GMT.150 - Longitude) + E_0T \quad (8)$$

$$E_0T = 9.87\ \sin(2B) - 7.53\, cosB - 1.5\, sinB \quad (9)$$

$$B = \frac{360}{365} * (d - 81) \quad (10)$$

Where,

LST is the local solar time

LT is the local time

TC is time difference

E_0T is eccentricity of orbit

ΔGMT is Greenwich Mean Time difference, **+5.30** for Vijayapura, **"Longitude"** is the longitude, which is **75.68 degree** for Vijayapura [9].

ii) Incident angle θ

Another parameter which determines the solar panel position is the incident angle θ. θ is the angle between solar cell panel's normal line and incident ray. The θ determines how much energy is distributed to the solar-cell from direct beam radiation. Directed beam radiation collected by the solar-cell is calculated by I_b •*cos* θ, as show in Fig.4.

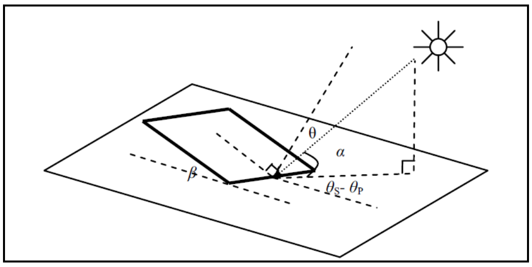

Fig.4: Relationships between angles [1]

Calculation of incident angle θ :

The incident angle θ could be calculated by equation

$$\theta = cos^{-1}[sin\alpha.\,cos\beta + cos\alpha.\,sin\beta.\,\cos(\theta_s - \theta_p)] \quad (11)$$

Where,

θ_s is sun azimuth angle and is given by,

θ_p is solar panel azimuth angle.

θ_s can be calculated by equation

$$\theta_s = \pi + sign(HRA)cos^{-1}[sin\emptyset - sin\alpha - sin\delta/(cos\alpha - cos\emptyset)] \quad (12)$$

Fig. 4 describes the relationship among the angles in equation (12).

In fixed solar panel system, θ_P is a constant value of π.

$$\theta_p = \pi; \quad (13)$$

It should be noted that in some application, the solar panel rotated constantly, in order to track the position of sun and to increase the direct beam insolation. For example, if an axis rotation solar system changes **15°** each hour, the θ_P can be calculated approximated as equation (13):

$$\theta_p = \pi + (LT - 12.4467) * [(15^0 * 2\pi)/360^0] \quad (14)$$

In this paper, the rotating solar panel system is selected, and θ_P has been obtained by equation (13)

B. Diffuse Beam Radiation

Fig.5 illustrates how to calculate the diffusion insolation. In this paper, it is assumed that the global diffusion radiation is equally distributed from all parts of the sky.

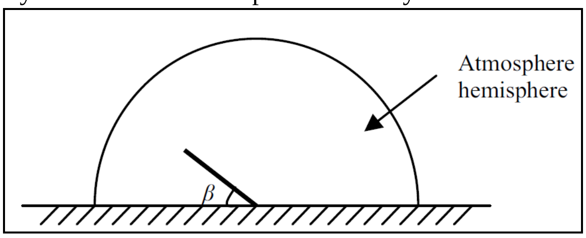

Fig.5: Diffusion radiation on a tilted panel [1]

The Fig.5 shows that, fraction of hemisphere of the panel seen by tilted panel is ***1-β/π***, and energy of the panel receives from diffusion radiation equals I_d***·(1- β/π)*** [1].

In this paper, the real insolation is given for one year. Therefore, there are two ways to model the solar radiation:

- Utilize this specific year's insolation for all year throughout the simulation, or, assuming for every year the solar insolation of every hour is all the same. In practice, these values may change randomly because of weather varying and slightly climate changes. But on average, these values in a given year will not change considerably.

- Using the specific year's data as mean values, generating new solar insolation data by adding random difference, which follows normal distributions.

C. Solar Radiation with a Given Solar Panel Position

Solar radiation is defined as how much energy that a 1m^2 horizontal area can receive. Solar radiation includes direct insolation (energy received directly from sunrays), diffusion insolation (energy received from diffused rays in the air), and ground-reflected radiation [1]. For fixed solar panels, the insolation energy it receives can be expressed by equation (1).

$$I_0 = I_b \cos\theta + I_d\left(1 - \frac{\pi}{\beta}\right) + I_r \quad (1)$$

Where,

I_0 is the total insolation energy on 1m^2 horizontal area;
I_b is the direct beam radiation;
I_d is the diffusion radiation;
I_r is the ground-reflected radiation;
θ is the incident angle;
β is the tilt angle.

D. Load Curve

Average value of monthly load at different hours from 110/11 kV Substation, Bijapur has been recorded. Seven hours per day load for one year has been considered for calculation as given in table 1 [9].

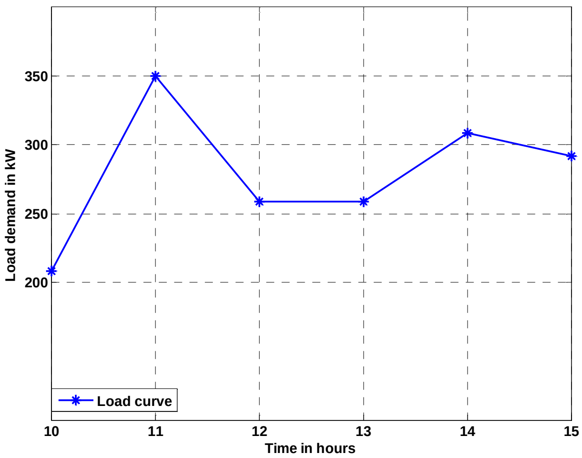

Fig. 6: Load curve for different hours of the day

Hourly average value of maximum load P_{Lmax} is shown in fig.6 and average value obtained is equal to 279.1667 kW

III. RELIABILITY EVALUATION

Failure rate (λ):

Failure rate is defined as the ratio of failures at particular time interval to the total number of samples at that interval.

λ is the Failure rate and is obtained by the equation,

$$\text{Failure Rate } (\lambda) = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} \quad (15)$$

Reliability (R):

Reliability measures the ability of the system to perform its function in stipulated time. Reliability has to do with the quality of measurement.

$$\text{Relaibility } (R) = e^{-(\lambda/t)} \quad (16)$$

Where, t is time period.

For the study, 3 different types of SPV systems are considered. The specifications of these SPV systems are listed in the table.1.

Table 1: Average Monthly Load in kW at different hours

Electrical Characteristics	BP 3150	STP190S	FS-PV210WATT
Pmax	150W	190 W	210W
Pmin	146W (BP 3150S); 143W (BP 3150U)	---	---
Vmp	34.5V	36.5 V	30V
Imp	4.35A	5.20 A	7.03A
Isc	4.75A	5.62 A	7.86 A
Voc	43.5V	45.2 V	36.12V
Temperature coefficient of Isc	(0.065±0.015)%/K	---	(0.065±0.015)%/°C
Temperature coefficient of Voc	-(160±10)mV/K	---	-(160±10)mV/°C
Temperature coefficient of Pmax	-(0.5±0.05)%/K	---	-(0.5±0.05)%/°C
Maximum series fuse rating	15A (BP 3150S); 20A (BP 3150U)	15 A	---
Maximum system voltage	600V (IEC 61215 rating)	600 V DC	1000V
Module Efficiency	---	14.9%	---
NOCT	---	47±2°C	25±2°C
Operating Temperature	---	-40 °C to +85 °C	---
Power Tolerance	---	0/+5 W	---

Standard test conditions (STC) - irradiance of 1000W/m2 at an AM1.5G solar spectrum and a temperature of 25°C.
NOCT (Air 20°C; Sun 0.8kW/m2; wind speed 1m/s)

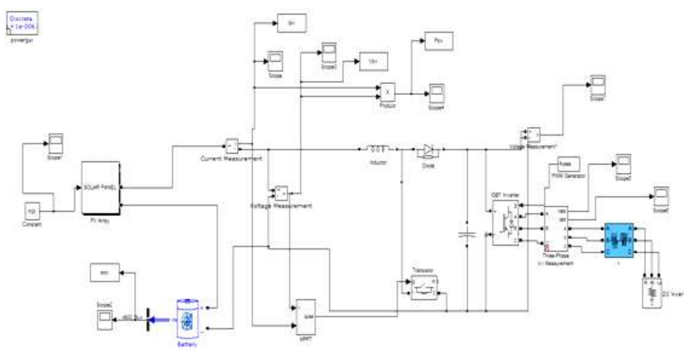

Fig. 7: MATLAB SIMULINK model for 150 watt, 190 watt and 210 watt SPV panel respectively to calculate power per panel using total solar radiation (I_0).

The flow chart for the determination of maximum power as a parameter that decides the reliability to meet the load demand has been illustrated in fig. 8.

Implementation of Reliability Algorithm:

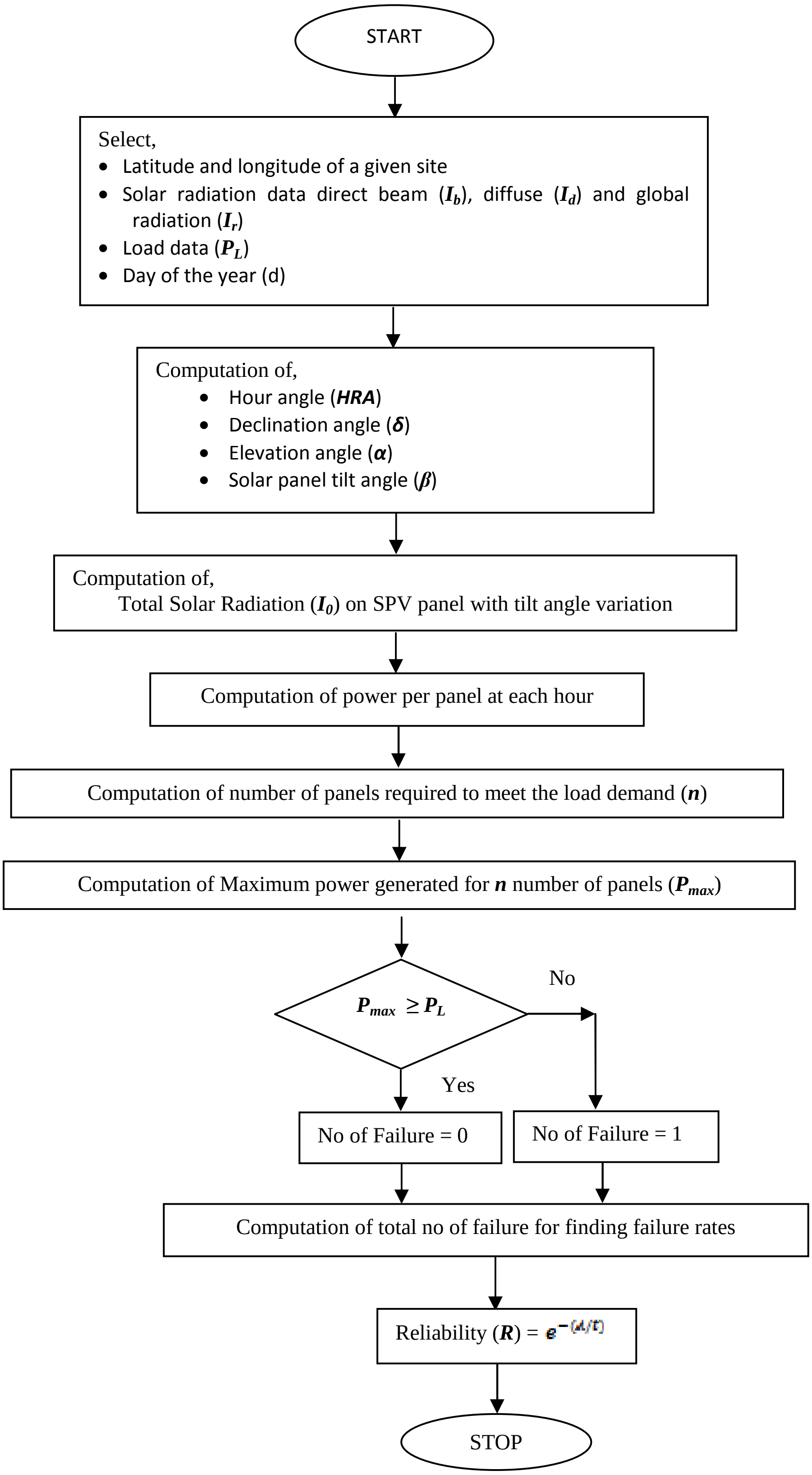

Fig. 8: Flowchart describing the methodology for the reliability evaluation

IV. Results and Discussions

***Case I:* Reliability evaluation using hourly average value**

The power generated by different types of SPV systems at different hours is shown in the fig.9

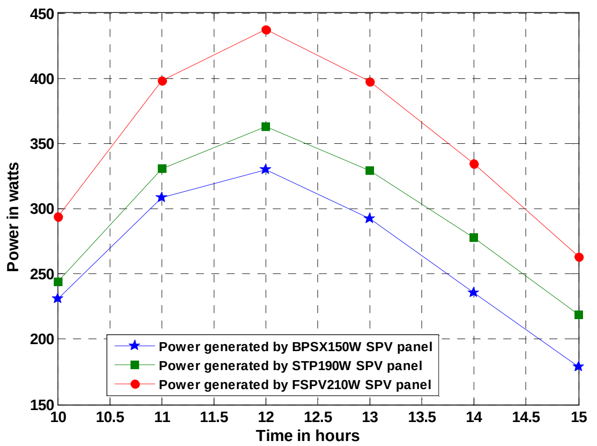

Fig.9: Power generated by different SPV systems Vs Time

The reliability is evaluated considering the average hourly values of solar radiation data at different hours of the day. Table 2 gives the comparison of reliability for different SPV systems and the graphical representation is shown in the fig.10

Table 2: Reliability of different SPV systems at different hours for one year

Time in hours	Type of SPV systems		
	BPSX150	STP190S	FSPV210W
10	0.7788	0.7788	0.7788
11	0.6592	0.558	0.558
12	0.7788	0.7165	0.7165
13	0.558	0.6666	0.7165
14	0.558	0.4724	0.4724
15	0.4345	0.3998	0.3998
Avg	**0.6278**	**0.5986**	**0.6070**

The power generated by different types of SPV systems and reliability at different hours is given as shown in fig. 10

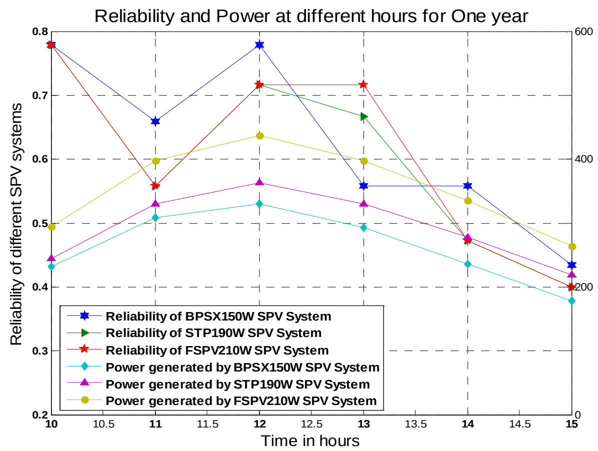

Fig. 10: Reliability and Generated Power of different SPV systems vs time

Reliability for different SPV systems is shown in the fig. 10, it reveals that at noon the power generated by different SPV panel is maximum and an appropriate system will be chosen as more reliable for the given load.

***Case II:* Reliability evaluation using monthly average value**

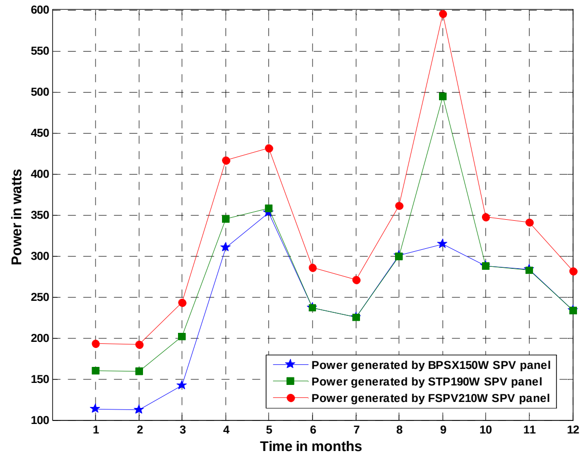

Fig.11: The power generated by different types of SPV systems at different months

The power generated by different types of SPV systems at different hours has shown in the fig.11, it reveals that during the 4th, 5th and 9th month of the year the maximum power generated by different SPV panels are more.

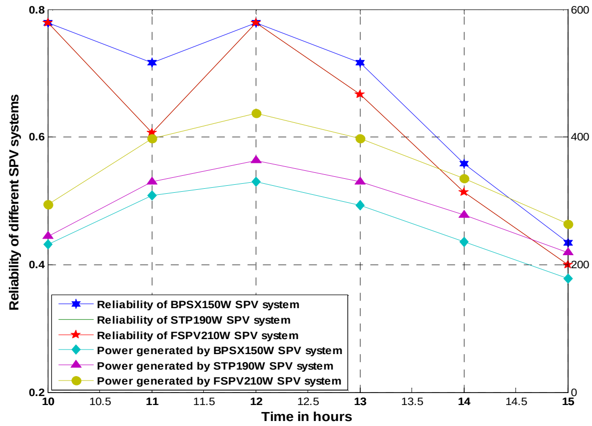

Fig.12: Reliability and Generated Power of different SPV systems vs time

Reliability for different SPV systems is shown in the fig.12, it reveals that at noon the power generated by different SPV panels is maximum and the SPV system "BPSX150W" has been chosen as more reliable system for the given load.

V. Conclusion and Future Scope

The selection of solar photovoltaic systems for a given site based on the reliability is presented in this paper. Three different types of solar panels have been considered for study. A methodology for evaluation of reliability of SPV system for maximum power tracking is developed in MATLAB/Simulink. In the present work, one year hourly radiation data from

Agricultural University, Hitanalli farm, Bijapur is considered. The values of reliability of each system were compared with the power generated by each SPV systems.

The methodology presented in the paper can be compared with more number of SPV systems for better reliability. Further the cost evaluation would be the important point in the power systems.

REFERENCES

[1] Haifeng Ge, Liqin Ni, Sohrab Asgarpoor, "Reliability-based Stand-alone Photovoltaic System Sizing Design- A Case Study", University of Nebraska – Lincoln, Digital Commons@University of Nebraska – Lincoln, Published in PMAPS '08. Proceedings of the 10th International Conference on Probabilistic Methods Applied to Power Systems, 2008, pp.1–8, Copyright 2008 IEEE.

[2] Burgio, A.; Menniti, D.; Picardi, C.; Pinnarelli, A., "A novel integrated configuration of Grid-connected photovoltaic plant with UPS: reliability estimation", Clean Electrical Power, 2007. ICCEP '07 International Conference on, vol., no., pp.142-147, 21-23 May 2007.

[3] Saengthong, S.; Premrudeepreechacham, S., "A simple method in sizing related to the reliability supply of small stand-alone photovoltaic systems", Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE, vol., no., pp.1630-1633, 2000

[4] Wohlgemuth, J.H.; Conway, M.; Meakin, D.H., "Reliability and performance testing of photovoltaic modules", Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE, vol., no., pp.1483-1486, 2000

[5] Kenji Otani; Takumi Takashima; Kosuke Kurokawa, "Performance and Reliability of 1 MW Photovoltaic Power Facilities in AIST", Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference on, vol.2, no., pp.2046-2049, May 2006

[6] Adelstein, J.; Sekulic, B., "Performance and reliability of a 1-kW amorphous silicon photovoltaic roofing system", Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE, vol., no., pp. 1627-1630, 3-7 Jan. 2005

[7] Tiberiu Tudorache, Liviu Kreindler, "Design of a Solar Tracker System for PV Power Plants", Acta Polytechnica Hungarica, Vol. 7, No. 1, 2010

[8] Shadi N. AlBarqouni, "Re-Evaluation and Re-Design Stand-Alone PV Solar Lighting Projects in Gaza Strip, Palestine", M.Sc Thesis under the supervision of Dr. Mohammed T. Hussein, the Islamic University of Gaza, Palestine.

[9] Agricultural University, Hittnali farm, Bijapur.

[10] A Guide to MATLAB for Beginners and Experienced Users - Hunt Lipsman & Rosenberg.

S. S. Kandagal was born in Bagalkot, Karnataka state, India, on 2nd September, 1984. He received B.E. Degree in Electrical and Electronics Engineering from Vishveshwaraya Technological University, Belgavi, and Masters Degree in Power and Energy Systems from Basaveshwar Engineering College (Autonomous), Bagalkot, Karnataka state, India, in 2009 and 2012 respectively.
Currently he is working as Assistant Professor in the Department of Electrical and Electronics Engineering, Tontadarya College of Engineering, Gadag district, Karnataka State, India. His current research interests include power systems, high voltage engineering and power electronics for renewable energy sources. He has published many national and international papers.

Smt. Suchitra G. was born in Bagalkot, Karnataka, India, on 10th May 1960. She obtained B.E degree in Electrical & Electronics from Basaveshwar Engineering College, Bagalkot. She did her post graduation at U. V. C. E., Bangalore University in the year 1990. Ph.D under VTU,Belgavi in the year 2015 and presently serving as an Associate professor in the Department of Electrical and Electronics at Basaveshwar Engineering College (Autonomous), Bagalkot.