International Journal of Scientific Research in Mathematical and Statistical Sciences
Research Paper
Volume-7, Issue-1, pp.64-68, February (2020) **E-ISSN:** 2348-4519

Reliability Analysis of Solar Energy Resources using Weibull distribution for a Standalone System in Indian Context

Surendra H.H.[1*], Seshachalam D.[2], Sudhindra K.R.[3]

[1,2,3]Department of Electronics and Communication, BMS College of Engineering, Bengaluru-560019, India

**Corresponding Author: surendrahh@gmail.com , Phone-9449859023*

Available online at: www.isroset.org

Received: 13/Jan/2020, Accepted: 20/Jan/2020, Online: 28/Feb/2020

***Abstract*:** The reliability of a standalone solar power plant is an important objective to deliver economical and quality power for any customer. The unreliable solar power has major socio-economic impact on utility and its customers. Weibull distribution function is used to analyse the time series solar data obtained from the weather stations. The nonlinear behaviour of solar irradiance has major impact on the performance and reliability of a solar power plant. Statistical data of solar energy resources under Indian conditions are simulated using system advisor model and reliability analytics tool kit for reliability analysis. In this paper, a study assessing the impact of the solar irradiance and losses on power generation is presented.

Keywords- *Reliability, Weibull, irradiance, probability distribution*

I. INTRODUCTION

Solar applications require failure models to analyse techno economic feasibility. Solar energy like wind is also a subjected to variation with time and solar power plant maintenance needs to be investigated. New sources of energy are being explored to compensate fossil fuels and conventional power. Even now excessive use of fossil fuel is causing global warming and fossil fuel occupies the majority global energy dependency [1].

The apparent disparity among people to lack of access for electrical energy is evident and it is necessary to find adequate solution to current and future needs even in remote places. More people still lack quality electric power and this makes renewable energy the alternate way for the energy generation [2]. The installation capacity of PV panels determines necessary energy production with load demand.

In this paper, a standalone PV system or a remote power supply is analysed using system advisor model at Bangalore. Standalone PV systems are not connected to grid but normally uses battery backup which delivers power to load after converting to AC [3]. This is extremely useful where public grid is not available as shown in fig1. The stochastic nature of the renewable energy resource such as irradiance or the wind speed or both impacts the system design.

The irradiance data is a bimodal distribution function which is a continuous probability distribution with two different modes. Statistical functions such as Beta, gamma, Weibull and lognormal distributions were used to relate the unpredictable distribution of irradiance data. The Kolmogorov-Smirnov method determines the function that fits the distribution of the irradiance data over a range of period [4]. Researchers describe the necessity of Weibull distribution for reliability analysis to optimally estimate its parameters.

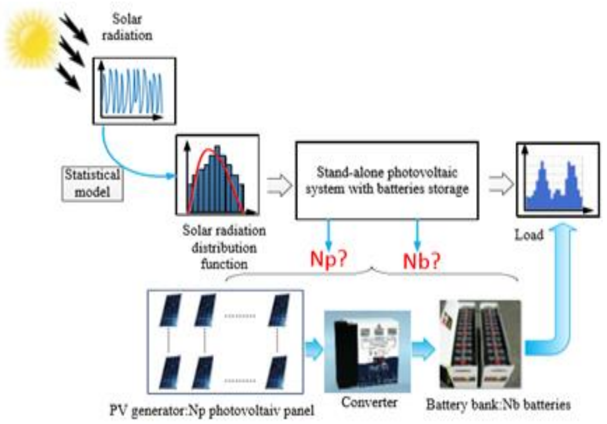

Fig. 1. Standalone photovoltaic system design [5]

It describes Life time of component, characterized by bath tub curve. The shape parameter β indicates when the component is in the setting phase for $\beta < 1$ it is similar to exponential shape. It will be in a random failures phase if $\beta = 1$. It will be in the degradation phase if $\beta > 1$ which is symmetrical like normal distribution. [6]

II. MODELLING OF SOLAR CELL

The PV module power output can be determined using the equivalent circuit of a solar cell presented in fig.2.

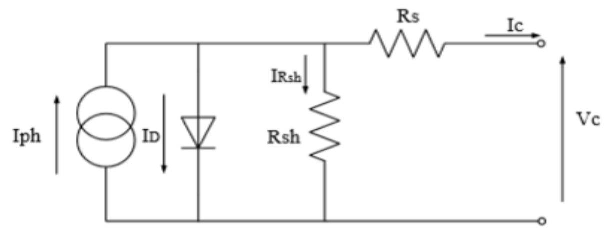

Fig. 2. Solar cell Equivalent circuit

Modelling solar photovoltaic cell can be computed and average power generated by it is given by the equation shown in (1).

$$P_{avg} = \int P(S)\, f(S) \quad (1)$$

P(S) is Photovoltaic module output power,
f(S) is irradiance probability density function.

Global Solar irradiance is single important parameter in calculating the average power output of a PV cell. Power generated every hour is varying in any day and so also average power in every month throughout the year.
Solar panel consists of combination of cells in series and parallel [7].
Np- cells in parallel
Ns- cells in series.
The power output is determined by multiplying the module output voltage and the output current [8]. So, considering cells in series and parallel together the output voltage of each module is V_p and output current is I_p expressed as follows in (2) and (3) [9].

$$V_p = N_s \times V_c \quad (2)$$

$$Ip = N_p \times I_c \quad (3)$$

Where V_c output voltage of a solar cell
and I_c output current of a Cell
Further if fill factor is included the output power of a PV module is given as follows in (4) [10]

$$P_{pv} = N*FF*V_p*I_p \quad (4)$$

N number of module; FF fill Factor

III. SIMULATION OF SOLAR DATA AT A GEOGRAPHICAL LOCATION

The first aspect is the use of System Advisor Model (SAM). It is a tool for renewable energy analysis developed by the National Renewable Energy Laboratory (NREL). Analytical modelling is performed considering geographical variations, weather conditions, chosen solar material etc. SAM can be used to compute both DC and AC power for a given irradiance at any location. SAM is a time domain software which can be analysed for statistical data-oriented systems. The tool allows to enter user designed parameters for analysis. The virtual simulation is important in the study of the solar power plant to be setup and its reliability [11].

IV. THE DATA CONSIDERED FOR THE STUDY

The site under consideration is situated in Bengaluru (latitude:12.9716° North, longitude :77.5946° East) which has a good roof top solar potential. The higher power levels load demand is in the day. Thus, solar power can meet most of the consumption peaks. Except in the early morning and evening solar power is almost directly used without much battery backup. Battery backup provides the extra needed power during off time of irradiation. The average solar power generated was based on statistical techniques. It is time varying one which influences the solar radiation modelling and the material chosen in design of PV panel 12].

The solar dataset is obtained from the National renewable energy Laboratory (NREL) and global horizontal irradiance is measured hourly (including both direct normal and diffuse horizontal irradiance).
The spectrum analysis of power data using system advisor model is used to determine the power variance caused by fluctuating weather and grid loads [13].

V. INDIAN SOLAR SCENARIO

India in a normal weather season receives nearly 300 sunny days in most of its region since it falls in tropic of cancer. Harnessing this solar energy is a green energy concept which is relevant in the generation of electricity in the present scenario. Also, it is important to utilize energy smartly. It should provide a worthwhile investment opportunity for industrialist and jobs for people.

Even now the share of renewable energy is far below that of fossil fuel. As of June 2016, 44.2 GW of renewable energy is contributed by solar energy (7.8 GW), wind energy (27.2 GW), biomass (5 GW) and small hydro power plant (4.3 GW). The grid connected solar energy is increasing with government commissioning even more deployment for future needs.

They have a target set at 100 GW by 2022 as per the mandate by the government of India during Conference of Parties 21(COP 21) held at Paris. Southern and western states have more solar parks due to vast dry lands compared to northern and eastern India. The socio-economic conditions have improved in these regions which gets less rainfall and prone to drought. In pavagada solar plant farmers have leased their land to government for 25 years and are getting regular income to sustain.

A time series database of Bangalore station is obtained from weather service provider (NREL). It provides hourly data as per Latitudes and longitudes in that particular location for sunny hours i.e. normally from 6 am to 7 pm of that site. The solar parks setup by public-private enterprises has enabled strong and weak factors to be taken care in future for better diffusion of global irradiance of solar PV technology.The Indian weather data has been analysed using Weibull distribution for reliability.

VI. RESULTS AND DISCUSSION

Reliability assessment

Time-to-Failure Distribution using Weibull distribution is assessed for solar irradiance over a area of around 6acres. The Hargreaves and beta distribution methods are also used to analyse the solar radiation to determine the reliability and potential of solar PV system installation [14]. Weibull distribution performs better than Gamma and Rayleigh in predicting the average wind power densities. A similar approach is made for solar irradiation data using Weibull. The findings in this paper can be further used in the areas that are having similar meteorological conditions with the study areas [15].

Analysis of Solar Radiation for the month of January in Bangalore station is considered for analysis. The hourly data sets are provided by NREL database and U.S. Department of Energy . Parameter estimates are based on linear regression rank regression on y (RRY), rank regression on x (RRX)

Reliability Function R(t):

It is the probability of a system performing its functions as desired for the intended operating period [16]. The variation in weather leads to high uncertainty associated with the system components. The reliability function is plotted as shown in fig 3 for an hourly irradiance data at Bangalore station. The exponential decaying equation is given by (5)

$$R(t)=e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (5)$$

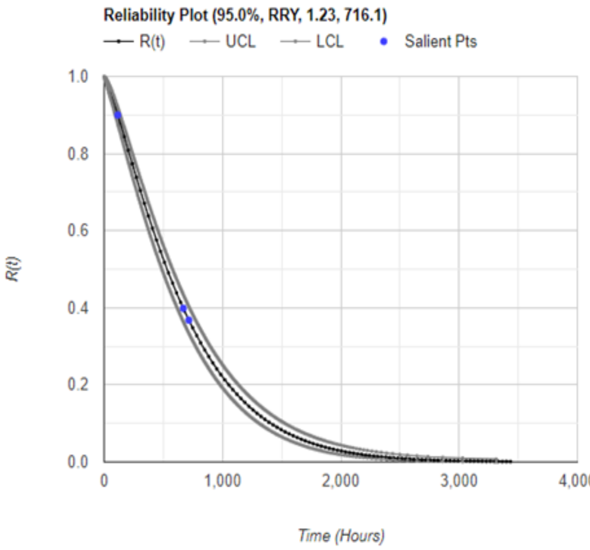

Fig. 3. Plot of reliability of solar power

The reliability plot of solar radiation is interpreted as to generate a typical day distribution for each month data. Once distribution plot is done one can choose the best fit for any irradiance data and that will be the best PDF. Then estimate of the energy production of your solar station can be determined.

Unreliability Function F(t):

Weibull distribution model will give forecast on unreliability based on failure rate over time. Unreliability plot as in fig 4 is required since more than 60% of time solar plant is not working for any given day. In most locations the variability in solar energy due to weather vastly exceeds any variability due to matters like misalignment of the array, or even latitude and longitudes or cloud cover. So, unreliability is more applicable for locations with more weather variations given in (6).

$$F(t)=1-e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (6)$$

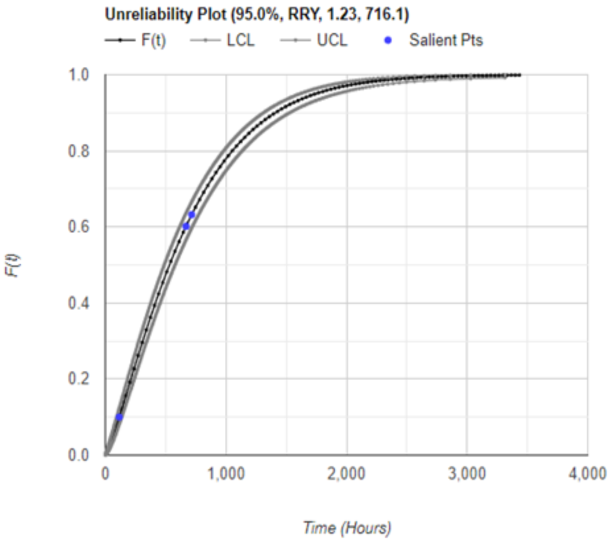

Fig. 4. Plot of unreliability of solar power

Probability Density Function (PDF) f(t) is given in (7)

$$f(t)=\frac{\beta(t)^{\beta-1}}{\eta^{\beta}}\ e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad (7)$$

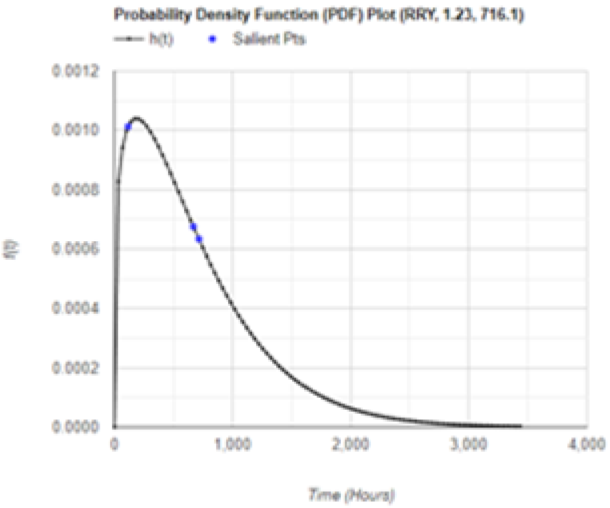

Fig. 5. Probability Density Function

Probability density function as in fig 5 is applied for modeling the PV output power based on the solar irradiance and the probability of any solar irradiance state can be estimated over a time.

Weibull Distribution

In this paper goodness of fit is applied for Weibull distribution model that fits the data. Parameter estimation is carried out using reliability analytics toolkit simulation software for modelling using both graphical and statistical methods. The shape parameter (β) and characteristic life (η) helps to specify the reliability over time (t). The radiance software can be used to analyse floor space index, urban density and compactness ratio is calculated for urban solar PV systems [18].

The Weibull probabilities of failure over a month duration is indicated in fig 6. The flat horizontal region between two dots indicate the successful solar irradiance which further leads to power generation.

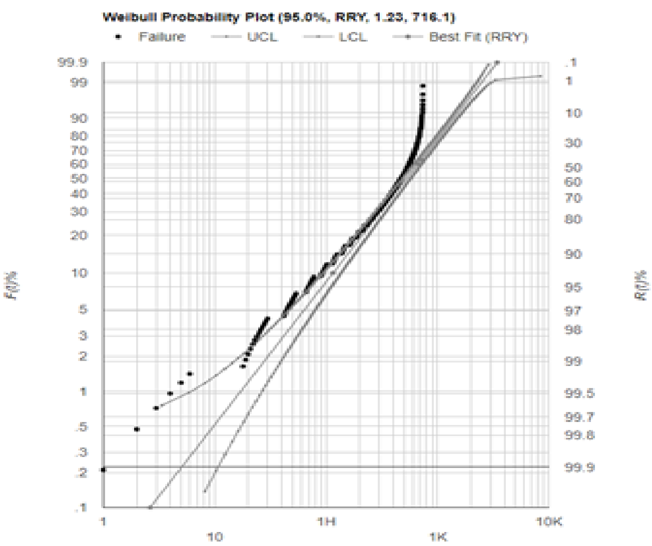

Fig. 6. Weibull probability distribution plot

Beta (β) implies the failure rate behaviour and if it is greater than 1, then the failure rate increases with time as in table 1. In Solar irradiance data the characteristic life is the time at which 63.2% of the power production fails. Mean life of failure is a function of characteristics life which implies unreliable nature of solar power over a month time.

Coefficient of determination is a fitness measure with higher r indicating greater fitness. Variance a function of the shape and scale parameters as in table1 depicts the higher randomness and spread of irradiance input to the solar panel over a month data. Weibull distribution is useful probability distribution for reliability analysis of complex systems [17].

Table 1 Weibull parameter table

Parameter	RRY	RRX
Shape parameter (β)	1.23	1.30
Characteristic life (η)	716.10	683.24
Coefficient of determination (r^2)	0.95	0.95
Mean life (μ)	669.14	631.42
Variance (σ^2)	297,943.65	241,310.40

VII. CONCLUSION

Reliability of solar irradiation and DC power generated is important for the evaluation and development of solar renewable energy systems at a given geographical location. Weibull models exhibit a wide range of shapes based on the density and failure rate functions. With proper simulation using weighting factors, statistical methods can achieve satisfactory results. The studies demonstrate satisfactory performance using statistical analyses which provides reference for PV system design and optimization. This paper presents an approach for reliability analysis using Weibull distribution models and the probability of the solar irradiance for every hour can be applied to study the reliability of the distribution system for a solar standalone system.

REFERENCES

[1] Malek Belouda, Jamel Belhadj, Bruno Sareni, Xavier Roboam, "Battery sizing for a stand-alone passive wind system using statistical techniques*", Eight International Multi-Conference on systems, Signals & Devices*, 2011. 10.1109/SSD.2011.5767373

[2] G. B. Shrestha, L. Goel, "A study on optimal sizing of stand-alone photovoltaic Stations". *IEEE Transactions on Energy Conversion*, Vol. **13**, No**. 4**, pp. **373-378**, December **1998**.

[3] Bogdan S. Borowy, Ziyad M. Salameh, "Optimum photovoltaic array size for a Wind/PV hybrid system *", IEEE Transactions on Energy Conversion*, vol. **9**, N. **3**, **482-488**, September **1994**.

[4] Bogdan S. Borowy, Ziyad M. Salameh, "Methodology for optimally sizing the combination of a battery bank and PV array in a Wind/PV hybrid system", *IEEE Transactions on Energy Conversion*, vol. **11**, No. **2**, pp. **367-375**, June **1996**.

[5] Safa Fezai , Jamel Belhadj."Optimal sizing of a Stand-alone photovoltaic system using statistical approach" *International journal of renewable energy research* Vol.**4**, No.**2**, **2014.**

[6] Hongxing Yang, Wei Zhou, Lin Lu, Zhaohong Fang, "Optimal sizing method for stand-alone hybrid solar– wind system with LPSP technology by using genetic algorithm", *Solar Energy* **82**, **354–367, 2008.**

[7] Ramos Hernanz, Campayo Martín, Zamora Belver, Larrañaga Lesaka, Zulueta Guerrero, Puelles Pérez, "Modeling of Photovoltaic Module ", *International Conference on Renewable Energies and Power Quality* , **2010**.

[8] Kinal Kachhiya, Makarand Lokhande, Mukesh Patel, "MATLAB/Simulink model of solar PV module and MPPT algorithm", *National Conference on Recent Trends in Engineering & Technology*, May **2011**.

[9] Sree Manju B, Ramaprabha R, Mathur B.L, "Design and Modeling of Standalone Solar Photovoltaic Charging System", *International Journal of Computer applications*, vol **18**, No.**2**, March **2011**.

[10] Hung D. Q., Mithulananthan N., K. Y. Lee Determining PV Penetration for Distribution Systems with Time-Varying Load Models. *IEEE Transactions on Power Systems*; **2014**,29(6), p.**3048-3057**.

[11] N. Blair, A. P. Dobos, J. Freeman, T. Neises, and M. Wagner, "System advisor model, general description," *NREL*, Feb. **2014**.

[12] Jussi Ekstrom, Matti Koivisto, Ilkka Mellin, Robert John Millar, Member, IEEE, and Matti Lehtonen, Member, IEEE "A Statistical Model for Hourly Large-Scale Wind and Photovoltaic Generation in New Locations" *IEEE Transactions On Sustainable Energy*, vol. **8**, no. **4**, October **2017**

[13] Peng Li, Roger Dargaville, Feng Liu, Jing Xia, and Yong-Duan Song, Senior Member, IEEE "Data-Based Statistical Property Analyzing and Storage Sizing for Hybrid Renewable Energy Systems" *IEEE Transactions On Industrial Electronics*, vol. **62**, no. **11**, november **2015**

[14] Syafawati A.N., I.Daut, S.S. Shema, M. Irwanto, Z. Farhana, N. Razliana, Shatri C. "Potential of wind and solar energy using Weibull and hargreaves method analysis*" The 5th International Power Engineering and Optimization Conference (PEOCO2011)*, Shah Alam, Selangor, **Malaysi**a : 6-7 June 2011.

[15] Abubakar Abdulkarim, Sobhy M. Abdelkader and D. John Morrow "Statistical Analyses of Wind and Solar Energy Resources for the Development of Hybrid Microgrid" *2nd International Congress on Energy Efficiency and Energy Related Materials*, Springer International Publishing Switzerland **2015**.

[16] Billinton R and Allen R.N., Reliability Evaluation of Engineering Systems, *Springer New York*, Plenum, page **6-18,1983.**

[17] Anwar M Hossain and William J Zimmer "Comparison of estimation methods for weibull parameters: complete and censored samples" *Journal of statistical computation and simulation* **2003** Vol **73(2) 145-153.**

[18] Shambhabi Chatterjee1, Kamalika Ghosh, Debashish Das "Analyzing various approaches for Measurement of Solar PV Potential through Urban Built Form Geometry modifications" *International Journal of Computer Sciences and Engineering*. Volume-**4**, Special Issue-**6**, Aug **2016**

Authors Profile

Mr. Surendra H.H. pursed Bachelor of Engineering from Bangalore University in 2000 and Master of Technology from Visvesvaraya Technological university in year 2004. He is currently pursuing Ph.D. and working as Assistant Professor in the Department of Electronics and Communication, BMS College of Engineering since 2008. His main research work focuses on solar energy analysis.

Mr Seshachalam D has completed his Phd from MNNIT, Allahabad and currently working as Professor in the Department of Electronics and Communication, BMS College of Engineering since 2009. His area of interest is Control Systems, Embedded System & Power electronics. He has over 25 years of teaching experience and 4 years in research experience. He is IEEE and ISTE member and is currently guiding five research scholars.

Mr Sudhindra K.R. has completed his Phd from VTU, Belgaum and is currently working as Department of Electronics and Communication, BMS College of Engineering. His area of interest is in wireless communication and is a member of LMISTE and AMIETE. He has 10 years of teaching experience and 6 years of industrial experience.