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Reliability oriented performance evaluation of PV inverter with bifacial panels considering albedos

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ABSTRACT

The recent advancements in the solar photovoltaic technology is bifacial panels. These panels are capable of producing higher energy than their conventional panels by capturing from both front and rear sides. By harvesting solar energy from both the front and rare surfaces of the panels, the load on the inverters can increase. This affects its reliability performance. Nevertheless, inverter is reported as the critical component in the photovoltaic (PV) system. Hence this work presents reliability-oriented performance evaluation of PV inverter with bifacial panels is proposed. A 3-kilowatt photovoltaic system has been considered with yearly mission profile data at Hyderabad, India. This evaluation is carried out under various albedos. Finally, a comparison between monofacial and bifacial PV panel are presented. The results show that the albedo significantly impacts the lifetime of a PV inverter and therefore, the albedo should be considered when designing a bifacial panel's inverter.

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1. INTRODUCTION

Photovoltaics is a dominant technology in the power sector. The increasing energy demand, government policies for the deployment of renewable energy sources, and environmental concerns are some of the factors that are driving the growth of the photovoltaic market. The rapid emergence and evolution of photovoltaic modules have contributed to the increasing number of power plants worldwide. One of the most promising developments in this field is the bifacial technology. The bifacial panels are capable of producing higher energy than their conventional panels by capturing from both front and rear sides as shown in Figure 1. Hence, the bifacial technology has gained widespread attention from the photovoltaic (PV) industry.

The total installed capacity of bifacial panels was 8530.6 KW by the end of August 2019 and it is expected to reach a peak of 21,000 MW by 2024. China led the global installation of bifacial projects with 6282 MW. Other countries such as Oman, Mexico, and Taiwan also installed about 100 MW. In European countries, around 10 to 35 MW of bifacial projects have been installed [1]. Desai *et al.* [2] analyzed the advantages of bifacial photovoltaic modules on a rooftop system at Gujarat, India. Also, the technical characteristics, economics, and advantages are compared with traditional monofacial panels. Kumbaroğlu *et al.* [3] comprehensive analysis of the economic effects of bifacial solar panels is performed for a farm with 35 MW of installed capacity. The study indicates that the panels can achieve a total system usage gain of around 7.9–16.8%, depending on the monthly yield. Tillmann *et al.* [4] presented a detailed model of bifacial photovoltaic modules that can be used in a large PV field. It also shows the annual energy output of the panels at different locations. Three low concentrating photovoltaic (LCPV) systems featuring bifacial panels are developed in [5]. Vijayan *et al.* [6] analyzed the effects of vertical and bifacial agri voltaic (AV) farms on the rice yield in a tropical climate in south-eastern India. Alam and Khan [7] presented a simple analytical method to improve the efficiency of bifacial tandem cells.

By harvesting solar energy from both the front and rare surfaces of the panels, the load on the inverters can increase. This affects its reliability performance. Nevertheless, inverter is reported as the critical component in the PV system. Kshatri *et al.* [8] analyzed the performance of a PV inverter based on geographical locations and environmental factors. Bouguerra *et al.* [9] evaluated the lifetime of a PV inverter with different orientation and tilt angles of panels. In addition, the degradation rate of these panels is taken into account. Gatla *et al.* [10] analyzed the influence of mission profile on the lifetime of a PV inverter. The minimum DC-link voltage regulation for two-stage PV inverters is proposed in [11]. This will help improve the reliability and efficiency of PV inverter. Sangwongwanich *et al.* [12] presented the reliability oriented accelerated testing of dc link capacitor of PV inverter. Chai *et al.* [13] proposed a method for improving the reliability of PV inverters by implementing a variable voltage distribution network under uncertain conditions.

As the PV inverter reliability is the major concern, this work presents the reliability-oriented performance evaluation of PV inverter with bifacial panels is proposed. A 3-kilowatt photovoltaic system is considered with yearly mission profile data at Hyderabad, India. This evaluation is carried out under various albedos. Finally, a comparison between monofacial and bifacial PV panel are presented. The results show that the albedo significantly impacts the lifetime of PV inverter and hence these factors should be taken into account when designing a PV inverter for bifacial panels.

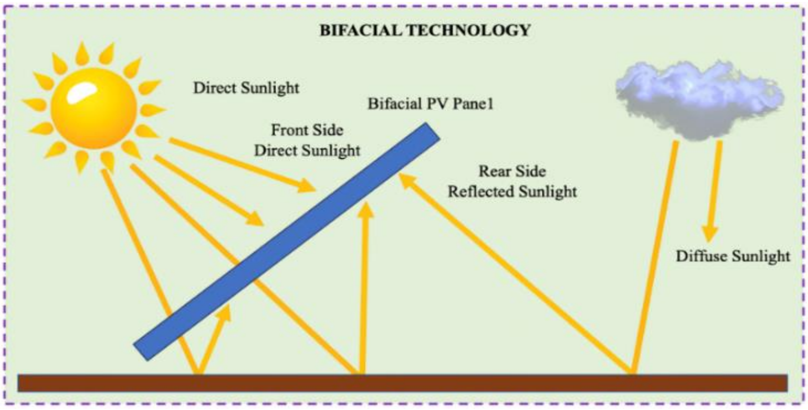

Figure 1. Bifacial technology

2. RELIABILITY ORIENTED PERFORMANCE ANALYSIS OF PV INVERTER

The reliability of PV inverter is obtained by calculating the reliability of insulated gate bipolar transistors (IGBT) at system level (L_s). Initially component level (L_c) reliability for IGBT (for single IGBT) is evaluated and system level (Ls) reliability is obtained by combining all IGBTs component level (L_c) reliability using series reliability block diagram. The reliability-oriented performance analysis of PV inverter involves several steps. The flow chart is presented in Figure 2.

Yearly solar irradiance (I_s) and ambient temperature (T_a) are logged as mission profile (MP) at Hyderabad, India between August 2018 to September 2019 [14]. Junction temperature (J_t) for the yearly MP is estimated using foster electro thermal model [15]. Rainflow counting is implemented to analyze the variation of J_t [16]. The lifetime (L_f) is calculated using the Bayerer's lifetime equation [17] show in (1).

$$L_f = \frac{1}{\sum \frac{\text{No.of cycles } (n_i)}{A(\Delta T_j)^{\beta_1} . e^{\frac{\beta_2}{(T_j + 273)}} . t_{on}^{\beta_3} . I^{\beta_4} . V^{\beta_5} . D^{\beta_6}}} \quad (1)$$

Monte Carlo simulation (MCS) generates a sample size of 10,000 was obtained with a 5% variation. Lf at each sample is calculated using (1) and fitted in Weibull distribution. Reliability evaluation at CL and SL are calculated using (2) and (3), respectively [18].

$$R_i(t) = e^{-\left(\frac{t}{\propto}\right)^{\gamma}} \quad (2)$$

Where: $R_i(t) =$ Reliability of individual component; $\propto =$ scale parameter; and $\gamma =$ shaper parameter.

$$R_{total}(t) = \prod_{i=1}^{n} R_i(t) \quad (3)$$

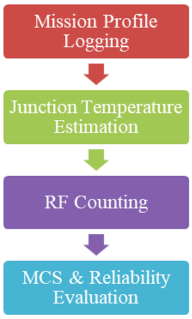

Figure 2. Flow chart for PV inverter reliability evaluation

3. TEST CASE

In this paper a test case of 3-kW PV system is considered as shown in Figure 3. A yearly MP from August 2018 to September 2019 is considered at Hyderabad, India as shown in Figure 4. The system specifications are tabulated in Table 1. In this paper performance of monofacial and bifacial panels are considered for comparison. The bifacial panels are modelled under the various albedos [19] keeping the module height from ground at 1 meter as shown in Figure 5 [20]-[25].

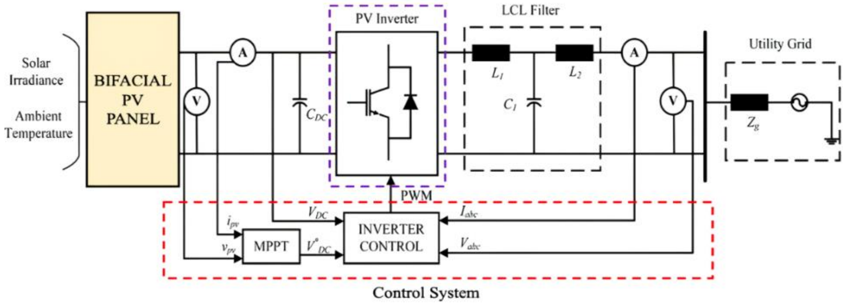

Figure 3. Test case

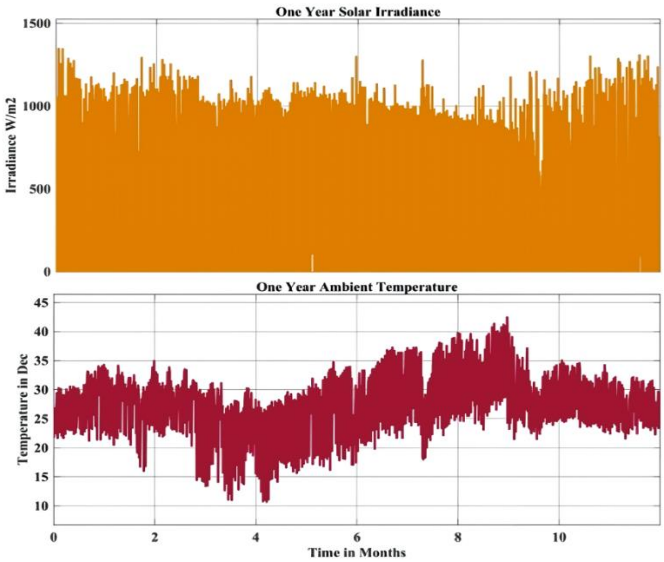

Figure 4. Monthly MP for one year

Table 1. System specifications

Item	Specifications
PV panel	BP (365)
IGBT	IGW30N60H3
Grid voltage	230 Volts
Grid frequency	50 Hz

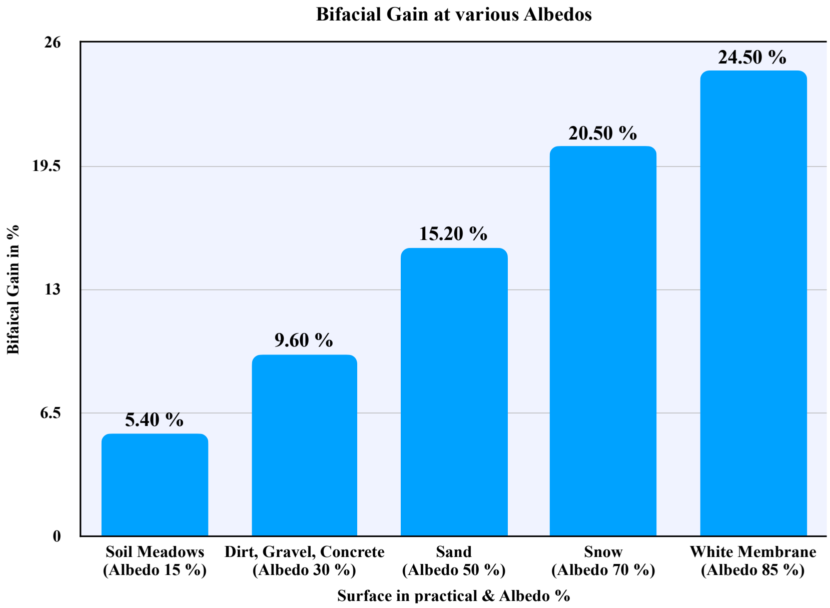

Figure 5. Bifacial gain at various albedos [19]

4. RESULTS AND DISCUSSIONS

This work presents reliability-oriented performance evaluation of PV inverter with bifacial panels is proposed. A 3-kilowatt photovoltaic system is considered with yearly mission profile data at Hyderabad, India. The following cases are evaluated: i) PV inverter with monofacial panels; and ii) PV inverter with bifacial panels.

4.1. PV inverter with monofacial panels

In this case conventional monofacial panel is considered for the assessment. Yearly MP is taken between August 2018 to September 2019 as shown in Figure 4. The MP follows the irregular pattern and average values are high at Indian location.

4.2. Junction temperature estimation

The yearly MP is translated to J_t using foster electro thermal model as shown in Figure 6. This thermal model is best suited for the semiconductors like IGBTs to analyses the thermal profile. The Jt traces the uneven nature, hence counting algorithm is needed to analyses. The J_t traces the uneven nature, hence counting algorithm is needed to analyses.

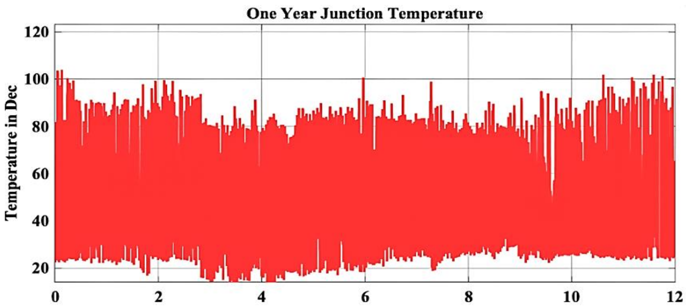

Figure 6. J_t for monofaical panel

4.3. RF counting

To extract the thermal profile from the J_t, rainflow counting algorithm is implemented. The algorithm helps in breaking down complex loading histories into simple, measurable fatigue cycles, which are then used to predict the life of the component under cyclic loading. The thermal profiles such as number for cycles, cycle average, cycle range are extracted as shown in Figure 7.

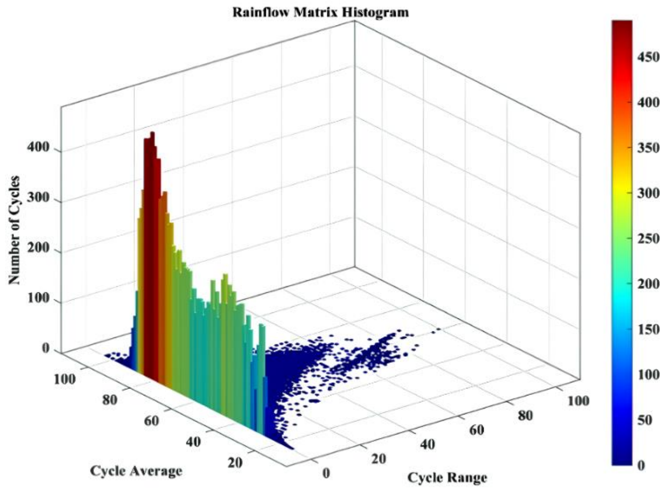

Figure 7. RF for monofacial panel

4.4. MCS and reliability evaluation

Monte Carlo simulation (MCS) generates a sample size of 10,000 was obtained with a 5% variation. L_f at each sample is calculated using (1) and distribution system of Weibull was fitted as shown in Figure 8. Here maximum density if falls between 40 to 50 years. From the Figure 8 scale parameter and shape parameter are extracted. Form these parameters' reliability evaluation at CL and SL are calculated using (2) and (3) as shown in Figures 9 and 10 respectively.

In the Figure 9 the B_{10} lifeline i.e., at 0.9 reliability line intersects the reliability curve at 33 years. Similarly, in the Figure 10 the B_{10} lifeline i.e., at 0.9 reliability line intersects the reliability curve at 24 years. Hence the B_{10} lifetime for PV inverter at CL is 33 years and for SL is 24 years.

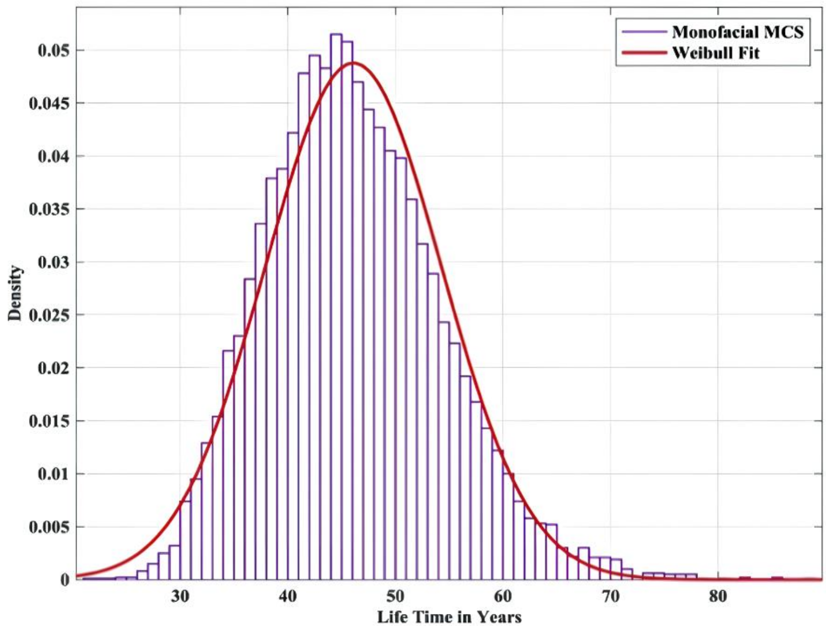

Figure 8. MCS for monofacial panel

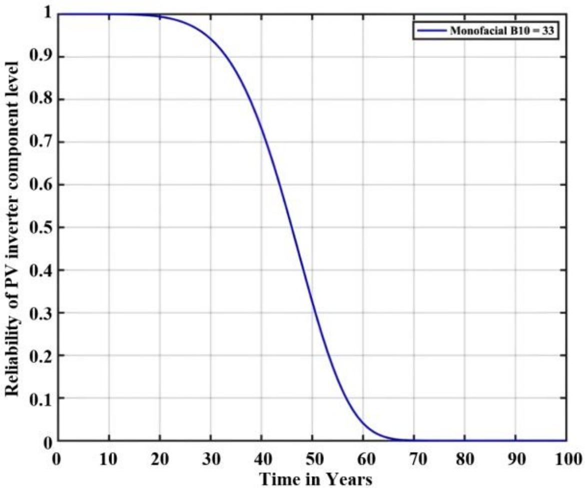

Figure 9. CL reliability for monofacial panel

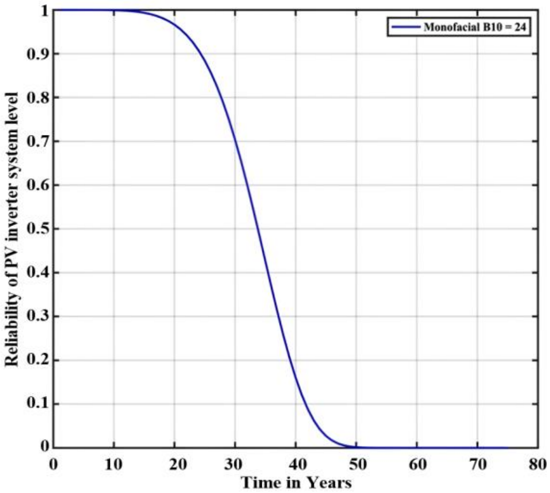

Figure 10. SL reliability for monofacial panel

4.5. PV inverter with bifacial panels

In this case conventional bifacial panel is considered for the assessment under various albedos as shown in Figure 5. Yearly MP is taken between August 2018 to September 2019 as shown in Figure 4. The MP follows the irregular pattern for bifacial MP and average values are high at Indian location

4.6. Junction temperature estimation for bifacial panel

The yearly MP is translated to J_t for various albedos using foster electro thermal model as shown in Figure 11. This thermal model is best suited for the semiconductors like IGBTs to analyses the thermal profile under various albedos of bifacial panel. The J_t traces the uneven nature, hence counting algorithm is needed to analyses.

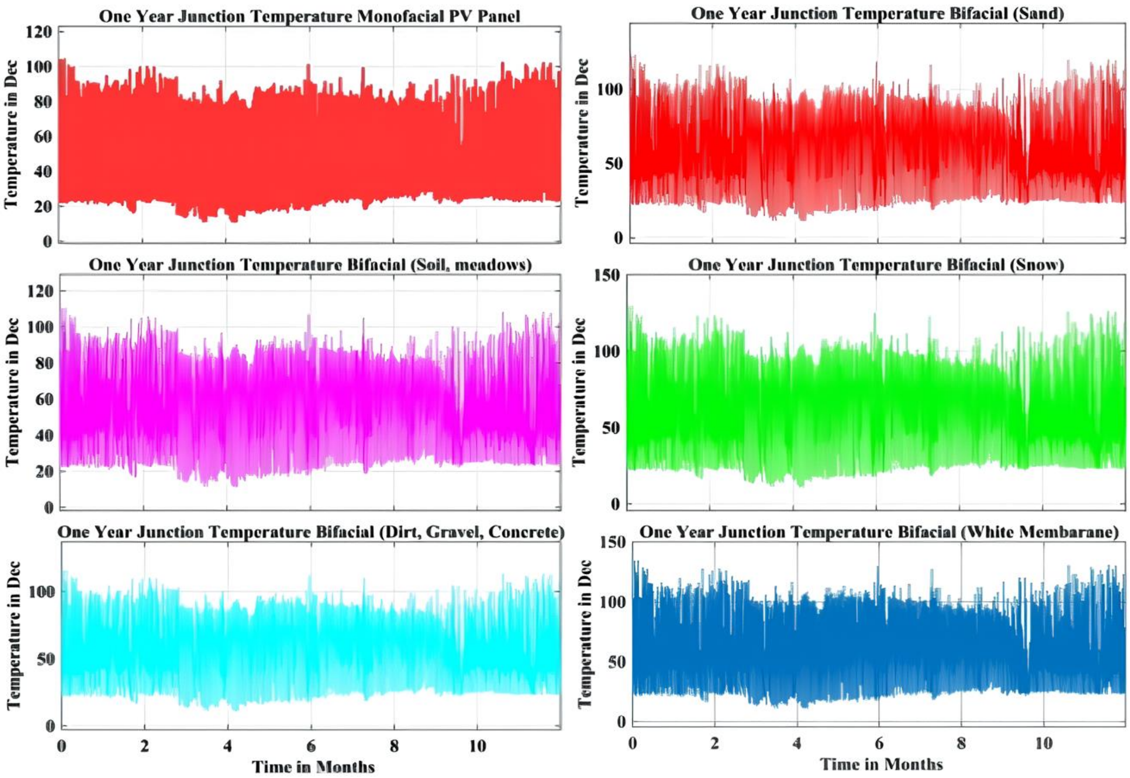

Figure 11. J_t for bifaical panel

4.7. RF counting for bifacial panel

To extract the thermal profile from the J_t for various albedos, rainflow counting algorithm is implemented. The thermal profiles such as number for cycles, cycle average, cycle range are extracted as shown in Figure 12. The thermal profiles are extracted for all the cases of albedos of bifacial panel.

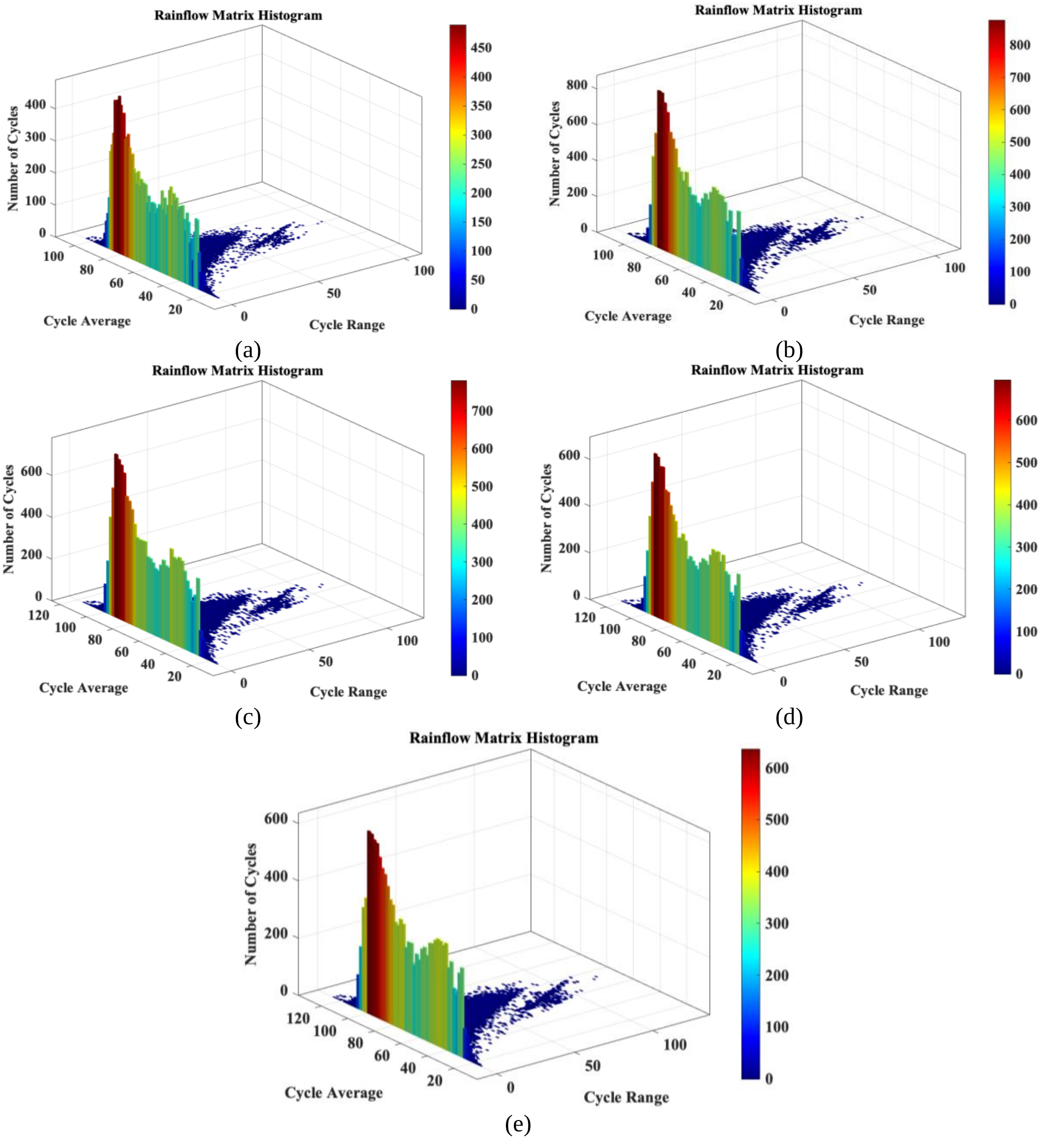

Figure 12. RF for bifacial panel: (a) soil, meadows; (b) dirt, gravel, concrete; (c) sand; (d) snow; and (e) white membrane

4.8. MCS and Weibull evaluation

Monte Carlo simulation (MCS) generates a sample size of 10,000 was obtained with a 5% variation for various albedos. L_f at each sample is calculated using (1) and fitted in Weibull distribution as shown in Figure 12. Here maximum desity is recorded for white membrane.

From the Figure 13 scale parameter and shape parameter are extracted. Form these parameters reliability evaluation at CL and SL are calculated using (2) and (3) as shown in Figures 14 and 15 respectively. In the Figure 14 the B_{10} lifeline i.e., at 0.9 reliability line intersects the reliability curves for various albedos at CL as:

- Soil meadows (albedo 15%) = 22 years
- Dirt, gravel, concrete (albedo 30%) = 16 years
- Sand (albedo 50%) = 8 years
- Snow (albedo 70%) = 5.8 years
- White membrane (albedo 85%) = 6 years

In the Figure 15 the B_{10} lifeline i.e., at 0.9 reliability line intersects the reliability curves for various albedos at SL as:

- Soil meadows (albedo 15%) = 16 years
- Dirt, gravel, concrete (albedo 30%) = 12 years
- Sand (albedo 50%) = 11 years
- Snow (albedo 70%) = 8 years
- White membrane (albedo 85%) = 5

4.9. Comparison analysis

In this paper PV inverter reliability performance is evaluated for monofacial and bifacial (considering albedos) panels at SL and CL as shown in Figure 16. Albedo significantly impact the reliability performance of PV inverter, as the albedo increases the reliability of PV inverter decreases. Hence impact of albedo needs to be considered during the design of bifacial system.

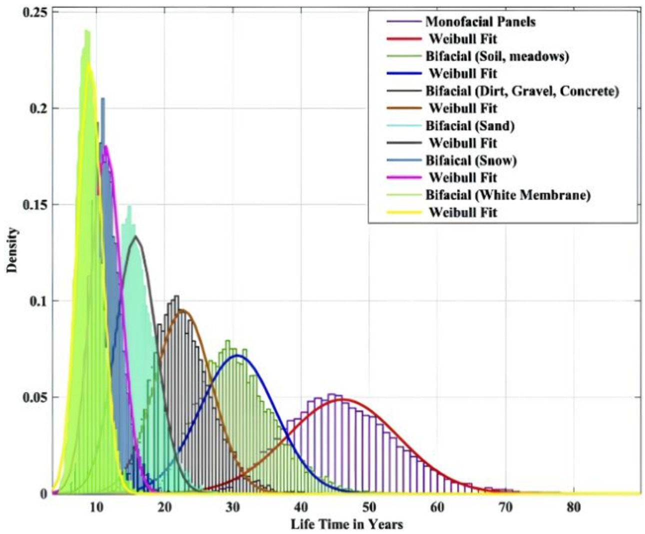

Figure 13. MCS for monofacial panel

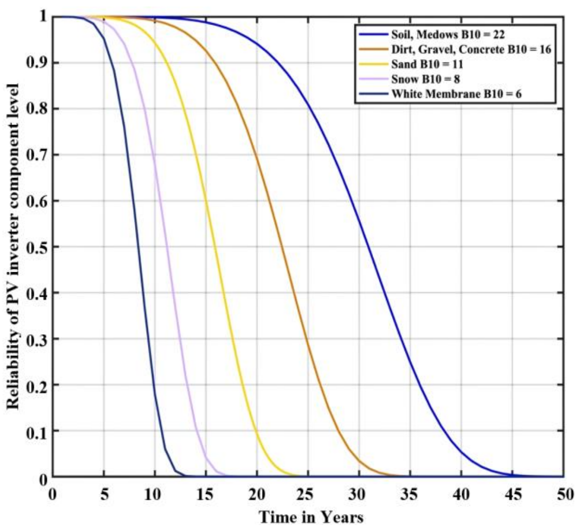

Figure 14. CL reliability for bifacial panel

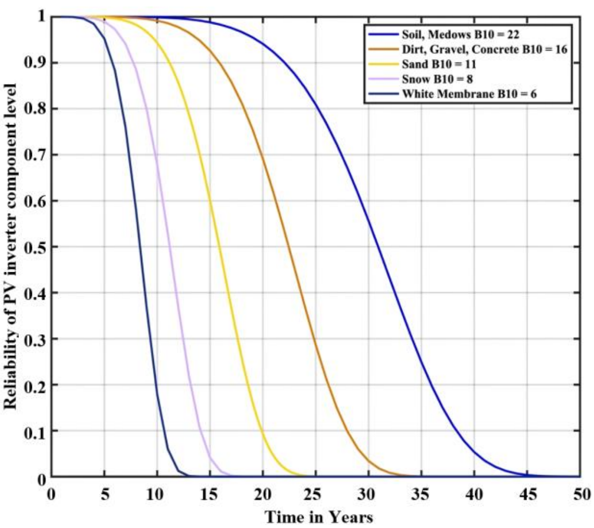

Figure 15. SL reliability for bifacial panel

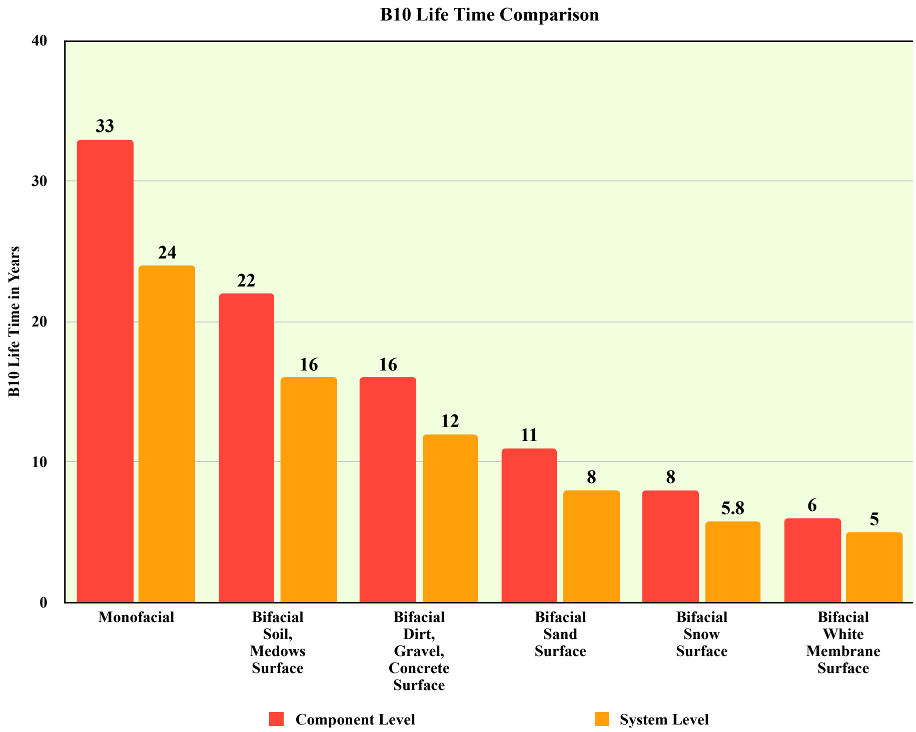

Figure 16. Comparison analysis

5. CONCLUSION

This work presents the reliability-oriented performance evaluation of PV inverter with bifacial panels is proposed. A 3-kilowatt photovoltaic system is considered with yearly MP data logged at Hyderabad, India. This evaluation is carried out under various albedos. J_t is obtained using FEM model. RF is implemented to obtain the thermal profile of J_t. MCS is implemented to generate a sample size of 10,000 was obtained with a 5% variation and fitted in Weibull distribution. Reliability at CL and SL are evaluated. Finally, a comparison between monofacial and bifacial PV panel are presented. The results show that the albedo significantly impacts the reliability performance of PV inverter, as the albedo increases the reliability of PV inverter decreases. Hence impact of albedo needs to be considered during the design of bifacial system.

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