Received: 11 April 2024 | Revised: 23 May 2024 | Accepted: 12 June 2024 | Published online: 18 June 2024

REVIEW

Archives of Advanced Engineering Science
2024, Vol. 00(00) 1–9
DOI: 10.47852/bonviewAAES42023083

BON VIEW PUBLISHING

Reliability Overview of Grid-Connected Solar PV System: A Review

Samuel O. Obatola[1,*]

[1]*State Key Laboratory of Power Transmission Equipment and System Security and New Technology, Chongqing University, China*

Abstract: Photovoltaic (PV) generation is the most practical renewable energy alternative since it receives adequate sun irradiation throughout the year. Solar systems are often first modeled using design tools including MATLAB/Simulink to rectify as well as tweak variables to achieve the direct current as well as voltage requirements with the irradiance as well as ambient high temperature. On simulated systems, reliability tests and analysis are done to determine the performance as well as high durability just before system components fail. This study overviews various systematic methods for evaluating the reliability performance of large-scale grid-connected PV systems while taking into account variations in power input as well as ambient condition relaying failure rates of critical components such as PV modules, inverters, switch gears, transformers, and capacitors. The total system dependability also comprises the mean time to failure as well as mean time to repair of a power system. The output of PV electricity fluctuates substantially and is affected by sun temperature and irradiation, giving intermittent as well as variable energy generation. A probabilistic analytical technique is used to analyze an existing model of grid-connected PV systems. The dependability or reliability of a grid-connected system is determined by the failure rate, and various PV grid components such as inverters, PV modules, switch gears, transformers, and so on are analyzed using established failure modes and effects analysis and Weibull models. This paper overviews the reliability of solar PV grid-connected systems and identify the factors that affect their performance. The paper provides a review of the current state of research on PV systems, including the components that make up the system, their operation, and the potential failure modes. Additionally, the paper identifies some of the key factors that contribute to the reliability of the solar PV grid-connected system, including environmental factors, design factors, and maintenance strategies.

Keywords: reliability, PV system, Weibull models, FMEA, MTTF, MTBF, MTTR

1. Introduction

The fast climate change that has characterized the previous several decades is closely tied to the influence of greenhouse gases in the atmosphere, namely, the pollutants (CO_2) releases produced by fossil fuels [1]. A significant reduction in CO_2 emissions may be achieved by radically shifting the energy generating mix: from the existing dominating fossil-fueled energy mix to nuclear and renewable energy, which includes wind, biofuels, solar, geothermal, and hydropower [2].

Photovoltaic (PV) systems under development must meet the needed levels of dependability for installation viability as well as economic payback. The reliability is the assumption that equipment in a PV system will work effectively for its intended purpose [3]. A PV system is made up of many parts and components that are linked together. Power electronics are prone to malfunction owing to design flaws and environmental variables [4]. Longevity, dependability, and the safety of the electrical system are all indicators of reliability [5]. A model of hierarchical reliability including all components is used to predict the overall system reliability. Solar energy is an erratic source that can improve reliability and security when connected to the electrical system [6]. The components that make up an electric grid's operation include generation, transmission, and distribution.

The layout of the PV system varies according to architectural design. It can be a single-inverter system, a string-inverter system, or a multi-inverter system. PV arrays are connected to three-phase inverters a DC-DC power (boost) converter for grid connected photovoltaic system (GCPV). Each component's failure rates are looked at separately. Calculating the rate of failure of the system's planned components involves various techniques like using the part load analytical technique. The reliability block diagram technique is often used to generate the PV systems reliability models and compute the mean time to failure (MTTF) and mean time to repair (MTTR). Additionally, it only assesses if consumers have access to energy when needed [7].

A smart grid technology is designed to achieve a high penetration of PV systems into homes and businesses; it is an intelligent system capable of sensing system overloads and rerouting power to prevent or minimize a potential outage of

*__Corresponding author:__ Samuel O. Obatola, State Key Laboratory of Power Transmission Equipment and System Security and New Technology, Chongqing University, China. Email: obatolasamuel@cqu.edu.cn

power over the grid. Additionally, reliability is defined by Institute of Electrical and Electronics Engineers (IEEE) as the ability of a system or device to carry out its desired function under predefined circumstances for a certain amount of time.

Power reliability is the extent to which the operation of a bulk system's components results in the delivery of power to consumers within recognized criteria and in the required amount [8].

The Weibull analysis technique may be used to model data sets having values greater than "0," such as failure data. Weibull analysis may be applied in many different industrial scenarios, including anticipating product life, comparing dependability, creating warranty policies scientifically, and actively managing spare parts inventories, to name a few. In fact, Weibull analysis methods are now essentially associated with dependability and achieving high reliability [9].

Numerous studies on the dependability of the electrical system have been published. Both the production of electricity from traditional forms of energy and that produced from renewable power like PV cells are essential given the existing imbalance between the demand for and supply of power [10]. There are various research and papers that detail how to build and size a grid-connected PV system [11]. It has also been done to design solar PV using yearly mean sun radiation [12]. Similar to this, the research of Campoccia et al. [13] assessed the workload, capacity of the PV system, and dependability through the numerous loads linked in a house. The design and size of a standalone PV system are covered in length in the publication Solar Photovoltaic Energy [14]. To determine the size as well as components of such a PV system, many computational tools have been designed in addition to these publications. The PV watts [15] may be used to calculate the location-specific PV generation. In addition to estimating the load size of a house for practically every region in the United States, the National Renewable Energy Laboratory [16] has supplied a wealth of information concerning renewable energy technologies.

The grid-connected PV systems and the components themselves are a synthesis of several parts. This system's dependability forecast is similarly crucial. The dependability of a system may be evaluated by comparing the loading, generation, and battery state of charge for the appropriate period with the expected size of both the PV system and its components [17]. A simulation approach can also be used to estimate reliability by analytical methods [18]. By considering the stochastic fluctuation of the electrical energy demand, a Monte Carlo technique is used to characterize the electrical load behavior. Due to the correlation between the unpredictability of the demand and the energy output, it is possible to calculate the likelihood that the load will go without power for a specific amount of time [19]. Recalculating the result with various-sized PV generators reveals that dependability is greater when using a large-scale PV generator as well as a battery.

System and component levels in the PV system determine dependability. Because there are numerous other parts in the PV system, a sufficient source and battery capacity that is system-level reliable won't be able to predict the precise dependability. The entire system will fail if any one of these components fails (component-level dependability). The PV systems, battery storage, inverters, charge controller, and cabling are the principal elements of a PV system. The research of Mishra and Joshi [20] may be utilized to estimate the rate of failure of a charge controller and battery. The failure rate of the traditional inverter is quite high. Through filtering, derating, and redundancy, the idea of a controller and further lowering the failure rate are considered. To assess the inverter's dependability, factors including the reliability of each individual component, how temperature and humidity affect the components, and how screening, thermal dissipation, and redundancy reduce failure rates are considered. This same work's calculating method and failure rate for electronic components are used [21]. The depth of battery depletion and the gap between two consecutive discharges are two factors that affect the battery failure rate, which is also covered in the study.

This paper provides a comprehensive review of the research work related to reliability assessment methodologies for grid-connected PV systems performed in recent literature.

1.1. Components of a solar PV grid-connected system

A solar PV grid-connected system consists of several components, including solar panels, inverters, batteries, and monitoring systems. The solar panels are responsible for converting sunlight into electricity, while the inverters convert the direct current power produced by the solar panels into alternating current (AC) power that can be used by the electrical grid. Batteries are used to store excess energy generated by the solar panels for use during times of low sunlight. Finally, monitoring systems are used to track the performance of the system and identify any potential issues.

The scientists explore several inverter types, their applications, and estimated failure rates. First, the size of the PV generator employed in this thesis is best suited for a multistring inverter. The total number of individual electronic components employed inside the inverter is used to assess the failure rate of the inverter. Since the inverter capacity is nearly identical to that needed in this thesis, the rate of failure of an inverter is obtained straight from this study [21–27].

With the appropriate scale factors, exponential distribution functions may describe failures that are not time-dependent. Additionally, a rising linear Weibull distribution with size and shape parameters is a superior initial method for representing the consequences of component deterioration based on time to failure [28–30]. Since PV system components have a constant, time-independent failure rate, the majority of their reliability may be evaluated using an exponential function. The failure rate of the several components and PV panels is independent of time. As time goes on, the power of the PV generator and the ability of the battery both decrease; therefore, the failure rate of the PV array and battery will change with time. Weibull distributions may be used to simulate these battery and PV generator properties. Since their calculation is based on a thorough bibliographic study of a laboratory and field system, Diaz et al. [31] work was used to determine the scale and form specifications for the PV generator and the failure rate for the wiring. Based on the battery's type, size, and discharge behavior, estimates were made for its Weibull scale as well as shape parameters.

1.2. Potential failure modes

There are several potential failure modes that can affect the performance of a solar PV grid-connected system. Some of the most common issues include module degradation, inverter failure, and battery degradation. Module degradation occurs over time due to exposure to the environment and can result in a decrease in the system's overall efficiency. Inverter failure can occur due to a variety of factors, including age, design flaws, or electrical faults.

Battery degradation is another common issue, as batteries can lose capacity over time due to repeated charge and discharge cycles. Also, the mass adoption and proliferation of GCPVS could create enormous stress on the electric grid.

1.3. Environmental factors

Environmental factors such as temperature, humidity, and solar radiation can affect the reliability of a solar PV grid-connected system. High temperatures can cause module degradation and reduce the efficiency of the system. Additionally, high humidity can lead to corrosion and electrical faults. Finally, solar radiation can cause module degradation and reduce the efficiency of the system over time.

1.4. Design factors

The design of a solar PV grid-connected system can also affect its reliability. Proper design considerations such as system sizing, shading, and orientation can improve the overall efficiency of the system. Additionally, the use of high-quality components and proper installation techniques can reduce the likelihood of failures and ensure that the system performs as intended.

2. Methods

The methods for computing reliability can be categorized into four broad categories: analytical methods, probabilistic methods, intelligent methods, and simulation methods. A comprehensive study is conducted to evaluate the reliability of solar PV grid-connected systems. The study details a review of relevant literature, a survey of experts in the field, and an analysis of data from existing PV systems. The reliability of different components of the solar PV system, including solar panels, inverters, and batteries, is evaluated using various reliability metrics. The failure modes of the solar PV system are identified, and the causes of failure are analyzed. The maintenance strategies that affect the performance of the system are also identified and analyzed.

2.1. Reliability and maintainability methods

The reliability, availability, maintainability and safety (RAMS) analysis for the PV system aimed to determine how the system and its components worked over a period. Reliability is concerned with estimating, preventing, and managing increased rates of lifetime design uncertainty as well as failure hazards. Though stochastic characteristics define as well as impact dependability, some experts on reliability believe that mathematics and statistics are also important. Some key RAM aspects include component quality, design considerations, inverter reliability, monitoring and maintenance, weather considerations, and system redundancy. Focusing on reliability and maintainability throughout the lifecycle of a grid-connected PV system, you can maximize its efficiency, longevity, and return on investment while minimizing operational disruptions. Some important methods/ways to improve RAMS includes regular inspections, data monitoring, proper installation, and quality assurance, use quality components and adhere to industry standards during system installation, system redundancy.

Statistics alone will not help you uncover the core reason. Almost all training and writing on the subject emphasize these characteristics while ignoring the fact that the range of uncertain situation renders statistical approaches for forecast and assessment mostly worthless. The three stages will be observed in this method which are explained below.

3. Predictive and Preventive Maintenance Tools

In order to identify irregularities in your operations and possible defects in processes and equipment so that you may correct them before they fail, proactive maintenance is a method that uses data processing tools and procedures. With predictive maintenance, the maintenance frequency may ideally be kept as low as practical to minimize unexpected reactive repairs and save money by not conducting too many preventative maintenance.

Preventive maintenance is indeed the routine, periodic repair of assets and machinery to maintain their functionality and prevent expensive unplanned downtime brought on by unforeseen equipment failure. Before a problem occurs, planning and scheduling equipment repairs is essential to a successful maintenance approach. Keeping track of prior inspections and equipment servicing is another essential component of an effective preventative maintenance plan. Preventive maintenance seems to be the routine, periodic maintenance of assets and machinery to maintain their functionality and prevent expensive unplanned downtime brought on by unforeseen equipment failure. Before a problem occurs, planning and scheduling equipment repairs are essential to a successful maintenance approach. Keeping track of prior inspections and equipment servicing is another essential component of an effective preventative maintenance plan.

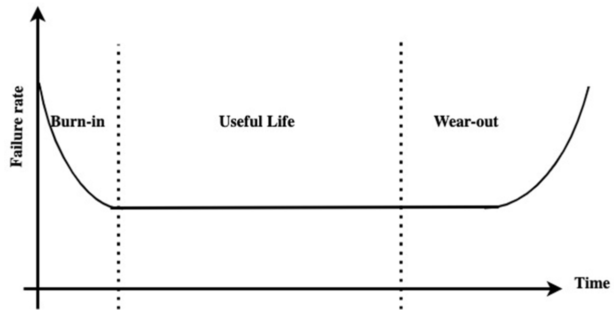
The precise amount of preventative maintenance required will vary based just on PV components and the task being performed. In the business world, standards are used to help specify periodic maintenance so that things don't break down too soon. These recommendations will also specify the sort of assessment or maintenance required. A preventative maintenance program, ideally, should provide proactive maintenance by following manufacturer or standard recommendations, instead of having to resort to maintenance operations when a component has actually begun to fail.

3.1. Models of reliability and availability for photovoltaic plants

The dependability analysis is a technique for calculating the likelihood of success of PV components or their capacity to carry out their functions over a time period Δt under specific operating and environmental conditions. However, there are a few prerequisites for this study, which are briefly discussed below.

The rate of failure λ is used to express the likelihood that such a thing will break down within a specific time frame. As a result, it offers quantifiable data on a device's failure frequency, which is stated in terms of the set of failures for every time unit. Additionally, the rate of failure changes depending on the component's stage of life; therefore, it is not constant across time. A device's life cycle is often broken down into three phases, namely, burn-in, usable life, and wear-out. Figure 1 displays the bathtub curve, a common profile of such failure rate in terms of time. After production, a component is exposed to validation testing, although unwanted failures, known as early failures, will occur owing to producing flaws and design problems that are not discovered in the testing stage. In the first phase, the failure rate is high and quickly declining. If no early failures happen, the component continues to function throughout its useful life; at this point, its failure probability has reached its lowest point, and only random failures are possible. The failure rate can be taken for granted at this point. Due to usage and deterioration, the probability of failure grows quickly over the wear-out phase. Components are considered in the current work to function for the

Figure 1
Time-dependent bathtub shape (curve) of a generic component



duration of their useful lives with a steady rate of failure. This presumption leads to the following exponential model, which is utilized to calculate the dependability (reliability) variable R at any given time t:

$$R(t) = e\wedge(-\lambda t) \tag{1}$$

The mean time to failure, or MTTF, seems to be a measure used for unrepairable components or for devices that are completely replaced rather than fixed since doing so is more cost-effective as well as takes less time overall. The anticipated amount of time until a component fails is known as the MTTF. In contrast, it is preferable to fix repairable parts rather than replace them entirely. The predicted time between two consecutive failures for these devices is quantified by the mean time between failures (MTBF).

These variables enable reliability comparisons between systems made up of various components. Repairable parts can be considered to restore their full functionality following repair, which is a reliability function equivalent to 1, if they fail in the same failure mode over their useful life. In this case, their MTBF is assumed to be comparable to their MTTF. An equation below may be used to estimate it:

$$MTTF = \int 0\infty e^{-\lambda t} dt \tag{2}$$

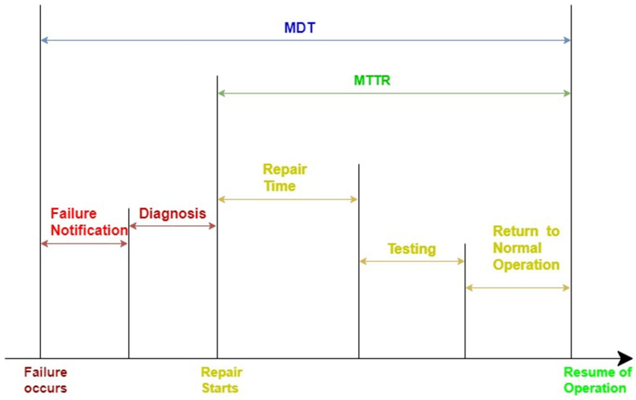
The MTTF can be considered to be equal to 1/λ if components are functioning at the end of their useful lives. By using the data from the MTTF, it is possible to plan preventative maintenance for components and hence increase dependability. In the event of a complicated system with several similar components, it is possible to calculate the reliability with Reliability of each individual component reduce the failure likelihood of grouped similar items Ri by beginning with the device's reliability and proceeding as follows:

$$Ri(t) = e^{-mi.\lambda i.t} \tag{3}$$

where λi is the equivalent rate of failure of a single device and mi is the number of similar units for every type of component.

When there is a breakdown, the MTTR and mean downtime (MDT) give information on how quickly maintenance procedures are carried out. Specifically, the MTTR measures the typical amount of time needed to fully restore a component, whereas the MDT measures the typical amount of time between a device's breakdown and return to normal functioning. Delays brought on by failure detection, diagnostic, logistical, or administrative concerns are thus included in MDT in addition to MTTR. The distinction between both the MTTR and also the MDT is seen in Figure 2. It is reasonable to presume that these numbers are similar under proper maintenance procedures. Increased stock levels of replacement parts may be used to cut down on repair times, and scheduling routine inspections of devices only with the greatest failure rates may be a useful strategy for cutting down on MDT.

Figure 2
Mean repair and downtime times for a common component



The capability of availability A is the part (proportion) of operating time in which the component is completely functional, that is, capable of performing its function when called upon. The ratio of a component's uptime to its lifespan, or availability, varies from 0% to 100%. The component's entire operational time is specifically expressed in the second term, whereas maintenance downtime and other sources of performance issues are not included in the numerator. Starting with the MTTF as well as the MDT, the availability could be determined in the following manner:

$$A = \frac{MTTF}{MTTF\ +\ MDT} \tag{4}$$

If the system's operating time is at least four or five times greater than its MDT, this equation is correct.

Reliability block diagrams establish a logical function structure of each and every component, security equipment, electronic circuitry, connections, and other components based on the design and architecture of the PV system. Due to the absence of redundant components, all of the components in the reliability schematic diagram (RBD) suggested design are connected in series, as illustrated in Figure 3.

3.2. Exponential distribution

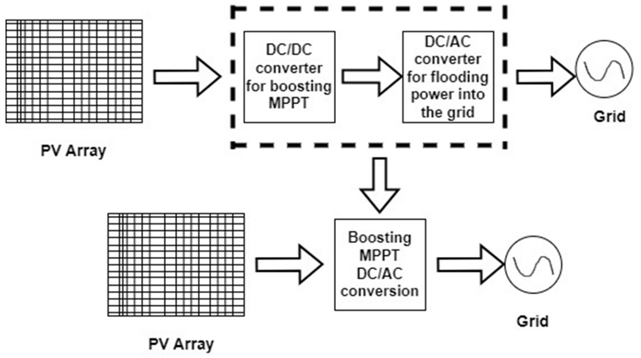
Most frequently, reliability analysis is done using the exponential distribution. As one of the features of the device during its useful lifetime, it consistently fails or poses a risk. It has a probability distribution, cumulative distribution function failure rate function, and reliability function, much $\ln[1 - f(x)] = -\left(\frac{x}{\alpha}\right)^{\beta}$ as other functions.

$$P(s) = e^{-\lambda t} \tag{5}$$

$$PDF = \frac{dR(t)}{dt} = e^{-\lambda t} \tag{6}$$

Modeling data sets with values larger than "0," such as failure data, may be done using the Weibull analysis approach. Weibull analysis may be used in a variety of industrial settings, including product life

Figure 3
PV system block diagram for reliability



prediction, reliability comparison, statistically establishing warranty policy, and proactive management of spare parts inventories, just to mention a few. In fact, dependability and obtaining high reliability have practically become synonymous with Weibull analysis approaches. However, while life analysis of data is a crucial component of the puzzle, it is not sufficient in and of itself to provide trustworthy goods.

Using actual failure returns data collected in the field, the Weibull distribution statistics might be used to estimate the rate of failure over time using this approach. One of the lifespan distributions that is most frequently utilized in reliability engineering is the Weibull distribution. It is a flexible distribution that may adopt the traits of other well-known distributions depending on the value of the shape parameter (β); it is also known as the slope parameter since ß is the slope inside the lines regression chart of Ln (Age) against Ln [Ln($R(t)$)]. The two-parameter Weibull distribution statistic depending on the scale as well as shape parameters and omitting the location parameter is sufficient in more general circumstances. Consequently, the density function of probabilities takes the shape shown below:

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

From the foregoing, one might construct the Weibull reliability function, which is defined as follows:

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)} \tag{8}$$

The probability density function $f(t)$ to reliability function $R(T)$ ratio is the Weibull failure rate function $\lambda(T)$:

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \tag{9}$$

The parameters β and η need to be determined in the aforementioned equation to calculate the rate of failure over time. The Weibull cumulative function of distribution may be reshaped to take on the familiar appearance of a straight line with some work: $Y = mx + b$

$$f(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{10}$$

$$1 - f(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{11}$$

$$\ln[1 - f(x)] = -\left(\frac{x}{\alpha}\right)^{\beta} \tag{12}$$

$$\ln\left(\frac{1}{1 - f(x)}\right) = \left(\frac{x}{\alpha}\right)^{\beta} \tag{13}$$

$$\ln\left[\ln\left(\frac{1}{[1 - f(x)]}\right)\right] = \beta \ln\left(\frac{x}{\alpha}\right) \tag{14}$$

$$\ln\left[\ln\left(\frac{1}{[1 - f(x)]}\right)\right] = \beta \ln - \beta \ln \alpha P(s) = e^{-\lambda t} \tag{15}$$

It is evident from comparing this equation to the straightforward equation for a line that the left equation's right side correlates to Y, lnx to X, β to m, and $-\beta$ ln α to b. As a result, the estimate for such Weibull β parameter during the linear regression process is derived directly from the line's slope. Calculate the estimate for the parameter using the following:

$$\alpha = e^{-\left(\frac{b}{\beta}\right)} \tag{16}$$

The factors governing form and size are modifiable in this distribution. Failure may become more frequent over time, less frequent with time, or remain constant over time:

$\beta < 1$; failure rate of decreasing time
$\beta = 1$; constant failure
$\beta > 1$; failure rate of increasing time

3.3. The failure mode and effect analysis (FMEA)

Failure modes and effects analysis (FMEA), a tried-and-true semi-qualitative reliability engineering technique, discovers failure modes and their effects on system component and other system components by methodically examining the simulation model on a component-by-component basis. It can assist with logistical assistance, testability, safety, fault tolerance design, and similar tasks.

FMEA, an inductive as well as conservative system reliability technique, is used in this instance to analyze a solar system. A system is a complicated collection of parts and subparts that communicate with one another through disciplinary and technological interfaces. FMEA analyzes each system's subcomponent individually with the goal of identifying the different failure modes that can impact each part, as well as their causes and effects on both the part and the system as a whole. Along with the final conclusions and applicable rating scales, the entire FMEA study is given.

The data for all the components is shown in Table 1 and Figure 4 displays the system and components considered. The data is collected based on the number of components used in a particular month. The components of The Grid linked Photovoltaic Solar systems to be considered are PV module, diode, insulated-gate bipolar transistor (IGBT), circuit breaker, inverter, and transformer.

4. Discussion

The results for each analysis (from diverse literature) are shown below. Table 2 indicates all the reliability for each component of a photovoltaic system. Table 3 shows their failure rate. Figures 5 and 6 depict the graph which are done after the reliability analysis of the data collected. The failure rate with respect to months is shown in Figure 5 while Figure 6 is the reliability of the components considered.

Table 1
Quantities of components used for each month

Month	PV modules	Diode	IGBT	Circuit breaker	Controller	Inverter	Transformer
January	194	28	12	17	8	24	2
February	195	24	14	15	9	25	2
March	189	22	17	14	7	34	3
April	195	18	20	15	9	25	2
May	192	25	26	16	6	18	4
June	193	16	24	17	7	42	2
July	195	23	22	13	8	45	3
August	198	25	15	14	6	27	2
September	196	24	25	15	9	27	1
October	189	23	16	12	10	29	2
November	190	19	23	14	8	43	3
December	191	20	25	18	9	32	2

Table 2
Reliability of the components

Month	PV modules	Diode	IGBT	Circuit breaker	Controller	Inverter	Transformer
January	99.25281	99.10404	99.25281	99.4018	99.1536	99.10404	99.1536
February	98.57032	97.70671	98.72816	98.49149	98.2554	98.17682	98.17682
March	97.42377	97.33612	98.30454	98.03947	96.98634	96.81193	97.07367
April	96.85066	96.17507	98.01987	97.14165	95.31338	95.6954	96.17507
May	91.28351	90.62863	94.62959	92.38551	87.6341	88.05575	90.19466
June	86.93582	85.42768	87.85346	87.24063	79.09662	81.34263	84.24003
July	78.00479	72.71664	80.57353	79.70802	68.89408	70.01925	75.92684
August	65.96803	68.11314	68.99059	68.99059	60.70161	62.67547	69.43355
September	58.37981	64.74589	62.98334	69.37109	56.79056	54.48744	65.19418
October	55.01304	62.62535	57.44168	60.84747	53.06779	53.45126	57.02959
November	52.07423	55.71059	55.29432	51.68513	50.15761	49.78283	54.06409
December	46.56132	46.92592	47.6637	46.19956	46.19956	46.56132	46.92592

Table 3
Each component with their corresponding failure rate for each month

Month	PV modules	Diode	IGBT	Circuit breaker	Controller	Inverter	Transformer
January	0.0015	0.0018	0.0010	0.0012	0.0017	0.0018	0.0017
February	0.0019	0.0029	0.0015	0.0019	0.0022	0.0023	0.0023
March	0.0029	0.0030	0.0019	0.0022	0.0034	0.0036	0.0033
April	0.0032	0.0039	0.0020	0.0029	0.0048	0.0044	0.0039
May	0.0038	0.0041	0.0023	0.0033	0.0055	0.0053	0.0043
June	0.0040	0.0045	0.0037	0.0039	0.0067	0.0059	0.0049
July	0.0041	0.0059	0.0040	0.0042	0.0069	0.0066	0.0051
August	0.005	0.0060	0.0058	0.0058	0.0078	0.0073	0.0057
September	0.0078	0.0063	0.0067	0.0053	0.0082	0.0088	0.0062
October	0.0083	0.0065	0.0077	0.0069	0.0088	0.0087	0.0078
November	0.0087	0.0078	0.0079	0.0088	0.0092	0.0093	0.0082
December	0.0098	0.0097	0.0095	0.0099	0.0099	0.0098	0.0097

Weibull distribution analysis is also performed to know the general reliability of the components of solar power generation. As seen in Figure 7, a model ($y = 0.3297\times - 2.6776$) is developed through the plot generated to know how reliable the components the system comprises. The Weibull model contains slope parameter (β) and scale parameter (η); these are used to estimate all the reliability or dependability of the equipment of the systems. The components are 80% reliable.

Figure 4
PV The simplified PV system diagram displaying the main and minor components taken into account during the analysis

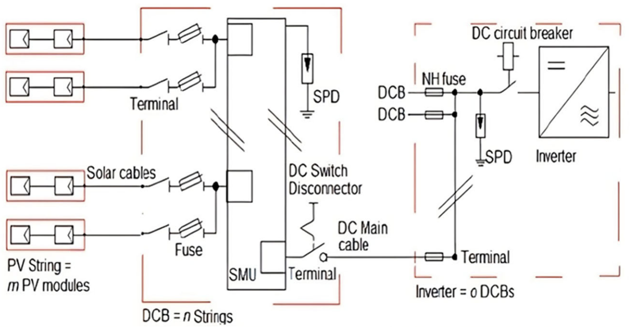


Figure 5
Failure rate for each month

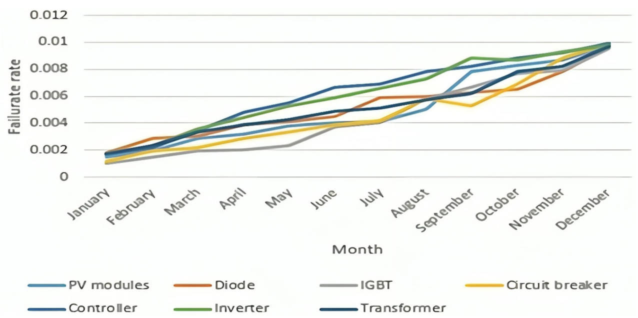
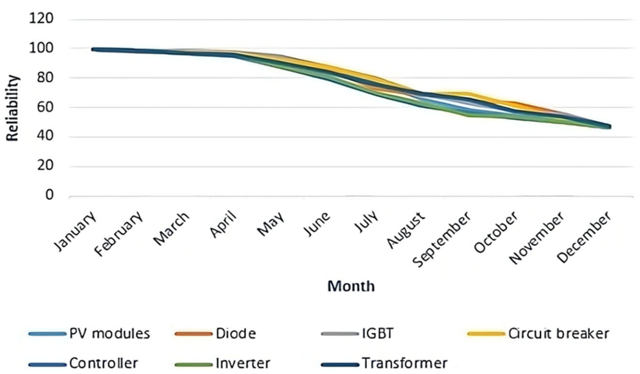


Figure 6
Reliability of each component



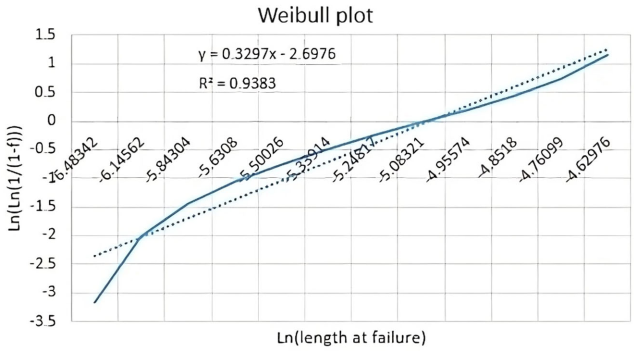
$\alpha = \eta = 3476$
$\beta = 0.3297$

When β is >1, the Weibull distribution represents a system with an increase in failure rate.

The average time in hours is 42 h; therefore, $R(t) = 0.8$ or 80%.

The reliability of all the components is 0.8 or 80%.

Figure 7
Weibull distribution plot



5. Conclusion

The reliability of solar PV systems that are connected to the grid is being evaluated from past related works in the study. This study's primary goal is to evaluate solar PV panel components' dependability. Vast data is collected for each component; the usage of PV modules, controllers, inverters, transformers, and others is employed. The reliability study is carried out to ascertain the system's reliability and failure rate. Weibull analysis is also done where an equation is modeled to know the general reliability of the system components, which is about 80%. In other words, the system is reliable by 80%.

The reliability of solar PV grid-connected systems is a significant factor in the successful deployment and operation of renewable energy systems. The study has highlighted the importance of identifying the failure modes and maintenance strategies that affect the performance of these systems.

The study has shown that the reliability of the system depends on the reliability of the individual components, including solar panels, inverters, and batteries. The failure modes of the system include environmental factors, manufacturing defects, and wear and tear. Therefore, regular maintenance and monitoring are essential to ensure the reliable operation of the system.

The study has also shown that the use of predictive maintenance techniques can help to improve the reliability of the system by detecting potential issues before they cause system failure. Predictive maintenance can also help to optimize maintenance schedules, reducing downtime and costs associated with system maintenance.

In conclusion, the results of this study can be used to develop effective maintenance strategies that will improve the reliability of these systems and ensure the stable operation of the power system.

Acknowledgment

The author is grateful to AAES for the opportunity to publish with the journal.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Samuel O. Obatola: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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How to Cite: Obatola, S. O. (2024). Reliability Overview of Grid-Connected Solar PV System: A Review. *Archives of Advanced Engineering Science*. https://doi.org/10.47852/bonviewAAES42023083