An Improved Method for Examining Solar PV Module Failure and Reliability Rate

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DOI: https://doi.org/10.51583/IJLTEMAS.2025.1407000072

Received: 22 June 2025; Accepted: 30 June 2025; Published: 11 August 2025

Abstract- Failure, in general, refers to a situation where the system's performance is significantly impaired, usually dropping below a preset level, such as 80% of its nominal power output. This degradation is caused by a variety of factors, including physical damage, manufacturing defects, and environmental factors. The ability of the PV system to continuously generate electricity over its anticipated lifespan, even in the face of changing environmental conditions, is referred to as reliability. This includes weather resistance, performance, and the system's capacity to continue operating without significant malfunctions. A new method for examining the failure and dependability rate of a solar PV module was examined in this study. The method includes a reliability model called linear degradation model. A PV reliability model was designed based on degradation. On evaluating the model, it was applied to a practical case based on state-of- the-art parameter of crystalline silicon PV technology. This model uses time-dependent power variability and measured degradation rates to produce reliable data, including relevant and tenable power warranties. Examining the reliability and failure of the monocrystalline DSP 210 and polycrystalline SPP 280W PV modules was part of the strategy. With monocrystalline DSP 210, the computed power was 191.134 watts, whereas with polycrystalline DSP 210, it was 267.8 watts. Comparing them to the calculated power for the same model demonstrates their relative reliability. The cells' dependability indicates that they are reliant on the amount of solar radiation present during a specific time of day. Analytical tests and testing revealed that the panels' failure rate was significantly higher in some months than their reliability rate. The bright sunlight over those months was the cause of that.

Keywords: Peak Sun Hour, Solar PV model, short circuit and Open circuit.

I. Introduction

When a PV module fails, it causes a power degradation that cannot be undone by regular operation or poses a safety risk. A merely aesthetic problem is not regarded as a PV module failure since it does not bear the repercussions of (1) or (2). When a PV module fails in circumstances it typically encounters, it is covered under warranty [1]. In this report, a problem that results from poor management or the local environment is not regarded as a "failure." We provide a few samples here. Authors in [2] said that soiling of the module or a failure brought on by lightning are not regarded as PV module failures. The operator must deal with the soiling issue, and lightning is a force majeure event that the module is not intended to manage [3]. However, if the module is designed for severe snow load, then flaws brought on by the heavy snow load are regarded as module failure. The majority of PV module failures fall into one of three categories: wearout, midlife, or infant failures. Many PV modules exhibit light-induced power degradation (LID) immediately after installation in addition to these module faults. The rated power displayed on the PV module is typically modified by the anticipated standardized saturation power loss resulting from the LID failure, which happens regardless [4]. When the saturation power loss is equal to or less than anticipated, it equally happens. Infant mortality problems happen early in a PV module's life; a defective PV module can cost a lot of money to make and install because the installer has the responsibility for these failures. The majority of PV modules experience wear and tear [5]. The best-case yield study is based on this scenario, which also establishes the cost-effectiveness of PV modules that operate properly. When PV modules reach the end of their useful lives, wear failures happen. They establish a PV module's maximum operating life. The working life of a PV module power drops under a certain level, which is typically defined between 80% and 70% of the initial power rating [6]. A new method for examining the failure and dependability rate of a solar PV module was examined in this study. The method will include a reliability model based on degradation. A PV reliability model was designed based on degradation. On evaluating the model, it was applied to a practical case based on state-of- the-art parameter of crystalline silicon PV technology. This model uses time-dependent power variability and measured degradation rates to produce reliable data, including relevant and tenable power warranties.

Related Works

Several failure case studies have demonstrated how the problem statement for this study was formulated. A variety of literary works were examined. Below are a selection of the literature. According to [7], presentation on PV Durability and Reliability Issues, initial PV qualification tests, including those required by the IEC and UL, among others, are neither meant to or able to forecast long-term performance. Consequently, the use of accelerated environmental testing (AET) and accelerated life testing (ALT) for PV module and system service life prediction (SLP) has evolved. With the exception of real-time 25-year testing, of course, no test tool can guarantee that a module will operate correctly in an environment for more than 25 years. A 30-year module life and the testing procedure that they feel is necessary to get such a prediction are defined by [8]. They do not, however, think that such a prediction can be produced using a universal test (or set of tests). Although they can test for many things, they don't think any PV module that

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

is submitted for testing can be certified for 30 years. John Wohlgemuth of BP Solar claims that the majority of their crystalline silicon PV modules are currently covered by a 25-year warranty. Even though the modules must be exposed to the elements for 25 years, we can't wait that long to observe how they function. No BP/Solarex module has been operational for more than a decade. Only 15 years have passed since the first 20-year warranty modules were introduced.

Basic Parameter of Solar Pv Cell

A PV cell's electrical properties are typically shown as a relationship between the cell voltage and power as well as a relationship between the cell voltage and current. Nonetheless, a number of electric parameters are crucial for characterizing the PV cell's functioning. These electric quantities include the cell voltage, current, and power at the maximum power point (VMPP, IMPP, and PMPP, respectively), the cell voltage under open circuit conditions (VOC), and the cell current under short circuit conditions (ISC) [9].

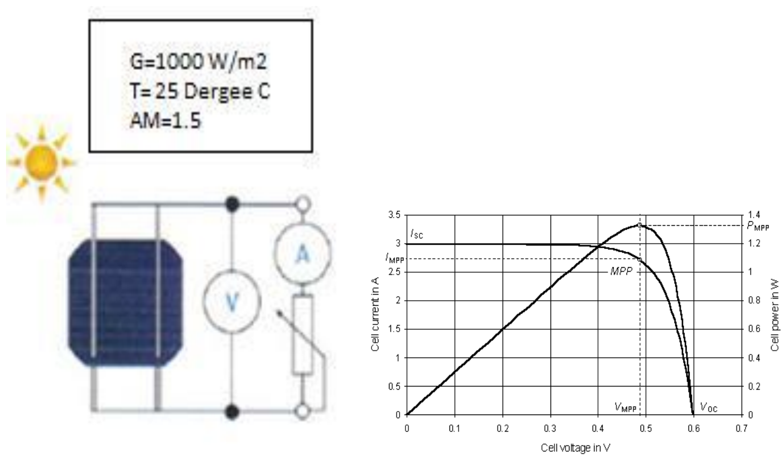

Figure 1: Current–voltage and power–voltage solar cell characteristics

Short Circuit Current (I_{SC})

Short circuit current is the maximum possible current in the circuit, at zero voltage. In other words, when there is negligible electrical load in the circuit. This case occurs by connecting the positive and negative terminals together. The short circuit current is directly proportional to the available sunlight.

Open Circuit Voltage (V_{OC})

Open circuit voltage is the maximum voltage, at zero current. In other words, open circuit voltage represents the maximum possible voltage value, which occurs when a huge load is connected to the circuit or in case of no load.

Maximum Power Point (P_{MPP}) In case of short circuit or open circuit operating points, no power is generated. As a result, the operating point should fall into the range of the maximum power output of PV cell. This operating point is determined by choosing the correct value of the connected load.

The maximum power output is defined as the multiplication of the voltage and the current at the MPP:

$$P_{MPP} = V_{MPP} \times I_{MPP} \quad (1)$$

Where V_{MPP} and I_{MPP} are voltage and current, the values that gives the maximum operating power. MPP is the rate of the unit by Wp (watt peak).

Fill Factor (FF)

The fill factor is an indicator of the quality of the PV cell. The sharpness of the knee in an I-V curve (e.g. Figure 1) indicates how well a (p-n) junction is manufactured [10]. The maximum value of the fill factor is one, which is theoretical value only. The maximum practical value in silicon is 0.88. FF is defined as the ratio between the maximum generated power at MPP and the maximum theoretical power (I_{sc} multiply by Voc).

$$FF = \frac{P_{max.practical}}{Pmax.theorotical} = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} \quad (2)$$

For a good I-V curve profile with fill factor close to unity, the current should stay constant while the voltage increases till the operating point reach the knee of the curve. After that point, the current of PV cell should also gradually decrease.

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Efficiency of Solar Cell

Only part of the solar radiation incident on the solar cell is converted to electricity. The conversion efficiency of PV cell is defined as "the ratio between the produced electrical power and the amount of incident solar energy per second"

The equation of solar cell power conversion efficiency is:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{max} \times V_{max}}{\text{Incident solar radiation} \times \text{Area of solar cell}} \quad (3)$$

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{I_t \times A_c} \quad (4)$$

Where I_{max} and V_{max} are the current and voltage for maximum power, corresponding to solar intensity. It illustrates the relationship between the FF and the efficiency of the cell.

Effect of Solar Radiation on Efficiency

We can safely assume that the short circuit current is proportional to the intensity of radiation. Also, expression for Voc can be written as

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_o} + 1\right) = \frac{kT}{q} \ln\left(\frac{I_L}{I_o}\right) \quad (5)$$

Using expression no 5 the expression for cell efficiency can be written as:

$$\eta = \frac{I_{sc}\, V_{OC}\, FF}{P_{in}} = \frac{n I_L \frac{kT}{q} \ln\left(\frac{I_L}{I_o}\right) FF}{P_{in}} \quad (6)$$

Where P_{in} is intensity of solar radiation and n is the factor accounting for radiation intensity (wherein n=1 for one sun, n=0.5 for half sun or half radiation intensity, etc.). Here, dependency of FF on radiation is not considered. From equation 6 one can say that as the radiation intensity decreases, the efficiency of solar cell should decrease. This will happen because of decrease in V_{OC} with decrease in I_L. Following the same line, the cell efficiency increases if the radiation intensity is increased beyond 1 sun intensity.

Effect of Increasing Temperature

As the temperature rises, the semiconductor material's band gap will contract. A greater portion of the light spectrum can be used when the band gap is reduced because more photons will have the energy to excite an electron to the conduction band. The short-circuit current will rise as a result [11]. For silicon, a rise of 0.06%/K is a frequently used value. Since it is easier to migrate between the valence and conduction bands at higher temperatures, more and more electrons and holes are able to move freely within the materialAs a result, the recombination rate rises and, since it is constrained, the open-circuit voltage falls. About -0.3%/K is the reduction for silicon cells. As the temperature rises, the fill factor FF falls and is only a function of the open circuit voltage to the first order. By -0.15%/K, FF falls for a typical silicon cell. The efficiency is proportional to FF, which causes it to drop by -0.4%/K. Therefore, keeping the cells as cold as possible is crucial, particularly in concentrator systems where excessive temperatures may result from improper system design that ignores cooling [12].

Knowing how much sunlight is available at a specific area at a given time is crucial for designing photovoltaic systems. Solar brightness (or radiation) and solar isolation are the two widely used techniques to describe solar radiation. The instantaneous power density, expressed in kW/m2, is the sun radiance. From 0 kW/m2 at night to a maximum of roughly 1 kW/m2, the sun radiance fluctuates during the day. The location and local weather have a significant impact on solar radiance [13]. Global and/or direct radiation measurements made at various points during the day make up solar radiance measurements. A pyranometer, which measures global radiation, or a pyrheliometer, which measures direct radiation, are used to take the measurements. In well-established locations, this data has been collected for more than twenty years.

Using a sunlight recorder is an alternate technique for monitoring solar radiation that is less precise but also less costly. The number of hours in a day when the sunshine is above a specific level (usually 200 mW/cm2) is measured by these sunshine recorders, sometimes called Campbell-Stokes recorders [14]. By comparing the recorded number of sunshine hours with those derived from calculations and taking into account many correction factors, data gathered in this manner may be used to calculate the solar isolation. A final method to estimate solar isolation is cloud cover data taken from existing satellite images. Solar isolation is a more popular type of radiation data utilized in system design, even though solar irradiance is the most frequently observed. The total amount of sun energy received at a specific area during a given time period is known as solar isolation, and it is frequently expressed in kWh/(m2 day). Solar isolation and solar irradiance are both measured in power density units (the "hours" in the numerator and the "day" in the denominator for solar isolation are time measurements), but they are not the same thing. Solar isolation is the instantaneous solar irradiance averaged over a specific time period. Simple PV system designs often employ solar isolation data, but more complex PV system performance calculations that determine the system performance throughout the day use sun radiance data [15]. Solar isolation can also be expressed in units of MJ/m^2 per year and other units and conversions are given in the unit's page.

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Solar radiation for a particular location can be given in several ways including:

- Typical mean year data for a particular location
- Average daily, monthly or yearly solar isolation for a given location
- Global isoflux contours either for a full year, a quarter year or a particular month
- Sunshine hours data
- Solar Isolation Based on Satellite Cloud-Cover Data
- Calculations of Solar Radiation Top of Form
- The power incident on a PV module depends not only on the power contained in the sunlight, but also on the angle between the module and the sun. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the PV module is perpendicular to the sun). However, as the angle between the sun and a fixed surface is continually changing, the power density on a fixed PV module is less than that of the incident sunlight [16].
- The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The

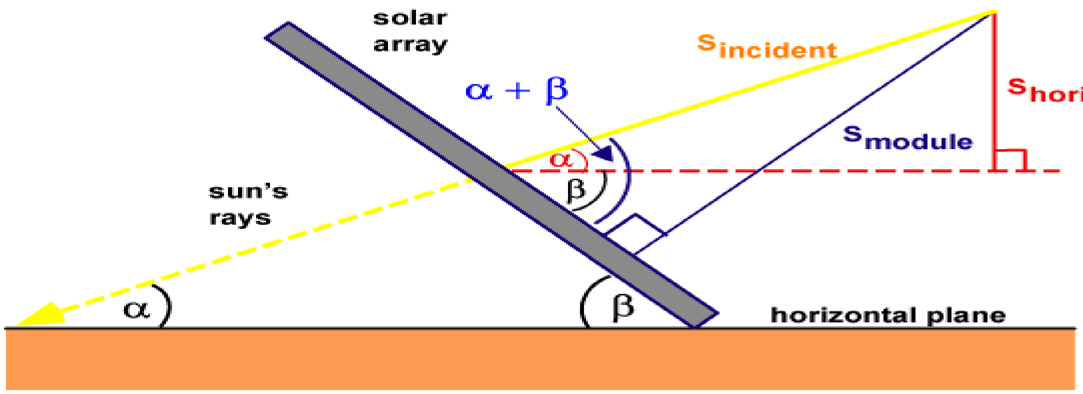

Figure 2: Solar Incidence on a plane

following figure shows how to calculate the radiation incident on a tilted surface (S_{module}) given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun ($S_{incident}$).

- radiation measured perpendicular to the sun ($S_{incident}$).
- Tilting the module to the incoming light reduces the module output.
- The animation shows the calculation of the various isolations. In each case the length of the vector gives the relative intensity of the radiation.
- The equations relating S_{module}, S_{horiz} and $S_{incident}$ are:

$$\delta = 23.45^\circ \sin\left[\frac{360}{365}(284 + d)\right] \tag{7}$$

$$\alpha = 90 - \phi + \delta \tag{8}$$

$$S_{horizontal} = S_{incident} \sin \alpha \tag{9}$$

$$S_{module} = S_{incident} \sin(\alpha + \beta) \tag{10}$$

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$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin \alpha} \quad (11)$$

where

α is the elevation angle; and

β is the tilt angle of the module measured from the horizontal.

The elevation angle has been previously given as:

where φ is the latitude; and

δ is the declination angle previously given as:

where d is the day of the year. Note that from simple math (284+d) is equivalent to (d-81) which was used before. Two equations are used interchangeably in literature.

The following active equations show the calculation of the incident and horizontal solar radiation and that on the module. Enter only one of S_{module}, S_{horiz} and $S_{incident}$ and the program will calculate the others.

The tilt angle significantly affects the amount of solar energy that strikes a surface. For a fixed tilt angle, the tilt angle equaling the location's latitude yields the highest power over a complete year. A higher percentage of light is used in the summer by lower title angles, whilst steeper tilt angles are best suited for heavy winter loads. As a function of latitude and module angle, the simulation below determines the maximum amount of solar insolation. The amount of solar radiation that strikes a slanted module is known as the module power. The horizontal is used to calculate the module tilt angle [17]. A module that precisely follows the sun would receive incident power, which is the solar energy perpendicular to the sun's rays. The power received by a module that lies flat on the ground is known as "horizontal power," which is the result of solar radiation hitting the ground. Since these values do not account for the impacts of cloud cover, they should be viewed as the highest values that may be found at the specific site. In the northern hemisphere, the module is presumed to face south, and in the southern hemisphere, north. For some angles, the light is incident from the rear of the module and in these cases the module power drops to 0.

Since the module is flat on the ground at a module tilt of 0°, the module power and power on horizontal are equal, as seen in the animation above. The module is nearly vertical at an 80° inclination. With the exception of situations in which the values are equal and the module is perpendicular to the sun's beams, the module power is smaller than the incident power. The module faces south in the Northern Hemisphere and north in the Southern Hemisphere due to its equator orientation [18]. The module is turned to face the other direction as it travels from the Northern to the Southern Hemisphere (latitude = 0°), causing the module power curve to flip.When the light is incident from the rear of the module the Module Power drops to zero. Try setting the latitude to your location and then varying the module tilt to see the effect on the amount of power received throughout the year.

A basic system analysis can easily be conducted using the average daily solar radiation at a place in a given month, even though TMY data is frequently utilized for PV system modeling. Both horizontal and perpendicular measurements of the measuring surface to the solar radiation (corresponding to a PV system that tracks the sun) are possible ways to convey this data. To calculate the amount of solar radiation available to a PV module, an extra angular dependence must be included to account for the module's tilt in either scenario.

Peak Sun Hours

One term for "peak sun hours" is the average daily solar isolation, expressed in kWh/m2 per day. A location's solar isolation would be referred to as "peak sun hours" if the sun were to shine at its brightest for a specific number of hours [19] . The average daily solar isolation and the number of peak sun hours are numerically equal because the peak solar radiation is 1 kW/m2. An area that receives 8 kWh/m2 per day, for instance, can be considered to have received 8 hours of sunlight at a rate of 1 kW/m2. It is helpful to be able to determine the peak solar hours because PV modules are frequently rated at an input value of 1kW/m2.

Modelling of Solar Cell

In this chapter the most commonly used solar cell model is introduced and the problem of model parameter determination based on the five-parameter model is addressed. This is followed by simplified analytic formulae describing the five-parameter model for diagnostic purposes.

Solar PV Model

The standard five parameter model of SPV module is shown in Figure 2.

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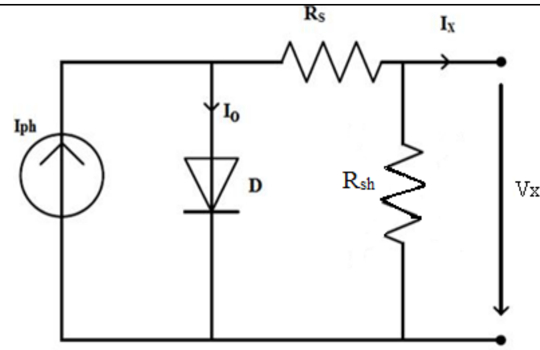

Figure 3: Electrical Equivalent Circuit model of single diode SPV module

A solar cell is basically a p-n semiconductor junction, when exposed to light, a current proportional to solar irradiance is generated. The solar cell is modeled as a constant current source I_{ph}, the photovoltaic current is proportional to the ambient irradiance level and to the temperature of the panel. To allow for losses, a series (R_s) and parallel resistance (R_{sh}) are commonly included in the circuit. In this model, the parallel resistance was neglected in order to simplify the model [20].

The diode, D represents the PN junction of the PV solar cells. During darkness, the solar cell is not an active device, it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However if it is connected to an external supply(large voltage) it generates a current I_0 called diode current or dark saturation current. V_X and I_X are the output voltage and output current of the solar panel.

Modeling PV Reliabilty

The Linear Degradation Model was used to model the reliability of both Monocrystalline and Polycrystalline solar PVs.

Assumes uniform linear loss over time, which is often observed in field data.

Degradation Function:

P(t)=P0−αtP(t) = P_0 - \alpha tP(t)=P0−αt

Where α\alphaα is the annual degradation (e.g., 0.8% of P0P_0P0 per year)

Reliability Criterion:
A system is considered reliable if P(t)≥PthresholdP(t) \geq P_{threshold}P(t)≥Pthreshold for the system lifetime.

On applying time-to-failure analysis of PV modules/components.

Reliability Function gives

R(t)=e−(t/η)βR(t) = e^{-(t/\eta)^\beta}R(t)=e−(t/η)β

Where:

η\etaη: Characteristic life

β\betaβ: Shape parameter (β < 1: early failures; β = 1: random; β > 1: wear-out failures).

On using accelerated lifetime testing of PV modules,

Reliability Function gives

R(t)=e−(t/η)βR(t) = e^{-(t/\eta)^\beta}R(t)=e−(t/η)β

Where:

η\etaη: Characteristic life

β\betaβ: Shape parameter (β < 1: early failures; β = 1: random; β > 1: wear-out failures).

Modeling Failure Rate of a PV System

This model assumes a constant probability of failure over time, typically used during the useful life phase of a product.

Equation gives

Failure rate:

λ(t)=λ0\lambda(t) = \lambda_0λ(t)=λ0

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Reliability function:

R(t)=e−λ0tR(t) = e^{-\lambda_0 t}R(t)=e−λ0t

MTTF (Mean Time To Failure):

MTTF=1λ0\text{MTTF} = \frac{1}{\lambda_0}MTTF=λ01

Solar Output Power

Output Power from Solar Panel in Watts

$P_X = V_X * I_X$ (12)

V_X = Solar Panel Output Voltage in volts..

I_X = Solar Panel Output Current in Amps.

$I_X = I_{SC} * C_{TI} * C_{SI}$ (13)

I_{SC} = Short Circuit Current in Standard Test Condition(from manufacturer data sheet).

C_{TI} = Temperature correction factor for current.

$C_{TI} = 1 + \beta_T * \alpha_T * (T_X - T_C) / S_C$ (14)

α_T = Normalized current Temperature coefficient.

$\alpha_T = \frac{k_i}{I_{SC}} = \frac{\text{Temperature coefficient of } I_{SC} \text{ (A/°C)}}{I_{SC}\text{(A)}}$ (15)

k_i = Temperature coefficient of I_{SC} (A/°C) (from manufacturer data sheet).

β_T = Normalized voltage Temperature coefficient.

$\beta_T = \frac{k_V}{V_{OC}} = \frac{\text{Temperature coefficient of } V_{OC} \text{ mV/°C}}{V_{OC}\text{ (V)}}$ (16)

k_V = Temperature coefficient of V_{OC} mV/°C (from manufacturer data sheet).

V_{OC} = Open Circuit Voltage (from manufacturer data sheet).

T_X = Variable Temperature (From Temperature data Sheet)

T_C = 25°C = (25+273)K = 298K = Temperature under Standard Test Condition.

C_{SI} = Radiation correction factor for current.

$C_{SI} = 1 + \frac{(S_X - S_C)}{S_C}$ (17)

S_X = Variable radiation (From Radiation data sheet)

S_C = $1000 w/m^2$ = Radiation under Standard Test Condition.

Applying correction factor with respect to temperature and radiation, the panel output volt is,

$V_{CX} = V_{OC} * C_{TV} * C_{SV}$ (18)

C_{TV} = Temperature correction factor for voltage.

$C_{TV} = 1 + \beta_T * (T_C - T_X)$ (19)

C_{SV} = Radiation correction factor for voltage.

$C_{SV} = 1 + \beta_T * \alpha_T * (S_X - S_C)$ (20)

R_S = Series resistance of panel in Ω

$= 0.1 * \frac{V_{OC}}{I_{SC}}$ (21)

Actual panel output voltage across load point is

$V_X = V_{CX} - (I_X * R_S)$ (22)

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Failure Rate

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

$$\text{Failure Rate} = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} \quad (23)$$

Specimen Calculation of Failure Rate and Reliability:

The failure of DSP 210 Mono Crystalline Solar Panel and were calculated SPP-280W-24 poly Crystalline Solar Panel

DSP 210D Mono Crystalline Solar Panel:

Failure Rate = λ = $\frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}}$ **and Reliability = R =** $e^{-\lambda t}$

If no of Failures = 8 at n = 900, then

Failure Rate = $\lambda_8 = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} = \frac{8}{12 * 1}$ = **0.6667**

Reliability = $R_8 = e^{-\lambda t} = e^{-0.6667*1} = 0.5134$

If no of Failures = 4 at n = 1050, then

Failure Rate = $\lambda_{1050} = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} = \frac{4}{12 * 1}$ = **0.3333**

Reliability = $R_{1050} = e^{-\lambda t} = e^{-0.3333*1} = 0.7165$

If no of Failures=3 at n=1200, then

Failure Rate = $\lambda_{1200} = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} = \frac{3}{12 * 1}$ = **0.25**

Reliability = $R_{1200} = e^{-\lambda t} = e^{-0.25*1} = 0.7788$

If no of Failures=1 at n=1350 and 1500, then

Failure Rate = $\lambda_{1350,\,1500} = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} = \frac{1}{12 * 1}$ = **0.08333**

Reliability = $R_{1350,\,1500} = e^{-\lambda t} = e^{-0.08333*1} = 0.9200$

If no of Failures=0 at n=1650, then

Failure Rate = $\lambda_{1650} = \frac{\text{Total number of failures}}{\text{Total number of samples} * \text{time interval}} = \frac{0}{12 * 1}$ = **0**

Reliability = $R_{1650} = e^{-\lambda t} = e^{-0*1} = 1.0000$

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SPP-280W-24 Poly Crystalline Solar Panel:

Failure Rate = λ = $\frac{\text{Total number of failures}}{\text{Total number of samples * time interval}}$ **and Reliability = R** = $e^{-\lambda t}$

If no of Failures=6 at n=750, then

Failure Rate = $\lambda_{700} = \frac{\text{Total number of failures}}{\text{Total number of samples * time interval}} = \frac{6}{12 * 1} = 0.5$

Reliability = $R_{750} = e^{-\lambda t} = e^{-0.5*1} = 0.6065$

If no of Failures=3 at n=900, then

Failure Rate = $\lambda_{900} = \frac{\text{Total number of failures}}{\text{Total number of samples * time interval}} = \frac{3}{12 * 1} = 0.25$

Reliability = $R_{900} = e^{-\lambda t} = e^{-0.25*1} = 0.7788$

If no of Failures=1 at n=1050 and 1200, then

Failure Rate = $\lambda_{1050,\,1200} = \frac{\text{Total number of failures}}{\text{Total number of samples * time interval}} = \frac{1}{12 * 1} = 0.6667$

Reliability = $R_{1050,\,1200} = e^{-\lambda t} = e^{-0.08333*1} = 0.9200$

If no of Failures=0 at n=1350, then

Failure Rate = $\lambda_{1350} = \frac{\text{Total number of failures}}{\text{Total number of samples * time interval}} = \frac{0}{12 * 1} = 0$

Reliability = $R_{1350} = e^{-\lambda t} = e^{-0*1} = 1.0000$

Table 2: Failure rate and Reliability analysis

No of failures	Failure Rate (λ)	Reliability (R)
0	0	1.0000
1	0.0833	0.9200``
2	0.1667	0.8464

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3	0.2500	0.7788
4	0.3333	0.7165
5	0.4166	0.6593
6	0.5000	0.6065
7	0.5833	0.5580
8	0.6667	0.5134
9	0.7500	0.4723
10	0.8333	0.4346
11	0.9167	0.3998

Graphical Results

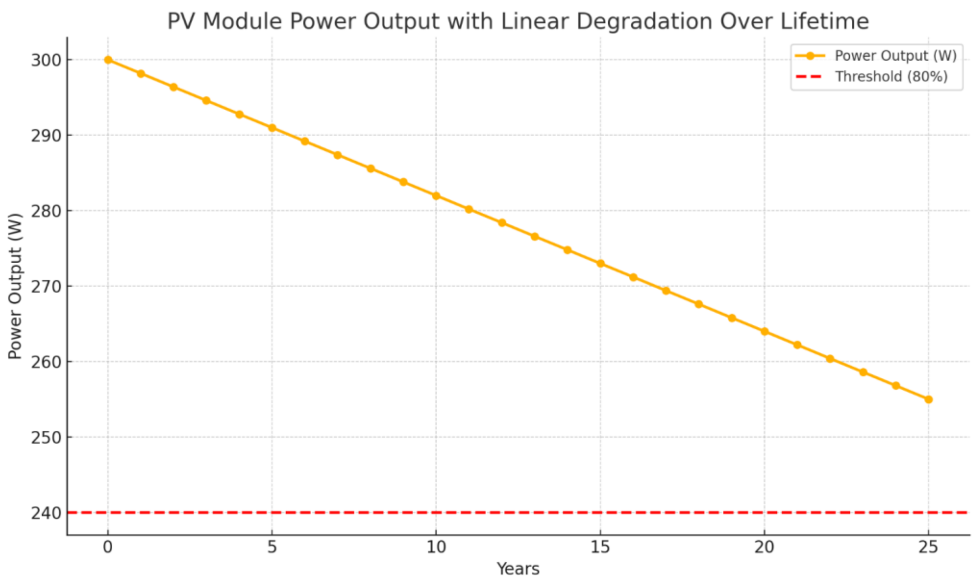
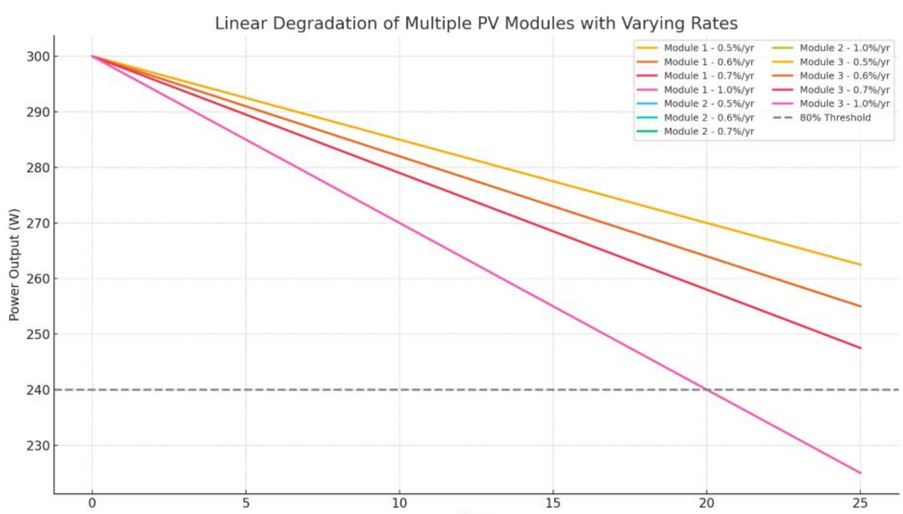


Figure 3: PV power output with linear degradation

Here is the graph showing the linear degradation of a 300W solar PV module over 25 years. The red dashed line represents the 80% power threshold, which is commonly used to define the end of useful module life.



ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

Here's the graph showing linear degradation of a 300W solar PV module across multiple units (3 modules) with different annual degradation rates (0.5%, 0.6%, 0.7%, and 1%).

Each curve represents a different module-rate combination. The dashed line shows the 80% power threshold. This helps visualize how varying degradation rates impact performance over 25 years.

Conclusion

If a PV module's power output drops by more than 20% after 30 years in its intended application, it is no longer functional. Furthermore, 95% of the modules in the area will succeed, therefore "a high probability" or something similar is used. According to the accessible data sheet, the monocrystalline (DSP 210) cell's manufacturer-rated power is 210 watts, whereas the computed power is 191.134 watts. The polycrystalline (SPP 280W) has a rated power of 280 watts, but the estimated power, taking into account all the characteristics, is 267.80 watts. When comparing these two figures, it is evident that the models are reasonably dependable under ideal circumstances. It will be concluded that Mono 210D is the most dependable solar cell overall. The cells' dependability indicates that they are reliant on the amount of solar radiation at a specific time of day. The optimal PV module is the monocrystalline (DSP 210) since it is most dependable. According to the experiment and analytical investigations, there were months when the panel's failure rate was significantly higher than its reliability rate. The bright sunlight over those months was the cause of that.

Recommendation

The reliability and failure analysis of PV system should be done using different PV modules other than DSP 210 and SPP 280 PV module.

References

1. Dunlop, E.D.; Halton, D.; Ossenbrink, H.A.; 20 years of life and more: where is the end of life of a PV module?, Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE Proceedings 2005, Page(s): 1593 - 1596.
2. Wohlgemuth .J, “Reliability of PV Systems, Reliability of Photovoltaic Cells, Modules, Components and Systems,” edited by Neelkanth G. Dhere, Proc. of SPIE ,Vol. 7048, 704802-1, (2008).
3. Wohlgemuth, John H., 2003.Long Term Photovoltaic Module Reliability,NCPV and Solar Program Review Meeting 2003, NREL/CD-520-33586 pp 179-183, http://www.physics.unc.edu/~cecil/laptopStuff/33586015.pdf
4. Osterwald, C. R., and T. J. McMahon.. History of accelerated and qualification testing of terrestrial photovoltaic modules: A literature review. Progress in Photovoltaics 2009: Research and Applications 17, no. 1: 11-33.
5. T. McMahon, G. Jorgensen, R. Hulstrom. “Module 30 Year Life: What Does it Mean and Is It Predictable/Achievable?,” National Renewable Energy Laboratory,Conference: National Center for Photovoltaics Program Review, Denver, CO (US), 04/17/2000--04/19/2000. 2000 Apr 11, http://www.osti.gov/bridge//product.biblio.jsp?query_id=0&page=0&osti_id=755637
6. Patil, R. B., Khalkar, A., Al-Dahidi, S., Pimpalkar, R. S., Bhandari, S., & Pecht, M. (2024). A reliability and risk assessment of solar photovoltaic panels using a failure mode and effects analysis approach: A case study. Sustainability, 16(10), 4183.
7. Pimpalkar, R., Sahu, A., Patil, R. B., & Roy, A. (2023). A comprehensive review on failure modes and effect analysis of solar photovoltaic system. Materials Today: Proceedings, 77, 687-691.
8. Sonawane, P. R., Bhandari, S., Patil, R. B., & Al-Dahidi, S. (2023). Reliability and criticality analysis of a large-scale solar photovoltaic system using fault tree analysis approach. Sustainability, 15(5), 4609.
9. Abunima, H., & Teh, J. (2020). Reliability modeling of PV systems based on time-varying failure rates. IEEE Access, 8, 14367-14376.
10. Sharma, V., & Chandel, S. S. (2013). Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review. Renewable and sustainable energy reviews, 27, 753-767.
11. Jordan, D. C., Marion, B., Deline, C., Barnes, T., & Bolinger, M. (2020). PV field reliability status—Analysis of 100 000 solar systems. Progress in Photovoltaics: Research and Applications, 28(8), 739-754.
12. Perveen, S., Ashfaq, H., & Asjad, M. (2019). Reliability assessment of solar photovoltaic systems based on fuzzy fault tree analysis. Life Cycle Reliability and Safety Engineering, 8, 129-139.
13. Golnas, A. (2012, June). PV system reliability: An operator's perspective. In 2012 IEEE 38th Photovoltaic Specialists Conference (PVSC) PART 2 (pp. 1-6). IEEE.
14. Sayed, A., El-Shimy, M., El-Metwally, M., & Elshahed, M. (2019). Reliability, availability and maintainability analysis for grid-connected solar photovoltaic systems. Energies, 12(7), 1213.
15. Alimi, O. A., Meyer, E. L., & Olayiwola, O. I. (2022). Solar photovoltaic modules’ performance reliability and degradation analysis—a review. Energies, 15(16), 5964.
16. Formica, T. J., Khan, H. A., & Pecht, M. G. (2017). The effect of inverter failures on the return on investment of solar photovoltaic systems. IEEE Access, 5, 21336-21343.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VII, July 2025

17. Alimi, O. A., Meyer, E. L., & Olayiwola, O. I. (2022). Solar photovoltaic modules' performance reliability and degradation analysis—a review. Energies, 15(16), 5964.
18. Lawani, A. O., Adeleke, T. B., & Osuizugbo, I. C. (2024, November). Solar Photovoltaic Systems: A Review of Risks, Fault Detection, and Mitigation Strategies. In 2024 IEEE 5th International Conference on Electro-Computing Technologies for Humanity (NIGERCON) (pp. 1-5). IEEE.
19. Pandit, D., Nguyen, N., Elsaiah, S., & Mitra, J. (2021, September). Reliability evaluation of solar PV system incorporating insolation-dependent failure rates. In 2021 International Conference on Smart Energy Systems and Technologies (SEST) (pp. 1-6). IEEE.
20. Al Mahdi, H., Leahy, P. G., Alghoul, M., & Morrison, A. P. (2024, January). A review of photovoltaic module failure and degradation mechanisms: causes and detection techniques. In Solar (Vol. 4, No. 1, pp. 43-82). MDPI.
21. Shi, X., & Bazzi, A. M. (2015, September). Solar photovoltaic power electronic systems: Design for reliability approach. In 2015 17th European Conference on Power Electronics and Applications (EPE'15 ECCE-Europe) (pp. 1-8). IEEE.