



# Reliability and performance prediction of a small serial solar photovoltaic system for rural consumption using the Gumbel-Hougaard family copula

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Received: 3 June 2021 / Accepted: 21 October 2021 / Published online: 11 November 2021  
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## Abstract

The current study looks into the dependability and performance of a solar photovoltaic system that is configured in series. The system's performance is measured using system strength indicators such as reliability, availability, mean time to failure, and cost measures. The system is made up of four subsystems: a 3-out-of-5 panel, a charge controller, a 2-out-of-3 battery bank, and an inverter. In contrast to some industrial and manufacturing systems, the system is assumed to operate at full capacity. In the current study, failure is classified as complete or incomplete. A complete failure occurs when any of the subsystems fails, whereas an incomplete failure occurs when a unit in the panel subsystem or battery bank fails. The system is analyzed using the linear differential-difference equation, supplementary variable technique, Gumbel-Hougaard family of copula to obtain expressions of reliability measures of determining system strength such as availability, reliability, mean time to failure (MTTF), and profit function. To illustrate the obtained results and to analyze the effect of various system parameters, numerical examples are provided. The current study is beneficial to areas with low energy consumption, such as schools and homes, in alleviating some of the challenges they face.

**Keywords** Copula · Solar panel · Availability · Parallel · Photovoltaic

## Abbreviations

$s$	Laplace transform variable for all expressions
$t$	Time variable on a time scale
$\beta_1$	Failure rate of the unit in subsystem 1
$\beta_2$	Failure rate of the unit in subsystem 2
$\beta_3$	Failure rate of the unit in subsystem 3
$\beta_4$	Failure rate of the unit in subsystem 4
$\phi(x)$	Repair of the failed unit in subsystem 1
$\phi(y)$	Repair of the failed unit in subsystem 2
$\phi(z)$	Repair of the failed unit in subsystem 3
$\phi(h)$	Repair of the failed unit in subsystem 4
$\mu_0(x)$	Copula repair of full failure of unit in subsystem 1
$\mu_0(y)$	Copula repair of full failure of unit in subsystem 2

$\mu_0(z)$	Copula repair of full failure of unit in subsystem 3
$\mu_0(k)$	Copula repair of full failure of unit in subsystem 4

## 1 Introduction

Electricity is one of the primary drivers of development, influencing all aspects of our socioeconomic lives. It can be found in residential, educational, commercial, and industrial structures. Educational sectors, residential buildings, commercial buildings, and so on rely on the National grid as their primary sources of electricity for the majority of Nigerian residential buildings. The primary goal of an electrical utility is to provide its customers with affordable, dependable, and high-quality electricity. The demand for electrical energy has risen rapidly over the decades and continues to rise to this day. Power outages have serious socioeconomic ramifications for utilities and their customers. While much emphasis is placed on supply availability and dependability, which drives businesses and critical utilities such as schools and telecommunication networks, power grid disruption is unpredictable and at times difficult to manage. Failure may not only result in revenue losses for utilities and supply

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disruptions for customers, but it may also have an indirect impact on society and the nation.

The advancement of science and technology is linked to the advancement of manufacturing, and studies on the evaluation or assessment of the reliability and performance of some serial industrial and manufacturing systems under various operating conditions have been conducted. Gulati et al. (2016) presented the performance analysis of the complex system in the series configuration under different failure and repair discipline using copula. Yang and Tsao (2019) have studied reliability and availability analysis of standby systems with working vacations and retrial of failed components. Abubakar and Singh et al. (2019) gave the study of performance assessment of an industrial system through copula linguistic approach. Gahlot et al. (2018) presented a performance assessment of repairable system in the series configuration under different types of failure and repair policies using copula linguistics. Ram and Kumar (2015) have presented the performability analysis of a system under 1-out-of-2: G scheme with perfect reworking.

## 2 Literature review

Numerous researchers have previously presented methods in the field of reliability analysis of solar photovoltaic systems by examining system performance under various conditions. To name a few, Ahadi et al. (2016) proposed a mathematical model for improving photovoltaic system reliability through component reliability improvement. Baschel et al. (2018) discussed the effect of unit reliability on the performance of large-scale photovoltaic systems. The effect of reliability and availability for two inverter configurations is demonstrated using fault tree analysis. Gupta et al. (2020) discussed the operational availability of power plant. Belaout et al. (2018) presented a multiclass adaptive neuro-fuzzy classifier for detecting fault and classification in a photovoltaic array. Benkercha and Moulahourn (2018) proposed an approach using a decision tree algorithm to detect and diagnose the faults in a grid-connected photovoltaic system. Kumar and Saini (2014) studied the profit of solar photovoltaic system incorporating preventive maintenance. Kumar and Saini (2018a) analyzed the availability of marine power plant using the fuzzy method. Kumar and Saini (2018b) discuss the impact of preventive maintenance and repair priority on the profit of a computer system. Kumar et al. (2018) presented stochastic modelling of a non-identical system following Weibull distribution with priority and preventive maintenance. Saini et al. (2021) investigate the reliability of the power generating unit of the sewage treatment plant.

Wang et al. (2021) investigate the reliability and performance of the warm standby system. Cai et al. (2015) dealt with the reliability evaluation of photovoltaic systems with intermittent faults using dynamic Bayesian networks. Three-state Markov model which represents the state transition relationship of no faults, intermittent faults, and permanent faults for the system components is obtained. Chen et al. (2017) proposed a methodology for detecting and diagnosis fault in photovoltaic systems using extreme machine learning. Chiacchio et al. (2018) discuss the performance evaluation of photovoltaic power plant through stochastic hybrid fault tree automation mode. Colli (2015) studied failure mode and effect analysis for photovoltaic systems. Cristaldi et al. (2017) discuss the root cause and risk analysis of photovoltaic balance system failure. Das et al. (2018) focus on metaheuristic optimization-based diagnosis of fault for a photovoltaic system with nonuniform irradiance. Garoudja et al. (2017) proposed a fault-detection approach for detecting of shading of a photovoltaic system based on the direct current by combining the flexibility, and simplicity of a one-diode model.

Because of the non-availability of data of the PV system, the present paper introduced a reliability modelling approach to study the overall performance of the PV system. In this paper, we have introduced a new model of the photovoltaic system consisting of four subsystems namely, panel, inverter, battery bank and control charger. Following Ismail et al. (2021), the units in each subsystem are assumed to have exponential failure and repair time.

The paper is organized into different parts. The introduction portion that focuses on the relevant literature reviewed for the study of the proposed model is defined in Sect. 2. The state description and notation used for the analysis of the proposed model are covered in Sect. 3. Section 4 presents reliability models of the system in which some particular cases are discussed. The paper is concluded with results in Sect. 5.

## 3 State description and assumptions

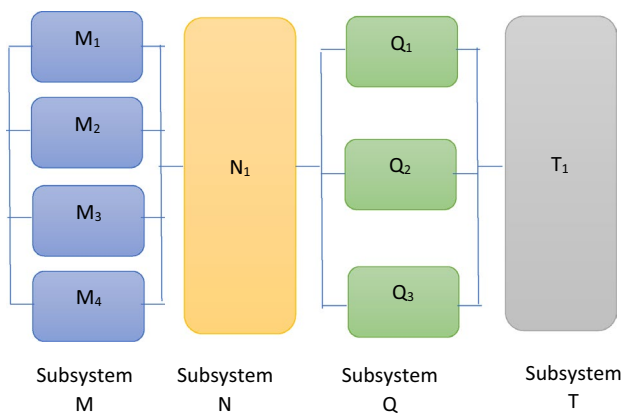
### 3.1 Assumptions

The following are taken throughout the discussion of the model.

1. Initially, both subsystems are in good working condition.
2. Three units from subsystem 1 and two units from subsystem 3 in consecutive are necessary for operational mode.

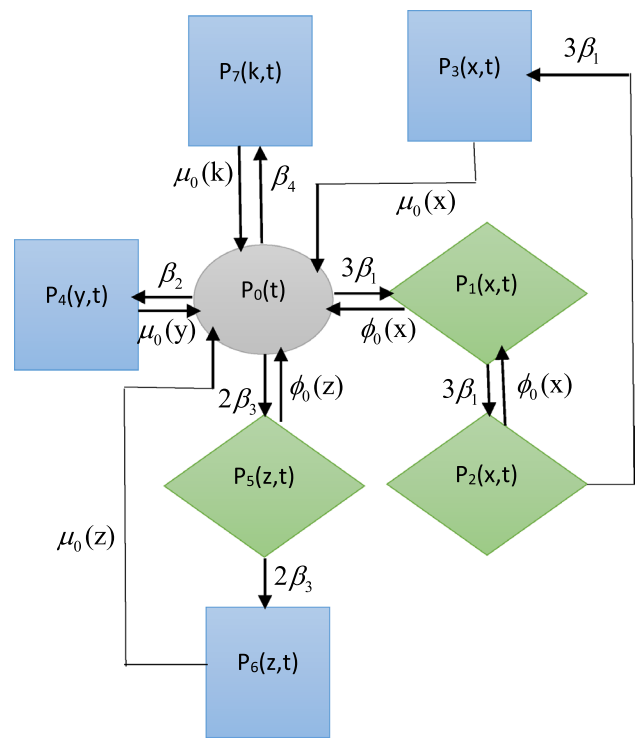
**Table 1** Description of the states of the system

State	Description
$S_0$	Initial state. Unit $M_1, M_2$ and $M_3$ are working. Unit $M_4$ is on Standby mode hotly And the system is in operational condition. Unit $N_1$ in the sub-system N is in a working state. In subsystem Q, the unit $Q_1$ and $Q_2$ are in operation, while $Q_3$ is in hot standby. In subsystem T, the units $T_1$ is on operational state
$S_1$	In this state, the unit $M_1$ failed and under repair. And the elapsed repair time is $(x, t)$ . While the units $M_2, M_3, M_4, N_1, Q_1, Q_2, T_1$ are on operation and $Q_3$ are on standby
$S_2$	The units $Q_1$ has failed. While the units $M_1, M_2, M_3, N_1, Q_2, Q_3,$ and $T_1$ are on operation. While $M_4$ is on standby
$S_3$	In this state, the unit $M_1$ from subsystem 1. And $Q_1$ from subsystem 3 are have failed and are under repair. While the units $M_2, M_3$ and $M_4$ from subsystem 1, $N_1$ from subsystem 2. $Q_2$ and $Q_3$ from subsystem 3. And $T_1$ from subsystem 4 are on operations
$S_4$	The state $S_4$ is a complete failed state due to the failure of subsystem 2
$S_5$	The state $S_5$ is a complete failed state due to the failure of subsystem 1
$S_6$	The state $S_6$ is a complete failed state due to the failure of subsystem 3
$S_7$	The state $S_7$ is a complete failed state due to the failure of subsystem 4



**Fig. 1** Block diagram for the system

- The one unit in subsystem 2 is necessary for operational mode. Also the one units out of one in subsystem 4 are necessary for operational mode.
- The system will be inoperative if three units from subsystem 1 failed. In addition, if two units from subsystem 3 failed.
- The system will also be inoperative if one unit failed from either of subsystem 2 and 4, respectively.
- Failed unit of the system can be repaired when it is inoperative or failed state.
- Copula repair follows a total failure of a unit in the subsystem.
- It is assumed that a repaired system by copula works like a new system and no damage appears during the repair.
- As soon as the failed unit gets repaired, it is ready to perform the task.



**Fig. 2** Transition diagram of the system. ■ Complete failure ◆ Reduced capacity ● Perfect state

## 4 Reliability modelling

### 4.1 Formulation and solution of a mathematical model

By the probability of considerations and continuity of arguments, through Table 1, Figs. 1 and 2 the following set of difference-differential equations are associated with the above mathematical model.

$$\begin{aligned} & \left[ \frac{\partial}{\partial t} + 3\beta_1 + \beta_2 + 2\beta_3 + \beta_4 \right] P_0(t) \\ &= \int_0^\infty \phi(x) P_1(x, t) dx + \int_0^\infty \mu_0(x) P_3(x, t) dx \\ &+ \int_0^\infty \mu_0(y) P_4(y, t) dy + \int_0^\infty \mu_0(x) P_6(z, t) dz \\ &+ \int_0^\infty \mu_0(k) P_7(k, t) dk \end{aligned} \quad (1)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + 3\beta_1 + 2\beta_3 + \phi(x) \right] P_1(x, t) = 0 \quad (2)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + 3\beta_1 + \phi(x) \right] P_2(x, t) = 0 \quad (3)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \mu_0(x) \right] P_3(x, t) = 0 \quad (4)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial y} + \mu_0(y) \right] P_4(y, t) = 0 \quad (5)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial z} + 2\beta_3 + \phi(z) \right] P_5(z, t) = 0 \quad (6)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial z} + \mu_0(z) \right] P_6(z, t) = 0 \quad (7)$$

$$\left[ \frac{\partial}{\partial t} + \frac{\partial}{\partial k} + \mu_0(k) \right] P_7(k, t) = 0 \quad (8)$$

### 4.2 Boundary conditions

$$P_1(0, t) = 3\beta_1 P_0(t) \quad (9)$$

$$P_2(0, t) = 9\beta_1^2 P_0(t) \quad (10)$$

$$P_3(0, t) = 27\beta_1^3 P_0(t) \quad (11)$$

$$P_4(0, t) = 3\beta_2 P_0(t) \quad (12)$$

$$P_5(0, t) = 2\beta_3 P_0(t) \quad (13)$$

$$P_6(0, t) = 4\beta_3^2 P_0(t) \quad (14)$$

$$P_6(0, t) = \beta_4 P_0(t) \quad (15)$$

$$\begin{aligned} & \text{Initial condition } P_0(t) \\ &= 1 \text{ and other transition probability at } t = 0 \text{ are zero} \end{aligned} \quad (16)$$

Taking Laplace transformation of Eqs. (1)–(15) and using the equation with the help of (16), one can obtain

$$\begin{aligned} & [S + 3\beta_1 + \beta_2 + 2\beta_3 + \beta_4] \bar{P}_0(s) \\ &= 1 + \int_0^\infty \phi(x) \bar{P}_1(x, s) dx + \int_0^\infty \mu_0(x) \bar{P}_3(x, s) dx \\ &+ \int_0^\infty \mu_0(y) \bar{P}_4(y, s) dy + \int_0^\infty \mu_0(x) \bar{P}_6(z, s) dz \\ &+ \int_0^\infty \mu_0(k) \bar{P}_7(k, s) dk \end{aligned} \quad (17)$$

$$\left[ S + \frac{\partial}{\partial x} + 3\beta_1 + 2\beta_3 + \phi(x) \right] \bar{P}_1(x, s) = 0 \quad (18)$$

$$\left[ S + \frac{\partial}{\partial x} + 3\beta_1 + \phi(x) \right] \bar{P}_2(x, s) = 0 \quad (19)$$

$$\left[ S + \frac{\partial}{\partial x} + \mu_0(x) \right] \bar{P}_3(x, s) = 0 \quad (20)$$

$$\left[ S + \frac{\partial}{\partial y} + \mu_0(y) \right] \bar{P}_4(y, s) = 0 \quad (21)$$

$$\left[ S + \frac{\partial}{\partial z} + 2\beta_3 + \phi(z) \right] \bar{P}_5(z, s) = 0 \quad (22)$$

$$\left[ S + \frac{\partial}{\partial z} + \mu_0(z) \right] \bar{P}_6(z, s) = 0 \quad (23)$$

$$\left[ S + \frac{\partial}{\partial k} + \mu_0(k) \right] \bar{P}_7(k, s) = 0 \quad (24)$$

### 4.3 Laplace of the boundary condition

$$\bar{P}_1(0, t) = 3\beta_1 \bar{P}_0(s) \quad (25)$$

$$\bar{P}_2(0, t) = 9\beta_1^2 \bar{P}_0(s) \tag{26}$$

$$\bar{P}_3(0, t) = 27\beta_1^3 \bar{P}_0(s) \tag{27}$$

$$\bar{P}_4(0, t) = 3\beta_2 \bar{P}_0(s) \tag{28}$$

$$\bar{P}_5(0, t) = 2\beta_3 \bar{P}_0(s) \tag{29}$$

$$\bar{P}_6(0, t) = 4\beta_3^2 \bar{P}_0(s) \tag{30}$$

$$\bar{P}_7(0, t) = \beta_4 \bar{P}_0(s) \tag{31}$$

Solving Eqs. (18)–(24) with the help of boundary condition (25)–(31) and applying the below-shifting properties of Laplace:

$$\int_0^\infty [e^{-sx} \cdot e^{-\int_0^x f(x)dx}]dx = L\left\{\frac{1 - \bar{S}_f(x)}{S}\right\} = \frac{1 - \bar{S}_f(x)}{S} \tag{32}$$

$$\int_0^\infty [e^{-sx} \cdot f(x)e^{-\int_0^x f(x)dx}]dx = L\{\bar{S}_f(x)\} = \bar{S}_f(s) \tag{33}$$

$$\bar{P}_1(S) = \bar{P}_1(0, S) \left\{ \frac{1 - \bar{S}_\phi(S + 3\beta_1 + 2\beta_3)}{S + 3\beta_1 + 2\beta_3} \right\} \tag{34}$$

$$\bar{P}_2(S) = \bar{P}_2(0, S) \left\{ \frac{1 - \bar{S}_\phi(S + 3\beta_1)}{S + 3\beta_1} \right\} \tag{35}$$

$$\bar{P}_3(S) = \bar{P}_3(0, S) \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} \tag{36}$$

$$\bar{P}_4(S) = \bar{P}_4(0, S) \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} \tag{37}$$

$$\bar{P}_5(S) = \bar{P}_5(0, S) \left\{ \frac{1 - \bar{S}_\phi(S + 2\beta_3)}{S + 2\beta_3} \right\} \tag{38}$$

$$\bar{P}_6(S) = \bar{P}_6(0, S) \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} \tag{39}$$

$$\bar{P}_7(S) = \bar{P}_7(0, S) \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} \tag{40}$$

Substituting (25)–(31) in the Eqs. (34)–(40) we have

$$\bar{P}_1(S) = 3\beta_1 \left\{ \frac{1 - \bar{S}_\phi(S + 3\beta_1 + 2\beta_3)}{S + 3\beta_1 + 2\beta_3} \right\} P_0(t) \tag{41}$$

$$\bar{P}_2(S) = 9\beta_1^2 \left\{ \frac{1 - \bar{S}_\phi(S + 3\beta_1)}{S + 3\beta_1} \right\} P_0(t) \tag{42}$$

$$\bar{P}_3(S) = 27\beta_1^3 \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} P_0(t) \tag{43}$$

$$\bar{P}_4(S) = 3\beta_2 \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} P_0(t) \tag{44}$$

$$\bar{P}_5(S) = 2\beta_3 \left\{ \frac{1 - \bar{S}_\phi(S + 2\beta_3)}{S + 2\beta_3} \right\} P_0(t) \tag{45}$$

$$\bar{P}_6(S) = 4\beta_3^2 \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} P_0(t) \tag{46}$$

$$\bar{P}_7(S) = \beta_4 \left\{ \frac{1 - \bar{S}_\mu(S)}{S} \right\} P_0(t) \tag{47}$$

$$\begin{aligned} \bar{P}_0(S) &= \frac{1}{D(S)} \\ \text{where } D(S) &= \left[ [S + 3\beta_1 + \beta_2 + 2\beta_3 + \beta_4] - (3\beta_1 \bar{S}_\phi(S + 3\beta_1 + 2\beta_3) \right. \\ &\quad \left. + 27\beta_1^3 \bar{S}_\mu(S) + 3\beta_2 \bar{S}_\mu(S) + 4\beta_3^2 \bar{S}_\mu(S) + \beta_4 \bar{S}_\mu(S)) \right] \end{aligned} \tag{48}$$

$$\text{But } D(S) \cdot \bar{P}_0(S) = 1 \tag{49}$$

$$\Rightarrow \bar{P}_0(S) = \frac{1}{D(S)} \tag{50}$$

$$\bar{P}_{up}(S) = \bar{P}_0(S) + \bar{P}_1(S) + \bar{P}_2(S) + \bar{P}_5(S) \tag{51}$$

$$\bar{P}_{down}(S) = 1 - \bar{P}_{up}(S) \tag{52}$$

### 5 Analytical study of a model for particular cases

Setting all repairs to 1. i.e.  $\phi(x) = \mu_0(x) = \mu_0(y) = 1$

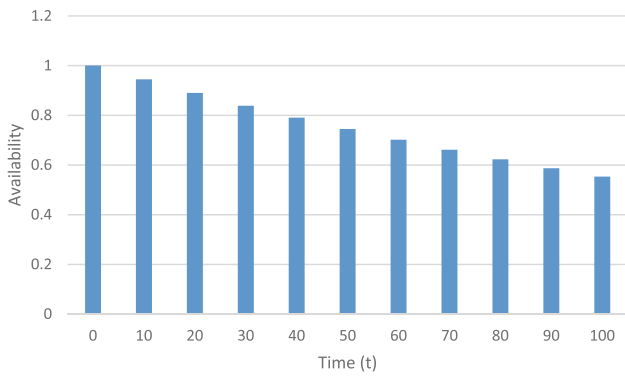


Fig. 3 Availabilities as a function of time

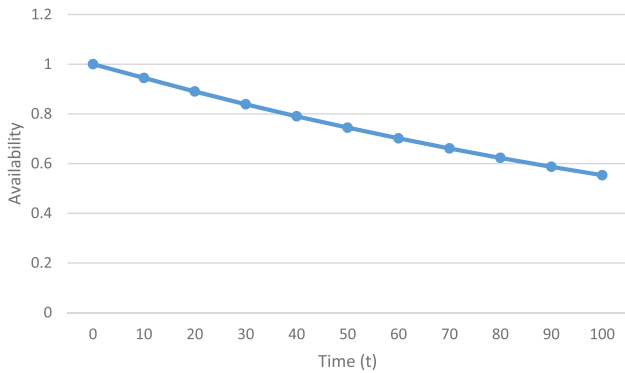


Fig. 4 Availabilities as a function of time

Table 2 Variation of availability with respect to time

Time (t)	$\bar{P}_{up}(t)$	$\bar{P}_{down}(S)$
0	0.9999999998	0.0000000002
10	0.9444604953	0.0555395047
20	0.8899392794	0.1106072060
30	0.8385651973	0.1614348027
40	0.7901568190	0.2098431810
50	0.7445429415	0.2554570585
60	0.7015622448	0.2984377552
70	0.6610627217	0.3389372783
80	0.6229011400	0.3770988600
90	0.5869425358	0.4130574642
100	0.5530597365	0.4469402635

Taking the values of different parameters as  $\beta_1 = 0.001$ ,  $\beta_2 = 0.002$ ,  $\beta_3 = 0.003$  and  $\beta_4 = 0.004$ . In (51) then taking the inverse Laplace transform, we can obtain, the expression for availability as:

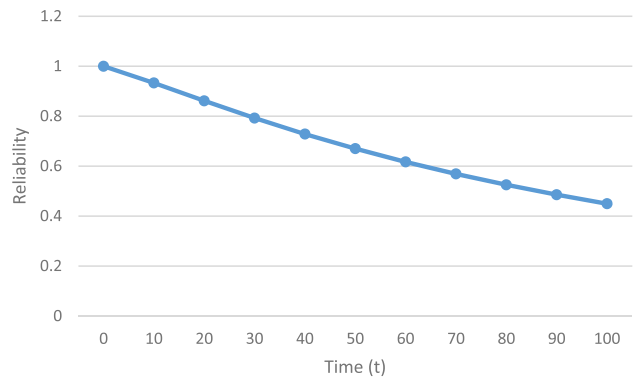


Fig. 5 Reliability as a function of time (t)

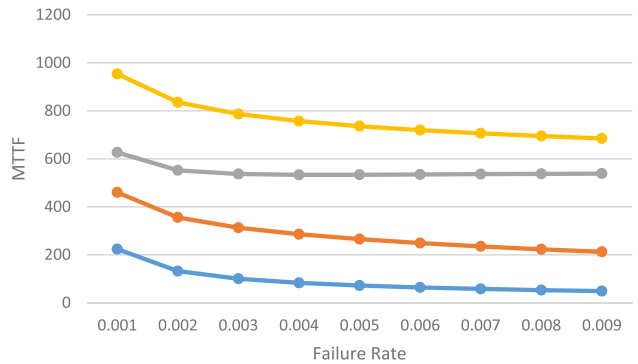


Fig. 6 MTTF as a function of failure rate

$$0.0007500000000e^{-0.003000000000t} + 0.6666666667e^{-0.006000000000t} + 0.3725833333e^{-0.01500000000t} - 0.04000000000e^{-0.09000000000t} \quad (53)$$

For different values of time  $t=0, 10, 20, 30, 40, 50, 60, 70, 80, 90,$  and  $100$ .

Unit of time, we may get different of  $\bar{P}_{up}(t)$  with the help of (53) as shown in Table 1 and corresponding figure.

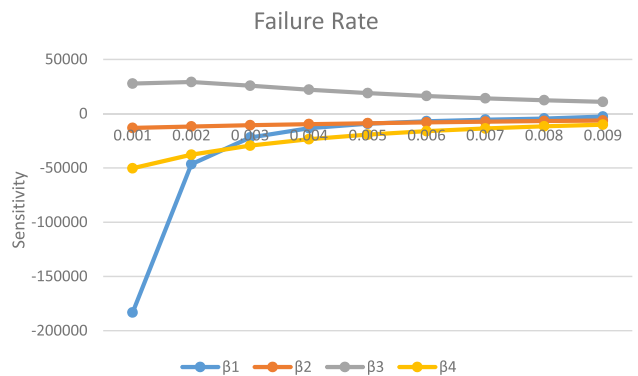


Fig. 7 Sensitivity analysis of the system as a function of failure rate

### 6 Reliability analysis

Taking all repair rate  $\phi(x) = \mu_0(x) = \mu_0(y) = 0$  in Eq. (53) and for the same values of failure rate as  $\beta_1 = 0.001$ ,  $\beta_2 = 0.002$ ,  $\beta_3 = 0.003$  and  $\beta_4 = 0.004$ .

And then taking inverse Laplace transform, one may have the expression for reliability for the system. Expression for the reliability of the system is given as;

$$R(t) = 0.0007500000000e^{-0.003000000000t} + 0.6666666667e^{-0.006000000000t} + 0.3725833333e^{-0.01500000000t} - 0.04000000000e^{-0.09000000000t}$$

**Table 3** Computation of reliability for different values of time

Time (t)	Reliability
0	1.000000000
10	0.9074434835
20	0.8277061126
30	0.7588013693
40	0.6990615674
50	0.6470859537
60	0.6016973111
70	0.5619056663
80	0.5268779367
90	0.4959125388
100	0.4684181454

For different values of time  $t=0, 10, 20, 30, 40, 50, 60, 70, 80, 90,$  and  $100$ .

Unit of time, we may get different values of Reliability that shown in the table.

### 7 Analysis and concluding remark

Through Table 2, Figs. 3 and 4, the results show that the energy availability of the test system is as high as 99.02% in contrast to a time availability of only 90.68%. The rationale behind the results is that any derated states or partial failures of the PV system are counted in the time unavailability. On the other hand, the PV system is still able to generate electricity during derated hours, resulting in relatively higher energy availability.

System’s reliability is much more sensitive with respect to simultaneous failure rate of one unit of the solar panel and one unit of Battery as elaborated in Table 3 and Fig. 5. Model investigated the reliability measures and sensitivity analysis for a system of solar installation work. The result reveals that system reliability is more sensitive with respect to failure rates of the system and MTTF of the system is more sensitive with respect to failure rate of subsystem 1. The Model which consists of  $n$  unit in parallel configuration with a standby unit considered system can fail due to unit

**Table 4** MTTF as a function of failure rate

Failure rate	MTTF $\delta_1$	MTTF $\delta_2$	MTTF $\delta_3$	MTTF $\delta_4$
0.001	223.7907368	236.2235556	166.8005333	327.0787692
0.002	132.0021818	223.7907369	196.1970196	283.4682667
0.003	100.2428800	212.6012000	223.7907368	250.1190588
0.004	83.19730611	202.4773333	247.7158095	223.7907369
0.005	72.10064516	193.2738182	268.2046377	202.4773333
0.006	64.08266668	184.8706087	285.7962057	184.8706087
0.007	57.91187646	177.1676667	301.0020741	170.0809600
0.008	52.96161818	170.0809600	314.2474176	157.4823704
0.009	48.87324030	163.5393846	325.8732903	146.6215172

**Table 5** MTTF sensitivity as a function of failure rate

Failure rate	$\frac{\partial(\text{MTTF})}{\beta_1}$	$\frac{\partial(\text{MTTF})}{\beta_2}$	$\frac{\partial(\text{MTTF})}{\beta_3}$	$\frac{\partial(\text{MTTF})}{\beta_4}$
0.001	-183,255.169	-13,123.53086	27,760.46221	-50,319.81065
0.002	-46,544.66116	-11,778.45983	-29,206.04999	-37,795.76889
0.003	-21,948.1856	-10,630.00600	-25,785.60666	-29,425.77162
0.004	-13,351.55102	-9641.777777	-22,122.68481	-23,556.91966
0.005	-9271.062434	-8785.173552	-18,948.73683	-19,283.55555
0.006	-6956.479304	-8037.852551	-16,320.29701	-16,075.70510
0.007	-5484.759977	-7381.986111	-14,162.17969	-13,606.47680
0.008	-4473.561652	-6803.238401	-12,385.08571	-11,665.36076
0.009	-2693.384842	-6289.976332	-10,911.6587	-10,111.83877



failure, catastrophic failure, and the failure of standby unit and resulted in that system's reliability is more sensitive with respect to battery and charge controller failure. It is concluded that the MTTF of the system is equally sensitive with respect to the failure rate charge controller and distributor of the system as demonstrated in Table 4, Fig. 6 and Table 5, Fig. 7 respectively.

In future, reliability and performance analysis of multi-unit photovoltaic system for consumption of small- and large-scale enterprises is going to be using fuzzy method.

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