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Research Article

Keywords: Solar panels, Photovoltaic, Batteries, Copula, Availability

Posted Date: September 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-939621/v1

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Abstract

The main objective of the present study is to analyze the availability of solar photovoltaic system. The solar photovoltaic system in this paper is simple one consisting of four subsystems namely, solar panel subsystem, charge controller subsystem, batteries subsystem and inverter subsystem. Through the schematic diagram of state of the system, availability model is formulated and Chapman-Kolmogorov differential equations are developed and solved using Gumbel Haugaard family Copula technique. The numerical values for availability, reliability, mean time to failure (MTTF), cost analysis as well as sensitivity analysis are presented. The effects of failure rates to various solar photovoltaic subsystems were developed.

Keywords: Solar panels, Photovoltaic, Batteries, Copula, Availability

1. Introduction


To address the concerns mentioned in earlier work on grid-connected PV system reliability, this study presents a full thorough Copula analysis for all sub-assemblies of grid-connected solar PV systems with a low dependability grid, taking failure specifics and repair intervals into consideration (period of identification and replacement of the PV system). Furthermore, the goal of this work is to explain the dependability of each sub-assembly of grid-connected PV systems. The scope of this study has also been expanded to determine the optimum probability density function for each solar-PV device subassembly's failure rate.

Because data for the PV system is not readily available, the current work uses a reliability modeling technique to investigate the PV system's overall performance. In this work, we provide a novel solar system model that consists of four subsystems: panel, inverter, battery bank, and control charger. The units in each subsystem are considered to have exponential failure and repair times, according to Ismail et al. (2021).

The authors looked at a variety of systems that are related to solar photovoltaic systems. Typically, they haven't paid much attention to their operations when using k-out-of-n: systems, which can be seen in a variety of real-world scenarios. However, in many locations, such as banks, factories, schools, and other communication channels, we see redundancy in subsystems, particularly solar panels, there is provision for another panel to continue to function even when others fail. We have examined this home based modest scaled photovoltaic, with redundancy in the solar panels and batteries alone, in light of this outstanding construction. The setup is series-parallel with a k-out-
of-n: G operation scheme. A flawless state, a degraded state, and a failing state are the three states of the system. When there are k excellent states in the system, the entire system is functioning, but when there are less than k good clients, the system is on the verge of failing completely. The failure of the primary panel is considered as a partial failure, whereas the failure of the redundant ones is treated as a full failure before the primary ones are repaired. Charge controller and inverter failures are total system failures, copula repair is used to quickly restore the system. For varied values of failure and repair rates, the system was evaluated using the supplementary variable technique, and various reliability indices were produced.

![Block Diagram for the System](image)

**Figure 1: Block Diagram for the System**

2. **Table 1: STATE DESCRIPTION AND ASSUMPTIONS**

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₀</td>
<td>Initial state, Unit A₁, B₁, C₁ and D₁ are working. Unit A₂, A₃ and C₂ are on Standby mode hotly. And the system is in operational condition.</td>
</tr>
<tr>
<td>S₁</td>
<td>In this state, the unit A₁ failed and under repair. And the elapsed repair time is (x, t). While the units A₂, B₁, C₁, and D₁, are on operation and the units A₃ and C₂ are on standby.</td>
</tr>
</tbody>
</table>
In this state, the unit \( A_1 \) and \( A_2 \) failed and under repair. And the elapsed repair time is \((x, t)\). While the units \( A_2, B_1, C_1, \) and \( D_1 \), are on operation and the units \( A_3 \) and \( C_2 \) are on standby.

The units \( A_1 \) and \( C_1 \) has failed. While the units \( A_2, B_1, C_2, \) and \( D_1 \), are on operation. While \( A_2 \) and \( A_3 \) are on standby.

In this state, the unit \( A_1 \) and \( A_2 \) from subsystem 1. And \( C_1 \) from subsystem 3 are have failed and are under repair. While the units \( A_3, B_1, \) from subsystem1, \( B_1, \) from subsystem2 \( C_2 \) from subsystem 3 and \( D_1 \) from subsystem 4 are on operations.

The state \( S_5 \) is complete failed state due to the failure of subsystem 2.

The state \( S_6 \) is complete failed state due to the failure of subsystem 1.

The state \( S_7 \) is complete failed state due to the failure of subsystem 3.

The state \( S_8 \) is complete failed state due to the failure of subsystem 4.

**ASSUMPTIONS**

The following assumption are taken throughout the discussion of the model:

1) Initially, both subsystems are in good working condition.

2) One unit from subsystem, subsystem 2, subsystem 3 and subsystem 4 in consecutive are necessary for operational mode.

3) The system will be inoperative if three units from subsystem 1 failed. Also if two units from sub system 3 failed.

4) The system will also be inoperative if one unit failed from either of subsystem 2 and 4 respectively.

5) Failed unit of the system can be repaired when it is inoperative or failed state.

6) Copula repair follows a total failure of a unit in subsystem.

7) It is assumed that a repaired system by copula works like a new system and no damage appears during repair.

8) As soon as the failed the failed unit gets repaired, it is ready to perform the task.

**NOTATIONS**

\( s \) Laplace transform variable for all expressions.
Time variable on a time scale.

Failure rate of the unit in subsystem 1

Failure rate of the unit in subsystem 2

Failure rate of the unit in subsystem 3

Failure rate of the unit in subsystem 4

Repair of the failed unit in subsystem 1

Repair of the failed unit in subsystem 2

Repair of the failed unit in subsystem 3

Repair of the failed unit in subsystem 4

Copula repair of full failure of unit in subsystem 1

Copula repair of full failure of unit in subsystem 2

Copula repair of full failure of unit in subsystem 3

Copula repair of full failure of unit in subsystem 4
FORMULATION AND SOLUTION OF MATHEMATICAL MODEL

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

\[
\left[ \frac{\partial}{\partial t} + Q_1 + Q_2 + Q_3 + Q_4 \right] P_0(t) = \int_{0}^{\infty} \omega_1 P_1(x, t) \, dx + \int_{0}^{\infty} \Theta(y) P_4(y, t) \, dy +
\]
\[
\int_0^\infty \omega_2 P_2(z, t) dz + \int_0^\infty \Theta(k) P_3(k, t) dk + \int_0^\infty \Theta(x) (m) P_3(x, t) dx + \int_0^\infty \Theta(z) P_6(z, t) dz
\] (1)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Phi_1 + \Phi_3 + \omega_1) P_1(x, t) = 0
\] (2)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Phi_1 + \Phi_3 + \omega_1) P_2(x, t) = 0
\] (3)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Theta(x)) P_3(x, t) = 0
\] (4)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial y} + \Theta(y)) P_4(y, t) = 0
\] (5)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial z} + \Phi_1 + \Phi_3 + \omega_3) P_5(y, t) = 0
\] (6)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Theta(z)) P_6(z, t) = 0
\] (7)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Phi_3 + 2\omega_1) P_7(x, t) = 0
\] (8)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Phi_1 + \omega_3) P_8(x, t) = 0
\] (9)

\[
(\frac{\partial}{\partial t} + \frac{\partial}{\partial k} + \Theta(k)) P_9(k, t) = 0
\] (10)

Boundary conditions

\[
P_1(0, t) = \Phi_1 P_0(t)
\] (11)

\[
P_2(0, t) = \Phi_2^2 P_0(t)
\] (12)

\[
P_3(0, t) = (\Phi_1^3 + \Phi_3^2 \Phi_3) P_0(t)
\] (13)

\[
P_4(0, t) = \Phi_2 P_0(t)
\] (14)

\[
P_5(0, t) = \Phi_3 P_0(t)
\] (15)

\[
P_6(0, t) = \Phi_3^2 P_0(t)
\] (16)

\[
P_7(0, t) = 2\Phi_1 \Phi_3 P_0(t)
\] (17)

\[
P_8(0, t) = \Phi_3 \Phi_3 P_0(t)
\] (18)

\[
P_9(0, t) = \Phi_4 P_0(t)
\] (19)

Initial condition \(P_0(t) = 1\) and other transition probability at \(t=0\) are zero

(20)

Taking Laplace transformation of equation (1) – (19) with the help of (20), one can obtain

\[
[s + \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4] P_0(t) = \int_0^\infty \omega_1 P_1(x, s) dx + \int_0^\infty \Theta(y) P_4(y, s) dy +
\]
\[
\int_{0}^{\infty} \omega_3 \tilde{P}_3(z,s)dz + \int_{0}^{\infty} \Theta(k)\tilde{P}_3(k,s)dk + \int_{0}^{\infty} \Theta(x)(m)\tilde{P}_3(x,s)dx + \int_{0}^{\infty} \Theta(z)\tilde{P}_6(z,s)dz
\] (21)

\[
(s + \frac{\partial}{\partial x} + Q_1 + Q_3 + \omega_1)\tilde{P}_1(x,t) = 0
\] (22)

\[
(s + \frac{\partial}{\partial x} + Q_1 + Q_3 + \omega_1)\tilde{P}_2(x,s) = 0
\] (23)

\[
(s + \frac{\partial}{\partial x} + \Theta(x))\tilde{P}_3(x,s) = 0
\] (24)

\[
(s + \frac{\partial}{\partial y} + \Theta(y))\tilde{P}_4(y,s) = 0
\] (25)

\[
(s + \frac{\partial}{\partial z} + Q_1 + Q_3 + \omega_3)\tilde{P}_5(y,s) = 0
\] (26)

\[
(s + \frac{\partial}{\partial z} + \Theta(z))\tilde{P}_6(z,s) = 0
\] (27)

\[
(s + \frac{\partial}{\partial x} + Q_3 + 2\omega_1)\tilde{P}_7(x,s) = 0
\] (28)

\[
(s + \frac{\partial}{\partial x} + Q_1 + \omega_3)\tilde{P}_8(x,s) = 0
\] (29)

\[
(s + \frac{\partial}{\partial k} + \Theta(k))\tilde{P}_9(k,s) = 0
\] (30)

Boundary conditions

\[
\tilde{P}_1(0,s) = Q_1 \tilde{P}_0(s)
\] (31)

\[
\tilde{P}_2(0,s) = Q_3^2 \tilde{P}_0(s)
\] (32)

\[
\tilde{P}_3(0,s) = (Q_1^3 + Q_3^3 \Omega_3)\tilde{P}_0(s)
\] (33)

\[
\tilde{P}_4(0,s) = Q_2 \tilde{P}_0(s)
\] (34)

\[
\tilde{P}_5(0,s) = Q_3 \tilde{P}_0(s)
\] (35)

\[
\tilde{P}_6(0,s) = Q_3^2 \tilde{P}_0(s)
\] (36)

\[
\tilde{P}_7(0,s) = 2Q_1 Q_3 \tilde{P}_0(s)
\] (37)

\[
\tilde{P}_8(0,s) = Q_1^3 Q_3 \tilde{P}_0(s)
\] (38)

\[
\tilde{P}_9(0,s) = Q_4 \tilde{P}_0(s)
\] (39)

Solving equation (22) to (30) with the help of boundary condition (31) to (39) and applying the below shifting properties of Laplace.

\[
\int_{0}^{\infty} \left[ e^{-sx} \cdot e^{-\int_{0}^{x} f(x)dx} \right] dx = L \left\{ \frac{1 - s f(x)}{s} \right\} = \frac{1 - s f(x)}{s}
\] (40)
\[ \int_0^\infty e^{-sx} f(x) e^{-\int_0^x f(x)dx} \, dx = L\{\tilde{S}_f(x)\} = \tilde{S}_f(s) \]  \hspace{1cm} (41)

\[ P_1(S) = Q_1 \left\{ \frac{1 - \tilde{S}_{\omega_1}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (42)

\[ P_2(S) = Q_1^2 \left\{ \frac{1 - \tilde{S}_{\omega_1}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (43)

\[ P_3(S) = (Q_3^3 + Q_1^3 Q_3) \left\{ \frac{1 - \tilde{S}_0(s)}{s} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (44)

\[ P_4(S) = Q_2 \left\{ \frac{1 - \tilde{S}_0(s)}{s} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (45)

\[ P_5(S) = Q_3 \left\{ \frac{1 - \tilde{S}_{\omega_3}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (46)

\[ P_6(S) = Q_3^2 \left\{ \frac{1 - \tilde{S}_0(s)}{s} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (47)

\[ P_7(S) = 2Q_1 Q_3 \left\{ \frac{1 - \tilde{S}_{2\omega_1}(s + \varphi_1)}{s + \varphi_1} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (48)

\[ P_8(S) = Q_3^3 Q_3 \left\{ \frac{1 - \tilde{S}_{\omega_3}(s + \varphi_1)}{s + \varphi_1} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (49)

\[ P_9(S) = Q_4 \left\{ \frac{1 - \tilde{S}_0(s)}{s} \right\} \tilde{P}_0(s) \]  \hspace{1cm} (50)

\[ \tilde{P}_0(S) = \frac{1}{d(S)} \]  \hspace{1cm} (51)

\[ \Rightarrow \tilde{P}_0(S) = \frac{1}{d(S)} \]  \hspace{1cm} (52)

\[ \tilde{P}_{up}(S) = \tilde{P}_0(S) + \tilde{P}_1(S) + \tilde{P}_2(S) + \tilde{P}_5(S) + \tilde{P}_7(S) + \tilde{P}_8(S) \]  \hspace{1cm} (53)

\[ \tilde{P}_{down}(S) = 1 - \tilde{P}_{up}(S) \]  \hspace{1cm} (54)

\[ \tilde{P}_{up}(S) = \left[ 1 + Q_1 \left\{ \frac{1 - \tilde{S}_{\omega_1}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} + Q_1^2 \left\{ \frac{1 - \tilde{S}_{\omega_1}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} + Q_3 \left\{ \frac{1 - \tilde{S}_{\omega_3}(s + \varphi_1 + \varphi_3)}{s + \varphi_1 + \varphi_3} \right\} + 2Q_1 Q_3 \left\{ \frac{1 - \tilde{S}_{2\omega_1}(s + \varphi_1)}{s + \varphi_1} \right\} + Q_3^3 Q_3 \left\{ \frac{1 - \tilde{S}_{\omega_3}(s + \varphi_1)}{s + \varphi_1} \right\} \right] \tilde{P}_0(s) \]  \hspace{1cm} (55)
4. Formulation and Analysis of System Availability

Taking
\[ S_a(s) = \frac{\exp[x^\phi + \{\log \varphi(x)\}^\phi]}{s + \exp[x^\phi + \{\log \varphi(x)\}^\phi]} \],

\( \bar{P}_\phi(s) = \frac{\phi}{s + \phi} \) but \( \phi = 1 \) and \( \varphi_1 = 0.001, \varphi_2 = 0.002, \varphi_3 = 0.003, \varphi_4 = 0.004 \)

And repair rates \( \Theta(x) = \Theta(y) = \Theta(z) = \omega_1(x) = \omega_1(y) = \omega_1(z) = \omega_1(k) = 1 \) in equation (55),

and applying the inverse Laplace transform to (55), the expression for system availability is

\[
\bar{P}_{up}(t) = \left\{ 0.00002208861717 e^{-2.71836026t} + 0.000209099911 e^{-1.000779179t} - 0.000009109003812 + 0.9997779215 - 0.000000072008791910 + 0.00000000090021292210 \right\} (56)
\]

Taking \( t = 0, 10, \ldots, 100 \), availability of the system is obtained and presented in Table 1 below

<table>
<thead>
<tr>
<th>Time (in days)</th>
<th>Availability ( \bar{P}_{up}(t) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00000</td>
</tr>
<tr>
<td>10</td>
<td>0.99439</td>
</tr>
<tr>
<td>20</td>
<td>0.98904</td>
</tr>
<tr>
<td>30</td>
<td>0.98371</td>
</tr>
<tr>
<td>40</td>
<td>0.97842</td>
</tr>
<tr>
<td>50</td>
<td>0.97315</td>
</tr>
<tr>
<td>60</td>
<td>0.96791</td>
</tr>
<tr>
<td>70</td>
<td>0.96270</td>
</tr>
<tr>
<td>80</td>
<td>0.95751</td>
</tr>
<tr>
<td>90</td>
<td>0.95236</td>
</tr>
<tr>
<td>100</td>
<td>0.94723</td>
</tr>
</tbody>
</table>

Figure 3. Availability as function of time
b. Reliability analysis

Taking all repair rate $\Theta(x) = \Theta(y) = \Theta(z) = \Theta(k) = \omega_1(x) = \omega_1(y) = \omega_1(z) = \omega_1(k) = 0$ and for same values of failure rate as $\varphi_1 = 0.0001$, $\varphi_2 = 0.0002$, $\varphi_3 = 0.0003$, $\varphi_4 = 0.0004$

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

<table>
<thead>
<tr>
<th>Time(t)</th>
<th>Reliability R(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00000</td>
</tr>
<tr>
<td>10</td>
<td>0.99204</td>
</tr>
<tr>
<td>20</td>
<td>0.98415</td>
</tr>
<tr>
<td>30</td>
<td>0.97633</td>
</tr>
<tr>
<td>40</td>
<td>0.96858</td>
</tr>
<tr>
<td>50</td>
<td>0.96090</td>
</tr>
<tr>
<td>60</td>
<td>0.95329</td>
</tr>
<tr>
<td>70</td>
<td>0.94575</td>
</tr>
<tr>
<td>80</td>
<td>0.93828</td>
</tr>
<tr>
<td>90</td>
<td>0.93087</td>
</tr>
<tr>
<td>100</td>
<td>0.92353</td>
</tr>
</tbody>
</table>
c. Mean Time to Failure (MTTF) analysis

Taking all repair rate \( \theta(x) = \theta(y) = \theta(z) = \theta(k) = \omega_1(x) = \omega_1(y) = \omega_1(z) = \omega_1(k) = 0 \) in equation (60) and taking limit, as \( x \) tend to zero we obtain the expression for MTTF as:

\[
MTTF = \lim_{x \to 0} P_{up}(S).
\]

Setting the values of failure rate as \( \varphi_2 = 0.002, \varphi_3 = 0.003, \varphi_4 = 0.004 \)

and varying \( \varphi_1 \) one by one respectively as 0.0001, 0.0002, 0.0003, 0.0004, 0.0005, 0.0006, 0.0007, 0.0008, and 0.0009.

Subsequently, we vary \( \varphi_2, \varphi_3 \) and \( \varphi_4 \) respectively by fixing the values of others.

<table>
<thead>
<tr>
<th>Failure Rate</th>
<th>MTTF ( \delta_1 )</th>
<th>MTTF ( \delta_2 )</th>
<th>MTTF ( \delta_3 )</th>
<th>MTTF ( \delta_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>1087.86</td>
<td>250.278</td>
<td>229.458</td>
<td>297.953</td>
</tr>
<tr>
<td>0.002</td>
<td>705.291</td>
<td>208.567</td>
<td>222.482</td>
<td>260.709</td>
</tr>
<tr>
<td>0.003</td>
<td>522.365</td>
<td>182.023</td>
<td>208.567</td>
<td>231.741</td>
</tr>
<tr>
<td>0.004</td>
<td>415.094</td>
<td>162.684</td>
<td>194.152</td>
<td>208.567</td>
</tr>
<tr>
<td>0.005</td>
<td>344.568</td>
<td>147.603</td>
<td>180.750</td>
<td>189.606</td>
</tr>
<tr>
<td>0.006</td>
<td>294.662</td>
<td>135.357</td>
<td>168.678</td>
<td>173.806</td>
</tr>
<tr>
<td>0.007</td>
<td>257.484</td>
<td>25.142</td>
<td>157.905</td>
<td>160.436</td>
</tr>
<tr>
<td>0.008</td>
<td>228.715</td>
<td>116.452</td>
<td>148.304</td>
<td>148.976</td>
</tr>
</tbody>
</table>
d. Sensitivity analysis corresponding to \( (MTTF) \)

The sensitivity in MTTF of the system can be studied through the partial differentiation of MTTF with respect to the failure rate of the system. By applying the set of parameters \( \varphi_1 = 0.001, \varphi_2 = 0.002, \varphi_3 = 0.003, \varphi_4 = 0.004 \), in the partial differentiation of MTTF, one can calculate the MTTF sensitivity as shown in the Table below and corresponding graphs shown in Figure…

![Figure 5. MTTF as function of Failure rate](image-url)

Table 5. MTTF sensitivity as function of failure rate

<table>
<thead>
<tr>
<th>Failure Rate</th>
<th>( \frac{\partial (MTTF)}{\varphi_1} )</th>
<th>( \frac{\partial (MTTF)}{\varphi_2} )</th>
<th>( \frac{\partial (MTTF)}{\varphi_3} )</th>
<th>( \frac{\partial (MTTF)}{\varphi_4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>-500000</td>
<td>-55614.2</td>
<td>2567.81</td>
<td>-42564.6</td>
</tr>
<tr>
<td>0.002</td>
<td>-200000</td>
<td>-31978.9</td>
<td>-12374.4</td>
<td>-32588.6</td>
</tr>
<tr>
<td>0.003</td>
<td>-100000</td>
<td>-22235.0</td>
<td>-14606.6</td>
<td>-25749.0</td>
</tr>
<tr>
<td>0.004</td>
<td>-85098.5</td>
<td>-16893.6</td>
<td>-14013.8</td>
<td>-20856.7</td>
</tr>
<tr>
<td>0.005</td>
<td>-58449.6</td>
<td>-13492.9</td>
<td>-12747.6</td>
<td>-17236.9</td>
</tr>
<tr>
<td>0.006</td>
<td>-42611.4</td>
<td>-11127.6</td>
<td>-11405.3</td>
<td>-14483.8</td>
</tr>
<tr>
<td>0.007</td>
<td>-32437.5</td>
<td>-9385.50</td>
<td>-10162.8</td>
<td>-12341.2</td>
</tr>
<tr>
<td>0.008</td>
<td>-25516.3</td>
<td>-8050.60</td>
<td>-9063.84</td>
<td>-10641.2</td>
</tr>
<tr>
<td>0.009</td>
<td>-20595.5</td>
<td>-6997.48</td>
<td>-8108.04</td>
<td>-9269.64</td>
</tr>
</tbody>
</table>
e. Cost analysis

The expression for the expected profit incurred in \([0,t]\)

\[
E_p(t) = K_2 \int_0^t P_{wp}(t) dt - K_2 t
\]  

Taking fixed values of parameters of equation (56), the subsequent equation (62) follows;

\[
E_p(t) = \{-0.0000159e^{-1.003t} + 0.00371706e^{-2.728442t} + 0.00343665e^{-1.025044t} - 0.0005797e^{-1.0148018t} + 0.99656124e^{-0.000051053} - 0.00311935e^{-1.0060000t}\} - K_2 t
\]

Supposing \(K_1 = 1\) and \(K_2 = 0.1, 0.2..., 0.6\), respectively and varying \(t = 0, 1, 2...10\), units of time, the expected profit calculations are done in Table below.

Table 6: Expected profit as a function of time

<table>
<thead>
<tr>
<th>Time</th>
<th>(E_p(t)) K_2=0.6</th>
<th>(E_p(t)) K_2=0.5</th>
<th>(E_p(t)) K_2=0.4</th>
<th>(E_p(t)) K_2=0.3</th>
<th>(E_p(t)) K_2=0.2</th>
<th>(E_p(t)) K_2=0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>3.9710</td>
<td>4.9710</td>
<td>5.9711</td>
<td>6.9710</td>
<td>7.9710</td>
<td>8.9710</td>
</tr>
<tr>
<td>20</td>
<td>7.8882</td>
<td>9.8882</td>
<td>11.888</td>
<td>13.888</td>
<td>15.888</td>
<td>17.888</td>
</tr>
<tr>
<td>30</td>
<td>11.752</td>
<td>14.752</td>
<td>17.752</td>
<td>20.752</td>
<td>23.752</td>
<td>26.752</td>
</tr>
<tr>
<td>50</td>
<td>19.320</td>
<td>24.320</td>
<td>29.320</td>
<td>34.320</td>
<td>39.320</td>
<td>44.320</td>
</tr>
<tr>
<td>60</td>
<td>23.026</td>
<td>29.026</td>
<td>35.026</td>
<td>41.026</td>
<td>47.026</td>
<td>53.026</td>
</tr>
<tr>
<td>70</td>
<td>26.679</td>
<td>33.678</td>
<td>40.678</td>
<td>47.679</td>
<td>54.679</td>
<td>61.679</td>
</tr>
</tbody>
</table>
Table 2 and Figure 3 demonstrate how the availability and likelihood of failure of the complicated repairable device change over time when failure rates are set at different values. As failure rates are reduced to lower levels, such as $\varphi_1 = 0.0001$, $\varphi_2 = 0.0002$, $\varphi_3 = 0.0003$, and $\varphi_4 = 0.0004$, the availability of the system diminishes with time and eventually stabilizes at the value. As a result, the graphical representation of the model shows that one may reliably portray the future behavior of a complex system at any moment for any given set of parametric parameters. The addition of copula increases the system's dependability substantially, as seen in Table 3 and Figure 4. As the model's graphical depiction demonstrates, any collection of parametric values may be used to forecast the future behavior of a complex system at any moment. Figure 4 of the investigation focused on the system's reliability while a fix is unavailable. When the availability and reliability numbers in Tables 2 and 3 are compared, it is obvious that the device performs significantly better when fixed than when replaced. When all other parameters are maintained...
constant, Table 4 and Figure 5 give the system's mean-time-to-failure (MTTF) with respect to variation in failure rates, $\varphi_1$, $\varphi_2$, $\varphi_3$, and $\varphi_4$. Color graphs (blue, green, pink, and yellow) are used to display the information. The Gumbel-Hougaard family copula is also used to evaluate the system. The study found that including copula substantially enhances the system's reliability.

The paper's analytic section includes a sensitivity analysis of the system. The fluctuation in sensitivity with variation in parameter values is shown in Table 5 and Figure 6.

Fuzzy methods will be used in the future to analyze the reliability and performance of multi-unit solar systems for small and large-scale industrial usage.

References


