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Cost Analysis of Solar Water Pumping System for Small Town Water Supply

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Abstract: This study investigates the economics of a solar water pumping system for usage in small towns. The system consists of two solar panels, an inverter, a water pumping mechanism, and two parallel tanks. Using the transition diagram, a system of first-order linear ordinary differential equations is generated and used to generate a statement of system availability and profit. To validate the expressions of system availability and profit, numerical experiments in the MATLAB software in the form of tables and graphs are utilized. According to the findings, the system's profitability increases as the value of repair rates across all subsystems increases, while it decreases when the value of failure rates across all subsystems increases.

Keywords: reliability, availability, profitability, sensitivity, solar, repairman

1. Introduction

The descriptive and analytical performance of a component or machine can be evaluated using reliability modeling. The term "reliability" refers to a wide range of fundamental and practical concerns. The main purpose of dependability modeling is to maximize available resources under all possible system situations, including profit forecasting. System dependability modeling has received a lot of attention, with separate failure and repair solutions being considered. The consequences of various failures, great, little, and so on, must be considered. There has been a lot of effort done on dependability, and as a result of that work, a cost–benefit analysis of numerous systems has been completed.

In today's technologically advanced world, operating repairable systems with a spare unit to limit risk or meet any emergency requirements has become standard practice. In the event of a power loss, redundancy has proven to be one of the most effective strategies to improve the efficiency of such systems over time. In actuality, it is nothing more than a result of academics' probabilistic analysis of backup systems receiving increased attention. It is well acknowledged that the majority of units, as well as big systems with many distinct types of components, fail over time owing to random causes. A probabilistic event is a set of time-indexed findings from a haphazard experiment, and it is one of the most useful tools for predicting future behavior statistically.

Many academics have already proposed a range of approaches for system strength and efficiency across diverse situations in the field of solar photovoltaic system and solar water pumping system dependability analysis. Under various weather conditions, Barak et al. (2018) investigated the performance of a two-unit cold standby system model. In addition, Barak et al. (2018) looked into the profit analysis of a two-unit cold standby system that was inspected while in operation under various weather conditions. Kumar et al. (2019) investigated the profitability of a warm standby nonidentical unit system with a single server that was subjected to preventative maintenance. Hu et al. (2020) investigated the planning of periodic preventive maintenance for systems that operate under Markov operating circumstances. The performance and cost of a repairable complicated system with two linked subsystems were explored by Lado et al. (2018). Manglik and Ram (2013) used the Markov process to analyze the reliability of a two-unit cold standby system. Pundir et al. (2018) investigated the probabilistic future of two nonidentical unit parallel systems with different repair priorities. Lado and Singh (2019) used the Gumbel Hougaard family copula to calculate the cost of a repairable complex system with two subsystems. Shekhar et al. (2020) investigated load-sharing redundant repairable systems with switching and robot delays. Abunima and Teh (2020) investigated photovoltaic system reliability modeling using time-varying failure rates. Uswarman and Rushdi (2021) used coherent threshold systems to assess the reliability of rooftop solar photovoltaic systems. Bhardwaj and Kaur (2021) used exponential Rayleigh–Weibull distributions to analyze the performance of a standby system. Aggarwal et al. (2021) investigated the profitability of a standby repairable system, focusing on preventive maintenance and the rest of the server in between repairs. Bhaskaran et al. (2021) dealt with analysis and design for application meant for E-learning, a cluster-based hybrid system. Marappan and Sethumadhavan (2022) discussed the solution to graph coloring problem with the aid of particle swamp optimization.

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Modibbo et al. (2021) dealt with estimation and optimization in reliability allocation problems. Kundu and Garg (2022) present algorithm for reliability optimization problem. Kamal et al. (2021) present fuzzy goal programming in selective maintenance allocation problems. Garg (2022) focuses on reliability problems and analysis in some industrial engineering systems. Khan et al. (2022) dealt with nonlinear optimization problems in maintenance allocation. He et al. (2017) developed mission reliability models for multi-station production systems. He et al. (2018) proposed cost-oriented predictive maintenance models for mission reliability.

Due to a shortage of piped water projects and insufficient potable water, residents in rural regions continue to rely on untreated surface water for drinking and other household reasons. Because certain rural communities lack access to electricity, solar applications can be used to offer residential power using photovoltaic systems, which are common in these areas as a source of electricity. This study is inspired by the fact that, in contrast to the aforementioned literature, solar and wind energy can provide power without the use of additional water. This means less competition for resources and lower irrigation expenses for neighboring agricultural firms. Furthermore, solar and wind energy have no negative effects on nearby water supplies. This research looks into the dependability of solar water pumping devices for small town water supply. The study's three aims are as follows: The first step is to create a robust system dependability model that takes into account availability, the possibility of repairing or servicing malfunctioning units, and a profit function. Next, run a sensitivity analysis to examine how changing system parameters affects performance. The third stage involves calculating the profit impact of failure and repair rates.

The following is the paper's outline: The system description, notations, assumptions, and states are contained in the second portion; the mathematical formulation of the model, development of the availability model, likelihood of repairing or servicing failing units, and profit function are contained in the third section. The fourth section contains the results, discussion, and conclusion.

2. System Description, Notations, Assumptions, and State of the System

2.1. System description

In this part, we have provided a brief overview of the solar water pumping system and its components. This system is made up of four essential subsystems, as shown in Figure 1.

Solar panel: This subsystem consists of two solar panel units that are connected in series to the subsystem below. Each solar panel unit will also produce 36 watts of power. Both units are in use; if one fails, the system will continue to function; but, if both fail, the system will shut down.

Inverter: This subsystem consists of only one unit, which is connected to the next subsystem in parallel. If this component fails, the entire system will fail.

Water pumping machine: In this subsystem as well, there is only one unit. This unit subsystem required 36 watts of electrical energy to pump water into a tank. The failure of this subsystem could result in the overall system failing.

Tank: In this subsystem, there are two tank units, each of which can hold 1,000 liters of water. The system will come crashing down if both units' tanks fail.

2.2. Notations

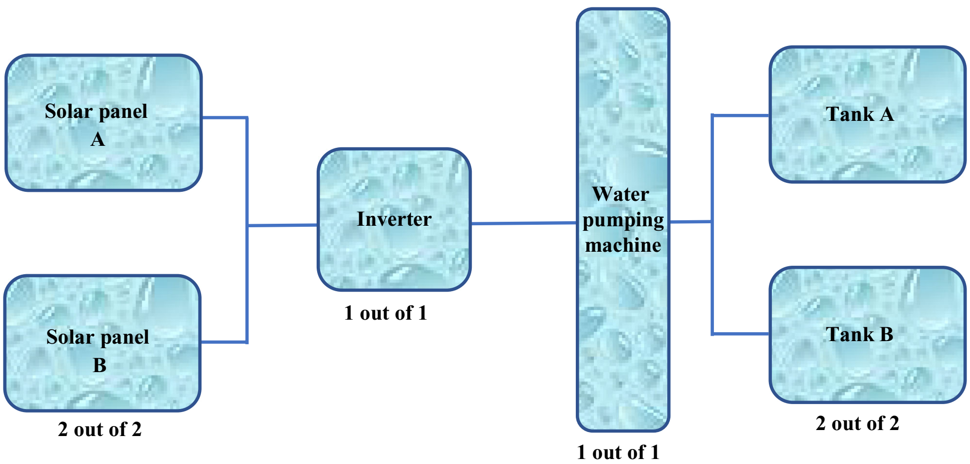
Let d_i, q_i, and BP_i represent failure rate, repair rate, and probability of repairing or servicing failed units of all subsystems, respectively, for some i ¼ 1; 2; 3; 4, as shown in Table 1.

Table 1
System annotations

Subsystem	Failure rate (d_i)	Repair rate (q_i)
Solar panel	d_1	q_1
Inverter	d_2	q_2
Water pumping machine	d_3	q_3
Tank	d_4	q_4

AV is an availability when the system is in a state of operation.
BP_1 is the probability of repairing or servicing failed unit of solar panel.
BP_2 is the probability of repairing or servicing failed unit of inverter.
BP_3 is the probability of repairing or servicing failed unit of pump machine.
BP_4 is the probability of repairing or servicing failed unit of tank.
k_0 is the generated revenue.
k_1 is the cost of repairing units of solar panel, when it has failed.
k_2 is the cost of repairing inverter, when it has failed.
k_3 is the cost of repairing pump machine, when it has failed.
k_4 is the cost of repairing units of tank, when it has failed.
P_i is a time taken to repair the failure of the first or second unit of all subsystems in the state St_i for some $i = 1, 2, 3, \ldots 15$.

Figure 1
Block schematic system's diagram



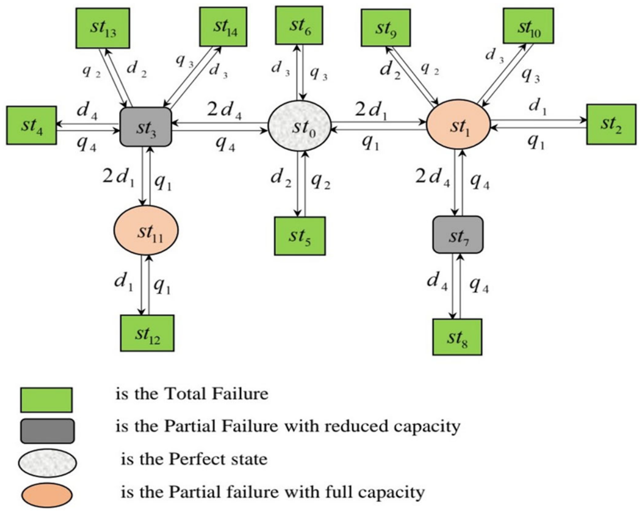
2.3. Assumptions

1. All of the subsystems are in good functioning order at first.
2. Each subsystem's early unit failures are perfectly repaired, allowing the system to finish its full duty cycle.
3. Each unit's failure is unrelated to the others.

2.4. The states of the system

Figure 2 shows a transition diagram in which St_0 is considered to as a state of perfection, in which all of the units in each subsystem are operational, that is, the system is fully operational. In the subsystem 1, states St_1 and St_{11} are states which have partially failed with full capacity. Total failure states St_2 and St_{12} are induced by the perished of two sections in subsystem 1. In the subsystem 4, St_3 and St_7 are partly failed states with limited ability. Two units were unable to function due to failure in subsystem 4, and states St_4 and St_8 are fully failed. As a result of the subsystem 2 unit failing, states St_5, St_9, and St_{13} are entirely failed. As a result of the unit's failure in subsystem 3, states St_6, St_{10}, and St_{14} are entirely failed.

Figure 2
The state transition diagram for the system



3. The Model's Mathematical Formulation

If the Mnemonic rule is used to build model equations at every state St_i for some $i = 0, 1, 2, \ldots 14$, the system of first-order linear ordinary differential equations (ODEs) can be determined using the state transition diagram in Figure 2.

3.1. Construction of the availability model

Figure 2 shows the availability formulation of the system, which is generated by applying the Mnemonic rule to the following system of first-order linear ODEs:

$$\frac{dH_0(t)}{dt} = q_1H_1(t) + q_2H_5(t) + q_3H_6(t) + q_4H_3(t) - (2d_1 + d_2 + d_3 + 2d_4)H_0(t) \tag{1}$$

$$\frac{dH_1(t)}{dt} = 2d_1H_0(t) + q_1H_2(t) + q_2H_9(t) + q_3H_{10}(t) + q_4H_7(t) - (q_1 + d_1 + d_2 + d_3 + 2d_4)H_1(t) \tag{2}$$

$$\frac{dH_2(t)}{dt} = d_1H_1(t) - q_1H_2(t) \tag{3}$$

$$\frac{dH_3(t)}{dt} = 2d_4H_0(t) + q_1H_{11}(t) + q_2H_{13}(t) + q_3H_{14}(t) + q_4H_4(t) - (q_4 + 2d_1 + d_2 + d_3 + d_4)H_3(t) \tag{4}$$

$$\frac{dH_4(t)}{dt} = d_4H_3(t) - q_4H_4(t) \tag{5}$$

$$\frac{dH_5(t)}{dt} = d_2H_0(t) - q_2H_5(t) \tag{6}$$

$$\frac{dH_6(t)}{dt} = d_3H_0(t) - q_3H_6(t) \tag{7}$$

$$\frac{dH_7(t)}{dt} = 2d_4H_1(t) + q_4H_8(t) - (d_4 + q_4)H_7(t) \tag{8}$$

$$\frac{dH_8(t)}{dt} = d_4H_7(t) - q_4H_8(t) \tag{9}$$

$$\frac{dH_9(t)}{dt} = d_2H_1(t) - q_2H_9(t) \tag{10}$$

$$\frac{dH_{10}(t)}{dt} = d_3H_1(t) - q_3H_{10}(t) \tag{11}$$

$$\frac{dH_{11}(t)}{dt} = 2d_1H_3(t) + q_1H_{12}(t) - (d_1 + q_1)H_{11}(t) \tag{12}$$

$$\frac{dH_{12}(t)}{dt} = d_1H_{11}(t) - q_1H_{12}(t) \tag{13}$$

$$\frac{dH_{13}(t)}{dt} = d_2H_3(t) - q_2H_{13}(t) \tag{14}$$

$$\frac{dH_{14}(t)}{dt} = d_3H_3(t) - q_3H_{14}(t) \tag{15}$$

where

$$a_0 = 2d_1 + d_2 + d_3 + 2d_4 \tag{16}$$

$$a_1 = q_1 + d_1 + d_2 + d_3 + 2d_4 \tag{17}$$

$$a_2 = q_4 + 2d_1 + d_2 + d_3 + d_4 \tag{18}$$

$$a_3 = d_4 + q_4 \tag{19}$$

$$a_4 = d_1 + q_1 \tag{20}$$

The next step is to convert the above model equations into matrix form by taking the coefficients of $H_0(t), H_1(t), H_2(t), H_3(t), \ldots H_{14}(t)$ as entries in the matrix column by column from equations (1)–(15).

$$\frac{dH}{dt}=\begin{pmatrix} -a_0 & q_1 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_1 & -a_1 & q_1 & 0 & 0 & 0 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 \\ 0 & d_1 & -q_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_4 & 0 & 0 & -a_2 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 & q_1 & 0 & q_2 & q_3 \\ 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2d_4 & 0 & 0 & 0 & 0 & 0 & -a_3 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2d_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_4 & q_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_1 & -q_1 & 0 & 0 \\ 0 & 0 & 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 \\ 0 & 0 & 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 \end{pmatrix}\begin{pmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \\ H_4(t) \\ H_5(t) \\ H_6(t) \\ H_7(t) \\ H_8(t) \\ H_9(t) \\ H_{10}(t) \\ H_{11}(t) \\ H_{12}(t) \\ H_{13}(t) \\ H_{14}(t) \end{pmatrix} \tag{21}$$

$$\frac{dH}{dt}=\begin{pmatrix} H_0'(t) \\ H_1'(t) \\ H_2'(t) \\ H_3'(t) \\ H_4'(t) \\ H_5'(t) \\ H_6'(t) \\ H_7'(t) \\ H_8'(t) \\ H_9'(t) \\ H_{10}'(t) \\ H_{11}'(t) \\ H_{12}'(t) \\ H_{13}'(t) \\ H_{14}'(t) \end{pmatrix}=\begin{pmatrix} -a_0 & q_1 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_1 & -a_1 & q_1 & 0 & 0 & 0 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 \\ 0 & d_1 & -q_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_4 & 0 & 0 & -a_2 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 & q_1 & 0 & q_2 & q_3 \\ 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2d_4 & 0 & 0 & 0 & 0 & 0 & -a_3 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2d_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_4 & q_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_1 & -q_1 & 0 & 0 \\ 0 & 0 & 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 \\ 0 & 0 & 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 \end{pmatrix}\begin{pmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \\ H_4(t) \\ H_5(t) \\ H_6(t) \\ H_7(t) \\ H_8(t) \\ H_9(t) \\ H_{10}(t) \\ H_{11}(t) \\ H_{12}(t) \\ H_{13}(t) \\ H_{14}(t) \end{pmatrix} \tag{22}$$

In a stable state $\frac{dH}{dt}=0$, equation (22) now becomes

$$\begin{pmatrix} -a_0 & q_1 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_1 & -a_1 & q_1 & 0 & 0 & 0 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 \\ 0 & d_1 & -q_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_4 & 0 & 0 & -a_2 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 & q_1 & 0 & q_2 & q_3 \\ 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2d_4 & 0 & 0 & 0 & 0 & 0 & -a_3 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2d_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_4 & q_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_1 & -q_1 & 0 & 0 \\ 0 & 0 & 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 \\ 0 & 0 & 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 \end{pmatrix}\begin{pmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \\ H_4(t) \\ H_5(t) \\ H_6(t) \\ H_7(t) \\ H_8(t) \\ H_9(t) \\ H_{10}(t) \\ H_{11}(t) \\ H_{12}(t) \\ H_{13}(t) \\ H_{14}(t) \end{pmatrix}=\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{23}$$

since the sum of all probabilities equals one.

Therefore, $\sum_{i=0}^{14} H_i(t) = 1$. Consequently, equation (23) becomes

$$\begin{pmatrix} -a_0 & q_1 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_1 & -a_1 & q_1 & 0 & 0 & 0 & 0 & q_4 & 0 & q_2 & q_3 & 0 & 0 & 0 & 0 \\ 0 & d_1 & -q_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2d_4 & 0 & 0 & -a_2 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 & q_1 & 0 & q_2 & q_3 \\ 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2d_4 & 0 & 0 & 0 & 0 & 0 & -a_3 & q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_4 & -q_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2d_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_4 & q_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_1 & -q_1 & 0 & 0 \\ 0 & 0 & 0 & d_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -q_2 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \\ H_4(t) \\ H_5(t) \\ H_6(t) \\ H_7(t) \\ H_8(t) \\ H_9(t) \\ H_{10}(t) \\ H_{11}(t) \\ H_{12}(t) \\ H_{13}(t) \\ H_{14}(t) \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \tag{24}$$

To this end, the probabilities of states $H_i(t)$ need to be found, for some $i = 0, 1, 2, 3, \ldots 14$ in order to discover the system's availability function. The system's steady-state availability function, predicted profit function, and probability of repairing or servicing failed units of each subsystem must be obtained using the MATLAB software package as follows:

$$AV = H_0(t) + H_1(t) + H_3(t) + H_7(t) + H_{11}(t) \tag{25}$$

$$AV = \frac{E}{F} \tag{26}$$

Where

$$E = q_1^2 q_2 q_3 q_4^2 + 2q_1 q_2 q_3 q_4^2 d_1 + 2q_1^2 q_2 q_3 q_4 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \tag{27}$$

$$F = \left\{ \begin{array}{l} q_1^2 q_2 q_3 q_4^2 + 2q_2 q_3 q_4^2 d_1^2 + 2q_1^2 q_2 q_3 d_4^2 + q_1^2 q_2 q_4^2 d_3 + q_1^2 q_3 q_4^2 d_2 + 2q_1 q_2 q_3 q_4^2 d_1 \\ +2q_1^2 q_2 q_3 q_4 d_4 + 4q_1 q_2 q_3 d_1 d_4^2 + 2q_1 q_2 q_4^2 d_1 d_3 + 2q_1 q_3 q_4^2 d_1 d_2 + 4q_2 q_3 q_4 d_1^2 d_4 \\ +2q_1^2 q_2 q_4 d_3 d_4 + 2q_1^2 q_3 q_4 d_2 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \end{array} \right\} \tag{28}$$

$$AV = \frac{q_1^2 q_2 q_3 q_4^2 + 2q_1 q_2 q_3 q_4^2 d_1 + 2q_1^2 q_2 q_3 q_4 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4}{\left\{ \begin{array}{l} q_1^2 q_2 q_3 q_4^2 + 2q_2 q_3 q_4^2 d_1^2 + 2q_1^2 q_2 q_3 d_4^2 + q_1^2 q_2 q_4^2 d_3 + q_1^2 q_3 q_4^2 d_2 + 2q_1 q_2 q_3 q_4^2 d_1 \\ +2q_1^2 q_2 q_3 q_4 d_4 + 4q_1 q_2 q_3 d_1 d_4^2 + 2q_1 q_2 q_4^2 d_1 d_3 + 2q_1 q_3 q_4^2 d_1 d_2 + 4q_2 q_3 q_4 d_1^2 d_4 \\ +2q_1^2 q_2 q_4 d_3 d_4 + 2q_1^2 q_3 q_4 d_2 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \end{array} \right\}} \tag{29}$$

From the transition diagram above, the probability of repairing or servicing failed units of the subsystems across their states is

$$BP_1 = P_1 + P_2 + P_{11} + P_{12} \tag{30}$$

$$BP_2 = P_5 + P_9 + P_{13} \tag{31}$$

$$BP_3 = P_6 + P_{10} + P_{14} \tag{32}$$

$$BP_4 = P_3 + P_4 + P_7 + P_8 \tag{33}$$

by using MATLAB software package, equation (30) to (33) become

$$BP_1 = \frac{W + X + Y + 4q_1 q_2 q_3 q_4 d_1 d_4}{Z} \tag{34}$$

where

$$z = \begin{pmatrix} q_1^2 q_2 q_3 q_4^2 + W + 2q_1^2 q_2 q_3 d_4^2 + q_1^2 q_2 q_4^2 d_3 + q_1^2 q_3 q_4^2 d_2 + Y + 2q_1^2 q_2 q_3 q_4 d_4 + 4q_1 q_2 q_3 d_1 d_4^2 \\ +2q_1 q_2 q_4^2 d_1 d_3 + 2q_1 q_3 q_4^2 d_1 d_2 + X + 2q_1^2 q_2 q_4 d_3 d_4 + 2q_1^2 q_3 q_4 d_2 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \end{pmatrix} \tag{35}$$

$$W = 2q_2 q_3 q_4^2 d_1^2 \tag{36}$$

$$X = 4q_2 q_3 q_4 d_1^2 d_4 \tag{37}$$

$$Y = 2q_1 q_2 q_3 q_4^2 d_1 \tag{38}$$

Substituting equation (35) to (38) into equation (34), one has to get

$$BP_1 = \frac{2q_2 q_3 q_4^2 d_1^2 + 4q_2 q_3 q_4 d_1^2 d_4 + 2q_1 q_2 q_3 q_4^2 d_1 + 4q_1 q_2 q_3 q_4 d_1 d_4}{\begin{pmatrix} q_1^2 q_2 q_3 q_4^2 + 2q_2 q_3 q_4^2 d_1^2 + 2q_1^2 q_2 q_3 d_4^2 + q_1^2 q_2 q_4^2 d_3 + q_1^2 q_3 q_4^2 d_2 + 2q_1 q_2 q_3 q_4^2 d_1 + 2q_1^2 q_2 q_3 q_4 d_4 + 4q_1 q_2 q_3 d_1 d_4^2 \\ +2q_1 q_2 q_4^2 d_1 d_3 + 2q_1 q_3 q_4^2 d_1 d_2 + 4q_2 q_3 q_4 d_1^2 d_4 + 2q_1^2 q_2 q_4 d_3 d_4 + 2q_1^2 q_3 q_4 d_2 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \end{pmatrix}} \tag{39}$$

$$BP_1 = \frac{W + X + Y + G}{F} \tag{40}$$

where

$$G = 4q_1 q_2 q_3 q_4 d_1 d_4 \tag{41}$$

$$F = \begin{pmatrix} q_1^2 q_2 q_3 q_4^2 + 2q_2 q_3 q_4^2 d_1^2 + 2q_1^2 q_2 q_3 d_4^2 + q_1^2 q_2 q_4^2 d_3 + q_1^2 q_3 q_4^2 d_2 + 2q_1 q_2 q_3 q_4^2 d_1 + 2q_1^2 q_2 q_3 q_4 d_4 + 4q_1 q_2 q_3 d_1 d_4^2 \\ +2q_1 q_2 q_4^2 d_1 d_3 + 2q_1 q_3 q_4^2 d_1 d_2 + 4q_2 q_3 q_4 d_1^2 d_4 + 2q_1^2 q_2 q_4 d_3 d_4 + 2q_1^2 q_3 q_4 d_2 d_4 + 8q_1 q_2 q_3 q_4 d_1 d_4 \end{pmatrix} \tag{42}$$

$$BP_2 = \frac{Q + R + S}{U} \tag{43}$$

where

$$U = \begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + 2q_1^2q_2q_3d_4^2 + q_1^2q_2q_4^2d_3 + Q + 2q_1q_2q_3q_4^2d_1 + 2q_1^2q_2q_3q_4d_4 \\ +4q_1q_2q_3d_1d_4^2 + 2q_1q_2q_4^2d_1d_3 + S + 4q_2q_3q_4d_1^2d_4 + 2q_1^2q_2q_4d_3d_4 + R + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix} \quad (44)$$

$$Q = q_1^2q_3q_4^2d_2 \quad (45)$$

$$R = 2q_1^2q_3q_4d_2d_4 \quad (46)$$

$$S = 2q_1q_3q_4^2d_1d_2 \quad (47)$$

Substituting equations (44)–(47) into equation (43), one has to get

$$BP_2 = \frac{q_1^2q_3q_4^2d_2 + 2q_1^2q_3q_4d_2d_4 + 2q_1q_3q_4^2d_1d_2}{\begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + 2q_1^2q_2q_3d_4^2 + q_1^2q_2q_4^2d_3 + q_1^2q_3q_4^2d_2 + 2q_1q_2q_3q_4^2d_1 + 2q_1^2q_2q_3q_4d_4 + 4q_1q_2q_3d_1d_4^2 \\ +2q_1q_2q_4^2d_1d_3 + 2q_1q_3q_4^2d_1d_2 + 4q_2q_3q_4d_1^2d_4 + 2q_1^2q_2q_4d_3d_4 + 2q_1^2q_3q_4d_2d_4 + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix}} \quad (48)$$

$$BP_2 = \frac{Q + R + S}{F} \quad (49)$$

$$BP_3 = \frac{L + M + N}{J} \quad (50)$$

where

$$J = \begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + 2q_1^2q_2q_3d_4^2 + L + q_1^2q_3q_4^2d_2 + 2q_1q_2q_3q_4^2d_1 + 2q_1^2q_2q_3q_4d_4 \\ +4q_1q_2q_3d_1d_4^2 + N + 2q_1q_3q_4^2d_1d_2 + 4q_2q_3q_4d_1^2d_4 + M + 2q_1^2q_3q_4d_2d_4 + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix} \quad (51)$$

$$L = q_1^2q_2q_4^2d_3 \quad (52)$$

$$M = 2q_1^2q_2q_4d_3d_4 \quad (53)$$

$$N = 2q_1q_2q_4^2d_1d_3 \quad (54)$$

Substituting equations (51)–(54) into equation (50), one has to get

$$BP_3 = \frac{q_1^2q_2q_4^2d_3 + 2q_1^2q_2q_4d_3d_4 + 2q_1q_2q_4^2d_1d_3}{\begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + 2q_1^2q_2q_3d_4^2 + q_1^2q_2q_4^2d_3 + q_1^2q_3q_4^2d_2 + 2q_1q_2q_3q_4^2d_1 + 2q_1^2q_2q_3q_4d_4 + 4q_1q_2q_3d_1d_4^2 \\ +2q_1q_2q_4^2d_1d_3 + 2q_1q_3q_4^2d_1d_2 + 4q_2q_3q_4d_1^2d_4 + 2q_1^2q_2q_4d_3d_4 + 2q_1^2q_3q_4d_2d_4 + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix}} \quad (55)$$

$$BP_3 = \frac{L + M + N}{F} \quad (56)$$

$$BP_4 = \frac{A + C + I + 4q_1q_2q_3q_4d_1d_4}{T} \quad (57)$$

where

$$T = \begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + A + q_1^2q_2q_4^2d_3 + q_1^2q_3q_4^2d_2 + 2q_1q_2q_3q_4^2d_1 + I + C + 2q_1q_2q_4^2d_1d_3 \\ +2q_1q_3q_4^2d_1d_2 + 4q_2q_3q_4d_1^2d_4 + 2q_1^2q_2q_4d_3d_4 + 2q_1^2q_3q_4d_2d_4 + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix} \quad (58)$$

$$A = 2q_1^2q_2q_3d_4^2 \quad (59)$$

$$C = 4q_1q_2q_3d_1d_4^2 \quad (60)$$

$$I = 2q_1^2q_2q_3q_4d_4 \quad (61)$$

Substituting equations (58)–(61) into equation (57), one has to get

$$BP_4 = \frac{2q_1^2q_2q_3d_4^2 + 4q_1q_2q_3d_1d_4^2 + 2q_1^2q_2q_3q_4d_4 + 4q_1q_2q_3q_4d_1d_4}{\begin{pmatrix} q_1^2q_2q_3q_4^2 + 2q_2q_3q_4^2d_1^2 + 2q_1^2q_2q_3d_4^2 + q_1^2q_2q_4^2d_3 + q_1^2q_3q_4^2d_2 + 2q_1q_2q_3q_4^2d_1 + 2q_1^2q_2q_3q_4d_4 + 4q_1q_2q_3d_1d_4^2 \\ +2q_1q_2q_4^2d_1d_3 + 2q_1q_3q_4^2d_1d_2 + 4q_2q_3q_4d_1^2d_4 + 2q_1^2q_2q_4d_3d_4 + 2q_1^2q_3q_4d_2d_4 + 8q_1q_2q_3q_4d_1d_4 \end{pmatrix}} \quad (62)$$

$$BP_4 = \frac{A + C + I + G}{F} \quad (56)$$

Now, the expected profitability function will be

$$\Pr ofit = k_0AV - k_1BP_1 - k_2BP_2 - k_3BP_3 - k_4BP_4 \quad (57)$$

$$\Pr ofit = \frac{k_0E - [k_1(W + X + Y + G) + k_2(Q + R + S) + k_3(L + M + N) + k_4(A + C + I + G)]}{F} \quad (58)$$

4. Results, Discussion, and Conclusion

This section shows illustrative simulations of the model using MATLAB software package, and these numerical simulations are based on the following example.

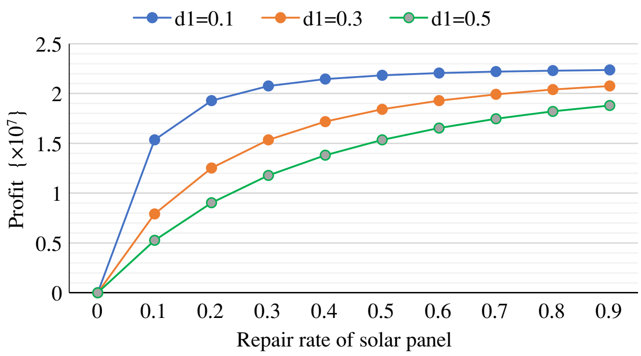
4.1. Profitability analysis

The values of the following parameters are used in this case by setting $k_0 = 25,000,000$ $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_2 = 0.02$, $d_3 = 0.04$, $d_4 = 0.06$, $q_2 = 0.5$, $q_3 = 0.7$, $q_4 = 0.9$ as well as modifying q_1 from 0 to 0.9, as indicated in Table 2 and Figure 3.

Table 2
Profitability of the system in relation to solar panel repair rate at various failure rates

q_1	$d_1 = 0.1$ Profit $\times 10^7$	$d_1 = 0.3$ Profit $\times 10^7$	$d_1 = 0.5$ Profit $\times 10^7$
0	0	0	0
0.1	1.5350	0.7913	0.5265
0.2	1.9287	1.2523	0.9037
0.3	2.0761	1.5350	1.1779
0.4	2.1455	1.7177	1.3812
0.5	2.1832	1.8415	1.5350
0.6	2.2059	1.9287	1.6534
0.7	2.2204	1.9921	1.7463
0.8	2.2303	2.0397	1.8202
0.9	2.2372	2.0761	1.8799

Figure 3
Profitability of the system in relation to solar panel repair rate for various failure rates



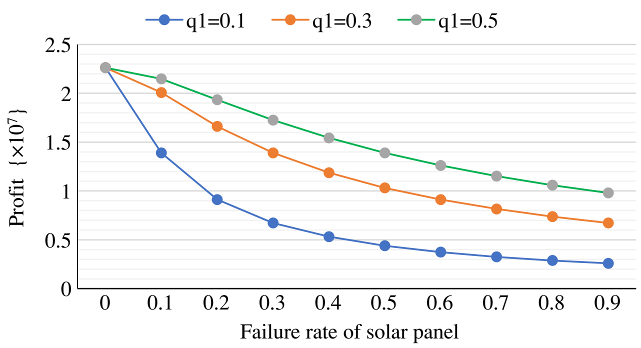
Thus, according to Table 2 and Figure 3, the system's profitability rises as the repair rate rises, whereas profit declines for three different failure rates.

Setting $k_0 = 25,000,000.00$, $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_2 = 0.02$, $d_3 = 0.04$, $d_4 = 0.06$, $q_2 = 0.5$, $q_3 = 0.7$, $q_4 = 0.9$ as well as modifying d_1 from 0 to 0.9, as indicated in Table 3 and Figure 4 below.

Table 3
System profitability as a function of solar panel failure rate at various repair rates

d_1	$q_1 = 0.1$ Profit $\times 10^7$	$q_1 = 0.3$ Profit $\times 10^7$	$q_1 = 0.5$ Profit $\times 10^7$
0	2.2625	2.2625	2.2625
0.1	1.3900	2.0073	2.1479
0.2	0.9116	1.6612	1.9341
0.3	0.6728	1.3900	1.7251
0.4	0.5321	1.1867	1.5433
0.5	0.4397	1.0320	1.3900
0.6	0.3745	0.9116	1.2611
0.7	0.3261	0.8156	1.1524
0.8	0.2888	0.7375	1.0598
0.9	0.2591	0.6728	0.9804

Figure 4
Profitability of the system as a function of solar panel failure rate at various repair rates



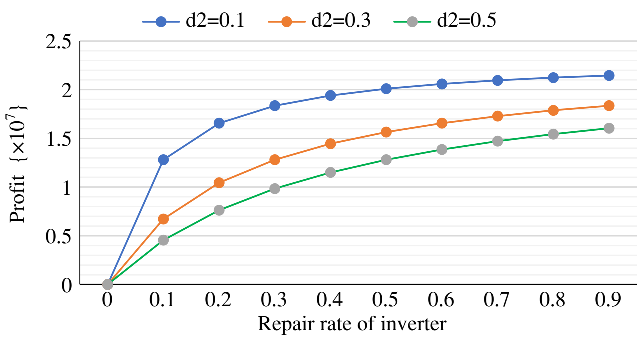
The system's profitability drops as the failure rate rises but increases for three separate repair rates, according to Table 3 and Figure 4.

Setting $k_0 = 25,000,000.00, k_1 = 150, k_2 = 250, k_3 = 500, k_4 = 100, d_1 = 0.02, d_3 = 0.04, d_4 = 0.06, q_1 = 0.5, q_3 = 0.7, q_4 = 0.9$ as well as modifying q_2 from 0 to 0.9, as indicated in Table 4 and Figure 5.

Table 4
Profitability of the system as a function of inverter repair rate at various failure rates

q_2	$d_2 = 0.1$ Profit $\times 10^7$	$d_2 = 0.3$ Profit $\times 10^7$	$d_2 = 0.5$ Profit $\times 10^7$
0	0	0	0
0.1	1.2812	0.6720	0.4554
0.2	1.6566	1.0445	0.7626
0.3	1.8360	1.2812	0.9839
0.4	1.9410	1.4449	1.1508
0.5	2.0100	1.5649	1.2812
0.6	2.0588	1.6566	1.3859
0.7	2.0952	1.7290	1.4718
0.8	2.1233	1.7876	1.5435
0.9	2.1457	1.8360	1.6044

Figure 5
Profitability of the system as a function of inverter repair rate for various failure rates



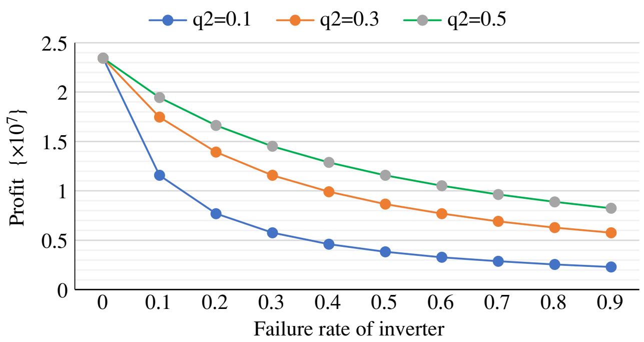
Thus, according to Table 4 and Figure 5, the system's profitability rises as the repair rate rises, whereas profit declines for three different failure rates.

Setting $k_0 = 25,000,000.00, k_1 = 150, k_2 = 250, k_3 = 500, k_4 = 100, d_1 = 0.02, d_3 = 0.04, d_4 = 0.06, q_1 = 0.5, q_3 = 0.7, q_4 = 0.9$ as well as modifying d_2 from 0 to 0.9, as indicated in Table 5 and Figure 6.

Table 5
System profitability as a function of inverter failure rate at various repair rates

d_2	$q_2 = 0.1$ Profit $\times 10^7$	$q_2 = 0.3$ Profit $\times 10^7$	$q_2 = 0.5$ Profit $\times 10^7$
0	2.3433	2.3433	2.3433
0.1	1.1580	1.7472	1.9451
0.2	0.7690	1.3929	1.6626
0.3	0.5757	1.1580	1.4518
0.4	0.4600	0.9910	1.2884
0.5	0.3830	0.8660	1.1580
0.6	0.3281	0.7690	1.0517
0.7	0.2870	0.6916	0.9632
0.8	0.2550	0.6283	0.8884
0.9	0.2295	0.5757	0.8244

Figure 6
Profitability of the system in relation to inverter failure rate at various repair rates



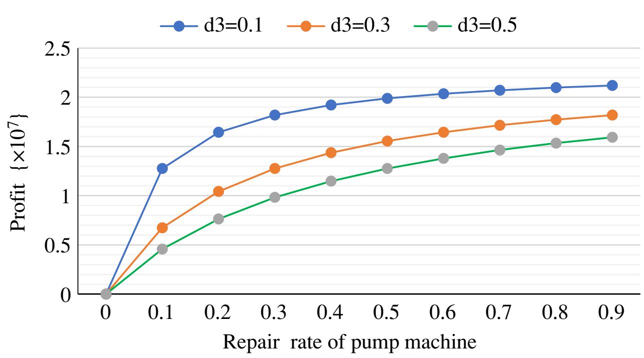
The system's profitability drops as the failure rate rises but increases for three separate repair rates, according to Table 5 and Figure 6.

Setting $k_0 = 25,000,000.00$, $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_1 = 0.02$, $d_2 = 0.04$, $d_4 = 0.06$, $q_1 = 0.4$, $q_2 = 0.6$, $q_4 = 0.7$ as well as modifying q_3 from 0 to 0.9, as indicated in Table 6 and Figure 7.

Table 6
System profitability as a function of pump machine repair rate at various failure rates

q_3	$d_3 = 0.1$ Profit $\times 10^7$	$d_3 = 0.3$ Profit $\times 10^7$	$d_3 = 0.5$ Profit $\times 10^7$
0	0	0	0
0.1	1.2767	0.6737	0.4575
0.2	1.6448	1.0432	0.7639
0.3	1.8196	1.2767	0.9833
0.4	1.9218	1.4375	1.1482
0.5	1.9888	1.5551	1.2767
0.6	2.0361	1.6448	1.3796
0.7	2.0713	1.7154	1.4639
0.8	2.0985	1.7725	1.5342
0.9	2.1202	1.8196	1.5937

Figure 7
Profitability of the system as a function of pump machine repair rate for various failure rates



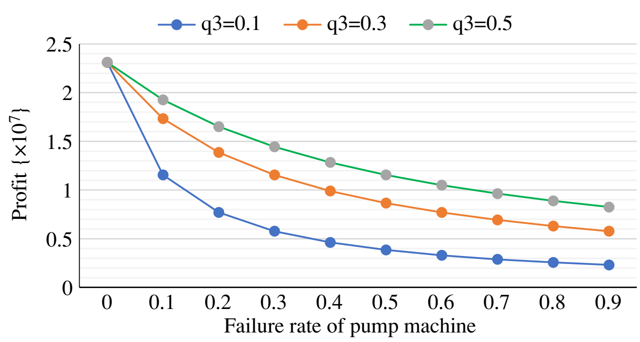
Thus, according to Table 6 and Figure 7, the system's profitability rises as the repair rate rises, whereas profit declines for three different failure rates.

Setting $k_0 = 25,000,000.00$, $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_1 = 0.02$, $d_2 = 0.04$, $d_4 = 0.06$, $q_1 = 0.4$, $q_2 = 0.6$, $q_4 = 0.7$ as well as modifying d_3 from 0 to 0.9, as indicated in Table 7 and Figure 8.

Table 7
System profitability as a function of pump machine failure rate at various repair rates

d_3	$q_3 = 0.1$ Profit $\times 10^7$	$q_3 = 0.3$ Profit $\times 10^7$	$q_3 = 0.5$ Profit $\times 10^7$
0	2.3110	2.3110	2.3110
0.1	1.1554	1.7332	1.9258
0.2	0.7702	1.3865	1.6506
0.3	0.5777	1.1554	1.4443
0.4	0.4621	0.9903	1.2838
0.5	0.3851	0.8665	1.1554
0.6	0.3301	0.7702	1.0503
0.7	0.2888	0.6932	0.9628
0.8	0.2567	0.6302	0.8887
0.9	0.2310	0.5777	0.8252

Figure 8
Profitability of the system in relation to pump machine failure rate at various repair rates



The system's profitability drops as the failure rate rises but increases for three separate repair rates, according to Table 7 and Figure 8.

Setting $k_0 = 25,000,000.00$, $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_1 = 0.02$, $d_2 = 0.04$, $d_3 = 0.06$, $q_1 = 0.5$, $q_2 = 0.7$, $q_3 = 0.9$ as well as modifying q_4 from 0 to 0.9, as indicated in Table 8 and Figure 9.

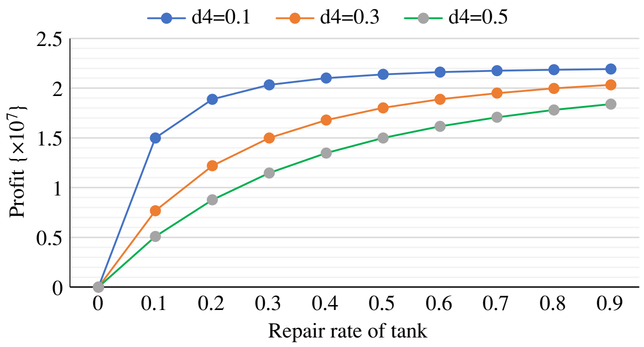
Thus, according to Table 8 and Figure 9, the system's profitability rises as the repair rate rises, whereas profit declines for three different failure rates.

Setting $k_0 = 25,000,000.00$, $k_1 = 150$, $k_2 = 250$, $k_3 = 500$, $k_4 = 100$, $d_1 = 0.02$, $d_2 = 0.04$, $d_3 = 0.06$, $q_1 = 0.5$, $q_2 = 0.7$,

Table 8
System profitability as a function of tank repair rate at various failure rates

q_4	$d_4 = 0.1$ Profit $\times 10^7$	$d_4 = 0.3$ Profit $\times 10^7$	$d_4 = 0.5$ Profit $\times 10^7$
0	0	0	0
0.1	1.4991	0.7678	0.5094
0.2	1.8879	1.2204	0.8777
0.3	2.0334	1.4991	1.1471
0.4	2.1019	1.6796	1.3474
0.5	2.1392	1.8018	1.4991
0.6	2.1615	1.8879	1.6161
0.7	2.1759	1.9506	1.7078
0.8	2.1857	1.9975	1.7808
0.9	2.1926	2.0334	1.8397

Figure 9
Profitability of the system as a function of tank repair rate for various failure rates



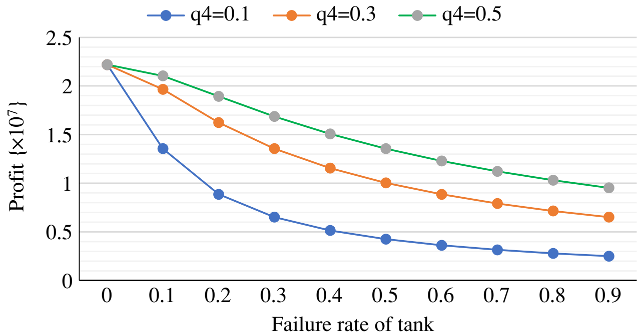
$q_3 = 0.9$ as well as modifying d_4 from 0 to 0.9, as indicated in Table 9 and Figure 10.

The system's profitability drops as the failure rate rises but increases for three separate repair rates, according to Table 9 and Figure 10.

Table 9
System profitability as a function of tank failure rate at various repair rates

d_4	$q_4 = 0.1$ Profit $\times 10^7$	$q_4 = 0.3$ Profit $\times 10^7$	$q_4 = 0.5$ Profit $\times 10^7$
0	2.2187	2.2187	2.2187
0.1	1.3560	1.9655	2.1043
0.2	0.8855	1.6237	1.8933
0.3	0.6519	1.3560	1.6868
0.4	0.5147	1.1557	1.5073
0.5	0.4249	1.0037	1.3560
0.6	0.3617	0.8855	1.2290
0.7	0.3147	0.7915	1.1220
0.8	0.2786	0.7151	1.0310
0.9	0.2498	0.6519	0.9530

Figure 10
Profitability of the system in relation to tank failure rate at various repair rates



5. Conclusion

This study report looked into the availability and profitability of a solar water pumping system. Two solar panels, one inverter, one water pumping apparatus, and two tanks are the major components of this system. When constructing and validating the steady-state condition availability and profitability functions, first-order ODEs as well as simulation data are taken into account. The impact of system parameters is then determined using MATLAB software.

As shown in Tables 2, 4, 6, and 8 and Figures 3, 5, 7, and 9, the system's profitability increases as the repair rates increase, whereas the system's profitability decreases as the failure rates increase, as shown in Tables 3, 5, 7, and 9 and Figures 4, 6, 8, and 10. The system's profitability, on the other hand, decreases for three different failure rates in Tables 2, 4, 6, and 8 and Figures 3, 5, 7, and 9 but increases for three different repair rates in Tables 3, 5, 7, and 9 and Figures 4, 6, 8, and 10.

The concept of law maintenance is backed up by the net profit generated by system operations. Based on the findings, management, reliability engineers, maintenance managers, and system designers can benefit from this research.

Future direction of the current paper will address optimization of some reliability metrics such as reliability, availability, profit, mean time to repair, and mean time to failure using optimization techniques such as genetic algorithm, particle swamp optimization, and Tabu search.

Ethical Statement

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

Conflicts of Interest

The authors declare that they have 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.

References

Abunima, H., & Teh, J. (2020). Reliability of PV systems based on Tim-varying failure rates. *IEEE Access*, *8*, 14367–14376. https://doi.org/10.1109/ACCESS.2020.2966922

Aggarwal, C., Ahlawat, N., & Malik, S. C. (2021). Profit analysis of a standby repairable system with priority to preventive maintenance and rest of server between repairs. *Journal of Reliability and Statistical Studies*, *14*(1), 57–80. https://doi.org/10.13052/jrss0974-8024.1414

Bhaskaran, S., Marappan, R., & Santhi, B. (2021). Design and analysis of a cluster-based intelligent hybrid recommendation system for e-learning applications. *Mathematics*, *9*(2), 197. https://doi.org/10.3390/math9020197

Barak, M., Neeraj, S., & Barak, S. K. (2018). Profit analysis of a two-unit cold standby system model operating under different weather conditions. *Life Cycle Reliability and Safety Engineering*, *7*(3), 173–183. https://doi.org/10.1007/s41872-018-0048-6

Bhardwaj, R. K., & Kaur, K. (2021). Performance analysis of a standby system using exponential-Rayleigh-Weibull distributions. *Turkish Journal of Computer and Mathematics Education*, *12*(2), 2881–2892.

Garg, H. (2022). Reliability and industrial engineering problems: Theory and applications. *Recent Advances in Computer Science and Communications*, *15*(4), 480–480. https://doi.org/10.2174/266625581504220314232058

He, Y., Gu, C., Han, X., Cui, J., & Chen, Z. (2017). Mission reliability modeling for multi-station manufacturing system based on quality state task network. *Journal of Risk and Reliability, 231*(6), 701–715. https://doi.org/10.1177/1748006X17728599.

He, Y., Han, X., Gu, C., & Chen, Z. (2018). Cost-oriented predictive maintenance based on mission reliability state for cyber manufacturing systems. *Advances in Mechanical Engineering, 10*(1), 1–15. https://doi.org/10.1177/1687814017751467

Hu, J., Shen, J., & Shen, L. (2020). Periodic preventive maintenance planning for systems working under a Markovian operating condition. *Computers & Industrial Engineering*, *142*, 106291. https://doi.org/10.1016/j.cie.2020.106291.

Kamal, M., Modibbo, U. M., AlArjani, A., & Ali, I. (2021). Neutrosophic fuzzy goal programming approach in selective maintenance allocation of system reliability. *Complex & Intelligent Systems*, *7*(2), 1045–1059. https://doi.org/10.1007/s40747-021-00269-1

Khan, M. F., Modibbo, U. M., Ahmad, N., & Ali, I. (2022). Nonlinear optimization in bi-level selective maintenance allocation problem. *Journal of King Saud University-Science*, *34*(4), 101933. https://doi.org/10.1016/j.jksus.2022.101933

Kumar, A., Pawar, D., & Malik, S. C. (2019). Profit analysis of a warm standby non-identical units system with single server subject to preventive maintenance. *International Journal of Agricultural and Statistical Sciences*, *15*(1), 261–269.

Kundu, T., & Garg, H. (2022). A hybrid TLNNABC algorithm for reliability optimization and engineering design problems. *Engineering with Computers, 38*(6), 5251–5295. https://doi.org/10.1007/s00366-021-01572-8

Lado, A., & Singh, V. (2019). Cost assessment of complex repairable system consisting two subsystems in series configuration using Gumbel Hougaard family copula. *International Journal of Quality & Reliability Management*, *36*(10), 1683–1698, https://doi.org/10.1108/IJQRM-12-2018-0322.

Lado, A. K., Singh, V. V., Ismail, K. H., & Ibrahim, Y. (2018). Performance and cost assessment of repairable complex system with two subsystems connected in series configuration. *International Journal of Reliability and Applications*, *19*(1), 27–42.

Manglik, M., & Ram, M. (2013). Reliability analysis of a two-unit cold standby system using Markov process. *Journal of Reliability and Statistical Studies*, *6*(2), 65–80.

Marappan, R., & Sethumadhavan, G. (2022). Solving graph coloring problem using divide and conquer-based turbulent particle swarm optimization. *Arabian Journal for Science and Engineering, 47*(8), 9695–9712. https://doi.org/10.1007/s13369-021-06323-x

Modibbo, U. M., Arshad, M., Abdalghani, O., & Ali, I. (2021). Optimization and estimation in system reliability allocation problem. *Reliability Engineering & System Safety*, *212*, 107620. https://doi.org/10.1016/j.ress.2021.107620

Pundir, P. S., Patawa, R., & Gupta, P. K. (2018). Stochastic outlook of two non-identical unit Parallel system with priority in repair. *Cogent Mathematics & Statistics*, *5*(1), 1467208, https://doi.org/10.1080/25742558.2018.1467208.

Shekhar, C., Kumar, A., & Varshney, S. (2020). Load sharing redundant repairable systems with switching and reboot delay. *Reliability Engineering & System Safety*, *193*, 106656. https://doi.org/10.1016/j.ress.2019.106656.

Uswarman, R., & Rushdi, A. M. (2021). Reliability evaluation of rooftop solar photovoltaic using coherent threshold systems. *Journal of Engineering Research and Reports*, *20*(2), 32–44.

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