Modelling and Reliability Analysis of Power Cables Used as a Two Unit Hot Standby System with Preference of Repair over Replacement in the Metro Railways

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Abstract: In this study we aim to do an analysis of the profitability and reliability of a system used primarily in Metro Train Networks consisting of a power cable rated for 33KV. The wires for the feed to each substation are laid in loops. As a starting point, two cables of the same voltage are laid with one being operational and another being a hot standby for backup. The moment the primary operational cable fails the backup cable immediately becomes operational. In the situation of a cable failure, it is considered if repairing the damaged cable can be done as opposed to repairing it. The moment both the operational as well as the back-up cables fail, the system is brought to a complete halt. Cable failures are categorized in two groups viz. irreparable failures & repairable failures. Regenerative Point Technique & Semi-Markov Processes are the methodologies used to derive the data that depicts real-failure situations or any other parameters of system effectiveness. This analysis is being done to enable multiple cases to detect and realize essential profit-analysis results for the system in question.

Keywords: power Cables; system effectiveness; semi-Markov processes; profit analysis; regenerative point technique.

1. Introduction

One of the studies that is of utmost importance to enable effective maintenance and optimal utilization of different industrial engineering systems is the Reliability study [1-3]. A huge amount of research has been carried out on the profit analysis and reliability of multiple types of redundant standby systems by various persons including [4-8], [14] and [16]. Mr. G. Taneja & B. Parashar[9] used real data collected from various industrial sources to analyze a PLC system. A three-unit parallel CC plant system was examined by A.G. Mathew et al. [10]. The various aspects of maintaining and variation of the demands of various systems were discussed by Z. Zhang et al. [11] and G. Taneja [15]. Work was also conducted on ID fans in a thermal plant by B. Parashar & A. Naithani [12&13] involving various conditions that made the system work at complete/partial capacity. The degradation of a system was studied by S. Zhao et al. [17] including random failure & condition monitoring. A discussion based upon real collected data was done by Ranu Pandey et al. [18] on a system comprising of power cables of a dual unit cold standby with inspection being done before the failure to be declared under Repair/Replacement for the Metro Railways. A robust study was conducted by Sunil
Bhardwaj et al. [19] about the effects of the neural network on the operating lifespan of a locomotive engine. In our modern day human life, Electricity is of paramount importance. Conductors are the medium through which Electrical Energy moves between two points. A conductor covered with insulation is known as a Cable, the have different ratings such as 110V, 220V, 440V, 11KV, 33KV, 66KV, 110KV, 220KV and so on. Therefore, cables are often known as the superhighways of energy transportation. Reduction of failure to lowest level [20] is vital in ensuring the systems works efficiently. In this, tools that use mathematical modelling are extremely handy as they help in predicting & assessing the breakdown/failure. In order to critically investigate the issues of breakdown/failure & for achieving solutions that are near-reality, probability analysis is used. In the discussed system of Metro Railways, the greater availability of the present Electrical Systems can be directly improved by reducing the number of break-down events. As a result of the above, monetary reward can be correlated to the reduction in time loss for reworking & maintenance of the system to make it operational again.

In today’s connected world, Railway and other transport network are an important and integral part of life. The concept of Metro Transportation Networks has been introduced by the Ministry of Railways as they allow us to reach from one destination to another within a city with convenience and ease. These projects have turned out to be a resounding success. For the particular metro network, power is supplied using various cable of rated capacities (220, 132, 66, 33, 25 KV) to allow the system to work efficiently. An extensive failure data collection effort spanning 7 years has been conducted on the 33 KV electric supply cable. These supply cable/cables feeding to individual stations are laid in loops. This is done to reduce the damage of cables as a result of various defects. Therefore, the primary concern is the maintaining of the cables as this directly impacts the functioning of our Metro Railways network. This paper has been aimed at studying if and how a 2-unit standby/backup power cable setup of the 33 KV capacity line can impact the reliability of the overall system. The observation was that if for any reason the main/operational power cable fails, the back-up/standby cable can immediately take over the load and continue supplying the power thereby enabling immediate repairing of the damaged cable without any delay or system down-time, it was also noted that repairing the damaged cable was a better alternative to replacement. Regenerative point technique and semi-markov processes are the methodologies used to analyze the system effectiveness:

- Mean Time to System Failure
- The Steady State Availability Analysis
- A occupied period in which the repairman shall conduct repairs/replacements in the power cable at \( t = 0 \)
- The number of times, expectedly, the repairman visits at \( t = 0 \)
- Number of repairs expected
- The profit expectations from the system

2. Symbols and Notations

\[ O \] Power cable is in operative state

\[ O_{hs} \] Power cable is in hot standby

\[ \lambda \] Rate of failure of the power cable that is in operative state (constant)
\( p \) Probability of the failure being repairable

\( q \) Probability of the failure being irreparable

\( F_t \) A major failure, resulting the unit being in repair

\( F_{rp} \) Unit is being replaced

\( F_R \) From its previous state the unit is in continuation of repair.

\( F_{RP} \) From its previous state the unit is in continuation of replacement.

\( w_r \) Unit that has failed and is awaiting repair

\( w_{rp} \) Unit that has failed and is awaiting replacement

\( \alpha \) Repairable failure rate (constant)

\( \beta \) Replacement failure rate (constant)

\( g(t), G(t) \) p.d.f. and c.d.f. of time taken to repair unit after a major failure

\( g_s(t), G_s(t) \) p.d.f. and c.d.f. of time taken to replace unit after a major failure

\( w(t), W(t) \) p.d.f. and c.d.f. of time a failed unit is waiting

\( q_{ij}(t), Q_{ij}(t) \) First passage of time \( i \) to \( j \) or to a state of failure \( j \), from a regenerative state p.d.f. and c.d.f. of the, without going to any other regenerative state in \( (0, t] \)

\( p_{ij} \) Probability of transition from a state of regeneration \( i \) to state of regeneration \( j \).

\( M_i(t) \) Probability of a system being up initially in the regenerative state \( i \) at time \( t \) without having passed through another regenerative state.

\( m_{ij} \) Transition from regenerative state \( i \) to state \( j \) without passing through any other regenerative state and its contribution to mean sojourn time

\( \mu_i(t) \) The mean sojourn time in one individual regenerative state before passing into any other regenerative state.

\( \mathcal{L}, \mathcal{S} \) Laplace Stieltje’s and Laplace convolution’s symbols

\( \ast, ** \) Laplace Stieltje’s and Laplace transform’s symbols

\( C_0 \) Revenue generated for every unit of up time

\( C_1 \) The cost of the repairman conducting repairs for every unit of up time.

\( C_2 \) The cost of the repairman conducting replacement for every unit of up time.
The cost for every repairman visit.

The cost to replace a single unit.

The system being in a Steady-State of availability.

At \( t = 0 \), the period in which the repairman is busy for repairs.

At \( t = 0 \), the period in which the repairman is busy for replacement.

At \( t = 0 \), the expected number of visits of the repairman.

The number of replacements as expected.

3. Data Summary

The captured data has given us the following values:

- The approximate value of failure rate \( \lambda = 0.00018 \) per hour
- The approximate value of repair rate \( \alpha = 0.066 \) per hour
- The approximate value of replacement rate \( \beta = 0.002 \) per hour
- The probability of repairable failure \( p = 0.8 \)
- The probability of replaceable failure \( q = 0.2 \)
- The expected cost of Revenue up time \( C_0 = 59000 \)
- The expected cost of repairman during repair \( C_1 = 608 \)
- The expected cost of repairman during replacement \( C_2 = 49 \)
- The expected cost of repairman per visit \( C_3 = 1000 \) per hour
- The expected cost of cable replacement \( C_4 = 151000 \)

(INR is the currency used in all costs.)

4. Description about the model and assumptions

In this probabilistic model, we are using the assumptions as mentioned below:

1) To start off, we are using a system at full capacity utilizing dual cables for supplying power, one of them is in an operative state while the other is a hot-standby/backup cable.
2) Both power cables are setup in parallel and are identical.
3) When the primary cable fails, the hot-standby automatically resumes operation, therefore there is no down-time.
4) Every time a unit fails, it gets marked for conducting repairs.
5) Rate of failure is same for both operational and the hot-standby unit.
6) Repair is the preferred choice over replacement of unit.
7) The repair times of the system and the failure of a unit are assumed to follow
general time and exponential distribution respectively.
8) On demand availability of the repairman is assumed for both replacement as well
as repair operations.
9) Post repair, the unit works with the same efficiency as a new unit.
10) When both units stop working, the system enters a state of Failure.
11) Independence of all variables that may randomly occur is assumed.

5. Transition Diagram

![Transition Diagram]

Fig.1: State Transition Diagram

- Point of regeneration
- System is in a Operative State
- System is in a Failed State

According to Fig.1, all points under consideration in the system are shown in the state
transition diagram. Regenerative states are all those points in which the regeneration points
are 0, 1, 2, 3, 4, 5, 6. Up states are points 0, 1, 2 and the failed states are 3, 4, 5, 6.

6. Mean Sojourn Times & Transition Probabilities

Probabilities of the steady-state are:

\[ dQ_{00}(t) = p(2\lambda)e^{-2\lambda t} dt, \quad dQ_{02}(t) = q(2\lambda)e^{-2\lambda t} dt, \quad dQ_{13}(t) = p\lambda e^{-\lambda t} \bar{G}(t)dt, \]
\[ dQ_{14}(t) = q\lambda e^{-\lambda t} \bar{G}(t)dt, \quad dQ_{16}(t) = e^{-\lambda t} g(t)dt, \quad dQ_{25}(t) = p\lambda e^{-\lambda t} \bar{G}_1(t)dt, \]
\[ dQ_{26}(t) = q\lambda e^{-\lambda t} \bar{G}_1(t)dt, \quad dQ_{28}(t) = e^{-\lambda t} g_1(t)dt, \quad dQ_{11}^{13}(t) = p[\lambda e^{-\lambda t} \bar{G}]g(t)dt, \]
\[ dQ_{11}^{14}(t) = q[\lambda e^{-\lambda t} \bar{G}]g_1(t)dt, \quad dQ_{11}^{25}(t) = g(t)dt, \quad (1) \]

\[ p_{ij} = \lim_{s \to 0} q_{ij}^*(s) \] are the non-zero elements, which can be obtained by

\[ p_{01} = p, \quad p_{02} = q, \quad p_{13} = p[1 - g^*(\lambda)], \quad p_{14} = q[1 - g^*(\lambda)], \quad p_{10} = g^*(\lambda), \quad p_{25} = p[1 - g^*(\lambda)]. \]
\[ p_{26} = q[1 - g^i(\lambda)], \quad p_{11}^i = p[1 - g^i(\lambda)], \quad p_{12}^i = q[1 - g^i(\lambda)], \quad p_{22}^i = q[1 - g^i(\lambda)], \quad p_{52} = 1. \]  \hspace{1cm} (2)

In accordance with the above probabilities of the steady-state transition, we can verify that

\[ p_{01} + p_{02} = 1, \quad p_{10} + p_{13} + p_{14} = p_{10} + p_{11}^i + p_{12}^i = 1, \quad p_{20} + p_{25} + p_{26} = p_{20} + p_{25} + p_{22}^i = 1. \]  \hspace{1cm} (3)

In state \( i \), the Mean Sojourn Time \( (\mu_i) \) is

\[ \mu_0 = \frac{1}{2\lambda}, \quad \mu_1 = \frac{1 - g^i(\lambda)}{\lambda}, \quad \mu_2 = \frac{1 - g^i(\lambda)}{\lambda}, \quad \mu_s = \int_0^\infty t g(t) dt. \]  \hspace{1cm} (4)

The mathematical expression for the unconditional mean time as required by the system from the time of entrance into state \( i \) transitioning to any regenerative state \( j \) is

\[ m_j = \int_0^\infty tdQ_j(t) = -q_j^i(0). \]  \hspace{1cm} (5)

Hence,

\[ m_{01} + m_{02} = \mu_0 + m_{10} + m_{13} + m_{14} = \mu_1 + m_{20} + m_{25} + m_{26} = \mu_2 + m_{10} + m_{11}^i + m_{12}^i = \kappa_1, \]

\[ m_{20} + m_{25} + m_{26} = p\mu_2 + q\kappa_2, \quad m_{52} = \mu_s = \kappa_1. \]  \hspace{1cm} (6)

In which,

\[ \mu_s = \kappa_1 = \int_0^\infty G(t) dt = \int_0^\infty t g(t) dt, \quad \kappa_2 = \int_0^\infty G_i(t) dt = \int_0^\infty t g_i(t) dt. \]

### 7. Measurement of the effectiveness of System

#### 7.1. Mean Time to System Failure (MTSF)

We take the absorbing state to be the state in which the system has failed, Therefore \( \phi_i(t) \), for \( i = 0,1,2,3,4,5,6 \); from the first passing of time from the \( i^{th} \) state to the state in which failure occurs, \( \phi_i(t) \), is the cumulative distribution function. Now, for the recursive relation for \( \phi_i(t) \) the MTSF of the discussed system may be calculated as

\[ \phi_0(t) = Q_{00}(t) \otimes \phi_0(t) + Q_{02}(t) \otimes \phi_2(t), \quad \phi_1(t) = Q_{10}(t) \otimes \phi_0(t) + Q_{13}(t) + Q_{14}(t), \]

\[ \phi_2(t) = Q_{20}(t) \otimes \phi_0(t) + Q_{25}(t) + Q_{26}(t). \]  \hspace{1cm} (7)

Now, if we take the Laplace-Stieltjes Transform (L.S.T.) for the give relation on both the sides as pointed out by (7) and and they are solved for \( \phi_0^*(s) \), we get the following

\[ \phi_0^*(s) = \frac{N_0(s)}{D_0(s)}, \]  \hspace{1cm} in which, the Laplace-Stieltjes Transformation of \( \phi_0(s) \) is \( \phi_0^*(s) \).
Hence, if the system starts from state ‘0’ the MTSF is given as

\[
MTSF = \lim_{s \to 0} \frac{1 - \phi^{\infty}_0(s)}{s} = \frac{D_0(0) - N_0'(0)}{D_0(0)} = \frac{N}{D},
\]

In which,

\[
N = \mu_0 + p_{01} \mu_1 + p_{02} \mu_2, D = 1 - p_{01} p_{10} - p_{02} p_{20}.
\]  

(8)

7.2. Availability Analysis

At an instant of time denoted as \(t\), if the system has entered into a regenerative state, then the probability of the system working is \(A_0(t)\)

Thus,

\[
A_0(t) = M_0(t) + q_{01}(t) \odot A_1(t) + q_{02}(t) \odot A_2(t),
\]

\[
A_1(t) = M_1(t) + q_{11}(t) \odot A_0(t) + q_{12}(t) \odot A_2(t) + q_{10}(t) \odot A_0(t),
\]

\[
A_2(t) = M_2(t) + q_{20}(t) \odot A_0(t) + q_{21}(t) \odot A_1(t) + q_{22}(t) \odot A_2(t),
\]

\[
A_0(t) = q_{02}(t) \odot A_2(t).
\]  

(9)

where, \(M_0(t) = e^{-\lambda t}, M_1(t) = e^{-\lambda t} \overline{G}(t), M_2(t) = e^{-\lambda t} \overline{G_1}(t)\).

Now if on the above equations we use Laplace transform to solve the equations for \(A_0^*(s)\), the result we get is

\[
A_0^*(s) = \frac{N_1(s)}{D_1(s)},
\]

\(A_0\) denoting the system availability in a steady state is found to be

\[
A_0 = \lim_{s \to 0} s \cdot \frac{N_1(s)}{D_1(s)} = \frac{N_1(0)}{D_1(0)} = \frac{N_1}{D_1},
\]

Where, \(N_1 = (\mu_0 p_{20} + \mu_2 p_{20})(1 - \mu_2^i) + p_{01}(\mu_1 p_{20} + \mu_2 p_{22})\),

\[
D_1 = \mu_0 p_{20}(1 - p_{11}^i) + \kappa_1 p_{01} p_{20} + (p_0 \mu_2 + q_0 \kappa_2 + \mu_3 p_2 + p_0 \kappa_1) (1 - p_{11}^i - p_{01} p_{10}).
\]  

(10)

7.3. Analysis of the busy period of the Repairman (Only during repairs)

\(B_0^*(s)\), the fraction of time during which the system is being repaired by the repairman is calculated using the below mentioned recursive relation

\[
B_0(t) = q_{01}(t) \odot B_1(t) + q_{02}(t) \odot B_2(t),
\]

\[
B_1(t) = W_1(t) + q_{10}(t) \odot B_0(t) + q_{11}(t) \odot B_1(t) + q_{12}(t) \odot B_2(t),
\]

\[
B_2(t) = W_2(t) + q_{20}(t) \odot B_0(t) + q_{21}(t) \odot B_1(t) + q_{22}(t) \odot B_2(t).
\]  

(11)
\[ B_2(t) = q_{20}(t) \otimes B_0(t) + q_{25}(t) \otimes B_5(t) + q_{25}(t) \otimes B_5(t) \]

In which, \( W_s(t) = \bar{G}(t), W_s(t) = \bar{G}(t). \)

Now if on the above equations we use Laplace transform to solve the equations for \( B_0'(s) \), the result we get is

\[ B_0'(s) = \frac{N_2(s)}{D_1(s)}. \]

The repairman’s busy period in a steady state is found by,

\[ B_0 = \lim_{s \to 0} sB_0'(s) = \frac{N_2}{D_1}. \]

In which, \( N_2 = \kappa_1(p_{02}P_{20} + p_{01}p_{12}P_{25} + p_{02}P_{20} - p_{02}P_{25}p_{31}) \) and we have already calculated \( D_1(s) \).

7.4. Analysis of the busy period of the Repairman (Only during replacement)

\[ BR_0(t) = q_{01}(t) \otimes BR_1(t) + q_{02}(t) \otimes BR_2(t), \]

\[ BR_1(t) = q_{10}(t) \otimes BR_0(t) + q_{11}(t) \otimes BR_1(t) + q_{12}(t) \otimes BR_2(t), \]

\[ BR_2(t) = W_2(t) + q_{20}(t) \otimes BR_0(t) + q_{25}(t) \otimes BR_5(t) + q_{25}(t) \otimes BR_5(t), \]

\[ BR_5(t) = W_5(t) + q_{52}(t) \otimes BR_2(t). \]

In which, \( W_2(t) = \bar{G}_1(t), W_5 = \bar{G}_5(t). \)

Now if on the above equations we use Laplace transform to solve the equations for \( BR_0'(s) \), the result we get is

\[ BR_0'(s) = \frac{N_3(s)}{D_3(s)}. \]

The repairman’s busy period in a steady state is found by,

\[ BR_0 = \lim_{s \to 0} sBR_0'(s) = \frac{N_3}{D_3}. \]

In which, \( N_3 = \kappa_2(1 + p_{25})(p_{01}p_{12} + p_{02} - p_{02}p_{31}) \) and it is already specified to us what \( D_3(s) \) is.

7.5. The Number of Visits the Repairman is expected to make

\[ V_0(t) = Q_{01}(t) \otimes [1 + V_1(t)] + Q_{02}(t) \otimes [1 + V_2(t)]. \]
\[ V_1(t) = Q_{30}(t) \otimes V_0(t) + Q_{11}^5(t) \otimes [1 + V_1(t)] + Q_{12}^4(t) \otimes [1 + V_2(t)]. \]  
(15)

\[ V_2(t) = Q_{20}(t) \otimes V_0(t) + Q_{12}^5(t) \otimes [1 + V_2(t)] + Q_{23}(t) \otimes [1 + V_3(t)]. \]  
\[ V_3(t) = Q_{32}(t) \otimes [1 + V_3(t)]. \]

Now if on the above equations we use Laplace transform to solve the equations for \( V_0^{**}(s) \), the result we get is

\[ V_0^{**}(s) = \frac{N_4(s)}{D_1(s)}. \]

The repairman’s number of visits per unit time (expected) in a steady state is found by,

\[ V_0 = \lim_{s \to 0} s V_0^{**}(s) = \frac{N_4}{D_1}. \]

In which, \( N_4 = (1 - p_{31}^4) p_{20} + p_{01} p_{20} (p_{31}^3 + p_{12}^1) + (p_{01} p_{12}^4 + p_{02} - p_{02} p_{11}^3)(2 p_{25} + p_{25}^4). \)  
(16)

7.6. The number of expected replacements.

\[ R_0(t) = Q_{30}(t) \otimes R_1(t) + Q_{12}(t) \otimes [1 + R_2(t)]. \]

\[ R_1(t) = Q_{10}(t) \otimes R_0(t) + Q_{11}^5(t) \otimes R_1(t) + Q_{12}^4(t) \otimes [1 + R_2(t)]. \]  
\[ R_2(t) = Q_{20}(t) \otimes R_0(t) + Q_{12}^5(t) \otimes [1 + R_2(t)] + Q_{23}(t) \otimes [1 + R_3(t)]. \]

\[ R_3(t) = Q_{32}(t) \otimes [1 + R_3(t)]. \]

Now if on the above equations we use Laplace transform to solve the equations for \( R_0^{**}(s) \), the result we get is

\[ R_0^{**}(s) = \frac{N_5(s)}{D_1(s)}. \]

The number of replacements (expected) in a steady state is found by,

\[ R_0 = \lim_{s \to 0} s R_0^{**}(s) = \frac{N_5}{D_1}. \]

In which, \( N_5 = (1 + p_{23}) (1 - p_{31}^3 - p_{01} p_{10}) \) and it is already specified to us what \( D_1(s) \) is.  
(18)

8. Analysis of Profit

In a steady state, the Total Revenue Generated (Expected) in \([0, t]\) minus The Total Repair Cost (Expected) in \([0, t]\) minus The Cost per Visit of the Repairman (Expected) in \([0, t]\) minus
The Total Costs of Replacement in \([0,t]\) equates to the expected Profit as denoted by \(P\). Therefore, \(P(0,t)\) is calculated as

\[
P = C_0A_0 - C_1B_0 - C_2BR_0 - C_3V_0 - C_4R_0,
\]

(19)

9. Particular Case

In any specific particular case, exponential distribution of the rate of repair and replacement is assumed, such as \(g(t) = \alpha e^{-\alpha t}; \quad g_1(t) = \beta e^{-\beta t}\)

Therefore we get the following system effectiveness measures when we use the values of the rate of repair or rate of replacement alongwith the various probabilities:

The MTSF is: 13930106.277 hours

\(A_0\), which is the value of the system availability is: .9999926

\(B_0\), denoting the busy period for a repairable case of failure of the repairman as expected is: .00044

\(BR_0\), denoting the busy period for a replacement case of failure of the repairman as expected is: .00364

\(V_0\), denoting the number of visits the repairman makes as expected is: .00003598

\(R_0\), denoting the number of replacements to be expected is: .00000729

10. Analysis using graphs

Fig.2: Mean Time to System Failure Vs Rate of Failure
Fig. 3: System Availability vs Rate of Failure

Fig. 4: For various units of revenue per unit up time ($C_0$), the Profit $P$ vs Rate of Failure $\lambda$

Fig. 5: For different values of Repair Rate ($\alpha$), the Profit $P$ vs Rate of Failure $\lambda$
Analysing the above graphs, we can make the following interpretations.

i. Fig. 2 shows the increment in the rate of failure \( \lambda \) with respect to the decrement in the Mean Time to System Failure.

ii. Fig. 3 shows that with an increase in the rate of failure \( \lambda \) the system availability decreases.

iii. Fig. 4 shows that for different values of revenue per unit up time \( C_0 \) for a given system; with an increase in the rate of failure \( \lambda \) the Profit \( P \) decreases. It is further noted, (a) For \( C_0=59000 \) therefore \( P \geq 0 \) according as \( \lambda \).
For benefiting the system for \( C_0 = 59000 \), \( \lambda \) must be lower than .1873. (b) Correspondingly, if \( C_0 = 59500 \) & 60,000; rate of failure \( \lambda \) should be lower to .1888 and .1941 respectively. Hence, to increase the system benefits, it is advised to keep \( C_0 \), the Revenue generated per unit of up time in such a way that the rate of failure does not go above the point of cut off.

iv. Fig.5 depicts that in the present study for different values of repair rate \( \alpha \); for an increase in rate of failure \( \lambda \) the profit \( P \) decreases. We also observe if \( \alpha = .064, .066, .068 \) in that case \( P > or< 0 \); hence as \( \lambda < or > \) point of cut off are .1873, .1874, .1875 respectively.

v. Fig.6 shows that for the present system; for different values of the rate of replacement \( \beta \); for an increase in the rate of failure \( \lambda \) there is a decrease of profit \( P \). We also note if \( \beta = .002, .0021, .0022 \) in that case \( P > or< 0 \) hence as \( \lambda < or > \) point of cut off are .1873, .1889, .1921 respectively.

vi. Fig.7 proves that for an increase in the system availability, the profit \( P \) increases.

vii. Fig.8 reveals that for various values of \( C_3 \), the Per visit cost of the repairman, with increments in revenue per unit uptime \( C_0 \) there is an increment in profit \( P \). We also determine that (1) For \( C_3 = 1000 \) therefore \( P > or< 0 \) hence as \( C_0 > or< 60000 \). Therefore for the system benefit, if \( C_3 = 1000 \), then \( C_0 \) must be above 60,000. (2) Correspondingly, For \( C_3 = 2000, 3000 \) therefore \( P > or< 0 \) hence as \( C_0 > or< 60500, 61000 \) respectively. Therefore, for the benefit of the system we must keep \( C_3 \), which is the cost price for each repairman visit in a way so that \( C_0 \), which is the revenue per unit of up time is not less than the point of cut off.

**Conclusion & Future Scope**

This study has been conducted with the aim of achieving the targeted optimization of the current system to make it more sustainable and economically viable to operate. To increase the effectiveness of the system, various measures and metrics have been considered and in accordance with them calculations have been made to compute the MSTF, and to make probable predictions of the system availability and its overall reliability. In order to mark off the points of cut off, graphical representations of all the calculations have also been implemented. Thus we shall hope to see a system that is modified and optimized to mitigate and reduce the losses thereby correspondingly resulting in higher operating profit margins for the system.

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