Reliability Parameters of a Power Generating System with Shared Load

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Abstract: This study presents a model, based on power generating system with shared load. The whole generating system consists of three subsystems viz: subsystem A, subsystem B and subsystem C. The subsystem A consists of one generating unit and one inbuilt transformer. The subsystem B also contains the same units and is connected in parallel to subsystem A. The output of this power system goes through the subsystem C that consists of one outer transformer and which may be further distributed as desired. The system has three types of states, viz: normal, degraded and failed. All types of failure rates and repair rates of inbuilt transformers are exponential while other repair rates are distributed quite generally. Supplementary Variable Technique has been employed to obtain various state probabilities and then the reliability parameters have been evaluated for the whole generating system.

Key words: Reliability, availability, MTTF, SVT

INTRODUCTION

Electric energy demand has been rapidly increasing all over the world. This is attributed to greater industrialization and large-scale use of electric energy for agricultural purpose. The demand is likely to increase exponentially for many more decades to come. There are no signs of saturation in the foreseeable future. Electric supply authorities are likely to pay more attention to improve the utilization of generating equipment. The reliability of electric supply in India is very low. The public is likely to become more and more conscious of its rights to get uninterrupted supply at proper voltage. This would force the electric supply undertakings to analyze the system and take corrective measures to improve reliability.

Keeping these points in view, the author has considered a mathematical model by which the reliability of the generating system can be improved. The whole generating system consists of three subsystems viz, subsystem A, subsystem B and subsystem C. The subsystem A consists of one generating unit and one inbuilt transformer. The subsystem B, arranged in parallel with subsystem A, is a redundant system and also consists of one generating unit and one inbuilt transformer. The output of these two subsystems goes through the subsystem C that consists of one outer transformer and the electric supply may be further distributed from this subsystem C as desired. The power required at subsystem C is shared by two subsystems, A and B which will increase the availability of power in comparison to that which is, instead, produced by a single subsystem A. Supplementary Variable Technique has been employed to evaluate various reliability parameters of the generating system. The mathematical model of the whole system is shown in the state transition diagram.

ASSUMPTIONS

- At time $t = 0$, the system is in operable state.
- The subsystem B works as the redundant unit.
- All the failure rates and repair rates of unit A2 and unit B2 (inbuilt transformers) are exponential while other repair rates are distributed quite generally.
- The failure rate of all units is distinct.
- After the complete breakdown of the system, the repair rate is assumed as same.
- The system is in degraded state after the failure of either unit of subsystem A or subsystem B, or completely subsystem A or subsystem B.
- All the units recover their functioning perfectly after repair.

Formulation of the model: The probabilities given above are mutually exclusive and provide the complete markovian characteristic of the process. Therefore, using continuity arguments and elementary probability considerations, one get the following difference
differential equations governing the stochastic behaviour of the complex system, which is discrete in space and continuous in time:

\[
\begin{align*}
\frac{d}{dt}P(x,t) &+ \lambda_x + \lambda_n + \lambda_1 + \lambda_2 + \lambda P(t) = \\
&\int \mu_1(x)P_1(x,t)dx + \int \mu(z)P_1(z,t)dz + \int \mu_2(x)P_2(x,t)dx + \int \mu(z)P_2(z,t)dz + \\
&\int \mu_3(z)P_3(z,t)dz + \int \mu_4(y)P_4(y,t)dy + \\
&\int \mu(z)P_3(z,t)dz + \int \mu(z)P_4(z,t)dz + \\
&\int \mu(z)P_5(z,t)dz + \\
&\left(\frac{\partial}{\partial x} + \frac{\partial}{\partial t} + \lambda + \lambda_n + \mu_1(x)\right)P_1(x,t) = 0
\end{align*}
\]

(1)

\[
\begin{align*}
\frac{\partial}{\partial x} + \frac{\partial}{\partial t} + \lambda + \lambda_n + \mu_1(x)P_1(x,t) = 0
\end{align*}
\]

(2)

\[
\begin{align*}
\frac{\partial}{\partial x} + \frac{\partial}{\partial t} + \lambda + \lambda_n + \mu_1(z)P_2(z,t) = 0
\end{align*}
\]

(3)

\[
\begin{align*}
\frac{\partial}{\partial x} + \frac{\partial}{\partial t} + \mu(z)P_4(z,t) = 0
\end{align*}
\]

(4)

\[
\begin{align*}
\frac{\partial}{\partial y} + \frac{\partial}{\partial t} + \lambda + \lambda_n + \mu_2(y) + \lambda P_4(y,t) = 0
\end{align*}
\]

(5)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_4(z,t) = 0
\end{align*}
\]

(6)

\[
\begin{align*}
\frac{\partial}{\partial x} + \frac{\partial}{\partial t} + \mu(z)P_5(z,t) = 0
\end{align*}
\]

(7)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_3(z,t) = 0
\end{align*}
\]

(8)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_3(z,t) = 0
\end{align*}
\]

(9)

\[
\begin{align*}
\frac{d}{dt} + \lambda + \lambda_n + \lambda_1 + \lambda_2 + \lambda P_1(t) = \lambda x P_2(t)
\end{align*}
\]

(10)

\[
\begin{align*}
\frac{\partial}{\partial y} + \frac{\partial}{\partial t} + \lambda + \lambda_n + \mu_2(y) + \lambda P_2(t) = 0
\end{align*}
\]

(11)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_3(z,t) = 0
\end{align*}
\]

(12)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_4(z,t) = 0
\end{align*}
\]

(13)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_5(z,t) = 0
\end{align*}
\]

(14)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_3(z,t) = 0
\end{align*}
\]

(15)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_5(z,t) = 0
\end{align*}
\]

(16)

\[
\begin{align*}
\frac{\partial}{\partial z} + \frac{\partial}{\partial t} + \mu(z)P_7(z,t) = 0
\end{align*}
\]

(17)

Boundary conditions:

\[
\begin{align*}
P_2(0,t) &= \lambda_1 P_1(t) \\
P_3(0,t) &= \lambda_3 P_1(t) \\
P_4(0,t) &= \lambda_5 P_5(t)
\end{align*}
\]

(18)

\[
\begin{align*}
P_5(0,t) &= \lambda_1 \int P_1(x,t)dx + \lambda_2 \int P_2(x,t)dx
\end{align*}
\]

(19)

\[
\begin{align*}
P_6(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(20)

\[
\begin{align*}
P_7(0,t) &= \lambda_1 \int P_5(x,t)dx \\
P_8(0,t) &= \lambda_3 P_3(t)
\end{align*}
\]

(21)

\[
\begin{align*}
P_9(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(22)

\[
\begin{align*}
P_{10}(0,t) &= \lambda_5 P_5(t)
\end{align*}
\]

(23)

\[
\begin{align*}
P_{11}(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(24)

\[
\begin{align*}
P_{12}(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(25)

\[
\begin{align*}
P_{13}(0,t) &= \lambda_1 \int P_3(x,t)dy \\
P_{14}(0,t) &= \lambda_3 \int P_3(x,t)dy
\end{align*}
\]

(26)

\[
\begin{align*}
P_{15}(0,t) &= \lambda_3 \int P_3(x,t)dy + \lambda \int P_5(x,t)dx + \\
&\lambda \int P_6(x,t)dx + \lambda \int P_8(x,t)dx + \\
&\lambda P_9(t) + \lambda P_{10}(t) + \lambda P_{11}(t)
\end{align*}
\]

(27)

\[
\begin{align*}
P_{16}(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(28)

\[
\begin{align*}
P_{17}(0,t) &= \lambda_1 \int P_5(x,t)dx
\end{align*}
\]

(29)

\[
\begin{align*}
P_{18}(0,t) &= \lambda_1 P_1(t)
\end{align*}
\]

(30)

\[
\begin{align*}
P_{19}(0,t) &= \lambda_1 \int P_5(x,t)dx + \lambda \int P_6(x,t)dx + \\
&\lambda \int P_8(x,t)dx + \lambda \int P_9(x,t)dx + \\
&\lambda \int P_{10}(t) + \lambda P_{11}(t)
\end{align*}
\]

(31)

Initial conditions: \(P_1(0)\) and other state probabilities are zero.

Solution of the model: Taking Laplace Transform of Eq. 1-31 and on further simplification one may obtain:

\[
\begin{align*}
\bar{P}_1(s) &= \frac{1}{A(s)} \\
\bar{P}_2(s) &= \lambda_2 k_2(s)P_1(s) \\
\bar{P}_3(s) &= \lambda_3 k_3(s)P_1(s)
\end{align*}
\]

(32)

(33)

(34)
\[
\begin{align*}
\bar{P}_1(s) &= \lambda \lambda_k k_2(s) k_3(s) p_1(s) \\
\bar{P}_2(s) &= \frac{\lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \nu)} p_1(s) \\
\bar{P}_3(s) &= k_4(s) p_1(s) \\
\bar{P}_4(s) &= k_5(s) k_4(s) p_1(s) \\
\bar{P}_5(s) &= k_6(s) k_4(s) p_1(s) \\
\bar{P}_6(s) &= k_7(s) k_4(s) p_1(s) \\
\bar{P}_7(s) &= k_8(s) k_4(s) p_1(s) \\
\bar{P}_8(s) &= \lambda_2 (s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \nu) p_1(s) \\
\bar{P}_9(s) &= k_9(s) p_1(s) \\
\bar{P}_{10}(s) &= k_{10}(s) p_1(s) \\
\bar{P}_{11}(s) &= \lambda_2 \lambda_3 (s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \nu) p_1(s) \\
\bar{P}_{12}(s) &= k_{12}(s) p_1(s) \\
\bar{P}_{13}(s) &= k_{13}(s) k_4(s) p_1(s) \\
\bar{P}_{14}(s) &= k_{14}(s) k_4(s) p_1(s) \\
\bar{P}_{15}(s) &= k_{15}(s) k_4(s) p_1(s) \\
\bar{P}_{16}(s) &= k_{16}(s) k_4(s) p_1(s) \\
\bar{P}_{17}(s) &= k_{17}(s) k_4(s) p_1(s)
\end{align*}
\]

where,

\[
A(s) = (s + \lambda_a + \lambda_b + \lambda_1 + \lambda_2 + \lambda) - C(s) - C_1(s) - C_2(s) - C_3(s) - C_4(s) - C_5(s) - C_6(s) - C_7(s) - C_8(s) - C_9(s) - C_{10}(s) - C_{11}(s) - C_{12}(s) - C_{13}(s) - C_{14}(s)
\]

\[
k_1(s) = \frac{1 - S(s + \lambda + \lambda_b)}{s + \lambda + \lambda_b} \\
k_2(s) = \frac{1 - S(s + \lambda + \lambda_b)}{s + \lambda + \lambda_2}, k_3(s) = \frac{1 - S(s)}{s} \\
k_4(s) = (k_2(s) + k_3(s)) \\
k_5(s) = \frac{\lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} k_4(s) \\
k_6(s) = \frac{\lambda_2}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} k_4(s) \\
k_7(s) = \lambda_4 k_5(s), k_8(s) = \lambda_2 k_5(s) \\
k_9(s) = \frac{\lambda_3}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} k_4(s) \\
k_{10}(s) = \frac{\lambda_4}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} k_4(s) \\
k_{11}(s) = \frac{1 - S(s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \lambda)}{s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \lambda} k_{10}(s) \\
k_{12}(s) = \frac{\lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \lambda)} k_{10}(s) \\
k_{13}(s) = \frac{\lambda_2}{(s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \lambda)} k_{10}(s) \\
k_{14}(s) = \lambda_3 k_{12}(s), k_{15}(s) = \lambda_2 k_{12}(s) \\
k_{16}(s) = \frac{\lambda_2}{(s + \lambda + \lambda_a + \lambda_b + \lambda_1 + \lambda)} k_{10}(s) \\
k_{17}(s) = \lambda_4 k_4(s) + \lambda \lambda_2 k_2(s) + \lambda + \frac{\lambda \lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} + \lambda k_4(s) + \lambda k_4(s)
\]

\[
C_1(s) = \lambda_5 \bar{S}(s + \lambda + \lambda_b), \\
C_2(s) = \lambda_5 \bar{S}(s + \lambda + \lambda_b), \\
C_3(s) = \lambda_5 \bar{S}(s + \lambda + \lambda_b), \\
C_4(s) = k_6(s) \lambda_5 \bar{S}(s), \\
C_5(s) = k_6(s) \lambda_5 \bar{S}(s) \\
C_6(s) = \frac{\lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} \bar{S}(s + \lambda + \lambda_2 + \lambda_b) \\
C_7(s) = \frac{\lambda_1}{(s + \lambda + \lambda_a + \lambda_b + \lambda_2 + \lambda)} \bar{S}(s)
\]
The Laplace Transform of the probabilities that the system is in operable and down state at time \( t \), are given as follows:

\[
\begin{align*}
\mathcal{P}_{up}(s) &= \mathcal{P}_u(s) + \mathcal{P}_2(s) + \mathcal{P}_4(s) + \mathcal{P}_6(s) + \mathcal{P}_{11}(s) + \\
\mathcal{P}_{down}(s) &= \mathcal{P}_4(s) + \mathcal{P}_6(s) + \mathcal{P}_8(s) + \mathcal{P}_{10}(s) + \mathcal{P}_{12}(s)
\end{align*}
\]

\[
\begin{align*}
\mathcal{P}_{up}(s) &= \frac{1}{A'(0)} \left[ 1 + \lambda_2 k_2(0) + \lambda_3 k_3(0) + \right. \\
&+ \lambda_1 \left( \frac{\lambda_2}{v + \lambda_1 + \lambda_3 + \lambda_2 + \lambda} k_4(s) + \right. \\
&+ \left. \lambda_2 \left( \frac{\lambda_1}{v + \lambda_1 + \lambda_3 + \lambda_2 + \lambda} + k_{12}(s) \right) \right]
\end{align*}
\]

\[
\begin{align*}
\mathcal{P}_{down}(s) &= \frac{M_0}{A'(0)} \left[ \lambda_3 s k_6(0) + k_7(0) + k_8(0) + k_{12}(0) + k_{14}(0) + k_{16}(0) + \right. \\
&+ \left. k_{17}(0) \right]
\end{align*}
\]

**Particular Case:** When all repairs follow exponential distribution

\[
\mathcal{S}_I = \frac{\mu_I}{s + \mu_I}, \quad \mathcal{S}_I = \frac{\mu_I}{s + \mu_I}, \quad I = 1, 2
\]

Setting

\[
\mathcal{P}_u(s) = \frac{1}{g_i(s)}
\]

\[
\mathcal{P}_2(s) = g_i(s) P_2(s)
\]

\[
\mathcal{P}_4(s) = g_i(s) P_4(s)
\]

\[
\mathcal{P}_6(s) = g_i(s) P_6(s)
\]

\[
\mathcal{P}_{10}(s) = g_i(s) P_{10}(s)
\]

\[
\mathcal{P}_{12}(s) = g_i(s) P_{12}(s)
\]

\[
\mathcal{P}_{14}(s) = g_i(s) P_{14}(s)
\]

\[
\mathcal{P}_{16}(s) = g_i(s) P_{16}(s)
\]

\[
\mathcal{P}_{17}(s) = g_i(s) P_{17}(s)
\]
\[ \bar{P}_s(s) = g_s(s)P(s) \]  
\[ \bar{P}_o(s) = g_o(s)P(s) \]  
\[ \bar{P}_1(s) = g_1(s)P(s) \]  
\[ \bar{P}_{12}(s) = g_{12}(s)P(s) \]  
\[ \bar{P}_{31}(s) = g_{31}(s)P(s) \]  
\[ \bar{P}_{41}(s) = g_{41}(s)P(s) \]  
\[ \bar{P}_{42}(s) = g_{42}(s)P(s) \]  
\[ \bar{P}_5(s) = g_5(s)P(s) \]  

where,

\[ g_1(s) = \frac{\lambda_1}{s + \lambda_b + \lambda_1 + \lambda_2 + v} \]
\[ g_{12}(s) = \frac{\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_1 + \lambda_2 + \mu_1)} \]
\[ g_{13}(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda_2 + \mu_1)} \]
\[ g_{14}(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \mu_1)} \]
\[ g_{15}(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \mu_1)} \]
\[ g_{16}(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \mu)} \]

\[ g_2(s) = \frac{\lambda_1^2}{(s + \lambda + \lambda_b + \lambda_2 + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]
\[ g_3(s) = \frac{\lambda_1\lambda_2^2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]
\[ g_4(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]

\[ g_5(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]

\[ g_6(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]

\[ g_7(s) = \frac{\lambda_1\lambda_2}{(s + \lambda + \lambda_b + \lambda_1 + \lambda_2 + v)(s + \lambda + \lambda_2 + \lambda_b + \mu_1)} \]

**OPERATIONAL AVAILABILITY AND NON AVAILABILITY**

The Laplace Transform of the probabilities that the system is in operable and down state at time \(t\), are given as follows:

\[ \bar{P}_{up}(s) = \bar{P}_1(s) + \bar{P}_2(s) + \bar{P}_3(s) + \bar{P}_4(s) + \bar{P}_{12}(s) + \bar{P}_{31}(s) + \bar{P}_{41}(s) + \bar{P}_{42}(s) = \bar{P}_5(s) \]
\[ \bar{P}_{down}(s) = 1 - \bar{P}_{up}(s) \]

**Reliability:** The reliability is given by:

\[ R(t) = m_1e^{-\lambda t} + m_2e^{-\lambda t} + m_3e^{-\lambda t} + m_4e^{-\lambda t} + m_5e^{-\lambda t} \]  
where,

\[ q_1 = \lambda_1 + \lambda_b + \lambda_1 + \lambda_2 + \lambda, q_2 = \lambda_b + \lambda, q_3 = \lambda_1 + \lambda \]
\[ q_4 = \lambda_2 + \lambda, q_5 = \lambda_b + \lambda_1 + \lambda \]
\[ m_1 = m_b + m_b - 1 - m_2 - m_3 \]
NUMERICAL ILLUSTRATIONS

Analysis of availability: Setting

\[
\lambda_a = 0.001, \quad \lambda_b = 0.002, \quad \lambda_1 = 0.001, \\
\lambda_2 = 0.002, \quad \lambda = 0.009, \\
v = 0.95, \quad \mu_1 = 0.92, \quad \mu_2 = 0.86
\]

in the Eq. 70 and then taking the inverse Laplace transform, the operational availability is obtained as:

\[
P_{op}(t) = z_1 e^{-\lambda t} + z_2 e^{-\lambda t} + z_3 e^{-\lambda t} + \\
z_4 e^{-\lambda t} + z_5 e^{-\lambda t} + z_7 e^{-\lambda t}
\]

Substituting different values of \( t \) in equation (74) one may obtain Table 1 and Fig. 1.

Reliability analysis: Setting \( \lambda_3 = 0.001, \lambda_b = 0.002, \lambda_1 = 0.011, \lambda_2 = 0.015, \lambda = 0.05 \) in the Eq. 72 one may obtain the variations in reliability of the system with time as shown in Table 2 and Fig. 2.
Table 1: Variation of availability with time

| Time (t) | Availability [P_{up}(t)] |
|----------|---------------------------|
| 0        | 0.999982                  |
| 1        | 0.988951                  |
| 2        | 0.975725                  |
| 3        | 0.96178                   |
| 4        | 0.947687                  |
| 5        | 0.933666                  |
| 6        | 0.9198                    |
| 7        | 0.906119                  |
| 8        | 0.892634                  |
| 9        | 0.879346                  |
| 10       | 0.866255                  |
| 11       | 0.853359                  |
| 12       | 0.840654                  |
| 13       | 0.828138                  |
| 14       | 0.815809                  |
| 15       | 0.803663                  |

Table 2: Variation of reliability with time

| Time (t) | Reliability [R(t)] |
|----------|--------------------|
| 0        | 1                  |
| 1        | 0.951056           |
| 2        | 0.904185           |
| 3        | 0.859332           |
| 4        | 0.816437           |
| 5        | 0.77544            |
| 6        | 0.736279           |
| 7        | 0.698895           |
| 8        | 0.663224           |
| 9        | 0.629205           |
| 10       | 0.596777           |
| 11       | 0.565881           |
| 12       | 0.536456           |
| 13       | 0.508444           |
| 14       | 0.481789           |
| 15       | 0.456433           |

MTTF analysis:

- Setting the values $\lambda_2 = 0.02$, $\lambda_1 = 0.01$, $\lambda_b = 0.002$ and taking different values of $\lambda_a$ in the Eq. 73 one may obtain the variations of MTTF of the system against the failure rate of unit A1, ($\lambda_a$) as shown in Table 3 and Fig. 3.

- Setting the values $\lambda_2 = 0.02$, $\lambda_1 = 0.01$, $\lambda_a = 0.001$ and taking different values of $\lambda_b$ in the Eq. 73 one may obtain the variations of M.T.T.F. of the system against the failure rate of unit B1 ($\lambda_b$) as shown in Table 4 and Fig. 4.

- Setting the values $\lambda_2 = 0.02$, $\lambda_a = 0.001$, $\lambda_b = 0.002$ and taking different values of $\lambda$ in the Eq. 73 one may

Fig. 4: M.T.T.F. v/s Failure rate of unit B1

Table 3: Variation of M. T. T. F. with failure rate of A1 unit

| M.T.T.F. | 0.001 | 9.712430 | 4.955933 | 3.319280 |
|----------|-------|----------|----------|----------|
|          | 0.002 | 9.699658 | 4.953789 | 3.318573 |
|          | 0.003 | 9.687316 | 4.951683 | 3.317875 |

Fig. 5: M.T.T.F. v/s Failure rate of unit A2

Fig. 6: M.T.T.F. v/s Failure rate of unit B2
Table 4: Variation of M. T. T. F. with failure rate of B1 unit

| M.T.T.F. | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.1 |
|----------|------|------|------|------|------|------|------|------|------|------|
|          | 9.716869 | 9.71243 | 9.708154 | 9.704035 | 9.700066 | 9.696241 | 9.692557 | 9.689009 | 9.68559 | 9.682298 |
|          | 4.956836 | 4.955933 | 4.955048 | 4.954179 | 4.953325 | 4.952488 | 4.951665 | 4.950858 | 4.950065 | 4.949286 |
| MTTF     | 3.319596 | 3.31928 | 3.318968 | 3.318661 | 3.318357 | 3.318056 | 3.31776 | 3.317467 | 3.317177 | 3.316892 |

obtain the variations of MTTF of the system against the failure rate of unit A1 (λa) as shown in Table 5 and Fig. 5.

![State Transition Diagram](image)

Fig. 7: STATE TRANSITION DIAGRAM

Table 5: Variation of M. T. T. F. with failure rate of A2 unit

| M.T.T.F. | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.1 |
|----------|------|------|------|------|------|------|------|------|------|------|
|          | 22.274481 | 20.759512 | 19.765066 | 19.074417 | 18.53645 | 18.197981 | 17.908289 | 16.89009 | 16.8559 | 16.82298 |
|          | 15.618896 | 14.948854 | 14.650042 | 14.103583 | 13.825957 | 13.60778 | 13.432982 | 13.29058 | 13.290612 | 13.0746 |
| MTTF     | 11.988547 | 11.640022 | 11.362288 | 11.149179 | 10.978786 | 10.840281 | 10.726077 | 10.630732 | 10.550251 | 10.481655 |

...Concluding remarks...

CONCLUSION

The concept of redundancy of the generating unit can be applied to the areas where the electricity requirements are increasing at an alarming rate. The findings in Table 1 and 2 depicts that the system is available and reliable for a longer time period. The failures are considered to occur purely by chance for a component which is operating within its useful life period. So, under these conditions the calculations shown in Table 3-6 shows apparently that the failure rate is the reciprocal of the mean time to system failure (MTTF).

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NOTATIONS

- λi, u: Failure and constant repair rate of unit A2 or B2 (i = 1, 2).
- λj, μj(x): Failure and repair rate of unit A2 or B1 (j = a, b).
- λ2: Failure rate of subsystem C.
- μ(z): Repair rate when the system is in failed state.
- μ2(y): Repair rate of both units of subsystem A or subsystem B.
- P1(t): Probability that the system is in operable state at time t.
- Pj(t, Δt): Probability that the system is in degraded state at time t and elapsed repair time lies between x and x + Δ, where 9i = 2, 3)
- Pj(y, Δt): Probability that the system is in degraded state at time t and elapsed repair time lies between y and y + Δ, where (j = 6, 12)
$P_k(z, t) \Delta$: Probability that the system is in failed state at time $t$ and elapsed repair time lies between $z$ and $z + \Delta$, where ($k = 4, 7, 8, 9, 10, 13, 14, 15, 16, 17$)

$P_m(t)$: Probability that the system is in degraded state at time $t$ where ($m = 5, 11$)

$\int_0^{\infty}$, Otherwise stated.

 Operable $\quad$ Degraded $\quad$ Failed

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