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STOCHASTIC ANALYSIS OF A GAS TURBINE SYSTEM WITH PRIORITY AND RANDOM INSPECTION BY SINGLE SERVER UNDER DIFFERENT HUMID CONDITIONS

Pinki, Vijeta Kumari and Dalip Singh

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Department of Mathematics, Maharshi Dayanand University Rohtak, India
pinkichahar95@gmail.com, vijetadahiya1993@gmail.com and dsmdur@gmail.com

Abstract

In this study, we investigated the impact of two different humid levels on the reliability measures of a stochastic model for a gas turbine system composed of a gas turbine and a steam turbine. To enhance the system's overall performance, we prioritize gas turbine repair over steam turbine repair in addition to a combined inspection and preventative maintenance approach. To find some reliability measures, such as the mean time to system failure, availability, etc., semi-Markov process and regenerating point technique are utilized. These measures are analysed graphically based on the data obtained from a gas turbine power plant in Delhi, India.

Keywords: Gas Turbine, Steam Turbine; Reliability; Cost-Benefit; Maintenance;

1. Introduction

The growing global demand for electrical energy, driven by factors such as rapid industrialization, urbanization and the increasing number of electronic gadgets has put significant pressure on our existing power generation systems. Researchers from all around the world have conducted substantial research into the complex dynamics of energy supply, demand, and security in both developed and emerging economies [1-3]. The nation of India, which has to cope with its own unique issues and potential is the focus of in-depth research on electricity demand [4]. The study made by Zhang et al. goes beyond typical clustering algorithms to investigate novel approaches to analyse electricity usage trends [5]. Optimizing demand response initiatives within smart grids is studied by Derakhshan et al. using TBLO and SFL algorithms [6]. Furthermore, [7] points out the impact of these demand patterns on both power system costs and supply sufficiency. These research articles provide a comprehensive understanding of the complicated relationship between power demand and supply, as well as the issues created by shifting consumption patterns.

To address these issues, researchers and policymakers need to design and improve power generation systems that can satisfy the rising energy demands profitably and ensuring sustainability. Though, there are various ways to generate electricity, such as using water, sunlight, thermal energy from sources like coal, and harnessing nuclear reactions, leading to different types of power plants. In today's competitive energy markets, a new approach called the "Risk-Based Approach" is gaining attention for managing Virtual Power Plants. This approach is all about figuring out smart and efficient ways to schedule the activities of these virtual power plants [8]. Operating power generating systems in demanding environments indeed presents several challenges [9]. The performance of a system inevitably deteriorates when operated over lengthy periods of time under adverse conditions. When this degradation exceeds a certain threshold, it may lead components or subsystems to fail, compromising the overall safety of the system. As a result, one of the key objectives of engineering systems is to provide timely maintenance. Preventive maintenance and corrective maintenance are two essential approaches for maintaining and managing equipment and systems in various industries [10]. The primary objective of any maintenance strategy is to uphold the system functionality to the greatest extent possible while striking a balance between downtime and maintenance expenses, thereby avoiding catastrophic breakdowns. Zaho et al. studied the preventive maintenance scheduling on gas turbine power plant through a sequential approach [11].

The key objective of this research paper is to develop a comprehensive operational stochastic model for a combined cycle power plant. Gas turbines, a crucial part of combined cycle power plant, are responsible for this decision since they have amazing qualities including great efficiency, adaptability, and quick start-up times. The significance of our research lies in addressing a previously unexplored aspect of the literature. Although there is a lot of information on the reliability of combined cycle power plants, none of the existing studies have considered the impact of humidity with priority and random inspection within a stochastic model using the semi-Markov approach. Recognizing the importance of humidity in power plant management, we have addressed a research gap by incorporating this critical aspect into our analysis.

Statistical methods play a fundamental role in the development of reliability/stochastic models, offering valuable insights that can inform maintenance and repair planning for technical systems. These reliability criteria are used to measure the system's potential for maintenance and repair. Table 1 provides a comprehensive summary of the foundational statistical techniques employed during the creation of reliability/stochastic models for various gas turbine and combined cycle power plants within the domains of the energy sector in recent years. Many researchers in Table 1 studied the reliability models for gas turbine systems under different conditions using different methods but none of the existing studies have considered the impact of humidity with priority and random inspection within a stochastic model using the semi-Markov approach. Reliability models assist in figuring out how reliable a system is, how frequently it may fail, and how quickly it may recover from those failures. Creating such models for gas turbine power plants allows engineers and researchers to foresee future faults, develop effective maintenance procedures, and maximize the overall performance and operating efficiency of these systems.

This study aims to conduct a thorough investigation into the effects of two distinct humidity levels (i.e., humidity less than or equal to 50% and humidity greater than 50%) on the reliability measures of a stochastic model for a gas turbine system. The system comprises a gas turbine and a steam turbine and has been developed under specific assumptions that have not been addressed in the existing literature. Through a comprehensive investigation into the impact of humidity variations on the reliability measures of gas turbine systems, we aim to deepen our understanding and provide invaluable insights in this field. Thus it will provide a comprehensive analysis of our research methodology, the experimental setup, data collection, and, ultimately, the results and implications of our findings. By doing so, we aim to promote the efficient and reliable utilization of gas turbine systems, thus furthering the cause of sustainable energy generation and contributing to the broader goals of the industry.

Table 1: *Summary of literature review in recent years*

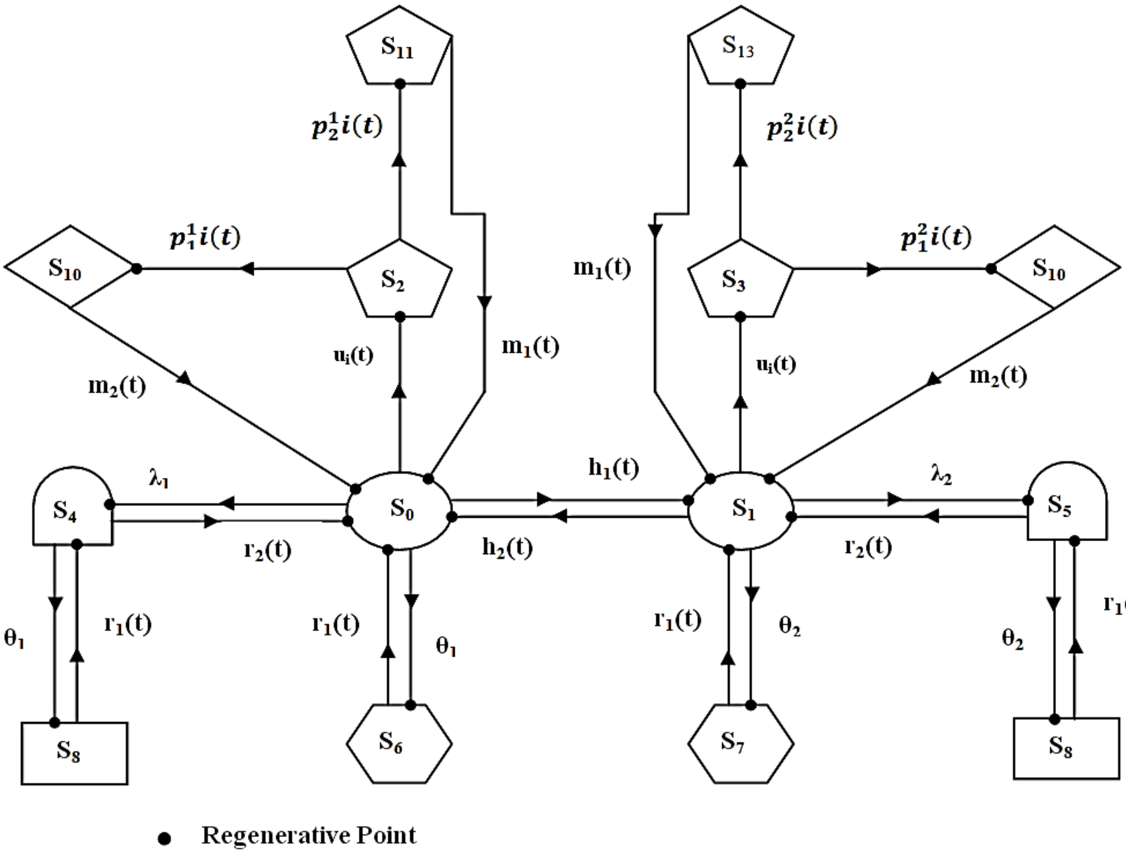
Methods	Model Structure	Characteristic of Study	References
Statistical Methods	Mathematical modeling	Impact of ambient conditions on CCPP in Syria	[12]
	AI-coherent modeling	Data-driven forecasting for a CCPP using BFGS algorithm	[13]
	Thermodynamic modelling	Effect of temperature and relative humidity on gas turbine	[14]
	Mathematical modeling	Effects of the intake air humidity on the gas turbine	[15]
Monte Carlo and MLE method	Stochastic modeling	CCPP study under temperature fluctuations in Tehran	[16]
PJM method	Four-state reliability model	Combined heat and power plants	[17]
Semi-Markov Process and RGT	Reliability modeling	CCPP with schedule inspection	[18]
	Reliability modeling	CCPP with random inspection	[19]
	Three-unit CCPP reliability modeling	Effect of ambient temperature with FCFS repair pattern on CCPP	[20]
	Reliability modeling	Effect of humidity on CCPP in Delhi	[21]

2. Modeling of System

In this paper, we discuss the impact of two different humid levels (i.e., humidity less than or equal to 50% and humidity greater than 50%) on the reliability measures of a stochastic model for a gas turbine system composed of a gas turbine and a steam turbine. To enhance the system's overall performance, we prioritize gas turbine repair over steam turbine repair in addition to a combined inspection and preventative maintenance approach as shown in Figure 1. To find some reliability measures, such as the mean time to system failure, availability, etc., we employ the semi-Markov process and regenerating point technique, which are well-suited for this type of analysis. At initial stage, both units, the gas turbine and the steam turbine are up and completely operational, operating together in a combined cycle. Steam turbine failure keeps the system in upstate mode with partially working and termed as single cycle. However, if the gas turbine fails, the system transitions to a downstate mode.

The following reasonable assumptions are used to create the model:

- The failure time distribution is presumed to be exponential, whereas the repair/maintenance time distribution is arbitrary.
- After each maintenance/repair activity, the unit is stated to be as satisfactory as new.
- The system's repair sequence adheres to a first come, first serve basis, except in cases of complete system failure, where priority is given to gas turbine repair over steam turbine repair.
- System failure is asserted when both units fail.



. **Figure 1:** *State Transition Diagram of the System*

Description of the states in Figure 1:

S_0/S_1 : Both units are operational when humidity is ≤ 50% / > 50%.
S_2/S_3 : System is down due to inspection when humidity is ≤ 50% / > 50%.
S_4/S_5 : System is operational with the gas turbine running and the steam turbine under repair when humidity is ≤ 50% / > 50%.
S_6/S_7 : System is down with the gas turbine under repair and the steam turbine also down when humidity is ≤ 50% / > 50%.
S_8/S_9 : System has failed, with the gas turbine under repair and the steam turbine awaiting repair when humidity is ≤ 50% / > 50%.
S_{10}/S_{12} : System is operational with the gas turbine running and the steam turbine under maintenance when humidity is ≤ 50% / > 50%.
S_{11}/S_{13} : System is down with the gas turbine under repair and the steam turbine also down when humidity is ≤ 50% / > 50%.

2.1 Notations

θ_1/θ_2 : rate of gas turbine failure when humidity is ≤/> 50%.

λ_1/λ_2 : rate of steam turbine failure when humidity is ≤/> 50%.

$BH_i^1(t)/BH_i^2(t)$: server is busy at a particular time t when the humidity is ≤/> 50%.

$DH_i^1(t)/DH_i^2(t)$: system is in a down state at specific time t when the humidity is ≤/> 50%.

$h_1(t)/H_1(t)$: pdf/cdf of time changing humidity from ≤ 50% to > 50%.

$h_2(t)/H_2(t)$: pdf/cdf of time changing humidity from > 50% to ≤ 50%.

$i(t)/I(t)$: pdf/cdf of the examination to identify the type of maintenance required.

$IH_i^1(t)/IH_i^2(t)$: system is under inspection at a particular time t when the humidity is ≤/> 50%.

$m_1(t)/M_1(t)$: pdf/cdf of gas turbine maintenance.

$m_2(t)/M_2(t)$: pdf/cdf of steam turbine maintenance.

p_1^1/p_1^2 : probability that an inspection will indicate the need for gas turbine maintenance when humidity is ≤/> 50%.

p_2^1/p_2^2 : probability that an inspection will indicate the need for steam turbine maintenance when humidity is ≤/> 50%.

$q_{ij}(t)/Q_{ij}(t)$: pdf/cdf of the first-passage time without visiting any other regenerative state from regenerative state i to a regenerative state j or a failed state j in (0, t).

$q_{ij}^{(k)}/Q_{ij}^{(k)}(t)$: pdf/cdf of first-passage time from regenerative state i to a regenerative state j, visiting state k one time in (0, t]

$r_1(t)/R_1(t)$: time for gas turbine repair in pdf/cdf respectively.

$r_2(t)/R_2(t)$: time for steam turbine repair in pdf/cdf respectively.

$u_i(t)/U_i(t)$: time required to inspect the system in pdf/cdf.

$VH_i^1(t)/VH_i^2(t)$: server's expected number of visits when humidity is ≤/> 50%.

©/ⓢ : Laplace convolution/ Laplace Stieltjes convolution

3. State Transition Probabilities and Mean Sojourn Time

The expression $dQ_{ij}(t)$ for all essential combinations of i and j is generated based on state transition diagram and the transition probabilities p_{ij} are computed by applying Laplace transform and utilizing $p_{ij} = \lim_{s\to 0} q_{ij}^*(s)$.

Table 2: *State Transition Probabilities*

$dQ_{01} = e^{-(\theta_1+\lambda_1)t}F_1$	$dQ_{02} = e^{-(\theta_1+\lambda_1)t}F_2$	$dQ_{04} = \lambda_1 e^{-(\theta_1+\lambda_1)t}F_4$
$dQ_{06} = \theta_1 e^{-(\theta_1+\lambda_1)t}F_4$	$dQ_{10} = e^{-(\theta_2+\lambda_2)t}F_0$	$dQ_{13} = e^{-(\theta_2+\lambda_2)t}F_3$,
$dQ_{15} = \lambda_2 e^{-(\theta_2+\lambda_2)t}F_5$	$dQ_{17} = \theta_2 e^{-(\theta_2+\lambda_2)t}F_5$	$dQ_{2,10} = p_1^1 i(t)$
$dQ_{2,11} = p_2^1 i(t)$	$dQ_{3,12} = p_1^2 i(t)$	$dQ_{3,13} = p_2^2 i(t)$
$dQ_{40} = e^{-\theta_1(t)}r_2(t)$	$dQ_{48} = \theta_1 e^{-\theta_1(t)}\overline{R_2(t)}$	$dQ_{51} = e^{-\theta_2(t)}r_2(t)$
$dQ_{59} = \theta_2 e^{-\theta_2(t)}\overline{R_2(t)}$	$dQ_{60} = r_1(t)$	$dQ_{71} = r_1(t)$
$dQ_{84} = r_1(t)$	$dQ_{95} = r_1(t)$	$dQ_{10,0} = m_2(t)$
$dQ_{11,0} = m_1(t)$	$dQ_{12,1} = m_2(t)$	$dQ_{13,1} = m_1(t)$

where, $F_0 = h_2(t)\overline{U_\iota(t)},\ F_1 = h_1(t)\overline{U_\iota(t)},\ F_2 = u_i(t)\overline{H_1(t)},\ F_3 = u_i(t)\overline{H_2(t)}$
$F_4 = \overline{H_1(t)U_\iota(t)},\ F_5 = \overline{H_2(t)U_\iota(t)}$

Mean Sojourn Time (μ_i) is the time the system expects to spend in state i. The expressions for μ_i are produced by using $\mu_i = \int_0^\infty P[T_i > t]dt$ where T_i denotes the system's stay time in state i.

Table 3: *Mean Sojourn Time*

$\boldsymbol{\mu_0 = F_4^*(\theta_1 + \lambda_1)}$	$\boldsymbol{\mu_1 = F_5^*(\theta_2 + \lambda_2)}$	$\boldsymbol{\mu_2 = \int_0^\infty \overline{I(t)}\, dt = \mu_3}$
$\boldsymbol{\mu_4 = \frac{1}{\theta_1}[1 - r_2^*(\theta_1)]}$	$\mu_5 = \frac{1}{\theta_2}[1 - r_2^*(\theta_2)]$	$\mu_6 = \int_0^\infty \overline{R_1(t)}\, dt = \mu_7$
$\boldsymbol{\mu_{10} = \int_0^\infty \overline{M_2(t)}\, d = \mu_{12}}$	$\mu_{11} = \int_0^\infty \overline{M_1(t)}\, d = \mu_{13}$	

4. Reliability Measures

4.1 Mean Time to System Failure (MTSF)

Assuming that $\phi_i(t)$ represents the cumulative distribution function of the initial-passage time from a failed state to a regenerative state i. The recursive relations listed below are employed to compute the system's mean time to failure.

$\phi_0(t) = Q_{01}(t)Ⓢ\phi_1(t) + Q_{02}(t)Ⓢ\phi_2(t)+Q_{04}(t)Ⓢ\phi_4(t) + Q_{06}(t)Ⓢ\phi_6(t)$ (1)

$\phi_1(t) = Q_{10}(t)Ⓢ\phi_0(t) + Q_{13}(t)Ⓢ\phi_3(t)+Q_{15}(t)Ⓢ\phi_5(t) + Q_{17}(t)Ⓢ\phi_7(t)$ (2)

$\phi_2(t) = Q_{2,10}(t)Ⓢ\phi_{10}(t) + Q_{2,11}(t)Ⓢ\phi_{11}(t)$ (3)

$\phi_3(t) = Q_{3,12}(t)Ⓢ\phi_{12}(t) + Q_{3,13}(t)Ⓢ\phi_{13}(t)$ (4)

$\phi_4(t) = Q_{40}(t)Ⓢ\phi_0(t) + Q_{48}(t)$ (5)

$\phi_5(t) = Q_{51}(t)Ⓢ\phi_1(t) + Q_{59}(t)$ (6)

$\phi_6(t) = Q_{60}(t)Ⓢ\phi_0(t)$ (7)

$\phi_7(t) = Q_{71}(t)Ⓢ\phi_1(t)$ (8)

$\phi_{10}(t) = Q_{10,0}(t)Ⓢ\phi_0(t)$ (9)

$\phi_{11}(t) = Q_{11,0}(t)Ⓢ\phi_0(t)$ (10)

$\phi_{12}(t) = Q_{12,1}(t)Ⓢ\phi_1(t)$ (11)

$\phi_{13}(t) = Q_{13,1}(t)Ⓢ\phi_1(t)$ (12)

Using Laplace Stieltjes Transform on both sides of aforementioned relations and Cramer's Rule to solve them, we get

$MTSF = \lim_{s\to 0} \frac{1-\phi_0^{**}(s)}{s} = \frac{N}{D}$ (13)

where, $N = (p_{10} + p_{15}p_{59})(\mu_0 + p_{02}\mu_2 + p_{04}\mu_4) + p_{01}p_{13}\mu_3 + p_{01}\mu_1 + p_{15}\mu_5(p_{01} + p_{04}p_{48})$

$D = p_{15}p_{59}(p_{01} + p_{04}p_{48}) + p_{04}p_{10}p_{48}$

4.2 Steady State Availability

$AH_i^1(t)/AH_i^{1s}(t)$ *and* $AH_i^2(t)/AH_i^{2s}(t)$ indicates how likely it is that the system will be in a combined cycle or single cycle at any given time t, assuming that it was in a regenerative condition at time t=0 when the humidity is ≤ and > 50%. We obtain the equations for availability in both combined and single cycles by studying empirical argumentation and solving the resulting equations by using the Laplace Transform, we get

$$V_1 = \begin{vmatrix} 1 & -p_{01} & -p_{02} & 0 & -p_{04} & 0 & -p_{06} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -p_{10} & 1 & 0 & -p_{13} & 0 & -p_{15} & 0 & -p_{17} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -p_{2,10} & -p_{2,11} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -p_{3,12} & -p_{3,13} \\ -p_{40} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -p_{48} & 0 & 0 & 0 & 0 & 0 \\ 0 & -p_{51} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -p_{59} & 0 & 0 & 0 & 0 \\ -p_{60} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -p_{71} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -p_{84} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -p_{95} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ -p_{10,0} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ -p_{11,0} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -p_{12,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -p_{13,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix}$$

Or $V_1 = |C_1 \quad C_2 \quad C_3 \quad C_4 \quad C_5 \quad C_6 \quad C_7 \quad C_8 \quad C_9 \quad C_{10} \quad C_{11} \quad C_{12} \quad C_{13} \quad C_{14}|$
where C_i ($1 \le i \le 14$), represents the i^{th} column of the V_1.
$U_1 = |C_1^{n1} \quad C_2 \quad C_3 \quad C_4 \quad C_5 \quad C_6 \quad C_7 \quad C_8 \quad C_9 \quad C_{10} \quad C_{11} \quad C_{12} \quad C_{13} \quad C_{14}|$
$C_1^{n1} = [\mu_0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$
$AH_0^1(t) = \frac{U_1}{V}$, where $V = V_1'$
Similarly, $AH_0^2(t) = \frac{U_2}{V}, \quad AH_0^{1s}(t) = \frac{U_3}{V}, \quad AH_0^{2s}(t) = \frac{U_4}{V}$ (14)
where, $U_j = |C_1^{nj} \quad C_2 \quad C_3 \quad C_4 \quad C_5 \quad C_6 \quad C_7 \quad C_8 \quad C_9 \quad C_{10} \quad C_{11} \quad C_{12} \quad C_{13} \quad C_{14}|$
and ($2 \le j \le 4$)
$C_1^{n2} = [0 \quad \mu_1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$
$C_1^{n3} = [0 \quad 0 \quad 0 \quad 0 \quad \mu_4 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_{10} \quad 0 \quad 0 \quad 0]$
$C_1^{n4} = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_5 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_{10} \quad 0]$

4.3 Other Performance Measures

$DH_0^1(t) = \frac{U_5}{V}$, $DH_0^2(t) = \frac{U_6}{V}$, $IH_0^1(t) = \frac{U_7}{V}$, $IH_0^2(t) = \frac{U_8}{V}$, $BH_0^1(t) = \frac{U_9}{V}$, $BH_0^2(t) = \frac{U_{10}}{V}$
$VH_0^1(t) = \frac{U_{11}}{V}$, $VH_0^2(t) = \frac{U_{12}}{V}$ (15)
where, ($5 \le j \le 12$)
$U_j = |C_1^{nj} \quad C_2 \quad C_3 \quad C_4 \quad C_5 \quad C_6 \quad C_7 \quad C_8 \quad C_9 \quad C_{10} \quad C_{11} \quad C_{12} \quad C_{13} \quad C_{14}|$
$C_1^{n5} = [0 \quad 0 \quad \mu_2 \quad 0 \quad 0 \quad 0 \quad \mu_6 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_{11} \quad 0 \quad 0]$
$C_1^{n6} = [0 \quad 0 \quad 0 \quad \mu_3 \quad 0 \quad 0 \quad 0 \quad \mu_6 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_{11}]$
$C_1^{n7} = [0 \quad 0 \quad \mu_2 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$
$C_1^{n8} = [0 \quad 0 \quad 0 \quad \mu_2 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$
$C_1^{n9} = [0 \quad 0 \quad 0 \quad 0 \quad \mu_4 \quad 0 \quad \mu_6 \quad 0 \quad 0 \quad 0 \quad \mu_{10} \quad \mu_{11} \quad 0 \quad 0]$
$C_1^{n10} = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_5 \quad 0 \quad \mu_6 \quad 0 \quad 0 \quad 0 \quad 0 \quad \mu_{10} \quad \mu_{11}]$
$C_1^{n11} = [p_{02} + p_{04} + p_{06} \quad 0 \quad 0 \quad \mu_2 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$
$C_1^{n12} = [0 \quad p_{13} + p_{15} + p_{17} \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$

4.4 Profit of the System

$$P = C_1 * AH_0^1 + C_2 * AH_0^2 + C_3 * AH_0^{1s} + C_4 * AH_0^{2s} - C_5 * BH_0^1 - C_6 * BH_0^2 - C_7 * VH_0^1 - C_8 * VH_0^2 - PE$$

C_1/C_2 : Revenue earned per unit when system works in combined cycle for humidity ≤/> 50%
C_3/C_4 : Revenue earned per unit when system works in single cycle for humidity ≤/> 50%
C_5/C_6 : Expense per unit time when server is busy for humidity ≤/> 50%
C_7/C_8 : Cost per visit by server when humidity is ≤/> 50%
PE : Additional expenses of Plant

5. Results and Discussion

For numerical calculations, we study the specific situation, in which all temporal distributions are assumed to be exponential which are best fitted over real time data, as established by Singh [22]. We examined one-year real-time data from a gas turbine power plant in Delhi, India, restricted the temperature range to up to 25°C, and the methodology used to obtain the values of all the parameters is provided in appendix, which are used to assess the graphical behaviour of reliability measures. The following distributions have been assumed for various times.

$i(t) = \gamma e^{-\gamma(t)}$, $r_1(t) = \alpha_1 e^{-\alpha_1(t)}$, $r_2(t) = \alpha_2 e^{-\alpha_2(t)}$, $m_1(t) = \alpha e^{-\alpha(t)}$, $m_2(t) = \beta e^{-\beta(t)}$
$h_1(t) = \beta_1 e^{-\beta_1(t)}$, $h_2(t) = \beta_2 e^{-\beta_2(t)}$, $u_i(t) = \theta e^{-\theta(t)}$

5.1 MTSF V/s Failure rate λ_1 for different values of θ_2

Figure 2 illustrate the behaviour of mean time to system failure v/s failure rate of steam turbine $\lambda_1$for different values of θ_2. MTSF decreases with increase in any one of the failure rate λ_1, θ_1, $\lambda_2$and θ_2.

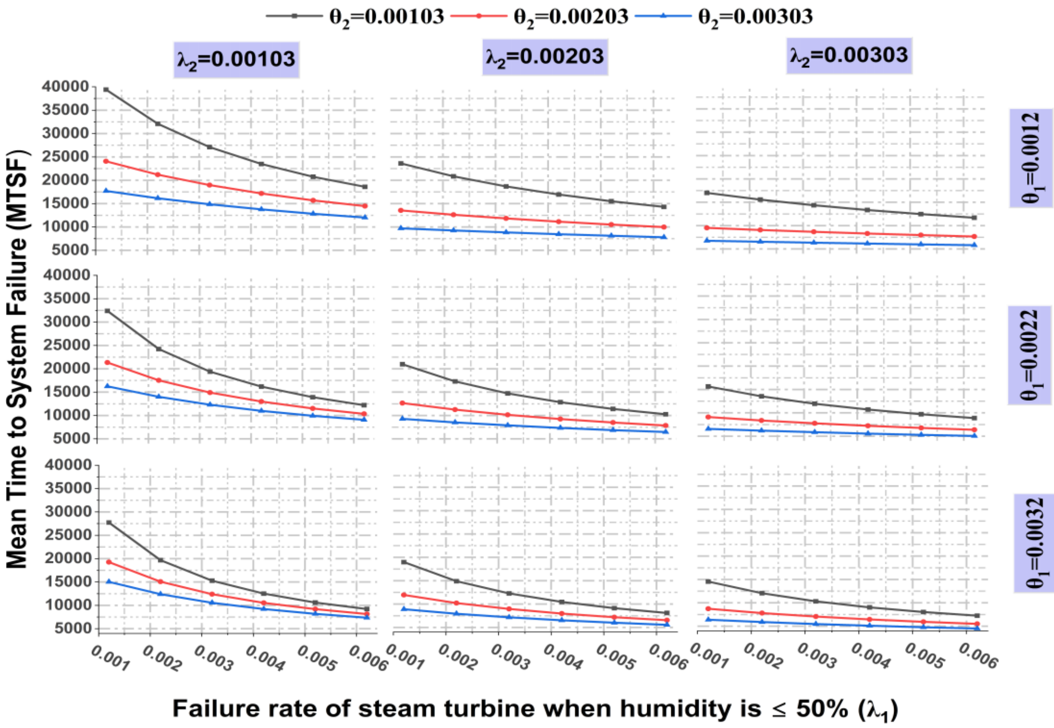


Figure 2: *MTSF Vs Failure rates* θ_1, θ_2,λ_1,λ_2

5.2 Availability in Steady State

Figure 3 demonstrates the availability in combined cycle when humidity is ≤ 50% and when humidity is > 50%

- Both availabilities (when humidity is ≤/> 50%) of combined cycle decreases as we increase any one of the failure rates.
- Availability in combined cycle when humidity is > 50% is higher than availability in combined cycle when humidity is ≤ 50%.

Figure 4 demonstrates the availability in single cycle when humidity is ≤ 50% and when humidity is > 50%

- Availability when humidity is ≤ 50%/> 50% of single cycle increases with increase in failure rate λ_1/λ_2 respectively.

- Availability in single cycle (when humidity is > 50%) decreases smoothly with increase in failure rate λ_1.

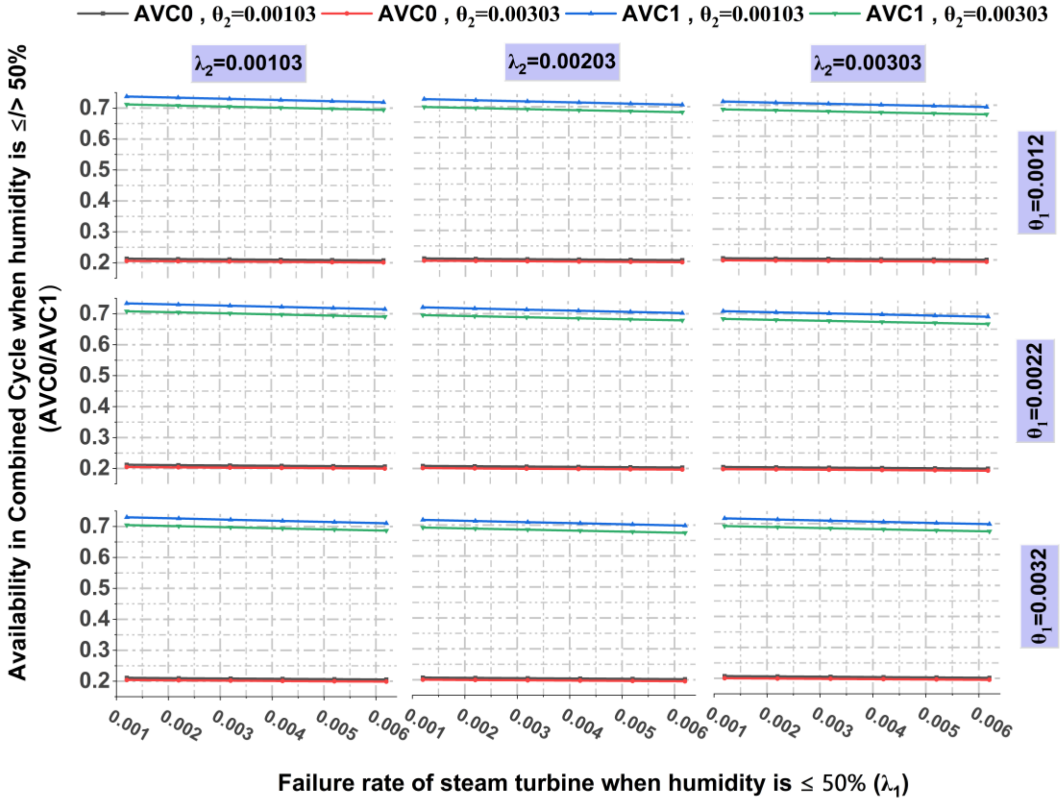


Figure 3: *Availability in Combined Cycle Vs Failure rates* θ_1, θ_2, λ_1 *and* λ_2

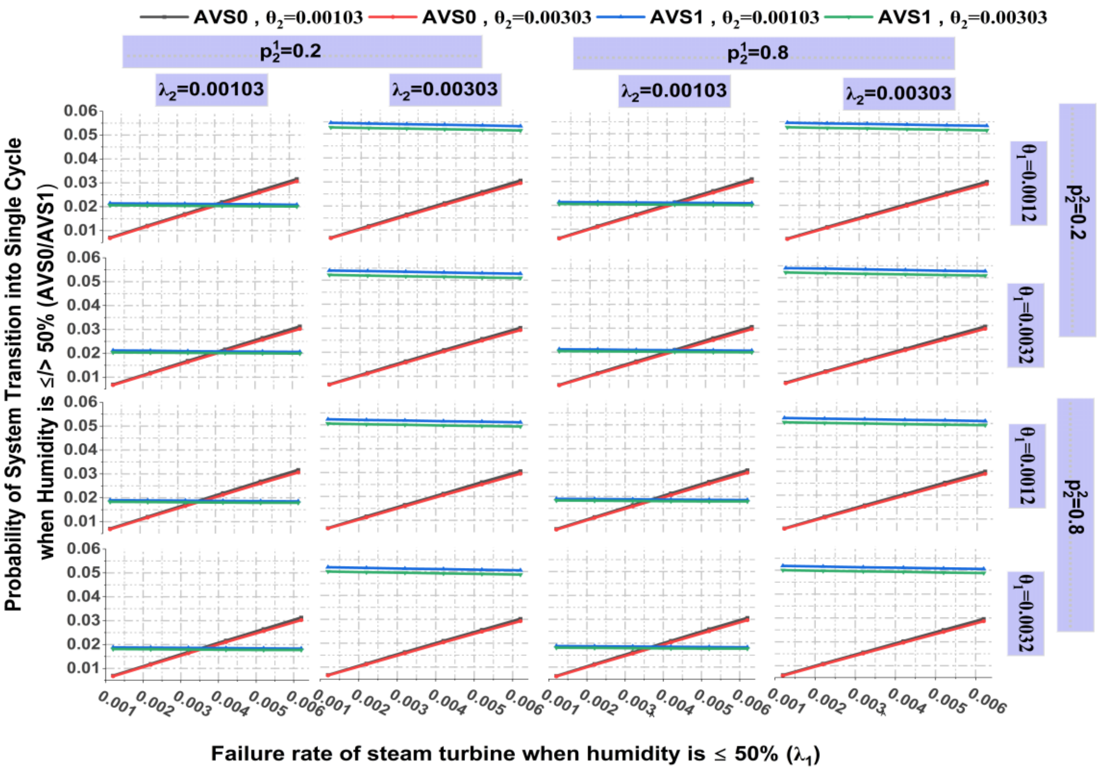


Figure 4: *Availability in Single Cycle Vs Failure rates* θ_1, θ_2, λ_1 and λ_2

5.3 Profit V/s Plant Expenses (PE) for different values of Price of Electricity (P)

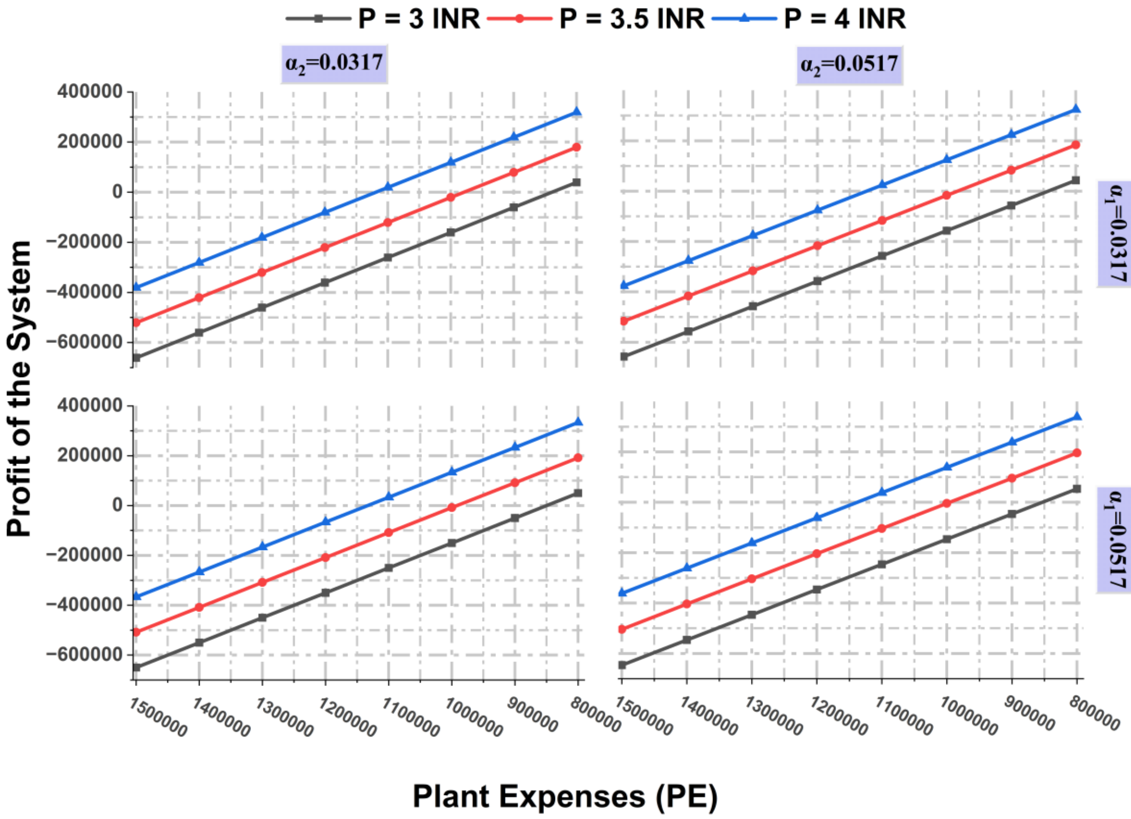


Figure 5: *Profit Vs Plant Expenses for different P Values*

Figure 5 illustrates the behavior of Profit of plant with respect to Plant Expenses.

- Profit increases with decrease in plant expenses.
- Profit increases with increase in values of P.

Table 4: *Cut-off Values of PE* for different values of α_1 and α_2

Price Per Unit	$\alpha_2 = 0.0317$		$\alpha_2 = 0.0517$	
	$\alpha_1 = 0.0317$	$\alpha_1 = 0.0517$	$\alpha_1 = 0.0317$	$\alpha_1 = 0.0517$
P=3 INR	839173.20	842787.19	849834.18	853495.72
P=3.5 INR	979100.50	983291.64	991540.49	995786.31
P=4 INR	1119027.81	1123796.09	1133246.81	1138076.91

Table 4 shows threshold points of plant expenses at particular price of electricity to achieve profit.

6. Conclusion

For two different humidity conditions (i.e., humidity less than or equal to 50% and humidity greater than 50%), a stochastic model of a gas turbine system composed of one gas turbine and one steam turbine is developed by prioritizing repair of gas turbine over steam turbine and applying random inspection and maintenance policy of a system using single service facility. Various reliability measures like system's mean time to failure, availability for steady state, etc. have been obtained and the graphical analysis of the effects of failure rates of steam turbines when humidity is ≤/> 50%. Finding shows that mean time to system failure declines as failure rate increases. Trends in availability for both cycles and varied humidity levels, i.e. when humidity is ≤/> 50%, have been depicted with respect to steam turbine failure rate, and many interesting results about availability have been found. Profit for the plant is shown, which declines as the price of electricity decreases. Furthermore, a thorough study of gas turbine systems may be beneficial to people involved in the industry of electricity generation.

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