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Research Article

Performance Modelling and Analysis of Power Generation System using Petri Nets

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Abstract

Ensuring the thermal power plant remains highly reliable necessitates the implementation of a suitable maintenance strategy. This importance is underscored by the intricate composition of the power plant, comprising diverse subsystems interlinked through series or parallel configurations. This paper introduces a novel decision support system designed to prioritize maintenance orders, a crucial aspect for maintaining optimal maintenance operations. Additionally, it explores the Performability Evaluation of a power generation system within a coal-based Thermal Power Plant, employing the Stochastic Petri Nets (SPN) methodology. The modelling process utilized the Licensed Version of Petri GRIF-predicates Software. The study focuses on assessing the long-term availabilities of various subsystems by varying Failure and Repair Rates (FRR) within permissible ranges during the performance modelling of the plant. The research investigates the influence of altering failure and repair rates of subsystems on the overall performance and performability of the power generation system. Furthermore, the impact of varying available repair facilities on the system's performability is also assessed. This critical analysis aids maintenance engineers in proactively planning the allocation of repair resources for different subsystems, based on the severity of potential failures.

Keywords: *Performance Evaluation, Petri Nets, Decision Support System, Maintenance Order Priorities, DSS, Performance Analysis*

Introduction

The global surge in electricity demand has resulted in an extensive reliance on thermal power plants fueled by fossil fuels. These plants constitute approximately 65% of the total global electricity generation (Khaleel et al. 2021). The surge in electricity demand has underscored the imperative of prioritizing the maintenance of power generation resources in India. Among these resources, the thermal power plant (TPP) stands out as a primary contributor to electricity generation. It is crucial to ensure the continuous operation of TPP. However, achieving this is challenging as equipment failures are unavoidable, despite efforts to minimize them through appropriate maintenance strategies. In recent years, the reliability, availability, and maintenance planning of TPP have gained heightened importance due to society's increasing electricity needs (Kuo and Ke, 2019). Attaining optimal levels of reliability and availability is not only beneficial for cost reduction in production but also for mitigating the risks of potential hazards (Yang et al., 2016).

Plant failures are often the result of inadequate maintenance and an inability to predict issues that might arise during plant operation. Nonetheless, with a judicious focus on reliability, availability, and maintainability, the frequency of failures and their associated consequences can be significantly diminished. Previous scholarly work indicates that researchers have employed diverse qualitative and quantitative methods to assess system performance concerning reliability and availability. These methods encompass fault tree analysis (FTA) (Pariaman et al., 2015), failure mode effect analysis (Burgazzi, 2006), functional analysis (FA) (Nord et al., 2009), reliability block diagram (RBD) (Bhangu et al., 2018), the Markov approach (Malik et al., 2021), Monte Carlo simulation (Du et al., 2017) and Petri-Nets (Kumar et al. 2022).

Gupta and Tewari (2009) devised a probabilistic model for the flue gas and air system, delving into the evaluation of subsystem performances. Optimal values of failure rate and repair rate were used to determine maintenance priorities for the subsystems. Additionally, Gupta and Tewari (2010) explored the potential of predictive availability modeling for the steam generation system in TPP, employing Markov

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and probabilistic approaches. Kumar et al. (2012) developed an availability simulation for assessing the turbine subsystem's performance within a coal-fired TPP. Their findings underscored the elevated priority of maintaining the turbine-governing system. Furthermore, Kumar (2012a) proposed a decision support system for the TPP's boiler subsystem. Mathematical modeling and a probabilistic approach were employed to construct this system, complete with decision matrices. These matrices facilitated maintenance decisions for critical points where subsystem repairs should be prioritized. Results indicated the re-heater as the most critical subsystem in terms of maintenance, warranting the highest priority due to its substantial impact on device availability compared to other subsystems. Accordingly, maintenance priority was suggested as follows: (a) re-heater, (b) economizer, (c) boiler drum, (d) superheater, (e) furnace.

Zhang et al. (2014) presented a case study focusing on enhancing energy efficiency in an industrial boiler system. The study explored options such as adjusting system vapor pressure, implementing VFDs for FD fans, optimizing the multi-burner configuration, and fine-tuning the feedwater system. Emphasis was placed on single burner mode investigation, resulting in optimized air/fuel ratios. The analysis revealed potential fuel consumption savings of up to 7% during lower load operation. Malik and Tewari (2018) devised decision matrices for evaluating the water circulation system's performance. The results identified the condensate extraction pump as the most critical subsystem, necessitating top priority for maintenance. Kumar et al. (2011) conducted a performance assessment of the furnace draft air cycle in TPP, considering the influence of subsystem failure and repair rates on overall system availability. Furthermore, Yogesh Kumar and Sanjeev Kumar (2013) conducted a reliability analysis of the coal handling unit at Badarpur TPP, offering maintenance priorities based on subsystem criticality levels.

In recent years, the focus on optimizing performance across various domains has captured the attention of researchers. Performance optimization stands as a crucial factor in process industries (Kumar et al., 2017; Raugei and Leccisi, 2016). Previous studies have been conducted to analyze the behavior of Thermal Power Plants (TPP) using optimization techniques. These techniques encompass genetic algorithms, simulated annealing (Mohanta et al., 2007), particle swarm optimization (PSO) (Kundu et al., 2019; Pant et al., 2015; Patwal et al., 2017; Roy et al., 2017; Zhao et al., 2015). Mukerji et al. (1991) demonstrated the application of optimization techniques for reliability assessment and plant outage rescheduling. Furthermore, Lapa et al. (2006) optimized preventive maintenance policies through a cost-reliability model. Garg (2014) proposed a methodology for reliability, maintainability, and availability analysis in a crankcase manufacturing plant using uncertain data for time-varying failure and repair rate models. Their approach employed PSO and fuzzy set theory, obtaining optimal design parameters by solving an availability cost optimization model through PSO. To address challenges in constructing multi-state system reliability optimization models and mitigating PSO algorithm convergence issues, Yao et al. (2013) introduced a novel reliability optimization model based on T–S fault tree and extended PSO algorithm.

Existing literature reveals consistent efforts by previous researchers to explore reliability-based maintenance scheduling for systems within various process industries, including TPP (Hemmati et al., 2018; Kumar et al., 2018). With the aim of improving plant availability, optimized availability parameters can influence the decision-making or modification of existing maintenance schedules. Prior studies predominantly concentrated on theoretical model development and analysis, with only a handful attempting realistic implementation. Additionally, recent studies have placed less emphasis on applying contemporary optimization techniques to availability optimization for TPP subsystems. There's a noticeable demand for a systematic approach to performance analysis of TPP subsystems, bridging this research gap. This paper strives to address this identified gap in research. This paper introduces a novel approach by developing an availability simulation model for the power generation system of TPP based on the Stochastic Petri Nets Module. By utilizing known availability parameters (failure rate and repair rate), the system's performance is assessed. Furthermore, the study identifies optimal availability parameters through the Petri Nets approach and determines the maintenance priority of the power generation system based on its criticality level. To optimize the availability of the power generation system, the paper employs the particle swarm optimization (PSO) method. The impact of particle count on the \system's performance is investigated, leading to the determination of the optimal availability level. The derived optimized availability parameters are subsequently used to refine the existing maintenance strategy for the power generation system within the plant.

System Description

A coal-based thermal power plant is a form of thermal power generation where coal is burned to generate heat energy, which is then transformed into electrical energy through a series of components and processes. Within a coal-fired thermal power plant, the power generation process involves converting the stored chemical energy in coal into electricity. This process centers on driving an electric generator via the directed high-pressure steam that propels a turbine. The steam subsequently traverses the turbine before being condensed within a condenser. The efficiency of this system hinges upon the configuration and performance of its constituent parts. A typical system is composed of interconnected subsystems, organized in series, parallel, or hybrid configurations. The power generation system comprises of five distinct subsystems are represented by Figure.1 and elucidated as follows:

Subsystem F1: This unit encompasses the turbine blades and operates in series with other subsystems. A failure in this component could lead to the complete breakdown of the entire system. The turbine blades are attached to the rotor of the steam turbine, playing a pivotal role in converting the kinetic energy of high-pressure steam into mechanical energy. When the high-pressure steam engages with these blades, their rapid rotation occurs due to the steam's high velocity and pressure.

Subsystem F2 (j=1, 2): This subsystem combines the condensate evacuation unit and the regenerative unit. The failure of either unit results in diminished plant capacity and subsequent production loss. By evacuating air from the condenser and preheating boiler feedwater, the power plant can generate more electricity using the same fuel amount, thereby improving overall performance and reducing environmental impact.

Subsystem F3: Comprising the turbine governing unit, this subsystem operates in series with other subsystems. Its failure could lead to the complete system breakdown. Turbine governing is a crucial control mechanism in the power generation system of a thermal power plant, overseeing the regulation of speed and power output of the steam turbine to match electricity demand on the grid.

Subsystem F4: This unit involves the turbine lubrication unit, and its failure results in a reduction of plant capacity and subsequent production loss. The turbine lubrication subsystem is integral to the power generation system, ensuring smooth operation of the turbine by supplying lubrication to its moving and rotating parts.

Subsystem F5 (i=1, 2): This particular subsystem integrates a generator cooling unit and a seal oil unit. Failure in either unit leads to decreased plant capacity and production loss. The Generator Cooling and Seal Oil (GC) subsystem is crucial, maintaining the optimal operating temperature of the electric generator and ensuring effective sealing of vital components.

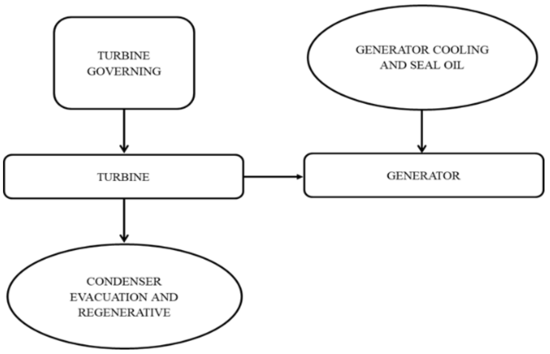

Fig.1: Schematic Flow Diagram for Power Generation System

Petri Nets Model of the Power Generation System

The modeling of interactions within the Power Generation System was accomplished using Stochastic Petri Nets (SPN). The failure-repair rates (FRR) were derived from maintenance records and consultations with plant staff. The investigation operates under the premise of a solitary repair facility, implying that in the event of multiple system failures concurrently, they would need to wait in a queue for repairs.

Places:

- sys_available: Indicates the operational state of the steam generation system.
- sys_full_cap.: Represents the system's state when it operates at its full capacity like a newly installed unit.
- sys_works_red_cap.: Depicts the scenario where the system functions at reduced efficiency.
- sys_failed: Represents the state of the system when it is down and unavailable for use until repaired.
- rep_fac_available: Indicates the availability of repair facilities.
- SBS1_up, SBS2_up, SBS3_up, SBS4_up, SBS5_up: Denotes the operational status of SBS1, Subsystem1, Subsystem2, Subsystem3, Subsystem4, Subsystem5 respectively, when they are functioning properly.
- SBS1_down, SBS2_down, SBS3_down, SBS4_down, SBS5_down: Represents the state of SBS1, Subsystem1, Subsystem2, Subsystem3, Subsystem4, Subsystem5, respectively, when they are not operational (down state).
- SBS1_Rep, SBS2_Rep, SBS3_Rep, SBS4_Rep, SBS5_Rep: Indicates the repair state of SBS1, Subsystem1, Subsystem2, Subsystem3, Subsystem4, Subsystem5, respectively, when they are undergoing repairs.

Transitions:

- SBS1_fail, SBS2_fail, SBS3_fail, SBS4_fail, and SBS5_fail: These transitions represent the occurrence of failure in Subsystem1, Subsystem2, Subsystem3, Subsystem4, Subsystem5, respectively.
- SBS1_REC, SBS2_REC, SBS3_REC, SBS4_REC, and SBS5_REC: These transitions represent the repair rate of Subsystem1, Subsystem2, Subsystem3, Subsystem4, Subsystem5, respectively.
- rep.avail_ SBS1, rep.avail_SBS2, rep.avail_SBS3, rep.avail_SBS4, rep.avail_SBS5: These transitions indicate the availability of repair facilities for the various subsystems.
- sys._red., sys._rec., sys_down, sys_up: These transitions correspond to the system's states of reduced capacity, repaired state, downstate, and upstate, respectively.

Guard functions

Below are the descriptions of the guard functions associated with different transitions:

- [G1]: = (#7>0 and #17>0) is guard function for the transition rep.avail_ SBS1. This Guard Function makes enable this transition.
- [G2]: = (#9>0 and #17>0) is guard function for the transition rep.avail_ SBS2 which enables with guard function.
- [G3]: = (#11>0 and #17>0) is guard function for the transition rep.avail_ SBS3. This particular guard function enables this transition.
- [G4]: = (#13>0 and #17>0) is guard function which make enables the transition rep.avail_ SBS4.
- [G5]: = (#15>0 and #17>0) is guard function for the transition rep.avail_ SBS5.
- [G6]: = (#1<3 and #1>0) is guard function for the transition sys_red.
- [G7]: = (#1>2) is guard function for the transition sys_recovered. This transition disabled by this guard function.
- [G8]: = (#1>0 or #2>0, or #2>3, or #4>0, or #5>0) enables the transition sys_fail.
- [G9]: = (#1>0 and #2>0, and #2>3, and #4>0, and #5>0) is guard function for the transition sys_ok. This transition disabled by this guard function.

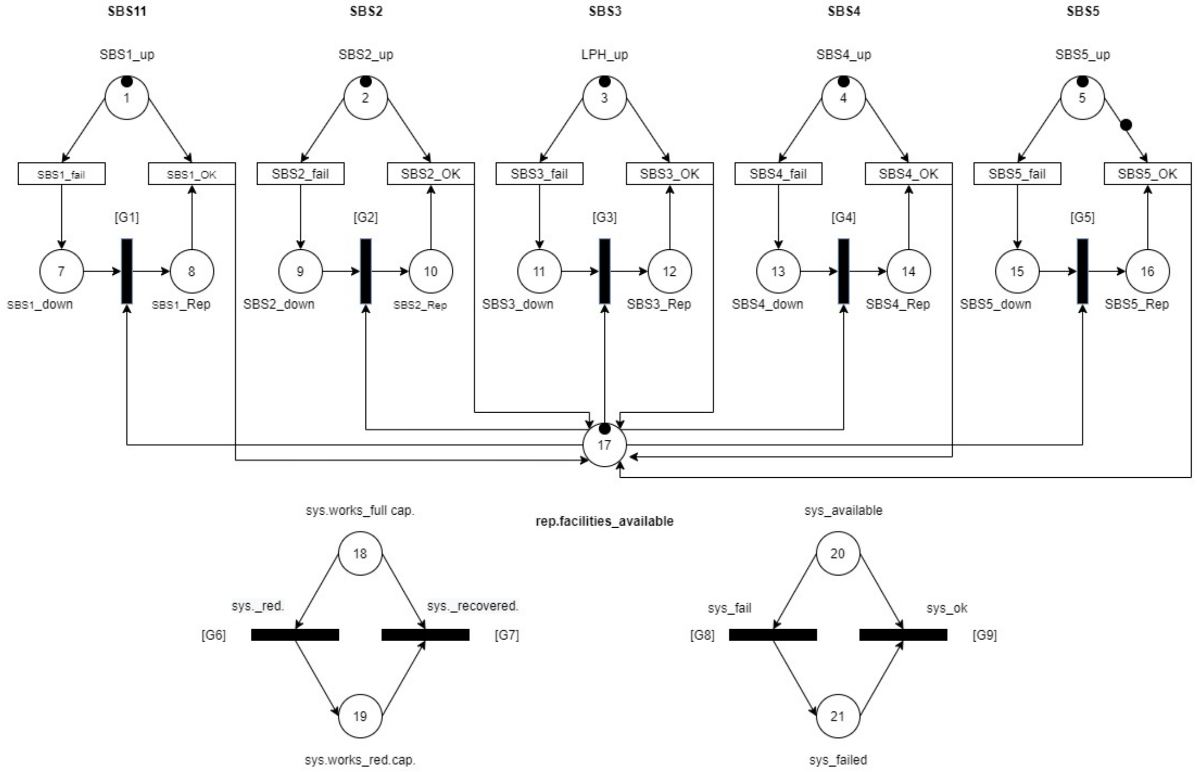

Fig.2: PN Model of Power Generation System

The existing model incorporates a solitary repair facility that employs tokens to signify subsystem statuses. In the event of a breakdown, a token is transferred from the operational state of the affected subsystem to the "wait for repair" location within the same subsystem. If the repair facility has capacity and a token resides in the "wait for repair" area, an immediate enabled transition is activated. This transition moves the token to the available location within the repair facility, denoting the initiation of the repair process. However, should multiple subsystem failures coincide, tokens are relocated from their operational positions to the "system down" location, indicating these subsystems are inoperative. The model employs immediate transitions, enabled or disabled by specific guard functions ([g1] and [g2]). When all subsystems function normally, tokens are present in Ps_up and each subsystem's operational site. In the event of subsystem failure, the [g1] guard becomes active, enabling the Tsys_fail transition, which moves the token from Ps_up to Ps_down, signifying system failure.

Upon successful repair of a failed subsystem, the [g2] guard triggers the Tsystem_REC transition, returning the token from Ps_down to Ps_up, indicating the system's restoration to operational status. The existence or absence of the token in Ps_up determines the system's availability, ensuring it conforms to a predefined 95% confidence level.

Performance Analysis of System

The primary objective of the evaluation was to assess the availability and overall performance of the power generation system within a thermal power plant context. A Petri Net (PN) model, illustrated in Figure 2, was developed for this purpose, assuming an exponential distribution for failure and repair data.

Comprehensive failure and repair data for significant subsystems can be found in Table 1. The availability matrix was obtained through the use of the GRIF-predicates Petri module (2018), and the outcomes are displayed in Tables 3 to 7. The assessment involved the systematic consideration of various parameters and predefined values to holistically gauge the system's availability.

To analyze the ramifications of differing failure and repair rates on system availability, Figures 3, 4, 5, 6, and 7 were generated and presented. These visualizations offer valuable insights into how the system's availability is shaped under diverse failure and repair rate scenarios. The evaluation encompassed MOCA RP computation and simulation over a duration of 10,000 hours, incorporating multiple replications ranging from 10 to 21,000, as facilitated by the specified software.

Table 1: Exponential Failure and Repair Data of Power Generation System

Name of Subsystem	Mean Failure Rate (ρ_i)/ hr	Mean Repair Rate (μ_i)/ hr
Subsystem 1	1.0×10^{-2}	2.0×10^{-1}
Subsystem 2	5.0×10^{-3}	1.5×10^{-1}
Subsystem 3	2.5×10^{-3}	1.25×10^{-1}
Subsystem 4	5.0×10^{-3}	1.5×10^{-2}
Subsystem 5	1.5×10^{-2}	5.0×10^{-2}

Table 2: Availability matrix showing the effect of variation in Failure (ρ_1) and Repair (μ_1) rates of 'Subsystem1' subsystem on system Availability

μ_1 / ρ_1	0.18	0.19	0.20	0.21	0.22	Constant Parameters
0.008	0.7175	0.7197	0.7216	0.7233	0.7248	$\mu_2=0.005$ $\rho_2=0.15$ $\mu_3=0.0025$ $\rho_3=0.125$ $\mu_4=0.005$ $\rho_4=0.015$ $\mu_5=0.015$ $\rho_5=0.05$
0.009	0.7140	0.7165	0.7186	0.7205	0.7221	
0.010	0.7107	0.7133	0.7156	0.7177	0.7195	
0.011	0.7073	0.7102	0.7127	0.7149	0.7168	
0.012	0.6940	0.7071	0.7098	0.7121	0.7142	

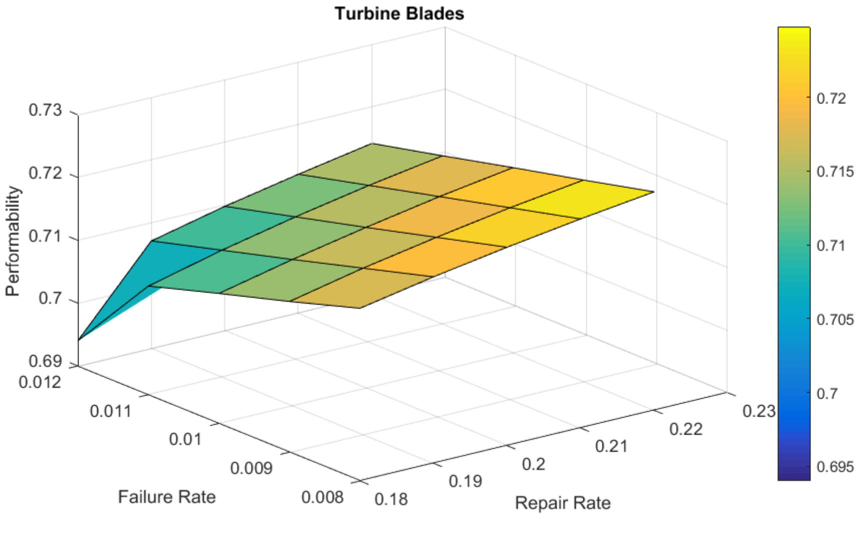

Fig.3: Effect of Failure and Repair Rates of Subsystem1 on System Availability

Table 2 and Figure 3 present the influence of varying failure and repair rates specifically for subsystem 1, which is the turbine blade unit, on the Performability of the Power Generation System. All other subsystems' failure and repair rates are held constant during these analyses. The findings reveal that as the failure rate of the turbine blade unit increases, its availability decreases correspondingly, and the reverse is true as well. A noteworthy observation is that when the failure rate increases from 0.008 to 0.012, there is a significant decrease in the system's overall availability.

Conversely, the system's overall availability improves with an increase in the repair rate of the turbine blade unit. As depicted in Figure 3, when the repair rate rises from 0.18 to 0.22, there is a noticeable increase in the availability of the entire system.

Table 3: Availability matrix showing the effect of variation in Failure (ρ_2) and Repair (μ_2) rates of 'Subsystem2' subsystem on system Availability

μ_2 ρ_2	0.05	0.10	0.15	0.20	0.25	Constant Parameters
0.003	0.7143	0.7167	0.7176	0.7181	0.7184	μ1=0.010 ρ1 =0.20 μ3=0.0025 ρ3=0.125 μ4=0.005 ρ4=0.015 μ 5=0.015 ρ 5=0.05
0.004	0. 7114	0.7153	0.7166	0.7174	0.7178	
0.005	0.7085	0.7138	0.7156	0.7166	0.7172	
0.006	0. 7055	0.7122	0.7146	0.7158	0.7166	
0.007	0. 7023	0.7107	0.7136	0.7150	0.7159	

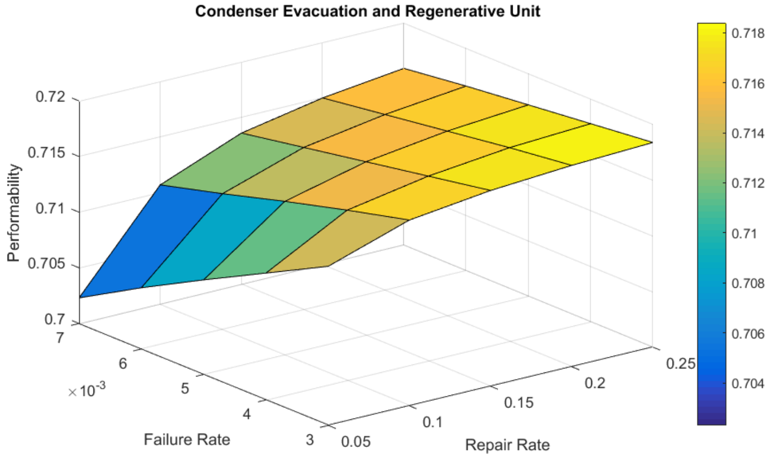

Fig.4: Effect of Failure and Repair Rates of Subsystem2 on System Availability

The results obtained from Table 3 and Figure 4 indicate that the performability of subsystem 2 exhibits an improvement with an increase in the repair rate, and conversely, it shows a decline when the failure rate decreases. Throughout these analyses, the failure and repair rates of other systems are held constant. Notably, Figure 4 vividly demonstrates a significant increase in the availability of subsystem 2 when the repair rate is raised from 0.05 to 0.25. Conversely, a considerable decrease in the system's availability is observed when the failure rate increases from 0.003 to 0.007.

Table 4: Availability matrix showing the effect of variation in Failure (ρ_3) and Repair (μ_3) rates of 'Subsystem3' subsystem on system Availability

μ_3 ρ_3	0.110	0.120	0.125	0.130	0.135	Constant Parameters
0.0023	0.7157	0.7160	0.7163	0.7166	0.7169	μ1=0.010 ρ1 =0.20 μ2=0.005 ρ2 =0.15 μ4=0.005 ρ4=0.014 μ5=0.015 ρ5=0.05
0.0024	0.7153	0.7156	0.7160	0.7163	0.7166	
0.0025	0.7149	0.7153	0.7156	0.7160	0.7163	
0.0026	0.7145	0.7149	0.7153	0.7156	0.7159	
0.0027	0.7141	0.7146	0.7149	0.7153	0.7156	

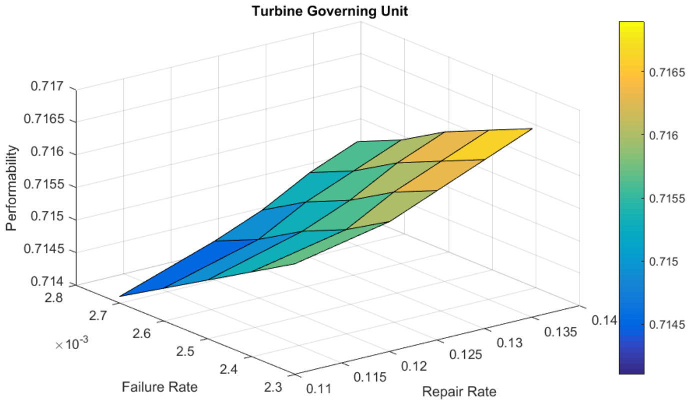

Fig.5: Effect of Failure and Repair Rates of Subsystem3 on System Availability

Table 4 and Figure 5 illustrate that maintaining all other parameters constant, an escalation in the failure rate of subsystem 3 results in a reduction of the system's performability. Conversely, an increase in the repair rate leads to an improvement in the overall availability of the system. Notably, Figure 5 clearly demonstrates that as the failure rate rises from 0.0023 to 0.0027, the overall system availability decreases proportionally. However, when the repair rate increases from 0.110 to 0.135, there is a remarkable increase in the availability of the entire system.

Table 5: Availability matrix showing the effect of variation in Failure (ρ 4) and Repair (μ4) rates of 'Subsystem4' subsystem on system Availability

μ4 ρ 4	0.014	0.034	0.054	0.074	0.094	Constant Parameters
0.004	0.7156	0.7263	0.7856	0.8174	0.8372	μ1=0.010 ρ1 =0.20 μ2=0.005 ρ2 =0.15 μ3=0.0025 ρ3=0.125 μ5= 0.015 ρ5=0.05
0.0045	0.6762	0.6791	0.7488	0.7876	0.8123	
0.005	0.6476	0.6380	0.7156	0.7600	0.7888	
0.0055	0.6279	0.6020	0.6854	0.7345	0.7667	
0.006	0.6007	0.6011	0.6578	0.7107	0.7460	

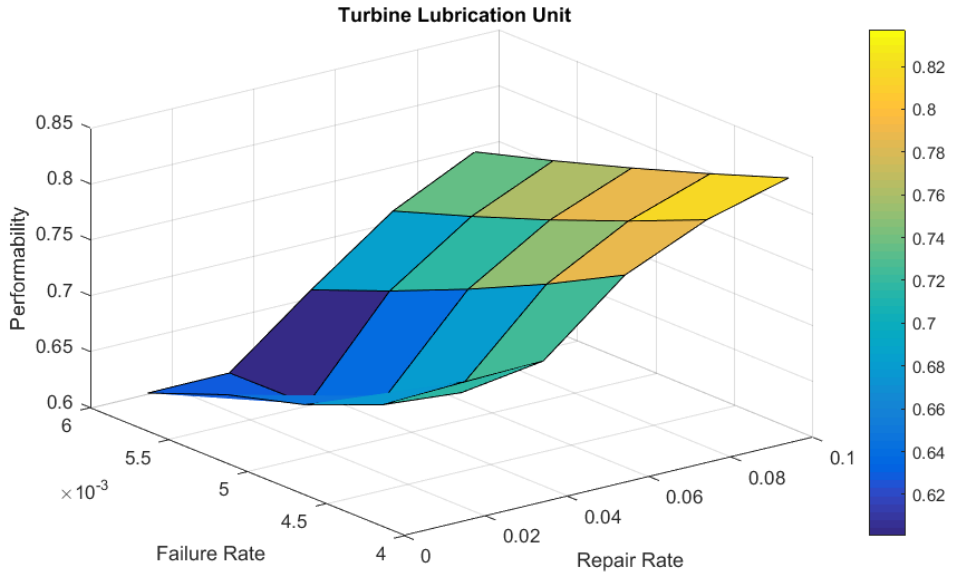

Fig.6: Effect of Failure and Repair Rates of Subsystem4 on System Availability

Table 5 and Figure 6 offer valuable insights into how the failure and repair rates of subsystem 4 impact the performability of the Power Generation System. It becomes evident that as the failure rate of subsystem 4 increases, the system's availability decreases, while the opposite holds true as well. Similarly, an increase in the repair rate leads to an enhancement in the overall performability of the system. Notably, there is a noticeable increase in the system's availability when the repair rate is raised from 0.014 to 0.094. Conversely, a significant decrease is observed in the system's availability when the failure rate increases from 0.004 to 0.006.

Table 6: Availability matrix showing the effect of variation in Failure (ρ 5) and Repair (μ5) rates of 'Subsystem5' subsystem on system Availability

μ5 ρ 5	0.03	0.04	0.05	0.06	0.07	Constant Parameters
0.013	0.7156	0.7175	0.7208	0.7250	0.7278	μ1=0.010 ρ1 =0.20 μ2=0.005 ρ2 =0.15 μ3=0.0025 ρ3=0.125 μ4=0.005 ρ4=0.014
0.014	0.6993	0.7112	0.7183	0.7230	0.7262	
0.015	0.6945	0.7076	0.7156	0.7209	0.7245	
0.016	0.6896	0.7040	0.7129	0.7187	0.7227	
0.017	0.6845	0.7003	0.7100	0.7164	0.7209	

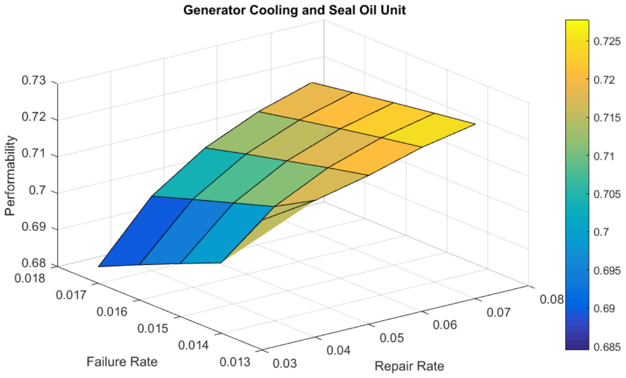

Fig.7: Effect of Failure and Repair Rates of 'Subsystem5' on System Availability

Table 7: Variation in the Overall Performability of Power Generation System with increase in Repair Facilities

No. of Repair Facilities	1	2	3	4	5
Availability	0.7156	0.7323	0.7399	0.7403	0.7402

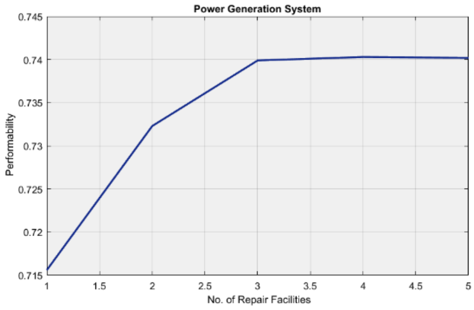

Fig.8: Effect of the Number of Repair Facilities on Availability of Power Generation System

Table 6 and Figure 7 present a comprehensive view of how the failure and repair rates of subsystem 5 influence the performability of the Power Generation System. Notably, the results demonstrate that the performability of subsystem 5 shows improvement with an increase in the repair rate, while it experiences a decline with an increase in the failure rate. Moreover, the availability of the entire system exhibits a positive trend with an increase in the repair rate from 0.03 to 0.07. However, there is a slight decrease in the system's availability with an increase in the failure rate from 0.013 to 0.017.

Table 7 and Figure 8 above illustrate how the performance and reliability of the steam generation system are affected by increasing the number of repair facilities. The results indicate that initially, the system's performance improves with the addition of more repair facilities. However, once a certain threshold value of repair facilities is reached, the system's performance stabilizes, and further increases do not significantly impact the overall performance. This implies that economically, it may not be justified to continue adding more repair facilities beyond this point since there is minimal variation in the system's overall performance.

Table 8: Maintenance Priorities for Various Subsystems of Power Generation System

Subsystem	Failure Rates	Decrease in Performability	Repair Rates	Increase in Performability	Repair Priority
SBS-1 Turbine Blades	0.008 to 0.012	3.27 %	0.18 to 0.22	1.01%	III
SBS-2 Condenser Evacuation & Regenerative	0.003 to 0.007	1.70%	0.05 to 0.25	0.57%	IV
SBS-3 Turbine Governing	0.0023 to 0.0027	0.22%	0.110 to 0.135	0.16%	V
SBS-4 Turbine Lubrication	0.004 to 0.006	16.05%	0.014 to 0.094	16.99%	I
SBS-5 Generator Cooling and Seal Oil	0.013 to 0.017	4.34%	0.03 to 0.07	1.70%	II

Table 8 provides the Maintenance Priorities for Various Subsystems of Power Generation System. It is clear that subsystem 4 has maximum impact of varying FRR on the overall performability, thus the subsystem 4 is the most critical subsystem. Similarly, subsystem 3 has least impact of varying FRR on overall performability of system, thus it is least critical.

Conclusion & Future Scope

Performability analysis involves the assessment of a system's performance and its ability to meet both performance and reliability criteria. The examination of performability matrices helps in understanding the criticality of various subsystems within a larger system. The performability matrices likely consider factors such as system performance, reliability, availability, maintainability, and safety. These matrices are used to quantitatively analyze and compare the performance and reliability of different subsystems. The higher the criticality level, the more important and sensitive a subsystem is to the overall performance of the entire system. The examination of the five performability matrices indicates that the turbine lubrication subsystem holds the highest level of criticality, whereas the turbine governing subsystem is the least critical. Consequently, maintenance decisions will prioritize the turbine lubrication subsystem as the topmost concern, while the turbine governing subsystem will be given the lowest priority. Further the obtained result can be optimized using the various techniques discusses in the reported literature. Such techniques could include Reliability-cantered Maintenance (RCM), Failure Mode and Effects Analysis (FMEA), Condition-Based Monitoring (CBM), Spare Parts Optimization, Predictive Analytics:

Root Cause Analysis, Advanced Maintenance Technologies etc.

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