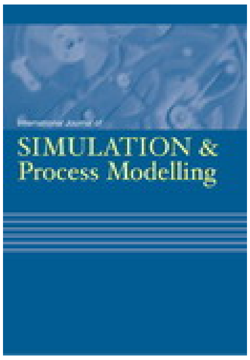

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Performance optimisation of the feed water system of thermal power plant using stochastic Petri nets with comparative analysis using PSO

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Abstract: This study applies the stochastic Petri nets method for the performance evaluation of the feed water system of thermal power plants. The availability analysis of subsystems has been used to determine the maintenance priorities. Further the particle swarm optimisation technique has been applied for the comparative analysis and optimised results. A licensed software package has been used to examine the effects of different failure and repair rates, as well as the availability of repair facilities, on the performance behaviour and availability of the system. An algorithm has been applied in MATLAB software for optimisation using particle swarm optimisation. On the basis of the availability matrices obtained by Petri nets, a decision support system for maintenance order priority has been proposed. The proposed maintenance order will help the maintenance personnel to identify the criticality among various subsystems and to plan the maintenance policies and schedule in advance.

Keywords: Petri nets; performance modelling; availability assessment; decision support system; feed water system.

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1 Introduction

As the need for electricity grows, power plants must operate constantly with a minimum of subsystem failures and maximum availability. India is the world's fifth-largest energy user, and coal-based thermal power plants supply 65 percent of this country's energy needs (Behera and Dash, 2010). These crucial thermal power plants are so important that even the slightest interruption or malfunction could result in a major energy shortage. Unexpected power plant shutdowns could result in significant income loss (Tan et al., 1997). This system is made up of several smaller systems such the coal crushing unit, feed water system, steam generation systems, water cooling system, coal handling system, etc. that are often logically connected in series or parallel form. The logical link and the unit performance of the subsystems are the major determinants of the system's overall performance (Gupta and Tewari, 2009). For all manufacturing and process industries, including automotive, food, oil, sheet metal, etc. performance analysis using reliability, availability, and maintainability (RAM) approaches has been found to be helpful. The layout and functionality of all production lines have also been immediately improved as a result of this (Tsarouhas, 2020). The reliability-availability-maintainability (RAM) techniques are highly helpful in examining the many problems associated to the upkeep and performance of the relevant systems in terms of availability.

Different scholars used various strategies for modelling the functioning of industrial systems. These include the following: genetic algorithms, fault tree analysis, failure mode analyses, effect analyses Lambda-Tau techniques, degradation modelling techniques, supplementary variable techniques, Markov technique, and Petri nets, among others. There are many modelling strategies, such the Markovian approach, which is a useful tool for modelling performance and gauging availability. It is typically applied to time-based reliability and availability studies (Kumar et al., 2020). The Markov approach was utilised by Kumar et al. (2021), Okafsor et al. (2016), Tomasz et al. (2017), Kumar and Modgil (2018), Dahiya et al. (2019) and Gupta et al. (2020) to model the performance of various complex industrial systems and to examine their availability. However, these methods have certain drawbacks, such as the explosion of states that occurs in systems with extensive subsystems that require time-consuming, difficult mathematical calculations. PN modelling is much easier to use and more precise than the Markov approach.

Carl Adam Petri used Petri net tool for the first time in his PhD research thesis and it is useful for the graphical modelling of systems. Since then, this technique has undergone further iterations with additional modelling and analysis elements. Garg and Rani (2013) proposed a method to compute the intuitionistic fuzzy set (IFS) membership functions using PSO and identify the important component using performance analysis. Ting et al. (2014) used the mixed integer programming (MIG) model to illustrate the shortest overall handling and waiting time for the berth allocation problem, which is solved using the PSO techniques. Zhang et al. (2014) described the reliability of an oil production system by using the simulation and compared with Petri net model.

Parkash and Tewari (2022) proposed performance modelling and analysis using Petri nets of assembly line system of leaf spring manufacturing plant. Kumar and Tewari (2022) discussed the performability analysis of ash handling system of a thermal power plant having hot redundancy and stochastic behaviour with stochastic Petri nets (SPNs). Orozco et al. (2022) deals with modelling and simulation as a tool for study and assessment of the design and manufacturing process of automotive prototypes using Petri networks. Cozac et al. (2022) developed a real-time monitoring algorithm for the elevators in apartment buildings. A Markov decision-making process was used to develop a model for the elevator setting procedure.

2 System description

The four primary subsystems that make up the feed water system are as follows:

- Condenser: Condensers are primarily used to condense steam from steam turbine exhaust and transform it into pure water. This steam is used as feed water in the boiler once more. One condenser is thought to be present in this subsystem. Due to a lack of redundancy in this area, the system would completely fail if one condenser failed.
- Condensate extraction pump (CEP): The condensate from the hot well is extracted using a CEP. The parallel setup of three CEPs is connected. If one or more of these extraction pumps failed, the system would operate at a reduced capacity. Similar to this, the system will stop working if all three extraction pumps fail.
- Low pressure heaters (LPH): In order to make the plant more fuel-efficient, LPH are utilised to collect the steam from the turbine and heat the water before it is given to the boiler. It is made up of three series-connected LP heaters. The system will operate at a reduced capacity if one LPH fails, however the feed water system will completely fail if all three fails.
- Deaerator: Before water is fed to the boiler, gases are removed from it using a deaerator. It is a single device with no redundancy, and if it fails, the entire feed water system will stop working.

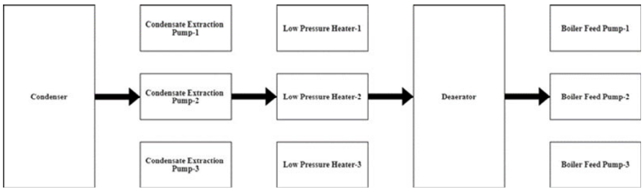
2.1 Assumptions and notations

The notations and presumptions below are used to expand the system's overall performance modelling using Petri nets:

- The configuration and nature of the active and standby systems are identical.
- When a subsystem fails, redundant units operating in parallel might only function to a limited extent.
- It is assumed that subsystems do not fail all at once.
- For a predetermined amount of time a component is as good as new after repair.
- After the subsystems fail immediately, the repair facilities are provided without delay.
- The distribution of subsystem failure and repairs is exponential.

- Depending on their states, the components were repaired or replaced during system servicing.
- The failure and repair rates (FRRs) are both taken into account to be statistically independent and steady throughout time.

Figure 1 Illustrative diagram of feed water system of thermal power plant



2.2 Places

- *sys_available:* It implies that has the entire system available and in upstate.
- *sys.works_full cap:* Demonstrates that the system as a whole is operating at its highest level of performance.
- *sys.works_red.cap:* Symbolises the system's operation at a reduced capacity.
- *sys_failed:* Represents the system's downstate.
- *rep.facilities_available:* Indicates the presence of a facility for instant repairs.
- *Condenser_up, CEP_up, LPH_up, Deaerator_up, and BEP_up:* Indicates the operational state of the BEPs, deaerator, condenser, CEPs, and LPHs.
- *Condenser_down, CEP_down, LPH_down, Deaerator_down, and BEP_down:* Depicts the down state of the condenser, CEPs, LPHs, deaerator, and BEPs, which is the non-working state.
- *Condenser_Rep, CEP_Rep, LPH_Rep, Deaerator_Rep, and BEP_Rep:* Represents the condenser, CEPs, LPHs, deaerator, and BEPs in their repaired states.

2.3 Transitions

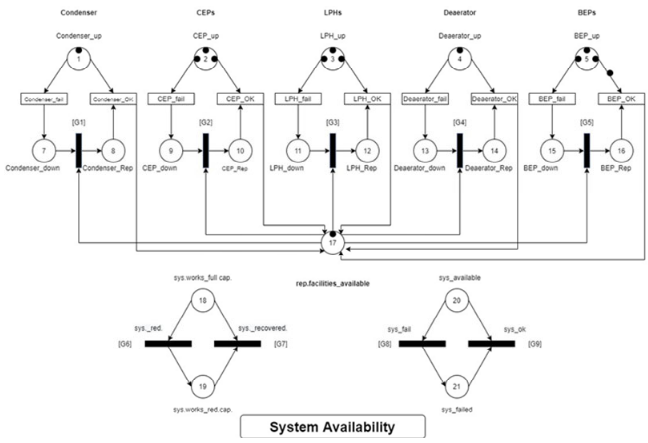
- *Condenser_fail, CEP_fail, LPH_fail, Deaerator_fail, and BEP_fail:* Exhibits timid transitions connected to the failure pattern of the condenser, CEPs, LPHs, Deaerator, and BEPs.Condenser_OK, CEP_OK, and LPH_OK.
- *Deaerator_OK and BEP_OK:* Shows timid transitions linked to the failure pattern of the condenser, CEPs, LPHs, deaerator, and BEPs.
- *rep.avail_Condenser, rep.avail_CEP, rep.avail_LPH rep.avail_Deaerator, and rep.avail_BEP:* Represents immediate transitions associated with availability of repair facility for condenser, CEPs, LPHs, deaerator, and BEPs.
- *sys_red, sys_recovered, sys_fail, and sys_ok:* Represents immediate transitions fired without any delay associated with system when it works in full and reduced capacity.

2.4 Program guard functions

The following is a description of the guard functions connected to various transitions:

- [G1]: = (#7 > 0 and #17 > 0) permits firing of rep.avail_Condenser transition.
- [G2]: = (#9 > 0 and #17 > 0) permits firing of rep.avail_CEP transition.
- [G3]: = (#11 > 0 and #17 > 0) permits firing of rep.avail_LPH transition.
- [G4]: = (#13 > 0 and #17 > 0) permits firing of rep.avail_Deaerator transition.
- [G5]: = (#15 > 0 and #17 > 0) permits firing of rep.avail_BEP the transition.
- [G6]: = #2 < 3 and #2 > 0 or #3 < 3 and #3 > 0 or #5 < 3 and #5>0) permits firing of the sys_red transition.
- [G7]: = (#2 > 2 and #3 > 2 and #5 > 2) deny firing of the sys_recovered transition.
- [G8]: = (#1 > 0 or #2 > 0, or #2 > 3, or #4 > 0, or #5 > 0) permits firing of the sys_fail transition.
- [G9]: = (#1 > 0 and #2 > 0, and #2 > 3, and #4 > 0, and #5>0) deny firing of the sys_ok transition.

Figure 2 Modelling of feed water system of thermal power plant using Petri nets



3 Performance analysis

The performance of the thermal power plant's feed water system was modelled using the Petri nets technique. In order to comprehend the long-term availability performance of FWS, performance analysis was determined. A licensed Petri nets software program called GRIF-predicates was employed for this. In the current analysis of performance in terms of availability, failure rates and repair rates were expected to follow the Weibull distribution and exponential distribution patterns, respectively. With a 95% confidence level, the Monte Carlo simulation was used to determine the plant's behavioural traits for up to 10,000 hours and about 21,000 replications. By entering the appropriate number for FRRs in the performability models, performability matrices are created. The created model in MATLAB is solved to produce the various performability levels listed in the matrices for each subsystem of the feed water system. Each subsystem's repair and failure rates were changed within allowable ranges while maintaining the other subsystem characteristics constant in order to analyse performance. Table 1 performance matrices and statistics for different feed water system subsystems demonstrate the effect of varying FRRs on the system's ability to function.

Table 1 Performability matrix for condenser subsystem of FWS

Φ_1 \ ρ_1	*0.055*	*0.060*	*0.065*	*0.070*	*0.075*	*Constant parameters*
0.005	0.8887	0.8933	0.8965	0.9071	0.9100	$\Phi_2 = 0.014$, $\rho_2 = 0.15$ $\Phi_3 = 0.004$, $\rho_3 = 0.15$ $\Phi_4 = 0.0025$, $\rho_4 = 0.125$ $\Phi_5 = 0.00005$, $\rho_5 = 0.015$
0.010	0.8165	0.8233	0.8423	0.8447	0.8451	
0.015	0.7503	0.7598	0.7732	0.7840	0.7982	
0.020	0.6950	0.6956	0.7296	0.7415	0.7492	
0.025	0.6483	0.6639	0.682	0.6906	0.7101	

Figure 3 Influence of varying FRR of condenser on the performability of FWS (see online version for colours)

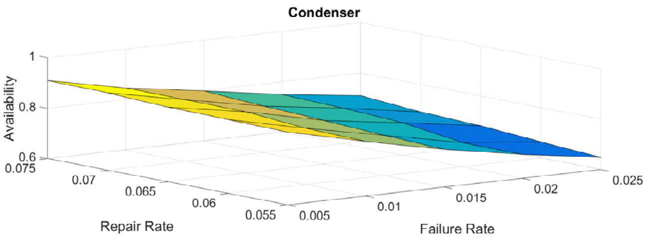


Table 2 Performability matrix for CEP subsystem of FWS

Φ_2 \ ρ_2	*0.05*	*0.100*	*0.15*	*0.200*	*0.25*	*Constant parameters*
0.012	0.7167	0.7711	0.7816	0.7835	0.7884	$\Phi_1 = 0.015$, $\rho_1 = 0.065$ $\Phi_3 = 0.004$, $\rho_3 = 0.15$ $\Phi_4 = 0.0025$, $\rho_4 = 0.125$ $\Phi_5 = 0.00005$, $\rho_5 = 0.015$
0.013	0.7111	0.7677	0.7725	0.779	0.7836	
0.014	0.7005	0.7562	0.7732	0.7859	0.7869	
0.015	0.7027	0.7601	0.7771	0.7809	0.7818	
0.016	0.6834	0.7516	0.774	0.7805	0.7814	

The impact of different condenser subsystem FRRs on the performance of FWS in terms of availability is shown in Table 1 and Figure 3. For a known failure rate (Φ) and repair rate (ρ), it can be seen that, while maintaining other parameters constant as shown in the table, the availability of the FWS drops rapidly from 91% to 71% (20% approx.) as the failure rate climbs from 0.005 to 0.025. Similar to this, the availability of the FWS rises from 64.8% to 71.01% (about 7%) when the repair rate rises from 0.055 to 0.075, whereas the overall availability of the FWS fluctuates from 64.8% to 91% with various combinations of condenser FRRs.

Figure 4 Influence of varying FRR of CEP on the performability of FWS (see online version for colours)

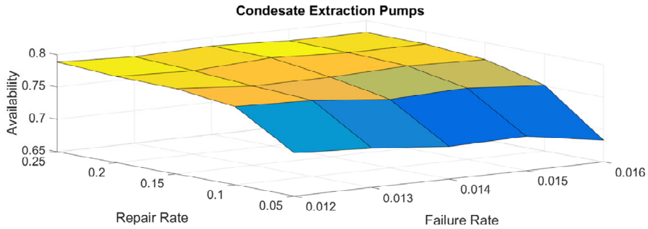
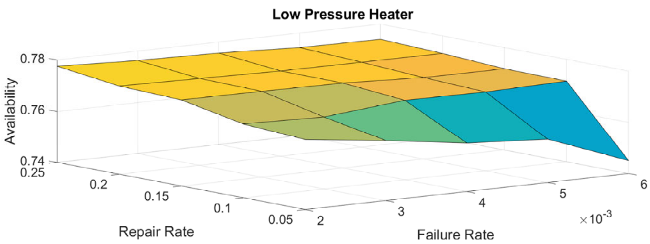


Table 2 and Figure 4 demonstrate how the CEPs subsystem's FRRs affect the performance of the FWS in terms of availability. For a known failure rate (Φ) and repair rate (ρ), it can be seen that, while all other parameters constant as shown in the table, the availability of the FWS drops sharply from 71.67% to 68.34% (3.5% approx.) as the failure rate rises from 0.012 to 0.016. Similar to this, the availability of the FWS improves from 68.34% to 78.14% (about 10%) as the repair rate of CEPs increases from 0.05 to 0.25, while the overall availability of FWS fluctuates from 68.34% to 78.84% with various combinations of CEP FRRs.

Table 3 Performability matrix for LPH subsystem of FWS

Φ_3 \ ρ_3	*0.05*	*0.1*	*0.15*	*0.2*	*0.25*	*Constant parameters*
0.002	0.7673	0.7689	0.7737	0.7745	0.7776	$\Phi_1 = 0.015$, $\rho_1 = 0.065$ $\Phi_2 = 0.014$, $\rho_2 = 0.15$ $\Phi_4 = 0.0025$, $\rho_4 = 0.125$ $\Phi_5 = 0.00005$, $\rho_5 = 0.015$
0.003	0.7634	0.7681	0.7735	0.7739	0.7763	
0.004	0.7589	0.7711	0.7732	0.7733	0.7757	
0.005	0.7569	0.7708	0.7718	0.7732	0.7743	
0.006	0.745	0.7715	0.7717	0.7731	0.774	

Figure 5 Influence of varying FRR of LPH on the performability of FWS (see online version for colours)

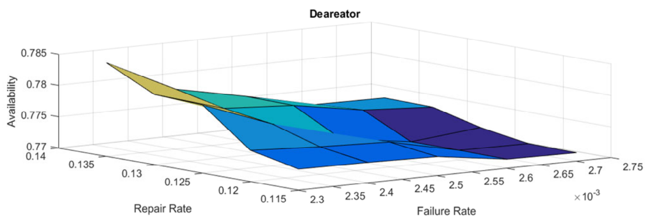


The impact of various LPHs subsystem FRRs on the performance of FWS in terms of availability is shown in Table 3 and Figure 5. For a known failure rate (Φ) and repair rate (ρ), it can be seen that, while maintaining other parameters constant as shown in the table, the availability of the FWS drops drastically from 76.73% to 74.50% (approximately) as the failure rate rises from 0.002 to 0.026. Similar to this, the availability of the FWS improves from 74.50% to 77.40% (about 10%) as the repair rate of LPHs increases from 0.05 to 0.25, while the overall availability of FWS varies from 74.50% to 77.76% with various combinations of FRRs of LPHs.

Table 4 Performability matrix for deaerator subsystem of FWS

Φ_4 \ ρ_4	*0.115*	*0.12*	*0.125*	*0.13*	*0.135*	*Constant parameters*
0.0023	0.7734	0.7751	0.781	0.7813	0.785	$\Phi_1 = 0.015$, $\rho_1 = 0.065$ $\Phi_2 = 0.014$, $\rho_2 = 0.15$ $\Phi_3 = 0.004$, $\rho_3 = 0.15$ $\Phi_5 = 0.00005$, $\rho_5 = 0.015$
0.0024	0.7733	0.7745	0.7768	0.7779	0.7796	
0.0025	0.7731	0.7741	0.7732	0.7772	0.7773	
0.0026	0.7715	0.7716	0.7716	0.7753	0.7748	
0.0027	0.7714	0.7715	0.7727	0.7746	0.7747	

Figure 6 Influence of varying FRR of deaerator on the performability of feed water system (see online version for colours)



The impact of various deaerator subsystem FRRs on the performance of FWS in terms of availability is shown in Table 4 and Figure 6. For a known failure rate (Φ) and repair rate (ρ), it can be seen that, while maintaining other parameters constant as shown in the table, the availability of the FWS drops drastically from 77.47% to 78.50% (about 1.03%) as the failure rate rises from 0.0023 to 0.0027. Similar to this, the availability of the FWS increases from 77.14% to 77.47% (approximately 0.33%) as the repair rate of the deaerator increases from 0.115 to 0.135, while the overall availability of the FWS varies from 77.14% to 78.50% with different combinations of FRRs of the deaerator.

The impact of altering BEP subsystem FRRs on the performance of the FWS in terms of availability is shown in Table 5 and Figure 7. For a known failure rate (Φ) and repair rate (ρ), it can be seen that, while maintaining other parameters constant as shown in the table, the availability of the FWS drops drastically from 77.63% to 76.47% (about 1.15%) as the failure rate rises from 0.00003 to 0.00007. Similar to this, the availability of the FWS increases from 76.47% to 77.18% (about 0.65%) when the repair rate of BEP rises from 0.009 to 0.0.021, while the overall availability of FWS varies from 76.20% to 77.84% with various combinations of BEP FRRs.

Table 5 Performability matrix for BEPs subsystem of FWS

μ_5 \ ρ_5	*0.009*	*0.012*	*0.015*	*0.018*	*0.021*	*Constant parameters*
0.00003	0.7763	0.7764	0.7776	0.7779	0.7784	$\Phi_1 = 0.015$, $\rho_1 = 0.065$ $\Phi_2 = 0.014$, $\rho_2 = 0.15$ $\Phi_3 = 0.004$, $\rho_3 = 0.15$ $\Phi_4 = 0.0025$, $\rho_4 = 0.125$
0.00004	0.7756	0.7762	0.7762	0.7771	0.7773	
0.00005	0.773	0.7731	0.7732	0.7738	0.7757	
0.00006	0.7712	0.7731	0.7732	0.7733	0.7757	
0.00007	0.7620	0.764	0.768	0.7715	0.7718	

Figure 7 Influence of varying FRR of BEPs on the performability of feed water system (see online version for colours)

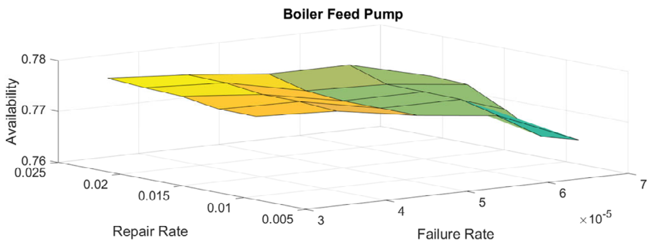
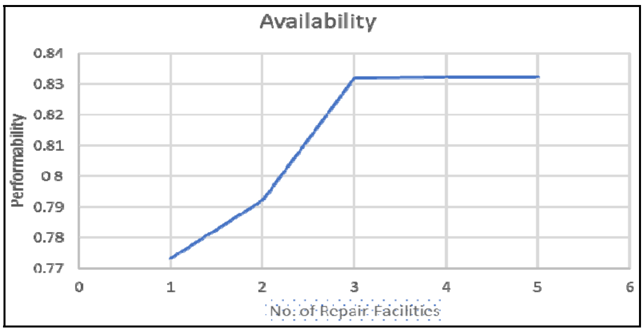


Table 6 Influence of variation in the repair facilities on performability of feed water system

No. of repair facilities	1	2	3	4	5
Availability	0.7732	0.7923	0.8320	0.8321	0.8321

Figure 8 Influence of variation in repair facilities on the performability of feed water system (see online version for colours)



The influence of the number of repair facilities on system performance is depicted in Figure 8. When there are two or more repairmen in the system, the performance improves and stabilise after some level. It leads to the conclusion that two separate repair facilities are required to obtain the best system performance.

4 Results and discussion

The behaviour of the feed water system performability with the change in the FRR of various subsystems is represented by the performability matrices shown in Tables 1 through 5. These matrices aid in formulating maintenance priorities that take into account the importance of various subsystems, enabling maintenance engineers to promptly take corrective action for the most critical subsystem. With various combinations of FRR of condenser, the overall availability of FWS varies from 64.8% to 91%, as was previously discussed. Similar to how CEP availability varies with different FRR, FWS availability ranges from 68.34% to 78.84%. It ranges for LPHs from 74.50% to 77.76%. When adjusting the deaerator and BEP availability, there is a discernible change.

Table 7 Maintenance priorities for various subsystems of feed water system

Name of subsystem	*Variation in failure rates (Φ)*	*Variation in repair rates (ρ)*	*% change in availability*	*Repair priority*
Condenser	0.005 to 0.025	0.055 to 0.075	64.8% to 91%	1
Low pressure heater	0.002 to 0.026	0.05 to 0.25	74.50% to 77.76%	3
Condensate extraction pump	0.012 to 0.016	0.05 to 0.25	68.34% to 78.84%	2
Deaerator	0.0023 to 0.0027	0.115 to 0.135	77.14% to 78.50%	5
Boiler feed pump	0.00003 to 0.00007	0.009 to 0.021	76.20% to 77.84%	4

According to the study, the deaerator is the least important subsystem and the condenser is the most important one. Therefore, while making maintenance decisions, the condenser will be given the highest priority and the deaerator the lowest.

5 Performability optimisation of feed water system

This section deals with the performability optimisation of feed water system of thermal power plant using PSO. It provides the best performance values in terms of performability at various FRR to enhance the overall performance. The performability of various systems in the selected system is examined in relation to performance criteria, such as FRR, by adjusting the population size and generation size. The PSO is a stochastic optimisation technique based on population that draws social behaviour from flocks of birds as its inspiration.

In their pursuit of food, flying birds adjust their position by altering their velocity (depending on prior knowledge and feedback from their neighbours). As a result, for this searching process, optimisation problems are solved artificially. Every solution is viewed as a bird (particle) with a fitness-value. To determine the fitness-value, an objective function is employed. Each individual is referred to as a 'particle' in the PSO algorithm and represents a potential solution in the issue space.

In order to arrive at the best solution, the particles maintain track of their positions and update them depending on their own flying experience as well as that of the other particles in the issue space. In order to find the best position, the velocity and position are updated as the particles move across the multi-dimensional search space (optimum solution). To move toward its best position and the global best position, each particle in the PSO algorithm adjusts its velocity and position using the following equations:

$$V_i^{k+1} = wV_i^k + C_1 r_1 \left(pBest_i - x_i^k \right) + C_2 r_2 \left(gBest - x_i^k \right) \quad (1)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (2)$$

N represents the population's size, $I = 1, 2, \ldots, N$, and V_{ik} stands for the particle's velocity at iteration k. x_i^k indicates the position of particle I at iteration k; $pBest_i$ represents the personal best of specific particle i; $gBest$ indicates the best position nearby; w is the weight of inertia; c_1 and c_2 are coefficients of acceleration; and r_1 and r_2 are random numbers varying from 0 to 1.

Table 8 Various parameters for PSO implemented

Sr. no.	*Parameter*	*Range/value*	*Remarks*
1	Population size (*PS*)	10.00 to 100.00	For optimum performability
2	Generation number (*GS*)	5.0 to 50.0	Optimum performability
3	Weight of inertia (*w*)	0 to 1	Its value lies between 0–1
4	Cognitive-factor (c_1)	1.490	Arbitrarily selected
5	Social-factor (c_2)	1.490	Arbitrarily selected
6	Constant random number (R_1)	0–1	Arbitrarily selected
7	Random number (R_2)	0–1	Arbitrarily selected

Figure 9 Transition diagram of states of feed water system

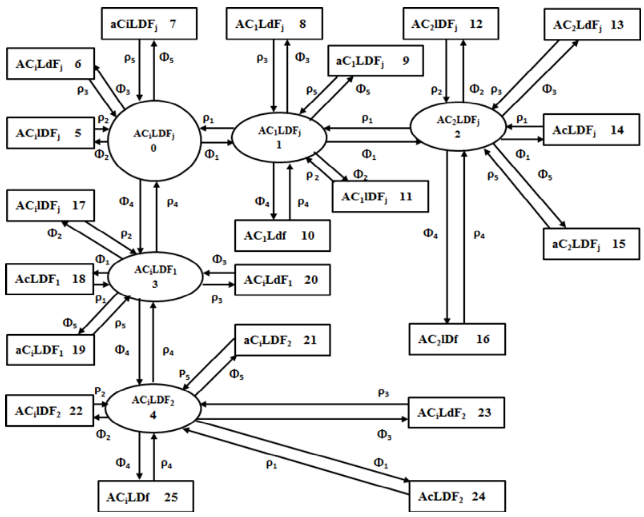


Table 9 Effect of particle size on performability of FWS at constant GS (100)

FRR	*PS-5*	*PS-10*	*PS-15*	*PS-20*	*PS-25*	*PS-30*	*PS-35*	*PS-40*	*PS-45*	*PS-50*
Φ-1	0.013	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Φ-2	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005
Φ-3	0.0024	0.0023	0.0023	0.0023	0.0023	0.0023	0.0024	0.0024	0.0024	0.0024
Φ-4	0.00006	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
Φ-5	0.0015	0.0010	0.0010	0.0010	0.0010	0.0010	0.0008	0.0008	0.0008	0.0008
ρ-1	0.29	0.29	0.29	0.29	0.30	0.29	0.31	0.31	0.31	0.31
ρ-2	0.11	0.19	0.19	0.19	0.19	0.19	0.25	0.25	0.25	0.25
ρ-3	0.134	0.124	0.124	0.123	0.123	0.123	0.133	0.133	0.133	0.133
ρ-4	0.008	0.014	0.014	0.014	0.015	0.015	0.009	0.009	0.008	0.008
ρ-5	0.09	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08

Table 10 Effect of generation size on performability of FWS at constant PS (40)

FRR	*GS-10*	*GS-20*	*GS-30*	*GS-40*	*GS-50*	*GS-60*	*GS-70*	*GS-80*	*GS-90*	*GS-100*
Φ-1	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Φ-2	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Φ-3	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
Φ-4	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
Φ-5	0.0009	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
ρ-1	0.29	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
ρ-2	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25
ρ-3	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133	0.133
ρ-4	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
ρ-5	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Figure 10 Flowchart of implemented PSO

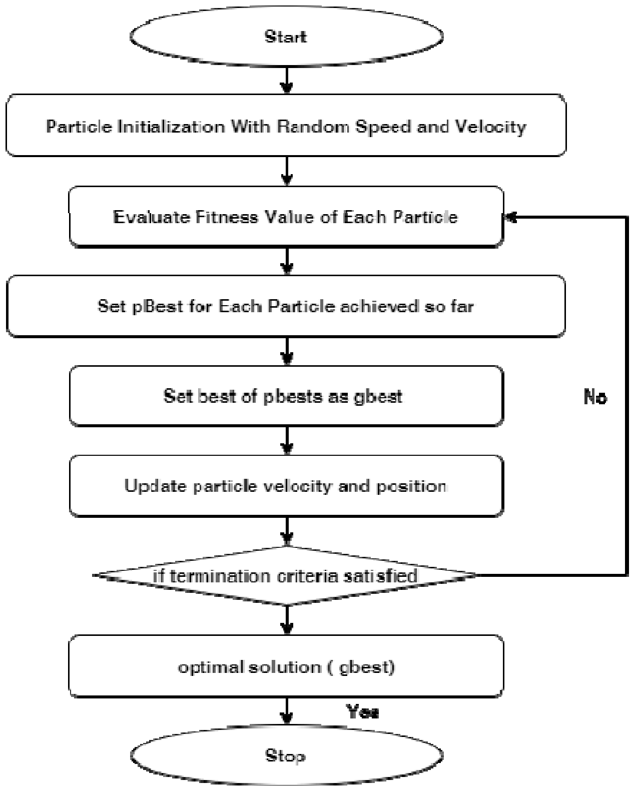


Table 7 indicates the numerous parameters used for the PSO algorithm in the present study are shown.

The transition diagram of the feed water system was obtained as shown in Figure 9. After solving the transition diagram of coal handling system using the Markovian approach the following equation has been obtained for the performance measurement.

$$P_0 = 1\Big/\left[(1+K_1+K_1\cdot K_1+K_4+K_4\cdot K_4)(K_1+K_2+K_4+K_5)\right]$$

where

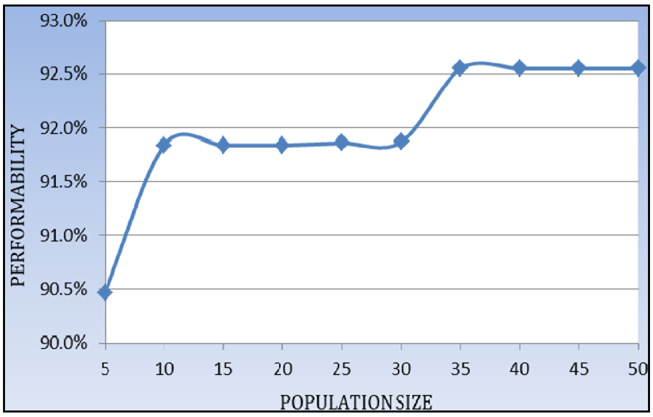
$$K_i = \phi_i/\rho_i.$$

By adjusting two factors, PS and the number of generations, the performance was optimised using the aforementioned approach. The following list illustrates the designed ranges for the failure (ϕ) and repair rate (ρ) parameters of the various subsystems of:

- ϕ_1 (0.005 to 0.025), ρ_1 (0.055 to 0.075) – condenser
- ϕ_2 (0.002 to 0.026), ρ_2 (0.05 to 0.25) – LPH
- ϕ_3 (0.012 to 0.016), ρ_3 (0.05 to 0.25) – CEP
- ϕ_4 (0.0023 to 0.0027), ρ_4 (0.115 to 0.135) – deaerator
- ϕ_5 (0.00003 to 0.00007), ρ_5 (0.009 to 0.021) – boiler feed pump (BEP).

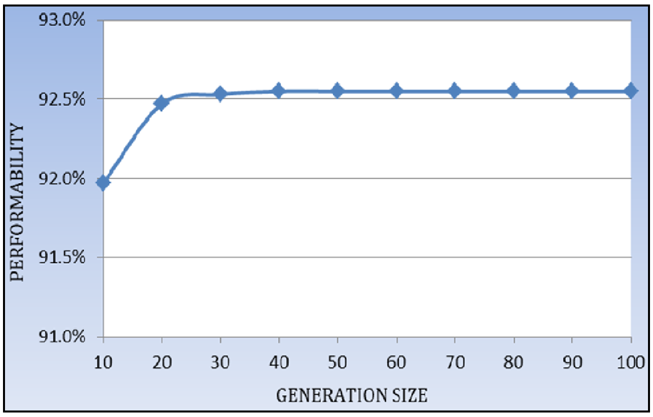
Using the algorithm of PSO at a population size of 35 and a generation size of 100, i.e., constant, the optimal performability for the feed water system was obtained, and it is 92.55%. Table 8 lists the optimal FRR combinations as $\Phi_1 = 0.011$, $\Phi_2 = 0.004$, $\Phi_3 = 0.0023$, $\Phi_4 = 0.00004$, $\Phi_5 = 0.0007$, $\rho_1 = 0.30$, $\rho_2 = 0.24$, $\rho_3 = 0.132$, $\rho_4 = 0.008$ and $\rho_5 = 0.07$. Figure 11 illustrates the influence of parameter particle size at constant generation size, on the system's performability. Following are the performability levels for the feed water system at PS, which ranged from 5 to 50 in a step of 5 while maintaining a constant GS.

Figure 11 Effect of particle size on performability of FWS (see online version for colours)



By employing the PSO algorithm at a GS of 40 and a constant PS of 40, the feed water system's optimal performability of 92.55% is attained. The proper FRR combinations are shown in Table 9 as follows: 1 = 0.011, 2 = 0.004, 3 = 0.0023, 4 = 0.00004, 5 = 0.0007, 1 = 0.03, 2 = 0.24, 3 = 0.132, 4 = 0.008 and 5 = 0.07. Figure 12 illustrates the impact of typical parameters like PS and constant GS. The following are the performability levels for the GS feed water system, which ranged from 10 to 100 in steps of 10 while maintaining a constant PS:

Figure 12 Effect of generation-size on performability of FWS (see online version for colours)



6 Conclusions

In the present work, performance modelling and evaluation for the feed water system of thermal power plant has been carried out based on availability analysis. The study shows that the condenser is the most crucial subsystem of the feed water system and should be prioritised when making maintenance decisions. Frequent preventive maintenance needs to be implemented for the condenser to prevent an unexpected shutdown of the entire system, while the deaerator can be viewed as the least important subsystem and requires less maintenance while keeping in mind the economy of maintenance. According to the severity of failure of each subsystem, the overall study will assist the maintenance engineers in planning ahead for the allocation of repair facilities for the various subsystems. The results of the present study highlight the FRR and optimal performability level for a number of subsystems, which is very beneficial to plant administration when deciding on maintenance planning. For validation, it is also possible to compare the relevant PSO algorithm against other optimisation methods like simulated annealing, ant colony, genetic algorithm, and so forth.

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