Summary of past works of maintenance prioritization and optimization mechanisms for power plant

Firas B Ismail¹, N Fazreen A Fuzi¹, N A Kamal¹

¹Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

Firas@uniten.edu.my

Abstract. Annual maintenance is vital for any heavy industries including power plant to ensure the plants operate consistently. A proper maintenance management can reduce the failures occurrence and maintain the good performances. This paper reviews the literature on maintenance optimization mechanisms that have been utilized to solve the difficult and complex problems in power system. A brief introduction and literature review on the turnaround maintenance are included in this paper. In order to optimize the maintenance tasks of power plant systems, the tasks need to be prioritized first. Hence, this paper also presented several literatures on the methods used for maintenance prioritization. This paper includes the most related case studies and references on maintenance actions involved in power plants. The main outcome of this reviewed paper is to become a reference for the power plant people in choosing the best mechanism to be implemented in their plant so that the plant performance can be improved, specifically in term of maintenance practice.

1. Introduction

Power plant that made up of many complex equipment and machinery runs interdependent towards each other. These equipment and machinery need a good attention because they have a tendency to degenerate over time. Deteriorate of equipment and machinery such as corrosion, erosion, fatigue and other reasons may result in consequences of failure and in extreme cases it may leads to unplanned shutdown. Therefore, maintenance teams must be responsible to adopt a proper maintenance scheduling strategy in optimizing the systems in order for the plant may keep on operating in a smooth and continuous way. Effective, accurate and efficient maintenance management is vital for the power plants in order to enhance the system design as well as to make the maintenance easier rather than just conducting maintenance actions. Maintenance consists of a wide range of tasks for different parts and equipment in power plant system such as boiler, turbine, generator and various of its auxiliaries [1]. In order to optimize these tasks, it requires a real data set of historical data from power plant equipment which includes the associated information such as turnaround time, overall cost, failure rate and other related measurement.

Recent research and studied in the past two decades have presented and introduced several new methods called heuristic methods that used to optimize the systems of power plant in order to address the difficult and complex problems as well as presenting the solution in minimizing both the project duration and associated cost during the power plant turnaround maintenance. This review paper focuses on the overview on power plant systems and presents some literature on turnaround scheduling and the variety of optimization models to be adopt for turnaround.
2. Turnaround Maintenance

According to C. H. Wang et al. [2], maintenance known as a group of various activities that is executed to retain or restore the status of functioning and working for a system. Maintenance commonly has been categorized into three types which are preventive maintenance, corrective maintenance and predictive maintenance. Turnaround can be described as a scheduled event which taken off-stream for a longer span for renewal or overhaul the whole industrial plant on each process unit such as oil refinery, nuclear power plant, petrochemical plant, steam power plant and other associated industries. Turnaround maintenance of plant is necessary for good performance [3]. This process involves a very high-cost while the time allocated is very limited. Thus, all the activities related to plant turnaround need to be planned properly by a good management system. A quality management is required to the activities of turnaround achieve the planned goals resulting in better performance. This is because, some previous research has shown that although the organizations have the best turnaround methodologies, yet some of them still completely failed to achieve the purposes [4].

Ben-Daya et al. [5] in their book have described that turnaround management has a potential in saving the cost of maintenance and directly contributes profits in bottom line of company. The most important element in maintenance management is the maintenance planning and scheduling. This element works well in managing complex turnarounds [6]. According to Ben-Daya et al., there are six objectives of turnaround maintenances which are to provide an efficiency enhancement and throughput of plat by suitable modification, to contribute an improvement in equipment reliability during operation, to ensure the plant is safe for operation till upcoming turnaround, to perform the best quality of workmanship, to contribute a cost minimization in routine maintenance and to present an enhancement in technology by providing modern techniques and equipment.

Lenahan [7] noted that there are several performance indices that can be used to rate the performance of turnaround maintenance such as safety, cost, duration, efficiency and quality. Dickson et al., also has highlighted in their research that in order to guard against misleading factors, the balanced criteria for measuring the performance must be considered [8].

Maintenance plays an important role in modern plant industries and manufacturing systems. Even more, most of the companies adopting maintenance as a generating business element to ensure the operation in such an efficient, effective and economic way in sustaining their long period time of survival. One of the purposes of the maintenance operation is to achieve and gaining a profit towards organization [9]. Utilizing the appropriate way of maintenance practices will benefit the companies in term of maximize profit by reducing maintenance cost. Turnaround also must be completed in shortest possible time as production opportunity during turnaround period is totally lost or at least major portion of plant since the plant has been shutting down [10].

It has been clear that preventive maintenance should be done when production is least affected which can be carried out using preventive maintenance. In previous research study, it has been stated that preventive maintenance has a cheaper cost than corrective maintenance [11]. Frost and Dechter stated that the power generating units that have been scheduled their preventive maintenance within a power has become the matter of satisfaction. The common reason in setting the maintenance schedule for power generating units is to verify the its period and cycle of outages over a given time period, therefore the operating and maintenance costs can be minimized over the planning period [12].

According to Amaran et al., plant turnarounds need to be done periodically. Therefore, the disruptions in material flow through production sites or due to the equipment damages may incur enormous costs and consume resources that may resulted in lost sales can be avoided. Thus, a practical consideration is needed in choosing the right modelling approach for maintenance scheduling to optimize and minimize the plant turnaround and effects on profits and production, respectively [13]. A successful maintenance scheduling job has bringing together six elements in appropriate timing which are mechanics, tools, materials, availability of unit to be serviced, adequate information and permissions to complete the task. [14].Huang et al. noted in their article that maintenance scheduling has a valuable significant to the economic and reliable operation of a power system. Preventive maintenance must be performed to keep the premature aging and the failure of equipment from occurring in a power system,
otherwise the plant may be facing the unplanned and costly power outages. Scheduling and executing an actual work must be involved in order to secure a reliable operation of a system. Modern power system nowadays become larger due to high demand of electricity making the maintenance scheduling problems even more complex. Thus, the application of optimization approaches was proposed to solve these problems [15].

3. Steam Power Plants

Power plant that generates steam is called as steam power plant. A steam power plant that establish from Rankine cycle expands the steam that generated through boiler in steam turbine while the condenser used to collect the condensed steam before it been pumped back into boiler again [16]. Steam is used as a working fluid as it can be processed using water which is available in abundance. Generally, as can be seen in Figure 1, power plant system consists of several equipment such as furnace, steam generator, main power unit such as turbine, the piping system in order to convey steam and water to each equipment, boiler drum and air preheater [17]. Power plants not only depend on the main equipment as mentioned above as it also requires various auxiliaries and accessories.

![Figure 1. Steam power plant schematic diagram.](image)

One of the crucial in power plant system is steam boiler, used to generate steam. Usually boilers are coal- and oil-fired. Boilers consist of several components and its major components are air pre-heater, soot blowers, super heater, reheater, economizers and others. All the components in the system need to fulfill some requirement in order to ensure a good performance from it. Some requirements that need to be fulfilled are safety, accessibility, capacity and efficiency. These requirements can be fulfilled by a good operation and maintenance management.

According to Magnus due to the various of activities and equipment as well as the dependency between task and activities, maintenance process commonly known as high-cost and taking a lot of time. Thus, it is crucial for the maintenance team in setting up the maintenance schedule to ensure the shutdown maintenance can be completed within the time range [18]. It is so important to plan and schedule the maintenance to reduce the maintenance cost and designated the best procedures to improve the quality of maintenance work. Again, Sharma et al. in their article stated that maintenance control carried a critical role in optimizing the maintenance as maintenance is considered as value adding activity for expenses instead of as a necessary evil.

4. Maintenance Ranking and Prioritization

Maintenance prioritization and ranking for the components or activities is the effective method to be used in order to save and reduce the cost. Shah noted that in order to ensure a proper decision of maintenance prioritization, it requires the consideration of multiples factors and some knowledge and
understanding in this area [19]. In another study, it was stated that decision makers tend to be more efficient instead of being effective in managing the maintenance activities. Managers usually only focused on prioritization based on the number of maintenances that have been done rather than investigate the overall factors such as downtime, capacity, bottleneck constraints and spare part cost [20].

Anthony noted that the purpose of prioritization of a maintenance work in power plant is to ensure the performing of the right work at the right time which can minimize the impact on plant operation [21]. An effective prioritization process should be designed based on the accountability of a system. The prioritization action or work in power generation should be documented formally to ensure the work is scheduled based on equipment criticality, resource availability and time required to plan the work. An organized search regarding the prioritization methods on literature has been reviewed. Most of the literatures found by using the main keywords of maintenance prioritization and ranking, maintenance priority, power plant maintenance and turnaround maintenance.

Through detailed analysis of the literatures, there are several methods can be used to prioritize the maintenance task such as priority criterion, matrix-based measurement, Analytical Hierarchy Process (AHP), reliability analysis method, Failure Mode and Effect Analysis (FMEA), Risk-Based Maintenance (RBM) and many more. Some of least used methods are simple comparison, criticality index, Fault Tree Analysis (FTA), Additive Ration Assessment (ARAS), Probabilistic-Based Assessment (PBA), Event Tree Analysis (ETA) and Failure Modes, Effects and Criticality Analysis (FMECA) [22].

4.1. Reliability Analysis

The function of reliability analysis method is to provide a safety, quality, and operational availability enhancement for the system by applying at the phase of a lifetime of a system. The reliability problems can be set out by a state of a system, or in a complex system that exist in one of the multiple states. All of the system states are individual, recognizable, and constant in time. In addition, some of stochastic processes of reliability analysis method are applied to the repairable system for analyzation process, such as the Homogeneous Poisson Processes, Markov Processes and others which are widely used as an analysis method as it can be utilized to model systems with several states and transitions between the states [23]. Figure 2 shows the work flow of maintenance reliability analysis.

4.2. Risk-Based Analysis

The decision-making using risk-based task prioritization usually associated with the outages of plant for a collection of maintenance tasks. There are two elements in forming the risk-based prioritization method which are the consequences of not performing the task and the probability of the consequences occurring. RBM method make decisions by deriving the information on the condition of equipment, the task to be performed, the equipment’s failure rates, consequences and probabilities and the task’s financial impact. The amount of risk that depend on these elements can be expressed in (1) [24-25].

---

**Figure 2.** Work flow of reliability analysis.
Risk = \text{Probability of failure} \times \text{Consequences} \quad (1)

According to Hameed et al., the most notable effect of equipment failures onto the system need to be highlighted in order to provide an optimization to the system. Typically, the plant dealing with various activities during turnaround maintenance thus, it is so unrealistic to claim the interval of turnaround be able to situate on all the equipment. The cost due to the turnaround maintenance can be offset by reducing and prioritizing the activities which is by removing and ranking those lesser risk to availability, reliability and safety activities. This module proposes an assessment in selecting the critical equipment that highly affected towards the system functionality [26].

4.3. Failure Mode and Effect Analysis
FMEA is a planning tool designed to recognize and keep the potential problems from occurring. The procedure of this method starts with identifying the mode of possible and also unknown failure and correlate those failure modes with potential causes and effects. In the next stage, the failure is ranked based on three parameters which are the occurrence, detectability and severity. The result of multiplication of these three parameters form Risk Priority Number (RPN) that can be expressed as in (2).

\[ \text{RPN} = S \times O \times D \]  

Where, S is for failures severity, O is for probability of failure occurrence and D is for detectability of failure before occurring [27].

4.4. Analytical Hierarchy Process
AHP method is utilized to assess the alternatives in relation to the criteria and sub-criteria in order to achieve the goals. It is calculated in a reciprocal matrix form and the step is repeated for subsequent sub-criteria until the process reaches to the best alternatives. The basic steps for AHP is the construction of hierarchy, followed by data collection and finally data analysis to calculate global weights [28].
Suebsomran et al. have implemented the combination of FMEA and AHP approaches in their work for critical maintenance of thermal power plant in order to find the critical ranking that considering three criteria which are cost, labor workforce and priority line. Using FMEA, the most important maintenance the equipment is chosen based on the damage level with proper intensity as FMEA is developed to recognize the system failure. Then, AHP is proposed to provide ranking based on the required criteria. The developed results show satisfaction for the management operator and have been applied into real maintenance scheduling at thermal power plant [29].

5. Maintenance Optimization
Based on the maintenance context, optimization is described as searching for an equitable solution of maintenance using preferred approach that accessible to the objective under certain criteria. It works by identifying the values of the modelled variables, either to minimize or maximize the objective function. Optimization process usually involves different information level according to the method selected. With higher level of information, the optimization results can be more accurate [30]. The literature revealed that many researchers recently have considered the usage of computational methods in optimizing the maintenance actions in power plants, called computational intelligence (CI). CI is a soft-computing subset of Artificial Intelligence is referring to the potential of a computer to gain knowledge from an experimental observations or specific task. Generally, optimization computational and mathematical methods are designed for finding the best solution of a certain problems that aiming for minimizing or maximizing the objective functions based on the variables and subject to a set of constraints.
Traditionally, some methods were used to perform an optimization process. Upon that many researchers emphasized on the challenges of using these traditional methods in handling constraints,
passing over local optima solution and other difficulties related to computing. A heuristic is an alternative optimization method that able to determine a solution by setting a quality approximation to exact solution. The main characteristics of heuristic method is that it is designed to provide better performance in term of computational at the expense of lower accuracy, compared to conventional optimization techniques.

The term of metaheuristic was proposed as a family of searching algorithms that be able to establish a high degree of heuristic method that can guide other heuristics to get a better evolution in the search space. There are several types of metaheuristic method which are Simulated Annealing (SA), Tabu Search (TS), evolutionary computation techniques, artificial immune systems, Ant Colony Algorithm (ACO), harmony search and honey-bee colony optimization. Also, there are techniques under the evolutionary computation such as GA and PSO. Detailed discussion on the metaheuristic techniques are introduced in the following sections. Similar to the previous section, an organized search has been reviewed but this time is regarding the optimization methods used in power plant on literature. Most of the literatures found by using the main keywords of maintenance optimization, metaheuristic techniques, power plant optimization maintenance.

5.1. Genetic Algorithm

Genetic Algorithm (GA) are a heuristic solution search technique has good performance in searching a close value for global maximum and minimum by exploring into a space whether with mutation or derive satisfactory results using selection and crossover. A natural parameter set of optimization problem is essential for GAs to be coded as a chromosome (string length) containing characters and features that have been taken from some string alphabets. Package of strings in total is known as a population or structure [31-32]. Many researchers have presented an application of GA in their works. Damousis et al. in their article presented a GA-based solution to economic dispatch problem in power plant. About 72 generating units with non-convex cost function was tested with the system. The result shows that GA has the superiority over the dynamic programming solution [33]. While Angela et al. developed a GA based method for solving the problem related to the distribution system and Yalcinoz et al. proposed the real coded GA that relies on elitism, crossover and mutation to present solution to economic dispatch problem. Both of works are done with the large population [34-36].

5.2. Simulated Annealing

Simulated Annealing was first introduced by Kirkpatrick is a complete correlation with annealing in solids that presents a structure to optimize the properties of large and complex systems [37]. SA depends on the temperature parameter which is diminishing along the search process. Referring to the concept of thermodynamics, SA governed under this principle where the liquids crystallize as its freeze or metals anneal as its cool. Thus, in order for algorithm to have a good performance, the selection of cooling schedule become crucial. SA has been utilized in in several Combinatorial Optimization (CO) problems where the common problems of CO is timetabling and scheduling [38].

Keshav et al. presented the implementation and performance of SA and combine GA/SA in their works for the generator maintenance scheduling (GMS). A maintenance action with the period of 52 weeks on 21 generating units considered as a test problem with parameters requirement of capacities, allowed periods and duration of maintenance and manpower required for each unit. SA results show that all the parameters values were successfully identified to be reasonable for the test problem. The study show that SA approach is stable for solving the GMS problems [39].

5.3. Particle Swarm Optimization

This technique that was introduced by Kennedy and Eberhart [40] is energized by the behavior of biological swarms and social adaption. A structure of swarm in PSO will encode the solution candidates (particle) to find for the opima regions by flying into the n-dimensional search space of the optimization problem. The solution candidate position is represented by the swarm particle, while the velocity of particle indicates the information about direction and changing rate. The particles are directed by two
components which are cognitive and social information based on its own experienced and observation of neighbors, respectively. Figure 3 below shows the basic algorithm for PSO.

Zhang et al. in their article proposed PSO-based method with the objective to minimize the project duration in solving the RCPSB. This study which aiming for the optimization issue of construction project management demonstrated that performance of PSO can achieve same result as GA approach and even better result when compared to the general heuristic rules. However, due to the features of one-way experience sharing mechanism, PSO approach become more efficient than GA and has the capability to search for global optima [41].

Yimin et al. have studied the PSO algorithm application to optimize the unit scheduling and maintenance of generators. A hybrid PSO is introduced for mutation and selection for minimum operational cost objective with the constraint of load balance, spinning reverse, thermal stability and safety requirement. Throughout the experiment performed for maintenance plan, PSO shows better power efficiency, reliability and reduced energy costs achievement when compared to GA [42].

5.4. Ant Colony Optimization
Ant Colony Optimization (ACO) introduced by Dorigo et al. is one of the new metaheuristic methods that is based in the behavior of ant colonies. ACO has been compared to the other heuristic method which is GA and the result shows that ACO produce better solutions in term of computational efficiency and quality [43]. This method able to solve the problems involving a combinatorial optimization by applying the simulation with artificial ant. These artificial ants are responsible in searching for the solution space so that the high-quality of solution can be generated [44].

In these recent years, many researchers become interested the learning and optimization techniques that are dealing with ACO algorithms with the relation to other methods. The work presented in [45] is one of the examples that relates ACO to the fields of optimal control and reinforcement learning. Other than that, a more well-known example is the work that purposely done to find sameness between ACO algorithms and other probabilistic learning algorithms such as stochastic gradient ascent and the cross-entropy method [46].

6. Conclusion
As a conclusion, it can be said that the maintenance management has grown and become crucial throughout the years. In refineries for example, it is not uncommon that the maintenance and operation have become the largest departments. A systematic and efficient in maintenance management has a positive impact to the operation of a system.

This paper focusing on the maintenance practices in power plant specifically on the steam boiler known as a complex system thus it is essential to be maintained wisely. There are a lot of papers reported
the implementation of new technology as a tool to optimize the maintenance practices. These optimized models may be useful to the maintenance engineers incorporating information about maintenance strategy and repair and the method of prevent the failure occurrences and failure detection. Other than that, a trend for maintenance optimization using contemporary method has changed the view towards maintenance goals.

In order to ensure the good impact from maintenance optimization process, the maintenance activities need to be identified and evaluated then be prioritized through ranking or priority criterions using maintenance ranking and prioritization tools. Many of previous researchers have studied the methods to ranking the maintenance activities. A few methods such as Reliability Analysis, Failure Mode and Effect Analysis (FMEA) and Analytical Hierarchy Process (AHP) have been explored by previous researchers. FMEA have found to be frequently applied in industry that usually cannot afford to have critical breakdowns or downtimes such as steam boiler and steam turbine in power plant. It is used to prioritize equipment and improving the process of the business. However, there are still some industries utilize the traditional maintenance method such as priority risk assessment and reliability-based maintenance (RBM).

Then the optimum and feasible maintenance optimization strategy is implemented onto the new maintenance tasks that have been prioritized in order to achieve the high performance of steam boiler. Other than that, the impact of optimization process that have been implemented is determined whether it is able to reduce the annual budget, operational time and workforce productivity. There were many journals related to the maintenance optimization were reviewed. In this recent year, maintenance optimization mostly been handled using computation methods called computational intelligence. Few techniques under the heading of CI were explained in the literature which are Genetic algorithm, Simulated Annealing, Particle Swarm Optimization and Ant Colony Optimization.

Acknowledgments
Authors wishing to express gratitude to Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional (UNITEN) and Tenaga Nasional Berhad (TNB) for providing research grant to carry out this research.

References
[1] S Agarwal, A Suhane Study of boiler maintenance for enhanced reliability of system a review 2017 Materials Today: Proc. 4
[2] C H Wang and T W Lin 2010 Optimizing minimize periodic preventive maintenance model for series-parallel systems based on particle swarm optimization The 40- Int Conf on Comp Ind Eng (Awaji, Japan) p 1-6
[3] M Ashok, S Biswajit and M Jibitesh Activity crashing in shutdown maintenance through qualitative assessment: a case study 2011 Adv Prod Eng Manag 6 4 pp 239-48
[4] J D Akbar and Z B Ghazali The mediating influence of team alignment on the relationship between plant turnaround maintenance planning and plant turnaround maintenance performance 2016 Int J of Economics and Financial Issue 6 3 pp 76-82
[5] M Ben-Daya, S O Duffuaa, A Raouf, J Knezevic, D Ait-Kadi 2009 Handbook of maintenance management and engineering (London: Springer) p 225
[6] V Ishekwene Nov 2011 Improving the turnaround maintenance of the Escravos gas plant Potchefstroom Campus of the North-West University(South Africa)
[7] T Lenahan 2006 Turnaround, shutdown and outage management: effective planning and step-by-step Butterworth-Heinemann (Elsevier)
[8] D R Dickson, R C Ford, R Upchurch A case study in hotel organizational alignment 2006 Int J Hosp Manag 25 3 pp 463-77
[9] A Sharma, G S Yadava, S G Deshmukh A literature review and future perspectives on maintenance optimization 2011 J of Quality in Maintenance Engineering 17 1 pp 5-25
[10] Z Ghazali, M Halib, S M Nordin and M C Ghazali Rusty bolts and broken valves: a study on the
plant technology, size, and organizational structure of plant turnaround maintenance in malaysian process-based industries 2009 Int Review of Business Research Papers

[11] H Javanmard and A W Koraeizadeh Optimizing the preventive maintenance scheduling by genetic algorithm based on cost and reliability in National Iranian Drilling Company 2016 J Ind Eng Int 12 pp 509-16

[12] D Frost and R Dechter Optimizing with constraints: a case study in scheduling maintenance of electric power units 1998 Lecture Notes in Computer Science 1520 pp 469-88

[13] S Amaran, N V Sahinidis, B Sharda, M Morrison, S J Bury, S Miller and J M Wassick Long-term turnaround planning for integrated chemical sites 2015 Computers and Chemical Eng 72 pp 145-58

[14] A Garg and S G Deshmukh Maintenance management: literature review and directions 2006 J of Quality in Maintenance Engineering 12 3 pp 205-38

[15] Y C Huang, H C Sun and K Y Huang Applications of Simulated Annealing-based approaches to electric power systems 2012 Simulated Annealing--Advances, Applications and Hybridizations INTECH 6 pp 105-28

[16] R K Kapooria, S Kumar and K S Kasana An analysis of a thermal power plant working on a Rankine cycle: A theoretical investigation 2008 J Energy (Southern Africa) 19 1 pp 77-83.

[17] V I Ugursal 2016 Supplementary Notes on Steam Power Plants Dalhousie University (India)

[18] M T Johnson 2015 Power plant maintenance scheduling using dependency structure matrix and evolutionary optimization Proc of the World Cong on Eng and Comp Sc (San Francisco, USA)

[19] Shah Cost decision making in building maintenance practice in Malaysia 2009 J of Facilities Management 7 4 pp 298-306.

[20] N. Kawasaki 1993 Parametric study of thermal and chemical nonequilibrium nozzle flow Dept. Electron. Eng, Osaka Univ (Osaka, Japan)

[21] W Labib, G B Williams and R F O’Connor An intelligent maintenance model (system): an application of the analytic hierarchy process and a fuzzy logic rule-based controller 1998 J Oper Res Soc 49 7 pp 745-57.

[22] V Covato Prioritizing power plant maintenance work 2008 Power Eng 112 3 pp 50-52

[23] Chong K Wing, A H Mohammed and M N Abdullah A review of maintenance priority setting methods 2016 Int J Real Estate Studies 10 2 pp 35-43.

[24] J Jinming, X Wei, W Gao, S Kuroki, and Z Liu Reliability and maintenance prioritization analysis of combined cooling, heating and power systems 2018 Energies 11 pp 1519.

[25] N L M Hamata, A Shibli 2006 A Risk Based Maintenance model for power plant boilers. european technology development (Surrey, UK)

[26] F Elfeituri, S M Elemmifi 2007 Optimizing turnaround maintenance performance The 8th Pan-Pacific Conference on Occupational Ergonomics (Bangkok, Thailand)

[27] Hameed and F Khan A framework to estimate the risk-based shutdown interval for a processing plant 2014 J Loss Prevent Proc 32 pp 18-29.

[28] F I Khan, M S Rahman, A Shaikh, S Ahmed, S Imitiaz Development of risk model for marine logistics support to offshore oil and gas operations in remote and harsh environment 2019 Ocean Eng 174 pp 125-34.

[29] N F A Fuzi, F B Ismail Intelligent optimization systems for steam boiler maintenance: real case study 2019 J of Adv Research in Dynamical & Control Syst 11 03 Special Issue.

[30] Suebsomran A and Talabkreaw S 2011 Critical maintenance of thermal power plant using the combination of failure mode effect analysis and AHP approaches King Mongkut’s University of Technology North Bangkok Press (Bangkok, Thailand)

[31] S H Ding and Shahrul K Maintenance policy optimization—literature review and directions 2014 Int J Adv Manuf Tech 76 pp 1263-83.

[32] J. McCall Genetic Algorithms for modelling and optimization 2005 J Comput Appl Math 184 1 pp 205-22.

[33] D E Goldberg 1993 Genetic Algorithm in search, optimization and machine learning Addison-
[34] G A Damousis and A Bakirtzis Genetic algorithm solution to the economic dispatch problem 1996 IEEE Proc-C 141 4 128-49.

[35] S C Angela, W Felix An extensible genetic algorithm framework for problem solving in a common environment 2002 IEEE T Power Syst 5 1 pp 269-75.

[36] T Yalcinoz, H Altun and M Uzam 2001 Economic dispatch solution using genetic algorithm based on arithmetic crossover Power Tech Conference (Portugal).

[37] S Kirkpatrick, C D Gelatt, Jr. and M P Vecchi 1983 Optimization by Simulated Annealing. Science 220 4598 pp 671-80.

[38] P R Lopez, N R Reyes, S G Galan and F Jurado Comparison of metaheuristic techniques to determine optimal placement of biomass power plants 2009 Energ Convers Manage 50 8 2020-28.

[39] K P Duhal and N Chakpitak Generator maintenance scheduling in power systems using metaheuristic-based hybrid approaches 2007 Electr Pow Syst Res 77 pp 771-79

[40] J Kennedy, R C Eberhart Particle Swarm Optimization 1995 Proc of IEEE Int Conf on Neural Networks 4 pp 1942-48

[41] H Zhang, H Li and C M Tam Particle swarm optimization for resource-constrained project scheduling 2006 Int J Proj Manag 24 pp 83-92

[42] Z Yimin, L Zhifei, H Zhou and L Ronghui 2016 The application of PSO in the power grid: a review Proc of the 35th Chinese Control Conf (Chengdu, China)

[43] M Dorigo and G D Cano 1999 The Ant Colony Optimization Meta-Heuristic New Ideas in Optimization (McGraw-Hill)

[44] Bauer, B Bernd, R F Harlt and C Straus An ant colony optimization approach for the single machine total tardiness problem 1999 IEEE Press New York 2 pp 1445-50

[45] M Birattari, G Di Caro, M Dorigo 2002 Toward the formal foundation of ant programming Ant Algorithms-Proc ANTS 3- Int Workshop Lecture Notes in Comp Sc (Berlin, Germany: Springer) 2463 pp 188–01

[46] W K Foong, H R Maier and A R Simpson 2005 Ant colony optimization for power plant scheduling optimization GECCO ’05 (Washington DC, USA)