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Application of Genetic Algorithms to Estimate Preventive Maintenance Interval: A Pump Device as a Case Study.

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Abstract

Genetic Algorithms is one of the techniques which has been applied in recent years to contribute to the scheduling of Preventive Maintenance (PM) to improve the whole system performance and run efficiently and effectively. This paper aims to estimate the interval of preventive maintenance for any processing equipment using genetic algorithms. A centrifugal pump is presented as critical equipment to apply a genetic algorithm to prolong the interval of PM. The obtained results show that a genetic algorithm is effective and practical in estimating the optimum time of preventive maintenance for centrifugal pumps.

Keywords: *Application of genetic algorithm, Centrifugal Pumps Maintenance, Preventive maintenance*

1. Introduction

Preventive Maintenance (PM) is an integral part of scheduling maintenance that contributes in the failures diagnosis and addresses the design and improvement in the intelligent maintenance systems. Application of GA technique in PM has become an important role to address the maintenance modelling and make proper decisions associates with planning management in order to provide an up-to-date overview to the maintenance activities and define proper trends of maintenance approach. Most researchers have taken new theoretical approaches for PM of equipment/component into account such as design and operation aspects without focusing on the maintenance scheduling related to duration and interval of maintenance for any power system. PM of pump for any a power plant is a complex and constrained problem in terms of economic, security, reliability and operational requirements must be identified an efficient approach and developed in order to be solved any a problem may be caused Serious consequences of plant on the short term.

Most conventional methods are based on heuristic techniques and mathematical methods to cover integer and dynamic programming.[1] The heuristic approach uses a trial-and-error method to detect the main objective of maintenance function. This means that each unit/equipment should be considered separately. In this way, this needs big data inputs associated with components of the system, tools and man-powers to schedule the maintenance activities. Sometimes situations, this case may fail in producing even feasible solutions with comparing to a real situation of the maintenance event. Therefore, these mathematical approaches are considered limited use due to poor in dealing with the nonlinear programming constraint functions that specialize sometimes in solving the problem related to PM of pumps.

In order to overcome the above constraints, many techniques can be implemented for scheduling maintenance such as applications of Knowledge-Based Systems (KBS), Simulated Annealing (SA), Genetic Algorithms (GA), Simulated Evolution (SE), Neural Networks (NN), Tabu Search (TS), Fuzzy Logic (FL) and their hybrid methods to solve problems related to the maintenance scheduling of the critical equipment.

A genetic Algorithm (GA) is the most common technique in maintenance strategies. Most publications associated with applying GA in PM programs focus on the operational aspects rather than the strategic nature. Therefore, this paper will highlight the GA to estimate the interval period of PM for any processing environment.

2. The PM Problems

Generally, the reliability of the system and the cost of maintenance are two tools that play an important role in scheduling Preventive Maintenance (PM).[2] The entire operational planning period is the most common reliability criterion for each piece of equipment run under harsh operating conditions to avoid the random shutdown of any unit.

Based on cost criteria is to minimize the total costs, which consist of the maintenance costs and operation costs. If maintenance duration is allowed to reduce the minimization of the operation cost of the unit. This creates a balance solution between the production cost and the maintenance cost. Therefore, higher maintenance costs lead to shorter maintenance duration. This, consequently, reduces the system load of expensive generation, increases possible energy purchases, and reduces the energy production. The production cost can be as an indicator to select the key objective of maintenance event by minimizing the total replacement cost of PM. Most problems that often face maintenance event in determining PM. These problems are included the following questions:

i. What are the used maintenance strategies to decrease and increase duration and interval of maintenance time, respectively?

ii. What is an approach related to selecting critical equipment to reduce maintenance cost?

3. Application of GAs

GA is one of the optimisation tools which was developed in the 1970s. GAs are based on the principles of natural genetic and evolution mechanisms. These principles solutions can be evolved through mutation and weaker solutions become extinct. It has superior and versatile features compared with the classic optimisation and search techniques. It can deal with a large number of continuous or discrete variables and optimise complicated cost functions though it has the drawback of requiring high computing power that may require the use of parallel processing.[3]

Due to its features, GA is able in solving many complex preventive maintenance problems. Due to PM problems, applications of PM were used large scale and complex because of the large number of variables involved and their interdependence. PM is indeed one of the most complex activities due to the nature of the problem and the typical lack of data. Lapa *et al.*, (2016) present a model for PM planning using GAs.[4] Their work aimed to present a GA approach to optimize PM schedules automatically considering factors such as the probabilities of requiring repairs and their costs, the typical downtime, PM costs, PM impact on the systems reliability, probability of imperfect maintenance, etc. A case study of the High-Pressure Injection System of a typical 4-loop Pressurized Water Reactor was used to evaluate the methodology. Volkanovski *et al.*, (2008) identified a GA approach to optimise PM of generating equipment of a power system.[5] Tsai *et al.*, (2001) optimised PM for a mechanical component.[6] GAs considers a choice of either a PM intervention to partially renew the component or a replacement with a new component. The optimal activities-combination at each PM stage is decided by using GA to minimise the system unit-cost life. The optimal minimum-cost life is reached at the point in time when the system's unit-cost life is less than its discarded life at PM intervention. Sortrakul *et al.*, (2005) presented a heuristic based on GA for integrated PM planning and production scheduling for a single machine.[7] Yang and Yang (2012) applied GA in improving the PM of aircraft.[8]

The application of GAs is to optimise PM for series and parallel series systems. Levitin and Lisnianski (2000) overcame most problems of redundancy and reliability for a multi-system with various levels of output during a certain time.[9] The optimal system structure and replacement policy provide the desired level of system reliability with minimal cost of PM and failures measured by unsupplied demand. Monga and Zuo (2001) identified an optimum design of series-parallel systems considering PM.[10] A reliability-based design model is developed with deteriorating components and considering the effects of PM. GA was applied to optimize the system cost subjected to both active and non-active constraints. Nahas *et al.*, (2008) optimised a new approach to find the optimal PM activities using the extended great deluge algorithm which is simpler and produced the best solution.[11] Nourelfath *et al.*, (2012) addressed the redundancy and imperfect

PM related to a series-parallel of degraded system.

Monte Carlo simulation was used to evaluate the cost of PM and economic loss to assess PM performance.[12] The GA approach can plan PM activities over a multi-year planning time using Monte Carlo simulation. Marseguerra *et al.,* (2002) used Monte Carlo simulation in terms of economic costs and revenues of the operation of a plant. GA was then used to optimise the components' maintenance periods and the number of repair teams. Marseguerra *et al.,* (2002) determined the optimal degradation level using GA which PM had to be performed for a continuously monitored multi-component system.[13] Chootinan *et al.,* (2006) presented a PM methodology that accounts for uncertainty in pavement deterioration using a simulation-based GA approach.[14]

Application of GAs in optimizing PM for Nuclear Power Systems matched with the proposal of Lapa *et al.,* (2006) which used GA to maximise the availability of nuclear power systems through PM scheduling.[4] Jiejuan *et al.,* (2004) proposed a probabilistic safety assessment approach to identify the effect of PM on component unavailability and build a PM risk-cost model for global PM optimisation in a nuclear power plant.[15] Tan and Kramer (1997) suggested a framework of PM optimization in chemical process operations using both GA and Monte Carlo simulation to integrate general process planning and scheduling PM. Tan and Kramer (1997) also proposed GA to optimise PM scheduling in a processing plant.[16]

Applications of GA present a new style to allow integer solutions in order to use the maximum function in the integers to adapt the code (C) and each chromosome (Ch) to an interval of maintenance. Therefore, it makes more sense to make each chromosome an array of real numbers. The chromosomes cannot be decoded before testing their fitness with maintenance functions.[17] In this case, each chromosome can be encoded as an np element array as shown in the following equation. Each chromosome has a number of genes. Each gene consists of two numbers 0 or 1.

$$Ch = (p_1, p_2, \ldots\ldots p_n) \tag{1}$$

Where: Pi is a real number (Predicted operating time)

In this case, a MATLAB program is used to solve the problem with precision in the solutions to demonstrate a slightly different approach in order to keep the suitable part of the population and generate the other part of the new generation based on the selection and crossover.

GAs search from a population of potential solutions, rather than from a single point. The GAs help in determining optimum solutions without the threat to maintenance performance. These solutions give the GAs its power in searching very large domains in order to schedule maintenance periods and improve the reliability of the system.

The Optimum Maintenance Interval (OMT)

$$= \text{System capacity} - \text{Pi} - \sum_{j}^{n} (\text{capacity of unit j} \times Z_{ij}) \qquad (2)$$

Where: Z_{ij} = gene number (0 or 1) $= \begin{cases} 1 \ if\ interval\ maintenance\ is\ fit\ for\ unit \\ 0\ otherwise \end{cases}$

$$\text{System capacity} = \sum_{j}^{n} (\text{capacity of unit j})$$

GAs selects objective function information directly, with the need for derivations of other information such as population size, selection bias, and mutation probability. The objective function of GAs can involve other data structures based on failure rate, shape and scale parameters, as long as a coding scheme can be devised to represent the parameter set to decrease duration, increase the interval of maintenance and reduce maintenance costs.

4. Cost of Preventive Maintenance

The cost is a direct measure of PM performance. The immensity of the costs is one of the challenges that faced most processing companies. Maintenance costs for any processing plant may exceed the allocated budget for maintenance activities, also the production losses during the shutdown period of plants. Therefore, these plants incur losses in the profit margin due to the PM activities. The total cost of maintenance can be expressed by Eq. 3:

$$\mathrm{TC} = \mathrm{PMC} \times \mathrm{N} \times \mathrm{Dt} + \mathrm{CMC} \times \mathrm{N} \times \sum \mathrm{PoF} \times \mathrm{Dt} \qquad (3)$$

Where: PMC is Preventive Maintenance Cost per equipment, CMC the Corrective Maintenance Cost per equipment, PoF the Probability of Failure for equipment, N the Number of equipment and Dt the Duration of Maintenance.

5. A Case Study of Centrifugal Pumps (CPs)

Selection of CPs as a case study is to apply the PM event for any processing plant. CPs is one of rotating equipment pieces that use to transform rotational energy to hydraulic energy of fluid flow. Most failures that occur in the CPs are due to many indictors resulting from vibration, leakage, rubbing and wear. The mechanical failures of the CPs can be listed by bearings, casing, bearing housing, and mechanical seal. It is necessary to focus on the mechanical seal and bearing of CP in any processing plant, because are essential parts of the pump especially with hazardous product which, in case of leakage, can engender risk in production and environmental issues. Therefore, pumps are considered part of critical equipment that can affect the entire production and manufacturing process chain.[18] CPs pumps are considered sensitive equipment due to several factors: liquid viscosity, fluctuating temperature, variations in pressure and volume of fluid, energy demand excessive, and maintenance-related problems.

5.1 Mean Time to Maintenance (MTTM) of CPs

MTTM is the expected time to start the maintenance of both repairable and replaceable components of CPs. MTTM is considered one of the most widely used measures to identify reliability of system based on failure rate (λ), shape (β) and scale parameters (η). It can be expressed by integrating of reliability function R(t):

$$\mathrm{MTTM} = \int_0^\infty \mathrm{R(t)\ dt} \tag{4}$$

Where: t is the time

$$\mathrm{R(t)} = \mathrm{e}^{-\lambda \mathrm{t}} \qquad \mathrm{t} > \ \text{zero} \tag{5}$$

$$\mathrm{R(t)} = \mathrm{e}^{-(\frac{\mathrm{t}}{\eta})\beta} \tag{6}$$

$$\mathrm{PoM} = 1 - \mathrm{R(t)} \tag{7}$$

6. Results and Discussions

The principle of the GA comes to solve PM for pump in order to test 14 components during a planning period once ever a year with aiming the schedule shutdown maintenance of the pumps to minimize the sum of the squares of the reserve generation. The problem involves many features such as a planned PM and load constraints. The GA is applied based on the publicly available genitor package.

Integer strings use to present candidate solutions to the problem in the population. Each integer of the string indicates the period when PM for each unit starts. The evaluation function is the weighted sum of penalty values for each constraint violation and the objective function itself. All the rated solutions with high evaluation measures have low fitness measures while the rated solutions with low evaluation measures have high fitness values.

Several GA runs are executed to observe the sensitivity of the GA for the variation of mutation probability, selection bias and population size. Tables (1) and (2) show the test results for probability of mutation (PoM) and selection bias values, respectively that were selected by other GA parameters as constant. Each case provides the minimum, average and maximum evaluation measures of the best solutions obtained for 6 GA runs. The total number of trials for each run was fixed at 15000.

If selection bias is very high, then a superior solution strongly dominates the less fit solutions and this may lead the GA to converge prematurely to a local minimum. There is a different little between mean evaluation measures of the best solutions for the determined problem.

Two points are applied in each iteration when the exchanged information is unique for each parent. The mutation probability can change within the allowed integer interval. The population size can specify the number of individuals in the solution population. The selection bias value can specify the amount of preference to be given to the superior individuals in the population.

Table (1) shows that the mean evaluation measure of the best time is 600 days with the variation for the probability of mutation at 0.05. For this particular problem, higher than generally expects values of mutation probability are determined to give better results.

Table 1. Mutation Probability of GA for Centrifugal pump.

GA runs	**1**	**2**	**3**	**4**	**5**	**6**
Probability of Mutation	0.001	0.005	0.01	**0.05**	0.1	0.5
λ (10^{-3}) per day	1.438	1.49	1.56	1.66	1.6	1.5
MTTM (days)	695	670	640	600	620	660

Population size (60), Mutation Probability (0.05)

Table (2) shows also that a trade-off needs to be applied in the choice of the selection bias value at 2.5. This means that PM of CP should be implemented every 600 days to avoid any unexpected failure that may be occurred after 600 days.

Table 2. Selection Bias of GA for Centrifugal Pump

GA runs	**1**	**2**	**3**	**4**	**5**	**6**
Selection Bias	1	1.5	2.0	**2.5**	3.0	3.5
Mean Time to Maint. (days)	750	710	660	600	680	720

Population size (60), Selection Bias (2.5)

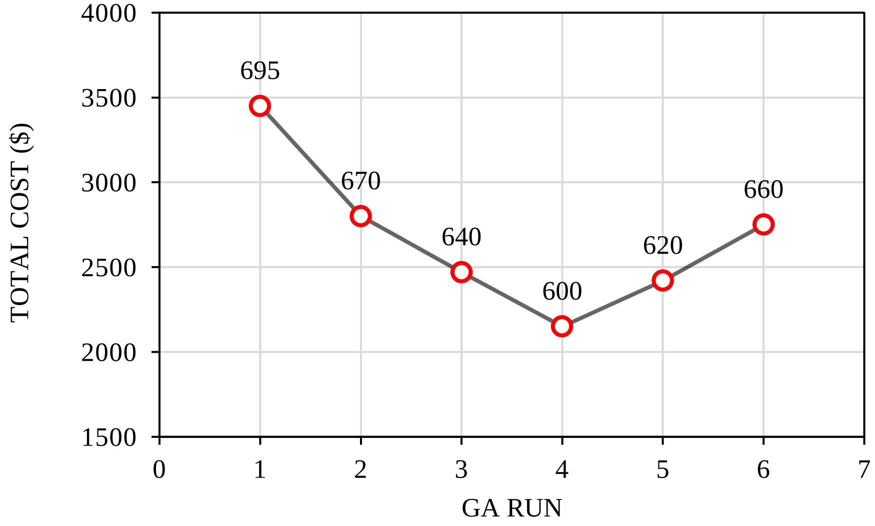

Figure 1: The relationship between total costs and mean time to maintenance.[19]

The GA tests also by many samples of population sizes between 10 and 100, with keeping GA parameters for selection bias is 2.5, mutation probability is 0.05 and population size is 60. It is seen from the above results that the integer GA is rated very stable related to variation in the GA parameters. The best solution was found by the GA, which estimated the cost between $2150 to $3450 per centrifugal pump. This means that the best solution is based on the ranking of the centrifugal pump components to improve pumping capacity to the required level. Therefore, the optimal interval for the pump should be once every 600 days with the lowest costs of maintenance which may be estimated to be around $2150 as shown in Figure (1).

Conclusions

The GAs technique has been applied to overcome the conventional methods in addressing PM of pump problems with various degrees of success. Many studies have used many techniques and assumptions to find which method is most appropriate for PM of pump problems. The success of a method is based on many aspects such as the size and composition of the power system, the targets, applications and constraints that should be taken into account. GA techniques are not perfect to determine the optimum solutions, but they may achieve appropriate solutions to complex pieces of equipment.

Based on a case study associated with applying GA in the PM of pump problems was demonstrated. Optimum solutions can be identified if appropriate problem encoding, evaluation function and GA parameters were predetermined. The use of integer encoding to represent PM of pump problem variables in a genetic structure can be implicitly considered some of the problem constraints and greatly reduced the PM of pump search space. The results presented above give the integer GA was a robust technique for PM of pump problems and can determine optimum solutions with a wide range of variations in GA parameters. The application of KBS, the formulation of the evaluation function and the design of the GA operators can help in optimizing the GA technique to solve genuine large-scale PM of a pump.

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