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Maintenance Management Cost Analysis using Strategy Optimization for Electric Power Plant

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Abstract: Countries around the world are expected to innovate a sustainable energy policy in line with the principles of environmental sensitivity, dependency, efficiency, economy, and uninterrupted service. The services are expected to maintain their energy supply to strengthen their global competitiveness as in the case of UAE electricity sector. This makes the process of maintaining electric power plants demand higher costs due to time allocated, labour and resources, and generation issues and loss. The analytical approach of maintenance and planning strategy is feasible in power plants due to its flexibility during research. This paper focus on maintenance strategy optimization as an initial planning approach of maintaining power plant using large and complex electrical equipment. The cost of maintenance account for up to 40% of operational costs and can rise further if not properly planned, affecting manufacturing systems' productivity and useful life productivity and useful life of manufacturing systems. Simulation results are obtained using AHP analysis for effective decision making at all maintenance management stages especially for dynamic and complex electrical equipment. Also, the direct impact of power plant equipment to operate under a smooth, uninterrupted, and cost-effective electricity generation is analyzed. The analysis involves selecting a single parameter of benefit, cost and requirement and integrated using integer programming technique for optimal maintenance strategy.

Keywords: *Maintenance; AHP Equipment, Electricity, UAE, Cost, and Production.*

1. Introduction

As a result of the remarkable transformation of the industry and population growth in the UAE, the demand for energy has increased considerably [1]. To meet the needs of the growing population in UAE, the quantum of energy generated must be increased. However, the most challenging task of the 21st century work is to provide an efficient technique to avert any form of energy disaster around the world. This is also critical to be deployed in the UAE energy sector. The economic development and prosperity in all countries depends largely on their energy capacity. Electricity is a versatile energy source that can drive and power all industries [2]. However, considering the Pakistan energy sector, they experience abysmal energy issues due to failure in government policies relating to energy resource usage. These policy challenges have left the country in the grip of a massive power crisis, causing financial damage over the last two decades. For efficient energy supply, the rate of power consumption in a country should directly relate to its gross domestic product (GDP) for better funding and policy. This also can enhance a country's economic growth and development process. In 2011, UAE's electricity consumption is up to 66,108 kilotons of oil equivalent (KTOE) IEA energy balance tables) [3] [4]. The total amount of final energy consumed in UAE was 48,675 KTOE and this report is exclusive of consumption in the energy transformation sector. The UAE industries consumed energy of up to 62% of overall final energy consumption or 30,063 KTOE. Based on these reports, petrochemical raw material

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consumes a larger portion of non-energy resources. Therefore, the industrial sector represents an approximate percentage of 70% in the overall final energy consumption. On the other hand, the UAE Transportation sector consumes energy resources of 21% of gross final energy consumption. This is equivalent to 10,391 KTOE. Also, the UAE buildings which includes the residential, commercial, and others consume up to 13% and is equivalent to 6,388 KTOE [4] [5].

1.1. Maintenance Management

Generally, Maintenance management is a term that relates to an assessment conducted on a system or components and how it operates based on its standard operation procedure. Maintenance of a device is termed as the tendency of that device to function under specified operational conditions to preserve/restore for efficient function. The process of maintenance management is a critical and entails decision-making at various stages of operations in manufacturing systems particularly for dynamic and complex systems. For effective maintenance management, poor decisions by the maintenance administrator can lead to an unprecedented loss of resources such as high maintenance cost, materials loss, malfunction of machines, and waste of time. Maintenance costs can account for up to 40% of operational costs and can rise further if not properly planned, affecting the productivity and useful life of manufacturing systems [6] [7].

An efficient and effective maintenance of an asset require a strategic and operational framework. Therefore, the maintenance manager must have a comprehensive maintenance management framework that is well established to guarantee maintenance is complementary to the organization's corporate and service delivery needs [8]. The strategic and operational framework can be presented below as follows.

i. Determine management responsibilities.
ii. Allocate maintenance resources.
iii. Develop a maintenance information system.
iv. Finance maintenance
v. Assess maintenance effectiveness.
vi. Train maintenance personnel.

The above framework standards of maintenance management are required to be reviewed regularly for enhancement to meet changing demands. At any point, responsibility for maintenance delivery is assigned to a third-party provider, contract terms and conditions must be agreed upon to ensure customer interest is protected. This agreement defines the roles of the provider and the customer. Hence lessen or avoid challenges of accountability [9].

1.2 Factors Influencing the Maintenance Cost

Reviews of relevant research present the factors that influence maintenance cost in energy industry and facility. The cost of electrical energy is largely influenced by fuel costs. The fuel cost sometimes increases and decreases over time. This change results in high power tariffs for consumers. The Energy Information Administration [10] conducted research on the influence of electrical energy cost on transmission and distribution systems with respect to maintenance cost. The maintenance cost in the energy industry largely consists of repairs of system faults, and impact of extreme weather conditions. In the electrical industry, an Unreliable electronic device increases the operational cost. This is because of its untimely fault it can cause and require immediate repairs. This means electricity cost will be increased because of maintenance cost and tariff price [11]. Considering consumption phase, electrical energy cost differs due to consumption capacity, customer nature and tariffs for domestic use. This cost differs when compared with the manufacturing industrial sector. This difference is also similar in terms of small, medium, and large business enterprises.

Related research in [12] [13] [14] presents the deployment of smart and digital technologies in the UAE energy industry. These smart management has its cost implication but efficient during service delivery. The areas of deploying smart maintenance management include smart manufacturing, digital manufacturing, cloud manufacturing, cyber-physical systems, and Internet of Things, similarly, an application of digital technology in electrical energy maintenance is currently the standard operational procedure deployed by the UAE government across the energy sectors.

This paper considers the following three types of maintenance management [15].

i. Predictive maintenance, like condition-based maintenance, is initiated based on failure predictions made using studied data such as temperature, noise, and vibration.
ii. Preventive maintenance, like scheduled and planned maintenance, is scheduled, timed, or based on a cycle.
iii. Reactive maintenance, also known as run-to-failure maintenance, corrective maintenance, failure-based maintenance, and breakdown maintenance, is maintenance performed after equipment has failed or stopped working.

Other maintenance strategy terms include maintenance prevention, reliability-centred maintenance, productive maintenance, automated maintenance, total proactive maintenance, and total quality management, each with its own characteristics and focus. Some of the terms are not used consistently in literature. For instance, Wang et al. discuss time-based, condition-based, and predictive maintenance as subcategories of preventive maintenance while others tend to discuss predictive and condition-based maintenance as being separate. This report will primarily rely on the terms predictive, preventive, and reactive maintenance.

1.3 Abu Dhabi Electricity Sector

In this paper, a critical assessment is conducted on the Abu Dhabi electrical energy sector and the maintenance strategy used in managing their electronic systems and costs. This section contains the description of Abu Dhabi Electricity Sector [16]. Abu Dhabi was the first Gulf Cooperation Council (GCC) emirate to develop and implement initiatives designed to shift away from a wholly state vertically integrated power industry structure. Beginning in 1998, some policy, legislative, structural, and structural frameworks were put in place in Abu Dhabi's power sector and the associated water desalination industry. The key characteristics of the emirate's power industry, as well as the difficulties and opportunities associated with increased participation in cross-border electricity trading, are as follows: The emirate's primary supply-side planning criterion is likely to remain national self-sufficiency in power on an economically competitive basis. As a necessary consequence, any potential reduction in Abu Dhabi's overall cost of electricity procurement via provincial interconnections is regarded as an important emerging driver for market integration [17]. This is in addition to any possible provincial savings. The development of a regionally integrated electricity market presents numerous opportunities for Abu Dhabi. Allowing open transmission grid access should encourage electricity trading. Existing regulatory provisions in Abu Dhabi permit the use of its transmission system for cross-border electricity trading on the same terms as other eligible Abu Dhabi users. The current single-buyer (SB) model offers limited 'implicit' competition in bulk supply procurement. Because power generation companies (generators) do not have direct market access (they cannot sell their power to anyone other than the SB), there is little or no pressure on generators to compete daily. The prospects for electricity trading are also limited by a lack of volume and time-specific marginal costs for trading opportunities [18]. However, to facilitate cross-border electricity trade, it is necessary to conduct a realistic assessment of volume and time-specific marginal costs. There are efforts underway to develop and evaluate a reliable system for calculating volume and time-specific marginal costs, allowing the SB (or generators, as the case may be) to offer bids for trading surplus electricity. At the generation level, the emirate's water and power producers do not receive explicit fuel (natural gas) subsidies. Despite significant reforms to Abu Dhabi's electricity sector and the implementation of higher and, in some cases, cost-reflective tariffs for different consumer categories in the past two decades, electricity tariffs for many domestic customers remain heavily subsidized. Abu Dhabi is considering several options for further liberalizing its energy market. These include loosening the terms of SBS's 100% offtake guarantees to generators. Another possibility is to permit generators to participate in future wholesale markets when their contracts expire [19].

Previous research has affirmed maintenance acceptance in general businesses, but only the cost component has been studied, not the production factor. Risk-based maintenance aims to reduce the likelihood of equipment faults and the negative consequences of equipment failure, as well as to reduce total cost of maintenance by increasing equipment dependability [20]. These objectives are dependent on many system characteristics, variables, and constraints, and developing a maintenance plan is a difficult task. [21]. Maintenance planning is required since several criteria affecting these objectives (defect losses, unnecessary maintenance, non-conformities in selected maintenance strategies, etc.) reveal the problem's multi-objective and multi-criteria structure. Researchers have used meta-intuitive techniques due to factors such as the complex system structure, the number of interconnected restrictions, the maintenance approach, and the abundance of possibilities [22]. As a result, researchers used particle pile optimization to address the challenge of complex maintenance planning/scheduling problems for multi-objective maintenance optimization [23]. Furthermore, the issue of maintenance planning has been addressed in a variety of industries, ranging from the construction sector to the automotive sector, and from the textile industry to the chemical. [24] proposed a new method of maintenance planning based on ten identical generator grouping strategies and human considerations. There are numerous maintenance planning studies in wind farms for electricity generation facilities that use renewable energy sources. A comparative analysis based on three independent risk assessments performed on a hydroelectric power station, one of the few studies in hydro power facilities. In their study, the researchers examined and evaluated the analysis, as well as the significant differences in performance and outcomes, and the numerous factors that influence the quality of the analyses. The study emphasizes the importance of a well-planned demand definition, as well as examining and comprehending risk assessment data before making maintenance decisions. A risk-based maintenance strategy is used in this study, and a high-priority procedure is followed by a method that determines maintenance priority. The initial study on this maintenance philosophy is by [25], which attempts to save money by prioritizing high-risk equipment due to a limited amount of cash available. Subsequent research employed a variety of methods to calculate risk estimates.

2. Methodology

In this paper, the maintenance management of electrical equipment of a power plant is conducted. The rate of wear in different units of the power plant can be determined to identify the differences in some similar electrical components of the plant. For determination purposes, a multi-criteria structure approach of solving problem using AHP simulation is used. The approach can be used with no restriction during power plant computations or electrical computations. Using the adopted values of [1], the proposed research increased its values when analyzing each maintenance strategy in the power plant. This enables the use of Analytic Hierarchy Process (AHP) simulation for multi-criteria structure. Based on the maintenance analysis, some critical levels of the electrical equipment can be identified.

This paper uses analytic hierarchy process (AHP) simulation to determine the best decision during maintenance management of electric power plant. The choice of using AHP simulation is its flexibility to give the decision maker a better approach of evaluating criteria and alternatives of successful management with priorities. AHP simulation approach is widely accepted by researchers in terms of sharing ideas and targets using independent alternatives and better analysis technique to achieve precise results. Research with AHP approach is conducted to generate functional algorithms in several fields such as engineering, health, management, environment, transport energy etc.

Using AHP simulation in our first step, we can identify our decision of maintenance management based on criteria and parameters used. In the second step, we carry out the maintenance analysis using opinions of experts and comparing the criteria and alternatives based on priority. In the third step, the simulation is set to conduct a procedural normalization. This is conducted by dividing each value according to the algorithms established in this paper.

$$b_{ii} = \frac{a_{ij}}{\sum^{n} \dots} \qquad i, j = 1,2, \dots, n$$

Step four is presented as follows.

$$w_i = \sum_{i=1}^{n} b_{ii} / n \qquad i, j = 1, 2, \dots, n$$

Step five is presented as follows.

$$E_i = d_i / w_i \qquad i=1, 2, \dots, n$$

$$\lambda = \sum_{i=1}^{n} E_i / n \qquad i = 1, 2, \dots, n$$

$$CI = (-n) / (n-1)$$

$$CR = CI / RI$$

2.1. Maintenance Planning

In identifying maintenance strategy for an electric power plant, planning is the initial stage to consider in terms of generation and transmission. The electric power plant has several advantages and is environmentally friendly. Based on planning, it is identified that the most challenging unit to maintain and operate is the transmission of electricity in the plant. This has a direct impact in lessening the plant transmission output to consumers during operation. This makes the proposed research consider placing all electrical equipment in the power plant to be maintained within the system. For an optimal maintenance strategy to be achieved in the UAE power plant, a sum total of the equipment must be taken in records. The equipment includes current transformers, voltage transformers, breakers, disconnectors, main power transformers, drive motors, auxiliary transformers, excitation transformers, slipring and carbon brushes, relays, transformer expansion tanks, bushings, generator rotors and generator stators and subcomponents of these equipment groups. Identifying this equipment can ensure optimal maintenance strategies for all electrical equipment in the power plant. It can also enhance device efficiency and energy supply security to the UAE government. In addition, this research is conducted by consulting electric power plant experts to generate accurate maintenance data. These plant experts include industrial, electrical, electrical-electronic, and mechanical engineers with more than 20 years of working experience in operation and maintenance of electric power plants.

To obtain an optimal maintenance strategy, the parameters below can be used as follows.

i. Computing the rate of wear of power plant unit.
ii. Computing the additional value of maintenance strategy used in the power plant.
iii. Computing level of critical situation of power plant equipment.
iv. Establishing some mathematical approach of maintenance strategy.
v. Determining the best and optimal maintenance strategy for the electric power plant.
vi. Result evaluation.

2.2. Maintenance Strategy Optimization (MSO)

In the proposed research, an intellectual property framework is developed using algorithm to generate qualitative values. This can be computed using mathematical formulars to lessen the electricity generation downtime in a power plant. This is to enhance the UAE electrical power plant maintenance management. The proposed work uses maintenance strategy to optimize a single parameter. However, there are several goals considered in analyzing the result. This process ensures all power equipment functions efficiently and is provided with a sustainable power generation framework. Below are notations and decision variables used in the proposed framework as adopted in [1]. The process of formulating algorithmic in the proposed framework is presented below as follows.

$$\text{Min } Z = \sum_{i=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{i} T_{iik} * X_{iik}$$

$$\sum_{i=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{i} D_{iik} * X_{iik} \leq Td$$

$$\sum_{i=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{i} C_{iik} * X_{iik} \leq Tc$$

$$\sum_{k=1}^{i} X_{iik} \geq Td \qquad i=0, \dots, m \qquad j=1\dots, n$$

If $CR_{ii} \geq 85$

$$\sum_{k=1}^{i} W_k X_{iik} \geq 0.85; \; i=0, \dots, m \; j=1\dots, n$$

If $CR_{ii} \geq 70 \vee CR_{ii} < 51$

$$\sum_{k=1}^{i} W_k X_{iik} \geq 0.70; \; i=0, \dots, m \qquad j=1\dots, n$$

$$\sum_{k=1}^{i} W_k X_{iik} \leq 0.85; \; i=0, \dots, m \qquad j=1\dots, n$$

If $CR_{ii} \geq 51 \vee CR_{ii} < 70$

$\sum_{k=1}^{i} W_k X_{iik} \geq 0.51$ *i=0, …., m* *j=1…, n*

$\sum_{k=1}^{i} W_k X_{iik} \leq 0.70$ *i=0, …., m* *j=1…, n*

$X_{ii1} = 0$ *i=0, …., m* *j=1…, n*

Else if $CR_{ii} < 51$

$X_{ii1} = 0$ *i=0, …., m* *j=1…, n*

$X_{ii2} = 0$ *i=0, …., m* *j=1…, n*

$X_{ii3} = 0$ *i=0, …., m* *j=1…, n*

$X_{ii4} = 1$ *i=0, …., m* *j=1…, n*

If $Y_i \geq 80 \wedge CR_{ii} \geq 70$

$X_{ii2} = 1$ *i=0, …., m* *j=1…, n*

Where I represent Unit index (i=0,…,8), j represent the Equipment index (j=1,…,n), k represent the maintenance strategy index using (1 as revision, 2 as preventive, 3 as predictive, and 4 as corrective), T_{ijk} represent ith unit, jth equipment downtime any time kth maintenance strategy is initiated, D_{ijk} represent ith unit, jth equipment kth maintenance strategy implementation time, C_{ijk} represent ith unit, jth equipment kth maintenance strategy implementation cost using (sum of labor and material cost), T_c represent maintenance budget, T_d represent Maintenance time measured in hours, CR_{ij} represent ith unit to critical level of jth equipment, Yi represent ith unit attrition rate and W_k represent kth weight of maintenance strategy Decision variables by assigning i= 0,…,m j= 1,…,n k= 1,…,l.

3. Results

For the results, the wear rate of power plant units was computed using AHP simulation. This is to identify the variation of wear rate of different units in the plant. Additional value benefit of power plant maintenance strategies is also determined. The criticality levels of the power plant equipment are also assessed by applying mathematical models to lessen the plant generation downtime. This involves lessening costs, increasing plant capacity for security, and minimizing risk.

3.1. Analysis of wear in the power plant Units

In UAE, the electric power plants are massive infrastructure investments. This makes it unrealistic to combine the units in the plant into generation. The power plant units is put in operation at different time intervals using different generation plans. Under this strategy, a record of varying wear rate across the power plant units will be noticed. Based on the planning strategy used in the proposed paper, it is required to address all power plant equipment based on their individual wear rate. For the wear rate determination, three criteria are considered. These include: -

i. Identify the commissioning date of equipment.
ii. Identify the working time and principles of equipment.
iii. Identify the generation capacity of electricity in the plant.

During implementation, a hierarchical structure is organized in the initial stage. This can be presented and adopted in [1] (as in figure 1) below.

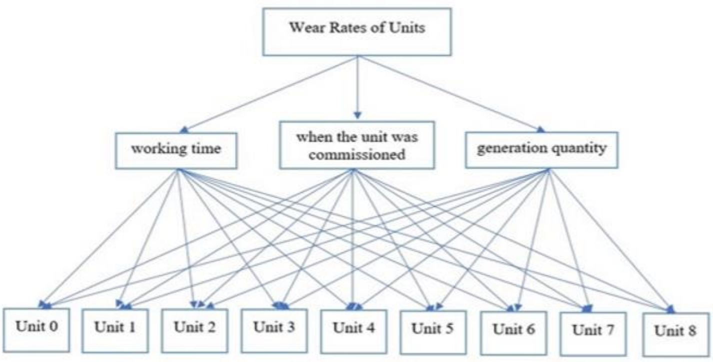

Figure 1. Hierarchy structure

The next stage is to determine the weights of each criterion. This involves pairwise comparison of algorithm used. The computation is presented (as in table 1) below as follows.

Table 1. Comparison of Pairwise Criteria

When the unit was commissioned	Working time	Generation quantity
1.5	3	6
0.677	1.5	3
0.322	0.677	1.5

In computing the criterion weights, row averages values of decision matrix are only considered. The weights generated after successful maintenance process are presented (as in the table 2) below.

Table 2. Weight of Criteria

Criteria	Weight
When the unit was commissioned	0.88
Working time	0.43
Generation quantity	0.29

Based on table above, the best criterion is when the unit was commissioned having a weight of 0.88. This identified based on working time interval having 0.43 weight. Lastly, 0.29 generation quantity weight was realized based on computation. The next procedure is to generate the criteria weights using AHP technique. The paper conducted a pairwise comparison of algorithm for each criterion as presented (as in table 3) below.

Table 3. Comparing Pairwise Algorithm using Criteria

	Benefits	Cost	Duration	Requirements
Benefits	1.25	4	8	6
Cost	0.545	1.25	4	3
Duration	0.341	0.432	1.25	0.65
Requirements	0.320	0.655	2.20	1.25

Based on the table above, the benchmark weights set as 0.579 to represent benefit, 0.233 to represent cost, 0.067 to represent duration, and 0.121 to represent requirements. After computation of the criteria weights, the best criterion is the benefit among the remaining three.

3.2 Analysis of Additional Value of Maintenance Strategy

A vital parameter to consider is the additional value for maintenance strategy in the power plant. This is applied on the whole power plant equipment.

In this research additional value is determined using the following

i. Evaluating the benefit
ii. Evaluating cost of maintenance process
iii. Evaluating duration
iv. Assessing the requirements for implementation of the strategy.

3.3 Analyzing Level of Critical Situation of Power Plant Equipment.

This paper examines the best and optimal maintenance management strategy to be applied in an electrical power plant. Based on the assessment of the above analysis, an optimum maintenance strategy can be determined based on the type and working principle of an electrical equipment. We used a mathematical model to determine the optimal strategy for efficient maintenance management.

Using mathematical model, the generated data must be converted from qualitative to quantitative data and ensure it corresponds with the varying aspects of an electrical equipment. This technique can guarantee determination of the criticality levels of an equipment in a power plant. After these processes, the levels criteria situation may not be equal. Therefore, the criterion weights must be determined. This will initiate the use of AHP to determine weighting of a criterion as one of a multi-criteria decision-making technique. Using the mathematical model of AHP above, this paper implements the process of analyzing level of critical situation using the data generated from plant experts. The pairwise comparison matrix generated from plant experts is based on Five criteria. The data is generated Based on the electrical equipment in the power plant. Therefore, computation of the criticality level can be conducted using proportional assessment. This is presented (as in table 4) below.

Table 4. Data of Equipment data and critical levels

Name of Equipment	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Level of Critical situation
A Busbar L1 Phase	2	0.40	0.33	0.12	3	83.555
Transformer	4	2	5	0.34	9	95.712
Motors L3 Phase	5	0.34	2	0.30	3	76.67
B Busbar L1 Phase	7	4	4	2	9	87.65
Generator Rotor	0.60	0.22	0.34	0.22	2	88.99
Generator group Breaker	3	0.30	0.33	0.30	0.52	96.76
Generator Stator	2	0.21	0.60	0.154	3	94.6

3. Conclusion

The fundamental purpose of conducting maintenance operation in a power plant is to enhance efficiency and effectiveness of electricity production and increase customer reliability. This purpose ensures maintenance process as a basic requirement for production, and a basic production processes for efficiency target. Therefore, the maintenance strategy optimization is the indispensable and an initial step in managing maintenance of a power plant.

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