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Optimization of Decision-Making for Rotor Turbine Recovery in Geothermal Power Plants Using AHP, DEMATEL, and TOPSIS Methods

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Abstract* – Geothermal Power Plants (GPPs) are a key source of renewable energy that plays a vital role in supporting national energy security. The operational reliability of GPPs is heavily influenced by the performance of steam turbines, particularly the turbine rotor, which converts thermal energy into mechanical energy. This study aims to optimize decision-making in geothermal power plant turbine rotor recovery by employing a multi-criteria decision-making approach through the integration of the Analytic Hierarchy Process (AHP), Decision Making Trial and Evaluation Laboratory (DEMATEL), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. The research findings are expected to provide recommendations for optimal turbine rotor recovery strategies that take into account technical, economic, and operational aspects, as well as support improvements in the reliability and operational efficiency of geothermal power plants in Indonesia.

Keywords: Decision-Making, Geothermal Power, AHP, DEMATEL, and TOPSIS Methods

I. INTRODUCTION

Geothermal Power Plants (PLTP) are a renewable energy source with significant potential to support national energy security. In operation, steam turbines act as crucial components, converting heat energy from steam into mechanical energy, which is then converted into electrical energy [1] . One of the turbine's key elements is the rotor blade [2], which captures the kinetic energy of the steam flow. From an operational management perspective, the effectiveness and efficiency of electrical energy production in geothermal power plants are highly dependent on the optimal performance and reliability of the entire system and its components, including the rotor blades .

Problems with rotor blades are always detected during overhauls (once a year) including wear, corrosion, and cracks due to extreme operating conditions. Extreme operating conditions in geothermal power plants refer to turbine operating conditions that are very challenging and exceed normal parameters, such as increasing water content in steam exceeding 0.02% [2] . These conditions can cause damage that leads to decreased performance, accelerated damage, and system failure if not managed properly. In the context of operational management, this is not only a technical problem, but also a strategic challenge related to asset management, maintenance planning, and risk mitigation. [3] .

Based on data from the International Renewable Energy Agency [5], more than 30% of total downtime at geothermal power plants is caused by damage to turbine components, including blades. rotor [5] . If downtime occurs due to blade failure , this can be estimated to require a recovery time ranging from 107 to 370 days, and potential revenue loss ranging from 130 billion to 210 billion rupiah.

Figure 1. Graph of changes in water pressure against the geothermal turbine
Source: [1]

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damage to turbine components, including blades. rotor [6] . An appropriate repair strategy is required to maintain the reliability and efficiency of the turbine system. The selection of this repair strategy is a crucial operational decision that must consider complex trade-offs between various factors: direct repair costs, potential losses due to.

In a multi-criteria decision-making approach, cost analysis is also an important aspect in determining improvement strategies. One relevant method is Life Cycle Cost Analysis. (LCCA) , which is an approach that calculates the total cost of ownership of an asset during its life cycle, including initial costs (procurement and installation), operating costs, maintenance costs, and final costs (disposal or replacement) [7] .

Selecting the right repair strategy is crucial in maintaining turbine performance and reliability. Each option has its own advantages and disadvantages, so a thorough analysis is needed to determine the most suitable solution [5] . By considering all these aspects, we can ensure that the turbine operates efficiently and safely, and minimize the risk of future damage. MCDM in the context of industrial management, such as supplier selection , project risk evaluation, and industrial equipment maintenance strategies [8] .

In an effort to support this complex decision making, a multi- criteria decision making (MCDM) approach can be applied. The AHP (Analytical Hierarchy Process) method is used to determine the importance weight of each criterion, while TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is used to evaluate and rank alternatives based on their proximity to the ideal solution [9] . In addition, DEMATEL (Decision Making Trial and Evaluation Laboratory) is used to analyze the cause-and-effect relationships between criteria.

II. LITERATURE REVIEW

2.1 Geothermal Power Plant (PLTP)

Geothermal Power Plants (PLTP) are a renewable energy source that is increasingly being considered in efforts to meet global electricity needs. PLTP utilizes heat stored within the earth, which comes from geothermal processes, to generate electricity [10] . This process begins by exploring the heat source within the earth, where hot steam is channeled to a turbine. This steam, which has a very high temperature, drives a turbine connected to a generator, and ultimately produces electricity [11] .

The main advantage of geothermal power is its minimal impact on the environment. Unlike fossil fuel power plants that produce large amounts of greenhouse gas emissions, geothermal power plants produce much lower emissions, thus contributing to reducing global warming. For example, a study shows that CO_2 emissions from geothermal power plants can be up to 90% lower than those from coal-fired power plants [12] .

Thus, geothermal power plants are not only an alternative energy source, but also an important step towards environmental sustainability. By harnessing existing natural resources, geothermal power plants can help reduce dependence on fossil fuels and mitigate negative climate impacts. Therefore, further investment and development in geothermal technology should be a priority on the global energy agenda, taking into account life-cycle cost (LCCA) and TCO analyses to ensure financial, technical, and operational sustainability.

2.2. Turbine Components and Rotor Blades

The turbine is the main component in a geothermal power plant, converting heat energy from steam into mechanical energy. This process is not only crucial for generating electricity but also plays a role in the overall efficiency of the system. One of the most important parts of the turbine is the blade. rotor , which functions to capture kinetic energy from the steam flow. The blades on the rotor consist of several rows of blades arranged radially and rotating with the rotor [13] .

When dealing with rotor blade problems, it is important to implement an effective and efficient repair strategy. One common strategy is to replace the damaged blade with a new blade [14] . This process not only involves removing the old blade , but also ensuring that the new blade installed meets the required quality standards and technical specifications.

Selecting the right repair strategy is crucial in maintaining turbine performance and reliability. Each option has its own advantages and disadvantages, so a thorough analysis is required to determine the most suitable solution [15] . By considering all these aspects, we can ensure that the turbine operates

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efficiently and safely, while minimizing the risk of future damage.

2.3 AHP Method

Analytical Hierarchy Process (AHP) is a very useful method in multi-criteria MCDM decision making. AHP was developed by Saaty (1980) as a useful method for constructing a hierarchy of criteria and determining their relative weights based on pairwise comparisons. AHP has been widely used in the evaluation of strategic alternatives, both in the manufacturing, energy, and logistics sectors, because of its ability to simplify complex decisions into a hierarchical structure [16] .

This method is very effective in situations where the decision to be taken involves various interacting factors. The AHP process begins with identifying the criteria relevant to the decision to be taken. For example, in selecting a location for a factory, criteria that might be considered include land cost, transportation accessibility, and labor availability [17].

2.6 TOPSIS method

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an MCDM method used to rank alternatives based on their proximity to the positive and negative ideal solutions. In the context of selecting a maintenance or spare parts procurement strategy, TOPSIS allows the identification of the option that has the best compromise between all the criteria being assessed [16] .

TOPSIS is widely used due to its computational simplicity and its ability to produce logical and intuitive results, especially when combined with other methods such as AHP and DEMATEL to form a comprehensive analysis framework [18] . A thorough analysis of the TOPSIS method shows that its main advantage lies in its ability to consider multiple criteria simultaneously. This allows decision makers to not only focus on one aspect, but also consider various factors that may interact with each other.

2.7 DEMATEL Method

Decision Making Trial and Evaluation Laboratory (DEMATEL) is a very effective method in multi-criteria decision making (MCDM) is a matrix-based method used to understand the structure of cause-effect relationships between criteria [19] . This method helps identify cause criteria and effect criteria , thus allowing decision designers to focus on key driving factors in the system.

The in-depth analysis produced by DEMATEL enables stakeholders to understand complex relationships that are often invisible at first glance [16] . This allows for more data-driven decisions and reduces the risk of failure.

2.8 LCCA Method

The Life Cycle Cost Analysis **(**LCCA**)** method is an economic analysis approach used to calculate the total cost of ownership of an asset or system over its entire life cycle [20] . The goal is to help decision makers choose the most economical and sustainable alternative, not just based on initial costs.

III. RESEARCH METHODS

This research design uses a descriptive analytical approach with a multi -criteria decision-making method (MCDM). This approach is the right choice in the context of research focused on blade repair. turbine rotor in Geothermal Power Plant (PLTP) [21] . By using MCDM, researchers can evaluate various alternative improvement strategies in a systematic and structured manner, which is very important considering the complexity and number of factors that must be considered in decision making.

The data used in this study consists of two main categories: primary and secondary data, each of which plays a crucial role in generating a comprehensive analysis. The combination of primary and secondary data in this study not only enriches the information obtained but also creates a more robust framework for understanding and addressing challenges in rotor blade repair. turbine .

The analysis process in this study involved three main methods, namely AHP, TOPSIS, and DEMATEL. The AHP (Analytical Hierarchy Process) method was used to determine the importance weight of each identified criterion. The TOPSIS Technique for Order Preference by Similarity to Ideal (Solution) method is used to evaluate and rank alternative strategies based on their proximity to the ideal solution. The DEMATEL (Decision Making Trial and Evaluation Laboratory) method is used to analyze the cause-effect relationship between criteria. The Life Cycle Cost Analysis (LCCA) method is used to calculate the total life cycle cost of each alternative

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blade repair strategy. turbine rotor [22]. The following data analysis flow is carried out as follows:

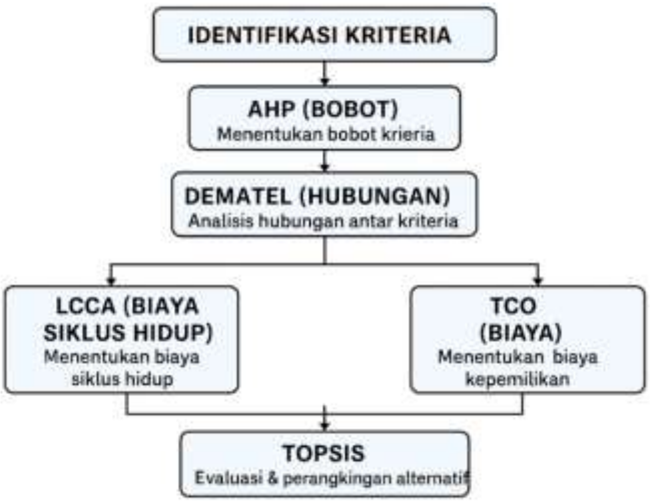

Figure 1. Research Flow

IV. RESULTS AND DISCUSSION

Results

Based on the results of the AHP analysis , the importance level of the criteria in this study was identified through the paired comparison questionnaire completed by the facilitator respondents. The data was then processed using the AHP method to generate priority weights for each criterion used in the decision-making process. The results of the criteria weight calculations based on the facilitator's assessment are presented in the following table:

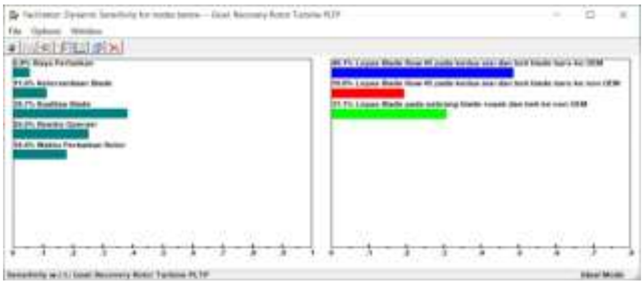

Figure 2. Facilitator Dynamic Sensitivity Results

Based on the results of Dynamic Sensitivity , it is known that the weight of the criteria in decision making consists of costs of 5.8%, blade availability of 11.6%, blade quality of 38.7%, operational risk of 25.5%, and repair time of 18.4%. In addition, the results of the sensitivity analysis also show that the alternative of removing blade row #5 on both sides and purchasing new blades from the OEM has the highest priority value of 49.1%.

The alternative of removing blade row #5 on both sides and purchasing blades from a non-OEM received a priority score of 19.8%, while the alternative of removing only the damaged blades and purchasing blades from a non-OEM received a priority score of 31.1%. Based on these results, the first alternative is the most recommended choice because it provides a higher level of component reliability and turbine operational safety compared to the other alternatives.

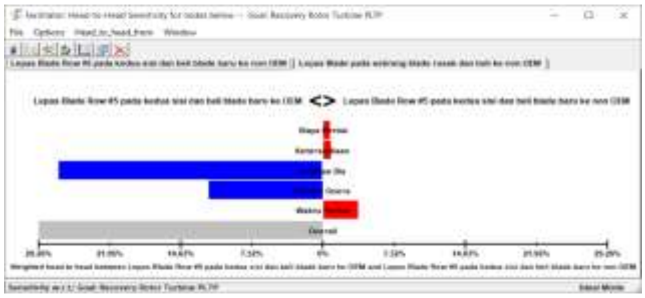

Figure 3. Head-to-Head Sensitivity Analysis Results of Facilitator

Furthermore, the results of the Head-to-Head Sensitivity Analysis show that the alternative of replacing blade row #5 on both sides by purchasing new blades from the OEM still has advantages over other alternatives in most criteria, especially in the blade quality criteria. And operational risk **,** which are two dominant factors in decision making.

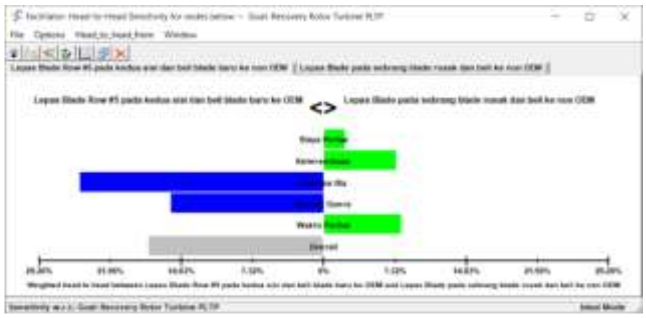

Figure 4. Head-to-Head Sensitivity Analysis Results of Facilitator

In other alternative comparisons, it can be seen that the criteria of repair costs, blade availability and repair time can influence changes in the priority value of alternatives if there is a change in weight. However, these changes do not significantly shift the

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position of the best alternative that was previously obtained.

Study continues the analysis using the Decision Making Trial and Evaluation Laboratory (DEMATEL) method to identify the level of influence between criteria and determine the criteria that act as causal factors (cause) and effect factors (effect) in the decision-making system. The results of this direct relationship matrix will then be used in the next stage in the DEMATEL method, namely the matrix normalization process to obtain the total relation matrix , as follows:

The normalized direct-relation matrix

	Biaya	Ketersediaan Blade	Kualitas Blade	Risiko Operasi	Waktu Perbaikan
Biaya	0	0.258	0.121	0.121	0.167
Ketersediaan Blade	0.212	0	0.121	0.076	0.182
Kualitas Blade	0.091	0.091	0	0.318	0.227
Risiko Operasi	0.348	0.091	0.212	0	0.121
Waktu Perbaikan	0.348	0.152	0.106	0.152	0

Figure 5. Stage in the DEMATEL

The normalization matrix table shows the level of influence between criteria in the rotor turbine recovery decision-making process after the scale adjustment process. Based on the table, it can be seen that the Cost criterion has the largest influence on Blade Availability with a value of 0.258, which indicates that decisions related to costs have a fairly strong relationship with the availability of blade components in the recovery process. The results of the total relation matrix calculation are shown in the following table.

The total relation matrix

	Biaya	Ketersediaan Blade	Kualitas Blade	Risiko Operasi	Waktu Perbaikan
Biaya	0.44	0.499	0.388	0.4	0.463
Ketersediaan Blade	0.575	0.266	0.343	0.342	0.448
Kualitas Blade	0.598	0.391	0.304	0.508	0.54
Risiko Operasi	0.757	0.39	0.473	0.343	0.487
Waktu Perbaikan	0.767	0.486	0.391	0.456	0.357

Figure 6. Normalization Matrix

The total relation matrix table, it can be seen that each criterion has a different level of influence on the other criteria. The Cost criterion shows a relatively large influence on Blade Availability of 0.499 and on Repair Time of 0.463. This indicates that cost considerations are closely related to component availability and the repair duration required in the recovery process .

Next, a TOPSIS analysis was performed on each respondent. The next step was to examine the overall results to determine the tendencies of alternative choices among all respondents involved in the study. The table shows the closeness coefficient values for each alternative based on the assessments of five respondents: R1, R2, R3, R4, and R5.

Table 1. Coefficient Values

Alternative	R1	R2	R3	R4	R5
A1	**0.73**	**0.78**	**0.64**	**0.59**	**0.67**
A2	0.20	0.39	0.47	0.50	0.43
A3	0.39	0.24	0.24	0.23	0.23

Based on the table, alternative A1 consistently obtained the highest closeness value compared to other alternatives across all respondents. The closeness values for A1 were 0.73 (R1), 0.78 (R2), 0.64 (R3), 0.59 (R4), and 0.67 (R5), respectively. These relatively high and consistent values indicate that alternative A1 has the highest level of closeness to the positive ideal solution according to all respondents. This indicates that alternative A1 is considered to have the best combination of performance in meeting the criteria used in the study, namely cost, blade availability , blade quality , operational risk, and repair time.

The results of the TOPSIS analysis from five respondents showed a fairly consistent pattern, where alternative A1 always ranked first, followed by alternative A2 in second place, and alternative A3 in third place. This indicates that alternative A1 is the most recommended alternative in the rotor turbine recovery decision-making process , because it has the highest level of closeness to the ideal solution based on the assessment of all respondents involved in the study.

Discussion

Research conducted by [23] shows that the DEMATEL method is able to identify the relationship between factors in selecting quality rice seeds in swampy areas with an accuracy level of 80.42%. This indicates that DEMATEL is effective for analyzing the relationship between criteria in a decision-making system.

In addition, research conducted by [24] and [25] shows that the DEMATEL method can be combined with other methods such as ANP to determine the most influential criteria in the decision-making process. In this study, DEMATEL was used to

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identify the relationship between criteria, while ANP was used to determine the priority weight of each criterion.

In addition, research [26] using Fuzzy AHP and TOPSIS shows that the integration of the two methods is able to determine the priority of increasing internet bandwidth more accurately based on the value of proximity to the ideal solution. Other research also shows that the TOPSIS method can be used to determine the best alternative marketing strategy after the criteria weights are obtained using the ANP method. A similar thing was also found in research [28] [28] which shows that the AHP method is effective for determining the level of importance of criteria, while TOPSIS is used to determine the best alternative systematically through a ranking process.

V. CONCLUSIONS AND SUGGESTIONS

The results of data processing using the AHP method show that each respondent has a relatively similar perception of the level of importance of the criteria used in the study. Based on the results of the aggregation of criteria weights from all respondents, it was found that risk criteria had the highest importance weight, followed by quality , cost , and availability . Through analysis of the direct relationship matrix and the total relationship matrix , it can be seen that several criteria act as factors that influence other criteria in the decision-making system. This analysis illustrates that each criterion does not stand alone, but rather is interrelated and influences each other in determining the best alternative.

Based on calculations using the TOPSIS method , it shows that of the three alternatives analyzed, alternative A1 consistently obtained the highest closeness coefficient value based on the assessment of five respondents, namely the facilitator, General Manager 1, General Manager 2, MTC Manager 1, and MTC Manager 2. The closeness value of alternative A1 to the positive ideal solution is higher than the other alternatives, so that this alternative is the most recommended alternative.

In further research, the method used can be developed by combining other multi-criteria decision-making methods **,** such as Fuzzy AHP, Analytic Network Process (ANP), or other MCDM methods **,** to obtain more comprehensive analysis results and are able to accommodate uncertainty in respondent assessments.

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