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CONDENSER REPLACEMENT LIFE PREDICTION BASED ON CONDENSER BACK PRESSURE LOSS FACTOR USING SIMPLE LIFE CYCLE COST MANAGEMENT METHOD: ECONOMIC LIFE

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ABSTRACT

Energy demand in Indonesia continues to increase, in line with the government's efforts to balance economic and population growth. In this context, the government-designed electricity supply policy prioritizes the use of coal as the main source of energy until 2050. Power plants face challenges in asset management, particularly in the replacement and maintenance of equipment such as condensers. This study aims to determine the economic life of condensers in Steam Power Plants (PLTU) with a capacity of 300 MW, as well as analyze the life cycle costs using the Simple Life Cycle Cost Management (LCCM) method. This method considers direct and indirect costs in decision-making related to equipment maintenance and replacement. The study also identified factors that affect the operational efficiency of the condenser, including backpressure and operational conditions. The results of the analysis show that careful monitoring and evaluation of the economic life of the condenser can optimize operating costs and improve the energy efficiency of the generation system. This study provides strategic recommendations for asset management in power generation, prioritizing a holistic approach in decision-making related to equipment maintenance and replacement. Thus, this research is expected to contribute to the development of more efficient energy policies in Indonesia.

KEYWORDS *condense, condensereconomic lifespan, economic lifespanlife cycle cost, life cycle costmaintenance management, maintenance managementenergy efficiency*

INTRODUCTION

Energy demand in Indonesia continues to increase, which is in line with the government's efforts to achieve a balance between economic growth and population in various regions (Wibawa et al., 2021). In order to meet this energy demand, the government has designed a policy for electricity supply with a capacity of 35 GW,

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as stated in Government Regulation No. 79 of 2014 (Government Regulation No. 79/2014). The National Energy Policy, which is directed until 2050, emphasizes the important role of coal in supporting national energy security (Government Regulation No.79/2014).

In the power generation industry, increasingly fierce business competition and the impact of the global economic crisis are forcing every company to optimize its operations and asset maintenance to achieve the best performance (Barros et al., 2016). Generation companies often face important decisions regarding whether existing assets should be discontinued, repaired (both minor and major), or replaced with new ones (Chowdhury et al., 2021). Every asset used by the company, whether in the production of electric power, transportation, or other services, is replaced within a certain period of time (Yum et al., 2020). Replacement is carried out when the asset is damaged and cannot be effectively repaired, operational costs are too high (for example, due to increased coal prices), or there are new technological developments that make old assets obsolete (Campbell et al., 2024). Asset replacement decisions are an important part of asset lifecycle management, where the economic age of assets is a major factor in decision-making (Prasanphan et al., 2024).

The performance of power plants is greatly influenced by the operational quality and maintenance of key equipment such as boilers, turbines, condensers, heaters, and generators (Chanda & Mukhopaddhyay, 2016). As a key component in the power generation cycle, condensers play an important role in converting steam into water, making a significant contribution to the overall efficiency of the generation (Basheer et al., 2024). The optimal efficiency of the condenser is required to minimize energy loss and reduce operating costs. According to a report from the Ministry of Energy and Mineral Resources (EMR, 2023), condensers are one of the main factors in the energy consumption of power generation systems (Ren, 2021). The effectiveness and efficiency of the condenser greatly affect the generation cycle and the overall efficiency of the plant, as well as the power generated by the plant. Therefore, careful monitoring of the energy conversion in the condenser is essential for optimal efficiency (Milovanović et al., 2023).

One of the important operational parameters related to condenser efficiency is the condenser back pressure. Deviation from optimal return pressure can indicate a problem in the condenser. Some of the factors that affect the return pressure of the condenser include the level of decontamination of the condenser, the ingress of outside air, the temperature of the cooling water, and the amount of cooling water used (Maswanganyi, 2021). If the back pressure decreases, this can lead to an increase in heat loss, which has an impact on increasing energy consumption by the power plant as a whole (Khan et al., 2022).

A Steam Power Plant (PLTU) with a capacity of 300 MW is often faced with the complex problem of asset replacement. The lack of a systematic approach in asset replacement decision-making casts doubt on the equipment replacement strategy used. Until now, the company only applied the general technical depreciation method to determine the lifespan of the equipment. Based on these conditions, the determination of the age of equipment, especially the main equipment, such as condensers, needs to be carried out comprehensively.

Simple Life Cycle Cost Management (LCCM) Method (Carbaugh, 2016; da Silva & de Souza, 2022) offers a holistic approach that considers the total cost of ownership of equipment throughout its lifecycle. In the context of condenser maintenance, this method takes into account not only the direct costs of maintenance activities but also the indirect costs associated with downtime, energy inefficiency, and potential system failures. The application of this method allows for a thorough evaluation of maintenance decisions by considering both short-term and long-term economic implications. Effective asset management in a generation is essential for the success of the generation business itself (Campbell et al., 2024).

Although several studies have explored condenser maintenance prediction models, few have examined the integration of condenser back pressure into maintenance prediction models. Moreover, there is no research that specifically discusses economic and technical aspects in decision-making related to the age of equipment replacement using the LCCM Economic Life method. The application of this method as a basis for condenser replacement decision-making became an original contribution to this study, as this approach combines life cycle costs with maintenance predictions, which have not been widely integrated with previous studies (Al Moussawi et al., 2016).

The purpose of this study is to determine the economic life of the Unit 2 condenser, calculate the minimum life cycle cost (EAC Minimum) based on the design life and economic life of the Unit 2 condenser, as well as based on the candidate age (new condenser life). In addition, this study aims to find out the recommendations needed to extend the life of the condenser, evaluate the energy savings in the condenser after repairs and if replaces (Replace), and determine the right options in making decisions between replacing or repairing the Unit 2 condenser.

The benefits of this research include determining the most economical replacement life of condensers, which can be used as a basis for company management decision-making in generating management, especially in planning the most economical condenser replacement life. This study also provides insight into the factors that affect the life of the condenser and the necessary recommendations. In addition, this research helps determine the right way to make decisions, whether the repair or replacement option is on the Unit 2 condenser. By using the same method, management and team can optimally plan the company's long-term (RJPP) until it reaches the service life of the plant. Overall, this research supports more optimal, reliable, and efficient generation management, both from the technical and non-technical sides.

RESEARCH METHOD

This research method is useful for compilers in conducting research and preparing a thesis so that in doing both things it is correct and does not violate the procedure.

1. Research Location

The location of research and data collection was carried out at a steam power plant (PLTU) in Central Java with a capacity of 2 x 315 MW.

Figure 1. Steam Power Plants (PLTU)

2. Research Flow Diagram and Frame of Mind

This type of research is a literature study that aims to analyze and predict the most economical time to replace condenser equipment based on the parameters of the efficiency factor of condenser equipment, namely *the Condenser Back Pressure* parameter factor, using the simple *LCCM Economic Life Method.* This method integrates Engineering and Management (*Financial*) factors. With this integration, the *analysis of EAC (Equivalent Annual Cost)* and decision-making is obtained from the *mean EAC* value and *Economic Life* produced by the condenser equipment. So, from the above results, decisions can be made regarding the repair of the equipment.

The stages carried out by the author in carrying out the Condenser Maintenance research Based on the Back Pressure Condenser Factor using the Simple LCCM method will be carried out based on the research flow diagram described in the following Figure 2:

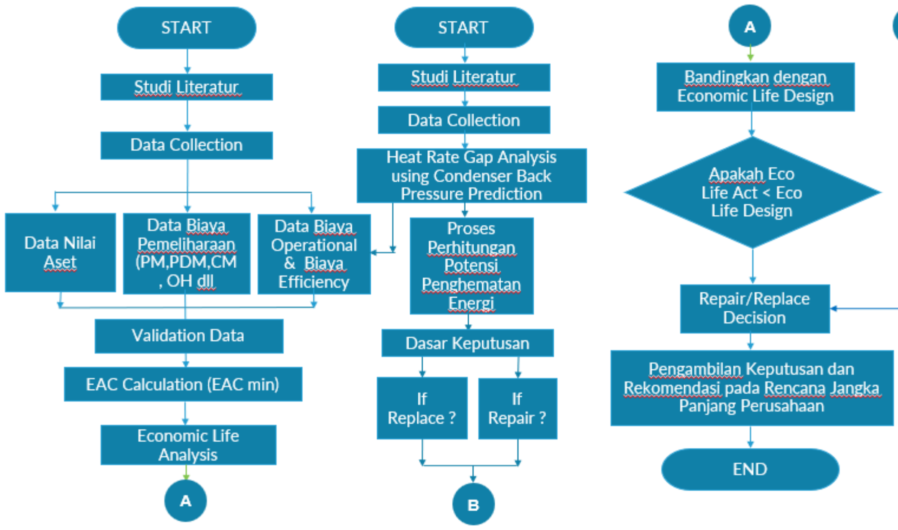

Figure 2. Research Flow Diagram and Research Mindset

The flow chart above is a design of the thinking process carried out by the researcher in designing the research process. In this case, the steps of the flow chart process will be explained.

3. Data Types and Sources

There are two types of data that will be taken, namely primary data and secondary data on the operational side, maintenance and costs needed by power plants in operating and maintenance starting from commissioning to the year of operation.

Primary Data Collection: data taken from DCS based on process, operational, and maintenance variables that will be used to analyze operating cost data. DCS data is in the form of Back Pressure Condenser, Load, and Coal Flow data.

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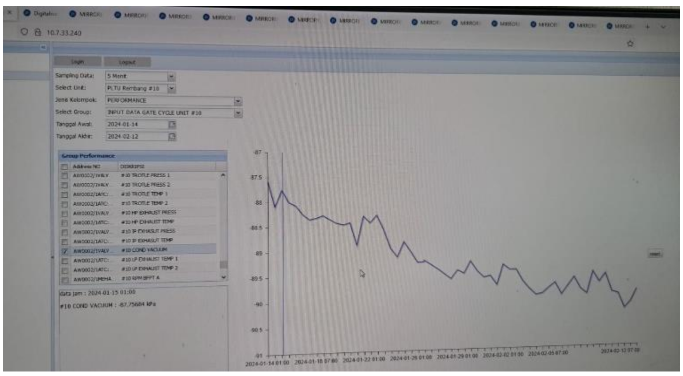


Figure 3. Data Operational Vacuum Condenser

Secondary Data Collection: that is, it comes from a literature study in the form of supporting data and references related to the research. The data is in the form of operation data derived from equipment manufacturing design and data from equipment commissioning, while maintenance data comes from work orders and maintenance costs of PM, PDM, CM, and OH, including the cost of material and labor needs. Other data, such as condenser purchase price, electricity consumption, fuel consumption, employee wages, interest rate value, and inflation rate, were also included.

4. Data Collection Techniques

Data collection in this study was carried out by:

1. Annual data collection of plant operations
2. Data collection Maintenance costs (CM, PM, PdM, OH) of condenser equipment
3. Collection of Investment Asset Value data from Condenser equipment
4. Data on the cost of the power plant needed to operate the plant should be collected, starting from commissioning to the year of operation.
5. Annual data collection of Condenser Performance and Cost of Condenser Equipment performance losses
6. Predicting the performance of the Condenser for 40 years of operation using data from 2011 to 2023 (13 years) and predicting from 2024 to the period of 2050 (27 years).

RESULT AND DISCUSSION

Based on calculations using the Simple Life Cycle Cost Management (LCCM) method, the minimum Equivalent Annual Cost (EAC Minimum) for the Unit 2 condenser was found to be IDR 45,850,892,031, which occurs in the year 2029. This indicates that the economic life of the condenser is approximately 19 years, although the design life is specified at 30 years.

Further analysis was conducted to compare the scenarios of maintaining the existing condenser versus replacing it with a new candidate unit. The following results were obtained:

a. EAC Design Life Existing: IDR 16,086,891,513
b. EAC Economic Life Existing: IDR 45,850,892,031
c. EAC Design Life Candidate: IDR 11,512,891,401
d. EAC Economic Life Candidate: IDR 108,580,552,913

Although the EAC value for the candidate's design life is lower than that of the existing unit, the economic life EAC of the existing condenser is significantly lower than that of the candidate replacement. Therefore, the study concludes that replacement is not recommended from an economic standpoint.

Key factors influencing the limited economic life of the condenser include:

a. High Cooling Water (CW) inlet temperature
b. Reduced condenser tube cleanliness
c. External air ingress through casing or valves
d. Equipment derating due to increased condenser back pressure

Recommendations to extend the economic life of the condenser:

a. Regular cleaning and maintenance of condenser tubes
b. Repairing casing and valve leaks to prevent air ingress
c. Optimizing operational conditions to control CW temperature and load

Energy savings potential:

a. If repaired: IDR 3,512,846,366 or approximately 76,894.10 GJ
b. If replaced: IDR 15,390,465,795 or approximately 336,888.07 GJ

Final decision based on the EAC comparison:

a. The optimal strategy is to "Keep and Improve" the existing condenser
b. Replacement is not advised, as it results in a higher overall economic cost

Discussion

Capital Cost Calculation

The cost of purchasing this condenser equipment asset is obtained from the value of the acquisition of fixed assets of the plant in 2011. The fixed asset value of this plant is Rp. 7,743,128,733,995 (7.7 Trillion), while the asset value of this condenser equipment is Rp. 110,145,394,222 (110 billion).

Table 1. Table Capital Cost Surface Condenser

NO.	URAIAN	PERHITUNGAN PROPORSIONAL	NILAI KONTRAK			
			VALAS	EQV RUPIAH	RUPIAH	TOTAL
		A	B	C=B*9200	D	E= C+D
3	Condenser & Feed Water Heating Plant	17,370,550,416.86	34,405,618.54	316,531,690,568	17,370,550,417	333,902,240,985
	- Feed Water Heating System	2,854,656,744.31	4,605,562.92	42,371,178,864	2,854,656,744	45,225,835,608
	- Condensate System	965,811,473.23	3,531,737.64	32,491,986,288	965,811,473	33,457,797,761
	- Surface Condenser and Associated Equipment	4,486,538,073.01	10,995,795.90	101,161,322,280	4,486,538,073	110,145,394,222
	- Circulating Water System	7,505,246,051.66	12,200,993.67	112,249,141,764	7,505,246,052	119,754,387,816
	- Closed Cooling Water System	1,558,298,074.65	3,071,528.41	28,258,061,372	1,558,298,075	29,816,359,447
TOTAL		2,248,801,000,000	1,073,724,979.64	2,833,600,000,000	2,248,801,000,000	7,743,128,733,995

$$A = \frac{Capital\ Cost}{\frac{(1+i)^n - 1}{i(1+i)^n}}$$

Where:

Capital Cost: Value of equipment acquisition in the early years

i: Interest Rate

n: Number of Years

In this study, the following values were used:

Table 2. Data on Capital Cost, Interest Rate and Condenser Operating Time

Description	Value	Information
Capital Cost	IDR 110,145,394,222	From Initial Acquisition Data

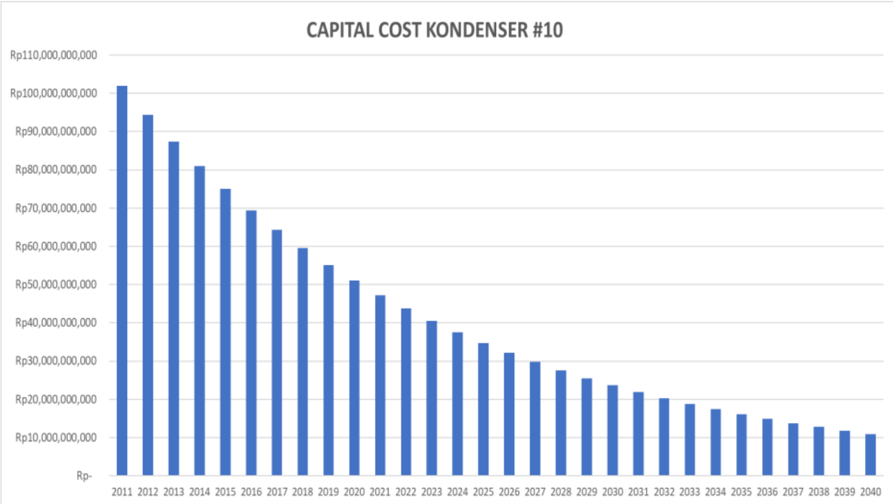
Interest Rate	8%	The discount rate for a power station: E. Dimson table comparative cost discount rate in Coal (8%), If uses reference from "Overpaid and Underutilized: How Capacity to CFPP could lock Indonesia into a high-cost electricity future (5%, discount rate based on gov bond coupon)
Number of Years	Year 1 - 40	Length of Time Equipment Operates

A = Rp. 110,145,394,222 / (1+8%) ^ 1st year - 1/8% * (1+8%) ^ 1st year
= IDR 101,986,476,118
The above calculation is carried out until the 30th year so that the following results are obtained:

Table 3. Capital Cost Condenser Value in 2011 - 2040

CAPITAL COST		Rp	110,145,394,222
Year	Tahun ke	A=Capital Cost/(1+i)^n-1/i(1+i)^n	
	0		
2011	1	Rp	101,986,476,118
2012	2	Rp	94,431,922,329
2013	3	Rp	87,436,965,117
2014	4	Rp	80,960,152,884
2015	5	Rp	74,963,104,520
2016	6	Rp	69,410,281,960
2017	7	Rp	64,268,779,589
2018	8	Rp	59,508,129,246
2019	9	Rp	55,100,119,669
2020	10	Rp	51,018,629,319
2021	11	Rp	47,239,471,588
2022	12	Rp	43,740,251,466
2023	13	Rp	40,500,232,834
2024	14	Rp	37,500,215,581
2025	15	Rp	34,722,421,829
2026	16	Rp	32,150,390,576
2027	17	Rp	29,768,880,157
2028	18	Rp	27,563,777,916
2029	19	Rp	25,522,016,581
2030	20	Rp	23,631,496,826
2031	21	Rp	21,881,015,571
2032	22	Rp	20,260,199,593
2033	23	Rp	18,759,444,057
2034	24	Rp	17,369,855,597
2035	25	Rp	16,083,199,614
2036	26	Rp	14,891,851,482
2037	27	Rp	13,788,751,358
2038	28	Rp	12,767,362,353
2039	29	Rp	11,821,631,792
2040	30	Rp	10,945,955,345

Figure 4. Capital Cost Chart 2011 - 2040



1. Consequential Cost Calculation

Consequential Cost is the cost caused by interference from condenser equipment. The disturbances caused are in the form of Force Derating (Forcible Load Reduction) and also in the form of Trip (Outage) generation.

From these disturbances, it can be calculated how much production loss of the plant is caused by the condenser in the form of Mwh Loss (Megawatt Hours Loss).

$$\sum \textit{Consequential Cost} = \sum \textit{Loss Output} \times \textit{Energy Price}$$

Where:

Σ Output Loss: Total energy loss due to outage and derating

Energy Price: Electricity Selling Price

In this study, the following value data was used:

Table 4. Consequential Cost Value in 2011 - 2023

Consequential Cost Actual				
Year	Type OH	Consequential Cost		Σ Consequential Cost
		Σ Loss Output	Energy Price	
2011	KOM	-	Rp 714.24	Rp -
2012	FYI	12,656,083.33	Rp 728.32	Rp 9,217,678,613
2013	SI	1,350,000.00	Rp 818.41	Rp 1,104,853,500
2014	ME	7,644,750.00	Rp 939.74	Rp 7,184,077,365
2015	SI	3,268,016.67	Rp 1,034.50	Rp 3,380,763,242
2016	SE	1,555,833.33	Rp 991.37	Rp 1,542,406,492
2017	SI	1,350,000.00	Rp 1,105.11	Rp 1,491,898,500
2018	ME	6,541,416.67	Rp 1,123.01	Rp 7,346,076,331
2019	SI	1,350,000.00	Rp 1,129.59	Rp 1,524,946,500
2020	FO/MD	4,562,596.67	Rp 1,352.00	Rp 6,168,630,693
2021	FO/MD	16,263,166.67	Rp 1,352.00	Rp 21,987,801,333
2022	SE	12,613,206.67	Rp 1,352.00	Rp 17,053,055,413
2023	SI	2,154,333.33	Rp 1,352.00	Rp 2,912,658,667

To determine the value of Consequential Cost from 2024 to 2040, using the Regression prediction method with Dependent variables (Y = Mwh Loss) with the correlation of Independent variables in 2011 to 2023 as follows (Doe et al., 2020):
X1 = Equipment Age (Years)
X2 = Operating Hours
X3 = Condenser Back Pressure (CBP)
X4 = Maintenance status, 1=Yes, 0=No (If there is a schedule OH = 1, otherwise = 0)
X5 = Outage / Derating Status, 1=Yes, 0=No (If there is an Outage/Derating = 1, otherwise = 0)
X6 = Derating/Maintenance Derating Hours

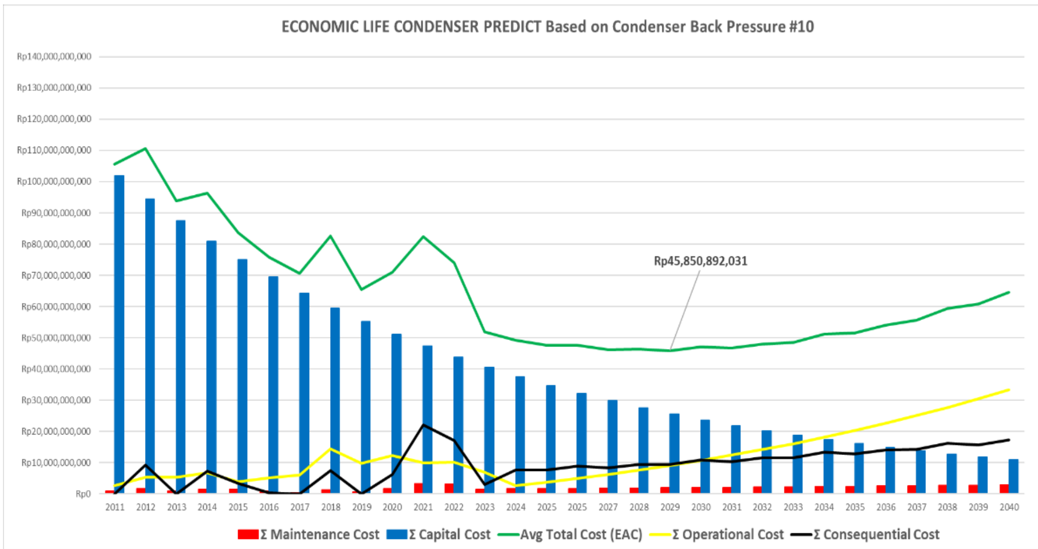


Figure 5. Condenser Existing Equivalent Annual Cost (EAC) Graph in 2011 – 2040

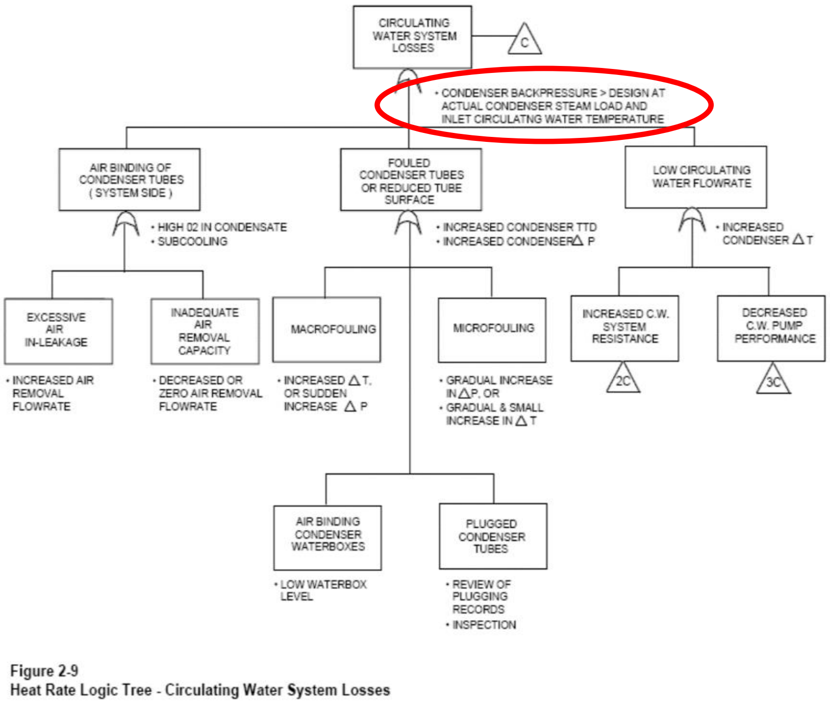
From the results of the study, it was found that the minimum EAC cost was Rp. 45,850,892,031. And the minimum EAC Cost value is in 2029.

This means that the Economic Life (Prediction of the replacement life) of condenser equipment based on the results of the study is 19 years or it can be said that it can be recommended that condenser equipment can be replaced based on its economic lifespan is in 2029.

2. Analysis of Causative Factors and recommendations to extend the life of condenser equipment.

With the results of EAC above, the economic life of condenser equipment is only 20 years, or it can be said that economically until 2030. Therefore, several factors are needed to be considered and recommendations needed to extend the economic life of condenser equipment.

Based on the EPRI Heat Rate Logic Tree reference, several factors that affect performance (Condenser Back Pressure) and that need to be considered in operations and maintenance are:



Picture 6. Diagram Heat Rate Logic Tree – Circulating Water System Losses

CONCLUSION

Based on the research results, the economic life of the Unit 2 condenser was determined to be 19 years, while its design life is 30 years. The minimum life cycle cost (EAC Design Life Existing) based on the design life is Rp. 16,086,891,513, whereas the EAC Economic Life Existing based on its economic life is Rp. 45,850,892,031. For a new condenser candidate with an age of 40 years, the minimum life cycle cost (EAC Design Life Candidate) is Rp. 11,512,891,401, and the EAC Economic Life Candidate is Rp. 108,580,552,913. Factors influencing the lifespan extension of the condenser equipment include high CW inlet temperature and condenser tube cleanliness (operating side) as well as water ingress or external air leakage (maintenance side). Recommendations to enhance longevity involve optimizing regular tube cleaning and fixing leaks in the condenser casing and drain valves. Energy savings following condenser repairs amount to Rp. 3,512,846,366 (76,894.10 Gigajoules), whereas full replacement would result in Rp. 15,390,465,795 (336,888.07 Gigajoules). Decision-making regarding Unit 2 condenser concludes that the "Keep and Improve" option is preferred over replacement, as the EAC Design Life Existing is greater than the EAC Design Life Candidate (Rp. 16,086,891,513 > Rp. 11,512,891,401), while the EAC Economic Life Existing is lower than the EAC Economic Life Candidate (Rp. 45,850,892,031 < Rp. 108,580,552,913).

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