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Monte Carlo simulation for predicting the reliability of a boiler in the Nagan Raya steam power plant

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Abstract. The Nagan Raya steam power plant 2x110 Megawatt is one of the power plants owned by PT. PLN (Persero) located in Aceh. The Nagan Raya steam power plant that operates continuously is often failure. An overhaul of maintenance activities that lasted only six months was the cause of frequent disruptions or failures. Performance evaluation in terms of reliability is urgently needed to minimize the failure. This study aims to determine the level of reliability and preventive maintenance time based on Monte Carlo simulation to the nine critical components of the boiler section. Monte Carlo simulations are used to predict precise maintenance time and future reliability values. Monte Carlo simulation results on nine important components of the boiler section, maintenance time is required within 40 days to 86 days of maintenance with a reliability value of 31% to 38%.

1. Introduction

The electric energy industry is currently acting in a very strategic role as electricity consumption increases. Adequate electrical energy industry is needed in community activities and economic growth. PT. PLN (Persero) as the sole manager of the electric energy industry in Indonesia and owned by the Indonesian government in the form of State Owned Enterprises (SOEs) is required to be able to meet the increasing electricity demand every year. Nagan Raya Power Plant 2x110 Megawatt is one of the power plants owned by PT. PLN (Persero) located in Aceh other than ArunLhokseumawe Gas Engine Power Station 184 Megawatt. Total electricity in Aceh reaches 344 MW, while electricity demand in Aceh is currently 325 MW. Means that electricity in Aceh has a surplus. However, power outages are still common if one factory is disrupted or fails, especially the Nagan Raya power plant.

The boiler is one of the parts that has the highest disrupted or failure frequency among other parts. Nagan Raya steam power system is highly dependent on boiler performance. The boiler serves as a water heater using heat resulting from coal combustion to produce high-pressure steam to drive the turbine. Each part of the boiler has many components and if one component is disrupted or failure it will affect the performance of the production system. An overhaul of maintenance activities that lasted only six months was the cause of frequent disruptions or failures. Some studies show that high frequency oh downtime happens due to applied traditional maintenance [1-3]. Performance evaluation in terms of reliability is needed to minimize such disrupted or failure.

The probability of reliability is the probability of a component or system to operate in accordance with the desired function for a given period of time when used under certain operational conditions

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[4]. Future reliability values are better known to easily prevent damage. Under such circumstances, Monte Carlo simulation is the only time effective way of estimating reliability [5-6]. Monte Carlo simulations are used to predict precise maintenance time and future reliability values. Monte Carlo simulations basically generate uniformly distributed random numbers (0,1) and then convert to non-uniform distributions using inverse transformation methods [7]. The benefits of the Monte Carlo simulation are easy to implement and the results are close to true values. Some reliability studies using Monte Carlo simulations show results close to the actual values[7-9].

The purpose of this study was to predict maintenance time and future reliability values based on Monte Carlo simulation results for each important component of the boiler section.

2. Methods

The object of research observed is boiler section, covering the extent of damage and maintenance activities performed on the machine. Data collection methods used in this study is through direct observation and interviews with the company. The results of this study are expected to be used as a reference for the implementation of scheduled or predictive maintenance. Flow chart of this research can be seen in Figure 1.

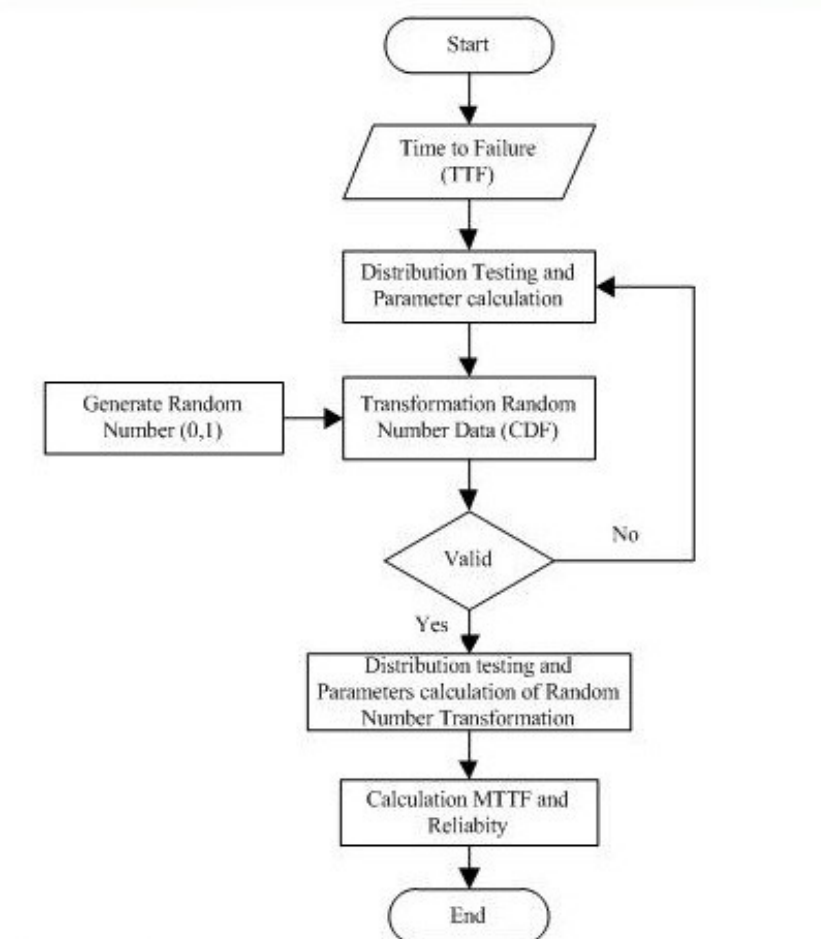


Figure 1. Flow Chart of Monte Carlo Simulation for Reliability

3. Result and Discussion

3.1. Determine the critical Components

Important components of the boiler will be determined based on components that have at least ten failures. The list of component names and the frequency of failure occurring in the period from June 2013 to August 2015 in Figure 2.

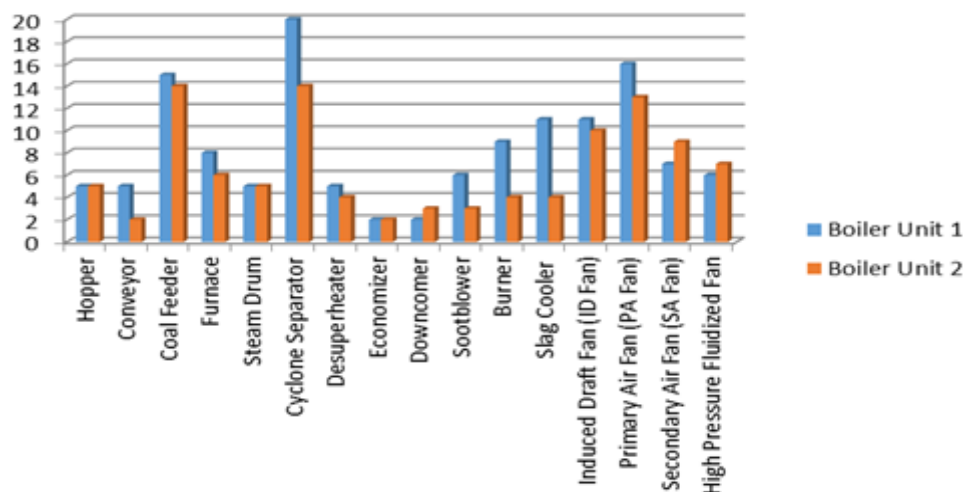


Figure 2. List of Failure Components in Boiler Units 1 and 2

Based on Figure 2, which includes important components in boiler unit 1 is a cyclone separator component, coal feeder, ID fan, PA fan and slag cooler. While in the boiler unit 2 is a cyclone separator component, coal feeder, fan ID and PA fan.

3.2. Distribution Testing and Parameter Calculation for the Actual Time to Failure (TTF)

The distribution test is performed on the actual time for failure (TTF). The distribution types used are normal, lognormal, weibull, and exponential distributions [10]. The selected distribution will be determined using two assessment methods: Anderson Darling (AD) and Pearson correlation coefficient. Anderson Darling's value uses a weighted square distance approach, where the value is determined by the smallest value of Anderson Darling. While the Pearson correlation coefficient value uses the least squares estimation approach, where the value is determined by the greatest correlation coefficient value. The parameters are determined based on the previously selected distribution [11]. Table 1 shows the recapitulation of the best distribution and parameter for the Actual Time to Failure.

Table 1. Recapitulation of the Best Distribution and Parameter for the Actual Time to Failure (TTF)

Boiler	Component	Distributions	Parameter				
			Weibull		Normal		
			θ	β	Γ	μ	Σ
Unit 1	Cyclone Separator	2P-Weibull	45,3291	1,60229	-	-	-
	Coal Feeder	3P-Weibull	41,5813	0,75295	10,7927	-	-
	ID Fan	3P-Weibull	36,1957	0,74912	12,0363	-	-
	PA Fan	3P-Weibull	24,9251	0,89009	19,2769	-	-
	Slag Cooler	3P-Weibull	43,7578	0,58997	9,5246	-	-
Unit 2	Cyclone Separator	Normal	-	-	-	56,3846	36,5654
	Coal Feeder	3P-Weibull	24,7725	0,73746	6,1975	-	-
	ID Fan	3P-Weibull	78,7161	1,36049	7,5417	-	-
	PA Fan	3P-Weibull	46,0149	0,74675	13,1217	-	-

3.3. Generate Random Number and Transformation Random Number Data

Random numbers used are uniformly distributed (0.1) and will be converted to a non-uniform distribution. The inversion transformation method using the cumulative distribution function is the conversion method used [7]. Random numbers are generated using Microsoft Excel programs with function = RAND (). While the inverse transformation process will use several cumulative distribution function equations according to the selected distribution [12]. The transformation process of random numbers in Weibull and Normal distributions will use equations 1 and 2 [12-13].

$$t = \gamma + \theta(-\ln(U))^{\frac{1}{\beta}} \quad (1)$$

$$t = \phi(U) \cdot \sigma + \frac{\mu}{\sigma} \quad (2)$$

One hundred random numbers will be generated and then transformed as in Table 2.

Table 2. Results of Random Number Generation and Random Number Transformation

No	Random Number	Boiler Unit 1					Boiler Unit 2			
		Cyclone Separator	Coal Feeder	ID Fan	PA Fan	Slag Cooler	Cyclone Separator	Coal Feeder	ID Fan	PA Fan
1	0,6462	27,03	24,63	24,01	29,10	20,27	15,26	14,25	50,35	28,29
2	0,0357	96,09	216,50	192,57	115,66	346,21	64,39	132,93	198,24	243,80
3	0,0536	88,59	183,85	163,79	102,55	279,58	57,36	112,44	180,85	206,92
4	0,3212	49,08	60,04	54,94	48,04	63,82	15,44	35,64	93,98	67,69
5	0,5621	32,13	30,78	29,37	32,69	26,70	7,26	17,92	60,02	35,10
6	0,8474	14,76	14,61	15,32	22,58	11,60	39,03	8,36	28,54	17,26
7	0,4014	42,82	47,63	44,08	41,78	47,02	7,59	28,09	81,16	53,85
8	0,0406	93,73	205,93	183,25	111,45	324,29	62,20	126,29	192,75	231,86
9	0,0197	106,47	266,67	236,85	135,20	454,35	73,80	164,57	222,72	300,59
10	0,3171	49,42	60,76	55,58	48,39	64,85	15,85	36,08	94,69	68,51
...										
98	0,8099	17,16	16,05	16,57	23,61	12,65	33,63	9,20	32,61	18,84
99	0,1479	67,92	109,09	97,98	70,89	140,73	36,69	65,83	134,27	122,68
100	0,8067	17,36	16,19	16,68	23,71	12,75	33,19	9,28	32,96	18,99

3.4. Validity Test

Validation is considered an important activity as part of the model development process. The validation process is done to ensure that the model developed is accurate enough for the purpose at hand [14]. Validity test in this study is to represent the results of the transformation of random numbers with actual data, whether it is significantly different or not. Validity test in this study uses the Mann-Whitney U method. Table 3 shows the results of the validity test.

Table 3. Recapitulation of the Validity Test

Boiler	Component	Asymp. Sig. (2-tailed)	α	Information
Unit 1	Cyclone Separator	0,612	0,05	H ₀ accepted
	Coal Feeder	0,604	0,05	H ₀ accepted
	ID Fan	0,708	0,05	H ₀ accepted
	PA Fan	0,607	0,05	H ₀ accepted
	Slag Cooler	0,724	0,05	H ₀ accepted
Unit 2	Cyclone Separator	0,089	0,05	H ₀ accepted
	Coal Feeder	0,646	0,05	H ₀ accepted
	ID Fan	0,754	0,05	H ₀ accepted
	PA Fan	0,679	0,05	H ₀ accepted

3.5. Distribution Testing and Parameter Calculation of Random Number Transformation

The test system is the same as distribution testing and parameter calculation for the actual time to failure. The test results will be used to run the simulation. Table 4 shows the recapitulation of the best distribution and parameter for the Random Number Transformations.

Table 4. Recapitulation of the Best Distribution and Parameter for Random Number Transformations

Boiler	Component	Distribution	Parameter		
			Weibull		
			θ	β	γ
Unit 1	Cyclone Separator	3P-Weibull	41,4054	1,10803	0,4299
	Coal Feeder	3P-Weibull	35,4626	0,52600	10,8048
	ID Fan	3P-Weibull	30,8456	0,52340	12,0456
	PA Fan	3P-Weibull	21,7429	0,61891	19,2995
	Slag Cooler	3P-Weibull	35,7479	0,41904	9,5262
Unit 2	Cyclone Separator	3P-Weibull	38,0162	1,23482	4,4035
	Coal Feeder	3P-Weibull	21,0600	0,15549	6,2037
	ID Fan	3P-Weibull	71,2574	0,94089	8,0189
	PA Fan	3P-Weibull	39,1944	0,52179	13,1343

3.6. Calculation of MTTF and Reliability Result of Monte Carlo Simulation

MTTF calculations and the reliability level of the Monte Carlo simulation results are as follows [12].

$$\begin{aligned}
 MTTF &= \gamma + \theta \Gamma \left(1 + \frac{1}{\beta} \right) \\
 &= 0,4299 + 41,4054 \times \Gamma \left(1 + \frac{1}{1,10803} \right) \\
 &= 0,4299 + 41,4054 \times \Gamma (0.9025) \\
 &= 40,25 = 40 \text{ hari}
 \end{aligned} \tag{3}$$

$$\begin{aligned}
 R(t) &= e^{-\left(\frac{t-\gamma}{\theta}\right)^{\beta}} \\
 &= \exp \left[- \left(\frac{40,25 - 0,4299}{41,4054} \right)^{1,10803} \right] = 0,3445 = 34,45\%
 \end{aligned} \tag{4}$$

The results of calculations on boiler unit 1 cyclone separator components were obtained, 40 days maintenance interval with 34.45% reliability. MTTF calculation results and Monte Carlo Simulation reliability are shown in the Table 5.

Table 5. Recapitulation of MTTF and Reliability Result of Monte Carlo Simulations

Boiler	Component	Monte Carlo Simulation	
		MTTF (Day)	Reliability
Unit 1	Cyclone Separator	40	34,45%
	Coal Feeder	75	38,24%
	ID Fan	68	38,10%
	PA Fan	50	40,73%
	Slag Cooler	83	41,87%
Unit 2	Cyclone Separator	39	31,56%
	Coal Feeder	46	37,68%
	ID Fan	81	38,05%
	PA Fan	86	37,89%

Based on Table 5, the mean time-to-failure (MTTF) of Monte Carlo simulations can be used as predictive maintenance.

4. Conclusion

The result of Monte Carlo simulation to nine critical components of boiler section were obtained. For the component of cyclone separator boiler unit 1 obtained 40 days maintenance interval with 34,45% reliability. Coal feeder boiler unit 1 obtained 75 days maintenance interval with 38,24% reliability. ID fan boiler unit 1 obtained 68 days maintenance interval with 38,10% reliability. PA fan boiler unit 1 obtained 50 days maintenance interval with 40,73% reliability. Slag cooler boiler unit 1 obtained at 83 days maintenance interval with 41,87% reliability. Cyclone separator boiler unit 2 obtained at 39 days maintenance interval with 31,56% reliability. Coal feeder boiler unit 2 obtained at 46 days maintenance interval with 37,68% reliability. ID fan boiler unit 2 obtained at 81 days maintenance interval with 38,05% reliability. While PA fan boiler unit 2 obtained 86 days maintenance interval with 37,89% reliability.

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