

Analysis of Preventive Maintenance on a 6 MW Horizontal-Type Francis Turbine Using the Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) Methods at the Pakkat Hydropower Plant of PT Energi Sakti Sentosa

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ABSTRACT

The reliability of a turbine is a crucial factor in ensuring the continuous operation of a hydropower plant. This study aims to analyze the effectiveness of preventive maintenance on a 6 MW horizontal Francis turbine at Pakkat Hydropower Plant, PT. Energi Sakti Sentosa, using the Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) methods. A quantitative approach was employed using historical turbine operation and maintenance data collected from May 2025 to May 2026. The data were obtained through field observations, interviews, documentation, and literature review. The analysis was conducted by calculating MTBF, MTTR, and availability as indicators of equipment reliability and maintenance performance. The results show that the turbine achieved an MTBF value of 558.19 hours, an MTTR value of 2.30 hours, and an availability of 92.24%. Based on the MTBF value, the recommended preventive maintenance interval is 446.55 operating hours, equivalent to approximately 18–19 days of continuous operation. These findings indicate that the existing preventive maintenance program has provided a satisfactory level of reliability. However, further improvement can be achieved by optimizing maintenance scheduling, performing regular condition monitoring of critical components, and implementing a condition-based maintenance approach to enhance equipment availability and reduce unplanned downtime.

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INTRODUCTION

PT. Kencana Energi Lestari, Tbk. through its subsidiary operates the Pakkat Hydroelectric Power Plant in Humbang Hasundutan, North Sumatra, using horizontal Francis turbines with generators to produce renewable electricity. Renewable energy sources such as hydropower have the

advantages of availability, environmental friendliness, and great potential. Annual maintenance and inspection of water turbines have important benefits, namely increasing reliability and availability, operational efficiency, and extending the life of the turbine. Turbine reliability and an effective maintenance system are essential to maintain continuity of electricity supply; observations in July 2025 showed frequent sudden breakdowns of the 6 MW unit with repair times of 6–7 hours, disrupting local electricity supply (Bancin, 2020; Guna & Mubarak, 2021; Hutajulu, 2024; Lubis, 2021; PT Energy Sakti Sentosa, 2025).

Proper maintenance of Francis turbines, including preventive, predictive, and scheduled maintenance, is necessary to reduce the frequency of failures, reduce repair costs, and extend component life. Maintenance management focuses on three main metrics: Reliability, Maintainability, and Availability, which are measured by MTBF (Mean Time Between Failure), MTTR (Mean Time To Repair), and availability calculations. MTBF indicates the average interval between failures, while MTTR indicates the average duration of repairs (Assauri, 2008; Fatma et al., 2020; Haerudin & Wibowo, 2024; Hamsi, 2004; Permatasari et al., 2025; Silvia et al., 2024).

This study aims to calculate the MTBF and MTTR of the 6 MW Francis turbine at PLTA Pakkat using historical maintenance data from May 2025 to May 2026, evaluate equipment reliability and availability, and propose a more data-driven preventive maintenance interval compared with the current fixed maintenance schedule. Studies on the application of MTBF and MTTR to horizontal Francis turbines in hydropower plants remain limited. Therefore, this study analyzes MTBF, MTTR, and Availability based on historical turbine failure data at PLTA Pakkat PT. Energy Sakti Sentosa to evaluate the effectiveness of the preventive maintenance program. The results are expected to provide a basis for improving equipment reliability and reducing downtime (Fahri et al., 2025; Habeahan et al., 2026; Khoir, 2024; Marbun, 2025; Novarika et al., 2023).

The analysis method supported by the Pareto diagram will help identify the dominant causes of damage so that preventive repairs can be prioritized. Previous studies have shown that determining preventive maintenance intervals based on MTBF–MTTR can reduce downtime and increase availability. Thus, this study is expected to provide a basis for making more effective maintenance decisions to improve the reliability of the Pakkat Hydroelectric Power Plant (Afiva et al., 2019; Muhaemin & Nugraha, 2022; Udin & Kartawidjaja, 2025; Wardhani, 2022).

METHOD

This research is a case study with a calculation approach of Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) on a horizontal Francis turbine with a capacity of 6 MW at Pakkat Hydroelectric Power Plant PT. Energy Sakti Sentosa. Data were obtained from field observations, interviews, operational log documentation, disturbance reports, preventive maintenance schedules, and technical manuals during the period of May 2025–May 2026. The analysis focused on

the main components of the turbine, including the spiral case, runner, shaft, bearing, guide vane, lubrication system, and cooling system.



Figure 1. Horizontal Francis Turbine with a Capacity of 6 MW

The research began with problem identification through direct field observations to understand the existing maintenance system, turbine operating conditions, and the history of equipment failures. This was followed by a literature review on preventive maintenance, reliability, maintainability, availability, Mean Time Between Failure (MTBF), and Mean Time To Repair (MTTR) to establish the theoretical foundation of the study. The next stage involved data collection. Primary data were obtained through field observations and interviews with operation and maintenance personnel. Secondary data were collected from company documentation, including operational logs, breakdown reports, maintenance records, preventive maintenance schedules, and technical manuals covering the period from May 2025 to May 2026. The analysis focused on the main turbine components, namely the spiral case, runner, shaft, bearing, guide vane, lubrication system, and cooling system.

Subsequently, the collected data were classified according to component type, failure frequency, operating time, and repair duration. The data were then analyzed using the Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and Availability methods to evaluate equipment reliability, maintainability, and operational readiness. The Availability value was used as an indicator of the turbine's operational readiness, while the analysis results served as the basis for evaluating the effectiveness of the preventive maintenance program and developing recommendations to improve the maintenance strategy.

Mean Time Between Failure (MTBF) is the average time interval between failures that occur when a machine or component is repaired, and the machine or component fails again (Nugroho, 2021). Mean Time Between Failures (MTBF) is calculated by comparing the total operating time of a piece of equipment to the number of failures that occur in a certain period. Mathematically, MTBF is formulated as follows:

$$MTBF = \frac{Operation\ Time - Repair\ Time}{Failure\ Frequency} \dots\dots\dots (1)$$

Mean Time to Repair (MTTR) is the average time to perform repairs required by a component (Nugroho, 2021). Mathematically, MTTR can be formulated as follows:

$$MTTR = \frac{Repair\ Time}{Failure\ Frequency} \dots\dots\dots (2)$$

Availability is the proportion of time that equipment/machines are actually available to perform a job to the time that they are targeted to be available for a job. Or, in another definition, *availability* is the ratio for viewing line stops viewed from the breakdown aspect only (Nugroho, 2021).

$$Availability = \frac{Total\ Operation\ Time}{Loading\ Time} \times 100\% \dots \dots \dots (3)$$

RESULTS AND DISCUSSION

Preventive maintenance research has been carried out on the Francis Strojirny Brno Turbine, a horizontal type with a capacity of 6 MW, at the Pakkat Hydroelectric Power Plant of PT. Energy Sakti Sentosa. The damage data and repair times that occurred on the turbine from May 2025 to May 2026 can be seen in Table 1 below.

Table 1. Damage data and repair time

NO	Date	Component	Repair Time		Downtime (Minute)
			Start	Finish	
1	06/05/25	Hossing hose broke	10:00	10:45	45
2	05/28/25	Replace the loware bushing	10:19	15:20	301
3	04/06/25	Shaft seal leaking	12:15	12:40	25
4	06/24/25	Guide vane seal leak	13:15	14:10	55
5	07/14/25	Replace the screw pump M323	10:20	10:55	35
6	19/07/25	Shaft seal leaking	09:05	09:37	32
7	02/08/25	Change oil + oil filter	08:00	10:45	165
8	08/23/25	Bearing shaft inspection	12:05	14:00	115
9	09/24/25	Runner (moving blade) jammed	09:25	13:32	247
10	04/10/25	Motor oil pump jammed	13:15	14:55	100
11	09/11/25	Shaft seal leaking	09:00	09:40	40
12	03/04/26	Bearing shaft inspection	10:20	12:08	108
13	04/22/26	Replace M323 motor	15:20	15:55	35
14	04/29/26	Draftube leak	08:00	11:45	225
15	05/20/26	Exhanger leaking at tail race	08:18	17:20	542
Total					

Calculation of Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Availability for each type of damage that occurs to Turbine components in May 2025 – May 2026. These three parameters are the main indicators in evaluating the reliability and maintenance performance of a turbine component.

1. The following is a calculation method to obtain the MTBF value for each damage that occurs to the turbine. namely, as follows:

$$MTBF_{kejadian} = (W_b - W_a) \dots \dots \dots (1)$$

Information:

$MTBF_{kejadian}$ = MTBF time per event (hours)

W_a = End time of incident repair (hours)

W_b = Time of next incident damage (hours)

2. Calculation for each turbine failure is done by calculating the repair time interval from start to finish for each incident. As follows:

$$MTTR_{kejadian} = (W_d - W_c) \dots \dots \dots (2)$$

Information:

$MTTR_{kejadian}$ = MTTR time per event (hours)

W_c = Repair start time (hours)

W_d = Time at the end of the repair (hours)

3. The availability value of each component is obtained from the calculation results of the MTBF and MTTR values for each component damage to the turbine for the period May 2025 – May 2026 using the following formula:

$$A = \frac{MTBF_{Kejadian}}{MTBF_{Kejadian} + MTTR_{Kejadian}} \times 100\% \dots \dots \dots (3)$$

Description:

A = Availability of each component (%)

$MTBF_{kejadian}$ = MTBF time of each incident (hours)

$MTTR_{kejadian}$ = MTTR time per event (hours)

Table 2. Cumulative calculation results of MTBF, MTTR and Availability values for each component damage.

NO	Date	Component	Repair Time		MTBF (Hours)	MTTR (O'clock)	Availability
			Start	Finish			
1	06/05/25	Hosing hose broke	10:00	10:45	527.57	0.75	99.85%
2	05/28/25	Replace the lower bushing	10:19	15:20	164.92	5.02	99.04%
3	04/06/25	Shaft seal leaking	12:15	12:40	480.58	0.42	99.91%
4	06/24/25	Guide vane seal leak	13:15	14:10	476.16	0.92	99.80%
5	07/14/25	Replace the screw pump M323	10:20	10:55	118.16	0.58	99.51%
6	19/07/25	Shaft seal leaking	09:05	09:37	334.38	0.53	99.84%
7	02/08/25	Change oil + oil filter	08:00	10:45	505.33	2.75	99.45%
8	08/23/25	Bearing shaft inspection	12:05	14:00	763.41	1.92	99.74%
9	09/24/25	Runner (moving blade) jammed	09:25	13:32	239.71	4.12	98.31%
10	04/10/25	Motor oil pump jammed	13:15	14:55	858.08	1.67	99.80%
11	09/11/25	Shaft seal leaking	09:00	09:40	2,784.66	0.67	99.98%
12	03/04/26	Bearing shaft inspection	10:20	12:08	459.2	1.80	99.60%
13	04/22/26	Replace M323 motor	15:20	15:55	160.16	0.58	98.88%
14	04/29/26	Draftube leak	08:00	11:45	500.55	3.75	99.25%
15	05/20/25	Exhanger leaking tail race	08:18	17:20	0	9.03	0%
Total					8,372.87	34.51	

Based on the data in Table 2, a graph of the cumulative calculation results of the MTBF and MTTR values for each component damage that occurred during the period from May 2025 to May 2026 is shown in Figure 2 below:

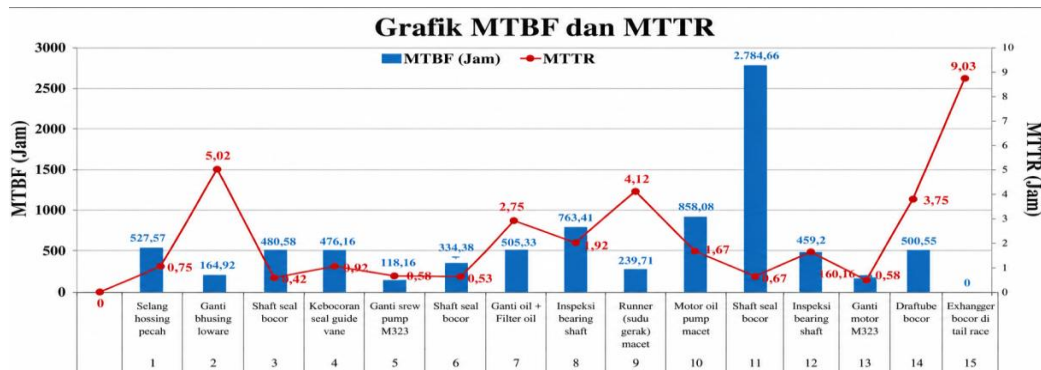


Figure 1. MTBF and MTTR charts

Based on the MTBF and MTTR graphs, variations between disturbances are shown: the highest MTBF was on a leaking shaft seal (09/11/2025), 2,783.66 hours, and the lowest was on the replacement of the M323 screw pump, 118.16 hours, while the value of 0 hours on the leaking draft tube was because it was the last incident; the overall MTBF indicates good turbine reliability. The average MTTR menu shows that repairs are generally fast; the longest was on the exchanger tail race inspection, 9.03 hours, due to dismantling and stopping operations. The fastest was on the leaking shaft seal 0.42 hours, 25 minutes), with most MTTRs <5 hours, so downtime can be reduced.

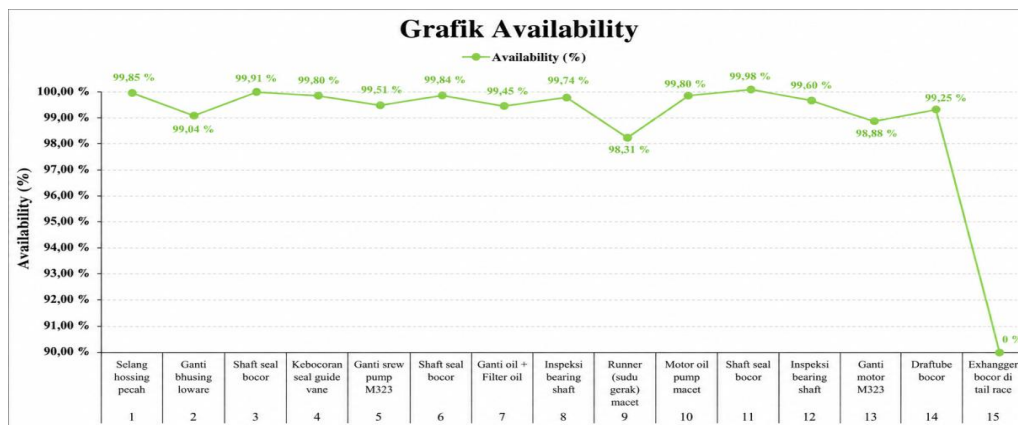


Figure 2. Availability Graph

Based on Figure 3, most of the turbine availability values are in the range of 98%–100%. The highest value of 99.98% occurs in cases of leaking shaft seals, while the lowest value of 98.31% occurs in cases of a leaking shaft seal. The runner (moving blade) is jammed. Value: 0%. The leaking draft tube was caused by the last major fault, so it had no MTBF value after repair. Overall, the high availability value indicates that the turbine has excellent reliability and operational readiness.

Calculation of MTBF, MTTR and Availability Value

From turbine component damage data that occurred over a period of 12 (twelve) months, from May 2025 to May 2026, calculations were carried out on Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR) and Availability for each damage. The calculations carried out are as follows.

1. MTBF calculation

The Mean Time Between Failure (MTBF) value is calculated to determine the average machine operating time between one failure and the next failure during the period of May 2025 to May 2026. The MTBF value is obtained based on the comparison between the total machine operating time and the number of failures. The MTBF calculation is as follows:

$$\begin{aligned} \text{MTBF} &= \frac{\text{Total Operation Time}}{\text{Failure Frequency}} \dots\dots\dots(1) \\ \text{MTBF} &= \frac{8.372,87}{15} \\ \text{MTBF} &= 558.19 \text{ Hours} \end{aligned}$$

2. Calculation of MTTR Value

The Mean Time To Repair (MTTR) calculation is carried out to determine the average time required for machine repairs for each breakdown occurring during the period of May 2025 to May 2026. The MTTR value is obtained by comparing the total repair time with the number of breakdowns. The formula used in the MTTR calculation is as follows:

$$\begin{aligned} \text{MTTR} &= \frac{\text{Repair Time}}{\text{Failure Frequency}} \dots\dots\dots(2) \\ \text{MTTR} &= \frac{34,51}{15} \\ \text{MTTR} &= 2.30 \text{ Hours} \end{aligned}$$

3. Calculation of Availability Value

Based on the calculation assumptions, during 12 months, the turbine is estimated to operate for 208 days, with a time of 4,992 hours. Assuming the turbine is not operating for 157 days in 12 months, the time the turbine is not operating is 3,768 hours.

$$\begin{aligned} \text{Availability} &= \frac{\text{Total Opation Time}}{\text{Loading Time}} \times 100\% \dots\dots\dots (3) \\ \text{Availability} &= \frac{8.372,87-3.768}{4.992} \times 100\% \\ \text{Availability} &= 92.24\% \end{aligned}$$

Table 3. MTBF, MTTR and Availability Values

Period	MTBF	MTTR	Availability
May 2025-May 2026	558.19 Hours	2.30 Hours	92.24%

Based on calculations, the MTBF value was 558.19 hours. This means the time between failures on the 6 MW horizontal Francis turbine is quite long, so disruptions during the observation period were relatively rare. The average MTTR of 3.59 hours indicates that the maintenance team was able to handle disruptions and quickly return the unit to operating condition. The Availability value of 92.24% indicates that the turbine is very ready for operation, with relatively small downtime compared to its operating time.

Analysis

The maintenance system at PLTA Pakkat applies both preventive maintenance and breakdown maintenance. Although this approach has maintained turbine operation, 15 failures were recorded during the period of May 2025–May 2026, indicating the need for a more effective condition-based maintenance strategy.

Historical failure data identified the shaft seal, bearing shaft, oil pump, motor oil pump, runner, draft tube, and heat exchanger as the most critical components contributing to failures and downtime. Pareto analysis was used to prioritize maintenance activities based on the components with the greatest impact on turbine reliability.

The calculated MTBF, MTTR, and Availability were 558.19 hours, 2.30 hours, and 92.24%, respectively. These results indicate that the turbine has good reliability and operational readiness. However, maintenance effectiveness can be further improved by implementing condition-based maintenance, ensuring the availability of critical spare parts, and prioritizing maintenance based on Pareto analysis to reduce downtime and improve turbine reliability.

Based on the Mean Time Between Failure (MTBF) value of 558.19 hours, the recommended preventive maintenance interval is 446.55 operating hours (approximately 447 hours or 18–19 days of continuous operation). This interval is expected to improve turbine reliability, reduce breakdowns, minimize downtime, and maintain a high level of availability.

CONCLUSION

Based on the research results, the Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Availability values were 558.19 hours, 2.30 hours, and 92.24%, respectively. These results indicate that the 6 MW horizontal Francis turbine at Pakkat Hydroelectric Power Plant (PLTA Pakkat) has good reliability and operational readiness, although several components, including the runner, heat exchanger, and draft tube, still contribute significantly to downtime. Based on the MTBF value, the recommended preventive maintenance interval is 446.55 operating hours (approximately 447 hours or 18–19 days of continuous operation) to improve turbine reliability, reduce breakdowns, and minimize downtime.

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