International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
ISSN Online: 2349-4182 ISSN Print: 2349-5979
Received: 05-08-2024, Accepted: 04-09-2024, Published: 19-09-2024
Volume 11, Issue 9, 2024, Page No. 20-26

Analysis of steam residue use during blackout to run steam turbine drive emergency lube oil pump at pt. puncakjaya power plant

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Abstract

The demand for electricity in Indonesia is increasing due to rapid development of industry, real estate, and technology, coupled with population growth. As a major electricity consumer, PT Freeport Indonesia significantly depends on electricity supplies from PT Puncak Jaya Power with a capacity of 3 x 75 MW. In steam turbine power plant (PLTU), the conversion of heat to mechanical energy unavoidably generates friction that causes bearing damage. To mitigate this issue, there is a need to optimize the lubricating system. A recent failure of DC pump in emergency lubrication system has led to significant damage to turbine and generator bearing, causing three months of inactivity. Therefore, this research proposed harnessing the remaining energy from steam drum to power a small turbine that was directly connected to the lubrication pump. Steam drum held a significant amount of thermal energy, with a mean of 1463 BTU/lb. This capacity was enough to run the small turbine for about 4 hours, typically long enough for AC power restoration. As a backup, battery-operated emergency pump was used particularly when the heating capacity of steam drum was insufficient. This innovative system does not interfere with recovery or startup procedure. Although the initial investment was substantial, operational costs were cheaper compared to traditional emergency pump. Consequently, this solution provided superior dependability and effectiveness in lubricating systems for steam turbine.

Keywords: Electric energy, emergency steam turbine lubrication, energy use

Introduction

The demand for electricity in Indonesia is increasing due to rapid development of industry, real estate, and technology, coupled with population growth. Consequently, there is a need for further development in the generation system and optimization of electricity usage, both in terms of consumption and the generation process. Recently, organizations particularly large companies such as PT Freeport Indonesia, have a high demand for electric energy to support operations. Moreover, energy requirements are met by PT Puncakjaya Power, an operation and maintenance (O&M) firm engaged in the operation of Steam Power Plant (PLTU), Diesel Power Plant, and Oil Gas Power Plant owned by PT Freeport Indonesia.

PLTU Amamapare is steam power plant of 3 x 75 MW design, which provides 65% total electric requirements of PT Freeport Indonesia. This PLTU is located on Amamapare Island in the Far East Mimika region of Mimika Regency, Central Papua Province. In power plant, there are both primary and secondary equipment. In addition, the Main equipment includes generator, turbine, cooling tower, condenser, pulverizer, boiler, fd fan, pa fan, and id fan, while the auxiliary equipment includes lube oil system, coal handling system, cooling water system, ash handling system, gas boiler system, demin water system, and water treatment system.

The equipment in PLTU serves specific purposes including turbine that aid in the conversion of thermal energy in steam into mechanical energy through rotation. Steam entering turbine is used to activate the rotation of turbine following the desired power output. Subsequently, steam is connected to a generator to produce electric energy.

When turbine rotates, friction is created between turbine shaft and the bearing, which generates heat, and excessive friction leading to material erosion. To minimize this friction, a lubricating system is required on steam turbine. Additionally, the system equipped with this steam turbine serves a dual purpose of minimizing friction and facilitating heat transmission, dirt movement, and cooling of turbine as well as generator bearings (Mustangin, 2018) [7].

A supplementary equipment called the lubrication system is included in the primary turbine and generator equipment. This system comprises the Main Oil Pump, Standby Oil Pump, Emergency Bearing Oil Pump powered by battery (DC), and Main Oil Tank. In addition, the system is designed to supply lubrication to the bearings of turbine and generator, which are pushed by the Main Oil Pump equipped with an AC motor. During blackout which causes a complete absence of AC power supply, Main Oil Pump is unable to provide lubrication oil to the bearings of turbine and generator. To solve this issue, emergency lubrication system is advised to be installed. Failure of AC lube oil pump or abnormality in turbine oil system will trigger the activation of DC lube oil pump (Ruicai *et al.*, 2021). Emergency lubricating oil pump often malfunctions, indicating the need for the use of additional and more reliable emergency power supply devices in case of a total power failure. Continuous lubrication of high pressure and low pressure turbine is necessary for steam power plants to avoid premature wear of the shafts and bearings. These equipment are lubricated with oil to create oil layer, which functions to reduce shaft friction (Priya and Jeyalakshmi, 2020) [8]. Following this discussion, the detection of anomalies in steam turbine is crucial for ensuring proper functioning and dependability (Yao *et al.*, 2022) [14]. Due to the frequent and severe occurrences of lubricant loss events in every turbine, the reliability of the lubricating oil system is very important (Latcovich *et al.*, 2005).

When there is power outage at PLTU power plant, turbine and generator rotor continue to rotate at an exceptionally high speed. Turbine speed at PT. Puncakjaya is – Electric, and during blackout, the speed experiences a temporary increase in excess up to 3600 rpm, followed by a gradual decline to 3 rpm. This decrease in speed leads to fatal damage due to friction between the bearing and the generator rotor shaft. Additionally, the start-up process is slow because it requires waiting for electricity from other facilities to power auxiliary equipment needed for the generator. Following the discussion, other complications also contribute to the slow restoration of electricity.

At the Amamapare PLTU, restarting power plant takes around 2 to 6 hours. When a total blackout occurs, steam in the boiler pipes and steam drums still contains a large amount of energy which over time will condense and can cause a water hammer. This condition can be used to rotate a small turbine which is applied to rotate pump to supply lubricant, thereby ensuring more reliable lubrication during a total blackout. The rationale generates interest among explorers to conduct research and evaluate the technical and economic dimensions of implementing this system.

The explorer is motivated to examine the topic with the following objectives which include (1) Calculate the remaining steam energy during operation when electricity fails in the boiler drum, (2) Analyze the reliability and performance evaluation of steam bearing oil pump (SBOP) in backing up the lubrication of turbine and generator bearings during blackout to prevent damage to generator and turbine rotor bearings, (3) Evaluate the impact of installing an SBOP on PLTU startup performance after a total outage by comparing startup times before and after pump installation, and (4) Conduct an economic analysis of the installation of steam-bearing oil pump.

Research method

A. Research type and data source

The research used quantitative data which consisted of numerical values. The primary data contained data collected directly from the subject of investigation. Moreover, the data sources used included boiler volume data from the manual book, as well as pressure and temperature measurements in steam drum to determine the residual steam energy after a complete power outage. Operational records from backup PI (process indicator) data were required to determine the reliability of emergency lubricating oil pump by analyzing the resulting rotational speed, pressure, and pump discharge lubricating oil flow during blackout.

The research used pressure and temperature data from steam inlet and steam outlet turbine obtained from PI, as well as pump specifications data from the manual book to assess the effectiveness of emergency lube oil pump in supporting steam turbine. In addition, past data on pump failures obtained from inspection reports, internal risk assessment of PLTU, and information provided in pump quotation of the manufacturer to conduct engineering and economic analysis were used. Moreover, a comparative analysis of the economic aspects was conducted before and after the implementation of the SBOP. This process was performed by using energy consumption data at the beginning of operation, pump-specific information, coal calorific value data, downtime records, maintenance reports, and equipment availability data.

B. Research location and time

The research was conducted in PLTU PT Puncakjaya Power Amamapare Island, located in the East Mimika District of Mimika Regency, the Central Papua province of Indonesia. The experimental investigation was performed from September 2023 to September 2024. During the exploration, tasks were divided into separate phases, which included preparation, data collection, analysis, and report generation.

C. Data Collection Method

Observational methods, documentation exploration, and direct data collecting methods were used to collect primary data directly in the field.

The necessary information, including steam flow rate, pressure, temperature, and pump rotational speed, was obtained by the research through the direct collection of data from the PI server during blackout. In addition, the research conducted experimental investigations by directly watching and gathering data on the functioning of steam turbine lubrication oil pump. This data was crucial for calculating the performance and efficiency of steam turbine. A comprehensive review was conducted to assess scientific literature, technical data, instruction books, and operating records related to emergency pump. This review included information provided by manufacturers of steam turbine drive pump.

D. Data analysis method

After collecting the data needed to analyze this research, the following data analysis methods were performed:

1. Method Analysis

- Calculating steam energy left in the boiler when blackout occurred.
- Calculating the amount of energy consumption based on the calorific value of the fuel used before and after the installation of the SBOP concerning the amount of energy consumption at the start-up of the unit.
- Calculating the prime-mover efficiency when emergency bearing oil pump driving steam turbine was working.
- Analyzing the reliability of the SBOP by looking at the response time in supplying lubrication when blackout occurred by checking historical data.
- Analyzing the ability of the SBOP in terms of the speed produced by pump and the length of operation, until energy stored in steam drum was no longer able to rotate steam turbine.

2. Economic Analysis

- Comparing the investment required before and after the installation of the SBOP.
- Comparing the lifetime of the equipment.
- Calculating the comparison of economic value from energy side before and after the installation of the SBOP.

3. Statistical Analysis

- Calculating the t-test statistic using the t-test statistical formula for paired samples.
- Determining the Critical Value or p-value.
- Comparing the t-test statistic with the critical value obtained from the t-distribution table or calculating p-value using statistical software.

Results

A. Energy stored in steam drum

The pressure and temperature measurement data were downloaded from the data stored on the server during blackout events on September 22, 2023, and February 4, 2024.

1. Blackout on september 22, 2023

Using steam program in the thermodynamic and Transport Properties of Water and Steam software, the pressure and temperature data obtained from the pressure device (PSIg) was transformed into absolute pressure (PSIa) to calculate enthalpy.

Table 1: U#1 blackout data September 22, 2023

No	Time	Load (MW)	Pressure (PSIg)	Absolute Pressure (PSIa)	Temperature (ºF)	Enthalpy (Steam Table) BTU/lb
1	13.30	49,81	1676,44	1691,14	967,67	1465,18
2	13.35	0,01	1728,15	1742,85	969,69	1464,17
3	13.40	0,01	1693,88	1708,58	962,90	1551,14
4	13.45	0,01	1632,83	1647,53	959,02	1460,93
5	13.50	0,01	1531,08	1545,78	955,28	1462,50

2. Blackout on february 4, 2024

Table 2: U#2 blackout data February 4, 2024

No	Time	Load (MW)	Pressure (PSIg)	Absolute Pressure (PSIa)	Temperature (ºF)	Enthalpy (Steam Table) BTU/lb
1	04:05	18.11	1725,54	1740,24	957,11	1456,30
2	04:10	0,07	1696,82	1711,52	953,31	1454,91
3	04:15	0,02	1655,53	1670,23	949,48	1453,96
4	04:20	0,03	1608,77	1623,47	946,53	1453,78
5	04:25	0,03	1560,41	1575,11	943,83	1453,83

Table 3: U#3 blackout data February 4, 2024

No	Time	Load (MW)	Pressure (PSIg)	Absolute Pressure (PSIa)	Temperature (ºF)	Enthalpy (Steam Table) BTU/lb
1	04:05	17.32	1676,33	1691,03	957,11	1458,05
2	04:10	0,00	1650,03	1664,73	953,31	1456,59
3	04:15	0,00	1618,38	1633,08	949,48	1455,31
4	04:20	0,00	1587,10	1601,80	946,53	1454,58
5	04:25	0,00	1550,36	1565,06	943,83	1454,21

B. Energy demand analysis of steam turbine emergency oil pump (EOP) DC

From the EOP DC specification, the following data was obtained.

DC motor flow = 158 A
DC motor voltages = 123 V
The calculation steps are as follows:

1. Required energy of DC motor

P = V x I
= 123 V x 158 A
= 19434 Watt
= 19434 Watt x $\frac{3{,}4121\ BTU/Hour}{1\ Watt}$
= 66310,7514 BTU/Hour

2. Energy required for DCS systems, open/close breakers, and emergency lights

P = V x I
= 130 V x 60 A
= 7800 Watt
= 7800 Watt x $\frac{3{,}4121\ BTU/Hour}{1\ \text{Watt}}$
= 26692,3800 BTU/Hour

3. Available energy in the battery bank

Number of battery cells = 58 Cells
Battery Type = AT-27P
Total Volts = 124,6 VDC
Battery Capacity = 1560 Ampere.Hour
Power bank battery = V x I
= 124,6 V x 1560 Ampere.Hour
= 194376 Watt.Hour

4. DC Oil Pump Emergency Bearing Usage Retention Time

Retention Time $= \frac{\text{Battery Power Bank}}{\text{DC motor required power}}$
$= \frac{194376\ \text{Watt.Hour}}{19434 + 7800\ \text{Watt}}$
= 7,14 Hours

C. Energy Requirement Analysis of Steam Turbine Emergency Oil Pump

- Coupling Output : 20 HP
- Turbine Inlet Steam Pressure : 600 PSIG
- Turbine Inlet Steam Temperature : 650°F
- Turbine Outlet Steam Pressure : 20 PSIG
- Turbine Outlet Steam Temperature : 487°F
- Turbine Efficiency : 70%

The calculation steps are as follows:

1. Calculating the Mechanical Energy Generated by turbine

Converted HP unit to BTU/Hour:
Mechanical Energy (BTU/Hour) = Coupling Output (HP) x HP to BTU/Hour Conversion Factor x turbine efficiency (70%)
Mechanical Energy = 20 HP x 2509.6260 BTU/hour/1 HP x 0.7
Mechanical Energy = 35120.764 BTU/hour

2. Calculating Thermal Energy of Incoming Vapor

- Using the saturated steam table in the thermodynamic and transport properties of water and steam software to find the enthalpy of steam at the inlet and outlet of turbine:
  Enthalpy at inlet (h1) at pressure 600 PSIG and temperature 650°F = 1320.23 BTU/lb Enthalpy at outlet (h2) at pressure 20 PSIG and temperature 487°F = 1279.24 BTU/lb

- Calculated the enthalpy change of steam (Δh):

Δh = h1 - h2
= 1320,23 BTU/lb–1279,24 BTU/lb
= 40,99 BTU/lb

- Calculated the mass of steam (m) required per hour

Mass of Steam (lb/hr) = Mechanical Energy (BTU/hr)/Change in Steam Enthalpy (BTU/lb)
Steam Mass = 35120.764 BTU/hour / 40.99 BTU/lb
Steam Mass = 856.8130 lb/hr

3. Calculating the Mass of Steam Available in steam Drum when There is a Total Blackout

Steam in steam drum was considered an ideal gas using the ideal gas equation, and the formula was as follows.

PV = n RT
Description:
P = Pressure on steam drum (Psia)
V = Steam drum volume (ft3)
n = Mole of water (mol)
R = Constant (10.7316 psia.ft^3/lbmol.R)
T = Steam temperature (oR)

From the data collected, the following results were obtained.

- Steam Drum Pressure = 1676.44 PSIg

PSia = PSIg + 14,7
= 1676,44 + 14,7
= 1591,14 PSIa

- Steam Drum Temperature = 967.67 oF

R = (4/9)*oF + 32
= (4/9)*967,67 + 32
= 462,08 Or

- Steam drum volume was calculated using https://checalc.com/calc/vessel.html and applying the following steam drum dimensions.

ID of steam drum = 66 Inch
Steam Drum Length = 22 Feet
Inside Dish Depth = 2,5
Steam Drum Volume = 598,4 ft3

- The mass of steam in the drum was calculated using the ideal gas equation:

$$\text{PV} = \text{n RT}$$

$$\text{PV} = \frac{\text{Mass}}{\text{Molecular Weight}} \text{ x R x T}$$

$$\text{Massa} = \frac{\text{P x V x Molecular Weight}}{R \; x \; T}$$

$$\text{Massa Steam} = \frac{1591{,}14 \; Psia \; x \; 598{,}40 \; ft3 \; x \; 18{,}02 \; lb/lbmol}{10.7316 \text{ psia.}\frac{\text{fts}}{\text{lbmol}}\text{.Rx462,08 R}}$$

$$= 3459{,}9762 \text{ lb}$$

$$\text{Retention Time} = \frac{\text{Mass of Steam Remaining in Steam Drum}}{\text{Steam mass required by turbine pump}}$$

$$= \frac{3459{,}9762 \; lb}{856{,}8130 \; {}^{lb}/_{hour}}$$

$$= 4{,}04 \text{ Hours}$$

D. Economic Analysis

1. CAPEX (capital expenditure) budget plan

Table 4: CAPEX Steam Bearing Oil Pump

Item	Specification	Quantity	Unit	Price Unit	Cost
Procurement Cost					
Turbine, Pump	Steam Turbine 18ZS-1	1	Unit	$200,000, -	$200,000, -
Pipe, Fitting, and Valve Special	-	1	Set	$96,384	$96,384
Installation and Supervision	-	1	Package	$63,503	$63,503
Service and Shipping Fee					
Administration	-	1	Package	$15,391	$15,391
Engineering and Design	-	1	Package	$21.178,33	$21.178,33
Commissioning	-	1	Package	$19.432,33	$19.432,33
Shipping Fee	-	1	Package	$6.554,67	$6.554,67
Total CAPEX Budget Plan					$422.443,33

Table 5: CAPEX Emergency Oil Pump DC

Item	Specification	Quantity	Unit	Price Unit	Cost
Procurement Cost					
DC motor	15 KW 3600 rpm	1	Unit	$30258, -	$30258, -
Pump	-	1	Set	$2000	$2000
Battery	AT-27P	58	Cell	$1325,944	$76904,752
Installation & Supervision	-	8	People	$5133,333	$5133,33
Service and Shipping Fee					
Shipping Fee	-	1	Package	$6.554,67	$6.554,67
Total CAPEX Budget Plan					$120850,752

2. OPEX (Operational Expenditure) Budget Plan per year

Table 6: DC Battery

Item	Specification	Quantity	Unit	Price Unit	Cost
Operational Cost					
Labor Wages for Preventive Maintenance	Mechanic & Electrician Technician	4	People	$44,44	$2133,33
Spare Part Cost (Battery maintenance)	AT-27P	10	Cell	$1325,944	$13250,944
Lubrication costs for pump	1 Year	1	Liter	$2,98	$2,98
Total					$15.387,254

Table 7: Steam turbine Steam Drive Emergency Pump

Item	Specification	Quantity	Unit	Price Unit	Cost
Operational Cost					
Labor Wages for Preventive Maintenance	Mechanic & Electrician Technician	4	People	$44,44	$2133,33
Spare Part Cost (Battery maintenance)		10	Liters	$2,98	$29,8
Total OPEX					$2.163,13

Discussion

Based on the research result, the outcomes were discussed as follows.

A. Energy requirement analysis of emergency oil pump DC

An essential function of EOP DC was to ensure the efficient functioning of turbine and generator in power installations. Failure of EOP caused damage to turbine and generator, unavailability of power, and substantial financial losses.

After analyzing both manual and field data, EOP had a retention duration of 7.14 hours. The mean power recovery data after a complete outage was around 2 hours. From a temporal perspective, the capabilities of EOP were rather satisfactory. However, the operational history of PT Puncak Jaya Power showed that there were two instances of failure to provide EOP lubrication to turbine and generator bearings, leading to significant damage and downtime. Consequently, both the plant and customers experienced financial losses.

The author proposed implementing an EOP Redundancy system, similar to traditional backup pump to improve dependability and reduce risks. This process guaranteed uninterrupted operation even in the event of a failure in the primary components.

B. Energy requirement analysis of steam bearing oil pump

SBOP played a crucial role in ensuring the efficient functioning of turbine and generator in power plants. The primary purpose of SBOP was to ensure sufficient lubrication for turbine bearings, particularly in emergency when there was a complete power failure. Moreover, analyzing SBOP energy requirements was important to guarantee the dependability and accessibility of the system.

Pump retention period was determined to be 4.04 hours based on the quantification of the remaining energy in steam drum. In comparison to the battery-powered emergency pump, SBOP retention time was reduced. However, the data showed that turbine-bearing lubrication system had never encountered any issues during a complete outage since the implementation of SBOP system. This process exemplified the very dependable nature of SBOP in practical application.

C. Energy remaining in steam drum after blackout

An all-inclusive power outage at PLTU might affect the stability of electric system. The durability of PLTU PT. Puncakjaya Power was shown by its use of the remaining energy in steam drum to power pump during a complete blackout.

Using data computations obtained from multiple total blackout episodes of PLTU PT. Puncakjaya Power, energy stored in steam drum was determined to be 1463.70 BTU/lb. Additionally, the data presented implied that energy remaining in steam drum was significantly affected by the load and operating circumstances. In the event of blackout, energy in the drum was substantially reduced as a result of the drop in both pressure and temperature.

D. Comparison of energy used by emergency bearing oil pump driving steam turbine and DC battery

Analysis of the research data showed that emergency bearing oil pump driving direct current (DC) motor consumed 66310.7514 BTU/hour, while emergency bearing oil pump driving steam turbine consumed 35120.7640 BTU/hour.

Energy usage of EBOP powered by steam turbine was less compared to the DC electricity source. The inefficiency of energy conversion from steam to mechanical energy in steam turbine was the causal factor for this phenomenon. Additionally, in conditions of low load, EBOP was significantly higher compared to DC battery EBOP.

E. Investment and operating costs

Table 8: Investment and Operating Costs

Economic Comparison	Emergency Oil Pump	
	DC Motor Drive	Steam Turbine Drive
Capital Expenditure (CAPEX)	$120.850,752	$422.443,33
Operational Expenditure (OPEX)	$13.250,944	$2.163,13

The acquired data showed that steam turbine drive EOP necessitated a higher initial investment compared to DC motor drive. However, the operational cost (OPEX) associated with steam turbine drive EOP was lower than that of DC motor drive.

Although the initial capital expenditure (CAPEX) was greater, steam turbine drive EOP was more dependable and experienced lower annual OPEX. Therefore, from an economic perspective, this system was highly essential and improved the reliability of PLTU system.

F. The effect of startup time before and after installation of steam bearing oil pump

The proposed hypothesis was as follows:

- **H_0:** There was no statistically significant difference between the mean startup time before and after the installation of the lube pump.

- **H_1:** There was a statistically significant difference between the mean startup time before and after the installation of the lube pump.

From the Table of statistical analysis results using the Excel formula in the attachment, the following results were obtained.

1. Unit 1

The Table showed the results of the unpaired two-sample t-test. In this case, two variables were compared which included Variables 1 and 2.

- **Mean:** Variable 1 had a mean of 7.98, while 2 had a mean of 6.67. This value showed that 1 had a higher mean value compared to 2.

- **Variance:** Variable 1 had a variance of 16.29, while 2 had a variance of 8.38. The higher variance in 1 implied that the data in 1 was more dispersed compared to 2.

- **Observations:** The number of observations for Variable 1 was 42 and for 2 was 49.

In conducting the t-test, the assumption was concluded that the mean difference between the two variables was zero (Hypothesized Mean Difference = 0). During this research, t-stat value of 1.76 was obtained with a degree of freedom (df) of 73.

- One-tail test produced a one-way p-value of 0.042, which was less than the designated alpha threshold of 0.05. Additionally, the t Stat value of 1.76 exceeded the critical t value of 1.67 for one-tail tests. This observation implied that a significant disparity existed between Variable 1 and 2 in a particular direction, based on the hypothesis proposed.
- There was no statistically significant difference between variables 1 and 2 when the direction of the difference was not specified. This result was based on two-way p-value of 0.083, which was higher than the significance level of 0.05, and t Stat value of 1.76 that was lower compared to the two-tail Critical t of 1.99.

In general, these results showed a significant disparity between Variable 1 and 2 when a specific assumption was made about the direction of the difference. However, in the absence specification of the direction of difference, no substantial disparity existed between the two variables.

2. Unit 2

The Table showed the results of the two-sample t-test assuming unequal variances. In this research, two variables were compared, namely Variable 1 and 2.

- **Mean:** Variable 1 had a mean of 7.64, while 2 had a mean of 7.30. These results showed that Variable 1 had a slightly higher mean value compared to 2.

- **Variance:** Variable 1 had a variance of 13.97, while Variable 2 had a variance of 16.54. The higher variance in Variable 2 implied that the data in 2 was more dispersed compared to 1.

- **Observations:** The number of observations for Variable 1 was 34 and for Variable 2 was 57.

In conducting t-test, an assumption was made that the mean difference between the two variables was zero (Hypothesized Mean Difference = 0). Following this process, t-stat value of 0.40 was achieved with a df of 74.

- **Statistical analysis:** P-value for one-way test was 0.344, exceeding the significance level of 0.05 (alpha level). Additionally, t-stat value of 0.40 was lower than the critical t-value of 1.67 for one-tail test. These results implied that there was no statistically significant distinction between Variable 1 and 2 in the particular direction, according to the hypothesis proposed.

- **Two-tail test:** The comparison of two-way p-value (0.689) and t Stat value (0.40) showed that there was no statistically significant difference between Variable 1 and 2 when the direction of the difference was not specified.

In general, the results implied that there was no statistically significant distinction between Variable 1 and 2, in the specified or non-specific directions. In this scenario, the null hypothesis stating that there was no difference between the two variables could not be rejected. This is because the available data was insufficient to establish a statistically significant disparity in the startup time before and after the installation of the lubricating oil pump.

3. Unit 3

The Table showed the outcomes of the two-sample t-test in the assumption of unequal variances. This analysis included the comparison of two variables, namely Variables 1 and 2.

- A mean of 8.96 was observed for Variable 1, while 2 had a mean of 6.71. These results implied that Variable 1 had a greater mean value in comparison to Variable 2.
- A variance of 22.49 was shown in Variable 1, where 2 had a variance of 7.40. In addition, Variable 1 showed a greater variance, implying that the data in 1 was widely spread out in comparison to 2.
- The number of observations for Variable 1 was 42, while for 2, the value was 51.

By assuming that the mean difference between the two variables was zero (Hypothesized Mean Difference = 0), t t-test was conducted. Given a df of 62, the coefficient of determination (t Stat) was 2.02.

- **Statistical analysis:** P-value for one-way test was 0.004, which was less than the significance level of 0.05 (alpha level). Additionally, t Stat value of 2.72 exceeded the critical t value of 1.67 for one-tail test. This observation implied that a significant disparity existed between Variable 1 and 2 in a particular direction, based on the hypothesis proposed.

- By assuming the two-way p-value (0.008) was less than 0.05 and t-stat value (2.72) was higher compared to two-tail t Critical (1.99), a conclusion could be made that there was a statistically significant difference between Variable 1 and 2 without specifying the direction of the difference.

In the present research, an independent t-test was used to compare the means of two samples in the assumption of unequal variances. Moreover, the null hypothesis (H0) showed that there was no statistically significant difference between the two means, with a predetermined hypothesis value of 0.

Conclusions and recommendations

A. Conclusions

In conclusion, the following assumptions were drawn based on the results of the research and discussion that was conducted.

1. The remaining energy in steam drum following a complete power outage could be harnessed to power essential auxiliary equipment, such as emergency lubrication pump.
2. Turbine steam drive emergency pump was essential for ensuring the efficient functioning of turbine, particularly in the event of an unexpected power failure. By guaranteeing constant lubrication, the lubrication served a crucial role in preventing damage to turbine components.

3. As steam turbine drive consumed more energy than the battery, the remaining steam energy in the boiler could be efficiently harnessed to power emergency pump. This process exemplified the effectiveness of the use of current resources.
4. Steam turbine-powered emergency pump provided a significantly quicker response time in comparison to batteries powered. This technology showed a high level of reliability in preserving bearing oil lubrication in emergency thereby reducing the potential for equipment damage.
5. Installation of the bearing oil emergency pump did not greatly affect the startup time following an unavailability. This process implied that the technology could be seamlessly incorporated into the existing system without causing any disturbance to operational procedures.
6. From an economic perspective,

   Capital Expenditure Analysis (CAPEX):

- **DC Motor Driven Pump:** Had an initial investment of $120,850.75.

- **Steam Turbine Driven Pump:** Had a higher initial investment of $422,443.33.

Operational Expenditure Analysis (OPEX):

- **DC Motor Driven Pump:** Annual operating cost was $13,250.94.

- **Pump with Steam Turbine Drive:** The annual running cost was much lower, at $2,163.13.

B. Recommendations

According to the results obtained, several recommendations could be proposed as follows.

1. A comprehensive investigation is proposed to determine the ideal steam quality necessary for the effective and sustainable operation of steam turbine.
2. Additional investigation is required to determine the optimal steam properties that can optimize the performance of steam turbine.
3. Installing an online monitoring system at the outlet of steam turbine and associated components is strongly advised to retrieve real-time and precise performance data, thereby facilitating the evaluation of turbine efficiency.
4. Battery-powered emergency lubrication pump should be used as the final precautionary measure in emergency lubrication system, particularly when the anticipated duration for AC power restoration is more than 4 hours.

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