

**EFFICIENCY ANALYSIS OF THE THREE-PHASE ELECTRIC MOTOR 011P-109B AS THE DRIVE FOR THE LDO PUMP IN THE FUEL OIL PRODUCT UNIT, COMPLEX II, PT KILANG PERTAMINA INTERNASIONAL**

**Alien Uis Wigati<sup>1\*</sup>, Bustanul Arifin<sup>2</sup>**

<sup>12</sup>Universitas Islam Sultan Agung, Semarang, Jawa Tengah, Indonesia

\*Correspondence Email: [alien.wigati@gmail.com](mailto:alien.wigati@gmail.com)

**ABSTRACT**

*Induction motors are electrical machines that operate based on electromagnetic principles to convert electrical energy into mechanical energy. In the oil and gas industry, electric motors are widely used for operational processes. This accounts for a large portion of operational costs. At the Fuel Oil Complex II operating unit, the 011P-109B drive motor for the LDO product pump was damaged, so the motor was replaced with one that exceeded the existing specifications, namely from 125HP to 150HP, 111.855 kW, 2 poles, and a frequency of 50 Hz. Research was conducted to test the efficiency of the motor. The method used in this test was a literature review of several publications that comply with national and international standards. Based on efficiency calculations, the 150HP induction motor has superior operational efficiency compared to the 125HP motor, with an average efficiency of 93.63% compared to 93.15%, as well as lower power loss of 4.8kW compared to the 125HP motor, which has a power loss of 5.01kW. The comparison results with the IEC 60034-30-1:2014 standard show that both motors are technically classified in the IE2 (High Efficiency) to IE2+ (Borderline IE3) category.*

*Keywords: induction motor; efficiency; IEC 60034-30-1.*

## INTRODUCTION

An induction motor is a type of alternating current motor in which the current flowing through the motor does not come directly from a power source, but is generated due to the difference between the rotational speed of the rotor and the rotating field produced by the stator current. An induction motor is an electrical machine that works on the electromagnetic principle to convert electrical energy into mechanical energy (Septianto et al., 2015). Electric motors can work on the principle of electromagnetic induction originating from the stator coil to the rotor coil. When the stator coil is connected to a 3-phase power source, a rotating magnetic field will arise. The lines of flux force that arise due to the electric force will cut or induce the rotor coil. According to Faraday's law of electromagnetic induction, the frequency of the induced emf is equal to the supply frequency. Its magnitude is proportional to the relative speed between the flux and the conductor, and its direction can be determined using the right-hand rule. Because the rotor bar or conductor is a closed circuit, the direction of the rotor current is generated in accordance with Lenz's law, flowing towards the rotor coil (Theraja & Theraja, 2005). The widespread use of electric motors in industry accounts for a large portion of operational costs. The use of motors that are unsuitable or too large for the load being served can result in waste. However, sometimes it is necessary to select a motor that is too large to accommodate peak load conditions, such as when a pump must meet very high demand (Wijaya, 2001). Therefore, it is important to determine the appropriate motor by analyzing the load and motor efficiency. The 011P-109B was damaged and recommended for replacement, but the motor specifications used in the 011P-109B were 150 HP, exceeding those of the existing motor, so a review of the motor's efficiency was conducted. Energy efficiency is an effort that must be made to reduce the large amount of energy used in a piece of equipment.

### Working Principle of Electric Motors

Electric motors work on the principle of electromagnetic induction originating from the stator coil on the rotor coil. When the stator coil is connected to a 3-phase power source, a rotating magnetic field is generated. The lines of flux force that arise due to the electric force will cut or induce the rotor coil. According to Faraday's law of electromagnetic induction, the frequency of the induced electromotive force is equal to the supply frequency. Its magnitude is proportional to the relative speed between the flux and the conductor, and its direction can be determined using the right-hand rule. Because the rotor bar or conductor is a closed circuit, the direction of the rotor current is generated in accordance with Lenz's law, flowing towards the rotor coil (Novianto, 2022).

The stator frame contains copper wire coils that are shaped to produce a magnetic field. The number of magnetic poles in an electric motor varies for each coil. This number of magnetic poles can affect the speed of the rotor in minutes, commonly referred to as RPM (Rotation Per Minute). The number of poles is the number of magnetic poles in one revolution/circle (3600) in each coil/winding. The more magnetic poles there are, the smaller the stator field rotation produced. Conversely, if there are fewer magnetic poles, the stator field rotation will be greater. This rotational speed is called synchronous speed.

Synchronous speed formula

$$N_s = \frac{120 \times f}{p} \tag{1}$$

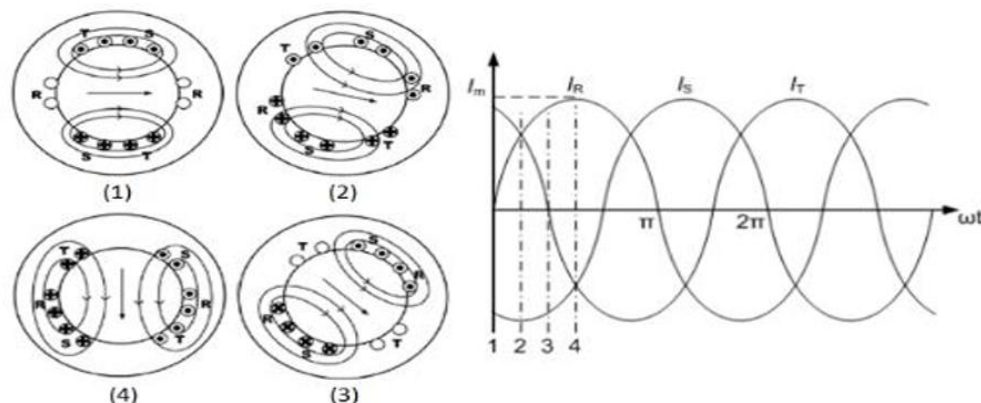


Figure 1. Working Principle of Induction Motors

### Slip Induction motor

The difference between the synchronous speed  $N_s$  and the actual speed  $N$  of the rotor is called slip. The relative rotational difference between the stator and rotor is called slip. As the load increases, the motor torque increases and the induction current in the rotor also increases, so that the slip generated between the stator rotating field and the rotor winding becomes greater (Prawira, 2022).

$$\% \text{ slip } S = \frac{N_s - N}{N_s} \times 100 \tag{2}$$

### Electric Motor Efficiency

The effectiveness of an electric motor can be calculated from the efficiency value of the machine in converting electrical energy into mechanical energy. This efficiency is directly related to losses in induction motors, regardless of the design of the machine itself. Efficiency is usually expressed as the ratio of output power to input power, often as a percentage, or as the ratio of output power to total output power plus losses (Barus, 2022), which can be formulated with the following equation:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \tag{3}$$

At low loads, fixed losses are greater than the output power, so the resulting efficiency tends to be low. As the load increases, efficiency also increases and peaks when core losses and variable losses are balanced. Maximum efficiency generally occurs in the range of 80–95% of the machine's output capacity, with higher values for larger motors. If the applied load exceeds the load that produces maximum efficiency, load losses will increase faster than output, resulting in a decrease in efficiency (Alam, 2022).

The efficiency of an induction motor can be calculated using the formula:

$$\text{Motor efficiency} = \eta = \frac{Pr \times \text{Load Factor}}{Pi} \times 100\% \tag{4}$$

$$\text{Load Factor} = \frac{I}{I_r} \times \frac{V}{V_r} \times 100\% \tag{5}$$

### RESEARCH METHODS

This research will be conducted in accordance with Figure 1, which is a research flowchart, to facilitate and assist the research process.



Figure 1. Research process

**RESULTS AND DISCUSSION**

The results of the data collected from the nameplate can be seen in the following table:

**Table 1. Specifications of Three-Phase Induction Motor 011P-109B 125HP**

Modle	5K444SS121
RPM-FL	2970
Voltage	380V
AMP-FL	161
HP	125
frequency	50 Hz
<i>Power Factor Full Load</i>	0.94
$\frac{3}{4}$ Load	0,94
$\frac{1}{2}$ Load	0,92
<i>Eficiency Full Load</i>	94,5%
$\frac{3}{4}$ Load	95,0%
$\frac{1}{2}$ Load	94,8%

**Table 2. Specifications of Three-Phase Induction Motor 011P-109B 150 HP**

Model	54DSO17BD
RPM-FL	2970
Voltage	380V
AMP-FL	191
HP	150
frequency	50 Hz
<i>Power Factor Full Load</i>	0.95
$\frac{3}{4}$ Load	0,95
$\frac{1}{2}$ Load	0,94
<i>Eficiency Full Load</i>	94,6%
$\frac{3}{4}$ Load	94,9%
$\frac{1}{2}$ Load	94,5%

**Table 3. Average Monitoring Data for BOC (Basic Operation Care) from July 2024 to September 2024 011P-109B 125HP**

No.	On average each month	Three-Phase Voltage			Rotor Speed	Measurement	
		R-S	S-T	T-R		Ampere	cos phi
1.	Jul-24	380	379	379	2976,4	122,9	0.94
2.	Aug-24	380	379,8	379	2976,0	125,0	0.94
3.	Sep-24	380	378	380	2975,6	126,6	0.94
4.	Oct-24	379,3	379	379	2976,0	130,0	0.94
5.	Nov-24	379,8	379,8	379	2977,3	121,4	0.94
6.	Dec-24	380	378	380	2979,5	113,9	0.94

**Table 4. Average Monitoring Data for BOC (Basic Operation Care) in September-November 011P-109B 150HP**

No.	On average each month	Three-Phase Voltage			Rotor Speed	Measurement	
		R-S	S-T	T-R		Ampere	R-S
1.	Jun-25	380	379	379	2979,6	130,0	0.95
2.	Jul-25	380	379,8	379	2979,6	130,0	0.95
3.	Aug-25	379,9	378	379	2979,6	130,0	0.95
4.	Sep-25	380	379	379	2982,9	111,0	0.95
5.	Oct-25	379	379,6	379	2977,3	128,3	0.95
6.	Nov-25	380	378	380	2976,9	148,0	0.95

**Calculation Results for Power & Efficiency of 125HP motor**

The nameplate data is used as a reference to calculate input power, output power, and efficiency at maximum load:

· July 2024

Input power calculation

$$P_{input} = \sqrt{3} \times V \times I \times \cos \phi \tag{6}$$

$$P_{input} = \sqrt{3} \times 379,3 \times 122,9 \times 0,94 \tag{7}$$

$$P_{input} = 75.896 \text{ Watt} \tag{8}$$

Slip Calculation:

$$s = \frac{ns-nr}{ns} \times 100\% \tag{9}$$

$$s = \frac{3000-2976,4}{3000} \times 100\% \tag{10}$$

$$s = 0,8 \%$$

Torque Calculation:

$$T = \frac{P_{mech} \times 60}{2\pi \times nr} \tag{11}$$

$$T = \frac{75.896 \times 60}{2(3,14) \times 2976,4} \tag{12}$$

$$T = 243,6 \text{ Nm} \tag{13}$$

Load Factor Calculation:

$$\text{Load Factor} = \frac{I}{I_r} \times \frac{V}{V_r} \tag{14}$$

$$LF = \frac{122,9}{161} \times \frac{379,3}{380} \tag{15}$$

$$LF = 0,76$$

Motor Efficiency:

$$Efisiensi \text{ Motor} = \eta = \frac{Pr \times \text{Load Factor}}{Pi} \times 100\% \tag{16}$$

$$\eta = \frac{93.212,5 \times 0,76}{75.896} \times 100\% \tag{17}$$

$$\eta = 93,3\% \tag{18}$$

Based on the above calculations, the following data can be generated:

**Table 5. Efficiency Calculation Analysis for Motor 011P-109B 125HP**

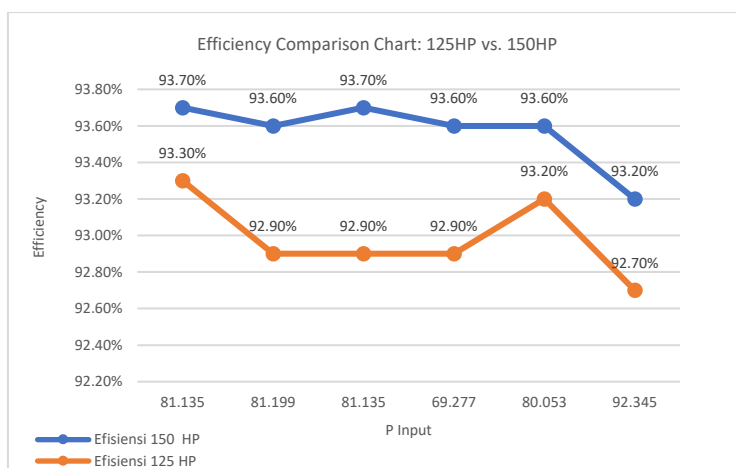
No.	Month	Pin (Watt)	Slip (%)	Torque (Nm)	Load Factor	Pout (Watt)	Loss	Efficiency
1.	Jul-24	75.896	0,8	243,6	0,76	70.811	5.085	93,30%
2.	Aug-24	77.254	0,8	248	0,77	71.769	5.485	92,90%
3.	Sep-24	78.181	0,8	251	0,78	72.630	5.551	92,90%
4.	Oct-24	80.239	0,8	257,6	0,8	74.542	5.697	92,90%
5.	Nov-24	75.009	0,7	240,7	0,75	69.908	5.101	93,20%
6.	Dec-24	70.338	0,68	225,54	0,7	65.203	5.135	92,70%

**Table 6. Efficiency Calculation Analysis of Motor 011P-109B 150HP**

No.	Month	Pin (Watt)	Slip (%)	Torque (Nm)	Load Factor	Pout (Watt)	Loss	Efficiency
1.	Jun-25	81.135	0,68	260	0,68	76.023	5.112	93,70%
2.	Jul-25	81.199	0,68	260	0,68	76.002	5.197	93,60%
3.	Aug-25	81.135	0,68	260	0,68	76.023	5.112	93,70%
4.	Sep-25	69.277	0,57	259	0,58	64.843	4.434	93,60%
5.	Oct-25	80.053	0,75	256	0,67	74.930	5.123	93,60%
6.	Nov-25	92.345	0,77	225,54	0,77	86.066	6.279	93,20%

**Table 7. Comparison of 125HP and 150HP engines**

Parameter	125HP	150HP	Lebih unggul
<b>Pin Avg</b>	76.153	80.857	125HP
<b>Eff Avg</b>	92,98%	93,57%	150HP
<b>Pout Avg</b>	70.811	75.648	150HP
<b>Loss Avg</b>	5.342	5.209	150HP
<b>Load Factor</b>	0,75	0,68	125HP
<b>Torsi rata-rata</b>	244	253	150HP



**Figure 1. Efficiency Comparison Chart**

Efficiency Comparison Chart: 125HP vs. 150HP

- The 150 HP motor has a higher average efficiency (93.57% vs. 92.98%) but it also consumes more input power (80,857 Watts vs. 76,153 Watts) and operates at a lower load factor (68% vs. 75%), indicating oversizing.
- The 125 HP motor can reach peak efficiency at  $\frac{3}{4}$  load (95%), in line with the motor's average operational data showing an average load of 76%, which is very close to the optimal point ( $\frac{3}{4}$  = 75%). If it is too often close to full load (Nov-Oct 80% LF), it can lead to heat risk and short life.
- In November 2025, it produced >85kW output, which exceeded the capacity of the 125HP motor, so only 150HP could handle the peak load of >85kW.

**Comparing the calculation results with IEC 60034-30-1**

According to IEC 60034-30-1:2014, the efficiency class of a three-phase squirrel cage, 2-pole, 50Hz, 380-420V induction motor can be determined based on the minimum efficiency at full load (100%).

**Table 8. IEC 60034-30-1 Efficiency Standard**

Output kW	IE1				IE2				IE3				IE4			
	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole
0.12	45.0	50.0	38.3	31.0	53.6	59.1	50.6	39.8	60.8	64.8	57.7	50.7	66.5	69.8	64.9	62.3
0.18	52.8	57.0	45.5	38.0	60.4	64.7	56.6	45.9	65.9	69.9	63.9	58.7	70.8	74.7	70.1	67.2
0.20	54.6	58.5	47.6	39.7	61.9	65.9	58.2	47.4	67.2	71.1	65.4	60.6	71.9	75.8	71.4	68.4
0.25	58.2	61.5	52.1	43.4	64.8	68.5	61.6	50.6	69.7	73.5	68.6	64.1	74.3	77.9	74.1	70.8
0.37	63.9	66.0	59.7	49.7	69.5	72.7	67.6	56.1	73.8	77.3	73.5	69.3	78.1	81.1	78.0	74.3
0.40	64.9	66.8	61.1	50.9	70.4	73.5	68.8	57.2	74.6	78.0	74.4	70.1	78.9	81.7	78.7	74.9
0.55	69.0	70.0	65.8	56.1	74.1	77.1	73.1	61.7	77.8	80.8	77.2	73.0	81.5	83.9	80.9	77.0
0.75	72.1	72.1	70.0	61.2	77.4	79.6	75.9	66.2	80.7	82.5	78.9	75.0	83.5	85.7	82.7	78.4
1.1	75.0	75.0	72.9	66.5	79.6	81.4	78.1	70.8	82.7	84.1	81.0	77.7	85.2	87.2	84.5	80.8
1.5	77.2	77.2	75.2	70.2	81.3	82.8	79.8	74.1	84.2	85.3	82.5	79.7	86.5	88.2	85.9	82.6
2.2	79.7	79.7	77.7	74.2	83.2	84.3	81.8	77.6	85.9	86.7	84.3	81.9	88.0	89.5	87.4	84.5
3	81.5	81.5	79.7	77.0	84.6	85.5	83.3	80.0	87.1	87.7	85.6	83.5	89.1	90.4	88.6	85.9
4	83.1	83.1	81.4	79.2	85.8	86.6	84.6	81.9	88.1	88.6	86.8	84.8	90.0	91.1	89.5	87.1
5.5	84.7	84.7	83.1	81.4	87.0	87.7	86.0	83.8	89.2	89.6	88.0	86.2	90.9	91.9	90.5	88.3
7.5	86.0	86.0	84.7	83.1	88.1	88.7	87.2	85.3	90.1	90.4	89.1	87.3	91.7	92.6	91.3	89.3
11	87.6	87.6	86.4	85.0	89.4	89.8	88.7	86.9	91.2	91.4	90.3	88.6	92.6	93.3	92.3	90.4
15	88.7	88.7	87.7	86.2	90.3	90.6	89.7	88.0	91.9	92.1	91.2	89.6	93.3	93.9	92.9	91.2
18.5	89.3	89.3	88.6	86.9	90.9	91.2	90.4	88.6	92.4	92.6	91.7	90.1	93.7	94.2	93.4	91.7
22	89.9	89.9	89.2	87.4	91.3	91.6	90.9	89.1	92.7	93.0	92.2	90.6	94.0	94.5	93.7	92.1
30	90.7	90.7	90.2	88.3	92.0	92.3	91.7	89.8	93.3	93.6	92.9	91.3	94.5	94.9	94.2	92.7
37	91.2	91.2	90.8	88.8	92.5	92.7	92.2	90.3	93.7	93.9	93.3	91.8	94.8	95.2	94.5	93.1
45	91.7	91.7	91.4	89.2	92.9	93.1	92.7	90.7	94.0	94.2	93.7	92.2	95.0	95.4	94.8	93.4
55	92.1	92.1	91.9	89.7	93.2	93.5	93.1	91.0	94.3	94.6	94.1	92.5	95.3	95.7	95.1	93.7
75	92.7	92.7	92.6	90.3	93.8	94.0	93.7	91.6	94.7	95.0	94.6	93.1	95.6	96.0	95.4	94.2
90	93.0	93.0	92.9	90.7	94.1	94.2	94.0	91.9	95.0	95.2	94.9	93.4	95.8	96.1	95.6	94.4
110	93.3	93.3	93.3	91.1	94.3	94.5	94.3	92.3	95.2	95.4	95.1	93.7	96.0	96.3	95.8	94.7
132	93.5	93.5	93.5	91.5	94.6	94.7	94.6	92.6	95.4	95.6	95.4	94.0	96.2	96.4	96.0	94.9
160	93.8	93.8	93.8	91.9	94.8	94.9	94.8	93.0	95.6	95.8	95.6	94.3	96.3	96.6	96.2	95.1
200	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.3	95.4
250	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.5	95.4
315	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
355	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
400	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
450	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
500-1000	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4

From the table above, motors with a capacity of 125HP (93.21kW) fall within the *range* of 90-100 kW, while those with a capacity of 150HP (111.86Kw) fall within the *range* of 100-125kW. This results in the following efficiency limits:

Motor	P (kW)	Class	Min $\eta$ (IE2)	Min $\eta$ (IE3)	Min $\eta$ (IE4)
125 HP	93.21	90–100 kW	93.5%	94.5%	95.4%
150 HP	111.86	100–125 kW	93.8%	94.8%	95.6%

According to the data in the 125HP motor factory specifications, the FL efficiency is 94.5%, which falls into the IE3 category ( $\geq 94.5\%$ ), but if it is IE4 (requires 95.4%). Meanwhile, the 150HP motor with an efficiency of FL 94.6% falls under the IE2+ category, approaching IE3 ( $\geq 94.8\%$ ), but falling short by 0.2%.

**Table 9. Efficiency Comparison Data for Motors in the Field with IEC 60034-30-1 Efficiency Standards**

Motor	Daya (kW)	Range IEC	$\eta$ FL (Spesifikasi)	Kelas IEC (Spesifikasi)	$\eta$ Rata (Operasional)	Kelas (Operasional)
125 HP	93.21	90–100 kW	94.5%	IE3	93.15%	IE2 ( <i>borderline</i> )
150 HP	111.86	100–125 kW	94.6%	IE2+ (butuh $\geq 94.8\%$ untuk IE3)	93.63%	IE2+ / Mendekati IE3

From the data above, the 150HP motor does not meet IEC standards in terms of factory specifications, but its operational performance is better than that of the 125HP motor. Meanwhile, the 125HP motor operates at its optimal point (75-80%), but its actual efficiency is lower than the

factory value. This is because there are indications of performance degradation that could be caused by worn bearings, misalignment, or dirt on the coil.

## CONCLUSIONS

Based on efficiency calculations, the 150HP induction motor has superior operational efficiency performance compared to the 125HP motor, with an average efficiency of 93.63% compared to 93.15%, as well as lower power loss of 4.8kW compared to the 125HP motor, which has a power loss of 5.01kW. Although the 125HP motor operates at an average load factor of 75.8%, which is close to the optimal load point (3/4 load), its actual efficiency is 1.35% lower than the manufacturer's specification (94.5%). This indicates a performance degradation factor, which may be caused by voltage imbalance, bearing wear, misalignment, or dirt accumulation in the cooling system. Comparison results with the IEC 60034-30-1:2014 standard show that both motors are technically classified as IE2 (High Efficiency) to IE2+ (Borderline IE3). The 125HP motor meets the minimum IE3 Class limit at full load ( $\eta = 94.5\% \geq 94.5\%$ ), while the 150HP motor ( $\eta = 94.6\%$ ) does not reach the IE3 threshold (minimum 94.8%) for the 100-125kW power range. Therefore, it is categorized as IE2. However, the operational performance of the 150HP motor at partial load (58%-77%) is consistent and approaches the characteristics of an IE3 class motor.

## BIBLIOGRAPHY

- Alam, M. M. (2022). Analisis Efisiensi Motor Induksi Tiga Fasa Pada Kipas Sentrifugal di PT. *Kimia Farma Tbk. Plant Semarang*. Skripsi Pada Universitas Semarang, Semarang.
- Barus, R. W. (2022). *Analisa Efisiensi Daya Motor Induksi 3 Fasa Squirrel Cage 250 Kw Dengan Inverter Sebagai Pengatur Speed Di PT Socimas*. Universitas Muhammadiyah Sumatera Utara.
- Novianto, D. (2022). *Analisis Efisiensi Motor Induksi Tiga Fasa Sebagai Penggerak Vacuum Di PT. Pindo Deli Perawang*. Universitas Lancang Kuning.
- Prawira, S. H. (2022). *Analisis Efisiensi Daya Motor 3 Phase Sebagai Penggerak Boiler Penghisap Abu PT Industri Invilon Sagita*. Universitas Pembangunan Panca Budi.
- Septianto, F., Widodo, A., & Sinaga, N. (2015). Analisa penurunan efisiensi motor induksi akibat cacat pada cage ball bantalan. *Jurnal Teknik Mesin*, 3(4), 397-407. <https://ejournal3.undip.ac.id/index.php/jtm/article/view/10935>
- Theraja, B. L., & Theraja, A. K. (2005). *A Textbook of Electrical Technology*. Chand & Company Ltd.
- Wijaya, M. (2001). *Dasar-Dasar Mesin Listrik*. Djambatan.