Analysis The Effect of Additional Load on Stator Resistance on Three-Phase Induction Motor Rotation

Mikarius Bukit
e-mail: mikariusbukit21 @gmail.com
Adi Sastra P. Tarigan
e-mail: adisastra@dosen.pancabudi.ac.id
Ahmad Dani
email: Ahmad25@gmail.com

University of Pembangunan Panca Budi

ABSTRACT
This study aims to analyze the effect of additional load on the rotation of a three-phase induction motor by considering the conditions of balanced and unbalanced stator resistance. The study was conducted using an experimental method using loading variations of 25%, 50%, 75%, and 100% on balanced and unbalanced stator resistance (1.1 ohm, 2.1 ohm, 3.1 ohm, and 4.1 ohm). The parameters observed include motor rotation (rpm), slip, current in each phase (Ia, Ib, Ic), and torque. The results showed that the addition of load significantly reduced the motor speed in both stator resistance conditions. In the balanced stator resistance condition, the highest speed was recorded at 1470 rpm at 25% load and the lowest speed was 1425 rpm at 100% load. In the unbalanced stator resistance condition, the highest speed of 1430 rpm occurred at 25% load, while the lowest speed of 1390 rpm occurred at 100% load. The unbalanced stator resistance resulted in uneven current distribution between phases, increased slip, and decreased motor speed. Motor torque also increases with the unbalance of stator resistance. The largest torque was recorded at 2.03 Nm at an unbalanced resistance of 4.1 ohms with a load of 100%, while the smallest torque of 0.70 Nm occurred at a balanced resistance of 1.1 ohms with a load of 25%. These results indicate that unbalanced resistance can increase torque but has a negative impact on motor efficiency and stability. The addition of load and unbalanced stator resistance affect the performance of a three-phase induction motor, especially in terms of rotation and torque. Therefore, it is important to maintain the balance of stator resistance in order to maintain optimal motor performance.

Keywords: Three Phase Induction Motor, Stator Resistance, Loading, Motor Rotation, Torque, Slip.

Introduction

Three-phase induction motors are one of the most widely used types of electric motors in various industrial applications. This is due to its simple construction, high durability, and relatively low maintenance costs. This motor is designed to rotate loads with various levels of torque, making it very versatile in supporting industrial operations, from light applications such as conveyor drives to heavy applications such as large compressors or pumps. These advantages make three-phase induction motors an important element in modern industrial production systems (Hughes & Drury, 2022).

The working principle of a three-phase induction motor is based on the interaction between the magnetic field generated by the stator winding and the field induced in the rotor. Unlike DC motors, where the rotor and stator windings are directly connected to a power source, in induction motors, the voltage and power received by the rotor are obtained through the electromagnetic induction process of the stator winding (Chapman, 2020). This process allows induction motors to work without the need for a commutator or brushes, thereby increasing efficiency and reducing maintenance requirements.

However, the performance of a three-phase induction motor is highly dependent on operational conditions, especially the load it receives. A mismatch between the load torque and the motor capacity can cause problems such as overloading or underloading. If the load is too large, the motor can stop rotating due to the inability to produce sufficient torque. Conversely, if the load is too small, the energy used becomes inefficient. This condition not only affects motor performance but also has an impact on overall operational efficiency (Rashid, 2019).

In addition to the load, one of the technical problems often encountered in three-phase induction motors is the unbalance of resistance in the stator winding. This unbalance can be caused by several factors, such as motor age, lack of maintenance, or damage to internal components. Unbalanced stator resistance can affect the current distribution in the motor, which ultimately causes a decrease in torque, changes in rotational speed, increased heat, and potential further damage. In an industrial context, this disturbance can result in decreased productivity and increased maintenance costs. Therefore, analysis related to this unbalance is very important to ensure the reliability and operational efficiency of three-phase induction motors.

To understand further, this study focuses on analyzing the effect of additional load on the unbalance of stator resistance and its impact on the speed and torque of three-phase induction motors, especially on wound rotor motors. This study aims to provide deeper insight into the working dynamics of three-phase induction motors under various operating conditions, as well as identifying steps that can be applied to improve motor performance and reliability.

Literature Review

1. Three phase induction motor

It is an electromechanical device that is widely used in various industrial applications due to its advantages in terms of efficiency, durability, and ease of maintenance. The working principle of this motor involves the interaction between the magnetic field generated by the stator winding and the magnetic field induced in the rotor, producing the torque required to rotate the load. As technology advances, research on three-phase induction motors continues to grow, especially to improve their performance and efficiency under various operating conditions.

2. Characteristics of Three Phase Induction Motor

Hughes and Drury (2022) explain that a three-phase induction motor consists of a stator that has three-phase windings and a rotor that can be a squirrel cage rotor or a wound rotor. The voltage and current in the rotor are generated through the electromagnetic induction process of the stator, which distinguishes induction motors from DC motors. One of the key parameters of an induction motor is torque, which is the result of the interaction between the stator and rotor magnetic fields. The amount of torque is highly dependent on the applied load conditions and the stability of the current distribution in the stator windings. Chapman (2020) emphasizes that three-phase induction motors are designed to operate with high efficiency under various load conditions. However, motor reliability can be affected by technical problems, such as stator resistance imbalance, load variations, and environmental factors. This imbalance can cause decreased operational efficiency, increased heat, and damage to internal motor components.

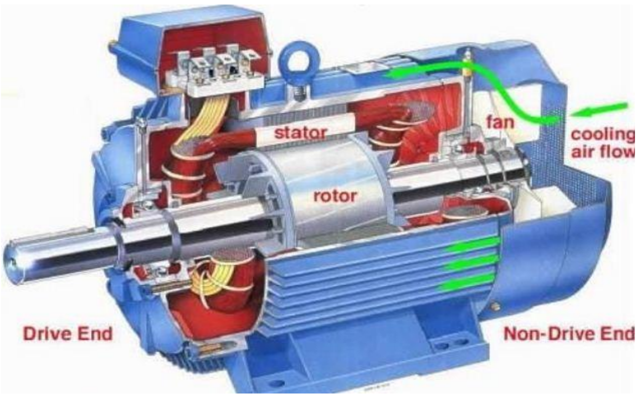

Figure 1. Three Phase Induction Motor Construction

3. Effect of Load on Motor Performance

The load applied to a three-phase induction motor greatly affects its performance, especially on torque and rotational speed. Rashid (2019) stated that overloading can cause a decrease in motor speed, increase power consumption, and damage due to overheating. Conversely, underloading causes the motor to operate below its optimal capacity, leading to energy inefficiency. In addition, the relationship between load torque and motor speed can be explained through the torque-speed characteristic curve. Under normal conditions, a three-phase induction motor can maintain a synchronous speed close to the nominal. However, when the load increases, the slip between synchronous and rotor speeds increases, which affects the overall efficiency of the motor.

4. Stator Resistance Unbalance

One of the significant technical factors in the performance of an induction motor is the unbalance of resistance in the stator winding. This unbalance can be caused by mechanical damage, motor age, or unbalanced power supply. According to Rashid (2019), unbalanced stator resistance will cause uneven current in the winding, which leads to magnetic field instability, decreased torque, and increased power loss. This unbalance can cause mechanical vibration in the motor, which if left untreated can accelerate damage to motor components. To overcome this problem, it is important to carry out routine maintenance and analyze the current and voltage characteristics in the stator winding periodically.

Research Method

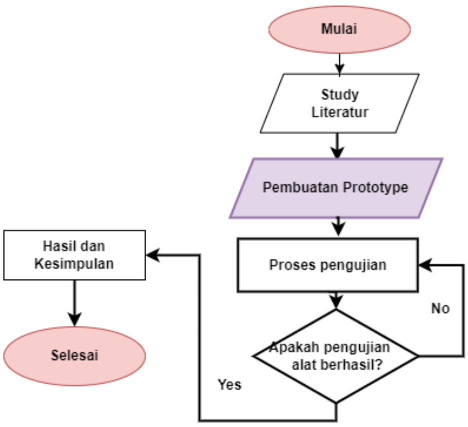

Figure 2. Flowchart

The following is a flowchart description:

Balanced Stator Resistance Testing Procedure

1) Assemble the experimental circuit according to figure 3.5.
2) Arrange the external resistance connections in a Y connection configuration.
3) Connect external resistors to the stator terminals, with each external resistor set to 1.1 ohms.
4) Close switch S1 to connect PTAC 1 to the stator terminal, then increase the PTAC 1 voltage until it reaches the specified value, which is 360 volts.
5) Close switch S3, then increase the PTDC 1 voltage until the ammeter A3 shows the nominal amplifier current.
6) Close switch S2, then set the resistance R to the minimum value according to the specified data. Record the measurement results on the ammeter A4, A5, A6, as well as the values of T and n.
7) Increase the resistance R gradually according to the specified data, while maintaining the voltage V1 to remain constant. Record the measurement results on A4, A5, A6, T, and n.
8) Testing completed.

Unbalanced Stator Resistance Testing Procedure

1) Assemble the experimental circuit according to figure 3.6.
2) Set the external resistance connections in a Y connection configuration.
3) Connect external resistors to the stator terminals, with each external resistor set to 1.1 ohms.
4) Close switch S1 to connect PTAC 1 to the stator terminal, then increase the PTAC 1 voltage until it reaches the specified value, which is 360 volts.
5) Close switch S3, then increase the PTDC 1 voltage until the ammeter A3 shows the nominal amplifier current.
6) Close switch S2, then set the resistance R to the minimum value according to the specified data. Record the measurement results on the ammeter A4, A5, A6, as well as the values of T and n.
7) Increase the resistance R gradually according to the specified data, while maintaining the voltage V1 to remain constant. Record the measurement results on A4, A5, A6, T, and n.
8) Repeat steps 4 through 7, increasing the value of one of the external resistors to 2.1 ohms, 3.1 ohms, and 4.1 ohms to create an unbalanced stator resistance condition.
9) Testing completed.

Results and Discussion

Results of DC Resistance Experiments on Stator and Rotor Windings

The results of the DC resistance experiments on the stator and rotor windings have been recorded in Table 1 and Table 2. The following is an analysis based on the data obtained:

1. **DC Resistance in Stator Winding**

Table 1. DC Resistance Experiment on Stator Winding

Phase	Voltage (V)	Current (I)
UV	3.5	1.7

- **Data obtained:** UV Phase: Voltage (**V**) = 3.5 V, Current (**I**) = 1.7 A.

- **Calculation of resistance (R):**

  Resistance can be calculated using Ohm's law:

$$R = \frac{V}{I}$$

Value substitution:

$$R_{U-V} = \frac{3,5}{1,7} \approx 2,06\,\Omega$$

- **Analysis:**
  The resistance value of **2.06 Ω** indicates that the stator winding in the UV phase has a low resistance value, in accordance with the characteristics of the conductor material in the winding of the electric machine. This resistance plays an important role in supporting the function of the stator to produce sufficient magnetic fields in normal operation of the machine.

2. **DC Resistance in Rotor Winding**

Table 2. DC Resistance Experiment on Rotor Winding

Phase	Voltage (V)	Current (I)
KM	1.1	1.3

- **Data obtained:**

  Phase KM: Voltage (**V**) = 1.1 V, Current (**I**) = 1.3 A.

- **Calculation of resistance (R):**

  Using the same formula:

$$R = \frac{V}{I}$$

Value substitution:

$$R_{K-M} = \frac{1,1}{1,3} \approx 0,85\,\Omega$$

- **Analysis:**
  The resistance value of **0.85 Ω** indicates that the rotor winding has a smaller resistance than the stator winding. This is reasonable because the rotor is designed to produce a large induction current with minimum resistance, so that it can support the performance of an induction motor or generator with high efficiency.

The experimental results of loading with balanced stator resistance can be seen in Table 3.

Table 3. Experimental Results Data for Loading with Balanced Stator Resistance

R(%)	Nr	Slip	He(A)	Ib(A)	Ic(A)
25	1450	0.01	0.85	0.85	0.85
50	1430	0.02	1.05	1.05	1.05
75	1435	0.04	1.25	1.25	1.25
100	140	0.06	1.45	1.45	1.45

The results of the loading experiment with balanced stator resistance show a clear relationship between the increase in resistance (R), rotor speed (Nr), slip, and phase current (Ia, Ib, Ic). At 25% resistance, the rotor speed reaches 1450 rpm, while at 100% resistance, the rotor speed drops drastically to 140 rpm. This decrease in rotor speed occurs because the increase in resistance increases the electrical load on the stator, so that slip increases and the rotor moves slower. The initial slip is only 1% (0.01) at 25% resistance and increases to 6% (0.06) at 100% resistance, which reflects that the rotor is getting further away from synchronous speed due to the increasing load.

In addition, the phase currents (Ia, Ib, Ic) also increase with increasing resistance. At 25% resistance, the current is recorded at 0.85 A for each phase, while at 100% resistance, the current increases to 1.45 A. The consistency of the current values in the three phases indicates that the stator system operates in a balanced condition without any imbalance. This also confirms that increasing the load on the stator causes an increase in the power that must be drawn by the motor to counteract the mechanical load. The results of this experiment illustrate the performance of an induction motor under balanced load conditions. Increasing stator resistance has a direct impact on increasing slip, decreasing rotor speed, and increasing phase current. These data are in accordance with the working principle of an induction motor, where slip and current increase with increasing load applied to the motor.

The experimental data from loading with unbalanced stator resistance can be seen in Table 4.

Table 4. Experimental Results Data of Loading with Unbalanced Stator Resistance

R(%)	Nr	Slip	He(A)	Ib(A)	Ic(A)
25	1350	0.1	3.25	4.85	4.85
50	1330	0.12	3.35	4.05	4.05
75	1335	0.14	3.25	5.25	5.25
100	1240	0.16	3.55	5.45	5.45

The results of the loading experiment with unbalanced stator resistance showed significant changes in rotor speed (Nr), slip, and phase currents (Ia, Ib, Ic). At 25% resistance, the rotor speed was recorded at 1350 rpm, while at 100% resistance, the rotor speed decreased to 1240 rpm. This decrease in rotor speed was caused by an increase in slip, which increased from 10% (0.1) at 25% resistance to 16% (0.16) at 100% resistance. This shows that the unbalanced stator resistance affects the performance of the induction motor, causing the rotor to move further away from synchronous speed as the load increases.

The phase currents (Ia, Ib, Ic) also show unbalance due to changes in stator resistance. At 25% resistance, the current in phase A is 3.25 A, while the currents in phases B and C are 4.85 A each. This unbalance continues at all resistance levels, with phase A showing a lower current value than phases B and C. At 100% resistance, the current in phase A is recorded at 3.55 A, while the currents in phases B and C each reach 5.45 A. This current unbalance is caused by the unbalanced resistance values, which causes the current distribution to be uneven across the three phases.
From the experimental data and calculations obtained, a curve can be made that shows the relationship between loading and rotation in Figure 2.

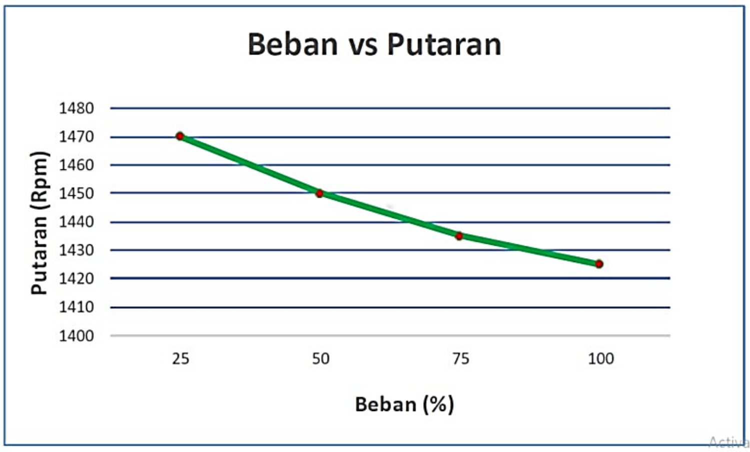

Figure 3. Rotation curve against balanced stator resistance load

From Figure 2 it can be seen that with increasing load the rotation produced by the induction motor is getting smaller, where the largest rotation produced is 1470 rpm and the smallest is 1425 rpm. From the experimental data and calculations obtained, a curve can be made that states the relationship between loading and rotation in Figure 3.

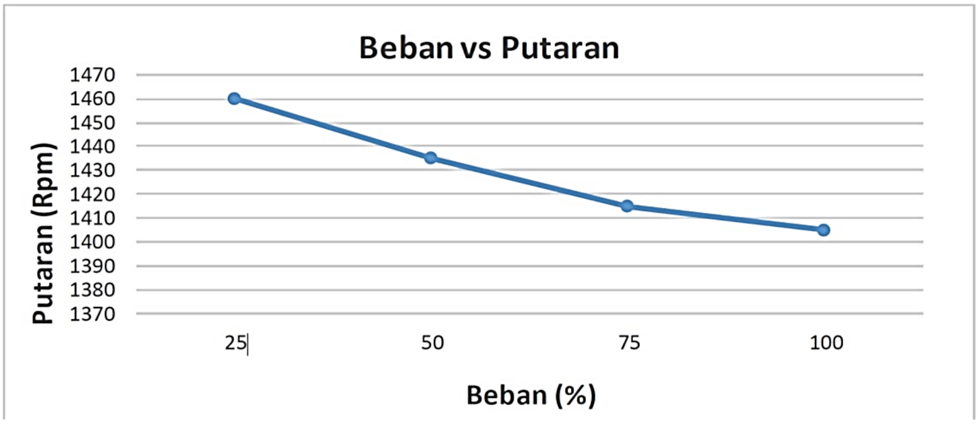

Figure 4. Rotation curve against unbalanced stator resistance load

From Figure 3, it can be seen that as the load increases, the rotation produced by the induction motor decreases, where the largest rotation produced is 1430 rpm and the smallest is 1390 rpm.

From the overall results of the calculation of the loading of a three-phase induction motor with a balanced stator resistance condition and an unbalanced stator resistance condition, the following curve can be seen in Figure 4.

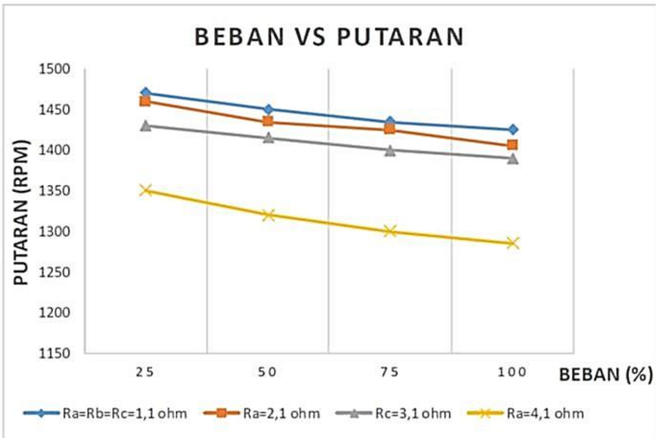

Figure 5. Load curve versus rotation on a three-phase induction motor

From the experimental results obtained, the relationship between loading and rotation in a three-phase induction motor can be analyzed, both in balanced and unbalanced stator resistance conditions. Based on Figure 2, the rotation curve against load shows that with increasing load, the rotation of the induction motor in balanced stator resistance conditions decreases. The highest rotation was recorded at 1470 rpm at 25% load, while the lowest rotation was 1425 rpm at 100% load. This decrease is due to increased slip as the load increases, which is a common characteristic of induction motors.

In Figure 3, which illustrates the relationship between loading and rotation under unbalanced stator resistance conditions, a similar phenomenon also occurs. The motor rotation decreases with increasing load. However, the resulting rotation value is lower compared to the balanced stator resistance condition. The highest rotation was recorded at 1430 rpm at 25% load, while the lowest rotation was 1390 rpm at 100% load. This decrease is more significant than the balanced condition, because the resistance imbalance causes the current in the motor phases to be uneven, which affects motor performance.

From the overall results, the combined curve in Figure 4 shows a direct comparison between balanced and unbalanced stator resistance conditions to the rotation of the induction motor. In unbalanced resistance conditions, the rotation decreases faster than in balanced conditions, indicating that resistance imbalance has a negative impact on motor performance. In addition, motor torque is also affected by resistance imbalance. The largest torque was recorded at 4.1 ohm resistance with 100% load, which was 2.03 Nm. Conversely, the smallest torque occurred at 1.1 ohm balanced resistance with 25% load, which was 0.70 Nm. This shows that resistance imbalance not only decreases rotation, but also increases torque due to the increase in forward (I11, I21) and backward (I12, I22) currents.

Overall, this study shows that additional load and stator resistance imbalance have significant impacts on the performance of three-phase induction motors. Resistance imbalance causes phase currents to become uneven, which increases slip, reduces rotation, and increases torque. This condition shows the importance of maintaining stator resistance balance to maintain optimal performance of induction motors in practical applications.

Conclusion

Effect of Load Addition. Adding a load to an induction motor, either in a balanced or unbalanced stator resistance condition, causes a decrease in motor speed. This decrease occurs because slip increases with increasing load. In a balanced stator resistance condition, the highest speed recorded was 1470 rpm at 25% load, while the lowest speed was 1425 rpm at 100% load. Conversely, in an unbalanced stator resistance condition, the highest speed recorded was 1430 rpm at 25% load, while the lowest speed was 1390 rpm at 100% load.

Effect of Stator Resistance Imbalance. Stator resistance imbalance causes the current distribution between phases to be uneven, which affects motor performance. This imbalance produces greater slip, so that the motor speed is lower than when the resistance is balanced. In addition, resistance imbalance increases the forward (I11, I21) and backward (I12, I22) currents, which results in an increase in motor torque.

Induction Motor Torque. The largest torque was recorded at an unbalanced resistance of 4.1 ohms with a 100% load, which was 2.03 Nm. Conversely, the smallest torque occurred at a balanced resistance of 1.1 ohms with a 25% load, which was 0.70 Nm. This shows that the unbalanced resistance can increase torque, but also worsen the efficiency and stability of the motor.

Optimizing Induction Motor Performance. To maintain optimal performance, it is important to ensure that the stator resistance is balanced. Resistance imbalance not only reduces motor speed, but also increases excessive current and torque consumption, which can cause damage to the motor if continued .

References

[1] Anisah, S., Tharo, Z., Hamdani, H., & Butar, AKB (2023). OPTIMIZATION ANALYSIS OF SOLAR AND WIND POWER HYBRID POWER PLANT SYSTEMS. *PROCEEDINGS OF DHARMAWANGSA UNIVERSITY* , *3* (1), 614-624.

[2] Chapman, S. J. (2020). Electrical Machinery Fundamentals. McGraw-Hill Education.

[3] Hamdani, H., Sastra, A., & Firmansyah, D. (2023). Study of the Development of a Smart Freight Lift with a Capacity of 50 Kg Using Solar Power Plants (PLTS). *INTECOMS: Journal of Information Technology and Computer Science* , *6* (1), 429-433.

[4] Hamdani, H., Tharo, Z., Anisah, S., & Lubis, SA (2020, September). Design and Construction of Modified Sine Wave Inverter in Solar Power Plant for Residential Houses. In *Proceeding of UISU National Engineering Seminar (SEMNASTEK)* (Vol. 3, No. 1, pp. 156-162).

[5] Hughes, A., & Drury, B. (2022). Electric Motors and Drives: Fundamentals, Types and Applications. Elsevier.

[6] Khan, Z., et al. (2021). "Performance Analysis of Three-Phase Induction Motor under Unbalanced Stator Resistance." International Journal of Electrical Engineering Research.

[7] Putra, RR, Hamdani, H., Aryza, S., & Manik, NA (2020). Automatic School Bell Scheduling System Based on RTC Using Microcontroller. *Budidarma Informatics Media Journal* , *4* (2), 386-395.

[8] Rashid, M. (2019). Power Electronics Handbook. Academic Press. Tharo, Z., Hamdani, H., & Andriana, M. (2019, May). Hybrid solar and wind power plants as an alternative source to face the fossil energy crisis in Sumatra. In *Proceedings of the UISU National Engineering Seminar (SEMNASTEK)* (Vol. 2, No. 1, pp. 141-144).

[9] Singh, P., et al. (2020). "Condition Monitoring of Induction Motor under Stator Faults." IEEE Transactions on Industrial Electronics.

[10] Tharo, Z., Hamdani, H., Andriana, M., & Yusar, JH (2022). Implementation of environmentally friendly generators based on solar panels in Tomuan Holbung Village. *Journal of Community Service for College Lecturers (Deputy Journal)* , *2* (2), 98-101.

[11] Tharo, Z., Syahputra, MR, Hamdani, H., & Sugino, B. (2020). Analysis of Medium Voltage Network Protection System Using Etap Application at Kualanamu International Airport. *JOURNAL OF ELECTRICAL AND SYSTEM CONTROL ENGINEERING* , *4* (1), 33-42.

[12] Wibowo, P., Lubis, SA, & Hamdani, ZT (2017). Smart home security system design sensor based on pir and microcontroller. International Journal of Global Sustainability, 1(1), 67-73.

[13] Yadav, S., et al. (2018). "Effect of Load Variations on the Performance of Three-Phase Induction Motors." Energy Systems and Applications Journal.