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Voltage Control System for a 3-Phase Induction Generator Using PLC

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Abstract

Induction motors are commonly used in power generation systems due to their ease of maintenance and the fact that their primary power source comes from renewable energy. However, one of the key challenges faced in such systems is the instability of the voltage output, which is often affected by varying load conditions. The objective of this paper is to explore methods for stabilizing the voltage output of a 3-phase induction generator using a PLC-based control system. To achieve this, a single-phase inverter operating at 50 Hz frequency is employed to regulate the speed of the induction motor. The voltage stabilization of the 3-phase generator is managed through an inverter circuit. The inverter is responsible for controlling the input power, whether it is 3-phase AC or 1-phase AC, in order to regulate the output frequency. The control system is implemented using CX-Programmer, which facilitates the control of the induction motor's speed via the inverter. The system allows for a controllable frequency range from 5 Hz to 60 Hz, resulting in motor speeds ranging from 124 rpm to 1441 rpm.

Keywords: Generator, Induction Motor, PLC

1. Introduction

In today's industrial landscape, we see a significant shift towards advanced industries, ranging from small-scale to large-scale operations. To keep up with this progress, there is an increasing need for systems and equipment that exhibit high efficiency in order to enhance profitability (Wasono, 2011). In most industries, electrical-powered equipment, such as electric motors, is widely used, with induction motors being the most commonly employed type due to their numerous advantages. However, controlling the speed and torque of these motors remains a challenge, as they tend to exhibit instability in their performance under varying load conditions. Therefore, a robust control system is necessary to stabilize the output of the generator (Darwanto & Budianto, 2009) .

Generators often operate under varying loads, which can affect the motor speed, but adjusting the motor speed directly by changing the load is not always the most efficient method. Several methods exist for controlling motor speed, including adjusting the number of pole pairs and regulating the frequency (Haryanto, 2011) . One of the most effective ways to control the generator's performance is by regulating the frequency, which can be achieved through a Programmable Logic Controller (PLC). This method of speed regulation is particularly advantageous when compared to others, especially for induction motors, due to its simplicity and effectiveness. By utilizing readily available control equipment, assembling the system according to the pre-planned program becomes much easier (Hari & Bambang, 2004).

Therefore, the application of the Omron PLC Type CJ1M to regulate the speed of a 3-phase induction motor is expected to provide an efficient solution for controlling motor speed. This control system is anticipated to ensure effective management of the generator's performance, and its operation can be carried out directly and seamlessly (Marappung, 1998).

2. Material and methods

2.1. Three phase induction Motor

A 3-phase induction motor is an electrical device that converts electrical energy into mechanical energy, with the electrical input being supplied in the form of 3-phase alternating current (AC). The fundamental characteristic of a 3-phase induction motor is its ability to maintain a constant speed under both no-load and

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full-load conditions. However, the speed of the motor is inherently linked to the operating frequency, making it difficult to regulate without additional control mechanisms. In modern applications, the motor's speed can now be effectively controlled using frequency control systems (Rashid, 2006).

The construction of an induction motor generally consists of two primary components: the stator and the rotor. The stator is the stationary part of the motor, and it includes the motor housing, stator core, stator windings, bearings, and terminal box. On the other hand, the rotor is the rotating part of the motor, typically consisting of a squirrel-cage rotor and rotor shaft. In induction motors, there is no direct contact between the stator and rotor. These components are separated by a small air gap, eliminating the need for lubrication to prevent friction. The design of induction motors is simpler compared to DC motors because they do not require components such as a commutator and carbon brushes, resulting in reduced maintenance needs, focusing primarily on the mechanical aspects (Tharo, Siahaan, & Evalina, 2016) .

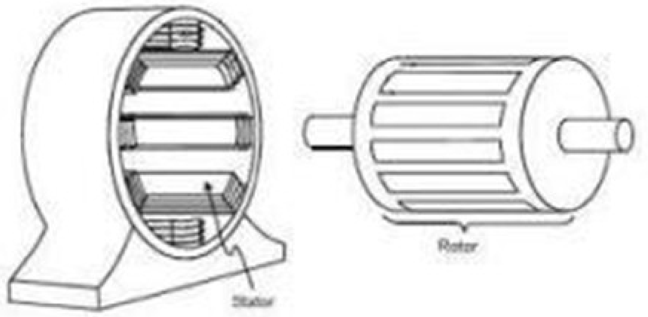

Figure 1. 3 Phase induction motor

An induction motor operates based on the principle of electromagnetic induction, where the stator windings induce a magnetic field that interacts with the rotor windings. When the stator windings of a 3-phase induction motor are connected to a 3-phase voltage source, they generate a rotating magnetic field. The flux lines induced by the stator windings cut through the rotor windings, generating an electromotive force (EMF) or induced voltage. Since the rotor windings form a closed loop, a current flows through them, and the rotor, being within the magnetic flux generated by the stator, experiences a Lorentz force. This force results in a torque that tends to rotate the rotor in the direction of the rotating stator magnetic field (Ardiansyah, 2012).

The rotating magnetic field produced by the stator interacts with the rotor conductors, inducing a current according to Faraday's Law of Induction. As a result, in accordance with Lenz's Law, the rotor will rotate to follow the rotating magnetic field of the stator. The relative difference in the speed between the stator's rotating field and the rotor's speed is referred to as "slip." When the load on the motor increases, the torque produced by the motor also increases, which in turn raises the induced current in the rotor. This leads to an increase in the slip between the stator's rotating field and the rotor speed. As a result, an increase in load causes a decrease in the rotor's speed (Dirgantara, 2010).

When a 3-phase voltage source is connected to the stator terminals, the stator windings produce a current that generates flux. The flux within the stator is typically constant, and the speed of the rotating magnetic field in the stator can be described using the following equation:

$$Ns = \frac{120.f}{P}$$

Where :
Ns =Speed Rotation of stator (rpm)
f = frequency (Hz)
P = Pole

The torque-speed characteristics of a 3-phase induction motor, as a function of time, power, and rotational speed, are shown in Figure 2. In the section AB of the graph, the torque is nearly proportional to the slip value, which represents the difference in speed due to the change in torque. Conversely, in section DE (when the motor is under load), the slip value continues to increase, but the torque gradually decreases, eventually causing the motor to stop. It is important to note that not all of the electrical energy absorbed by the induction motor is converted into useful mechanical energy; a portion of it is lost as heat. The mechanical power output

(W_mechanical) is equal to the electrical power input (W_electrical) minus the heat losses (W_heat). The efficiency (η) of the motor can be expressed as a function of mechanical and electrical power, as shown in Equation (Abubakar & Hardi, 2017) .

$$\eta = \frac{W_{mechanic}}{W_{electric}}$$

Where:
η = efficiency
W mechanic = mechanic power (watt)
W electric = electric power (watt)

2.2. Inverter

An inverter is an electrical device that converts direct current (DC) into alternating current (AC), with both voltage and frequency adjustable according to the application needs. The primary function of an inverter is to control the speed of an AC motor by varying the frequency of the input power, allowing for precise control over the motor's operation. This is particularly useful in industrial and automation systems where efficiency and adaptability are crucial for optimal performance (Darjad et al., 2008) .

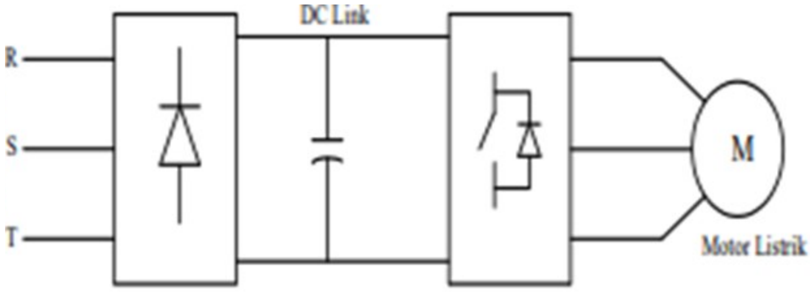

Figure 2. Main Components of an Inverter

The concept of an inverter involves the conversion of DC to AC by generating a waveform that alternates. However, it is important to note that the waveform produced by the inverter is not typically a pure sine wave; instead, it often takes the form of a square wave or other modified waveforms, depending on the inverter's design and the desired performance characteristics. The ability to generate variable frequency AC is essential for controlling the speed of induction motors in a voltage control system (Hardi, 2015a) .

The structure of an inverter consists of several key components: the converter, inverter, and control circuit. The first part is the converter circuit, which changes the commercial AC source into DC and eliminates ripple from the DC output (Hardi, 2015b). The second part is the inverter circuit, which converts DC to three-phase AC with adjustable frequencies. The third part is the control circuit, which regulates the main circuit. Together, these circuits form the inverter system. Inverters can be categorized based on their configuration and type, such as single-phase half-bridge or full-bridge inverters, and also by their voltage and frequency settings, which can either be constant or variable.

The inverter system generates alternating current (AC) by switching between two positions for switches S1 and S2 (Harahap, 2016). When the switches are in position A, the load receives positive voltage, and negative voltage is generated when the switches are in position B. The alternating movement of the switches results in a square wave AC voltage. Inverters are categorized based on their configuration into single-phase half-bridge and full-bridge types. They can also be divided based on the output voltage and frequency settings, either constant or variable. Inverters with variable output frequency and voltage are typically used for specific applications, such as three-phase electric motors with an AC voltage source.

To control the output voltage of the inverter, Pulse Width Modulation (PWM) is often used. PWM generates a series of on/off pulses with varying durations to modify the output voltage (Petruzela, 2001). The carrier frequency of the PWM is related to the motor's vibrations and noise, with higher carrier frequencies reducing motor noise. However, this may lead to increased leakage current between the motor and inverter. Proper grounding is necessary to manage this leakage current. Additionally, frequency control of the inverter can be achieved through a Programmable Logic Controller (PLC), which uses analog and digital inputs and outputs to manage the inverter and control the speed of three-phase induction motors efficiently (Hartono, 2016).

2.3. PLC

In 1969, the Programmable Logic Controller (PLC) was introduced by Modicon, now part of Gauld Electronics, for General Motors' Hydromatic Division. The PLC represents a pivotal development in automation, offering a control system that integrates input equipment such as sensors, controllers, and output devices (Shiddiq, Ramadhan, & Nugraha, 2021). Devices connected to the PLC, which send signals into the system, are classified as input equipment. These signals enter the PLC through terminals or pins connected to the unit. The entry points are referred to as input points, which are stored in memory based on their ON or OFF status within the PLC. The controller section of the PLC executes the logic necessary for processing these inputs, making decisions, and controlling outputs. Essentially, the PLC conducts all necessary operations—input, output, control, calculation, and decision-making by following pre-programmed instructions. In industrial applications, PLCs are crucial for feedback control, data processing, and centralized monitoring systems, simplifying complex tasks and enhancing operational efficiency (Zakariz, Poetro, & Nugraha, 2021).

A PLC generally consists of two key components: the Central Processing Unit (CPU) and the input/output (I/O) interface system (Tiwana, Adianto, & Nugraha, 2021). The CPU is the brain of the PLC, responsible for executing the control logic and decision-making processes. It processes the input data, performs calculations, and sends commands to the output devices based on programmed instructions. The I/O system is crucial for facilitating communication between the PLC and the external environment, as it connects the system to sensors, switches, and actuators, enabling the PLC to interact with the physical world.

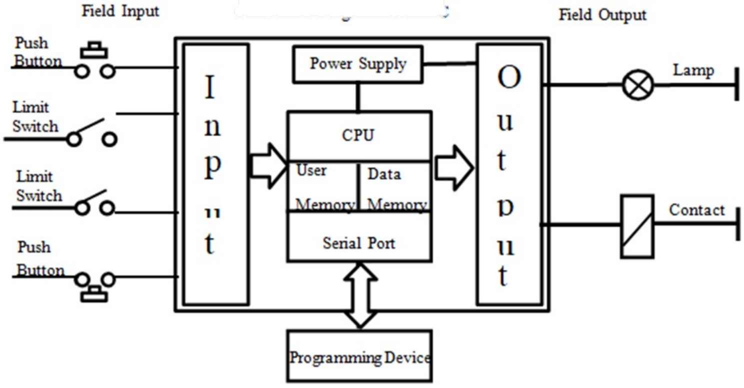

Figure 3. Block Diagram PLC

In the context of controlling a 3-phase induction generator, PLCs provide a reliable and flexible solution for voltage regulation and frequency adjustment. By utilizing a PLC system, an efficient voltage control mechanism can be implemented to regulate the output of a 3-phase induction generator, ensuring stable and consistent performance (Nugraha & Adi P., 2024). Through precise control of input signals, real-time data processing, and decision-making algorithms, PLCs enable dynamic control over the generator's operation, making them an invaluable tool in modern engineering applications.

In this paper, the implementation of a voltage control system for a 3-phase induction generator using PLC technology is explored. By integrating advanced feedback mechanisms and real-time control algorithms, the system ensures optimal performance and operational efficiency (Ramadhan, Shiddiq, & Nugraha, 2021). This paper contributes to the field of electrical engineering by offering innovative insights into improving voltage regulation in induction generators, an area of critical importance for various industrial applications. The study will further demonstrate the practical implementation of PLCs in managing complex systems, and the potential advantages of PLC-based control systems in industrial settings.

3. Results and discussion

3.1. PLC

The ladder diagram in the research can be seen in Figure 10, the green line shows that the line is live. When the Start button (W0.01) is pressed, the Q:1.00 output (internal relay) will turn on and immediately turn on the Q:100 output which can be connected directly to the external relay to start the motor. When finished, press the Stop button (W0.02) to stop or turn off the motor.

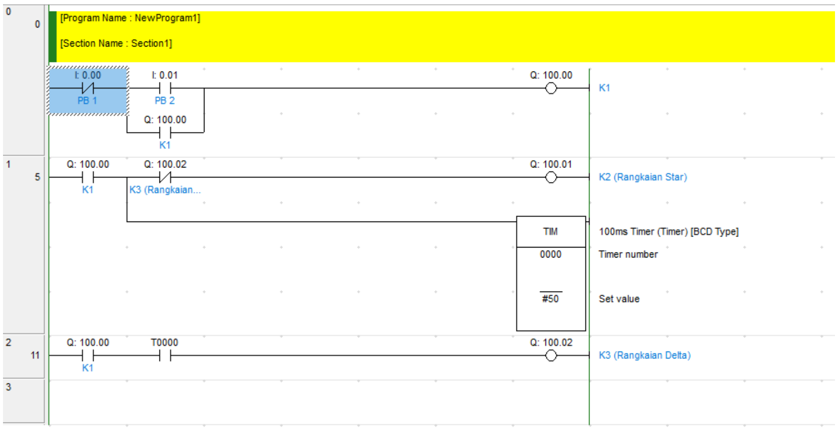

Figure 4. Leader Diagram speed rotation of motor

In Figure 4, at rung 0, the MOV(021) command is used to read the analog output data from the PLC. #FFFF is used to activate the 16-bit data, and D2010 is the memory location where the read data is stored. Below the MOV(021) command, the memory data from D200 is read and moved to the output Q:2011, representing the frequency setting result, which is then output through Q:2011. In rung 1, the multiplication factor for the analog data is applied. The analog data, which is in hexadecimal format, is converted into binary, and then into decimal, making it easier to adjust the frequency through the PLC. In rung 2, the SET command is used to enable the conversion bit, allowing the memory data to be activated. In rung 3, a series of instructions are used to start and stop the motor with internal relays, using normally open (NO) and normally closed (NC) contacts.

Testing Steps:

- Prepare the necessary tools and materials, ensuring they are in good condition.
- Assemble the wiring according to the circuit diagram (Figure 10).
- Double-check the circuit to ensure it is ready for testing.
- Supply power to the inverter training kit by activating the MCB.
- Once the inverter receives AC power, the display will show "00.0", indicating that the inverter is in standby mode.
- Press the up or down menu button until the display shows "Drv", then press the enter button. Select "1" and press enter again, enabling external control of the inverter.
- Next, find the "Frq" menu, press enter, then input the value "2" and press enter again. This allows frequency adjustments through the inverter's control buttons.
- Ensure the PLC has power and is in standby mode. Then, press the PLC power switch to make it ready for operation.
- Open the ladder diagram on the CX Programmer that has already been programmed, and transfer the data to the PLC.
- Start the motor by activating the Start input (W0.01) in the ladder diagram on the CX Programmer.
- Enter the desired frequency value into D100 in the ladder diagram by clicking the Toggle Watch Window icon. Double-click D100 to open the "Set New Value" window. Enter the required frequency and press Set Value. The motor will then start running at the set frequency.
- Measure the reference input voltage and output voltage using a multimeter, and measure the motor speed using a digital tachometer.
- Record the data in the test table.
- Perform multiple tests at different frequencies.
- Analyze the data obtained from the tests.
- After completing the tests, stop the motor by activating the Stop input (W0.02) in the ladder diagram on the CX Programmer.

3.2. Result

The data obtained from the research that has been carried out can be seen in Table 1.

Table 1. Result

Vrin (Volt)	**Vrout (Volt)**	**F (Hz) PLC**	**N (rpm) Practical**	**N (rpm) Measurement**
0.90	0.84	5	124.1	150
1.27	1.17	7	168.8	210
1.83	1.67	10	240	300
2.58	2.39	14	329.1	420
4.07	3.69	22	510.4	660
5.19	4.70	28	656.9	840
6.32	5.71	34	841.9	1020
7.05	6.38	38	939.2	1140
8.74	7.05	42	1023	1260
9.30	7.89	46	1145	1380
10.23	9.24	50	1296	1500

From Table 1, it can be seen that, in the first test, when a frequency of 5 Hz was set to the PLC, the rotation speed of the induction motor was 124.1 Rpm. Then we also get a reference input voltage of 0.90 Volts and a reference output voltage of 0.84 Volts, and the frequency read on the inverter is 5.10 Hz.

During the 5th test, when a frequency of 18 Hz was set to the PLC, the rotation speed of the induction motor was 432.5 Rpm. Then the input reference voltage is 3.33 Volts and the output reference voltage is 3.02 Volts, and the frequency read on the inverter is 18.38 Hz.

During the 10th test, when a frequency of 42 Hz was set to the PLC, the rotation speed of the induction motor was 1023 rpm. Then the input reference voltage is 7.80 Volts and the output reference voltage is 7.05 Volts, and the frequency read on the inverter is 42.93 Hz.

$$Ns=\frac{120.f}{P}-\frac{120.50}{4}=1500\,Rpm$$

According to calculations, it was obtained at 1500 rpm, whereas in the experiment when the frequency was 50 Hz, the measured rotation was 1296 rpm. This is very different from the calculations, this is because the input reference voltage which should be 10 volts is only 9 volts.

A. Comparison Between Rotation and Frequency

Graph in Figure 5. shows the relationship between the frequency input to the PLC and the rotation of the induction motor. The curve has a linear value where each increase in frequency is proportional to the increase in the rotation speed of the induction motor.

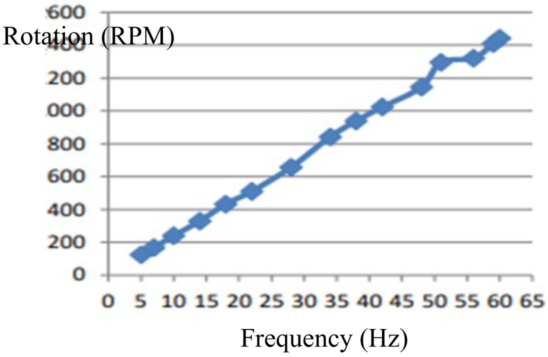

Figure 5. Leader comparison between induction motor rotation and frequency

B. Comparison Between Voltage and Frequency of Induction Motor Rotation
The graph in Figure 6 shows the relationship between the input reference voltage and the rotation of the induction motor. The value curve remains linear where each increase in frequency is followed by an increase in the reference input voltage and it is also proportional to the increase in the rotation speed of the induction motor

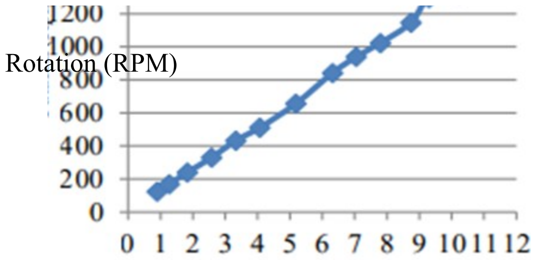

Figure 6. Comparison between induction motor rotation and voltage

C. Comparison of Voltage and Frequency of Induction Motor Rotation
The graph in Figure 7 shows the relationship between voltage and frequency of induction motor rotation where each increase in frequency is proportional to the increase in voltage and induction motor rotation.

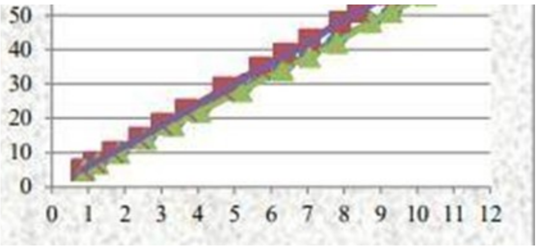

Figure 7. Comparison between voltage and frequency versus rotation

4. Conclusion

Based on testing on the Programmable Logic Controller (PLC) application as a three-phase induction motor speed controller, it can be concluded as follows:

1. The PLC can be used to control changes in the rotation of the induction motor with the help of the CX-Programer software. When the frequency set to the PLC is changed, the rotation speed of the induction motor will change.
2. Based on the research results, when the output reference voltage is 0.9 volts, the output frequency is 5 Hz and the motor rotation read through the encoder is 150 RPM up to a reference voltage of 10.23 volts with a reading frequency of 50 Hz and the rotation reading is 1296 RPM.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

References

Adi Wasono, 2011, Rancang Bangun Aplikasi Programmable Logic Controller (PLC) Sebagai Pengendali Kecepatan Motor Induksi Tiga Fasa Melalui Inverter, Jurnal Ilmiah (Vol.7 No. 3 November 2011 : 401-406), Politeknik Negeri Semarang.

Agus Darwanto, Pebri Budianto, 2009, Pengaturan Kecepatan Motor Induksi Tiga Fasa ¼ Hp 220/380 V Menggunakan Inverter Berbasis PLC Glofa, Majalah Ilmiah STTR Cepu.

Heri Haryanto, 2011, Pembuatan Modul Inverter Sebagai Kendali Kecepatan Putaran Motor Induksi, Jurnal Ilmiah , Vol 4 No. 1, April 2011: 149-159.

Hari, W,W., Bambang, S., 2004, Aplikasi Mikrocontroller AT89C51 Sebagai Pembangkit PWM Sinusoida 1 Fasa Untuk Mengendalikan Putaran Motor Sinkron, Jurnal Penelitian, Universitas Gajah Mada, Jogyakarta

Marappung M, 1998, Teknik Tenaga Listrik, Armico, Bandung.

Muhammad H Rashid, 2006, Elektronika Daya, Rangkaian, Devais dan Aplikasinya, Edisi Bahasa Indonesia Jilid satu edisi kedua, PT. Prenhallindo, Jakarta.

Z. Tharo, A.P.U. Siahaan N. Evalina, 2016, Improvisation analysis of reaktif power saving lamps based on Inverter, International journal of engineering and techniques, vol 2 no. 5, pp 141-145

Ardiansyah, Heri, 2012, Studi Regulasi Output Generator Induksi Dengan Voltage Source Inverter, Surabaya: FTI. Institude Teknologi Sepuluh November.

Dirgantara, Afiat. 2010, Analisis Dan Simulasi Pengaturan Tegangan Generator induksi Berpenguat Sendiri Dengan Menggunakan Konverter AC-DC-AC Pada Sifat Beban Yang Berbeda, Skripsi. FT.UI. Depok. ISSN : 2598 – 1099 (Online) ISSN : 2502 – 3624 (Cetak) Said Abubakar, Supri Hardi, Sistem Pengemdali 26 Journal of Electrical Technology, Vol. 2, No. 3, Oktobert 2017

Darjad, dkk., 2008, Aplikasi Kontrol Proporsional Integral Berbasis Mikrokontroler Atmega8535 Untuk Pengaturan Suhu Pada Alat Pengering Kertas, Seminar Ilmiah Nasional Komputer dan Sistem Intelijen . Depok : Universitas Gunadarma.

Hardi, Supri. dkk. 2015, Rancang Bangun Thyristor Controlled Reaktor (TCR) sebagai penstabil tegangan dan peredam harmonisa aplikasi pada generator induksi Pembangkit Mikrohidro. Lhokseumawe : Politeknik Negeri Lhokseumawe.

Hardi, Supri. 2015, Instrumentasi, Buku Ajar. Lhokseumawe : Politeknik Negeri Lhokseumawe.

Harahap, R., 2016, Motor Induksi, repository.usu.ac.id/bitstream/123456789/55591/4/Chapter%20II.pdf. Diakses 23 Desember 2016

Frank D. Petruzela (The McGraw-Hill Companies, Inc) (2001).Sistem distribusi daya, mencakup operasi dan aplikasi transformer, distribusiin-plant.Alat kendali industrial, mencakup saklar yang dioperasikan secara manual dan mekanis, transducer dan sensor, aktuator.

HartonoFandy (2016).Pengaturan Kecepatan Dan Posisi Motor AC 3 Phasa Menggunakan DT AVR Low Cost Micro System. Jurnal Teknik Elektro Institut Teknologi Sepuluh Nopember.

Shiddiq, Muhammad Jafar, Moch Fadhil Ramadhan, and Anggara Trisna Nugraha. "PERENCANAAN PEMBANGKIT LISTRIK ENERGI BAYU KINCIR SAVONIUS GUNA MEWUJUDKAN PEMANFAATAN RENEWABLE ENERGY PADA JEMBATAN SURAMADU." Seminar MASTER PPNS. Vol. 6. No. 1. 2021.

Zakariz, Naufal Praska, Joessianto Eko Poetro, and Anggara Trisna Nugraha. "PENGARUH VARIASI INLET NOTCH TERHADAP KECEPATAN DAN DAYA YANG DAPAT TERBANGKITKAN DARI GENERATOR PADA PEMBANGKIT LISTRIK TENAGA PIKOHIDRO." Seminar MASTER PPNS. Vol. 6. No. 1. 2021.

Tiwana, Mayda Zita Aliem, Adianto Adianto, and Anggara Trisna Nugraha. "PERANCANGAN SISTEM MONITORING DAN ALARM BERBASIS LOGIC PANEL DAN KOMUNIKASI MODBUS." Seminar MASTER PPNS. Vol. 6. No. 1. 2021.

Nugraha, Anggara Trisna, and Ahmad Efendi Adi P. Ahmad Efendi, and P. Adi. "Uji Kelayaakan Generator Sinkron dengan Metode Forward Chaining berbasis PLC dan HMI." MEDIA ELEKTRIKA 17.1 (2024): 10-21.

Ramadhan, Moch Fadhil, Muhammad Jafar Shiddiq, and Anggara Trisna Nugraha. "PERENCANAAN PEMBANGKIT LISTRIK ENERGI SURYA UNTUK KEBUTUHAN LISTRIK JEMBATAN SURAMADU GUNA MEWUJUDKAN TUJUAN PEMBANGUNAN BERKELANJUTAN." Seminar MASTER PPNS. Vol. 6. No. 1. 2021.