Control and Calculation of Industrial Machine Effectiveness Based on Programmable Logic Controller and Human Machine Interface

Brother Maryanto[1], Risky Via Yuliantari[2], Bagus Fatkhurrozi[3]
[1.2.3] Department of Electrical Mechatronics and Information Engineering, Faculty of Engineering, Tidar University, Magelang City, Indonesia
[1] email: adika.mar@students.untidar.ac.id

[*submitted*: 03-09-2024 | *review*: 24-10-2024 | *published*: 31-10-2024]

ABSTRACT: *In today's fast growing technology, industries need a system that is able to control machines more effectively and efficiently to improve quality and reduce production costs. In addition, an efficient control system can minimize excessive process time. PT Chemco Harapan Nusantara, a manufacturing company, requires a system to automate the control of the Vibratory Deburring Machine or barrel machine which is currently still operated manually. This manual operation increases the production process time. This research aims to develop an automation system for controlling and evaluating the effectiveness of industrial machines using a Programmable Logic Controller and Human Machine Interface to increase production efficiency and reduce processing time. Testing in this study was carried out by simulating the production process at PT Chemco Harapan Nusantara 28 times. The results showed that the highest percentage of effectiveness obtained was 99.94% with a loss time of 14 seconds, while the lowest percentage was 99.91% with a loss time of 23 seconds. The average effectiveness reached 99.96% with a loss time of 9 seconds. In addition, the process time was successfully reduced by 20 seconds from over 5 minutes 20 seconds to only 5 minutes.*

KEYWORDS: *Control, Effectiveness, PLC, HMI.*

I. INTRODUCTION

In the era of rapidly developing technology, industry requires an effective and efficient control system to improve production quality and reduce costs. One of the most widely applied technologies in industry today is the Programmable Logic Controller (PLC) and Human Machine Interface (HMI). PLC allows the adjustment of control logic according to company needs to control various industrial processes while HMI allows operators to monitor and control the system efficiently.

The use of PLCs in the industrial world has been proven to increase the effectiveness of industrial machines, one of which is the use of PLCs and HMIs in the Supervisory Control and Data Acquisition (SCADA) system which can reduce seven wastes and increase the effectiveness and efficiency of production [1]. The use of PLC and HMI in the design and implementation of pipe cutting machines with AC servo motors can also increase production effectiveness [2].

As a company engaged in the field of brake systems, aluminum casting wheels, and casting parts, PT Chemco Harapan Nusantara continues to update the technology used for industrial needs. PT Chemco Harapan Nusantara has various types of industrial machines that use PLC as their control, one of which is the Vibratory Deburring Machine which is also known as a barrel machine.

Barrel machine or Vibratory Deburring Machine is a tool used to smooth the surface of the workpiece. This machine utilizes the vibrations produced together with the friction of the abrasive media in the bowl to smooth the surface of the workpiece [3]. This machine is usually used in the manufacturing industry, such as for processing work equipment, machine components, and other products that require smooth surfaces. The barrel machine at PT Chemco Harapan Nusantara still has to be controlled manually, this is less efficient because the user has to repeatedly set the parameters. In addition, recording the effectiveness of the machine which is still done manually takes a long time and is prone to errors in recording and calculating which can cause repetition of the process.

II. THEORY

A. PROGRAMMABLE LOGIC CONTROLLER

Programmable Logic Controller(PLC) is an electronic device used to automate industrial processes. PLCs are designed to control various sensors and actuators. PLC inputs and outputs connected to sensors and actuators receive information based on programmed conditions. Signals from sensors are received by PLC inputs, then processed to produce output signals that control equipment such as valves, electric motors, or production machines. [4].

Programs on PLC can be created using special software, usually in the form of ladder diagrams or state diagrams. This state-based system describes various states in the system and the process of changing between these states that occurs quickly. The PLC image can be seen in fig 1.

Fig 1. Omron PLC

B. HUMAN MACHINE INTERFACE

Human Machine Interface (HMI) is a component commonly used in modern industry, functioning as a link between humans and machines.[5]. HMI provides visual displays and controls to monitor and control equipment or systems. Typically, HMIs are used in industrial and manufacturing environments to improve operational efficiency, equipment setup and monitoring, improve safety, and facilitate troubleshooting. HMIs can be either touchscreens or graphical displays on a computer monitor. A picture of an HMI can be seen in fig 2.

Fig 2. Human Machine Interface

C. PROGRAMMABLE LOGIC CONTROLLER ARRAY APB

Programmable Logic Controller Array Advanced Peripheral Busis a device that regulates time in PLC and HMI systems. PLC Array operates based on a coil, which will switch from Normally Closed (NC) to Normally Open (NO) when it reaches a predetermined time. The image of the PLC Array APB can be seen in fig 3.

Fig 3. PLC Array APB

D. MACHINE EFFECTIVENESS

In various industrial sectors, industrial machines are used to support the production process. To ensure efficiency and avoid increasing production costs, it is important to measure the effectiveness of the machine. Machine effectiveness is usually measured using Overall Equipment Effectiveness (OEE), which measures how efficiently a machine or equipment operates. OEE is calculated by evaluating machine availability, performance efficiency, and product quality.[6]. The formula for calculating the OEE value is as follows:

$$OEE = Availability\ (\%) \times Performance\ Rate\ (\%) \times Quality\ Rate\ (\%) \quad (1)$$

Availability measures how well the machine is used during the available time, Performance Rate evaluates the efficiency of the machine in achieving production targets, and Quality Rate is the ratio of products that meet quality standards. The international standard for minimum OEE is 85%[7].

In this study, the main focus is on Availability to determine the percentage of machine effectiveness in one day. Availability reflects the ratio of utilization of time available for machine operation in one shift. The data used to calculate Availability includes loading time and down time. Loading time is the time the machine is available to operate every day, while down time is the time when the machine is not operating due to setup, adjustment, or equipment damage. The formula for calculating Availability is:

$$Availability = \times 100\% \frac{Loading\ time - Down\ time}{Loading\ time} \quad (2)$$

In this study, loading time is determined based on the length of time the machine operates. Sunday to Friday loading time is 7 hours or 25200 seconds while on Saturday loading time is 5 hours or 18000 seconds.

E. CONTROL SYSTEM

A control system is a system consisting of various devices that work synergistically to regulate a particular process or system.[8]. In general, a control system includes three main components: input, control, and output. The control system diagram can be seen in Fig 4.

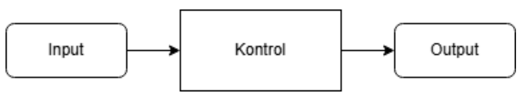


Fig 4. Control system diagram

Input components receive input signals for the control system, control components process the signals to produce output signals, and output components produce the results of the control process. There are two types of control systems, namely open-loop control and closed-loop control. An image of an open-loop control system can be seen in Fig 5.

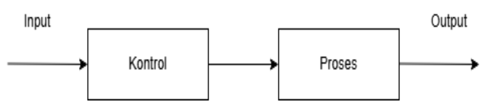


Fig 5. Open loop control system

Open loop control is a system that has no feedback, so the output does not affect the control process.[9]. In contrast, closed-loop control uses feedback, where the output signal influences the control process.[10]. The image of the closed loop control system can be seen in fig 6.

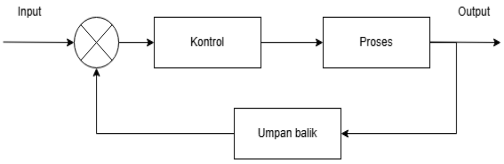


Fig 6. Closed loop control system

In a closed-loop control system, an error signal, which is the difference between the input signal and the feedback, is sent to the controller to minimize the error and ensure that the output is close to the desired result. This study uses a closed-loop control system.

III. METHODOLOGY

A. RESEARCH FLOW

To explain the research steps, a research flow is used. The research flow in this study can be seen in Fig 7.

Fig 7. Research flow

B. RESEARCH STAGE PROCEDURES

1) *Literature Study*

Literature study was conducted to gain insight into relevant research and information related to Programmable Logic Controller (PLC) and Human Machine Interface (HMI). Information was collected from various sources, including journals, e-books, books, and websites.

2) *System Design*

After the information is collected and relevant literature has been studied, the next stage is to design the system. This design includes all aspects, from interface design, system process design, machine effectiveness calculations, to controls applied in the system.

3) *Tool Manufacturing and Testing*

With the system design complete, the tool is manufactured and tested using an Omron CP1E-N30DR-A PLC, an Omron NB7W-TW00B HMI, and an APB-22MRDL Array PLC. The tool is tested to ensure that it is performing to the desired specifications. If any discrepancies or errors are found during testing, a redesign will be performed to correct the existing issues.

4) *Analysis*

Analysis is performed after the tool has been tested and proven to meet the requirements. The results of the control system and calculation tests are analyzed to ensure that they comply with applicable needs and standards. In addition, the analysis also includes an assessment of how the system works to ensure that all functions are running as desired.

IV. RESULTS AND DISCUSSION

A. SYSTEM DESIGN RESULTS

The results of the design of the control system and the calculation of the effectiveness of industrial machines using a programmable logic controller (PLC) and human machine interface (HMI) produce a system that can control and calculate the effectiveness of industrial machines, with the information displayed on the HMI screen. The results of the system design can be seen in Fig 8.

(a) (b)

Fig 8. Results of system design. (a) At PT Chemco Harapan Nusantara and (b) Experimental Simulation

B. PLC PROGRAM

The availability calculation program is used to calculate how long the machine is on in one work shift. The availability program can be seen in fig 9.

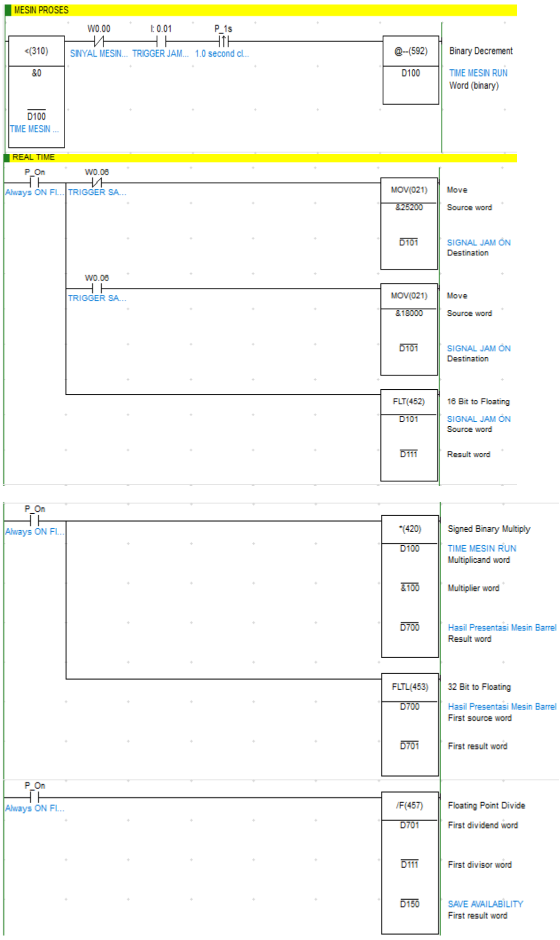


Fig 9. Program availability

Fig 9. explains the workday trigger to determine the loading time, after that the data when the machine is not operating according to working hours will be added up and stored in the D100 register. The machine data will be a reduction for the loading time then the result is divided by the loading time then multiplied by &100 and stored in the D150 register. This is in accordance with formula (2).

The design of the machine control program is to determine the frequency parameters and timer parameters that apply to each part processed on the barrel machine. The program for frequency parameters can be seen in Fig 10.

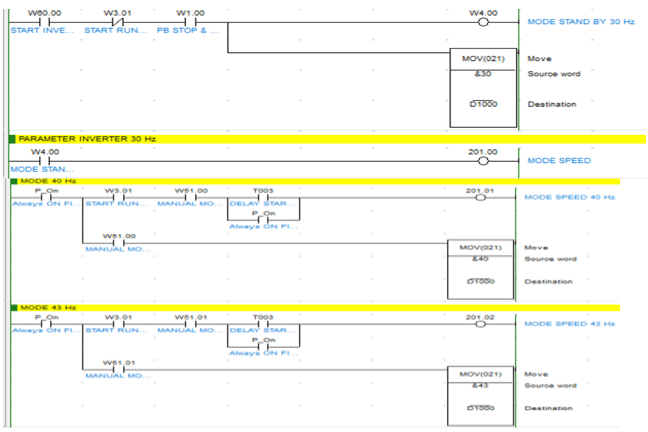


Fig 10. Frequency parameter program

In the frequency parameter program, the frequencies used include 30 Hz, 40 Hz, 43 Hz, and 45 Hz. At a frequency of 30 Hz, the machine is set in standby mode, so that when the system is activated, the machine will operate automatically at a frequency of 30 Hz. The address at this frequency is 201.00 which is connected to the output, while the coil used with the address W4.00 has inputs W60.00, W3.01, and W1.00, and uses the MOV instruction with the address D1000. At a frequency of 40 Hz, the address used is 201.01, which is connected to the inputs W3.01, W51.00, and T003 which are paralleled with the P_On contact. At this frequency, the MOV instruction is also implemented using the address D1000 with the input W51.00 which is paralleled. For 43 Hz frequency, address 201.02 is used with the same input and MOV address as at 40 Hz frequency, but with a difference in the MOV input, which is W51.01. While at 45 Hz frequency, address 201.03 is used and connected to inputs W3.01, W7.00 to W7.09, and W51.02 which are paralleled, along with T003 which is also paralleled with the P_On contact. MOV instructions at this frequency use address D1000 with inputs W7.00 to W7.09 and W51.02 which are paralleled. The 45 Hz frequency program can be seen in fig 11.

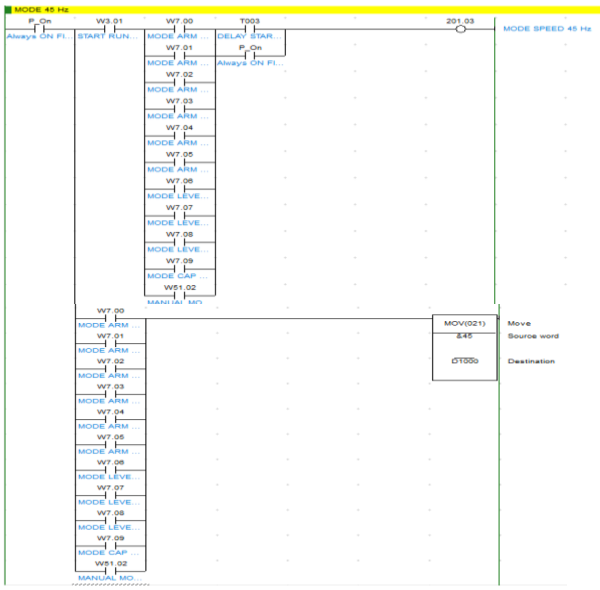


Fig 11. 45 Hz frequency program

The timer parameter is used to determine how long the process time is needed for each production part. The time used is 3 minutes and 5 minutes. The timer program can be seen in fig 12.

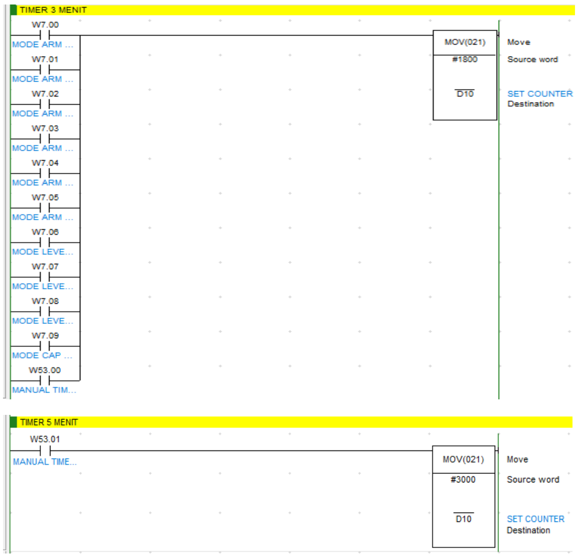


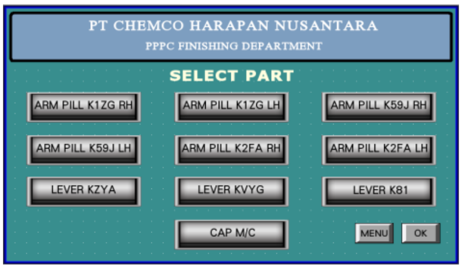
Fig 12. Timer program

In the timer program, the specified time is 3 minutes or 1800ms and 5 minutes or 3000ms because the timer on the PLC uses milliseconds (ms) units. The address of the timer is D10.

C. HMI Design

The HMI design displays the effectiveness of the machine to facilitate the recording of machine effectiveness data by the user. In addition, there is a part selection that is useful for selecting parts to be processed. The HMI display for machine effectiveness and part selection can be seen in Fig 13.

(a)



(b)

Fig. 13. HMI design. (a) Effectiveness view and (b) Part selection view.

D. Power Circuit

The power circuit used in this study can be seen in Fig 14.

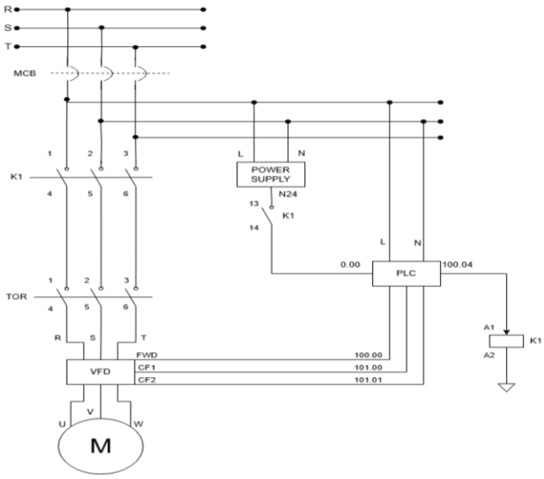


Fig 14. Power circuit

From Fig 14. it is explained that MCB gets power from RST source voltage then forwarded to contactor (K1) and TOR which enters RST input on Variable Frequency Drive (VFD). R and S voltage from MCB enters Power Supply via contacts L and N, then power supply output in the form of 24VDC or N24 enters contact 13 K1 and forwarded via contact 14 to input address 0.00 on PLC. Voltage source R and S also enter PLC as power via contacts L and L on PLC. Output on PLC, namely address 100.00 is forwarded and enters FWD input contact on VFD, address 101.00 is forwarded and enters CF1 input contact on VFD, address 101.01 is forwarded and enters CF2 input contact on VFD, and address 100.04 enters auxiliary contact A1 on K1. From VFD will regulate motor speed via contacts U, V, and W.

E. Test Results

After the system was successfully created, system testing was carried out by recreating the control and monitoring system at the Electrical Engineering Laboratory of Tidar University from July 18, 2024 to July 24, 2024, with a total of 28 tests over one week. Testing was carried out in four sessions per day, where the system was reset after every two sessions. Each session used a different part that was selected randomly, and the cycle time applied was 5 minutes. The test results can be seen in Tbl 1.

Tbl 1. Test Result Tbl

Date	The first attempt	Time	*Loss of time*(second)	Total Loss time	Percentage (%)
July 18, 2024	1	16.00-17.00	4	15	99.98
	2	17.00-18.00	11		99.94
	3	20.00-21.00	8	21	99.97

Date	The first attempt	Time	*Loss of time*(second)	Total Loss time	Percentage (%)
	4	21.00-22.00	13		99.92
July 19, 2024	5	16.00-17.00	9	20	99.96
	6	17.00-18.00	11		99.92
	7	20.00-21.00	12	23	99.95
	8	21.00-22.00	11		99.91
July 20, 2024	9	16.00-17.00	9	22	99.96
	10	17.00-18.00	13		99.91
	11	20.00-21.00	10	18	99.96
	12	21.00-22.00	8		99.93
July 21, 20224	13	16.00-17.00	13	20	99.95
	14	17.00-18.00	7		99.92
	15	20.00-21.00	5	16	99.98
	16	21.00-22.00	11		99.94
July 22, 2024	17	16.00-17.00	6	14	99.98
	18	17.00-18.00	8		99.94
	19	20.00-21.00	9	17	99.96
	20	21.00-22.00	8		99.93
July 23, 2024	21	16.00-17.00	9	17	99.96
	22	17.00-18.00	8		99.93
	23	20.00-21.00	7	18	99.97
	24	21.00-22.00	11		99.93
July 24, 2024	25	16.00-17.00	9	17	99.96
	26	17.00-18.00	8		99.93
	27	20.00-21.00	8	16	99.97
	28	21.00-22.00	8		99.94

Based on data from Tbl 1, the system effectiveness percentage is very high, reaching more than 99.90% during testing, with loss times varying from 4 seconds to 13 seconds. The test that showed the highest effectiveness percentage was conducted on July 22 2024 between 16:00 and 18:00 with a loss time of 14 seconds and an effectiveness percentage of 99.94%. In contrast, the lowest percentage was recorded on July 19 2024 between 20:00 and 22:00 with a loss time of 23 seconds and an effectiveness percentage of 99.91%. The effectiveness calculation was carried out using equation 2.2, with a loading time of 25,200 seconds for days other than Saturday. The average loss time during testing was 9 seconds, with an average effectiveness percentage of 99.96%.

The implementation of the control and calculation system in this study successfully reduced losses due to wasted time or loss time. Before the implementation of the system, the process time of one cycle exceeded 5 minutes because the user had to move to press the start and stop buttons. With the control and calculation system implemented, the user only needs to press the start button located close to the workplace and then the machine will operate automatically. Part selection is done only at the beginning of the process, so that time can be saved up to 20 seconds per part process.

V. CONCLUSION

Based on the tests and analysis that have been conducted, the research on the control system and calculation of the effectiveness of industrial machines based on PLC and HMI leads to several conclusions. The developed system shows good performance according to the needs. The control system is able to regulate the motor frequency through the Variable Frequency Drive (VFD). The highest percentage of effectiveness obtained during the test was 99.94% with a loss time of 14 seconds, while the lowest percentage was 99.91% with a loss time of 23 seconds. The average percentage of effectiveness was 99.96%, with an average loss time of 9 seconds. All test results, both the highest and the lowest, exceeded the applicable standard, which was 85%. This system also succeeded in reducing the process time by 20 seconds from the previous one cycle of 5 minutes 20 seconds or even more to 5 minutes per cycle. This time saved if accumulated will get one additional cycle.

REFERENCES

[1] A. Setiawan, Sugeng, KI Koesoema, S. Bakhri, and J. Aditya, "The SCADA system using PLC and HMI to improve the effectiveness and efficiency of production processes," inIOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Aug. 2019. doi: 10.1088/1757-899X/550/1/012008.
[2] [2] S. Syufrijal, M. Rif'an, AWR Prabumenang, and R. Wicaksono, "Design and implementation of pipecutting machine with AC servo motor and PLC based on HMI," IOP Conf Ser Mater Sci Eng, vol. 1098, no. 4, p. 042082, Mar. 2021, doi: 10.1088/1757-899x/1098/4/042082.
[3] [3] A. Rizaldi Kurniawan, P. Applied Bachelor of Manufacturing Studies, J. Mechanical Engineering, P. Negeri Jakarta, and JG A Siwabessy, "CHAMBER DESIGN ON VIBRATORY FINISHING BOWL MACHINE USING REVERSE ENGINEERING METHOD," 2023. [Online]. Available: http://prosiding.pnj.ac.id
[4] [4] I. Setiawan, "PROGRAMMABLE LOGIC CONTROLLER and CONTROL SYSTEM DESIGN TECHNIQUES (Iwan Setiawan)."
[5] [5] S. Sadi, "2561-7564-1-PB,"Engineering Journal: Muhammadiyah University of Tangerang,vol. 9, pp. 18–24, June. 2020.
[6] [6] H. Ariyah, Department of Industrial Engineering, Faculty of Science and Technology, UH Sultan Syarif Kasim Riau Jl Soebrantas No, and S. Baru, "Application of Overall Equipment Effectiveness (OEE) Method in Increasing Batching Plant Machine Efficiency (Case Study: PT. Lutvindo Wijaya Perkasa),"Journal of Applied Industrial Technology and Management (JTMIT), vol. 1, pp. 70–77, 2022.
[7] [7] G. Primula and MI Hamdy, "Evaluation of Ripple Mill Machine Effectiveness Through Overall Equipment Effectiveness (OEE) Approach,"Journal of Applied Industrial Technology and Management (JTMIT), vol. 2, no. 4, pp. 301–309, 2023.
[8] [8] Wachid Yahya,Automotive Control Systems Book. Yogyakarta: Deepublish, 2017.
[9] [9] English: Erni Yudaningtyas,Learning Control Systems: Questions and Discussions. Malang: UB Press, 2017.
[10] Z. Noer and I. Dayana,Control System Book. Medan: Guepedia, 2021.

Authors Biography and Contributions

Little Brother Maryanto, Sukoharjo, November 13, 2000. Currently pursuing a Bachelor's degree in the Electrical Engineering Study Program, Department of Electrical Mechatronics and Information Engineering, Faculty of Engineering, Tidar University with a concentration in Instrumentation and Control Systems.

Risky Via Yuliantari, S.Pd., M.Eng.,Tegal, March 26, 1991. Completed his undergraduate education at Semarang State University in 2013 and his postgraduate education at Gadjah Mada University in 2017. He is currently registered as a lecturer in the Department of Electrical Engineering, Faculty of Engineering, Tidar University. His contribution to this research is in writing articles and validating research data.

Ir. Good Fatkhurrozi, ST, MT, IPM,Batang, October 12, 1979. Completed his undergraduate education at Widya Gama University in 2002, his postgraduate education at Brawijaya University in 2013, and his professional education as an engineer at Diponegoro University in 2022. He is currently the head of the Department of Electrical, Mechatronics and Information Engineering, Faculty of Engineering, Tidar University for the period 2023 to 2028. In this article, his contribution is in wiring design and validation of research data.