Journal of Marine Electrical and Electronic Technology **Vol. …...., No. …….**
ISSN xxxxxx **Publication Periode**

Speed Control of DC Motors Using Full-Wave Uncontrolled Rectifiers: A Comparative Analysis

Yuda Irawan
Automation Engineering, Shipbuilding Institute of Polytechnic Surabaya
yudairawan@student.ppns.ac.id

Abstract

The regulation of DC motor speed can be effectively achieved through a variety of methods, such as adjusting the number of pole pairs, employing external resistance regulators, armature input voltage controllers, vector controllers, voltage converters, as well as utilizing Pulse Width Modulation (PWM) techniques and advanced electronic components. These methods allow for precise control of the motor's operational parameters, ensuring that the system can be adapted to various industrial and practical needs. For instance, by modifying the motor's operating conditions, different maximum output speeds can be achieved, making it versatile across different applications. A key aspect of motor speed regulation involves the use of simultaneous control techniques, particularly in cascade speed control systems. This allows for multi-level regulation, which optimizes performance by maintaining a balance between the motor's speed and load demands. In practice, DC motors offer simplicity in design, making them an attractive option for industrial applications. The ease of acquiring necessary components and the relatively low cost of these systems further enhance their popularity in the field of engineering. Moreover, the wide variety of DC motors available today means they can be tailored to meet the diverse needs of industries ranging from automation to precision machinery. The ability to adjust motor speeds with high efficiency ensures that DC motors are indispensable in driving a wide array of mechanical systems, contributing significantly to operational productivity and system stability.
.

Keywords: Motor Speed, Voltage, Motor DC

1. Introduction

As is well recognized, the industrial sector is currently experiencing significant and rapid advancements, with both large-scale and small-scale industries evolving to meet market demands. These developments are directly contributing to an increased need for electric motors, which are essential components across a wide range of industrial applications (Winardi, 2021).

One of the most widely used types of electric motors is the direct current (DC) motor, which plays a crucial role in converting direct current (DC) electrical energy into mechanical motion (Hartono & Nurcahyo, 2017). This motion, typically in the form of rotational power generated by the motor's rotor, is vital in various industrial systems. The primary advantage of DC motors in modern industry lies in their ability to easily adjust operating speeds across a broad range, offering flexibility in application (Evalina, Azis, & Zulfikar, 2018). This capability, combined with the variety of control methods available, makes DC motors an attractive choice for a wide array of engineering challenges.

Typically, there are three major methods employed for regulating the speed of DC motors: field current control, armature circuit resistance control, and armature terminal voltage control (Ambabunga, 2020). These methods are commonly used to modify the motor's operational characteristics, including the efficiency and performance of the motor. By adjusting key parameters through these control techniques, motor operators can optimize the efficiency of their systems and ensure reliable performance under varying operational conditions (Usman et al., 2017).

A popular and cost-effective method of controlling DC motor speed is the use of a potentiometer-based speed control circuit. This approach is highly practical due to its simplicity and ease of implementation, as it does not require complex circuitry (Mehar, n.d.). The potentiometer-based system is both economically viable and efficient, making it an ideal solution for small to medium-scale applications (Kamiriski, Wejrzanowski, & Koczara, 2004). This paper reviews the effectiveness of such a motor speed control system, which is designed to provide simultaneous speed regulation. This type of control system ensures that the motor operates at its optimal speed by adjusting the control parameters in real-time.

DOI xxxxxx

The goal of this research is to compare and contrast various DC motor speed control systems and evaluate their effectiveness in different industrial contexts. By examining the design concepts of previous studies and using a comparative analysis, this study aims to identify the most efficient system design that can be applied to real-world motor applications. Through literature review and analysis of relevant scientific journals, the paper discusses various system concepts and the components used to regulate DC motor speed. Although some of the reference journals may involve different system designs, this paper limits its focus to comparing the specific components and concepts relevant to speed regulation and their impact on system performance.

2. Material and methods

2.1. Direct Current Motor

A conductor through which an electric current flows generates a surrounding magnetic field (Hermawan, Aripriharta, & Homggowiyono, 2014). When this conductor is placed within an external magnetic field, it experiences a mechanical force due to the interaction between the magnetic field produced by the current in the conductor and the external magnetic field (Sufyani et al., 2019). This principle, known as the Lorentz force, forms the basis for the operation of electrical machines such as motors and actuators in various engineering applications. In the context of DC motor control, this force plays a crucial role in generating rotational motion from electrical energy, where the magnitude and direction of the force can be manipulated by adjusting the current and the magnetic field (Evalina, Azis, & Zulfikar, 2018).

2.2. Shunt DC Motor

A shunt motor is a type of self-excited DC motor in which the field winding, also known as the magnetic amplifier winding, is connected in parallel with the armature winding (Nugraha et al., 2023). Alternatively, it can be directly connected to an external voltage source, as shown in Figure 1. This configuration ensures that the field current remains relatively stable, allowing for a constant magnetic flux, which in turn provides consistent speed control under varying load conditions. In practice, this makes the shunt motor highly effective for applications requiring constant speed operation despite load fluctuations (Mutiar, 2017).

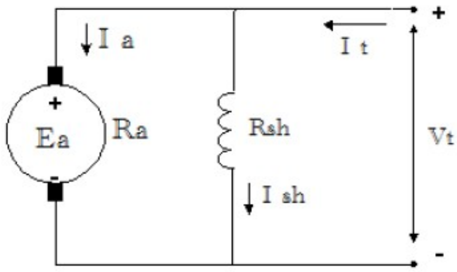

Figure 1. *Shunt DC Motor* Electrical Circuit

The equation that applies to the shunt motor is:

$Vt=Ea+(Ia \times Ra)$

$Ish=Vt/Rsh$

$IL=Ia+Ish$

When:

Vt = clamping voltage / input voltage to the motor (Volts)
Ea = induced electromotive force (Volts)
Ia = Armature current (Amperes)
Ra = Anchor resistance (Ohm)
Ish = shunt field coil current (Amperes)
Rsh = shunt field resistance (Ohm)
IL = Current from the grid (Amperes)

The characteristics of a DC shunt motor offer significant advantages in applications requiring stable and consistent speed under varying load conditions (Nugraha et al., 2024). This type of motor maintains a nearly constant rotational speed across a wide range of load variations, as long as the operating conditions remain within its rated capacity. Notably, the motor experiences a minimal reduction in speed when transitioning from no-load to full-load conditions, with the speed drop typically ranging between 5% to 15% of the motor's full speed. This variation in speed drop is influenced by several factors, including magnetic saturation, armature reaction, and the position of the brushes, which can vary depending on the motor's design and operational settings.

DOI xxxxxx

The torque-speed characteristic curve for a DC shunt motor, without any rheostatic adjustments, will typically resemble a near-vertical line. However, by introducing slight adjustments through a front resistor, the curve can be modified to exhibit a more gradual slope. This adjustment provides a more adaptable torque-speed performance, which is crucial in fine-tuning the motor's behavior for specific industrial applications. The ability to tweak the speed-torque characteristics ensures that the motor can efficiently meet the demands of different load conditions, thus enhancing its versatility.

2.3. Diode

Diodes, as one of the fundamental active components in electronic circuits, are extensively used across various applications due to their simplicity in design and wide-ranging functionalities (Sheila et al., 2024). These semiconductor devices are indispensable in converting electrical energy forms, serving pivotal roles in systems where direct current (DC) is required (Rosdianto & Toifur, 2017). Diodes are employed in multiple circuit configurations, including full-wave rectifiers, clipper circuits, clamper circuits, and voltage multipliers, each designed for specific tasks in voltage regulation, signal processing, and power conversion (Jatmika, Syakur, & Afrisal, 2021). Among these, full-wave rectifiers are particularly significant in converting alternating current (AC) into DC, a critical process in many industrial and consumer electronic applications.

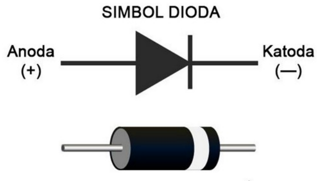

Figure 2. Diode Symbol

For context, a rectifier diode is commonly symbolized as a diode symbol, which consists of an arrow pointing from the positive side (anode) to the negative side (cathode), representing the direction of conventional current flow (Abidin, Priangkoso, & Darmanto, 2013). This simple yet effective visual representation reinforces the unidirectional current flow property of diodes, emphasizing their role in controlling current within circuits. The positive terminal (P), also known as the anode, is where current flows into the diode, while the negative terminal (N), or cathode, serves as the current exit point (Nugraha & Eviningsih, 2022a). The current direction aligns with the conventional flow, from the anode to the cathode, ensuring that electrical energy flows only in the desired direction.

When a diode is exposed to zero voltage, no electric field is present to attract electrons from the cathode, thus preventing the flow of current. In this situation, electrons, when heated at the cathode, are only capable of moving within a small range, creating a space charge that impedes further electron movement. For current to flow, sufficient voltage must be applied to overcome this barrier, enabling the electrons to gain enough energy to flow across the diode junction, thus facilitating the current flow from anode to cathode.

2.4. Full Wave Rectifier

A rectifier circuit is an essential component in electrical systems that converts alternating current (AC) into direct current (DC) (Nugraha & Eviningsih, 2022b). This conversion process is fundamental in many applications, including DC motor speed control and power supply systems. Rectifiers are employed to provide the necessary DC voltage for powering sensitive equipment, including motors, which require stable and regulated voltage. There are two primary types of rectifier circuits: the half-wave rectifier and the full-wave rectifier. The latter is often preferred due to its higher efficiency and smoother DC output (Nurfaizah, Istardi, & Toar, 2015).

In the context of DC motor control, the full-wave rectifier circuit is typically used to convert AC from a transformer secondary into DC, which is then used for regulating motor speed. The full-wave rectifier operates by utilizing a diode bridge or a configuration of four diodes arranged in a specific pattern to ensure that both the positive and negative half-cycles of the AC input are used for current flow, thereby providing a more efficient conversion compared to the half-wave rectifier.

The working principle of a full-wave rectifier is based on the behavior of diodes, which allow current to flow in one direction only. When the input signal is in the positive cycle, the diodes become forward biased, allowing current to pass through to the load. Conversely, during the negative cycle, the diodes are reverse biased, preventing current from flowing. This switching between forward and reverse bias ensures continuous current flow to the load, effectively converting AC into DC.

DOI xxxxxx

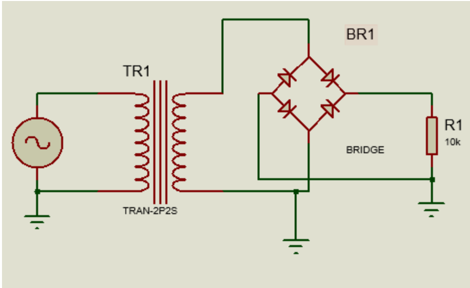

Figure 3. Full Wave Rectifier Circuit

To construct a full-wave rectifier circuit, the key component required is the diode, which is a semiconductor device with two electrodes: the P terminal (anode) and the N terminal (cathode). The operation of the diode depends on its P-N junction, which only allows current to flow when forward biased, meaning the P terminal is connected to the positive side of the circuit and the N terminal to the negative side. This diode behavior ensures that current flows unidirectionally, which is crucial for the rectification process.

Semiconductor diodes are made from the P-N junctions that serve as the core element in rectifiers. The ability of these diodes to only conduct current in one direction makes them indispensable in electronic circuits that require precise and controlled current direction, such as DC motor speed control systems using full-wave rectifiers. The efficiency of these rectifiers directly impacts the performance of DC motors, enabling accurate and reliable motor control.

2.5. DC Voltage Regulator

Voltage regulators are employed to maintain a consistent output voltage from a power source or power supply. A power supply unit typically includes a rectifier and filter circuit (Mutiar, 2017). The output voltage from an unstabilized power source is highly susceptible to fluctuations in the input voltage (mains electricity) and variations in load. Hence, the role of the voltage regulator is to mitigate these two factors, ensuring a stable output voltage.

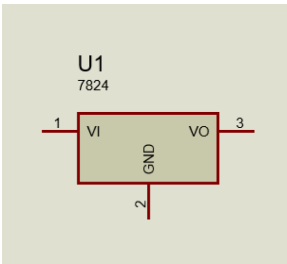

Figure 4. DC Voltage Regulator

2.6. Proteus

Proteus is a PCB design software that also includes PSPICE simulation at the schematic level, allowing you to test circuits before moving to PCB production (Nugraha & Eviningsih, 2022a). This helps ensure the correctness of the design before it's printed. Proteus integrates two key programs: ISIS, used for creating circuit schematic designs, and ARES, which is used for PCB layout creation from the schematic. It is particularly useful for designing microcontroller circuits and learning electronics, ranging from basic electronics to microcontroller applications. Additionally, Proteus comes with many built-in example designs to help users learn from pre-existing applications.

2.7. Schematic Circuit

In the domain of electrical and control systems engineering, the design and simulation of DC motor speed control systems using tools like Proteus software is pivotal for validating the system's functionality before transitioning to hardware implementation. Proteus, a widely recognized simulation software, enables engineers to model the entire motor control system virtually, offering a risk-free environment to test and optimize various components. This simulation encompasses critical elements such as the step-down transformer, full-wave rectifier circuit, voltage filter, DC voltage regulator, and the use of a potentiometer-based voltage divider to fine-tune the motor's speed.

For electrical engineers, this approach holds significant value, as it allows a comprehensive evaluation of the system's performance under different operational conditions without the immediate necessity for physical prototypes. By leveraging Proteus software, engineers can simulate the entire circuit, ensuring that each part interacts as designed and that the DC motor speed control system meets the required specifications. This early-stage simulation not only aids in debugging but also enhances the overall design process by detecting potential issues before hardware development begins.

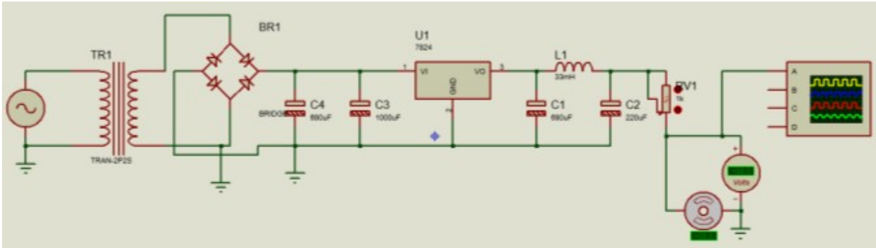

Figure 5. Single phase motor rotation control circuit with frequency parameter

In the system, a fixed DC voltage regulator is employed, which ensures a constant output voltage that cannot be adjusted directly. To enable the adjustment of the output voltage, a potentiometer is utilized as a voltage divider. This configuration allows for fine-tuning of the voltage, providing a variable output that can be controlled according to the specific requirements of the DC motor speed control system. By incorporating the potentiometer, the design offers flexibility in adjusting the voltage, which is essential for optimizing motor performance and ensuring the desired operating conditions.

3. Results and discussion

3.1. Full-wave Rectifier Design

The full-wave rectifier in this design is configured to use a single diode. The output of this rectifier is then directed to both the DC voltage regulator and the motor. The circuit for the full-wave rectifier consists of key components, including a diode, capacitors with values of 680µF and 1000µF, and a resistor with a value of 10kΩ

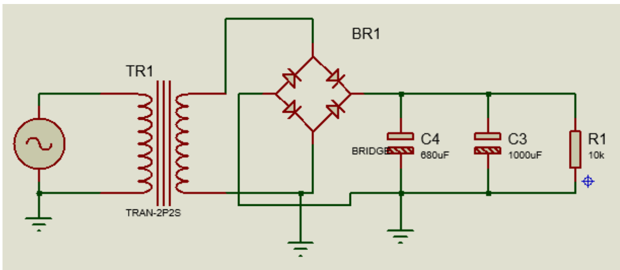

Figure 5. Full wave rectifier circuit using bridge diode

Figure 6 illustrates the full-wave rectifier circuit utilizing a bridge diode within the simulation software. The input voltage to the rectifier is first reduced by a step-down transformer, which lowers the voltage from 220V to 24V. This step-down conversion is essential for matching the voltage requirements of electronic components such as the DC voltage regulator, capacitors, and inductors. By calculating the inductance of the transformer, we can fine-tune the secondary voltage to meet the specific needs of the circuit and ensure optimal performance of the motor and associated components.

$$Lp = (Vin/Vout)^2 \times Ls$$

When,
Lp = Primary Inductance (H)
Ls = Secondary Inductance (H)
Vin = Primary Voltage (Volts)
Vout = Secondary Voltage (Volt)
By using the above formula, if the secondary voltage required is 24V and the primary voltage is 220V, assuming Ls = 1, then:

$$Lp = (220/24)^2 \times 1$$
$$Lp = 84.028 \text{ H}$$

Lp is obtained at 84,028 H, then enter this value into the transformer:
From the stepdown circuit and full-wave rectifier circuit using a diode as shown in Figure 10, the following waves are obtained:

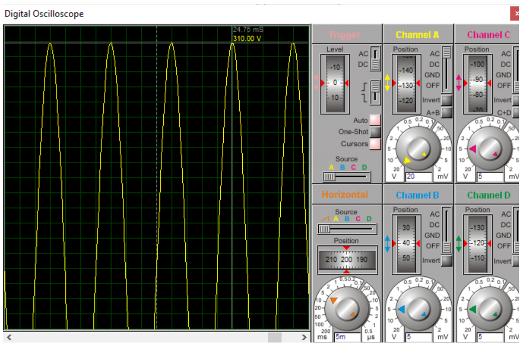

Figure 6. Sinusoidal AC waveform on the primary side of the transformer

The peak of the wave is 311V because the oscilloscope reads the maximum voltage, to get the rms voltage value by multiplying 0.707.

$311 \ x \ 0{,}707 = 220 \ V$.

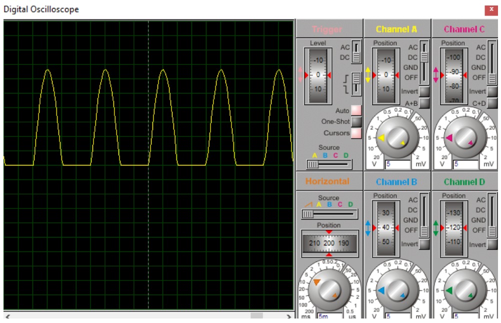

Figure 7. The waveform generated by the full-wave rectifier before being filtered

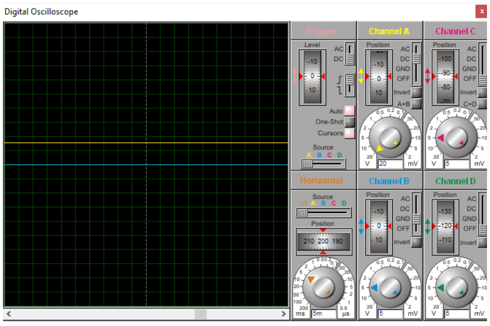

Figure 8. The waveform produced by the full-wave rectifier after filtering

The filter here serves to smooth the voltage resulting from the rectification so that the wave does not have ripple voltages that have the potential to damage electronic components. The filter can use a capacitor in parallel with the load.

3.2. DC Voltage Regulator Design

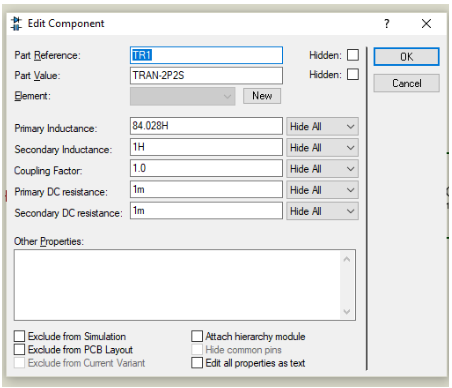

Figure 9. Settings on transformer

DOI xxxxxx

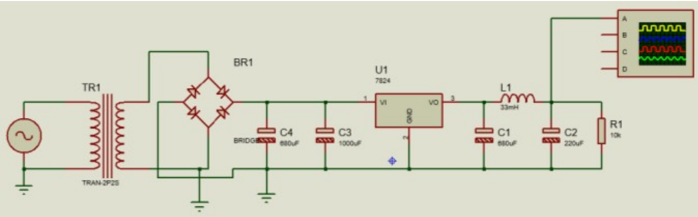

Figure 10. DC voltage regulator circuit.

At the output of the DC voltage regulator, filtering is carried out again to ensure that the resulting waveform is truly pure DC

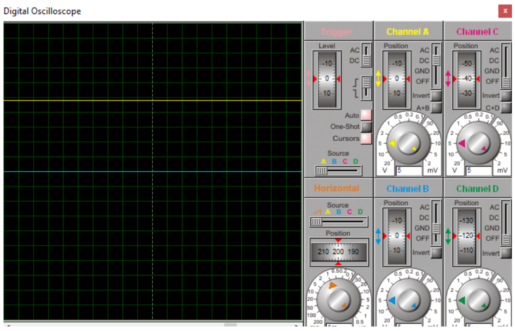

Figure 11. Output waveform of DC voltage regulator

3.3. Testing on DC Motor

The test is carried out when the entire circuit has been arranged and operates normally, so that it can produce an output that is suitable for use as a DC motor supply and reg ulates its rotational speed.

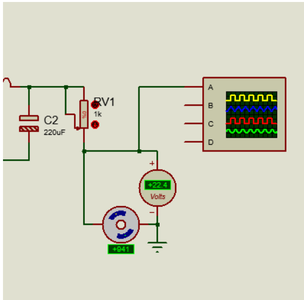

Figure 12. DC motor testing when the circuit is complete

In the experiment, it turned out that the voltage drop was 1.6Volt, it was because the load used was a motor composed of an inductor, so the load current and supply current were not in phase. It can be seen in Figure 13.

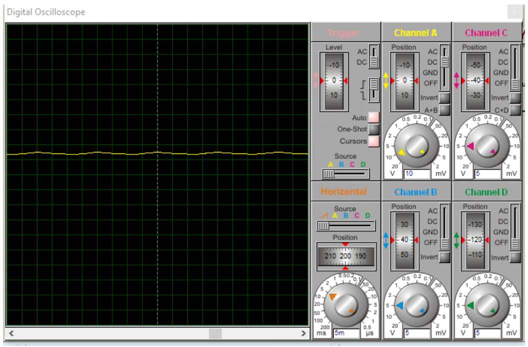

Figure 13. Voltage regulator output waveform when loaded with motor

From each design that has been done including stepdown design, full wave rectifier circuit, DC voltage regulator design, motor load design. Furthermore, it is connected into a circuit that is used to regulate the rotation of the DC motor.

4. Conclusion

Based on the experimental analysis, it can be concluded that controlling the speed of a DC motor is relatively straightforward, with one effective method being the adjustment of the armature voltage (input terminal voltage). This approach allows for fine-tuning the motor speed efficiently. However, it is important to note that if the applied input voltage exceeds the motor's nominal voltage, it can lead to overheating and potential damage to the motor. Conversely, when the voltage is below the nominal value, the motor may fail to operate if the current falls below the required tolerance levels for proper function.

While the simulation results provide useful insights, they are not always perfectly representative of real-world scenarios. For more accurate results, further experimentation with a physical DC motor and the corresponding circuitry is recommended. Although simulations offer valuable predictions, there are often minor discrepancies between simulated conditions and practical implementations. Therefore, for enhanced precision and validation, hands-on testing with actual hardware is crucial to better align with the actual performance of the DC motor system.

Credit authorship contribution statement

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

References

Winardi, Bambang. "PERANCANGAN PURWARUPA SEMIKONVERTER AC-DC 3 PHASE FULL WAVE." Transient: Jurnal Ilmiah Teknik Elektro 1.2 (2021).

Hartono, Bambang Prio, and Eko Nurcahyo. "Analisis Hemat Energi Pada Inverter Sebagai Pengatur Kecepatan Motor Induksi 3 Fasa." Elektrika: Jurnal Teknik Elektro 1.1 (2017): 8-16.

Evalina, Noorly, Abdul Azis, and Zulfikar Zulfikar. "Pengaturan Kecepatan Putaran Motor Induksi 3 Fasa Menggunakan Programmable Logic Controller." JET (Journal of Electrical Technology) 3.2 (2018): 73-80

Ambabunga, Yusri. "Peningkatan Effisiensi Kerja Motor Induksi 3 Phasa (Pengujian Karakteristik Motor Induksi 3 Phasa)." Journal Dynamic Saint 5.1 (2020): 884-889.

Usman, Usman, et al. "Perancangan dan Pembuatan Trainer Penyearah Terkendali 3 Fasa." JTT (Jurnal Teknologi Terpadu) 5.1 (2017)

Mehar, Hemant. "The case study of simulation of power converter circuits using Psim software in teaching." American Journal

Kamiriski, Barttomiej, Krzysztof Wejrzanowski, and Włodzimierz Koczara. "An application of PSIM simulation software for rapid prototyping of DSP based power electronics control systems." 2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No. 04CH37551). Vol. 1. IEEE, 2004.

Hermawan, Arga Tri Agung, Aripriharta Aripriharta, and Puger Homggowiyono. "PENGEMBANGAN BAHAN AJAR KONVERTER BOOST (Studi Kasus pada Mata Kuliah Praktikum Elektronika Daya)." INOVTEK POLBENG 4.2 (2014): 125-130.

Sufyani, Rosyidin, et al. "Kontrol Motor AC 3 Fasa Pada Peluncur Peluru Kendali." Prosiding Seminar Nasional Teknoka. Vol. 4. 2019.

Evalina, Noorly, Abdul Azis, and Zulfikar Zulfikar. "Pengaturan Kecepatan Putaran Motor Induksi 3 Fasa Menggunakan Programmable Logic Controller." JET (Journal of Electrical Technology) 3.2 (2018): 73-80.

Nugraha, Anggara Trisna, et al. "Design of 3-Phase Load Dividing Automatic System with Naive Bayes Method." Journal of Computer, Electronic, and Telecommunication 4.2 (2023).

Nugraha, Anggara Trisna, et al. "Comparison of Buck-Boost Converter with Sepic Converter for Optimization of Wind Power Plant Output Voltage." International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023). Atlantis Press, 2024.

Mutiar, Mutiar. "Jurnal Teknik Elektro PERUBAHAN SUDUT PENYALAAN TIRISTOR PADA PENYEARAH GELOMBANG PENUH TERKENALI PENUH TERHADAP PUTARAN MOTOR DC SERI." Jurnal Teknik Elektro 7.2 (2017): 42-59.

Sheila, Sindy Yurisma, et al. "Coffee Drying Tool with LQR-PID Control." MEIN: Journal of Mechanical, Electrical & Industrial Technology 1.2 (2024): 18-23

Rosdianto, Haris, and Moh Toifur. "Implementasi Teori Distribusi Probabilitas Gaussian Pada Kualitas Rangkaian Penyearah Gelombang Penuh." SPEKTRA: Jurnal Fisika dan Aplikasinya 2.1 (2017): 83-90.

Jatmika, Arifuddin, Abdul Syakur, and Hadha Afrisal. "PERANCANGAN SUMBER TEGANGAN DC SEBAGAI SUPLAI FLYBACK DRIVER DENGAN MENGGUNAKAN MODUL TRIAC DIMMER DAN PENYEARAH GELOMBANG PENUH SATU FASA TAK TERKONTROL BERBASIS WIRELESS UNTUK DIAPLIKASIKAN PADA JENDELA PERANGKAP." Transient: Jurnal Ilmiah Teknik Elektro 1.4 (2021).

Abidin, Zainal, Tabah Priangkoso, and Darmanto Darmanto. "Pengujian Performance Motor Listrik Ac 3 Fasa Dengan Daya 3 Hp Menggunakan Pembebanan Generator Listrik." Majalah Ilmiah MOMENTUM 9.1 (2013).

Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Konsep Dasar Elektronika Daya. Deepublish, 2022.

Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Penerapan Sistem Elektronika Daya: AC Regulator, DC Chopper, dan Inverter. Deepublish, 2022.

Nurfaizah, M., Didi Istardi, and Handri Toar. "Rancang Bangun Modul Praktikum Motor AC Dengan Aplikasi Pengaturan Posisi Dengan Menggunakan PID." Jurnal Integrasi 7.1 (2015): 50-56.