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

Analysis of Output Voltage Characteristics in a Single-Phase Half-Wave Controlled Rectifier Circuit for DC Motor

Lutfi Bimantara
Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya
lutfi.bimantara@student.ppns.ac.id

Abstract

A DC Electric Motor, also known as a Direct Current Motor, is a device that converts electrical energy into kinetic energy or motion. DC motors operate with two terminals and require direct current (DC) to function. These motors are widely utilized in electronic and electrical applications that rely on DC power sources, such as vibrators, DC fans, and electric drills. One of the key parameters for controlling the performance of a DC motor is its rotational speed, which is commonly measured in revolutions per minute (RPM). This speed can be adjusted to meet the requirements of various applications. To achieve variable speed control, a rectifier circuit is often employed. Specifically, a single-phase controlled rectifier circuit is used to convert alternating current (AC) from the power grid (typically 220V AC) into direct current (DC). The controlled rectifier circuit plays a crucial role in rectifying the input AC voltage and providing a stable and regulated DC output to drive the motor, ensuring optimal performance. This paper explores the output voltage characteristics of the single-phase half-wave controlled rectifier circuit and its impact on the performance of a DC motor. The study focuses on the design and analysis of the rectifier circuit, aiming to improve efficiency, stability, and motor control..

Keywords: Electric motor, controlled rectifier, half wave

1. Introduction

The single-phase half-wave controlled rectifier circuit is a fundamental and widely used configuration in power electronics, primarily composed of a single silicon-controlled rectifier (SCR) (Nugraha & Eviningsih, 2022). This simple circuit is typically applied to low-power DC loads that do not require high stability, such as indicator lights in various electronic systems. The rectifier circuit is effective for power conversion tasks where there is a mismatch between the power supply characteristics and the load requirements (Wibowo & Nugraha, 2023). The SCR in the circuit can be triggered at any desired angle (alpha) during both the positive and negative half cycles of the AC input, allowing for a controlled DC output voltage (Agna, Sobhita, & Nugraha, 2023). During the negative half cycle, the thyristor operates as an open switch, blocking the current flow.

The operation of the single-phase half-wave controlled rectifier is based on the switching characteristics of the SCR (Apriani et al., 2022). When a positive bias is applied to the anode of the SCR, with the cathode connected to the negative side of the power source, the SCR acts as a closed switch, allowing current to pass through and rectify the AC signal into DC power (Prastyawan & Nugraha, 2022). On the other hand, when the SCR is forward-biased during the negative half cycle, it behaves as an open switch, interrupting current flow and preventing DC conversion. This natural switching behavior occurs due to the inherent polarity changes of the AC input voltage (Dermawan et al., 2023). The SCR is activated or deactivated depending on the triggering angle, which determines the amount of rectified voltage produced at the output.

A thyristor, also known as a silicon-controlled rectifier (SCR), is a semiconductor device that consists of four alternating layers of N-type and P-type material, forming three terminals: cathode, anode, and gate (Ainudin, Ashlah, & Nugraha, 2022). The gate terminal controls the switching behavior of the SCR by allowing a small current to trigger the device. By adjusting the gate current, the trigger angle (alpha) can be set, which in turn controls the output voltage level of the rectifier (Sasongko et al., n.d.). The gate terminal essentially dictates the timing of the switch, influencing the rectification process and the final DC output.

The single-phase controlled rectifier circuit, utilizing an SCR as the main rectifying component, is referred to as a "controlled rectifier." Although the output voltage can only be set initially and does not dynamically change during operation, it offers a simple yet efficient method for converting AC to DC (Magriza et al., 2021). For example, when a resistive load is used with an AC voltage source, this rectifier circuit will produce a stable, adjustable DC output. The SCR serves as an electronic switch, allowing current to flow in only one direction, and it will remain "off" unless a trigger current is supplied to the gate (Nugraha & Eviningsih, 2022).

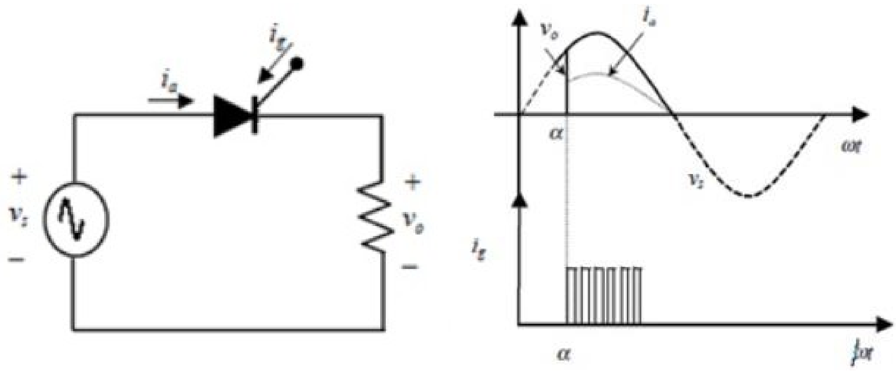
DOI xxxxxx

2. Material and methods

2.1. Rectifier

A wave rectifier is a crucial component in power supply circuits, primarily designed to convert alternating current (AC) signals into direct current (DC) signals (Xu et al., 2022). AC signals, typically in the form of sine waves, are transformed into steady-state DC signals through the rectification process. These converted signals can only be observed and analyzed using advanced measurement tools such as oscilloscopes. In many rectification applications, step-down transformers are employed to adjust the input AC voltage to a desired lower level, in accordance with the transformation ratio of the specific transformer used (Halimi et al., 2022).

- Half Wave Rectifier



(a) (b)

Figure 1. a) Half Wave Rectifier
b) Shape of wave

A half-wave rectifier is a simple rectification system that utilizes a single diode to convert alternating current (AC) voltage into direct current (DC) voltage. This system allows current to flow only during one half-cycle of the AC input, effectively blocking the negative half-cycle (Rotenberg et al., 2020). The output voltage produced by a half-wave rectifier is pulsating DC, which requires additional smoothing or filtering stages for practical applications that require stable DC output. Despite its simplicity, the half-wave rectifier serves as a fundamental circuit in power electronics, especially for low-power applications where precision in voltage regulation is not critical.

2.2. Controlled single-phase waveform rectifier circuit

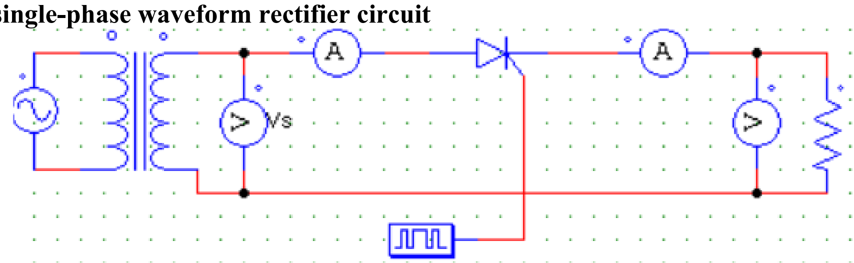


Figure 2. Wirring diagram

The single-phase half-wave controlled rectifier circuit is one of the most basic configurations in power electronics, consisting of a single silicon-controlled rectifier (SCR) that allows for controlled rectification. Typically used for DC loads that do not demand high levels of voltage stability, such as indicator lights in electronic circuits, the half-wave rectifier provides a simple yet effective means of converting alternating current (AC) to direct current (DC). In applications where the power supply and load characteristics may not perfectly match, the single-phase half-wave rectifier still serves as a viable solution. By adjusting the triggering angle (alpha) of the SCR, the rectifier is capable of producing a controllable output voltage during the positive half-cycle, while the SCR effectively acts as an open switch during the negative half-cycle (Chun et al., 2022).

Controlled single-phase half-wave rectifiers, utilizing components such as thyristors (SCR), Insulated Gate Bipolar Transistors (IGBT), or Metal Oxide Semiconductor Field Effect Transistors (MOSFET), offer enhanced flexibility in output control, enabling fine adjustment of the rectified DC voltage. These devices allow for efficient power conversion while maintaining the ability to regulate the output voltage with higher precision, which is especially beneficial in applications such as DC motor drives, where stable yet adjustable DC output is essential.

2.3. Thyristor (SCR)

Figure 3. Thyristor

A thyristor is a semiconductor device that consists of four alternating layers of N-type and P-type materials, which create three terminals: the anode, cathode, and gate (Song et al., 2021). The fundamental operating principle of a thyristor is its ability to control the flow of current through the device, which is regulated by the voltage applied to the gate terminal. The gate terminal, which is controlled by a specific ignition angle, plays a crucial role in determining the extent of AC voltage that is rectified. By adjusting the gate trigger angle, the thyristor regulates the power flow, thereby offering a precise control over the current and voltage in the circuit.

In principle, a thyristor with three terminals uses a relatively low control current or voltage applied to the gate terminal to modulate the flow of higher current or voltage between the anode and cathode terminals (He et al., 2022). This makes it a highly efficient switch for power applications. In contrast, a two-terminal thyristor, which lacks a gate terminal, operates as a simple switch that is activated once the voltage between the two terminals reaches a certain threshold, typically known as the breakdown or breakover voltage. When the applied voltage is below this breakdown voltage, the thyristor remains in an OFF state, blocking current flow. Once the voltage exceeds this threshold, the thyristor enters its ON state, allowing current to flow freely between the two terminals.

2.4. DC Motor

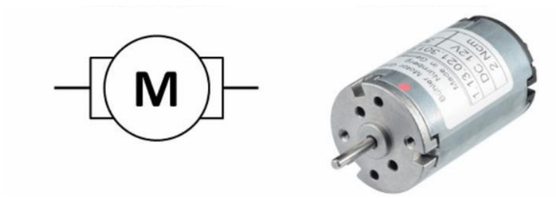


Figure 4. DC Motor

A DC motor is an electrical device that converts electrical energy into mechanical energy in the form of rotational motion, commonly known as kinetic energy (Hartanto, 2021). As indicated by its name, DC motors are powered by a Direct Current (DC) source, which is essential for their operation. These motors feature two terminals one for the positive connection and the other for the negative connection (Anggrila & Astrid, 2024). DC motors are widely utilized in various electronic and electrical devices that rely on DC power sources. Common applications include devices such as HP vibrators, DC fans, and DC electric drills.

One of the key characteristics of DC motors is their ability to produce rotation, commonly measured in revolutions per minute (RPM). The rotation direction, either clockwise or counterclockwise, can be easily controlled depending on the application requirements. The speed at which the motor rotates can also be adjusted within a specified range. DC motors typically operate within a speed range of 3000 to 8000 RPM, depending on the motor's design and the voltage applied. The operational voltage typically ranges from 1.5V to 24V. A reduction in voltage can significantly impede the motor's rotation, while an increase in the supplied voltage results in an increase in rotational speed (Lopatkin, 2021). Consequently, the output speed of the DC motor is directly proportional to the voltage supplied, making it crucial to regulate the voltage for optimal performance in practical applications (Yuniza, Agna, & Nugraha, 2022).

2.5. Methode

1. PSIM Circuit

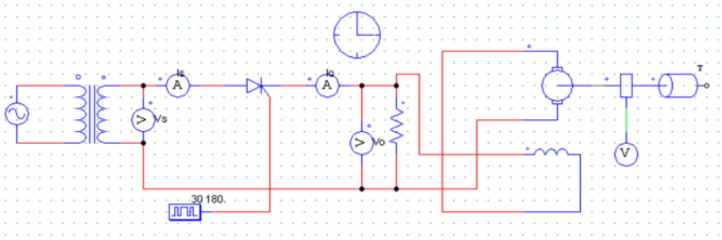


Figure 5. PSIM Wirring Circuit

2. RPM Formula

$$\frac{F \times 20}{P}$$

Where:
F = Frequency
P = Pole

3. Output DC Formula

$$V_{o(dc)} = \frac{3V_{mL-L}}{\pi} = 0.995V_{m,L-L} = 1.654V_{m,L-L}$$

4. Output DC Voltage Formula

$$V_{o(rms)} = V_{m,L-L}\sqrt{\left(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}\right)}$$

$$= 1.6554 \times V_{m,L-L}$$

$$V_{o(rms)} = \frac{V_{m,L-L}}{\sqrt{3}}\sqrt{\left(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}\right)}$$

$$= 0.95575 \times V_{m,L-L}$$

5. Output Ripple Voltage Formula

$$\Delta V_o = \frac{V_m}{6fRC} = \frac{V_{s(\max)(L-N)}}{6fRC}$$

3. Results and discussion

3.1. Wave Graph with oscilloscope measuring instrument

1. **α 30**

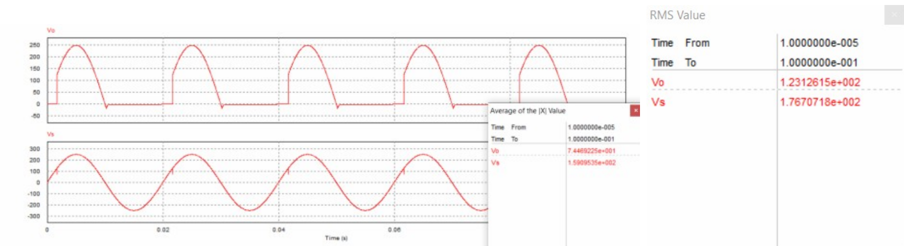


Figure 6. Wave a 30

2. **a 60**

DOI xxxxxx

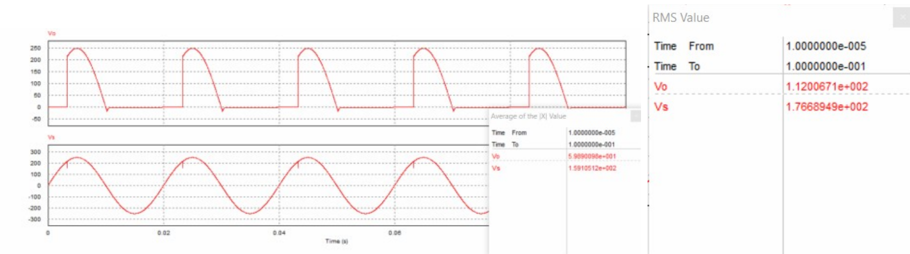


Figure 7. Wave a 60

3. **a.90**

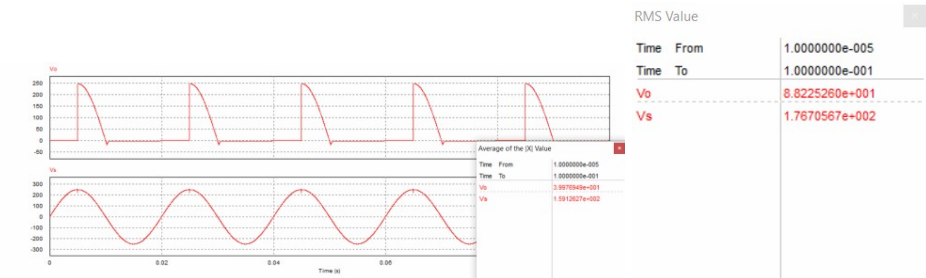


Figure 8. Wave a 90

Table 1. Comparasion

Angle (α)	Vo (DC)	Vo(rms)
30	7.447e+001	1.231e+002
60	5.989e+001	1.120e+002
90	3.997e+001	8.822e+001

Based on the experimental results conducted, the output voltage characteristics of the single-phase half-wave controlled rectifier circuit were analyzed, specifically focusing on both the DC voltage (Vo(DC)) and the RMS voltage (Vo(RMS)) at varying triggering angles. The measurements were taken at three different angles: 30°, 60°, and 90°.

For a trigger angle of 30°, the resulting DC voltage was 74.47 V, while the RMS voltage measured 123.1 V. When the angle was adjusted to 60°, the DC voltage decreased to 59.89 V, and the RMS voltage was recorded at 112 V. Further increasing the trigger angle to 90° led to a substantial reduction in both the DC and RMS voltages, with values of 39.97 V and 88.22 V, respectively.

Manual calculation Half-wave single-phase rectifier circuit.

- a 30

$$V_{o(dc)} = \frac{V_{S(MAX)}}{2\pi}[1+COSa] \qquad V_{o(RMS)} = \frac{V_{S(MAX)}}{2\pi}\sqrt{1-\frac{\propto}{\pi}+\frac{\sin(2a)}{2\pi}}$$

$$V_{o(dc)} = \frac{25}{6.28}[1+\cos 30] \qquad V_{o(RMS)} = \frac{25}{2}\sqrt{1-\frac{0.5236}{3.14}+\frac{\sin 1.0472}{6.28}}$$

$$V_{o(dc)} = 7.4284\text{V} \qquad V_{o(RMS)} = 11.4305\,V$$

- a 60

$$V_{o(dc)} = \frac{V_{S(MAX)}}{2\pi}[1+COSa] \qquad V_{o(RMS)} = \frac{V_{S(MAX)}}{2\pi}\sqrt{1-\frac{\propto}{\pi}+\frac{\sin(2a)}{2\pi}}$$

$$V_{o(dc)} = \frac{25}{6.28}[1 + \cos 60] \qquad V_{o(RMS)} = \frac{25}{2}\sqrt{1 - \frac{1.0472}{3.14} + \frac{\sin 2.0944}{6.28}}$$

$$V_{o(dc)} = 5.9714\text{V} \qquad V_{o(RMS)} = 10.2508\,V$$

- a 90

$$V_{o(dc)} = \frac{V_{S(MAX)}}{2\pi}[1 + COSa] \qquad V_{o(RMS)} = \frac{V_{S(MAX)}}{2\pi}\sqrt{1 - \frac{\propto}{\pi} + \frac{\sin(2a)}{2\pi}}$$

$$V_{o(dc)} = \frac{25}{6.28}[1 + \cos 90] \qquad V_{o(RMS)} = \frac{25}{2}\sqrt{1 - \frac{1.5708}{3.14} + \frac{\sin 3.1416}{6.28}}$$

$$V_{o(dc)} = 3.9809\text{V} \qquad V_{o(RMS)} = 8.9154\,V$$

4. Conclusion

Based on the experiments conducted, the following conclusions can be drawn:

1. Experimental Setup and Results: In the PSIM simulation experiment, the system was tested at three different triggering angles—30°, 60°, and 90°—to evaluate the output voltage characteristics of the single-phase half-wave controlled rectifier circuit. The measurements obtained for both DC voltage (Vo(DC)) and RMS voltage (Vo(RMS)) at these angles are as follows:
   - At an alpha angle of 30°, the output voltages recorded were Vo(DC) = 74.47 V and Vo(RMS) = 123.1 V.
   - At an alpha angle of 60°, the output voltages were Vo(DC) = 59.89 V and Vo(RMS) = 112 V.
   - At an alpha angle of 90°, the output voltages were significantly lower, with Vo(DC) = 39.97 V and Vo(RMS) = 88.22 V.
2. Manual Calculations and Comparison: The manual calculations performed for these angles provide further insight into the output voltage characteristics. The calculated values for Vo(DC) and Vo(RMS) are as follows:
   - For an alpha angle of 30°, the calculated values were Vo(DC) = 7.4284 V and Vo(RMS) = 11.4305 V.
   - For an alpha angle of 60°, the calculated output voltages were Vo(DC) = 5.9714 V and Vo(RMS) = 10.2508 V.
   - For an alpha angle of 90°, the calculated values were Vo(DC) = 3.9809 V and Vo(RMS) = 8.9154 V.
3. Analysis of Experimental and Calculated Results: There is a noticeable and significant discrepancy between the experimental and calculated results, with the experimental values being approximately 10 times higher than the calculated values. This difference suggests that certain external factors or ideal assumptions in the manual calculations may have influenced the accuracy of the theoretical predictions.
4. Trend Analysis: A clear trend is observed in both the experimental and calculated results: as the alpha angle increases, both the DC output voltage and the RMS voltage decrease proportionally. This also correlates with a reduction in the rotational speed (RPM) of the DC motor, which is controlled by the output voltage. The findings demonstrate that the rectifier's performance is highly sensitive to the triggering angle, making it crucial to control this parameter for optimal motor operation..

Credit authorship contribution statement

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

References

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

Wibowo, Muhammad Ferdiansyah, and Anggara Trisna Nugraha. "PERENCANAAN SISTEM PROPULSI ELEKTRIK PADA FAST PATROL BOAT 28 METER." Proceedings Conference on Marine Engineering and its Application. Vol. 6. No. 1. 2023.

Agna, Diego Ilham Yoga, Rama Arya Sobhita, and Anggara Trisna Nugraha. "Penyearah Gelombang Penuh 3 Fasa Tak Terkendali dari Generator Kapal AC 3 Fasa." Seminar MASTER PPNS. Vol. 8. No. 1. 2023.

DOI xxxxxx

Apriani, Mirna, et al. "Coastal Community Empowerment Recovery of cockle shell waste into eco-friendly artificial reefs in Mutiara Beach Trenggalek Indonesia." Frontiers in Community Service and Empowerment 1.4 (2022).

Prastyawan, Rikat Eka, and Anggara Trisna Nugraha. "PENERAPAN TEKNOLOGI INFORMASI UNTUK PEMBELAJARAN TEST OF ENGLISH FOR INTERNATIONAL COMMUNICATION PREPARATION." Jurnal Cakrawala Maritim 5.1 (2022): 4-8.

Dermawan, Deny, et al. "Penyearah Setengah Gelombang 3 Fasa Tak Terkendali dari Generator AC 3 Fasa." Seminar MASTER PPNS. Vol. 8. No. 1. 2023.

Ainudin, Fortunaviaza Habib, Muhammad Bilhaq Ashlah, and Anggara Trisna Nugraha. "Pengontrol Kecepatan Respon Motor dengan Pid dan Lqr." Seminar MASTER PPNS. Vol. 7. No. 1. 2022.

Sasongko, Adhy, et al. "Estimation of the thrust coefficient of a Quadcopter Propeller using Computational Fluid Dynamics."

Magriza, Rania Yasmin, et al. "Design and Implementation of Water Quality Control in Catfish Farming Using Fuzzy Logic Method with IoT-Based Monitoring System." Jurnal Teknologi Maritim 4.1 (2021): 13-18.

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

Xu, Z., Khalifa, A., Mittal, A., Nasrollahpourmotlaghzanjani, M., Etienne-Cummings, R., Sun, N. X., ... & Shrivastava, A. (2022). Analysis and design methodology of rf energy harvesting rectifier circuit for ultra-low power applications. IEEE open journal of circuits and systems, 3, 82-96.

Halimi, M. A., Khan, T., Kishk, A. A., & Antar, Y. M. (2022). Rectifier circuits for RF energy harvesting and wireless power transfer applications: A comprehensive review based on operating conditions. IEEE Microwave Magazine, 24(1), 46-61.

Rotenberg, S. A., Podilchak, S. K., Re, P. D. H., Mateo-Segura, C., Goussetis, G., & Lee, J. (2020). Efficient rectifier for wireless power transmission systems. *IEEE Transactions on Microwave Theory and Techniques*, *68*(5), 1921-1932.

Chun, A. C. C., Ramiah, H., & Mekhilef, S. (2022). Wide power dynamic range CMOS RF-DC rectifier for RF energy harvesting system: A review. *IEEE Access*, *10*, 23948-23963.

Song, X., Cairoli, P., Du, Y., & Antoniazzi, A. (2021). A review of thyristor based DC solid-state circuit breakers. IEEE Open Journal of Power Electronics, 2, 659-672.

He, J., Lyu, H., Li, B., Li, Y., Wen, W., Spier, D. W., ... & Gomis-Bellmunt, O. (2022). A passive thyristor-based hybrid DC circuit breaker. IEEE Transactions on Power Electronics, 38(2), 1791-1805.

Anggrila, B., & Astrid, E. (2024). Rancang Bangun DC Chopper Empat Kuadran untuk Motor DC dengan Monitoring Simulink Matlab. MSI Transaction on Education, 5(4), 185-196.

Hartanto, S. (2021). Pengaruh Beban Barang Pada Ban Berjalan Terhadap Kecepatan Motor Penggerak. Prosiding Penelitian Pendidikan dan Pengabdian 2021, 1(1), 1383-1388.

Lopatkin, N. N. (2021, November). Output Voltage and Current Waveforms' PSIM Simulation of Three-Phase Seven-Level Cascaded H-Bridge Inverter. In 2021 International Conference on Electrotechnical Complexes and Systems (ICOECS) (pp. 574-579). IEEE.

Yuniza, S. I., Agna, D. I. Y., & Nugraha, A. T. (2022). The Design of Effective Single-Phase Bridge Full Control Resistive Load Rectifying Circuit Based on MATLAB and PSIM. International Journal of Advanced Electrical and Computer Engineering, 3(3).