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Analysis of a 3-Phase Uncontrolled Full-Wave Rectifier Using a 3-Phase AC Generator

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Abstract

The rapid advancements in technology are influencing various sectors, with electrical engineering being one of the most affected fields. As access to information becomes increasingly easier, innovations in both science and technology progress at an accelerated pace. To keep up with these developments, there is a growing need to optimize existing knowledge for future use. In the realm of electrical engineering, optimizing theories and practical applications is crucial to improving the efficiency and functionality of power systems, particularly in the industrial sector where the demand for electricity is substantial. A significant way to achieve this optimization is through the study and analysis of the three-phase uncontrolled full-wave rectifier circuit powered by a three-phase AC generator. This paper aims to provide an in-depth analysis of this system, with the goal of enhancing its performance and efficiency for industrial applications. By understanding the theoretical foundations and practical challenges of this rectifier circuit, we can create more effective and sustainable power conversion systems for the future.

Keywords: 3 phasa, rectifier, full wave, generator

1. Introduction

The rapid advancements in technology have led to significant changes across various sectors, with the technological aspect being particularly influential (Nugraha & Eviningsih, 2022a). Technology has become an indispensable part of human life, simplifying and enhancing processes in numerous fields. As technology evolves, so too does the composition and complexity of electrical components, which now require specialized knowledge and expertise to design and implement correctly. Understanding the fundamentals of electrical components is essential for the advancement of future technologies and for ensuring that electrical systems are both efficient and reliable.

The scope of electrical components is vast, given their diversity and varied functions. Consequently, studying these components demands significant time and focus. For optimization purposes, this research narrows its focus to a specific area: the study of three-phase rectifiers, which are increasingly critical in industrial applications. The industrial sector, as we know, has seen a surge in electricity demand, and a deep understanding of electrical components, particularly those used in power conversion systems, is vital to ensure efficient and ergonomic operations.

Industrial processes, which account for a substantial portion of energy consumption, depend heavily on electric motor-driven systems. These systems, responsible for critical tasks such as refrigeration, pumps, fans, compressors, materials handling, and HVAC systems, consume around 68% of the total industrial electricity Department of Energy, n.d.). Industrial machinery, of various types and functions, has specific electricity requirements, such as power output and voltage specifications. Focusing on three-phase electricity, particularly in machinery and generators, is crucial for improving the efficiency of industrial operations.

This study aims to contribute to a better understanding of three-phase uncontrolled rectifier circuits, specifically those powered by an AC generator. By optimizing the performance of such circuits, the research seeks to enhance the efficiency of industrial systems, providing solutions that can advance the application of electricity in the industrial world (Nugraha & Eviningsih, 2022b). Ultimately, this study aims to offer new insights into the practical use of three-phase rectifiers in industries, leading to optimized energy use and improved performance in industrial machinery.

2. Material and methods

2.1. Generator

A generator is a fundamental device used to convert mechanical energy into electrical energy, playing a crucial role in the production of electrical power across various applications. By harnessing mechanical motion, a generator can produce electrical energy either in the form of alternating current (AC) or direct current (DC), depending on the specific needs and design of the generator. When a generator produces alternating current, it is commonly referred to as an alternator. This electrical conversion process is governed by key physical principles, particularly Faraday's Law of Induction, which describes how a change in magnetic flux generates an electric current, and Lenz's Law, which provides insight into the direction of induced currents. These laws are fundamental to understanding the operation of generators and the efficient conversion of mechanical energy into electrical power.

A. Use of generator

In accordance with the ability of a generator that is able to convert mechanical energy into electrical energy, generators have an important role in supplying power to other equipment, especially in the industrial world, which has a lot of loads and of course equipment and machines require an adequate and well-distributed electricity supply. well, either in the position of the main source or backup source. A three phase synchronous generator with rectifier may be subjected to various electrical faults during its operation. (Sabir, 2019)

B. Generator working system

The generator in its action produces a movement in the form of rotation, the rotation that occurs in the generator is powered by fuel in the form of diesel by moving the generator which is a copper coil in the form of a wire consisting of a static coil or stator and also a rotating coil or rotor. The rotation of this generator utilizes a magnetic field to generate electricity by utilizing Faraday's law and Lenz .'s law

- Faraday’s law

Faraday’s Law of induction is often stated as “a change in magnetic flux causes an electro-motive force (EMF)”; or, more cautiously, “a change in magnetic flux is associated with an EMF” (Kinsler, 2020). Faraday’s Law states that when a conductor moves through a magnetic field of given field strength, a voltage level is produced in the conductor that is dependent on the relative velocity between the conductor and the field (Kopp & Garrison, 2020).

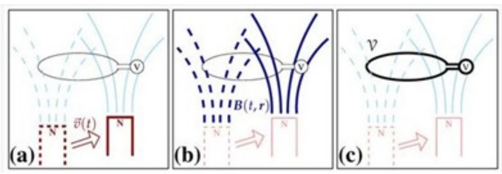


Figure 1 faraday magnets (Kinsler, 2020)

$$\varepsilon = \frac{-d\phi B}{dt}$$

Symbol:
ϕB = Fluks Magnetik (weber)

However, if the application is used on a solenoid which consists of several N turns, then the formula has developed to

$$\varepsilon = -N\frac{d\phi B}{dt} = \frac{d(N\phi B)}{dt}$$

Symbol:
ϕB = Fluks Magnetik (weber)
N = number of turn coil

- Lenz’s law

Lenz's law is one of the laws that also plays a role in the work of magnets in generators like Faraday's law. The law of Lenz as an energy conservation law between the electric field and the magnetic field allows the charge current and spin current generated by matters and antimatters to be symmetrical with each other (Oh & Liu, 2020). When a magnetic field is switched on in the presence of a conductive object, an eddy current (or Foucault current) is induced in the object. An eddy current is a loop of electrical current induced in a conductor by a time-varying magnetic field in the conductor (Williams, n.d.)

C. Construction of generator
Generators are broadly divided into 2 parts which are distinguished by the way they move, there are moving parts and immovable parts. The moving part is referred to as the "rotor" part. The stationary part of the generator is referred to as the "stator" part.

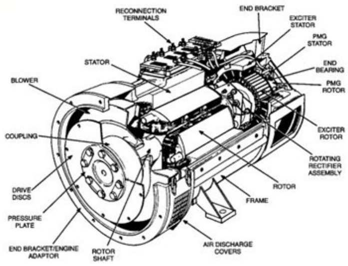


Figure 2. Generator structure (Juhari, 2014)

- Rotor

  The rotor is divided into 2 types according to the poles, namely the salient pole type and the cylindrical pole (Zhu et al., 2018). The protruding pole generator is often used for generators that are not fast or low and medium speeds, while in cylindrical pole type generators it will be used for high-speed generators. ctive control is one of the most important advantages of active magnetic bearing (AMB), and also can be used to suppress the imbalance of AMB rotor system (AMB-RS) (Ni, 2019).

  The rotor consists of several parts, namely:
  1. Field Coil
  2. Polar Core

- Stator

  The stator is the stationary part of the generator which functions to induce the magnetic field generated by the rotor Large generators are the principal pieces of equipment in power systems, and their operation reliability critically depends on the stator insulation. Damages in stator insulation will gradually lead to the failure and breakdown of generator (Li & Liu, 2018)
  The stator consists of several parts, namely:
  1. Stator winding
  2. Stator housing
  3. Stator core
  4. Stator groove

2.2. Diode

A diode is a fundamental semiconductor device commonly used in electronics. It consists of two terminals: the anode (A) and the cathode (K). These terminals are attached to opposite sides of the diode, with the anode serving as the positive terminal and the cathode as the negative terminal. The diode is essentially composed of two different semiconductor materials: n-type and p-type, which, when combined, form a p-n junction. This junction is the core of the diode’s functionality, allowing it to control the direction of electrical current (Ni, 2019).

Diodes play an integral role in modern electronics, primarily used for rectifying electric current (Achmad & Nugraha, 2022). The specific diode utilized in this study is a PN junction diode, which is crucial in converting alternating current (AC) into direct current (DC). Rectification is a vital process in various applications, particularly in power supplies, where converting AC to DC is necessary for the functioning of many electrical devices.

A. Applications of Diodes:
In practical applications, diodes function like a one-way valve for electrical current, permitting current to flow in only one direction while blocking it in the reverse direction (Ge et al., 2018). This behavior makes them indispensable in rectification processes. However, if the current or voltage exceeds the

diode's rated capacity, it may lead to diode failure, rendering it incapable of performing its rectification function effectively. Proper sizing and design considerations are essential to prevent such damage in high-voltage or high-current applications, such as in industrial machinery and power generation systems.

B. Diode Operation:
In an ideal diode, when it is in a conducting state (ON), the voltage drop across the anode-cathode junction (Vak) is zero. In this condition, the current passing through the diode is equal to the current flowing through the load, ensuring that the electrical energy is efficiently transferred to the system. Conversely, when the diode is in a non-conducting state (OFF), the voltage drop across the anode-cathode junction equals the supply voltage connected to the diode, while no current flows through the diode. This blocking behavior is essential for the diode to perform its rectifying role, preventing reverse current that could damage the circuit or connected components.

2.3. Rectifier Circuit

The rectifier circuit is an attempt to change the direction of an AC circuit that moves back and forth, into a DC circuit that moves in one direction by providing resistance that specifically blocks current and voltage from one direction only. The rectifier circuit is divided into uncontrolled rectifier circuit, half controlled rectifier circuit and controlled rectifier circuit. To make a half-wave rectifier circuit required components in the form of resistors, capacitors, diodes, transformers.

A. Uncontrolled rectifier circuit
Uncontrolled rectifier, is a form of power electronic circuit that has a function as a converter of AC voltage into DC voltage where these changes can be regulated and controlled so that they can produce various outputs as needed. The effectiveness of the proposed scheme is demonstrated on a variable power fed 3-φ uncontrolled rectifier connected to the boost converter (Jain, 2018).

2.4. Sinusoidal wave

A sinusoidal wave is an output wave in the form of a sine and a cosine. In this experiment, especially in the field of electricity, this wave signal is used to see the frequency emitted by electricity, making it easier for humans or researchers to study electricity.

Generally full wave and half wave. At full wave, the wave is shaped like a mountain and connected by a valley, this keeps repeating until the electricity is stopped. In half waves, as the name implies, only half waves that come out in the form of hills without valleys, will continue to move if electricity continues to be connected to the flow. The firstly generated waveform may not be perfectly linear, including unwanted harmonics. (Kweon & Kwon, 2022). In the following linearity-enhancement step, these harmonics are attenuated by using filters typically. As the linearity of the waveform is improved, the precision of the EIS system gets ensured (Kweon & Kwon, 2022).

2.5. Methods

The research method used in this paper is the participant observation method. This method positions the researcher as a dual actor, the role that is carried out is as an observer of the experiment and other roles that are carried out, namely as part of what will be observed. The author in this research is to get data from the magnitude of the voltage, current and power from a rectifier circuit that gets a supply voltage from a 3-phase generator to the load to be powered. This is measured to see how optimally the generator works in a rectifier circuit that flows to the existing load, so it is hoped that by obtaining this data, it will minimize damage to a machine tool powered by a generator.

A. Data Analysis Techniques
Data analysis in this study is to create an organized sequence, manipulate the amount and abbreviate the data, so that it is hoped that it will be easy to read later for review.

- Output DC

$$V_{o(dc)} = (3V\_(m.L\text{-}L))/\pi$$

$$V_{o(dc)} = 0{,}955\ V_{m,L\text{-}L} = 1{,}654 V_{m,L\text{-}N}$$

- Output RMS

DOI xxxxxx

$$V_{o\,(rms)} = V_{m,L\text{-}N} \times \sqrt{(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi} ¿)} = ¿¿ 1{,}6554 \text{ x } V_{m,L\text{-}N}$$

$$V_{o\,(rms)} = \frac{V_{m,L-L}}{\sqrt{3}} \times \sqrt{(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi} ¿)} = ¿¿ 0{,}95575 \text{ x } V_{m,L\text{-}L}$$

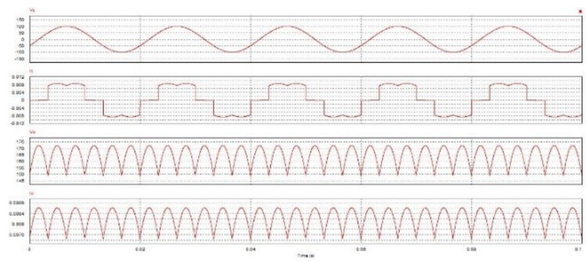
B. Research Media

Research media is an aspect that needs to be considered in making an experiment, with good and easy-to-use research media, it will make it easier for writers to collect data and make it easier for readers to digest the experimental results. The following are the media used in this study:

- PSIM Software

PSIM software or short for PowerSim is a virtual simulation-focused software designed for power electronics, motor drive and power conversion systems. This software is very helpful and makes it easier for researchers to indirectly carry out simulations only through laptops. Data retrieval is intentionally taken through software so it doesn't take up a lot of time.

PSIM software is not only adrift as a simulation medium, but this software is able to help enter data in the form of bits which can later be used as microcontroller media. That way it can be concluded that this software is very helpful in human tasks in various ways, especially in the world of electronics



3. Results and discussion

3.1. Result

The research results taken from this experiment came from the PSIM software simulation. The data taken has gone through the simulation process and has changed from the magnitude of the voltage released from the generator.

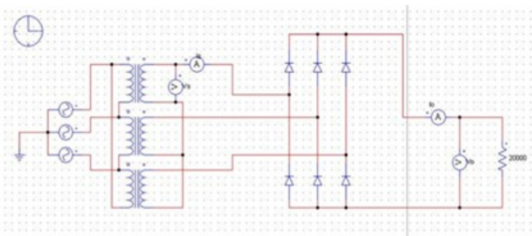


Figure 3. PSIM simulation and sinusoidal wave

In the results of this experimental sinusoidal wave, we can see that there are 4 kinds of waveforms in it which of the 4 waves represent the movement of the measuring instrument installed in the experimental circuit, namely the source voltage "Vs", the output voltage "Vo", the incoming current "Is" and Outflow “Io”. The following are the results of the measurement table from this experiment:

Table 1. Result of the project

No	Vs (V) (Volt)	weight	Is (rms) (A) (Ampere)	Is (Prct) (A) (Ampere)	Vo (rms) (V) (Volt)	Vo (Prct) (V) (Volt)	Io (rms) (A) (Ampere)	Io (Prct) (A) (Ampere)
1	100		0,006	0,005	164,5	164,4	0,008	0,008
2	120		0,008	0,006	197,7	197,5	0,009	0,009

3	140	20KΩ	0,009	0,007	230,9	230,7	0,011	0,011
4	160		0,010	0,008	264,1	263,9	0,013	0,013
5	200		0,013	0,011	330,5	330,2	0,016	0,016

The table above is the result of the simulation carried out on PSIM simulation softwear. We can see that there is a change in the values sought, therefore this experiment will be discussed in the discussion sub-chapter. Here is also attached the result of sinusoidal wave from PSIM software regarding one of the data attached in the table.

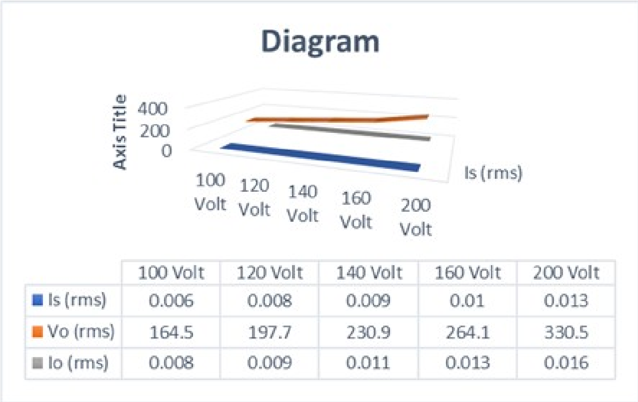


Figure 4. diagram simulation

Here, the authors include the experimental results on the PSIM simulation program in the form of pictures, tables and in the form of graphs, so that readers are easy to understand and easy to study. The discussion of the experimental results will be discussed in the discussion subsection.

A. Calculation

From the data obtained from the simulation results, a comparison will be carried out with direct calculations from the existing formula, namely using the following formula:

- Output DC

Vo(dc) = (3V_(m.L-L))/π =

Vo(dc)= 0,955 Vm,L-L = 1,654Vm,L-N

- *output* RMS

$$V_{o\,(rms)} = V_{m,L\text{-}N} \times \sqrt{(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}¿)} = ¿¿ 1{,}6554 \text{ x } V_{m,L\text{-}N}$$

$$V_{o\,(rms)} = \frac{V_{m,L-L}}{\sqrt{3}} \times \sqrt{(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}¿)} = ¿¿ 0{,}95575 \text{ x } V_{m,L\text{-}L}$$

The experimental circuit is mounted on a diode and resistor component in it, with the amount of voltage being changed

- Vm = 100 V

$V_{o\,(rms)} = 1{,}6554 \text{ x } V_{m,L\text{-}N} = 1{,}6554 \text{ x } 100 = 165{,}5$ V

$$Io_{\,(rms)} = \frac{V_o}{R} = \frac{165{,}5}{20000} = 0{,}008 \text{ A}$$

$$Is_{\,(rms)} = \frac{I_m}{\sqrt{2}} = \frac{0{,}009}{\sqrt{2}} = 0{,}006 \text{ A}$$

- Vm = 120 V

$V_{o\,(rms)} = 1{,}6554 \text{ x } V_{m,L\text{-}N} = 1{,}6554 \text{ x } 120 = 198{,}6$ V

DOI xxxxxx

Io $_{(rms)} = \frac{V_o}{R} = \frac{198,6}{20000} = 0,009$

Is $_{(rms)} = \frac{I_m}{\sqrt{2}} = \frac{0,011}{\sqrt{2}} = 0,008$ A

- Vm = 140 V

$V_{o\,(rms)} = 1,6554 \times V_{m,L\text{-}N} = 1,6554 \times 140 = 231,7$ V

Io $_{(rms)} = \frac{V_o}{R} = \frac{231,7}{20000} = 0,011$

Is $_{(rms)} = \frac{I_m}{\sqrt{2}} = \frac{0,012}{\sqrt{2}} = 0,009$ A

- Vm = 160 V

$V_{o\,(rms)} = 1,6554 \times V_{m,L\text{-}N} = 1,6554 \times 160 = 264,8$ V

Io $_{(rms)} = \frac{V_o}{R} = \frac{264,8}{20000} = 0,013$

Is $_{(rms)} = \frac{I_m}{\sqrt{2}} = \frac{0,014}{\sqrt{2}} = 0,010$ A

- Vm = 200 V

$V_{o\,(rms)} = 1,6554 \times V_{m,L\text{-}N} = 1,6554 \times 200 = 331,0$ V

Io $_{(rms)} = \frac{V_o}{R} = \frac{331,0}{20000} = 0,016$

Is $_{(rms)} = \frac{I_m}{\sqrt{2}} = \frac{0,018}{\sqrt{2}} = 0,013$ A

The calculation data is written in the following table:

Table 2. Simulation and manual

Vs	Is (rms) (Ampere)	Is (Teori) (Ampere)	Vo (rms) (Volt)	Vo (Teori) (Volt)	Io (rms) (Ampere)	Io (Teori) (Volt)
100	0,006	0,006	164,5	165,5	0,008	0,008
120	0,008	0,008	197,7	198,6	0,009	0,009
140	0,009	0,009	230,9	231,7	0,011	0,011
160	0,010	0,010	264,1	264,8	0,013	0,013
200	0,013	0,013	330,5	331,0	0,016	0,016

It can be seen from the results obtained from the comparison of the calculation and measurement data that the data is close to the same and the error is slightly different. Then it can be concluded that the data processed is appropriate

3.2. Discussion

The experiment focuses on the success of a 3-phase AC generator (alternator) in supplying AC electricity to a rectifier circuit with a load. The data obtained align well with the expected results. The waveforms from the experiment demonstrate the conversion of AC waves to DC, though not perfectly ripple-free. The source voltage (Vs) shows a perfect AC waveform, with one valley and one peak at ±100 volts, reflecting the 100-volt input. This is due to the alternator's AC output before passing through the rectifying diode.

DOI xxxxxx

The current source (Is) measurements indicate AC waves transitioning to DC due to the diode's rectifying action, appearing as partial waves rather than standard AC. The output voltage (Vo) and output current (Io) show truncated waves, with only peaks remaining, indicating DC electricity. However, the DC is not ideal, as ripples persist. Perfect DC electricity is achieved when the wave becomes a straight line without fluctuations, matching the input voltage.

This experiment highlights the limitations of achieving perfect unidirectional electricity and the importance of reducing ripples for efficiency. Sinusoidal ripple current charging (SRC) is noted for its high charging efficiency, and HVDC systems are seen as a promising solution to meet growing energy demands.

4. Conclusion

From the experiments that have been carried out this time, of course, a result has been obtained from the experiment and answered the existing questions. Thus we can conclude that:

- The AC generator can be converted to DC electricity using a rectifier circuit
- Diodes are semiconductor components that are capable of closing one direction of electricity flow into one direction, thus changing the AC power flow to DC
- The rectifier circuit can be effectively used with the help of capacitors to eliminate ripple or ripples in it

Credit authorship contribution statement

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

References

Aizat Azmi, N. A.-M. (2019). The use of enhancement material in grounding system: a review. Indonesian Journal of Electrical Engineering and Computer Science, 453-460.

ASWARDI, M. Y. (2020). TEKNIK ELEKTRONIKA DAYA. IRDH Book Publisher.

Chen, J.-G., lee, y.-d., & park, s.-y. (2015). Adaptive PI gain control to realize sinusoidal ripple current charging. IEEE Xplore. Seoul, South korea.

ENERGY, U. D. (n.d.). Electic machines. Retrieved from Advanced Mannufacturing: https://www.energy.gov/eere/amo/electric-machines

ge, B., Li, X., Zhang, H., Liu, Y., S.Balog, R., & Abu-Rub, H. (2018). Direct Instantaneous Ripple Power Predictive Control for Active Ripple Decoupling of Single-Phase Inverter. IEEE Xplore, 3165 - 3175.

J. G. Kopp, B. G. (2020). Magnetic Flowmeter. CRC Press.

Jain, T. (2018). Fault Diagnosis for Open-Circuited Faults in 3-Phase Uncontrolled Rectifier of Wind Energy Power Conversion Systems. International Conference on Control, Automation, Robotics and Vision (ICARCV) (pp. 92-97). IEE Xplore.

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.

Juhari, D. E. (2014). Generator. Kementerian Pendidikan dan Kebudayaan Republik Indonesia.

Kinsler, P. (2020, May 6). Faraday's Law and Magnetic Induction: Cause and Effect, Experiment and Theory. pp. 150-163.

Achmad, Irgi, and Anggara Trisna Nugraha. "Implementasi Buck-Boost Converter pada Hybrid Turbin Angin Savonius dan Panel Surya." Journal of Computer, Electronic, and Telecommunication (COMPLETE) 3.2 (2022).

Ni mo, Y. z. (2019). Unbalance Compensation and Automatic Balance of Active Magnetic Bearing Rotor System by Using Iterative Learning Control. IEEE xplore.

PatilSwapnil Sanjay, P. W. (2018). SYMMETRICAL MULTILEVEL CASCADED H-BRIDGE INVERTER USING. NAUVATEUR PUBLICATIONs.

Ruihua li, H. l. (2018, august 21). Damage Identification of Large Generator Stator Insulation Based on PZT Sensor Systems and Hybrid Features of Lamb Waves.

Russell Sabir, D. R. (2019). Detection and Localization of Electrical Faults in a Three Phase Synchronous Generator with Rectifier. International Conference on Electrical Drives & Power Electronics (EDPE). Yhe High Tatras, Slovakia: IEEE.

soon-jae kweon, A. k.-i. (2022). On-chip Sinusoidal Signal Generators for Electrical Impedance Spectroscopy: Methodological Review. IEE Xplore.

Teresa oh, X. L. (2020). Sensitivity of Dirac fermion and Weyl fermion by the Energy Conservation. Research Square.

williams, H. (n.d.). A perpetual motion machine powered by lenz's law. research gate.

Zhu, Y., Shi, S., Wang, F., Zhuo, F., Cheng, S., & Yi, H. (2018). Quasi Square Wave Modulation With Voltage Transformation Ability Applied to Modular Multilevel DC-DC Converter. 2018 IEEE Energy Conversion COngress and Exposition (pp. 23-27). Portland,OR,USA: IEE Explore.