Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi
Terakreditasi "**Peringkat 3**" berdasarkan SK Dirjendiktiristek, Nomor: 225/E/KPT/2022
Volume 6 Nomor 1 Tahun 2024, Januari 2024, Halaman 103-112
Website : http://journal.univpancasila.ac.id/index.php/asiimetrik/

p-ISSN 2655-1861
e-ISSN 2716-2923

Comparative Analysis of a Rectifier Performance in Power Generation Applications

Analisa Perbandingan Kinerja Rectifier pada Aplikasi Pembangkit Tenaga Listrik

Sri Agustina, Herlina Wahab*, Djulil Amri, Al Denton Mourzade
Electrical Dept of Engineering Faculty, Sriwijaya University, Inderalaya, Indonesia

Article information:

Received:
10/11/2023
Revised:
29/11/2023
Accepted:
02/12/2023

Abstract

Electrical energy's significance is critical to human life, as seen by the rising usage of this resource. Electricity-consuming machinery and technology are developing at an accelerating rate. A substantial electrical power supply is required to achieve these requirements. An effective method to address this issue is to use a generator set powered by an electric motor. This generator necessitates the use of a converter, which serves the purpose of transforming alternating waves (AC) into direct waves (DC), generally referred to as a rectifier. The rectifier's unsatisfactory performance necessitates the need for this research, which seeks to develop and construct a rectifier and subsequently compare its performance utilizing two distinct current sources. Rectifier performance is obtained through the utilization of direct computation and measuring methods. Two sources charge the battery: direct current from the motor and alternating current from the power grid. According to the test results, the converter using an electric power plant source had a higher current value. On the generator, the battery charges up to 13.4 volts in 55 minutes, which is 5 minutes quicker than on the PLN source.

Keywords: rectifier, generator set, power grid, performance, comparative.

***SDGs*:**

Abstrak

Konsumsi energi listrik yang makin meningkat merupakan salah satu indikasi bahwa perannya sangat penting bagi kehidupan manusia. Untuk memenuhi kondisi tersebut diperlukan sumber tenaga listrik yang besar. Salah satu bentuk upaya untuk mengatasi hal tersebut adalah dengan Generator set dengan motor listrik sebagai penggeraknya. Pada Pembangkit ini diperlukan konverter yang berfungsi sebagai pengubah gelombang bolak balik (AC) menjadi gelombang searah (DC) atau lazim disebut dengan *rectifier*. Permasalahan yang timbul pada *rectifier* adalah kinerja yang tidak begitu bagus, sehingga penelitian ini bertujuan untuk mendisain, membuat *rectifier* dan membandingkan kinerjanya dengan menggunakan dua sumber arus. Metode perhitungan dan pengukuran langsung digunakan untuk mendapatkan kinerja *rectifier*. Pengisian arus ke batere menggunakan dua sumber, yaitu dari motor langsung dan dari *power grid*. Dari hasil pengujian pada diperoleh nilai arus yang lebih besar pada rectifier dengan sumber Pembangkit Listrik Tenaga Listrik. Untuk waktu pengisian pada baterai selama 55 menit hingga 13,4 Volt lebih cepat 5 menit pada generator dibandingkan dengan Sumber PLN.

Kata Kunci: *rectifier*, generator set, PLN, kinerja, perbandingan.

*Correspondence Author
email : herlinawahab@unsri.ac.id

1. INTRODUCTION

The availability of electrical energy is crucial to modern community activities. Most of the work is carried out by electricity, which also makes a wide range of heating and lighting sources available and makes information gathering, processing, storing, and sharing easier. Electrical Engineering's power electronics division is responsible for utilizing electronic converters to convert and regulate electrical power. The electrical network supplies alternating current (AC) voltage with a consistent frequency and amplitude. Single-phase low-voltage power lines are typically used to supply electricity to residences and other small buildings. Electric power that is fixed at 60 Hz and must be conditioned for use is referred to as raw power. Power conditioning includes frequency and/or voltage regulation as well as conversion of AC to DC or vice versa (Rashid, 2018).

Prior studies have extensively employed and investigated the utilization of converters. The study conducted by Atmojo examined the utilization of a full-bridge DC-AC high-frequency resonant LCC parallel load converter. The findings indicate that the magnitude of the output gain is affected by the load resistance value. Experimental evidence demonstrated that using a resistance of 4k7 Ω resulted in a voltage of 122.8 V and a lighting intensity of 604 lux. Similarly, employing a resistance of 8k2 Ω yielded a voltage of 139.7 V and a lighting intensity of 432 lux (Atmojo, Facta and Karnoto, 2015; Zhu and Gao, 2022).

Vule develops and models split link DC capacitor balancing in a two-way three-phase three-stage AC/DC converter with changing power factor. It calculated and analyzed the dynamics of partial DC link voltage difference, established the relation between zero-sequence modulation signal and neutral point current, and gave actual instances of restricted and unconstrained modulation signals. Simulations supported analytical predictions and experimental data validated the technique (Vule, Siton and Kuperman, 2023). A different study models and formulates a three-phase three-level bidirectional AC/DC converter split DC link capacitor balancing with variable power factors. The study gives partial DC link voltage dynamics analytical equations, defines the zero-sequence component-neutral point current relationship, and provides practical applications (Bhat and Agarwal, 2008).

Converters are commonly employed in power production systems that utilize renewable energy sources, including wind turbines (Xie *et al.*, 2020; Bernal-Perez, Añó-Villalba and Blasco-Gimenez, 2021; Achitaev *et al.*, 2024), ocean energy (Wang *et al.*, 2023), solar power plants (Buzzio *et al.*, 2023; Ingilala and Vairavasundaram, 2023), Nano-grid (Sun *et al.*, 2022; Samiullah *et al.*, 2023), micro-grids (Estabragh, Dastfan and Rahimiyan, 2021; Aryani *et al.*, 2022; Heidari, Hatami and Eskandari, 2022; Molaee, Rokrok and Doostizadeh, 2022), energy harvesting systems (Yang, Pian and Liu, 2019; Eguchi *et al.*, 2020, 2021; Silveira *et al.*, 2023), energy storage (Silveira *et al.*, 2021; Li *et al.*, 2022), specific instances in electric vehicles (Turksoy, Yilmaz and Teke, 2021; Delcy *et al.*, 2022; Nahin *et al.*, 2022; Seyezhai *et al.*, 2022), and various other applications.

Given the background information above, it is critical to conduct additional research on converters. In particular, the rectifier, which is responsible for converting AC to DC waves. Hence, the objective of this study is to develop and produce a rectifier and evaluate its efficiency in charging batteries using two different current sources: direct motor power and power from the PLN grid, within the context of the power generation system being examined. Its performance was evaluated by load testing and battery charging methods.

2. METHODOLOGY

This study is conducted on power plants that have motor sets and generators. The power generation circuit in consideration involves a converter. The primary objective of this converter is to transform the oscillating electric current (AC) generated by the generator set into a direct current (DC). The study was carried out in the Electrical Machines Laboratory, located inside the Department of Electrical Engineering, Faculty of Engineering at Sriwijaya University. The representation of the generator and motor set, which will be the focus of the investigation and equipped with the suggested converter, can be seen in Figure 1.

Figure 1. Generator and motor set.

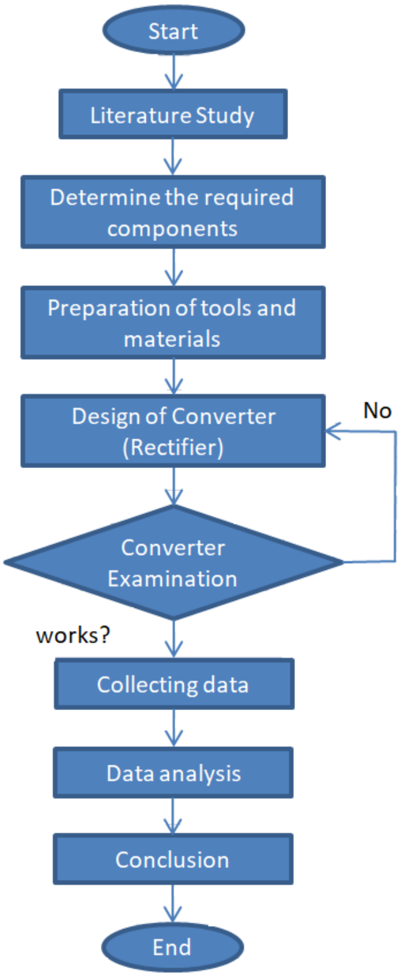


Figure 2. Research flow diagram.

The stages of this investigation were executed in accordance with the flowchart provided in Figure 2. The research flow is explained in the flowchart in Figure 2, which begins with a literature review that examines and reviews a few books, journals, and articles that are relevant to and support the central idea of this research issue. Next, select an observational approach to watch the research subject and gather the essential data and parameters. Designing a rectifier, the performance of which will be tested later. The last stage is coming to conclusions from the conducted research if there are no issues with the converter. We will proceed with data processing and analysis of the phenomena that arise.

2.1. The Application of Converters as Rectifiers

The generator output voltage in the electric power generation system (generator set) is intended to be DC and stable with the converter. Where, in accordance with motor capabilities and load consumption, the generator output voltage rises and stays constant. Subsequently the converter's output voltage and current have achieved a steady-state DC, it will be directed toward the battery to facilitate storage, hence allowing its utilization for diverse applications.

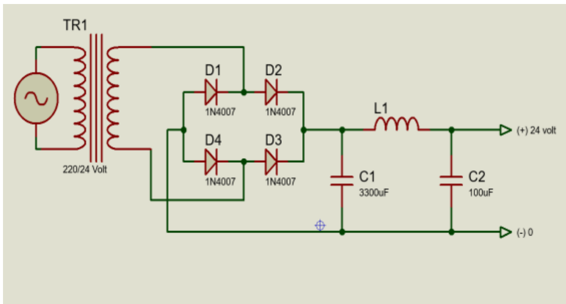


Figure 3. Circuit of a converter (Agarwal, 2023).

The primary component within a wave rectifier circuit is a diode. The diode is configured in a full-wave bridge rectifier configuration, resulting in the generation of a DC waveform as the output (Polleffliet, 2018; Agarwal, 2023). To attain a consistent rectification of the AC waveform and to secure a steady DC voltage, the rectifier circuit incorporates a capacitor filter at its output. The placement of the inductor near the output of the rectifier circuit serves to improve the stability of the waveform (Agarwal, 2023). **Figure 3** depicts the converter circuit.

The equation (1) and (2) can represent the resistive load voltage for the bridge rectifier (Rashid, 2018; Agarwal, 2023):

$$V_0 = \frac{1}{\pi}\int_0^{\pi} V_m \sin(\omega t) d(\omega t) = \frac{2V_m}{\pi} \quad (1)$$

$$I_0 = \frac{V_0}{R} = \frac{2V_m}{\pi R} \quad (2)$$

In this context, V_o represents the mean value of the output voltage, measured in volts. I_o, on the other hand, denotes the load current, which is obtained by dividing the voltage across the resistor by its resistance and is measured in amperes.

2.2. Converter Construction

Table 1 presents the tools and materials utilized in the design of the converter. The efficacy of the designed rectifier is evaluated through the process of charging current from the converter to the battery. Figure 4 illustrates the test series.

This converter operates in two circuit function modes for a single phase. The first mode involves rectifying the AC current input using a rectifier. In the second mode, the rectification results from the source are utilized as input to the DC circuit to amplify the DC output. The derivation of the formula for this converter follows the same process as previous boost converters, focusing on the rectification results in the single-phase rectifier circuit, which converts the AC current into DC. Initial data were collected from the circuit depicted in Figure 4, which measured the battery's current and voltage using energy from the generator set or the power grid (PLN).

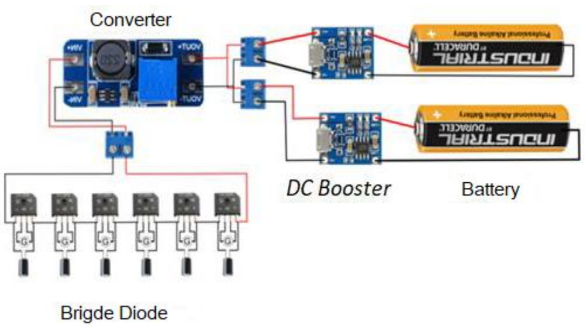


Figure 4. Electrical circuit assessment.

Table 1. Tools and materials for converter design.

Tools and Materials	Parameters	
	Name of Material	Function
	Diode	As an alternating voltage current (AC) rectifier
	Capacitor	As a ripple filter that refines the AC voltage rectification to D.C. and reduces ripple voltage both up and down.
	PCB Board	as a place to connect component legs or set up converter parts
	Tin	Connecting two parts, the converting part and the PCB board.
	Soldering	To put together or take apart circuits or parts on the PCB board
	Multi-meter	To measure the amount of electricity needed for research

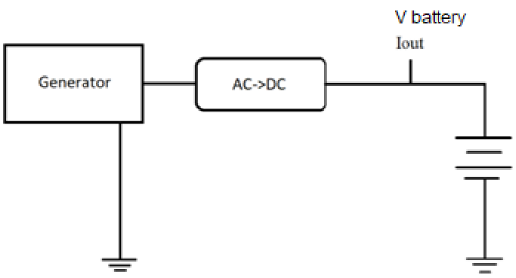
3. RESULTS AND DISCUSSION

The following section presents an analysis of the findings achieved concerning the design of an AC-to-DC converter within the specific context of an electric power-producing plant. An experimental investigation was conducted to assess the operational efficiency of the converter currently under development.

The current produced by the converter and the voltage increase detected on the charged battery are the parameters evaluated throughout the measurement procedure. The battery charging process is executed under two distinct situations. The first method involves utilizing a current source acquired from the generator set, while the second method comprises employing a power source obtained from a Public Electricity Company (PLN). The goal of the research is to determine whether the performance of the converter rectifier is consistent with the initial design expectations.

The battery voltage and the AC-DC converter's input current are measured for the purposes of assessing the converter's performance. This test is intended to ascertain whether the converter's performance can produce the required voltage. The measurement of converter current and voltage is conducted under two distinct settings, specifically utilizing the generator set and the PLN sources. The temporal interval for data collection has been established at every 5 minutes. The measurements were conducted on Monday, October 24th and 31st, 2022. Figure 5 shown the process of collecting data on battery charging.

(a) Real condition



(b) Wiring diagram

Figure 5. Battery charging process.

The data utilized in this research study originates from a rectifier device that is provided with an electrical current to generate a direct current (DC) voltage. The data-retrieving capacity is changed based on the prevailing battery conditions. The parameter data table that has been acquired and studied is shown in Table 2 and Table 3.

Table 2. Battery charging data (generator set using a rectifier).

Time (minute)	Parameters for data retrieval	
	Current (I, Ampere)	$V_{Battery}$ (Volt)
0	6.2	6.9
5	8.8	11.7
10	9.8	12.1
15	9.7	12.4
20	9.2	12.6
25	8.5	12.8
30	7.5	13.0
35	6.9	13.2
40	6.7	13.3
45	6.6	13.4
50	6.5	13.5
55	6.4	13.5

Table 2 shows the results from recording the current from the converter and the voltage increase on the battery with a current source from the generator set.

Table 3. Battery charging data (PLN source using a rectifier).

Time (minute)	Parameters for data retrieval	
	Current (I, Ampere)	$V_{Battery}$ (Volt)
0	7.2	6.9
5	6.9	11.2
10	6.7	11.6
15	6.5	11.8
20	6.2	11.9
25	6.0	12.1
30	5.6	12.2
35	5.3	12.8
40	4.7	13.0
45	4.6	13.2
50	3.9	13.4
55	3.2	13.2

The findings of the experiment, as presented in Table 3, illustrate the recorded values of current from the rectifier and the corresponding voltage increment on the battery. These measurements were obtained by utilizing a current source derived from the power grid (PLN).

The battery parameters that are being used are 12 V and 7 Ah in capacity. Battery charging at 13.8 V is the standard; in the research, the battery reached full charge in 55 minutes. Afterwards, the following computation can be used to determine the current value:

$$I = \frac{7\,Ah}{\left(\frac{55}{60}\right) hour} = 7.6\,Ampere$$

In the case of battery conditions that are inadequate, it is presumed that an extra current of around 20% is necessary to recharge the battery. To determine the overall electric current, refer to the subsequent computation:

$$I = 7.6 + 20\% == 9.16\,Ampere$$

The determination of the total power consumption required to completely charge the battery during a duration of 55 minutes is as follows:

$$P = VxI$$

$$P = 13.8V\,x 9.2\,A = 126.408\,W$$

Where $V_{maks=}V_{rms}\sqrt{2} = 24\sqrt{2} = 34V$, the following computation is used to obtain the output voltage and current values:

$$V_0 = \frac{1}{\pi}\int_0^{\pi} V_m \sin(\omega t) d(\omega t)$$

$$= \frac{2V}{\pi} = \frac{2x34}{\pi} = 21.6V$$

$$I_0 = \frac{V_0}{R} = \frac{2V_m}{\pi R} = \left(\frac{21.6}{R}\right) A$$

The generator set source uses 126.35 W of power for 55 minutes to fully charge the battery. The Io and R values can be obtained by entering the battery charging power into the output power calculation.

$$P_0 = 21.6x\left(\frac{21.6}{R}\right)$$

$$126.35W = 21.6x\left(\frac{21.6}{R}\right)$$

$$R = 3.69\ Ohm,\ \ I_0 = 5.85\,A$$

The computed value required to generate an output power equal to the measured output power is denoted by Io. This figure is comparable to the typical battery charging current of 7.3 A when using a producing source for 55 minutes. This is a result of the generator experiencing an increased demand while charging the batteries. This current is more in line with the 5.37 A average of current drawn from PLN during battery charging.

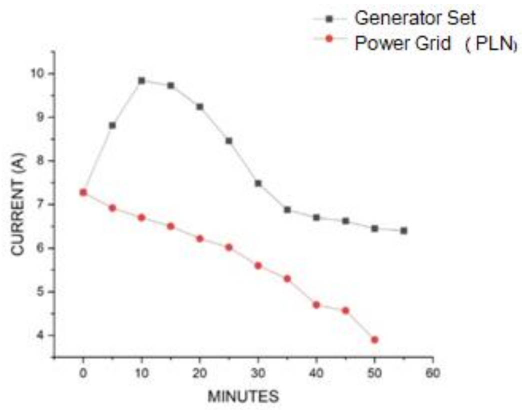


Figure 6. Rectifier current graph when charging battery with two sources.

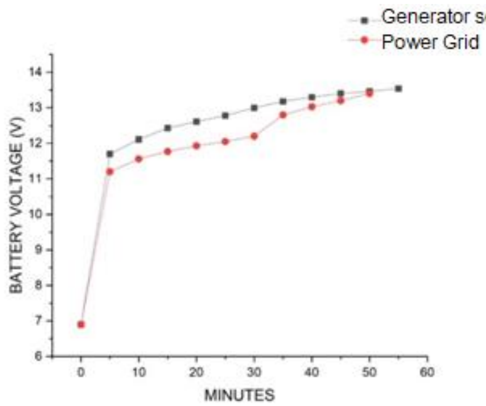


Figure 7. Rectifier voltage graph when charging battery with two sources.

A graph of the converter's current value while it charges the battery with a power source from the grid and a generator set is displayed in Figure 6. The voltage values of the converter with two distinct power sources are plotted on a graph in Figure 7. The values derived from the two sources differ when comparing the two graphs. The value obtained from the generator set is greater than the value gained from the power grid.

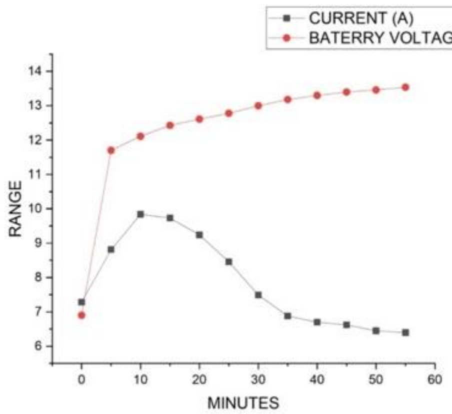


Figure 8. Battery charging: battery current and voltage graph with generation source.

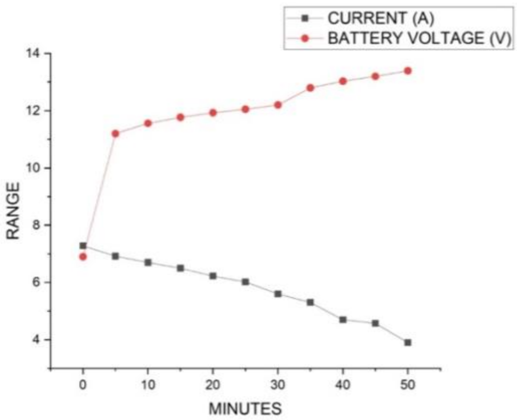


Figure 9. Battery charging: battery current and voltage graph with power grid (PLN).

The measurements of the AC-DC converter using a power generator source reveal that the generator's current value is higher than the PLN output, as seen in Figure 6, Figure 7, Figure 8 dan Figure 9. The generator takes five minutes less than the PLN source to bring the battery voltage up to 13.40 V. The circuit design's output voltage and current values, as calculated, are 21.6 V and 5.8 A. The power needed to charge a battery using a converter and generating source in 55 minutes can be calculated by multiplying the two numbers. The output power value is influenced by the resistance level. The primary purpose of the capacitor is to regulate the output voltage, thereby minimizing the presence of ripple. On the other hand, the inductor serves to stabilize the current originating from the rectifier, consequently mitigating the peak current experienced by the diode. Thus, the resistance, capacitor, and inductor values have a big impact on this AC-to-DC converter's efficiency (Pollefliet, 2018; Zhang, Corr and Ma, 2018).

In this study, charging the batteries was done in parallel with other loads. Unfortunately, because of the considerable rise in temperature of the drive motor and connected wires, loading can only be completed for 15 minutes, whilst fully charging the battery takes 55 minutes. It is believed that adding, withdrawing, and changing the load on the generator will cause a change in the amount of current going to the battery, relieving it of all burdens save battery charging.

Though more study with other aspects and variables, such as additional loads and larger volumes of data, is necessary, the usage of converters as current and voltage rectifiers can function effectively. Aside from that, measurements must be made with accuracy and precise timing.

4. CONCLUSION

The results of the investigation suggest that the current originating from the generator and flowing into the battery is of a greater magnitude than the current supplied by PLN, according to the research conducted. Ranging from 5-7 A for the generator to 6-4 A for the PLN source. Based on the test findings, it was discovered that when the power source is a generator instead of PLN, the converter output voltage enters the battery 5-7 minutes faster.

ACKNOWLEDGMENTS

The funding for this research was provided by the Sriwijaya University Public Service Agency's DIPA Budget for the Fiscal Year 2021, specifically under the reference number SP DIPA-023.17.2.677515/2022, which was issued on December 13, 2021. Pursuant to Chancellor's Decree Number: 0110/UN9.3.1/SK/2022, issued on April 28, 2022.

REFERENCES

Achitaev, A. *et al.* (2024) 'Life extension of AC-DC converters for hydrogen electrolysers operating as part of offshore wind turbines', *International Journal of Hydrogen Energy*, 51, pp. 137–159.

Agarwal, V. (2023) 'AC-DC converters (rectifiers)', in J. García (ed.) *Encyclopedia of Electrical and Electronic Power Engineering*. Oxford: Elsevier, pp. 6–23.

Aryani, D.R. *et al.* (2022) 'An improved model-based interlink converter control design in hybrid AC/DC microgrids', *Energy Reports*, 8, pp. 520–531.

Atmojo, S.S., Facta, M. and Karnoto, K. (2015) 'Analisis Perancangan Konverter DC-AC Full Bridge Frekuensi Tinggi Resonan LCC Beban Paralel', *Transient: Jurnal Ilmiah Teknik Elektro*, 4(1), pp. 200–207.

Bernal-Perez, S., Añó-Villalba, S. and Blasco-Gimenez, R. (2021) 'Stability analysis of multi-terminal HVDC with diode rectifier connected off-shore wind power plants', *International Journal of Electrical Power & Energy Systems*, 124, p. 106231.

Bhat, A.H. and Agarwal, P. (2008) 'Three-phase, power quality improvement ac/dc converters', *Electric Power Systems Research*, 78(2), pp. 276–289.

Buzzio, C. *et al.* (2023) 'A current-source DC-AC converter and control strategy for grid-connected PV applications', *International Journal of Electrical Power & Energy Systems*, 154, p. 109399.

Delcy, J.A.N. *et al.* (2022) 'A novel symmetrical three level boost DC-AC converter for electric vehicles with reduced switch counts', *Materials Today: Proceedings*, 65, pp. 235–241.

Eguchi, K. *et al.* (2020) 'Design of an inductor-less step-up ac/dc converter for 0.3 V@1 MHz vibration energy harvesting', *Energy Reports*, 6, pp. 159–165.

Eguchi, K. *et al.* (2021) 'A multi-input single-output Dickson-type AC/DC converter for vibration energy harvesting', *Energy Reports*, 7, pp. 78–83.

Estabragh, M.R., Dastfan, A. and Rahimiyan, M. (2021) 'Parallel AC-DC interlinking converters in the proposed grid-connected hybrid AC-DC microgrid; planning', *Electric Power Systems Research*, 200, p. 107476.

Heidari, S., Hatami, A. and Eskandari, M. (2022) 'An intelligent capacity management system for interface converter in AC-DC hybrid microgrids', *Applied Energy*, 316, p. 119112.

Ingilala, J. and Vairavasundaram, I. (2023) 'Investigation of high gain DC/DC converter for solar PV applications', *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 5, p. 100264.

Li, Y. *et al.* (2022) 'Modeling and control strategy analysis of a hydraulic energy-storage wave energy conversion system', *Renewable Energy*, 182, pp. 969–981.

Molaee, Z.S., Rokrok, E. and Doostizadeh, M. (2022) 'An optimal planning model for AC-DC distribution systems considering the converter lifetime', *International Journal of Electrical Power & Energy Systems*, 138, p. 107911.

Nahin, N.I. *et al.* (2022) 'Investigating the input power quality of multi-pulse AC-DC power converter fed induction motor drives', *Heliyon*, 8(12), p. e11733.

Pollefliet, J. (2018) '8 - Controlled Rectifiers', in J. Pollefliet (ed.) *Power Electronics*. Oxford: Academic Press, p. 8.1-8.58.

Rashid, M.H. (2018) *Power Electronics Handbook*. 4th edn. Florida: Butterworth-Heinemann. [Print].

Samiullah, M. *et al.* (2023) 'Inherently boosted switched inductor hybrid converter with AC and DC outputs for DC nanogrid applications', *Energy Reports*, 10, pp. 360–367. 06.042.

Seyezhai, R. *et al.* (2022) 'Simulation and hardware development of AC-DC power converter for Off- board charger of EV', *Materials Today: Proceedings*, 62, pp. 1189–1196.

Silveira, J.P.C. *et al.* (2021) 'Power management of energy storage system with modified interlinking converters topology in hybrid AC/DC microgrid', *International Journal of Electrical Power & Energy Systems*, 130, p. 106880.

Silveira, J.P.C. *et al.* (2023) 'Power management with BMS to modified interlinking converter topology in hybrid AC/DC microgrid', *Energy Reports*, 9, pp. 1743–1765.

Sun, P. *et al.* (2022) 'AC/DC fault handling and expanded DC power flow expression in hybrid multi-converter DC grids', *International Journal of Electrical Power & Energy Systems*, 141, p. 107989. s.2022.107989.

Turksoy, O., Yilmaz, U. and Teke, A. (2021) 'Efficient AC-DC power factor corrected boost converter design for battery charger in electric vehicles', *Energy*, 221, p. 119765.

Vule, Y., Siton, Y. and Kuperman, A. (2023) 'Comprehensive modeling and formulation of split DC link capacitors balancing problem in Three-Phase Three-Level bidirectional AC/DC converters operating with arbitrary power factor', *Alexandria Engineering Journal*, 83, pp. 195–211.

Wang, X. *et al.* (2023) 'Research on field testing and assessment technology of ocean energy converters', *Ocean Engineering*, 285, p. 115539.

Xie, L. *et al.* (2020) 'Coordinate control strategy for stability operation of offshore wind farm integrated with Diode-rectifier HVDC', *Global Energy Interconnection*, 3(3), pp. 205–216.

Yang, Y., Pian, Y. and Liu, Q. (2019) 'Design of energy harvester using rotating motion rectifier and its application on bicycle', *Energy*, 179, pp. 222–231.

Zhang, H., Corr, L.R. and Ma, T. (2018) 'Effects of electrical loads containing non-resistive components on piezoelectric energy harvesting', *Mechanical Systems and Signal Processing*, 111, pp. 210–221.

Zhu, G. and Gao, D. (2022) 'Analytical and experimental investigations of optimal load impedance in LCC-compensated inductive power transfer systems', *eTransportation*, 11, p. 100153.