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Converter as a Voltage Output Stabilizer for Wind Turbines

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Abstract

Technological developments continue to increase every day. All human activities and actions always involve the use of electricity. Fluctuations in world oil prices have encouraged the emergence of various new innovations, so that many renewable energy sources have been discovered to replace fossil energy which is increasingly depleting. One renewable energy source that is widely known and is being developed is the Savonius Vertical Wind Turbine. This tool is a power generator that utilizes energy from the wind. To ensure the operation of the Savonius Vertical Wind Turbine, a battery with specifications of 12 Volt / 7.2 Ah is needed. One of the problems that arises is how to ensure that the voltage produced by the Savonius Vertical Wind Turbine matches the maximum voltage required to charge the battery. Based on this problem, the idea arose to design a SEPIC converter that could increase and decrease the DC voltage. This SEPIC converter is equipped with current and voltage sensors, so we can monitor the current flow coming out of the converter.

Keywords: Renewable energy, DC-DC Converter, SEPIC Converter, Wind Turbine, Battery Charging

1. Introduction

Renewable energy has become a global priority due to the urgent need to address climate change, reduce greenhouse gas emissions, and transition away from finite fossil fuel resources (Aeni, 2022). Among the various renewable energy sources, wind energy stands out as a sustainable and environmentally friendly option with immense potential. Indonesia, as a country with abundant natural resources, holds significant potential in renewable energy, including wind energy, with wind speeds averaging between 3–6 m/s in various regions (ESDM, n.d.). However, the integration of wind energy into electrical systems presents challenges, particularly in managing the variability of wind speeds that result in fluctuating voltage outputs from wind turbines (Putra & Nugraha, 2021). To meet needs, it is not enough just to rely on fossil energy. It is also necessary to systematically develop new and renewable energy potential. Indonesia is one of the countries with the largest energy consumption levels in the world. Nevertheless, great potential is widespread in this country (Adzikry, 2018). Currently, approximately 80% of global energy and 66% of electricity generation is supplied from fossil fuels, contributing approximately 60% of greenhouse gas (GHG) emissions responsible for climate change (Priyambodo & Nugraha, 2021) (Utomo & Nugraha, 2021). fossil fuels must be immediately replaced with clean energy, such as sunlight, wind, water, geothermal and biomass (Humas, 2020). One use of renewable energy is wind energy. Wind is a form of energy available in nature that is obtained through the conversion of kinetic energy. Energy from the wind is converted into kinetic energy or electrical energy. Wind energy can make a significant contribution to reducing emissions because no CO2 emissions are produced during the production of electrical energy by windmills (Achmad & Nugraha, 2022). The availability of accurate wind energy potential maps throughout Indonesia is very necessary as a first step in identifying and selecting wind energy project locations. The map provides information about wind characteristics in various regions such as average wind speed, maximum and minimum speed which can be converted into a power density map and an annual energy map (in kWh/ or W/m2). This information is very useful as a basis for determining the location and selecting the right turbine technology (Sheila et al., 2024) (UGM, n.d.). From the data above, we can utilize wind energy as a source of electrical energy. This energy conversion can be done using a wind turbine (Arifuddin et al., 2024) (Nugraha, Ravi, & Priyambodo, 2021). In 2018, Indonesia should be proud of the operation of the first wind-powered power plant (PLTB) located in Mattirotasi Village, Sidrap Regency, Central Sulawesi. The plant has a large capacity, reaching 75 MW, consisting of 30 wind turbines (Paluga et al., 2024) (Almunawar et al., 2024).

To address this issue, advanced power electronics are crucial for ensuring stable and reliable energy delivery. The Single-Ended Primary Inductor Converter (SEPIC) is an efficient DC-DC converter capable of stabilizing output voltage regardless of variations in input voltage, making it an ideal choice for wind turbine systems (Rahman, 2022) (Administrator, n.d.). The SEPIC converter not only provides flexibility by functioning in both

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step-up and step-down modes but also ensures continuous current flow, which is critical for renewable energy applications (ESDM, n.d.) (P3TKEBT ESDM, n.d.).

This paper explores the implementation of the SEPIC converter as a voltage output stabilizer for wind turbines. By leveraging the SEPIC converter's unique characteristics, this study aims to improve the reliability of wind energy systems, making them more suitable for integration into grid systems or standalone applications. Furthermore, the research highlights the importance of utilizing accurate wind resource mapping and selecting appropriate turbine technologies to maximize the potential of wind energy in Indonesia and beyond.

This introduction sets the foundation for discussing the methodology, experimental setup, and analysis, ultimately demonstrating the effectiveness of the SEPIC converter in addressing one of the critical challenges in renewable energy integration (Indonesia Re, n.d.).

2. Material and methods

This research aims to design and implement a battery charging system that leverages a SEPIC (Single-Ended Primary Inductor Converter) to stabilize the output voltage generated by a wind turbine (Redondoasprila, 2017). The system is developed to address the challenges of fluctuating energy output from wind turbines, ensuring a steady voltage supply for optimal battery charging.

The methodology focuses on the integration of key components to achieve efficient energy conversion and storage. By utilizing a SEPIC converter, the system can regulate voltage levels effectively, accommodating the variable nature of wind turbine outputs. This integration ensures the stability required for reliable operation in diverse conditions (Ali, 2021).

Furthermore, the research emphasizes the importance of system efficiency and durability in renewable energy applications. The implementation process involves detailed testing and calibration to validate the system's performance in maintaining consistent voltage levels while minimizing energy losses. This approach underscores the potential of SEPIC-based systems in advancing sustainable energy solutions (Setiawan & Pratama, 2019).

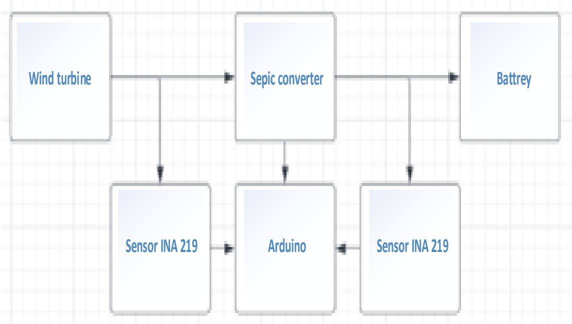

Figure 1. diagram Block

The output voltage generated by wind turbines is naturally unstable due to fluctuations in wind speeds (Hosseinzadeh et al., 2021). These variations pose challenges for consistent energy utilization and storage, making it necessary to implement stabilization mechanisms. To address this issue, an efficient voltage regulation system is required to ensure steady energy output suitable for charging batteries.

The process begins with measuring the voltage and current produced by the wind turbine using the INA219 sensor. This sensor provides accurate readings and is integrated into the system for real-time data collection. The data is then transmitted to an Arduino microcontroller, which processes the information and facilitates further system operations.

The next step involves directing the measured voltage and current values into a SEPIC converter. This converter is designed to stabilize the fluctuating voltage levels through pulse-width modulation (PWM) control. By dynamically adjusting the duty cycle of the PWM, the SEPIC converter can ensure a consistent output voltage, regardless of the variability in wind turbine output.

To maintain reliability, the output voltage from the SEPIC converter is monitored again using the INA219 sensor. This second measurement verifies that the stabilized voltage meets the predefined stability criteria. Any deviations are identified, allowing for immediate adjustments to ensure the system operates within the desired parameters.

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Finally, once the output voltage is confirmed to be stable, it is directed to charge the battery. This step ensures that the energy harnessed from the wind turbine is efficiently stored for later use. By integrating the INA219 sensor, Arduino microcontroller, and SEPIC converter, the system achieves a comprehensive approach to stabilizing wind energy for battery charging applications (Mukherjee & Rao, 2019).

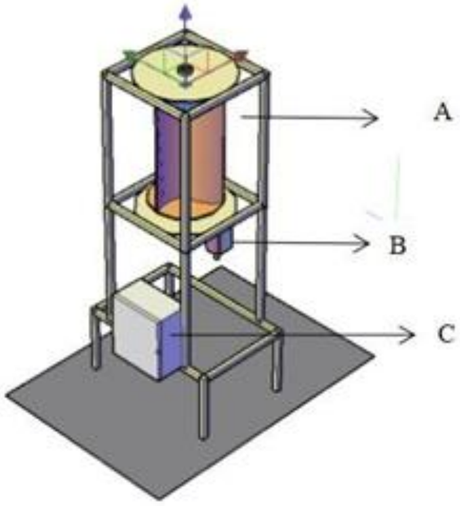

Figure 2. Mechanical Design

The system's design is illustrated in a block diagram (Figure 1), which outlines the flow of energy from the wind turbine to the battery. The block diagram serves as the basis for the mechanical design, as depicted in Figure 2, which showcases the integration of hardware components.

This methodology ensures precise voltage stabilization, effective energy storage, and reliable performance, forming the foundation for evaluating the efficiency and applicability of the proposed system in renewable energy applications.

3. Results and discussion

3.1. Result

The research aimed to evaluate the performance of a battery charging system powered by a wind turbine. The testing process was methodically structured and divided into three primary phases to ensure comprehensive analysis and accurate results. These phases included the calibration of INA219 sensors, the assessment of SEPIC converter efficiency, and the examination of the fully integrated system.

The first phase involved calibrating the INA219 sensors, which are critical for measuring voltage and current accurately. Proper calibration ensures that the data collected during the testing process is reliable and precise. This step was essential as it formed the foundation for analyzing the performance of the entire system.

In the second phase, the focus shifted to evaluating the efficiency of the SEPIC converter. The SEPIC converter plays a crucial role in stabilizing the variable output voltage from the wind turbine. By analyzing its performance, the researchers were able to determine how effectively the converter regulated voltage and minimized energy losses during the charging process.

The third phase of the research involved testing the fully integrated system. This phase aimed to combine all the components, including the wind turbine, INA219 sensors, SEPIC converter, and the battery, to assess how well they functioned as a complete unit. The integrated system was tested under various conditions to ensure stability, efficiency, and reliability.

Through these phases, the research provided valuable insights into the feasibility and effectiveness of using a wind turbine for battery charging. Each step of the testing process contributed to understanding the system's strengths and areas for improvement, paving the way for advancements in renewable energy storage technologies.

Tabel 1. Current Value

experiment	Sensor INA219 (mA)	Multimeter (mA)	*Error* (%)
1	17.5	18	2.78
2	38	40	5
3	47	49	4.3
4	72	73	1.3
5	80	81	1.23
avarege *Error*			2.9

- Calibration of INA219 Sensors

The INA219 sensor calibration test aimed to assess the accuracy of sensor readings within the battery charging system. The testing method involved comparing the readings displayed on the LCD with those obtained using a multimeter. The data collected is presented in Tables 1 and 2. Based on the results from these tables, the average percentage error for the INA219 sensors was found to be 2.9% and 0.6%, respectively. These results indicate that the INA219 sensor provides acceptable accuracy for use in this research, ensuring reliable data for further analysis.

Table 2. voltage velue

experiment	Sensor INA219 (v)	Multimeter (v)	*Error* (%)
1	7.84	7.88	0.51
2	8.05	8.13	0.98
3	8.73	8.8	0.79
4	9.42	9.48	0.63
5	11.03	11.04	0.09
Rata-Rata *Error*			0.60

- Efficiency of the SEPIC Converter

The efficiency test of the SEPIC Converter was conducted to evaluate the energy conversion performance of the system. The results from the tests showed that the average efficiency of the SEPIC Converter was consistent across the trials, as summarized in the following table. The converter demonstrated stable voltage stabilization, and the efficiency values fell within an acceptable range for renewable energy applications, ensuring that the SEPIC Converter functions effectively in stabilizing the output voltage of the wind turbine.

Tabel 3. Effesiency Sepic Converter

Duty cycle (%)	Daya Input (W)	Daya Output (W)	Efisiensi (%)
10	0.217	0.064	29
15	0.31	0.136	44
20	0.434	0.243	56
25	0.589	0.364	62
30	0.837	0.609	73
35	1.24	0.876	71
40	1.55	1.437	93
45	2.48	2.028	82
50	3.41	3.297	97
55	5.518	4.74	86
60	7.285	7.250	96
65	11.966	11.860	99
70	18.6	17.831	96
75	27.9	26.048	93
80	48.67	47.5	97

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- System Integration Test Results

The final phase of testing involved assessing the performance of the fully integrated system, including the wind turbine, INA219 sensors, SEPIC Converter, and battery storage. The results of this system integration test, which can be seen in Table 4, show that the battery charging system operated as expected, with stable voltage levels provided to the battery. The system efficiently stabilized the voltage output from the wind turbine, confirming the effectiveness of the SEPIC Converter in ensuring reliable battery charging. Additionally, the integration of all components resulted in a functional and reliable system for renewable energy storage.

Overall, the results confirm that the proposed system effectively stabilizes the output voltage of the wind turbine, optimizes energy conversion, and ensures reliable battery charging.

3.2. Discussion

The calibration process of the INA219 sensor yielded promising results, demonstrating its capability to deliver accurate voltage and current measurements. The sensor achieved a low error rate, with an average error ranging between 0.6% and 2%. This level of accuracy confirms the sensor's reliability and ensures that the data collected during the testing phases of the system is both precise and consistent.

These calibration results validate the INA219 sensor as a key component for this study, establishing a strong foundation for the subsequent testing phases. Reliable sensor data is critical for analyzing the system's performance and ensuring accurate insights into its operational efficiency.

From the efficiency testing of the SEPIC Converter, it was observed that its performance is directly influenced by the applied duty cycle. Table 3 highlights that higher duty cycles result in better voltage stabilization, which is essential for maintaining consistent energy output to the battery. This finding underscores the importance of optimizing the duty cycle to achieve maximum energy conversion efficiency while minimizing losses.

The SEPIC Converter demonstrated its effectiveness in stabilizing the fluctuating output from the wind turbine. It efficiently handled varying input voltages, ensuring that the energy delivered to the system remained reliable and consistent. This performance highlights the converter's suitability for renewable energy applications, where input conditions are often variable.

The system integration tests provided further validation of the setup's functionality. By combining the wind turbine, SEPIC Converter, INA219 sensors, and battery system, the integrated setup operated cohesively, resulting in stable energy storage. The system successfully managed fluctuations in wind turbine output, consistently providing steady voltage levels to the battery.

This successful integration confirms the compatibility and efficiency of the selected components in addressing the challenges associated with renewable energy systems. The combination of these components ensures a robust design capable of harnessing wind energy for effective and reliable battery charging.

In conclusion, the study's findings highlight the effectiveness of the proposed system design. The INA219 sensor delivers precise measurements, the SEPIC Converter optimizes voltage stabilization, and the fully integrated system demonstrates its feasibility in renewable energy applications. These insights contribute to the growing knowledge of renewable energy systems, emphasizing the critical role of precision and efficiency in their design and implementation.

4. Conclusion

The results of this study demonstrate that the battery charging system utilizing wind turbines with voltage stabilization through a SEPIC Converter performs adequately and is feasible for implementation. The calibration of the INA219 sensor revealed a high level of accuracy, with an average error rate between 0.6% and 2%, making it a reliable component for monitoring electrical parameters without significantly affecting measurement quality.

The efficiency testing of the SEPIC Converter confirmed its capability to effectively stabilize the output voltage. The results showed that higher duty cycle values improved the voltage regulation, which is crucial for maintaining consistent power delivery to the battery despite fluctuations in the input voltage from the wind turbine.

Furthermore, the integrated system testing, comprising the wind turbine, SEPIC Converter, INA219 sensor, and battery, demonstrated the system's ability to function synergistically. The voltage fluctuations from the wind turbine were successfully neutralized by the SEPIC Converter, ensuring stable charging conditions for the battery.

In summary, this study confirms that the proposed wind-energy-based battery charging system with a SEPIC Converter as a voltage stabilizer functions effectively. It provides a practical solution for renewable energy applications and holds significant potential for further development in clean energy systems. This work contributes to advancing the integration of renewable energy technologies for sustainable and efficient power systems..

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