IMPLEMENTATION OF A SEPIC CONVERTER IN AN OFF-GRID SOLAR POWER PLANT (PLTS) USING FUZZY LOGIC METHOD WITH A HAIWELL SCADA-BASED MONITORING SYSTEM

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ABSTRACT

Indonesia has great potential for solar energy. Solar energy has great potential to be utilized as an energy source. Solar cell devices (photovoltaic/PV) are needed to be used as power plants by connecting solar panels to solar charge controllers. This study aims to implement a SEPIC converter in an off-grid Solar Power Plant (PLTS) to stabilize the output voltage and monitor the system using SCADA HAIWELL. The SEPIC converter works by combining the working principles of buck and boost converters. The main components of the SEPIC converter are two inductors, two capacitors, and two switches. The switch used in this study is a MOSFET controlled by a NodeMCU microcontroller using the fuzzy logic method. The microcontroller also processes data from the INA219 sensor that measures voltage and current. The data is then sent to SCADA HAIWELL to be monitored in the form of HMI. The test results show that the system that has been built can work well. The SEPIC converter successfully stabilizes the output voltage of the solar panel at 14V and charges the battery efficiently. SCADA Haiwell can also monitor the system in real-time and provide accurate information about system conditions. Thus, this system can be used to optimize the performance of off-grid PV power plants.

Keywords: *SEPIC Converter, PLTS, Fuzzy Logic, SCADA HAIWELL*

1. INTRODUCTION

Indonesia, located in the equatorial region, receives sunlight for 10-12 hours each day, making it a country with enormous solar energy potential. The average solar energy potential in Indonesia is approximately 4.8 kWh/m² per day, equivalent to 112,000 GWp. However, to date, only about 10 MWp of this potential has been utilized. Solar energy can be converted into electricity through the use of solar cells (photovoltaic/PV), which are then connected to a solar charge controller to regulate the voltage and current delivered to electricity storage media such as batteries or accumulators.

Overcharging the battery can cause damage due to the heat and pressure generated, necessitating a control system to stabilize the output voltage from the solar panels. To achieve the desired voltage, a DC-DC converter like the SEPIC converter is required, which combines the functions of buck and boost converters, making it more efficient in power conversion without reducing or increasing the input power.

This research aims to implement a SEPIC converter and a Haiwell SCADA monitoring system in a small-scale off-grid solar power plant (PLTS) and to test the performance of these systems. By limiting the research to the implementation of the SEPIC converter and monitoring system on a small scale, this study is expected to make a significant contribution to improving the efficiency and reliability of PLTS.

2. THEORITICAL REVIEW

2.1 Solar Panels

Solar panels convert solar energy into electricity using photovoltaic (PV) technology, which utilizes semiconductors. When photons from sunlight interact with the semiconductor, they dislodge electrons from the atomic structure, generating an electric current. N-type semiconductors, which have free electrons, act as donors, while P-type semiconductors, known as "holes," accept electrons. The energy generated at the junction of the N-type and P-type semiconductors drives the electrons and holes in opposite directions, creating an electric current when a load, such as a light bulb, is applied.

There are several types of solar panels, including Monocrystalline Silicon panels, which are made from pure silicon crystals and offer high efficiency, exceeding

20%. Their advantages include long lifespan and a small cross-sectional area required to generate the same energy compared to other types. Thin Film Solar Cells use very thin solar cells (10 nm) coated onto flexible surfaces like plastic or glass. This type of panel is lightweight, flexible, and performs well at high temperatures, but it has low efficiency, around 10%. Polycrystalline Silicon panels are made from molten silicon, which is formed into square panels with a neat design. Although their efficiency is lower (around 17%) compared to monocrystalline panels, they are more affordable, making them a popular choice for more economical applications.

2.2 Buck-Boost Converter (SEPIC)

The SEPIC (Single-Ended Primary-Inductor Converter) is a type of DC-DC converter that allows the input DC voltage to be adjusted to provide a stable output voltage. SEPIC is similar to buck-boost and Cuk converters, as it can provide an output voltage that is greater than, less than, or equal to the input voltage. This converter combines the functions of buck and boost converters, using inductors and capacitors to generate an adjustable output, with advantages such as the same polarity for input and output voltage, high efficiency, and isolation between the input and output sides.

2.3 INA219

The INA219 is an exceptional electronic sensor module that can measure voltage and current with minimal calculation required. In terms of voltage, the INA219 can measure up to 26 Volts DC with +/- 3.2A, and its current measurement range is suitable for most smaller measurements

2.4 HAIWELL SCADA

Haiwell Cloud SCADA is a cloud-based platform for monitoring and managing industrial automation, developed using the .NET Framework by Xiamen Haiwell Technology Co., Ltd. Haiwell Cloud SCADA also serves as the programming and management software for Haiwell IIoT HMI, IIoT Cloud Box, and IPC.

2.5 Solar Charge Control (SCC)

In the use of solar panels with an off-grid system, there is an important device to consider. This device is the SCC (Solar Charge Controller), which is installed between the solar panels and the battery. The SCC is an electronic device that regulates the electrical current entering the battery (Solar Charge Controller, Cakrawala96, 2021).

2.6 Fuzzy Logic

Fuzzy logic is a form of multivalued logic whose boolean variable values range from 0 to 1. This logic is used in artificial intelligence systems to imitate human thinking and perception. In contrast to binary logic which only has two truth values (0 or 1), fuzzy logic allows for a spectrum of truth values between these extreme points, which represent different levels of truth. It is based on human language and aims to combine precise machine language with human language emphasis. Fuzzy logic is usually applied to problems involving uncertainty, inaccuracy, and noise. (Pengertian Logika Fuzzy, LamanIT, 2023).

2.7 Fuzzy Sugeno

Fuzzy Sugeno is a logic system designed to produce a single, crisp decision during the defuzzification process, tailored to the specific problem domain. It involves several key steps: fuzzyfication, rule application, defuzzification, and output generation. This approach builds upon the Fuzzy Mamdani and Fuzzy Tsukamoto methods, proving particularly effective in addressing problems with multiple variables that cannot be precisely defined or expressed as Boolean values (KANTINIT, Fuzzy Sugeno: Cara Kerja, Contoh Soal dan Implementasi, 2023).

The initial step, Membership Function, involves defining fuzzy sets, which are uncertain or ambiguous and represented by a range of values. For instance, the fuzzy set “Very High” might cover a range from 90 to 100. Fuzzyfication then transforms crisp input values into fuzzy values, which are expressed as membership levels in various categories based on predefined functions. The second step, Rule-Base Determination, involves creating fuzzy rules that define the relationships between inputs and outputs. For example, a rule like “if temperature is high and humidity is low, then comfort is low” indicates that high temperature combined with low humidity will result in low comfort.

Converting an unambiguous set derived from a rule structure into a single unique value is called defuzzification. The crisp value can be calculated using several defuzzification methods. The crisp value is calculated using the centroid method at the midpoint of the fuzzy area. The Means of Maximum (MOM) value is the average value of the domain with maximum membership. Maximum maximum (LOM) is the maximum value of a domain with maximum membership. Minimum maximum (SOM) is the minimum value of a domain with maximum membership.

3. METHODS

The overall research design is illustrated in the diagram below. In the Solar Power Plant, a SEPIC converter will be installed. The output voltage from the solar panels will be adjusted up or down according to the specified capacity. The voltage from the module will be used to charge the battery.

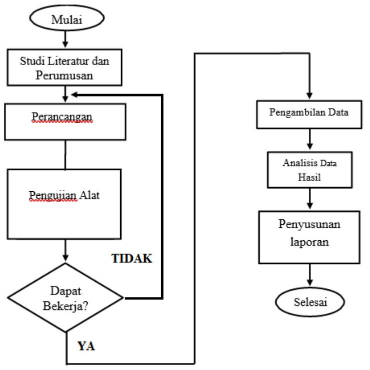

Figure 1. Research Design

4. RESULTS

4.1 Solar Panel Testing

An avometer was used to measure the output of the solar panel during testing, which took place every two hours from 9:00 AM to 3:00 PM. The results indicate that the solar panel is in good condition and that it may be handed on to the converter because its output voltage range is compatible with the nameplate specifications of 0-24V and does not exceed its maximum limit.

Table 1. Solar Panel Testing Data

Time	Voltage (V)	Current (A)
09.00	5,6	4,23
11.00	17,6	1,76
13.00	18,6	1,90
15.00	4,7	3,75

4.2 Buck Boost SEPIC Converter Testing

An AVometer was used to measure the converter's output voltage and current in order to test the buck-boost SEPIC converter. During testing, the converter's input voltage was connected to the solar panel.

Table 2. Buck Boost SEPIC Converter Data

Time	Voltage (V)	Current (A)
09.00	14,5	1,25
11.00	14,5	3,82
13.00	14,5	3,95
15.00	14,5	0,9

4.3 INA219 Sensor Testing

The sensor used in this system is the INA219, which measures the voltage and current output from both the solar panel and the buck-boost SEPIC converter. The measurement data is transmitted to the NodeMCU and processed for display on the SCADA Haiwell software.

The testing of the INA219 sensor involves assessing the accuracy of the measurements for both the solar panel and the buck-boost SEPIC converter.

The test is carried out by comparing the Avometer measurement results with the voltage value displayed in the software and then calculating the error value. An error value of less than 5% indicates a good condition of the electronic components.

Table 3. Measurement Comparison Data: Instrument vs. Sensor

Solar Panel Output				
No	**Instrumen Measurement (V)**	**Software Interface SCADA HAIWELL (V)**	**Discrepancy**	**Error**
1	5,2	5	0,2	3,8
2	17,5	17	0,5	2,8
3	18,9	18	0,9	4,7
4	4,1	4	0,1	0,1
Buck Boost SEPIC Converter Output				
No	**Instrumen Measurement (V)**	**Software Interface SCADA HAIWELL (V)**	**Discrepancy**	**Error**
1	14,5	14	0,5	3,4
2	14,5	14	0,5	3,4
3	14,5	14	0,5	3,4
4	14,5	14	0,5	3,4

According to the results of the testing, the sensor can be considered in good condition because the difference between the measurement results and the instrument readings has an error value of less than 5%.

4.4 Comprehensive Testing

After completing the testing of each component and confirming that they are in good condition, overall system testing is conducted. This testing aims to evaluate the performance of the converter monitored by SCADA Haiwell software and the voltage distribution to the load.

The solar panel generates electricity to start the entire system test, which is then read by the INA219 sensor to determine the output voltage. The microcontroller receives data from the INA219 sensor and processes it to determine the rule basis that controls the converter. The INA219 sensor then reads the output from the converter.

All sensor readings and load control can be monitored using the SCADA Haiwell software. The converter's output voltage is used for charging the battery, which in turn supplies power to the load, specifically a 12 VDC 5 Watt lamp.

The load can be controlled by pressing a switch on the SCADA Haiwell software, which instructs the microcontroller to activate a relay that connects the battery voltage to the load. Overall system testing is conducted at 09:00 AM, 11:00 AM, 01:00 PM, and 03:00 PM. The testing involves monitoring the voltage and current produced for battery charging.

Figure 2. Overall System

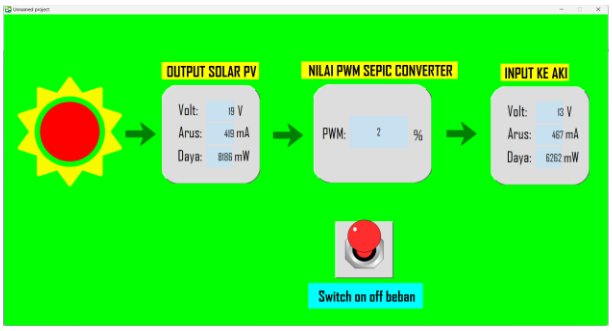

Figure 3. HAIWELL HMI SCADA

Table 4. Comprehensive Testing

Time	Voltage (V)	Charging Current (mA)	Power (mW)
09.00	13	363	4.840
11.00	13	467	6.262
13.00	13	469	6.298
15.00	13	370	4.908

According to the results above, SCADA HAIWELL effectively monitors the voltage and current data processed by the microcontroller. The power generated is adequate for supplying the DC load, with a stable output voltage ranging from 12-14V.

5. DISCUSSION

The results of the system testing indicate that the designed equipment functions according to the intended goals and specifications. Testing of the solar panel showed that the panel's output voltage is within the expected range as per the nameplate, indicating that the panel is in good condition and capable of delivering energy to the next component. Similarly, the buck-boost SEPIC converter operates effectively, providing a stable output voltage of 14V, which is ideal for battery charging. Testing of the INA219 sensor revealed that the accuracy of voltage and current measurements is within acceptable tolerance limits, with errors below 5%, indicating that the sensor is functioning well and the data produced is reliable.

Battery testing showed that the battery's output voltage is within the normal range of 13V, indicating that the battery is still in good condition for energy storage. The NodeMCU microcontroller also proved to be functioning correctly, with the LED indicator lit, showing that the microcontroller can control the system accurately. Software testing, including the Arduino IDE and fuzzy logic methods, demonstrated that the system can be effectively programmed and makes accurate decisions according to the defined fuzzy rules.

Finally, the use of Haiwell SCADA for system monitoring and control confirmed that the application can effectively monitor and regulate voltage and current values in real-time. Overall, the testing results show that the system, from the solar panel to the complete system testing, operates optimally, with stable output voltage and adequate charging current to supply the load. The SCADA Haiwell system is effective in integrating and monitoring all aspects of this setup, ensuring efficient battery charging and energy provision to the load in accordance with the expected standards for an off-grid solar power generation application.

CONCLUSION

The buck-boost SEPIC converter has been successfully implemented in an off-grid solar power system using the Sugeno fuzzy logic method, with an output setpoint of 14.4V. Testing showed that with input voltages of 4V, 7V, and 9.5V—categorized as LOW, MEDIUM, and HIGH—the corresponding PWM duty cycles were 64.6%, 48.6%, and 38.4%. These results indicate that the converter effectively stabilizes voltage for battery charging. Additionally, SCADA HAIWELL can be used for real-time monitoring and control of this system, employing ModbusRTU for communication between the SCADA application on the laptop and the microcontroller. Testing at various times demonstrates that the SEPIC converter, with Sugeno fuzzy logic control integrated with HMI SCADA HAIWELL, successfully stabilizes the voltage from a 20Wp solar panel and stores it in a 12V/12Ah battery, which can then power a 12VDC 5 Watt LED lamp.

RECOMMENDATIONS

Based on the conclusions, several suggestions for future development are proposed. First, exploring other fuzzy logic methods in future research is recommended. Second, considering the development of monitoring and control systems using alternative methods could enhance system effectiveness and flexibility. Third, further research should be conducted by applying the testing system to a broader range of case studies to gain a more comprehensive understanding of the system's application and performance in different contexts.

REFERENCES

[1] Advernesia. (2020, April 5). Pengertian MATLAB dan Kegunaannya. Retrieved from Advernesia: https://www.advernesia.com/blog/matlab/apa-itu-matlab/

[2] Ali Akbar, M. F., Iswahyudi, P., & Moonlight, L. S. (2018). RANCANG BANGUN KONTROL DAN MONITORING SISTEM PROTEKSI BEBAN TIDAK SEIMBANG BERBASIS PROGRAMMABLE LOGIC CONTROLLER. Retrieved from scholar.google.com: https://scholar.google.com/citations?view_op=view_citation&hl=id&user=r21iyb4AAAAJ&cstart=20&pagesize=80&citation_for_view=r21iyb4AAAAJ:qjMakFHDy7sC

[3] Bolt, O. (2023, November 17). Solar Charge Controller Settings. Retrieved from https://energytheory.com/: https://energytheory.com/solar-charge-controller-settings/

[4] Cakrawala96. (2021, Mei 19). Solar Charge Controller: Pengertian, Fungsi, dan Jenisnya. Retrieved from https://www.gesainstech.com/: https://www.gesainstech.com/2021/05/solar-charge-controller-pwm-mppt.html

[5] Carakami. (2024, Januari). Apa Itu Aki? Pengertian, Cara Kerja, dan Jenis. Retrieved from https://carakami.com/: https://carakami.com/apa-itu-aki-pengertian-cara-kerja-dan-jenis/

[6] Erintafifah. (2021, Oktober 8). Mengenal Perangkat Lunak Arduino IDE. Retrieved from KMTek: https://www.kmtech.id/post/mengenal-perangkat-lunak-arduino-ide

[7] Faudin, A. (2017, agustus 25). Cara mengukur tegangan & arus DC menggunakan sensor INA219. Retrieved from https://www.nyebarilmu.com/: https://www.nyebarilmu.com/cara-mengukur-tegangan-arus-dc-menggunakan-sensor-ina219/

[8] Haiwell. (2023, Desember 26). Cloud Scada. Retrieved from http://en.haiwell.com/: http://en.haiwell.com/hwproducts/SCADA.html

[9] Kamalogis_teknikfisika. (2021, Agustus 18). Mengenal Protokol Modbus. Retrieved from Kamalogis: https://kamalogis.ft.ugm.ac.id/2021/08/18/mengenal-protokol-modbus/

[10] KANTINIT. (2023, Januari 7). Fuzzy Sugeno: Cara Kerja, Contoh Soal dan Implementasi. Retrieved from kantinit.com: https://kantinit.com/kecerdasan-buatan/fuzzy-sugeno-cara-kerja-contoh-soal-dan-implementasi/

[11] Kho, D. (2022). Pengertian LED (Light Emitting Diode) dan Cara Kerjanya. Retrieved from https://teknikelektronika.com/: https://teknikelektronika.com/pengertian-led-light-emitting-diode-cara-kerja/

[12] LamanIT. (2023, Januari 14). Logika Fuzzy: Pengertian, Fungsi, Kelebihan dan Contoh. Retrieved from https://lamanit.com/: https://lamanit.com/logika-fuzzy/

[13] Muhamad Saleh, M. H. (2017). RANCANG BANGUN SISTEM KEAMANAN RUMAH MENGGUNAKAN RELAY. Jurnal Teknologi Elektro, Universitas Mercu Buana, 181-186.

[14] Naeem, A. (2021, Mei 3). 5 Simple Steps for Programming ESP8266 NodeMCU 12E using Arduino IDE. Retrieved from https://www.embedded-robotics.com: https://www.embedded-robotics.com/programming-esp8266/

[15] Noor, R. (2023, Agustus 26). Arduino: Pengertian, Komponen, Fungsi dan Jenisnya. Retrieved from https://ilmuelektro.id/: https://ilmuelektro.id/arduino/

[16] Pattria Dwin Cahyawati, D. R. (2023). Implementasi Konverter Berbasis SEPIC pada Modul Solar Panel dengan Algoritma Fuzzy Logic. Jurnal Elkolind Volume 10, Nomor 3, 282-291.

[17] Radya, M. (2024, Januari 16). Mengenal Nodemcu: Pengertian dan Fungsinya. Retrieved from blog.indobot: https://blog.indobot.co.id/mengenal-nodemcu-pengertian-dan-fungsinya/

[18] Saretta, I. R. (2022, Juni 10). Mengenal Panel Surya sebagai Pembangkit Listrik Ramah Lingkungan. Retrieved from www.cermati.com: https://www.cermati.com/artikel/panel-surya

[19] Superadmin. (2021, Juni 4). Apa dan Bagaimana Sistem Kerja Panel Surya? Retrieved from https://elektro.umy.ac.id/: https://elektro.umy.ac.id/apa-dan-bagaimana-sistem-kerja-panel-surya/

[20] Ta'Lim NurHidayat, R. S. (2021). ANALISIS OUTPUT DAYA PADA PEMBANGKIT LISTRIK TENAGA SURYA DENGAN KAPASITAS 10WP, 20WP, DAN 30WP. CRANKSHAFT, 9-18.

[22] VE. (2022, Maret 16). The Power of Solar: Energize Your Life. Retrieved from https://energysolarsun.blogspot.com/: https://energysolarsun.blogspot.com/2022/03/lead-acid-solar-panel-battery-storage.html