JURNAL RISET INFORMATIKA **P-ISSN: 2656-1743 |E-ISSN: 2656-1735**
Vol. 6, No. 2. March 2024 DOI: https://doi.org/10.34288/jri.v6i2.270
Accredited rank 4 (SINTA 4), excerpts from the decision of the DITJEN DIKTIRISTEK No. 230/E/KPT/2023

SIMULATION OF SMALL-SCALE SOLAR POWER GENERATION SYSTEM IN THE CENTRAL JAVA REGION: A CASE STUDY OF THE CILACAP AREA

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Abstract

The limitations of conventional non-renewable energy resources raise concerns about sustainability and energy supply security in the future. One of the worrying factors is the carbon dioxide emissions that can affect living organisms' health. Renewable energy sources, such as solar, wind, and hydropower, emerge as solutions capable of minimizing environmental impacts and reducing dependence on limited resources. Therefore, this research conducts the simulation and design of a small-scale renewable energy power generation system, particularly solar energy, in the Cilacap region, Central Java. The main components involved in this research include PV arrays, IGBT diodes, and universal bridges, supported by supporting elements such as displays, scopes, resistors, capacitors, inductors, and bus selectors. The technical data used as input are specific to the area. The simulation results show that the direct power generated by one modeled PV array is 221.7 W per hour. This research contributes to the optimization of small-scale solar power generation systems in the designated area, considering relevant components and parameters to enhance efficiency and sustainability.

Keywords: Renewable Energy; Sustainability; Solar Power; PV Array; Optimization

Abstrak

Keterbatasan sumber daya energi konvensional yang tidak dapat diperbaharui memunculkan kekhawatiran terkait ketidakberlanjutan dan keamanan pasokan energi di masa depan. Salah satu faktor yang mengkhawatirkan adalah emisi karbon dioksida yang dapat memengaruhi kesehatan organisme hidup. Sumber energi terbarukan, seperti matahari, angin, dan tenaga air, muncul sebagai solusi yang mampu meminimalkan dampak lingkungan dan mengurangi ketergantungan pada sumber daya yang terbatas. Oleh karena itu, penelitian ini melakukan simulasi dan perancangan sistem pembangkit energi terbarukan skala kecil, khususnya energi matahari, di wilayah Cilacap, Jawa Tengah. Komponen utama yang terlibat dalam penelitian ini termasuk larik PV, dioda IGBT, dan jembatan universal, didukung oleh elemen pendukung seperti layar, skop, resistor, kapasitor, induktor, dan pemilih bus. Data teknis yang digunakan sebagai masukan khusus untuk daerah tersebut. Hasil simulasi menunjukkan bahwa daya langsung yang dihasilkan oleh satu larik PV yang dimodelkan adalah 221,7 W per jam. Penelitian ini berkontribusi pada optimalisasi sistem pembangkit listrik tenaga surya skala kecil di wilayah yang ditentukan, dengan mempertimbangkan komponen dan parameter yang relevan untuk meningkatkan efisiensi dan keberlanjutan.

Kata kunci: Energi Terbarukan; Keberlanjutan; Tenaga Surya; PV array; optimisasi

INTRODUCTION

Solar energy, derived from the sun, stands as a common and frequently encountered form of renewable energy (Handayani et al., 2019; Paraschiv & Paraschiv, 2023; Saputri, Pranata, et al., 2023). Its conversion into electrical energy through solar panels has become a cornerstone in sustainable power generation (Guangul & Chala, 2019; Hassan et al., 2023). In addition to traditional solar panels, solar energy is also applied in various forms, including solar water heaters and solar cookers, showcasing its flexibility (Kapilakan, 2022; Todmal et al., 2023). One of the key advantages of solar energy, compared to other energy sources, lies in its flexibility, allowing implementation in various settings such as buildings, land areas, roofs, and bodies of water (Hachem-Vermette, 2022). Its environmentally friendly nature in operation and construction and relatively low operating costs further enhance its appeal (Chen et al., 2023; Liu et al., 2023). However, despite its numerous advantages, solar energy faces challenges that require further exploration and innovation(Hayat et al., 2019; Serlin, 2023).

Previous research assessing the power generation potential in the Cilacap region, Central Java, has already been conducted (Saputri, Linelson, et al., 2023). The researchers strive to gain a deeper understanding and address existing limitations. Previous simulations conducted with PVSyst and Retscreen have paved the way for more in-depth research in the effort to optimize solar power generation. Fahmy et al. also conducted the research using PVSyst and Retscreen (Saputri, Pranata, et al., 2023) This study proposes constructing solar power plants in Pekanbaru, Indonesia to address energy needs. The analysis indicates the feasibility of installing Longi Solar modules, with differing costs and energy output projections.

Another study aims to design a Photovoltaic system connected to a Brushless DC (BLDC) motor using an effective MPPT algorithm. The use of the P&O algorithm, buck converter, and three-phase inverter is modeled in Simulink in the MATLAB software (Fahmida et al., 2019). Another study related to PV technology was also conducted by other researchers, highlighting the importance of using solar trackers in PV technology to enhance the efficiency of harvesting renewable energy. Through model predictive control in Simulink in Matlab, this research demonstrates that precise positioning of PV can be achieved with minimal error between the angle of the solar tracker motor and the solar angle (Ikhwan et al., 2018). Through modeling using the same tool, the other study explores the potential for wind power generation in Tegal with a wind speed of 3 m/s, finding that the electrical energy potential reaches 768.55 W (Wijaya & Saputri, 2024).

Although previous studies have focused on optimizing solar power generation using tools such as PVSyst and RETScreen, there is a need for further research on the development of technology, algorithms, and additional elements to enhance the reliability of the system.

This research aims to contribute to this exploration by using simulation tools, to design a small-scale solar power generation circuit in a specific area. Then, in this research, the main components used in this study involve PV arrays, IGBT diodes, and a universal bridge, supported by supporting elements such as displays, scopes, resistors, capacitors, inductors, and bus selectors. As the research progresses, the main focus will be on designing the circuit in the software, with an emphasis on addressing challenges such as high initial investment costs, dependence on weather and environmental conditions, and the ongoing quest for improved efficiency. Additionally, technical data used in the research is based on the Cilacap region. With this research, it is hoped to provide insights and potential solutions to enhance the effectiveness and sustainability of small-scale renewable energy power generation systems, particularly solar energy, in a specific region.

RESEARCH METHODS

The initial step taken in this research is the determination of the concept of the power generation system to be simulated. Next is the selection of the location for the planned construction of the power generation system. This location is crucial because weather conditions, climate, and solar exposure vary. Then, identify the components available in Simulink to assemble the desired system. This involves selecting electronic components. Ultimately, several variables will be inputted according to the weather, climate, and/or sunlight conditions at the target location. Once everything is properly arranged, the simulation can commence.

In this study, the design and simulation of the solar power generation system in some areas were conducted. The location area for this simulation is in the coastal area, a case study in Cilacap. The circuit designed in this study is a small-scale solar power generation circuit. The components used include a PV array, diode, IGBT diode, capacitor, resistor, inductor, PWM generator, pulse generator, display, and scope.

The PV array serves as the model of solar panels. This is regarded as the essential power conversion unit of a PV generator system (Fadliah Baso et al., 2018; Roderick, 2021; Satpathy & Pamuru, 2021). The PV array requires two variables, namely sunlight intensity and tilt. Here, 1550 lux is used for sunlight intensity and 12 for tilt, according to data obtained from the Global Solar Atlas for the Cilacap area (Atlas, n.d.).

In the PV array node block in Figure 1, node m will be connected to a bus selector to measure the current and voltage of the PV array directly. The current and voltage can be used to measure the generated power. The positive and negative PV array nodes will be connected to the capacitor and inductor. Voltage measurement is also used to measure the voltage generated by the PV array. Next, from the inductor and capacitor, it will be connected to the IGBT diode, which functions to convert DC from the solar panel into AC that can be used in homes. Subsequently, the electric voltage

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generated by the IGBT diode will be measured again. From the IGBT diode, it will be connected to the universal bridge, where this universal bridge functions to stabilize the voltage generated by the PV array. From the universal bridge, there is a circuit of resistors, capacitors, and inductors that function to generate a signal.

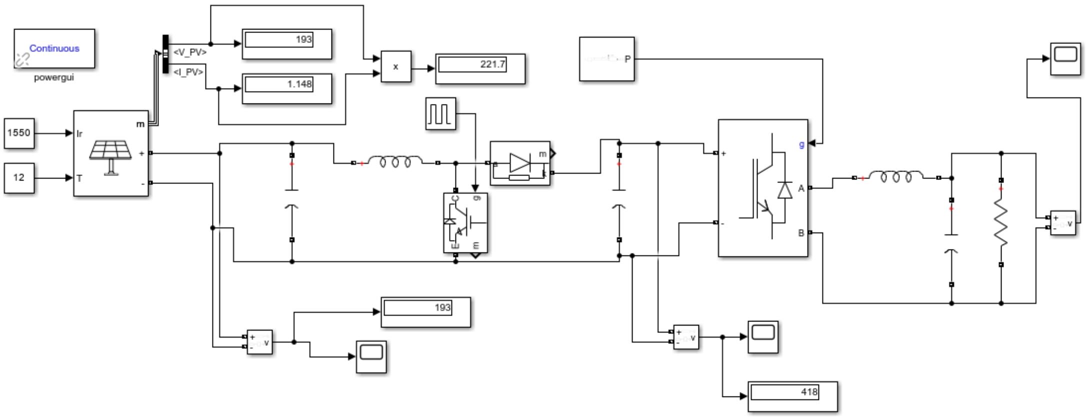

Figure 1. The Diagram Block of the System

Based on Figure 1, the PV array section M will be connected to a bus selector to measure the current and voltage of the PV array directly. A bus selector is a block that can select elements to be output as desired. With the bus selector, the current and voltage can be used to measure the power generated. The positive and negative parts of the PV array will be connected to a capacitor and inductor. Voltage measurement will also be used to measure the voltage produced by the PV array. Next, the inductor and capacitor will be connected to the IGBT diode. The IGBT diode is a combination block of an Insulated Gate Bipolar Transistor (IGBT), which is a semiconductor that functions to switch or amplify electric current, and a diode, which is a two-terminal semiconductor that allows electric current to flow in one direction and blocks it in the opposite direction. The IGBT/diode serves to convert DC from the solar panel into AC, which can then be used in households. The electric voltage produced by the IGBT diode will then be measured again. From the IGBT diode, it will be connected to a universal bridge, where the universal bridge functions to stabilize the voltage produced by the PV array. From the universal bridge, there is a circuit of resistors, capacitors, and inductors that function to generate a signal.

RESULTS AND DISCUSSION

In Figure 2, it can be observed that the signal generated by the PV array is a DC signal, as indicated by the flat graph.

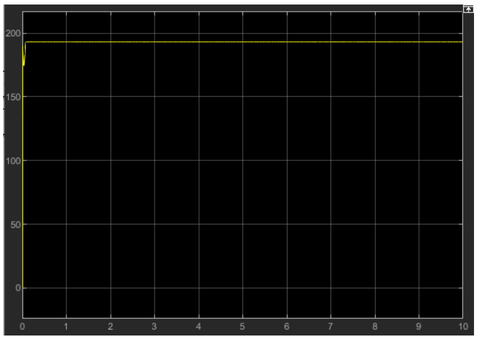
Figure 2. The Results of the Signal from the PV Array

In Figure 3, the generated graph has transformed into an AC signal after passing through the IGBT (Insulated Gate Bipolar Transistor) diode, although the signal is still not stable and exhibits jumps at the beginning of the graph. IGBT is an electronic component that functions as a switch and can be used to control high currents.

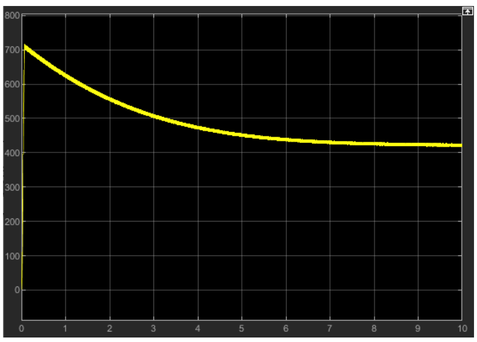
Figure 3. The Results of the Signal from the IGBT Diode

Figure 4 illustrates the final signal after passing through the resistor, capacitor, and inductor circuit, producing a stable signal. The final signal after passing through the resistor, capacitor, and inductor circuit becomes stable due to the interaction between these three components, resulting in a response that dampens signal fluctuations or variations.

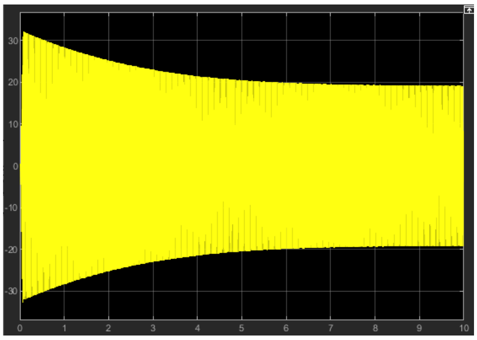

Figure 4. The Final Results

The resistor functions to control the current in the circuit and provides resistance to the flow of electricity. In this case, the resistor helps stabilize the signal by controlling the flow of current and reducing the effects of fluctuations. The capacitor can store and release electric charge. In this case, the capacitor acts as an energy storage device that can provide stable voltage and smooth out signal fluctuations. Meanwhile, the inductor has the property of storing energy in the form of a magnetic field. The function of the inductor in this circuit can help smooth out the signal and reduce sharp jumps or changes.

Table 1. Measurement of Voltage based on the Location

Measurement Point	Voltage
PV Array	193 V
IGBT Diode	418 V

Table 1 shows the measurement results at two points: the first point on the PV array and the second point on the IGBT/diode. The measurement on the PV array shows a voltage of 193 V generated by the PV array. Meanwhile, on the IGBT/diode, the voltage is measured at 418 V. The electric current passing through the IGBT/diode will undergo a change from DC to AC and will also experience an increase in voltage.

Table 2. Measurement in the PV Array

Voltage	193 V
Current	1.148 A
Power	221.7 W

Then Table 2 presents data on the measurement of voltage, current, and power generated by the PV array. The measurements are taken through a bus selector, where the first elements measured are voltage and current. The obtained voltage matches the voltage measurement, which is 193 V, while the current measures 1.148 A. Power can be found by multiplying the voltage and current. The generated power reaches 221.7 W. If the solar panels can effectively convert solar energy for 5 hours (10 am to 3 pm) sunlight is available maximally during this period. Thus, this circuit can produce approximately 221.7 W times 5 hours, is 1108.5 W every day.

Therefore, it can be concluded that this Matlab circuit is capable of providing daily electrical supply for a house as predicted. With this research, it is hoped that a simulation instrument can be developed to estimate the results of small-scale solar power generation.

CONCLUSIONS AND SUGGESTIONS

Conclusion

In this study, simulation using MATLAB was conducted to design and evaluate a small-scale solar power generation system in Cilacap, Central Java. The system comprises essential components like a PV array, IGBT diode, and universal bridge, alongside auxiliary elements such as displays, scopes, resistors, capacitors, inductors, and a bus selector. Specific data from the Cilacap region, particularly from the village of Adipala, including sunlight intensity (1550 lux) and tilt (12 degrees), were incorporated into the simulation. The results indicate that a single modeled PV array can generate 221.7 W of direct power per hour. Through this research, there is an aspiration to develop a simulation tool that can accurately predict the outcomes of small-scale solar power generation.

Suggestion

For future research, it is recommended to broaden the scope by including a wider range of locations within Cilacap or even other regions in Central Java. This would provide a more comprehensive understanding of the feasibility and performance of small-scale solar power generation systems across different geographical areas. Additionally, further investigations could explore the optimization of system components and parameters to enhance efficiency and output. Collaborating with local stakeholders and renewable energy experts can provide valuable insights and facilitate the practical implementation of solar power systems in the region. Moreover, continuous monitoring and evaluation of deployed systems will be crucial for assessing long-term performance and identifying areas for improvement.

ACKNOWLEDGMENT

We extend our sincere gratitude to Universitas Multimedia Nusantara for their support and resources that have greatly contributed to the success of this project.

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