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Analysis Of Solar Panel Efficiency In Solar Power Generation Systems As A Learning Media For Renewable Energy In Tropical Areas

Pipit Puspitasari
Teknik Energi Terbarukan, Akademi Komunitas Olat Maras
Email; pipit.akom@gmail.com

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Abstract

Renewable energy, particularly solar energy, plays a crucial role in addressing the limitations of fossil fuels and environmental sustainability issues, especially in tropical regions such as Indonesia. In addition to serving as an alternative energy source, Solar Power Generation Systems (SPGS/PLTS) also have potential as contextual learning media in vocational education. This study aims to analyze the efficiency of solar panels in a solar power generation system and examine their utilization as learning media for renewable energy education among students of the Renewable Energy Engineering Program at Akademi Komunitas Olat Maras (AKOM). This research employed a quantitative approach using descriptive methods and simple experiments. The research object was the solar power generation system and solar panels, while the research subjects were students involved in the learning activities. Data were collected through measurements of solar irradiance, input and output power, learning observations, and simple questionnaires. The results indicate that the solar panels achieved an operationally feasible efficiency level under tropical conditions. Furthermore, the use of the solar power system as a learning medium increased student engagement and improved their understanding of renewable energy concepts. This study concludes that solar power systems are effective as contextual and practical learning media in vocational education and have positive implications for the development of renewable energy learning and curriculum

Corresponding Author:
Pipit Puspitasari
Teknik Energi Terbarukan, Akademi Komunitas Olat Maras

1. INTRODUCTION

Background of the Problem

Indonesia's dependence on fossil fuels remains high, even though these sources are non-renewable and have negative impacts such as increased greenhouse gas emissions and climate change. Meanwhile, electricity demand continues to increase along with population growth and industrial development. As a solution, renewable energy is an important alternative to meet national energy needs while reducing environmental impacts. Solar energy, as a renewable energy source, has great potential because Indonesia is located on the equator with year-round exposure to sunlight, making it suitable for development in tropical regions like Indonesia. National studies show that the use of solar power plants (PLTS) as an alternative energy source has promising prospects for supporting energy security and reducing dependence on fossil fuels. Afif, (2022).

Indonesia has a relatively high solar radiation intensity throughout the year, thus offering significant potential for solar energy utilization through solar power plants (PLTS). National research indicates that the potential for solar panel use in Indonesia is still not optimal, despite

being an environmentally friendly and sustainable renewable energy source. Utilizing solar energy can help Indonesia diversify its energy sources and support the national renewable energy mix target, which is continuously increasing. Afif (2022).

In the context of vocational education, such as in the Renewable Energy Engineering Study Program of AKOM (Olat Maras Community Academy), the integration of renewable energy into the learning process is very important. Practice-based learning with technology media (such as PLTS and solar panels as trainers/practical) is believed to improve students' understanding of clean energy concepts and technical skills that are applicable in the world of work. Educational research shows that the use of renewable energy technology-based learning media in educational environments can improve learning effectiveness and graduate readiness to face the demands of the renewable energy industry. Irfan (2025).

This research is important because there is still a gap between renewable energy theory and practical learning in the field, particularly in the educational context of engineering students in tropical regions like Indonesia. The presence of solar power plants as a practical medium provides an opportunity to enrich students' learning experiences, but the effectiveness of their use and the efficiency of solar panels in tropical conditions require further study. Furthermore, this research is expected to provide contextual learning recommendations according to Indonesia's geographical characteristics, while also contributing to the development of renewable energy education curricula in vocational institutions such as AKOM.

PROBLEM FORMULATION

Based on the description above, the problem formulation in this research is:

1. How efficient are solar panels in a solar power system used as a learning medium for renewable energy in vocational education environments in tropical areas?
2. How effective is the use of PLTS as a learning medium in improving the understanding of AKOM Renewable Energy Engineering Study Program students regarding the concept of renewable energy?
3. What are the obstacles and opportunities for utilizing solar power plants in learning practices at vocational education institutions in tropical areas?

2. RESEARCH METHODS

1. Types and Approaches of Research

   This research uses a quantitative approach with a descriptive method and a simple experiment**.** A quantitative approach was used to obtain numerical data related to solar panel efficiency in a solar power plant (PLTS) system, while a descriptive method aimed to illustrate the use of PLTS as a learning tool for renewable energy. A simple experiment was conducted by measuring solar panel performance under operational conditions on a vocational campus.
2. Data Collection Techniques

   Data collection is done through:
   a. Direct measurement**,** namely taking data on voltage, current, and output power of solar panels in the PLTS system.
   b. Learning observation, to observe the use of PLTS as a learning medium by students.
   c. A simple questionnaire to determine students' responses and understanding of renewable energy learning based on PLTS.
3. Data Analysis Techniques

   Quantitative data is analyzed *descriptively* by calculating the efficiency of solar panels based on the ratio between output power and input power. Data from observations and questionnaires were analyzed using simple descriptive statistics (average and percentage) to describe the effectiveness of PLTS as a learning medium.
4. Location and Time of Research

   This research was conducted in AKOM (Olat Maras Community Academy) vocational campus as the location for the implementation of the PLTS system. The research was carried out on December 1, 2025**.**

5. Subjects and Objects of Research

The object of research is Solar Power Generation System (PLTS) and solar panels, which are used as a learning medium. The research subjects are students of the Renewable Energy Engineering Study Program, AKOM, who are directly involved in PLTS-based learning and practical activities.

Literature Review and Theoretical Framework

1. **Renewable Energy Concept and Solar Panels**
   a. How Solar Panels Work

      Renewable energy in the form of solar power utilizes the effect of **photovoltaics**, namely the conversion of sunlight into electrical energy through solar panels or solar cells. Solar panels consist of an array of semiconductor cells that, when exposed to solar radiation, produce a direct current (DC) that can then be converted to AC using an inverter in a solar power system. Analytical studies of solar panels as an alternative energy source show that they can generate electricity through current and voltage measurements, indicating a direct energy conversion process. Hasrul (2021).

      By understanding the photovoltaic effect, students can relate the theoretical concepts of semiconductors and direct solar radiation to the technical practice of generating electricity in solar power plants. This is essential as a foundation for understanding solar panel efficiency in tropical contexts.

   b. Factors Affecting Solar Panel Efficiency

      Solar panel efficiency is influenced by various factors such as solar radiation intensity, panel tilt angle, ambient temperature, and solar cell capacity and quality. National research examined the effects of solar panel capacity and tilt angle on energy conversion efficiency in off-grid solar power systems, demonstrating efficiency variations based on the panel's physical parameters. Vanesa (2025).

      These factors have direct implications for learning outcomes where students not only learn theory but also the practice of managing solar panel installations, for example, angle optimization and capacity selection, which are part of technical skills.

2. **Solar Power Generation System (PLTS)**
   a. Main Components of Solar Power Plants

      A solar power system consists of solar panels as the main component that converts solar energy into electricity, which is then controlled by a controller system, stored in batteries, and converted into AC through an inverter. Research results show that understanding these components is crucial for understanding the overall system efficiency, including the contribution of each component to electrical output. Rifaldi (2023).

      In the context of learning, the main components of a PLTS must be introduced in an integrated manner so that students understand the relationship between power system theory, hardware components, and their use in real campus PLTS scenarios.

   b. Characteristics of Solar Power Plants in Tropical Regions

      In tropical countries like Indonesia, solar power plants (PLTS) operate optimally due to year-round high levels of sunlight. Solar energy offers significant potential for meeting electricity needs while still considering the limitations of cloudy weather. This information is crucial for the design and operation of solar power plants (PLTS) on vocational campuses. Putri, (2022).

      Indonesia's tropical character strengthens the relevance of this research because the efficiency data generated under local conditions can provide students with a real picture of system performance in their own environment, rather than just theoretical literature.

3. **Renewable Energy Technology-Based Learning Media**
   a. The Concept of Contextual Learning Media

Learning media based on solar power plant trainer media can help students directly understand renewable energy concepts through practical experience. A study of the use of solar power plant trainer media in elementary schools showed that the use of solar power plants as an educational tool significantly increased participants' understanding of renewable energy. Dewi, (2024).

The idea of contextual learning media is in line with vocational principles, where learning is not only theory but also direct practice, thereby improving the technical skills of renewable energy engineering students.

b. Practice and Project-Based Learning

Practical and project-based learning in solar power systems provides students with hands-on experience in designing, operating, and optimizing solar power plants. This is crucial for enhancing students' vocational skills, preparing them for the workforce in the renewable energy sector.

This approach supports an active learning model that is relevant to the vocational curriculum, where students are not only recipients of information but also actors in technology experiments and development.

4. **Relevant Previous Research**

a. Previous research by Hasibuan et al. developed A 200 Wp off-grid solar power plant training module designed as a practical training tool in renewable energy education. The module is equipped with PV panels, lithium-ion batteries, an MPPT controller, and an inverter, and is designed for easy assembly and disassembly for educational purposes. Experimental test results show stable electrical output and a fully charged battery within 8 hours, as well as high inverter performance (±92%) under tropical conditions, demonstrating the module's practical potential as an effective technical learning medium. Sitorus (2025).

This research is relevant to yours because it combines the technical aspects of solar power plants with educational objectives. The difference is that this module focuses on complete learning device design and performance testing, while your research focuses on solar panel efficiency analysis and its impact on student understanding make new contributions in the context of vocational education at AKOM.

b. Analysis of Solar Power System Efficiency in Tropical Conditions, Rifaldi et al. conducted a study on the efficiency of solar power plants in solar power generation systems by directly measuring panels with a capacity of 50 Wp and a 300 W inverter. The test results showed a solar panel efficiency of 11.58% and an inverter efficiency of 77.21%**,** which is the operational benchmark for the PLTS system. Rifle, (2023).

This research provides quantitative empirical data on the efficiency of solar power plants in tropical conditions. The advantage of your research over this study is the direct link between the technical efficiency of solar power plants and the effectiveness of learning media. It's not just a technical measurement. This provides a new contribution to the integration of the technical aspects of renewable energy and the pedagogical aspects of vocational education.

c. IoT-Based Solar Power Plant Monitoring System as a Learning Medium, Research by Waluyo et al. developed an IoT-based solar power plant monitoring system called *Edu Solar*, which is capable of monitoring important parameters of the solar PV system in real-time (current, voltage, light intensity, etc.) via a web interface. This system is specifically designed as a learning medium in engineering education, so that students can understand the performance of PLTS interactively. Waluyo, (2024).

Unlike your research, which focused directly on solar panel efficiency, this study adds a digital and interactive component to solar power plant (PLTS) learning, demonstrating that incorporating IoT technology can enhance student engagement in understanding renewable energy systems. Your research remains superior in empirically evaluating the

relationship between solar power plant efficiency and vocational student learning outcomes.

3. RESEARCH RESULT

1. Solar Panel Efficiency Measurement Results

Solar panel efficiency measurements were conducted on a solar power plant (PLTS) system used as a learning tool on the AKOM vocational campus. Data collection was conducted under clear weather conditions with relatively stable sunlight intensity.

Measurements show that the sunlight intensity received by the solar panels is in the range of 700–1,000 W/m². This intensity reflects the characteristics of tropical regions, which experience high levels of sunlight throughout the day. The input power received by the solar panels is then converted into electrical output power, which is measured at the output of the solar power system.

Based on measurements, the solar panel's output power varies proportionally with changes in sunlight intensity. At the highest light intensity, the solar panel's output power is optimal, while at lower light intensities, output power decreases. Solar panel efficiency is calculated by comparing the output power to the input power received by the panel.

Calculations show that the solar panel efficiency is in the range of 12–15%, which is still considered good for solar panels operating in tropical environments. This efficiency value indicates that the solar power system is operating optimally and is suitable for use as a learning tool for renewable energy.

2. Results of Utilizing Solar Power Plants as Learning Media

The use of solar power plants as a learning medium was implemented by students of the Renewable Energy Engineering Study Program at AKOM through practical activities and direct observations of system performance. Observations showed that students were actively involved in the learning process, particularly in measuring voltage, current, and power, as well as calculating solar panel efficiency.

Level student involvement. This is evident in their participation in discussions, field data collection, and ability to re-explain how solar panels and solar power systems work. This hands-on learning encourages students to better understand the relationship between classroom theory and real-world conditions.

In addition, the results of a simple questionnaire showed that most students stated thattheir understanding of the concept of renewable energy increased. After participating in the solar power plant (PLTS) learning, students will have a better understanding of the concept of energy conversion, the factors affecting solar panel efficiency, and the role of solar energy as a sustainable energy solution in tropical regions.

In general, the research results show that PLTS does not only functions as a power generation system, but is also effectively used as contextual learning media which can increase student involvement and understanding of renewable energy.

Discussion

1. Solar Panel Efficiency Analysis in Tropical Conditions

The results of the study show that the efficiency of the solar panels used in the PLTS system is in the range of 12–15% in conditions of sunlight intensity between 700 – 1.000 W/m²**.** This efficiency value is in line with the theory of crystalline silicon solar panels, which generally have a working efficiency of between 10–20% in field operational conditions, especially in tropical areas that are affected by relatively high environmental temperatures.

When compared with previous research, these results show a consistent trend. Several national studies have reported that solar panel efficiency in tropical regions fluctuates due to temperature, panel tilt angle, and weather conditions, but remains within the acceptable efficiency range for electrical energy utilization. Therefore, these research

findings reinforce previous findings that solar PV systems can operate optimally in tropical regions despite environmental challenges such as increased panel surface temperatures.

The main difference between this study and previous studies lies in the context of utilization of the PLTS system, namely not only as an object of technical study, but also as instructional Media. In other words, the measured efficiency of solar panels is not only an indicator of system performance, but also a contextual learning material for students in understanding the relationship between solar energy theory and real conditions in the field.

2. Solar Power Plants as a Learning Medium for Renewable Energy

   The results of utilizing solar power plants as a learning medium indicate that students in the Renewable Energy Engineering Study Program at AKOM are actively engaged in the practice-based learning process. This involvement is evident in their ability to measure electrical parameters, analyze efficiency data, and re-explain the working principles of solar panels and solar power plant systems.

   This finding is in line with the concept of contextual learning, where students learn through hands-on experience and relate learning materials to real-world situations. The use of solar power plants (PLTS) allows students not only to theoretically understand renewable energy concepts but also to directly observe the process of converting solar energy into electricity.

   In addition, PLTS-based learning is also in accordance with the characteristics of vocational education, which emphasizes practical skills and job readiness. Through practical activities and direct observation of solar power systems, students gain technical experience relevant to the needs of the renewable energy industry. This strengthens solar power's position as an effective and applicable learning medium in renewable energy engineering education.

3. Educational Implications
   a. Implications for Educators

      The results of this study provide implications that educators in the field of renewable energy need to integrate **real technology-based learning media**, such as solar power plants, into the learning process. Educators act not only as theoretical presenters but also as facilitators, guiding students through practical activities, measurements, and data analysis. This approach can enhance students' conceptual understanding and technical skills.

   b. Implications for Renewable Energy Curriculum Development and Learning

      From the curriculum side, the use of PLTS as a learning medium supports the development of a curriculum based on industry practices and needs, particularly in vocational education. Renewable energy learning materials can be designed to be more contextual by incorporating efficiency measurement activities, system performance analysis, and evaluation of environmental factors affecting solar power plants.

      Furthermore, this study's results indicate that renewable energy learning will be more effective if linked to local conditions, such as the characteristics of tropical regions. Therefore, renewable energy curricula need to be adapted to local environmental potential and challenges to ensure graduates possess relevant and applicable competencies.

4. CONCLUSION AND SUGGESTIONS

Conclusion

Based on the research and discussion, it can be concluded that the Solar Power Generation (PLTS) system used on the AKOM vocational campus is capable of operating optimally in tropical conditions. Measurements indicate that the solar panels have an efficiency level within the operationally feasible range, allowing them to be effectively utilized as both a source of electrical energy and a learning object.

Furthermore, the use of solar power plants (PLTS) as a learning medium for renewable energy has been proven to increase student engagement in the learning process. Students not only understand the theoretical concepts of renewable energy but also gain hands-on practical experience through measuring and analyzing the performance of solar power plants (PLTS) systems. Therefore, solar power plants are considered effective as a contextual learning medium that supports the characteristics of vocational education, particularly in the Renewable Energy Engineering Study Program.

Suggestion

Based on the findings of this study, several suggestions that can be put forward are as follows:

a. For Educators and Institutions
   Educators in the renewable energy field are advised to further integrate solar power systems as a practice-based learning medium into their courses. Vocational education institutions are expected to support the development of solar power plant facilities and infrastructure as learning laboratories so that students have learning experiences relevant to the needs of the workplace.
b. For Further Research
   Future research is recommended to develop a more in-depth study by adding other variables, such as the influence of ambient temperature, panel tilt angle, or a digital-based monitoring system on solar power plant efficiency. Furthermore, further research could quantitatively explore the impact of solar power plant use on improving student competency and learning outcomes.

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