Development of EduSolar: An IoT-based Learning System to Improve Understanding of Solar Energy Technology in Electrical Engineering Education

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Abstract. The utilisation of solar energy as an alternative energy source is on the rise, yet the comprehension of this technology among students remains constrained. The absence of interactive and real-time learning media represents a significant obstacle in the learning process. The objective of this research is to develop EduSolar, an Internet of Things (IoT)-based Solar Power Plant (PLTS) monitoring system, with the aim of enhancing students' understanding of solar energy technology in the Department of Electrical Engineering Education at Universitas Negeri Medan. The study employs the structured and systematic ADDIE (Analysis, Design, Development, Implementation, Evaluation) development method. The findings of the research indicate that EduSolar, which consists of an Arduino UNO microcontroller and various sensors, is accurate and suitable as a learning tool. It achieved a feasibility rate of 81.28% among media experts and 80.83% among content experts. Student responses indicate a feasibility rate of 78.46% and a 25% increase in understanding following the use of EduSolar. Based on these results, it is recommended that EduSolar's features be enhanced, it be integrated into the curriculum, further research be conducted on long-term impacts, and the use of solar energy be promoted through EduSolar.

Keywords: Solar Energy, Internet of Things (IoT), EduSolar, Learning Media, Solar Power Plant.

1 Introduction

Electrical energy is a fundamental need of society in today's modern era [1]. With population growth and technological advancements, the demand for electrical energy continues to rise. However, fossil energy sources, which remain the primary means of electrical energy production, have limitations and adverse environmental impacts [2]. Consequently, the development of alternative, environmentally friendly energy sources is crucial, and solar energy emerges as a viable solution [3] [4].

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The utilization of renewable energy, particularly solar energy, is increasingly becoming a major focus in efforts to reduce dependence on conventional, non-environmentally friendly energy sources [5] [6]. Solar energy offers significant potential as a clean and sustainable energy source, capable of generating electricity without producing greenhouse gas emissions [7]. Solar power plants (PLTS) are a type of power plant that harnesses solar energy to produce electrical energy. PLTS has several advantages, including unlimited energy availability, environmental friendliness, and relatively low maintenance costs [8].

In Indonesia, the development of solar power plants has experienced rapid growth, supported by the country's tropical geographical conditions, which offer significant potential for solar energy. However, one of the main obstacles to the development of PLTS in Indonesia is the lack of public understanding, particularly regarding the operation and monitoring of PLTS systems. This often leads to hesitation in investing in renewable energy technology. A solid understanding of the PLTS monitoring system is crucial to ensuring optimal performance. The PLTS monitoring system can track important parameters such as voltage, current, power, and temperature [9]. With a monitoring system, PLTS users can monitor the condition of the PLTS in real-time and take appropriate action if any disturbances occur.

Currently, there are no teaching aids or learning media available in the Department of Electrical Engineering Education at Medan State University to help students learn the PLTS monitoring system. Therefore, it is essential to develop learning media that provide a more interactive learning experience. One approach is to utilize the Internet of Things (IoT), which can integrate the PLTS monitoring system with digital technology. In this context, the development of an Educational Solar (EduSolar) system that incorporates IoT for monitoring solar power plants on a laboratory scale is crucial. This system is expected to offer a deeper understanding of solar energy technology while providing opportunities for hands-on experimentation and data analysis.

This research aims to explore the potential and effectiveness of EduSolar as an interactive learning medium that integrates the concept of IoT for monitoring solar power plants on a laboratory scale. Through this approach, it is hoped that students' understanding and skills in using and managing renewable energy sources will improve, contributing positively to the development of educational technology in the energy sector.

2 Methods

This research was conducted in the Department of Electrical Engineering Education, Faculty of Engineering, at the State University of Medan. The developed product, EduSolar, is a solar power plant monitoring system integrated with the Internet of Things. EduSolar is designed as a learning medium, equipped with user manuals and teaching modules. These teaching modules are tailored to the industrial electronics engineering concentration.

Based on Figure 1, this system is designed using a combination of several hardware devices, including the Arduino UNO microcontroller, ACS712 sensor module, voltage sensor module, PZEM-004T sensor module, light sensor (LDR), and ESP8266 Wi-Fi module. The PZEM-004T sensor measures the current, voltage, and power of a single-phase AC source. The ACS712 sensor and voltage sensor module measure the current, voltage, and power from a DC source.

Meanwhile, the LDR sensor detects light intensity. All sensor measurement data are processed by the Arduino UNO and then transmitted via the internet using the ESP8266 module. This data can be accessed through a website using a computer or smartphone.

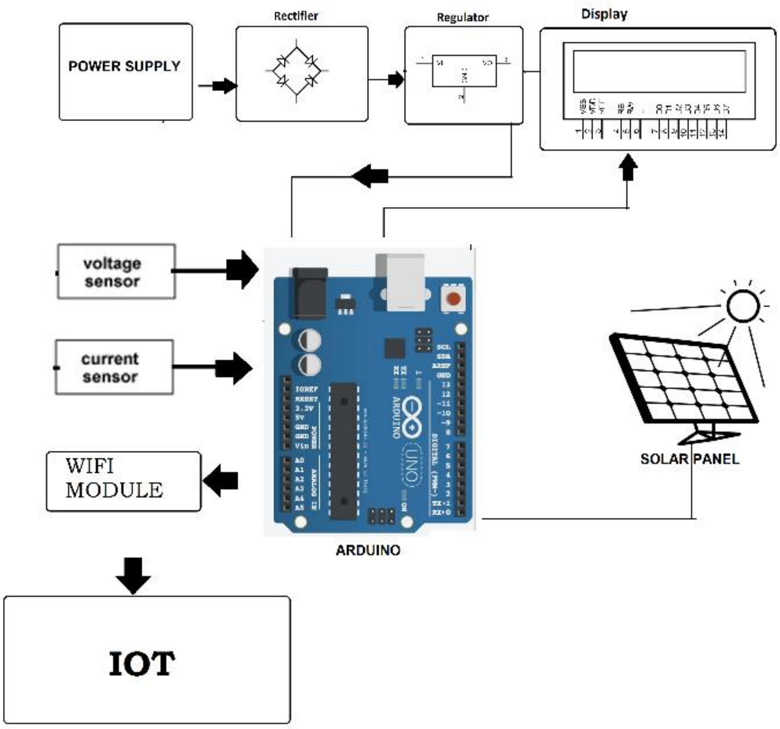

Fig. 1. System block diagram EduSolar.

2.1 Stages of Product Development

This research utilizes the ADDIE (Analysis, Design, Development, Implementation, Evaluation) product development method as described by Suratnu (2023) [10]. The stages of ADDIE applied in this study are presented in Table 1.

Table 1. Stages of ADDIE method development.

No.	Stage of ADDIE	Activities
1	Analysis	• Data collection was conducted through literature reviews, interviews with experts and target users, and surveys. • Key issues to be addressed by the system were identified and defined.
2	Design	• Determine the technical requirements for the monitoring system, including sensors for measurement, a data storage platform, a user interface, and IoT integration.

		• Design data flow diagrams, control logic, and interactions between system components. Develop an intuitive and attractive user interface to access solar power plant data and information.
3	Development	• Hardware implementation, including sensors, gateways, and other supporting hardware. • Software development, involving program code for data acquisition, processing, storage, and visualization of solar PV information. • IoT integration with appropriate IoT platforms or services to enable remote communication and control.
4	Implementation	• Install and configure the monitoring system at the designated solar power plant location. • Conduct thorough testing to ensure the system operates as designed and fulfills the learning objectives. • Provide training to users and facilitators on how to operate the monitoring system and utilize PV solar information for educational purposes.
5	Evaluation	• Conduct periodic evaluations during the implementation process to identify and rectify system shortcomings. • Perform a final evaluation to assess the system's effectiveness in enhancing students' knowledge of solar power plants. • Collect and analyze monitoring data and user feedback to measure learning progress and overall system effectiveness. • Based on the evaluation results, implement improvements and enhancements to increase learning effectiveness and better meet students' needs.

2.2 Data Collection Technique

The data collection techniques in this study are as follows:

1. The first data collection technique involves measuring the performance of the IoT-integrated PLTS monitoring system. Measurements are taken of various important parameters, such as sunlight intensity, electric current, and voltage. The data obtained is then sent directly to the server or data collection platform via the IoT network.
2. Observations were conducted of lecturers and the curriculum in the Electrical Engineering Education Study Program. In addition, researchers also observed student characteristics, facilities, and the learning media used.
3. Data collection was also conducted through questionnaires. Quality assessment questionnaires were administered to material experts and media experts to test the feasibility of the media and learning materials. Additionally, a response questionnaire was given to students to gather their feedback on the developed learning media.

2.2 Data Analysis Technique

Data analysis was conducted by validating the research instrument. Referring to Sugiyono (2013) in Lukman et al. (2023) [11], each instrument, both tests and non-tests, was validated by experts and further analyzed through item analysis. The reliability of the instrument was then tested using the Kuder-Richardson 21 (KR-21) technique, as performed by Azahra and Wasis (2023) [12]. Finally, the feasibility of the instrument was evaluated using a rating scale, as shown in Table 2.

Table 2. Feasibility categories.

No.	Score in Percent (%)	Feasibility Category
1	81% - 100%	Very Decent
2	61% - 80%	Feasible
3	41% - 60%	Decent Enough
4	21% - 40%	Not Decent
5	0% - 20%	Very Less Worthy

3 Results and Discussions

Figure 2 illustrates the final result of this research, which is a PLTS monitoring system integrated with IoT technology. Where it consists of PZEM-00T sensor, Arduino Uno, ACS712 Sensor, Voltage sensor module, LDR Sensor, ESP8266.

Fig. 2. IoT-integrated solar power plant monitoring system product.

3.1 IoT System Testing

The purpose of this test is to verify that sensor readings can be displayed in real-time on the Blynk platform and also stored on the web server for further analysis. Additionally, the test aimed to ensure that the data display on various devices, including computers and mobile phones, was consistent and responsive. The test results, as illustrated in Figure 3, show that the sensor data is successfully and accurately displayed on the Blynk server.

Testing is carried out to measure the performance of the monitoring system as a whole. This test includes monitoring the condition of the device periodically and sending data to the server. During the test, the system was operated using a 12 Ah battery, a 10 Wp solar panel, and a solar charger controller. Data transmission was done every 30 minutes for two hours, starting at 08:00 AM. The test results show that the system is able to transmit data accurately and on time.

Based on the data in Table 3, the solar panel exhibited optimal performance under sunny weather conditions by producing an average current of 1.04 A, a voltage of 13.87 V, and a power of 14.47 W. The high intensity of sunlight, ranging from 1872.5 to 2604.5 lux, significantly contributed to this increase in energy production. In contrast, under cloudy conditions (Table 4), the performance of the solar panel decreased. The average current produced was only 0.88 A, with a voltage of 9.33 V and a power output of 8.23 W. This decrease in performance corresponded to the drop in sunlight intensity, which ranged from 365.5 to 753.5 lux.

Sunlight intensity is a primary determinant of solar panel performance. Under optimal conditions, with light intensity reaching a peak of 1872.5 to 2604.5 lux, solar panels exhibit maximum efficiency, generating ample current, voltage, and power. Conversely, during cloudy weather, when light intensity diminishes to 365.5 to 753.5 lux, solar panel electricity production decreases significantly. This relationship can be likened to photosynthesis in plants: increased sunlight exposure correlates with enhanced energy output.

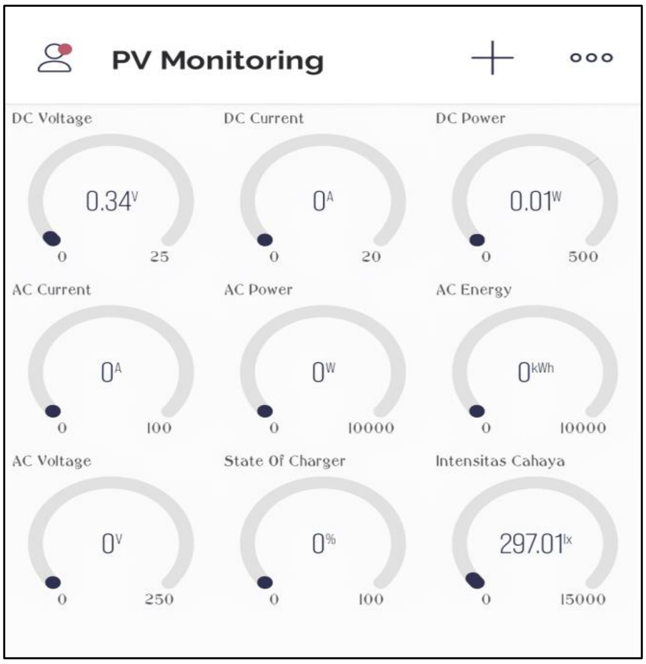

Fig. 3. Display of the PLTS monitring system.

Table 3. Monitoring results in clear weather.

Time	PV Current	PV Voltage	PV Power	Light Intensity
08:00	1,02	13,7	13,97	1872,5
09:00	1,04	13,76	14,31	2165,4
10:00	1,06	14	14,84	1605,5

Table 4. Monitoring results in cloudy weather.

Time	PV Current	PV Voltage	PV Power	Light Intensity
08:00	0,82	8,6	7,05	365,5
09:00	0,89	9,6	8,54	465,4
10:00	0,93	9,8	9,11	753,5

3.2 Media Feasibility

Expert evaluations of the IoT-integrated PLTS system monitoring media are summarized in Table 5. To enhance visualization, the percentage of media feasibility is presented in the form of a bar chart in Figure 4. This diagram provides a clear representation of the aspects of the media that meet the experts' assessment criteria. The EduSolar system was evaluated by media experts, yielding high feasibility ratings. Media experts rated the system at 81.28%, with scores for technical quality reaching 80.90% and instructional quality rated at 81.67%.

Table 5. Media validation results.

No.	Assessment aspects	Total Score for Each Aspect	Percentage Score of Each Aspect
1	Technical quality	44,5	80,90%
2	Instructional Quality	49	81,67%
	Average total score	46,75	
	Total Percentage		81,28%

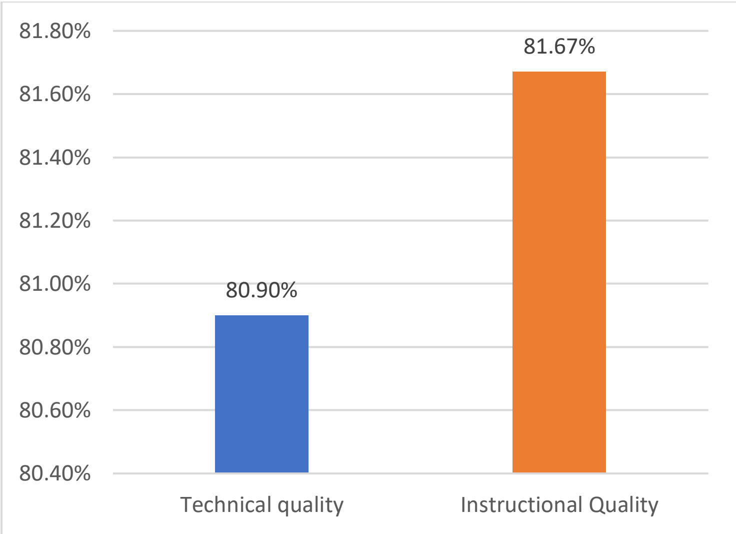

Fig. 4. Percentage of media feasibility.

3.3 Learning Materials Feasibility

The results of the material experts' assessment of the teaching module are summarized in Table 6. To facilitate visualization, the percentage of material feasibility is presented in the form of a bar chart in Figure 5. This chart provides a clear representation of the extent to which the teaching module meets important aspects such as content quality, suitability of learning objectives, and effectiveness of instructions. The EduSolar system was evaluated by content experts, and gave it score of 80.83%. Additionally, the feasibility of the learning materials was assessed, with scores for quality of objectives and content reaching 77.50% and instructional quality rated at 84.17%. These high ratings indicate that the learning modules developed for EduSolar are both comprehensive and effective in conveying key concepts in solar energy technology.

Table 6. Learning material validation results.

No.	Assessment aspects	Total Score for Each Aspect	Percentage Score of Each Aspect
1	Quality of objectives and content	46,5	77,5%
2	Instructional Quality	50,5	84,17%
	Average total score	48,5	
	Total Percentage		80,83%

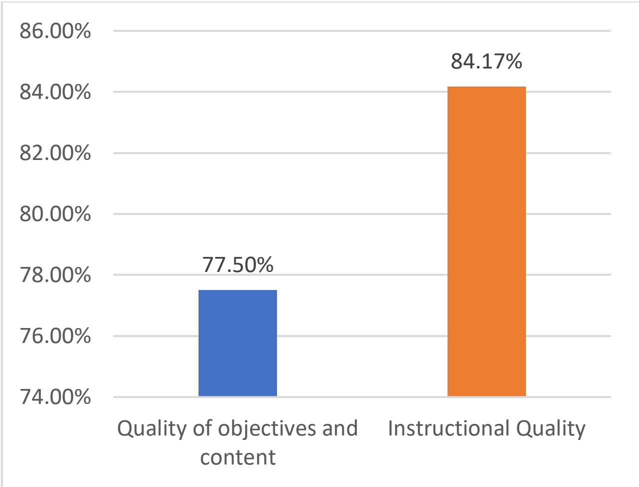

Fig. 5. Percentage of feasibility of learning materials.

3.4 Students Feedback

Student responses to the EduSolar system were overwhelmingly positive, with an average feasibility score of 78.46% across several key metrics, including technical quality at 79.00% and instructional quality rated at 84.17%. Importantly, students reported a 25% increase in their understanding of solar energy technology after engaging with EduSolar. This underscores the system's effectiveness in making complex concepts more accessible and understandable through practical application.

Students particularly appreciated the real-time data display and the ability to experiment with the system under different conditions. The IoT integration provided them with a more interactive learning experience, moving beyond theoretical knowledge to a hands-on understanding of solar power plant monitoring systems.

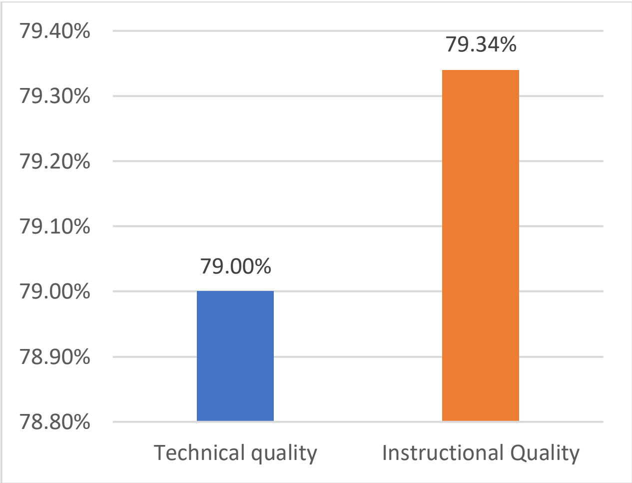

Fig. 6. Percentage of student responses.

3.5 Discussions

The success of EduSolar lies in its ability to bridge the gap between theoretical concepts and real-world application. The IoT integration allowed students to actively monitor and engage with solar energy technology, thus deepening their comprehension. The 25% improvement in student understanding is a testament to the system's educational impact, highlighting how interactive, real-time learning tools can significantly enhance traditional learning methods.

In addition to the educational benefits, EduSolar also promotes sustainable energy awareness by familiarizing students with renewable energy technologies. This hands-on experience with solar power monitoring aligns with the growing global emphasis on renewable energy education, preparing students for future careers in the energy sector.

The system's feasibility scores, both from experts and students, suggest that EduSolar is ready for broader implementation within the Electrical Engineering curriculum. However, there is room for improvement. Future research could focus on enhancing the system's features, such as adding more advanced sensors or improving the user interface to provide more detailed data analysis. Moreover, long-term studies could assess the sustained impact of EduSolar on student learning outcomes, particularly in terms of practical skills development.

In summary, EduSolar has proven to be an effective and innovative learning tool, capable of improving student engagement and understanding of solar energy technology. Its successful implementation in the classroom demonstrates its potential for broader application and integration into renewable energy education programs.

4 Conclusions

The objective of this research was to develop EduSolar, an Internet of Things (IoT)-based Solar Power Plant (PLTS) monitoring system, to enhance students' understanding of solar energy technology in the Department of Electrical Engineering Education at Universitas Negeri Medan. The study employed the structured and systematic ADDIE (Analysis, Design, Development, Implementation, Evaluation) development method to create the EduSolar system. The findings indicate that the EduSolar system, consisting of an Arduino UNO microcontroller and various sensors, is accurate and suitable as a learning tool. It achieved a feasibility rate of 81.28% among media experts and 80.83% among content experts. Student responses showed a feasibility rate of 78.46% for the EduSolar system and a 25% increase in understanding of solar energy technology after using the system.

Based on the results, the authors recommend: 1) Enhancing the features of the EduSolar system; 2) Integrating EduSolar into the curriculum; 3) Conducting further research on the long-term impacts of using EduSolar; 4) Promoting the use of solar energy through the EduSolar system

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