Design of Smart Microgrid as an Integration of Electrical Systems with Android Application

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The increasing demand for electrical energy, coupled with the need for sustainability, has led to the development of smart microgrids that integrate renewable energy sources and traditional grid systems. This paper presents the design and implementation of a smart microgrid system that integrates solar and wind power plants with the national grid (PLN), using an Automatic Transfer Switch (ATS) and a mobile application for real-time monitoring and control. The system optimizes energy distribution between renewable sources and PLN, ensuring a seamless transition in case of power supply interruptions. The mobile application, developed using Flutter and integrated with Firebase and Node.js, enables users to monitor energy consumption, control energy distribution, and manage financial costs. The results demonstrate the system's reliability in energy management, promoting renewable energy use while ensuring system resilience. This solution contributes to Indonesia's goal of achieving Net Zero Emissions (NZE) by 2060.

Index Terms— Smart microgrid, renewable energy, Automatic Transfer Switch (ATS), energy management, real-time monitoring.

I. Introduction

The demand for electrical energy is crucial for daily life. The use of electrical energy is projected to increase with an average growth rate of 5.9% per year, reaching 1,455 TWh by 2050 [1]. In reality, the installed capacity of power plants in the first semester of 2020 was only 71 GW, with coal still dominating at 35,220 MW [2]. The use of fossil energy such as coal can lead to increased carbon emissions, which contribute to global warming. Therefore, there is a need to develop power plants with a renewable energy transition to help meet this demand sustainably and preserve the natural ecosystem. By investing in renewable energy sources, we can reduce our reliance on fossil fuels and promote environmental sustainability.

The energy transition is one of the efforts towards achieving Net Zero Emission (NZE) by 2060. The energy transition can be carried out gradually, starting with the addition of power plants from renewable energy sources to the electrical grid. This aligns with the concept of hybrid power plants that use more than one type of energy source to supply electrical loads. This combination requires a system that transfers power from one source to another according to existing conditions. Using inappropriate technology to handle the transition from the primary energy source to the backup source, or vice versa, can cause issues with stability, reliability, and power quality in the main or backup electrical grid. Smart grid technology is key to automatically solving these energy source transition problems. Previous research has shown that smart grid systems work effectively, optimizing the use of solar power plants (PLTS) with a load of 770 Wh, demonstrating an average percentage of electricity use from the national grid (PLN) at 70.65% and electricity savings of 29.35% [3]. Furthermore, the implementation of smart grid technologies can facilitate better integration of diverse renewable energy sources.

The use of smart grid technology is adapted to the scope of power generation and loads operating as a unified network. This condition has led to a new concept known as smart microgrids, which provide advantages over conventional grid systems. Smart microgrids offer three benefits in three different areas: energy security and reliability, fuel savings, and environmental benefits [4]. Smart microgrids can be the first step in initiating the transition on a smaller scale. Intelligent systems can be applied to electrical networks, ranging from real-time monitoring of electrical parameters to automatic switching.

The potential for electrical energy that can be used is adjusted to the conditions of the area where the power plant is located. The potential use of renewable energy in Indonesia can include various types, such as solar energy at 2,898 GW and onshore and offshore wind energy at 608.6 GW [5]. The energy generated from the combination of solar power plants (PLTS) and wind power plants (PLTB) can be stored in batteries as a renewable energy source. The presence of batteries as a storage for electrical energy from PLTS and PLTB can be used to supply loads, in collaboration with the national grid (PLN) as a backup system.

Based on the existing problems and potential, this paper will discuss the integration of power plants based on smart microgrids. The integration design will include PLTS and PLTB as renewable energy sources, with PLN as a backup source. The transition of electrical energy sources will be equipped with an automatic transfer switch integrated with an Android application. This will facilitate the automatic operation of the electrical system and real-time monitoring.

The results obtained will impact the reliability of the electrical system and the transition to clean energy to support Net Zero Emission (NZE) 2060.

II. Literature Study

A. Smart Microgrid

A microgrid can be defined as a small electrical system consisting of distributed generation and loads that operate as an autonomous network, either connected to external systems or functioning in isolation. The term "smart" refers to new technology that combines information and communication technologies with conventional electrical technology. A smart microgrid is characterized by its ability to manage the integration of generation sources, energy storage, power quality, and real-time monitoring. Figure 1 shows a schematic diagram of a typical smart microgrid, where the use and production of electrical power can be monitored and communicated using smart meters to detect abnormalities in the electrical system [6].

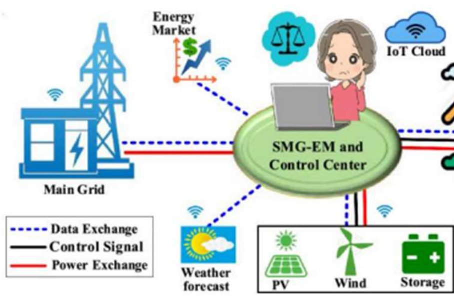

Fig. 1. Schematic Diagram of the Smart Microgrid [6].

B. Automatic Transfer Switch

Intelligent systems in a smart microgrid are designed to optimize the control of electrical parameters, thereby enhancing the overall reliability and efficiency of the energy distribution system. One of the critical components in this system is the control of electrical energy transfer between multiple power sources, which can be achieved through the use of an Automatic Transfer Switch (ATS). The ATS is a sophisticated device that automatically connects an electrical load to two or more power supply sources of different generation types, ensuring seamless continuity and reliability of the electrical system even in the event of a power source failure [7]. This is a significant advantage over traditional systems like the Change Over System (COS), which operates manually and lacks the efficiency of automatic switching. In contrast, the ATS functions autonomously, making real-time decisions based on the conditions and performance of the connected power sources. This automatic operation makes the ATS not only more efficient but also more reliable, as it can quickly detect issues with one power source and immediately switch to another without requiring human intervention [8].

The implementation of an ATS is considered a foundational step in advancing towards the smart microgrid concept, as it plays a crucial role in system resilience and reliability. By enabling the seamless transfer of power between sources, the ATS helps minimize any potential downtime, ensuring that the electrical load is continuously supplied with power. This is especially important in systems that rely on a combination of renewable energy sources, such as solar power plants (PLTS) and wind power plants (PLTB), in conjunction with traditional grid power from the national grid (PLN). The ATS allows these various power sources to work together efficiently, transferring energy from one source to another based on predefined parameters and real-time performance conditions.

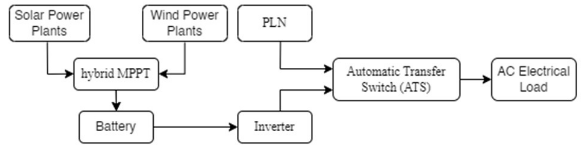

Fig. 2. Block Diagram of the ATS System

Essentially, an ATS operates as a position-switching device that automatically responds to predefined electrical source parameters, ensuring that the system remains functional even when one power source experiences an interruption or fault. In the event of such a disruption, the ATS seamlessly switches the power flow to an alternative source, thereby maintaining the proper supply of electricity to the load. This automatic switching capability is integral to the design of the system discussed in this paper, where the ATS manages the transfer of electrical energy between solar power (PLTS), wind power (PLTB), and the national grid (PLN). Energy from PLTS and PLTB is stored in batteries, converted to AC power using an inverter, and then transferred to the electrical load as needed. If either the renewable energy sources or the batteries encounter issues, the ATS ensures that the electrical load is supplied by switching to the national grid (PLN) without any noticeable disruption in power [7]. This is illustrated in Figure 2, which provides a schematic representation of how the ATS operates within the system to manage energy transfer between different power sources, enhancing the overall resilience of the smart microgrid.

C. Mobile Apps

The mobile application for the smart microgrid system, developed using Flutter, integrates seamlessly with Firebase and Node.js to support real-time monitoring and control of the microgrid components. These components include solar power plants (PLTS), wind power plants (PLTB), battery storage, and the national grid (PLN). Firebase serves as the cloud storage and synchronization platform, ensuring that energy consumption data and system states are updated in real-time.

In addition to Firebase, Node.js is integrated as the backend for managing data delivery and notifications. Node.js facilitates the real-time communication between the mobile application and the system, ensuring efficient data flow and timely notifications to users. Node.js handles server-side logic and ensures that the application receives crucial updates from the sensors, while Firebase manages the real-time database operations.

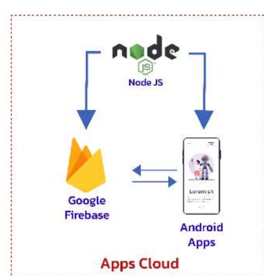

Fig. 3. Cloud Integration for Smart Microgrid Mobile Application.

This combined infrastructure of Firebase and Node.js optimizes the use of renewable energy sources, promoting energy efficiency and sustainability. Users can control the energy distribution and consumption directly from the mobile app, ensuring seamless transitions between renewable and grid energy sources. The comprehensive system design, illustrated in Figure 3, demonstrates how Node.js and Firebase work together to provide a reliable and efficient backend for the mobile application. This interaction ensures that users receive timely notifications, real-time updates, and smooth operation, all while maintaining scalability and performance in the smart microgrid system.

III. METODOLOGY.

A. Electrical System Integration

The design of the system for integrating renewable energy power plants with PLN consists of several interrelated parts. Each section of the system block will have its own function to support the overall performance of the device. This paper design will include the automatic transfer switch and the Android application, as shown in Figure 4.

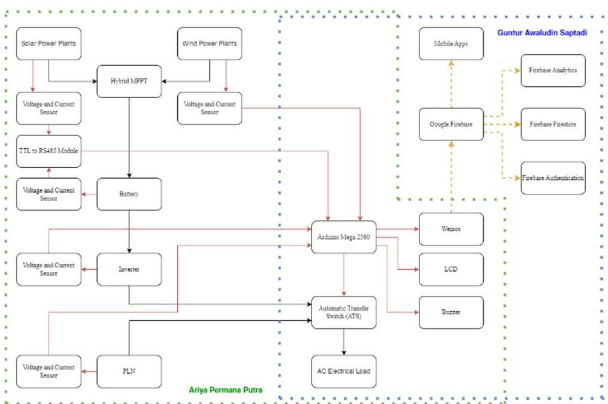

Fig. 4. Overall System Block Diagram.

B. Operation of the Automatic Transfer Switch

The design for transferring electrical energy originating from a single renewable energy source and PLN using an Automatic Transfer Switch (ATS) involves several parameters to achieve an efficient system. The first parameter is the State of Charge (SOC) of the battery, which indicates the stored electrical energy capacity. The second parameter is the battery voltage, which reflects the battery's condition and its quality depending on the duration of use. The third parameter is the PLN voltage, which serves as a backup system. These parameters result in the emergence of several switching conditions as follows:

- Switching to Battery Source: The system first checks the battery's State of Charge (SoC). If the SoC is ≥ 50% and the battery voltage is ≥ 11.5V, the microcontroller commands the battery relay to turn ON, allowing the load to be powered by renewable energy from the solar power plant (PLTS) and wind power plant (PLTB). If the battery voltage falls below 11.5V, the battery relay turns OFF, and the system proceeds to read other sensor data to determine the next appropriate action.
- Switching to PLN Source: If the SoC and battery voltage do not meet the required thresholds, the system will then check the condition of the PLN (grid) source. If the PLN voltage is ≥ 198V, the microcontroller will command the PLN relay to turn ON, ensuring that the load is powered by the grid as a backup energy source. If the PLN voltage drops below 198V, the relay will turn OFF, indicating that no energy supply is available. This may lead to an emergency state caused by either insufficient energy or sensor reading issues.
- Manual Mode Switching: The transfer of energy flow between sources can be managed manually if a sensor error or failure occurs. Activating manual mode halts the automatic control of relays, allowing the user to manually select the desired power source. Pressing the switch to enable the battery (RE) will power the load using energy from the battery, PLTS, and PLTB, while the PLN relay remains OFF. Conversely, pressing the switch for PLN will supply energy from the grid, turning the battery relay OFF. This manual control ensures flexibility and reliability in case of system errors.

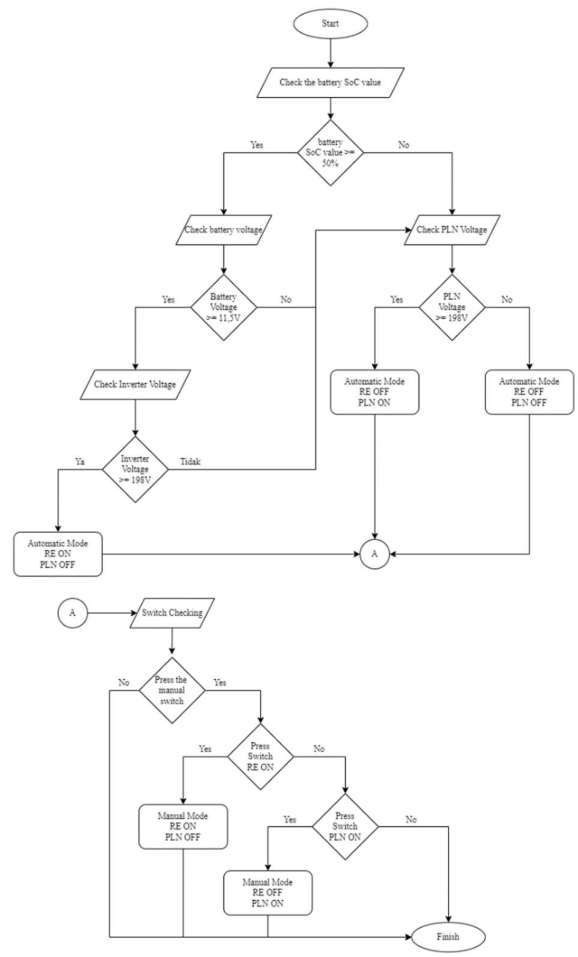

Fig. 5. ATS System Workflow Flowchart.

C. Flowchart system Mobile Apps

The mobile application for the smart microgrid system is designed to provide users with seamless interaction for monitoring and managing their energy consumption. The flowchart in Figure 6 illustrates the operational workflow of the mobile app, highlighting key functionalities such as user authentication, power usage monitoring, and billing management. Upon launching the app, users are prompted to input their username and password. The system then verifies the account credentials; if valid, users gain access to the main dashboard. From the main dashboard, users can navigate to view daily power usage statistics or manage their monthly billing information.

A critical feature of the application is the ability to switch power sources between the smart microgrid and the national grid (PLN). This decision point ensures that users can maintain a continuous power supply by automatically switching to the PLN if needed. The dashboard also provides detailed insights into the power usage from the PLN, allowing users to monitor and manage their energy consumption effectively. This integration with the smart microgrid system ensures that users have real-time access to crucial data, enhancing the overall efficiency and reliability of the energy management process, as shown in Figure 6.

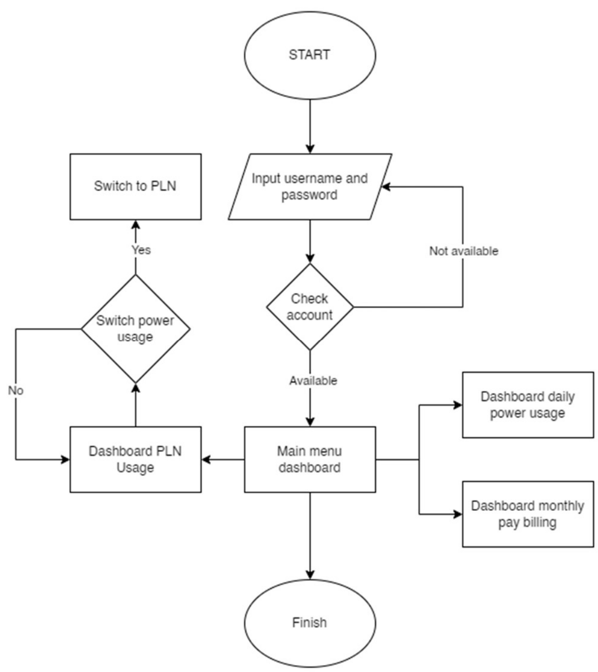

Fig. 6. Flowcharts mobile apps system

IV. SYSTEM FLOW TESTING AND RESULT

The system integrates renewable energy sources with advanced control and monitoring technologies, ensuring efficient energy management and seamless operation. Key components such as wind power plants, solar panels, an MPPT module, battery storage, and an inverter are managed by an Arduino Mega 2560 microcontroller. To evaluate the performance and reliability of the smart microgrid system, extensive testing was conducted under various operational scenarios. The integration with Cloud Firestores services facilitates real-time data management, monitoring, and remote control via an Android application. The following sections detail the methodologies, test scenarios, and performance metrics used to assess the system's effectiveness and efficiency.

A. *ATS Switching Time Testing*

The implementation of the Automatic Transfer Switch (ATS) in this paper focuses on the performance of the relay as it connects and disconnects the flow of electrical energy. The ATS has two modes: automatic, which responds to electrical parameters detected through sensor data, and manual, which serves as a backup system in case of issues beyond control. The switching time for each mode will be tested 10 times to obtain accurate data.

- Automatic ATS Mode (Battery to PLN):

In the first condition, the ATS operates when the battery parameters are outside the acceptable range, switching the power flow to the PLN. Based on Table 1, the relay testing results show 10 instances of automatic switching from battery to PLN, with transition times ranging from 1.54 to 1.98 seconds, and an average transition time of 1.62 seconds.

TABLE I. AUTOMATIC ATS MODE TESTING DATA (BATTERY TO PLN)

No.	Experimental Data-	Time (ms)
1.	1	1.08
2.	2	0.62
3.	3	0.80
4.	4	0.99
5.	5	0.42
6.	6	0.70
7.	7	0.44
8.	8	0.47
9.	9	0.63
10.	10	0.92
	Average	31,8

- Automatic ATS Mode (PLN to Battery):

In the second condition, the ATS switches the power flow from PLN to the battery when the sensor detects that the battery parameters meet the established standards. Based on Table 2, the relay testing results show 10 instances of automatic switching from PLN to the battery, with transition times ranging from 1.54 to 1.98 seconds, and an average transition time of 1.62 seconds.

TABLE II. AUTOMATIC ATS MODE TESTING DATA (PLN TO BATTERY)

No.	Experimental Data-	Time (ms)
1.	1	32
2.	2	32
3.	3	32
4.	4	30
5.	5	31
6.	6	32
7.	7	32
8.	8	33
9.	9	32
10.	10	31
	Average	31.7

B. *Application Interface and Functionality*

The interface of the smart microgrid mobile application, as shown in Fig. 7, offers users clear insights into energy usage and financial management. The intuitive layout allows monitoring of both renewable energy sources and PLN (state electricity company) consumption, alongside financial expenditures. The main dashboard provides real-time updates on power usage and costs, helping users quickly assess their energy consumption. Separate sections display real-time voltage, current, and status indicators for wind (PLTB) and solar energy (PLTS), alongside PLN grid data, allowing users to monitor system efficiency. A financial management feature highlights savings from renewable energy use, displayed as both a percentage and in currency, reinforcing the benefits of smart microgrid integration.

Fig. 7. Interface smartmicrogrid mobile apps

The interface also features a mode selector, located in the top-left corner, which allows users to switch between automatic and manual modes. In automatic mode, the system autonomously controls the energy flow between renewable sources and PLN based on predetermined conditions, enhancing the system's efficiency. This functionality is particularly useful for ensuring that energy management is optimized without requiring constant user input. Additionally, the application presents a detailed graph that visualizes energy usage trends over time, comparing the consumption of renewable energy and PLN. This visual representation is complemented by a log of daily energy consumption, which allows users to review their usage patterns and better understand their energy consumption behavior.

Real-time updates are a core feature of the application, providing users with up-to-date voltage and current readings for both wind and solar energy systems. These updates ensure that users can monitor the performance of their renewable energy sources at any given moment. The financial savings data is also refreshed dynamically, giving users an immediate understanding of their cost savings as they reduce their reliance on PLN energy.

C. Black Box testing

Black box testing is a software testing technique that assesses the functionality of an application without analyzing its internal code or structure. This method focuses on verifying outputs in response to specific inputs, ensuring the software meets the defined requirements and user expectations [11]. It plays a crucial role in validating user interfaces, workflows, and application behavior, making it integral to the software development lifecycle.

In the smart microgrid application, black box testing was performed to check features such as installation, splash screen display, login, media token input, and various dashboards, including daily billing and PLN usage. It also assessed real-time monitoring of voltage, power, and current, changes in power usage status, and push notifications. The results, as shown in Table V, indicate consistent success across all features on three different devices, proving the application's reliability and robustness [12].

D. Testing the CPU Profiler on all application features

In modern mobile application development, performance evaluation is critical to ensure smooth user experience and optimized resource usage. The use of CPU Profiler in application testing helps to analyze performance metrics, such as frame rate, jank, and frame times. Table III illustrates the results of CPU Profiler testing conducted on all features of the application. The table presents key metrics, including the average frame rate in frames per second (FPS), the number of instance jank occurrences, the average frame time, and the average raster time, both measured in milliseconds.

TABLE III. CPU PROFILER TESTING ON ALL APPLICATION FEATURES

Testing	Average Frame Rate (FPS)	Instance Jank	Average Frame Time (ms)	Average Time (Raster) (ms)
Login Screen	88	2	8	8
Register Screen	90	0	6	6
Home Screen	89	1	8	8
Electricity Usage	89	2	8	8
Cost Expenditure	86	1	8	8
Weather Forecast	87	2	8	8
Energy Control	90	0	8	8
Profile Page	88	1	8	8
Testing	88	2	8	8
Login Screen	90	0	6	6
Average	88,5	1,1	7,6	7,6

Upon analyzing the data from Table III, it is evident that the application's performance remained relatively stable across all test iterations. The average frame rate hovered around 88.5 FPS, which is close to the ideal target of 90 FPS, signifying smooth rendering throughout the application. The instance jank averaged at 1.1, which is an acceptable figure, indicating that there were minimal occurrences of unresponsiveness or dropped frames during the testing.

Furthermore, the average frame time and raster time were consistently maintained at approximately 7.6 ms, ensuring that the rendering pipeline processed frames quickly enough to avoid any noticeable delays in the UI. These metrics highlight the efficiency of the application's graphical rendering and suggest that the app was able to handle its visual load without significant lag or stuttering.

In conclusion, the results of the CPU Profiler testing demonstrate that the application performs efficiently across all features, with minimal performance issues. The low instance jank and fast frame processing times point to well-optimized graphics and responsiveness, which are crucial factors for delivering a seamless user experience in mobile applications. This analysis not only confirms the current state of the application's performance but also serves as a reference for further optimizations if needed.

TABLE IV. BLACK BOX UNIT TESTING

No	**Features**	**Result**		
		Device 1	***Device 2***	***Device 3***
1	*Aplication Installation*	V	V	V
2	Show *SplashScreen*	V	V	V
3	Login on LoginScreen	V	V	V
4	Register on RegisterScreen	V	V	V
5	Display Power Control Screen	V	V	V
6	Display main menu dashboard	V	V	V
7	Display daily monthly billing dashboard	V	V	V
8	Display daily PLN usage dashboard	V	V	V
9	Show detailed conditions of voltage, power, and current on MonitoringScreen	V	V	V
10	Edit profile in Profile Screen	V	V	V
11	Push Notification	V	V	V

V. CONCLUSION

The smart microgrid system integrates renewable energy sources (solar and wind) with the national grid (PLN), ensuring stable energy distribution using an Automatic Transfer Switch (ATS). The mobile application, developed with Flutter and supported by Firebase and Node.js, allows real-time monitoring and control, optimizing energy distribution between renewable sources and PLN.

Black-box testing, as shown in Table V, validated the application's core features such as installation, login, energy monitoring, and push notifications, with successful performance across all devices. ATS testing demonstrated a seamless power transition, with an average switch time of 1.62 seconds from battery to PLN and 31.7 milliseconds from PLN to battery.

The CPU Profiler analysis, detailed in Table III, revealed an average frame rate of 88.5 FPS with minimal jank, confirming the app's efficient handling of visual loads. Key screens, such as the Login Screen and Energy Control, maintained stable performance with frame rates close to 90 FPS.

Overall, the system provides a robust solution for managing renewable energy, contributing to Indonesia's sustainability goals. The combination of reliable performance and efficient real-time control makes it a viable option for modern energy management.

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