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A Robust Automatic Transfer Switch System for Managing Power Transitions between Grid, Solar PV, and Genset Sources

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Abstract—This article presents the design and implementation of an Automatic Transfer Switch (ATS) system with automatic generator activation, aimed at ensuring the continuity of electricity supply from the National Electricity Company (PLN) grid, photovoltaic (PV) systems, and generator sets (Gensets). As reliance on the PLN grid is often compromised by various disruptions, including short circuits and natural disasters, integrating reliable backup energy sources is essential for maintaining operational efficiency across critical sectors such as healthcare, education, and industry. The ATS is structured to facilitate seamless transitions between power sources, minimizing downtime and enhancing system reliability. Test results demonstrate the ATS's effectiveness in managing switching processes, showing minimal voltage fluctuations and flicker durations, which underscores its capability to sustain uninterrupted power supply. By employing advanced monitoring technologies, this ATS system not only optimizes energy management but also bolsters the resilience of electrical infrastructure, addressing the growing need for dependable electricity in an increasingly variable energy landscape.

Keywords: Automatic Transfer Switch, Electricity Supply Continuity, Photovoltaic Systems, and Generator Sets (Gensets).

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1. Introduction

The primary source of electrical energy utilized across various sectors, including industrial, residential, governmental, educational, and healthcare institutions, is predominantly supplied by the National Electricity Company (PLN) grid. The continuous availability of electrical energy is crucial for sustaining economic activities, educational processes, and healthcare services, thereby ensuring their operational efficiency and productivity [1][2]. However, the reliability of electricity supply from PLN grid is often compromised due to a range of factors such as short circuits, overloads on electrical lines, natural disasters, and disturbances within the power generation system [3], [4]. These disruptions can lead to significant power outages, which in turn can severely hinder activities that rely on electricity, affecting both economic output and social services [5][6]. The high costs of power outages have prompted organizations to invest in reliable backup systems [7].

Mitigating the adverse effects of power outages requires reliable backup energy sources to support the primary supply from PLN grid [8]. Ensuring the availability of these alternatives is essential for maintaining continuous operations during disruptions in the main electricity supply. PV system and generator sets (Gensets) are increasingly being recognized as viable alternatives to ensure a continuous power supply [9]. The shift towards renewable energy sources has prompted the development of cleaner backup technologies [10], [11]. The integration of these sources necessitates an automatic switching mechanism that can seamlessly transition between PLN grid, PV, and Gensets. Such a system is essential for maintaining operational continuity without requiring manual

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intervention during power disruptions [12].

The implementation of an Automatic Transfer Switch (ATS) is a critical component in this context. An ATS is designed to automatically switch the electrical supply from PLN grid or PV to Gensets when an outage is detected, thereby ensuring that essential services remain uninterrupted [13]. The development of this automatic control system not only enhances reliability but also reduces the response time during outages, which is vital for sectors where downtime can lead to significant economic losses [14]. Furthermore, the integration of advanced monitoring systems can improve the overall reliability of power supply by quickly identifying and addressing failures within the electrical network [15].

The ATS is structured into two systems: the main transfer switch, which manages the transition between PLN grid and PV system, and the backup by Genset. Conversely, when either PLN or PV system is restored, the Genset is automatically shut down. This dual-system approach enhances reliability and minimizes downtime during power interruptions, which is crucial for maintaining operational continuity in various sectors, including healthcare, industry dan data centers [16][17]. Potential power quality issues associated with integrating renewable energy sources into the grid, such as voltage fluctuations and harmonics [18]. The integration of advanced monitoring and control technologies is essential for optimizing the performance of the ATS and ensuring stable grid operation, particularly as the penetration of renewable energy sources increases [19]. By utilizing a well-coordinated ATS, the system can effectively manage power flows and enhance the overall resilience of the electrical infrastructure [20].

2. Method

2.1 Automatic Transfer Switch System Using Magnetic Contactors for Dual Power Sources

The design of the system in this research utilizes a magnetic contactor as the primary component of the ATS for switching between two power sources: PLN grid and PV system as Shown in Figure 1. A time delay relay is employed to delay the electricity output from the generator to household devices, helping to mitigate current and voltage surges. The main ATS comprises one magnetic contactor of type SN-21 with a maximum current rating of 32 Amperes, featuring two Normally Open (NO) control contacts and two Normally Closed (NC) control contacts. The output from the magnetic contactor is routed in parallel to the backup ATS and the magnetic contactor in the automatic generator activation circuit. In this setup, the PLN electricity is connected to the coil and the main NO contacts of the magnetic contactor, while the electricity from the PV is connected to the auxiliary NC contacts. When the PLN power is on, the coil becomes magnetized, attracting and connecting the main NO contacts to allow electricity to flow to the backup ATS and the magnetic contactor in the automatic generator activation circuit. If the PLN power fails, the main NO contacts disconnect, and the NC contacts connect, allowing the PV electricity to replace the lost PLN power.

The backup ATS employs two MK2P-I 220VAC relays, each connected to the outputs of the main ATS and the generator, along with one H3BA-A8 220VAC relay functioning as a delay for the electricity output from the generator to the load. This backup ATS is activated when both PLN and PV sources fail, enabling the generator to supply electricity to the load. The design for automatic on/off and starter activation of the generator uses an automatic generator activation circuit. This circuit consists of two 32 Ampere magnetic contactors with 2 NO and 2 NC contacts, two MK2P 12VDC relays, one H3BA-A8 220VAC time delay relay, and one H3CR-A8 12VDC time delay relay. When both PLN grid and PV power sources are down, the NC contact of the magnetic contactor connects the 12V 5A battery output of the generator to the H3CR-A8 12VDC time delay relay. This relay ensures that no power is flowing from the main ATS output by setting a delay before the battery output connects to the MK2P 12VDC relay, which controls the on/off operation of the generator. If there is any power from the main ATS, the H3CR-A8 relay cuts off the battery output to the MK2P 12VDC relay. Conversely, if there is no power, it connects the battery output to the MK2P 12VDC relay. When the generator is on, the 12V 5A battery powers the H3CR-A8 relay to anticipate any starter failure (using a timer mode with an OFF-delay of 5.5 seconds) and sends power to the MK2P 12VDC

relay, which controls the generator starter circuit, ensuring that the generator can produce a voltage output of 220VAC. The generator output is then connected to the H3BA-A8 220VAC time delay relay and the magnetic contactor, which serves to disconnect the starter circuit, preventing the generator from starting continuously.

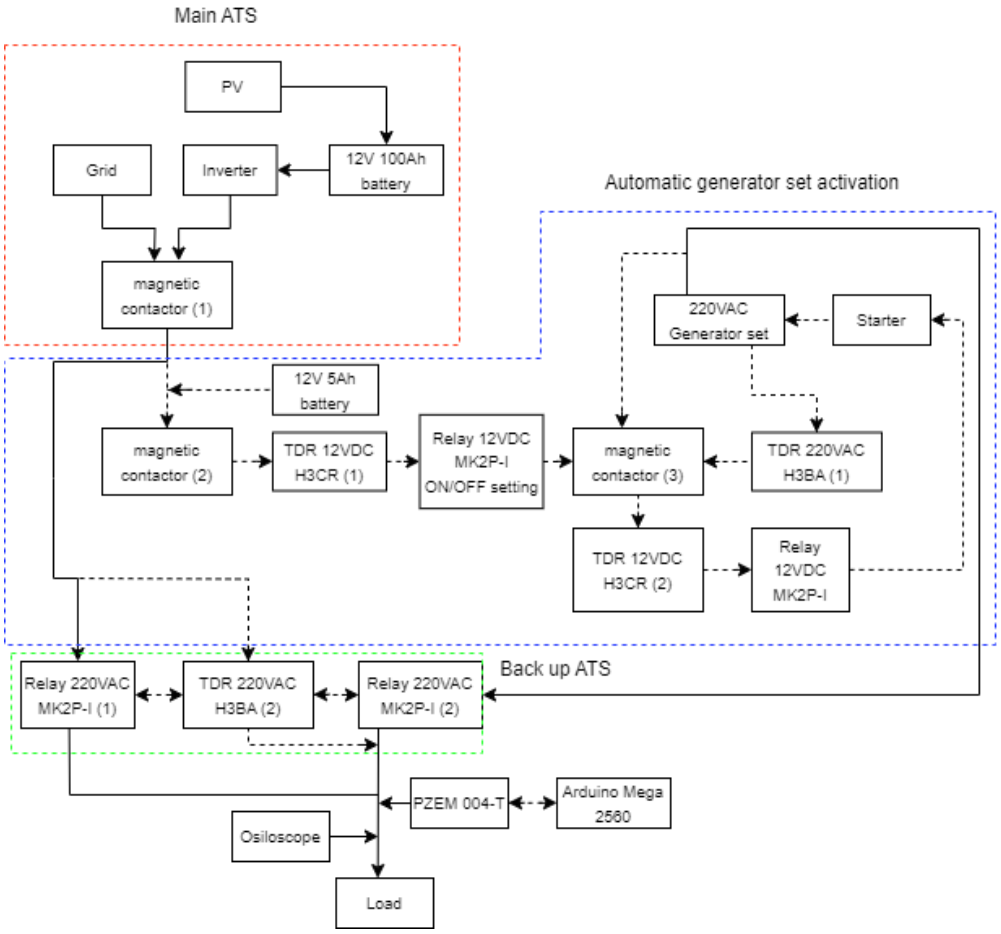


Figure 1. Block diagram of system designed

2.2 Wiring Diagram of Hardware Designed

The The system consists of several key components, including a NodeMCU ESP32, PZEM004T sensor, Hantek DSO5102P oscilloscope, SN-21 magnetic contactor (220V, 32A), H3CR-A8 time delay relay, MK2P-I relays (12VDC and 220VAC), a VRLA 12V 5Ah battery, and a Honda Excell SF2900DXE generator. For the solar power setup, the system incorporates a 250Wp monocrystalline solar panel, a Homaya inverter, and a VRLA 100Ah battery. These components work together to enable efficient power monitoring and management.

The system's operational design is structured around real-time monitoring and seamless switching between power sources. The PZEM-004T sensor continuously measures current and voltage, while the Hantek DSO5102P oscilloscope analyzes waveform changes during transitions between PLN (utility grid), PV power, and the generator. The SN-21 magnetic contactor acts as the primary switching mechanism, facilitating smooth transitions between PLN and PV power while also triggering the generator when needed.

To enhance system reliability, several relays are implemented for protection and automation. The H3CR-A8 time delay relay safeguards the generator by preventing continuous restarts in case of a failed start attempt. The H3BA-A8 time delay relay ensures a controlled delay before supplying

electricity to prevent power surges. Additionally, the MK2P-I 12VDC relay manages the generator's start and stop functions, while the MK2P-I 220VAC relay serves as a backup ATS, ensuring power availability when both PLN and PV sources are offline.

Data collection for the automatic transfer switch system and automatic generator activation was conducted to assess the continuity of electricity supply from PLN, PV, and the generator over a duration of 20 minutes for each operating condition. The study involved various switching processes, including transitions from PV to PLN grid and from PLN grid to PV, to evaluate the system's ability to seamlessly switch between solar power and the national grid. Additionally, the transition from PLN to the generator was tested to gauge the generator's responsiveness during power outages, followed by a return transition from the generator back to PLN to ensure smooth integration with the national grid. The switching from PV system to the generator was also monitored to assess the system's performance during periods of solar power deficiency, and the transition back from the generator to PV source was examined to confirm efficient operation when reverting to solar energy. Each switching process was carefully observed to ensure reliability and efficiency in maintaining continuous energy supply throughout these transitions. This process can be seen in wiring diagram of the hardware designed Figure 2.

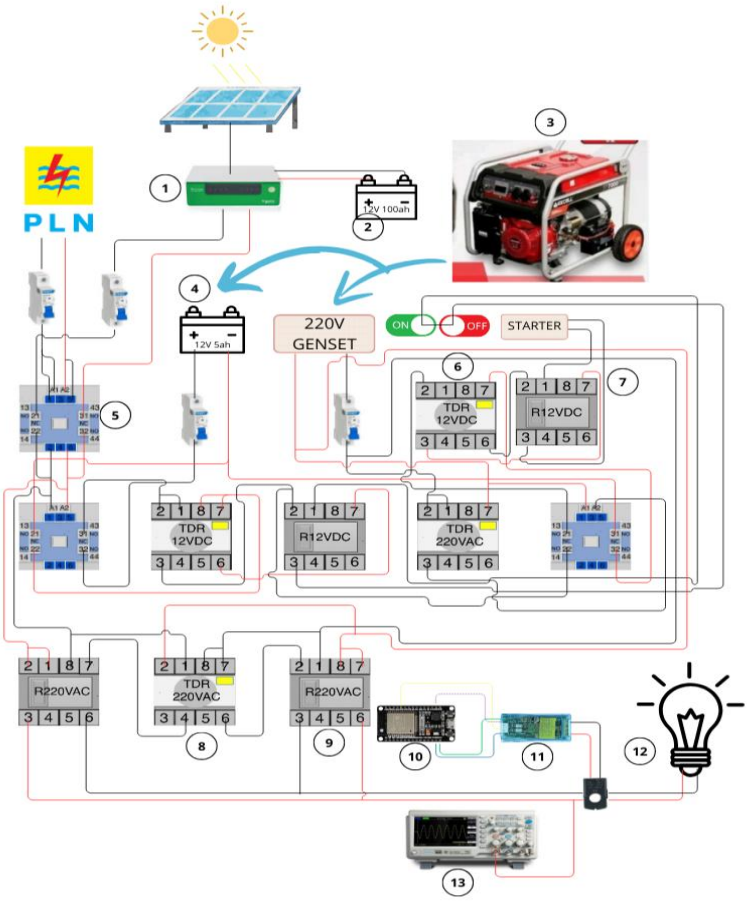


Figure 2. Wiring Diagram of Hardware Designed

3. Result and Discussion

3.1 PZEM sensor test

The ATS system for electric vehicle charging requires accurate transducers to send correct data to the database. This study used a standard Fluke digital multimeter for sensor calibration and accuracy measurement. The testing results are shown in Table 1.

Table 1. PZEM sensor validation

Component	Power Supply	Sensor	Multimeters	Difference	Average
PZEM AC Voltage (PZEM Sensor)	PLN	213,7	213,9	0,2	0,2
	PV	214,4	214,1	0,3	
	Genset	222,3	222,2	0,1	
PZEM AC Current (PZEM Sensor)	PLN	0,41	0,409	0,0001	0,002
	PV	0,41	0,412	0,002	
	Genset	0,41	0,414	0,003	

This voltage and current sensor will measure the load voltage during transitions between PLN, PV, and the generator using the PZEM device. The voltage sensor's performance is evaluated by comparing its readings with those from a calibrated voltage measuring instrument, specifically a Fluke Multimeter, which uses a power supply as the test voltage source. The test results comparing the voltage sensor's measurements to the multimeter readings across various voltage test values are presented in Table 1. These results indicate that the voltage readings from the sensor are closely aligned with those measured by the Fluke Multimeter. The average error value is 0.2%, suggesting that the voltage sensor in this load voltage monitoring system is accurate and suitable for use. Additionally, the current readings from the sensor are also accurate, with an average difference of 0.002. This further supports the reliability of the sensor in monitoring load conditions effectively.

3.2 Transfer switch process

The voltage switching graph between PLN and PV source illustrated in Figure 3. At the start of data collection, the initial voltage reading from PLN was 213.6 V, and just before the switching occurred (when PLN failed and PV activated), the final voltage reading from PLN was 213.3 V. When the switching took place, the graph shows a change in voltage, rising from 213.3 V to 215.2 V, indicating that the switching process between PLN and PV system had successfully occurred. As a result, the duration of the flicker experienced by the connected lights during the switching was minimal.

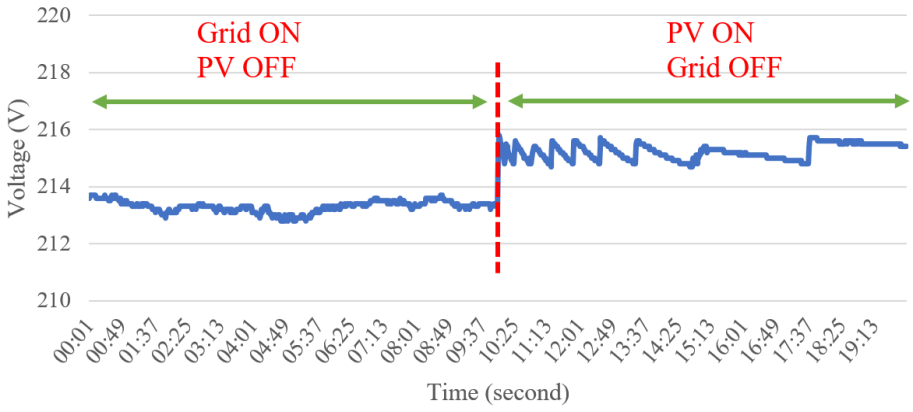


Figure 3. Voltage switching graph between PLN grid and PV

The voltage switching graph between the PV system and the PLN grid is shown in Figure 4. At

the start of data collection, the initial voltage reading from PV source was 215.2 V, and just before the switching occurred (when PLN failed and PV activated), the final voltage reading from PV was 215.4 V. When the switching took place, the graph shows a decrease in voltage from 215.4 V to 213.3 V, indicating that the switching process between PV system and PLN had successfully occurred. As a result, the duration of the flicker experienced by the connected lights during the switching was minimal.

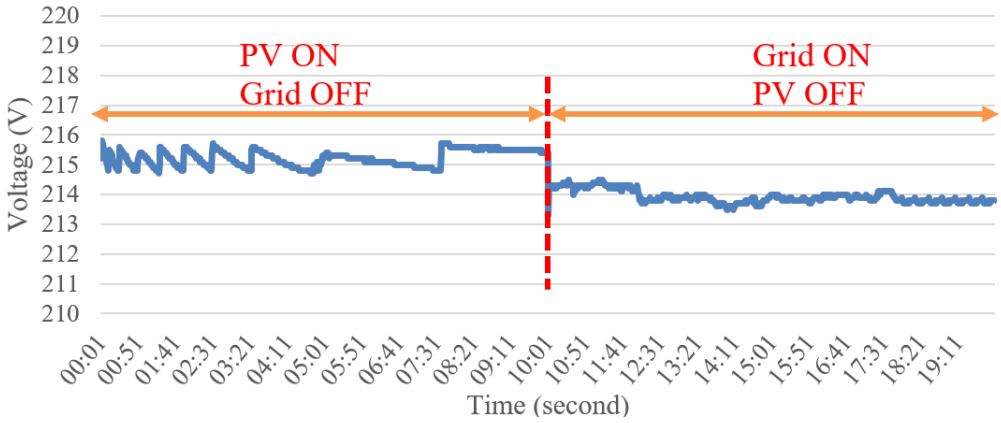


Figure 4. Voltage switching graph between PV source and PLN grid

The voltage switching graph between the PLN grid and the generator is illustrated in Figure 5. At the start of data collection, the initial voltage reading from PLN was 218.6 V, and just before the switching occurred (when PLN failed and the generator activated), the final voltage reading from PLN was 218.3 V. When PLN failed, the generator did not activate immediately because a starting process was necessary to power on and generate electricity. This is evident in the graph, where the red line marks the voltage boundary during the PLN failure and generator activation. The voltage dropped from 218.3 V to 0 V. After four seconds, the voltage rose from 0 V to 222.3 V, indicating that the switching process from PLN to the generator had successfully occurred. The automatic generator activation circuit required four seconds to activate the generator, enabling it to supply electricity to the load (lights).

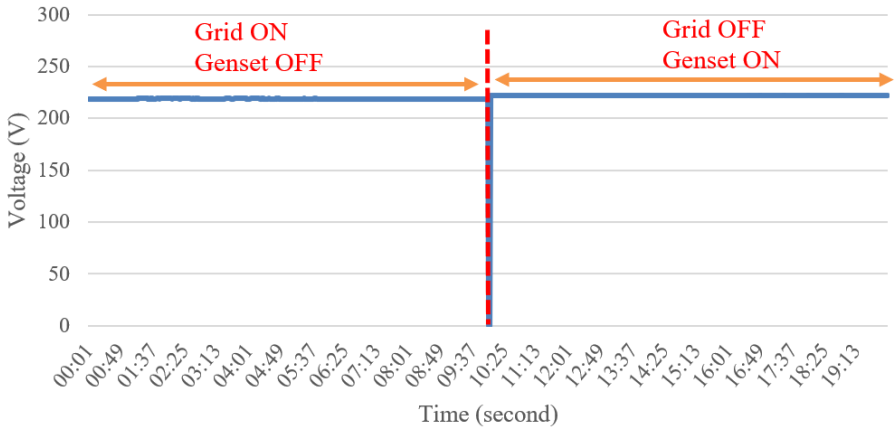


Figure 5. Results of voltage readings during the switching process from PLN to the generator

Figure igure 6 depicts the voltage switching graph between the generator and PLN. At the start of data collection, the initial voltage reading from the generator was 222.2 V, and just before the switching occurred (when the generator off and PLN activated), the final voltage reading from the generator was 222.3 V. When the switching took place, the graph shows a decrease in voltage from 222.3 V to 219.2 V, indicating that the switching process between the generator and PLN had successfully occurred.

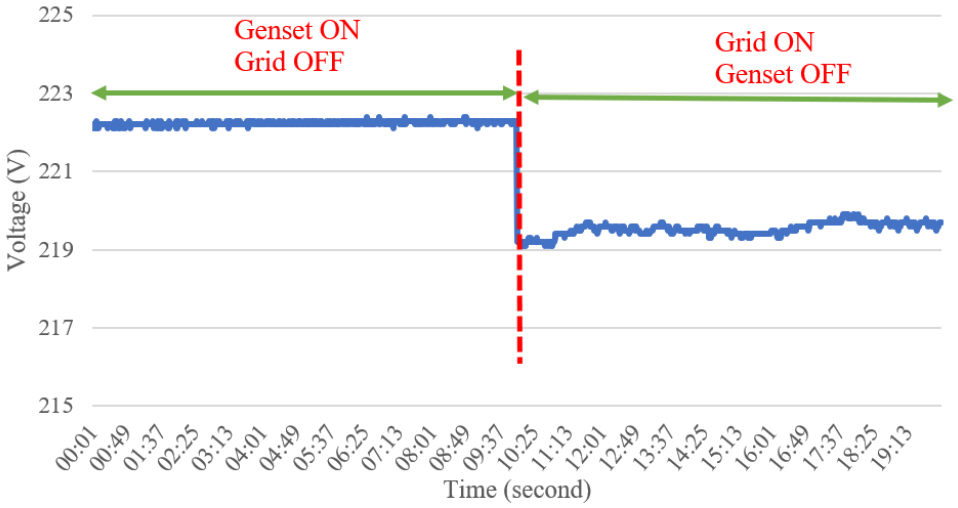


Figure 6. Results of voltage readings during the switching process from the generator to PLN

The voltage switching graph between the PV system and the generator is illustrated in Figure 7. At the start of data collection, the initial voltage reading from PV was 215 V, and just before the switching occurred (when PV unavailabe and the generator activated), the final voltage reading from PV was 215.1 V. When PV not availabe, the generator did not start immediately because a starting process was required to power on and generate electricity. This is evident in the graph, where the red line marks the voltage boundary during the PV off and generator activation. The voltage dropped from 215.1 V to 0 V. After five seconds, the voltage rose from 0 V to 222.5 V, indicating that the switching process from PV system to the generator had successfully occurred. The automatic generator activation circuit required five seconds to activate the generator, enabling it to supply electricity to the load (lights).

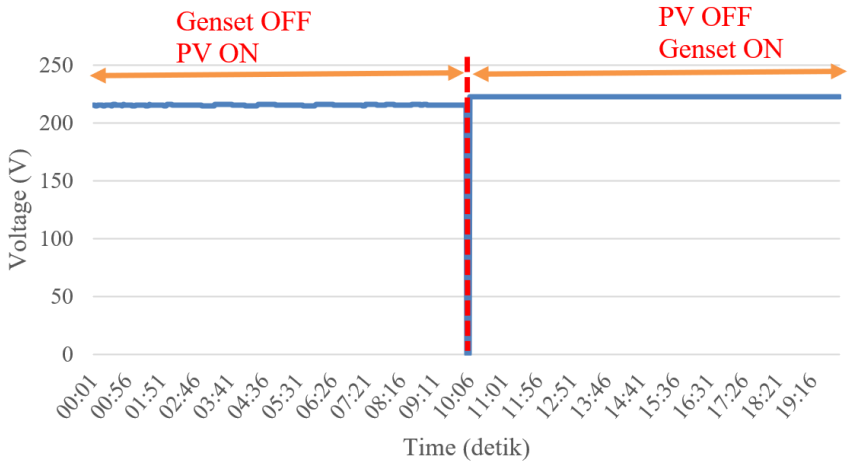


Figure 7. Results of voltage readings during the switching process from PV to the Genset

At the start of data collection, the initial voltage reading from the generator was 222.5 V, and just before the switching occurred (when the generator failed and PLN activated), the final voltage reading from the generator was 222.3 V. When the switching took place, the graph shows a decrease in voltage from 222.3 V to 214.9 V, indicating that the switching process between the generator and PV had successfully occurred. The Figure 8 displayed fluctuations in the waveform, representing the switching process occurring within a very short time frame, resulting in a minimal duration of flicker experienced by the connected lights during the switching Figure 8.

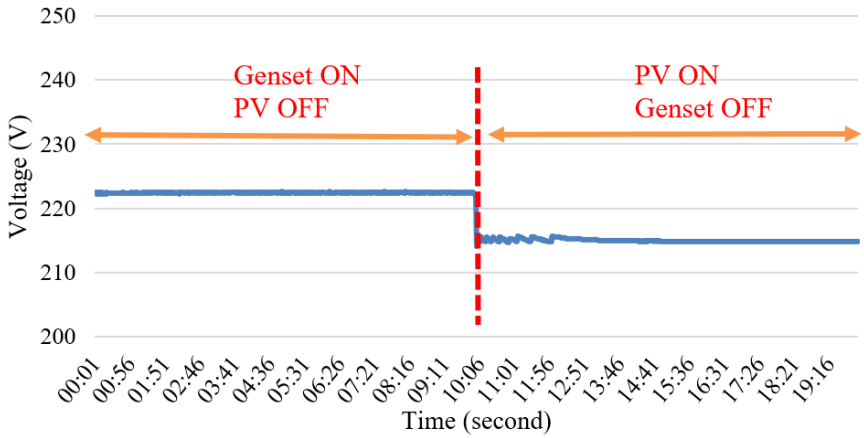


Figure 8. Results of voltage readings during the switching process from the Genset to PV

The results from the switching processes between PLN grid, PV, and the generator highlight the effectiveness of the ATS system in ensuring a seamless transition between power sources. The data collected during each switching event demonstrated minimal voltage fluctuations and flicker durations, indicating that the system effectively maintains power continuity. The smooth transitions observed, particularly the quick response times during the switching from PV system to the generator and vice versa, showcase the system's capability to adapt to changing energy demands. The detailed voltage readings and waveforms further confirm that the switching mechanisms operate efficiently, ensuring that energy supply remains stable and reliable. These findings not only validate the performance of the ATS system but also emphasize its potential for practical applications in enhancing energy management in diverse settings.

4. Conclusion

The results of the voltage and current switching tests between PLN grid, PV system, and the generator demonstrate the effectiveness and reliability of the ATS system in maintaining continuous power supply. Each switching process, whether from PLN to PV, from the generator to PLN, or between the generator and PV, was monitored closely, showing minimal flicker duration and accurate voltage readings. The high degree of alignment between the readings from the voltage sensors and the Fluke Multimeter, along with an average error value of just 0.2%, underscores the accuracy of the measurement systems employed. Additionally, the current readings also displayed a negligible average difference of 0.002, further affirming the reliability of the sensors. Overall, these findings confirm that the developed ATS system is well-equipped to ensure seamless transitions between power sources, thereby enhancing the stability and resilience of the energy supply in varying operational conditions.

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