Design and Build Automatic Transfer Switch (ATS) Based Internet of Things on Microgrid System

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***Abstract*— Electrical energy is a primary human requirement for continuously operating electronic devices. However, nonrenewable electrical energy is becoming increasingly scarce. As a backup power source, regenerative energy sources are an option. Because the conventional power grid transfer system takes a relatively long time, the application of a control system on the power grid transfer automatically can maximize efficiency, safety, and accuracy. In this study, an ATS system was developed using the electrical grid switching method for 300ms, 600ms, and 1000ms, as well as IoT to optimize the ATS manual override system with monitor voltage, current, and power. The test results show that the switching accuracy of 300ms is 98.40% and 98.18% with an average voltage of 19.65V and 41.22V when switching, 600ms switching is 98.14% and 99.25% with an average voltage of 17.77V and 18.18V when switching, and 1000ms switching is 99.40% and 99.41% with an average voltage of 17.52V and 21.05V, respectively. The voltage overshoot is obtained for 16ms and 40ms in linear loading and is stable within 2ms. There is harmonic distortion when loading non-linear for 9 cycles and 2 cycles of periodic frequency. The hardware data transmission accuracy is 97.94%, and the success rate of manual override is 100%.**

Keywords—ATS, switching, linear, non-linear, data transmission, manual override.

I. Introduction

Electrical energy becomes a primary human need in operating electronic devices, both on a residential, industrial scale, and others. This is evidenced by the total electricity demand in Indonesia of 1,109 kWh per capita in the third quarter of 2021, which is an increase of 0.4% from 2020 [1].

The increasing demand for electricity in Indonesia, especially for priority energy consumers, is a challenge in fulfilling electrical energy continuously. However, the availability of non-renewable sources of electrical energy is dwindling in line with consumer needs. One alternative energy that can be used in the tropics is solar energy. Regenerative energy sources are very important and are not limited in nature so that they become an option as a backup power supply that can be used if the main power source is interrupted [2].

The implementation of control systems is currently starting to shift to automation of control systems so as to minimize human intervention in control efforts. When compared to manual work, equipment controlled by automation will provide advantages in efficiency, safety, and accuracy [3]. Automatic Transfer System (ATS) is one method that implements the transfer of power sources by utilizing automatic control with the aim of reducing wasted time in power changes, device damage, and costs. Referring to previous research, where the transfer of the power source when there is a disturbance in the main electricity (PLN) does not require a long time of only 1 second so that there is no flickering of the lighting lamp [4].

The use of microcontroller for control based on voltage parameters is the basis for this research work. Along with the development of technology that is all practical and connected to the internet network, the use of the internet of things (IoT) is an option to optimize voltage monitoring so that it can send voltage data to the database server. In addition, the system can monitor and control the ATS system managed in real-time by an android smartphone remotely using the internet.

The purpose of this study focuses on the design of an ATS system with a lag time of changing the power source of less than one second to take advantage of the effects that occur during changes in the main power source with the aim of reducing the intermittent switching or the required pause. In this tool used ESP32, SPDT relay, voltage sensor, and current sensor. Integrated ESP32 and SPDT relays to run ATS systems with input as a condition of work (delayed open switching method), as well as a current sensor to read the load. In addition, IoT is used for monitoring systems for voltage, current, power, and manual control through the Blynk application.

II. Literature Review

A. Automatic Transfer Switch (ATS)

ATS is an integrated switching system with the function of transferring power from the main supply to the backup supply. Switching schemes are used for relatively faster power transfer transitions, and are capable of being consumed by circuits, equipment, or systems connected to the load. The following types of transitions on the transfer switch.

1) Open Transition

An open transition is a "break before make" transfer or it can be represented by a transfer switch that will disconnect the grid from the main supply before connecting the grid from the backup supply. The following types of open transitions.

a) Open Delayed

Open delayed is represented by giving a delay on the transfer switch when the grid is disconnected from the main supply to the backup supply.

b) Open in-Phase

Open in-phase is represented by giving a delay on the transfer switch when the grid is disconnected from the main supply to the backup supply by synchronizing the phase angle, voltage, and frequency so that the transition is less than 150 ms.

2) Closed Transition

Closed transition is a "make before break" transfer or can be represented by connecting the backup supply to the load before disconnecting the grid from the main supply. This has the effect of the transition being able to last less than 100 ms with the condition of synchronizing frequency, voltage, phase angle, and connecting the grid in parallel.

B. *Microgrid*

Microgrid is a small-scale distribution system byutilizing various regenerative energy sources including nonrenewable energy and regenerative energy equipped with energy storage media, one of which is a battery [5]. Microgrid operates at low voltage with connection to the grid (grid – connection) and is able to work in an emergency (islanded). The microgrid is located in the vicinity of the load center so as to increase reliability by utilizing the renewable energy.

C. *Linear and Non – Linear Loads*

1) Linear Load

Linear Load is a load that gives a parallel or linear output form. In other words, the current flowing is directly proportional to the impedance value and the voltage changes periodically so that when a sinusoidal voltage is applied it does not cause harmonic distortion. One of the linear loads is the lamp.

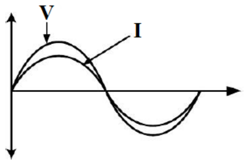


Fig 1. Current and Voltage Sinusoidal Waves

2) Non – Linear Load

Non-linear load is a load whose impedance value is not constant at each period of input voltage. In this period, the current is inversely proportional to the input voltage. This is contrary to Ohm's law which states that the current is directly proportional to the voltage. The result of non-linear loading causes distortion of the current and voltage sinusoidal waves. One of the nonlinear loads is the charger.

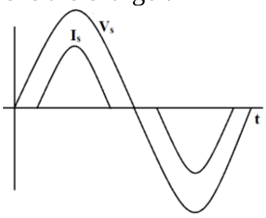


Fig 2. Non – Linear Loads Current and Voltage Waveforms

III. METHODOLOGY

This research method involves studying reference papers, datasheets, research reports on similar topics, and books. Figures 3 and 4 depict the system design.

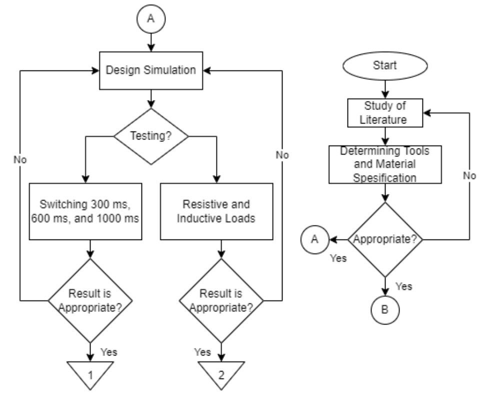


Fig 3. Methodology

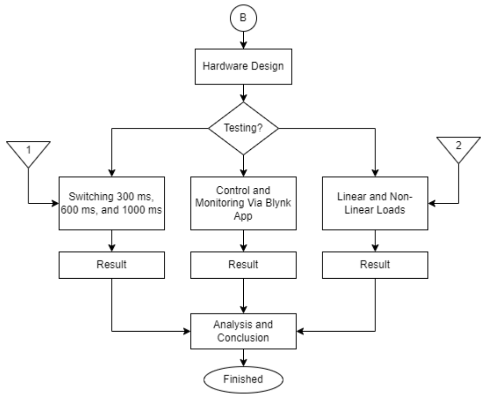


Fig 4. Methodology (continued)

Figures 3 and 4 describe how this research flowchart progresses through two processes: simulation and real-time design. This research resulted in an ATS system that can work automatically when the PLN grid undergoes problems, followed by backup from the microgrid. If the PLN grid returns to normal, the microgrid will be turned off, and the PLN grid will be operated again. Furthermore, the ATS system can be controlled and monitored manually using the Blynk application media. To analyze the impact of time on the ongoing power transfer, displacement methods of 300, 600, and 1000 ms were used. Then, analyze the effect of loading on the voltage waveform during power transfer with a displacement lag of 100 ms.

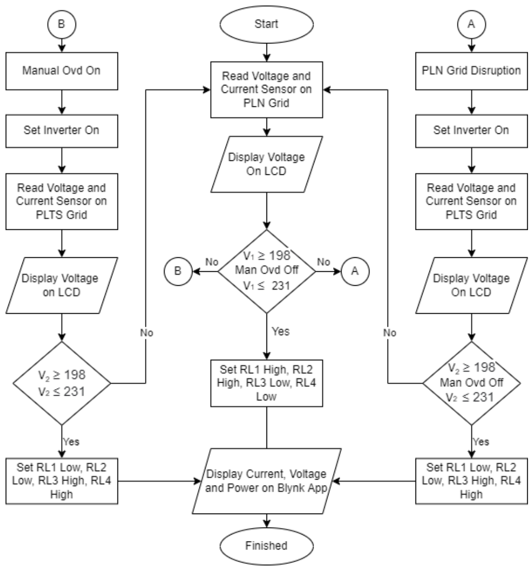


Fig 5. ATS System Algorithm

Figure 5 represents the design of the ATS system algorithm, which utilizes a relay as a switching component from two separate power sources. The input voltage (+5% and -10% of the nominal voltage, SPLN 1:1995) is read by the ATS system. If the algorithm's work requirements are met, the PLN grid will supply the load while the PLTS is turned off via the SPDT relay. The ATS system's working algorithm is described below.

TABLE 1. ATS ALGORITHM

Algorithm Condition	Relay Condition				
	RL1	RL2	RL3	RL4	RL5
Normal	1	1	0	0	0
PLN Disturbance	0	0	1	1	1
Interrupt Active	0	0	1	1	1

According to table 1, conditions 1 (high) represent working conditions and conditions 0 (low) represent outages. Furthermore, the ATS system has three algorithmic conditions: normal conditions, where the PLN voltage becomes the main supply, disturbed PLN conditions, which means the supply condition by the microgrid, and active interrupts. The interrupt feature (manual override) allows you to change the electricity supply without interfering with the PLN network by using the Blynk application, which can transfer power to the load with manual operation..

A. *Simulation Design*

The simulation in this experiment is designed to demonstrate that the ATS system can work with the 300 ms, 600 ms, and 1000 ms displacement methods. This is accomplished by examining the microcontroller's impulse response and the accuracy of the delay during the transfer. Loading tests were also performed to determine the effect on sinusoidal waves during supply switching. Proteus 8.0 was used for simulation design.

1) *Resistive Load*

Resistive load is implemented by connecting resistors and lamps in parallel, with a total load per block of 354 Figure 6 represents the resistive loading design.

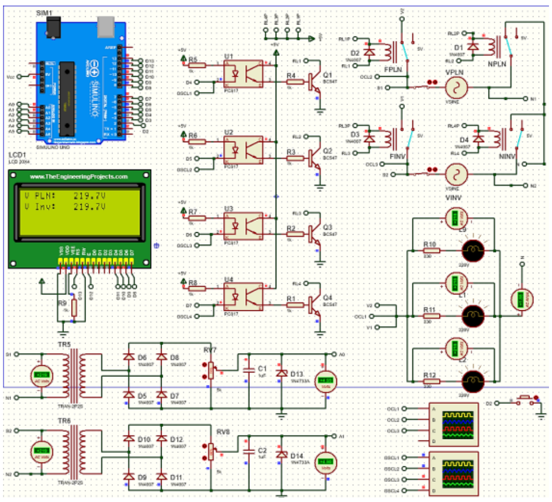


Fig 6. Resistive Load

2) *Inductive Load*

Inductive load is implemented by connecting inductor in parallel with a total load per block of 800 mH. The resistive loading design can be seen in Figure 7.

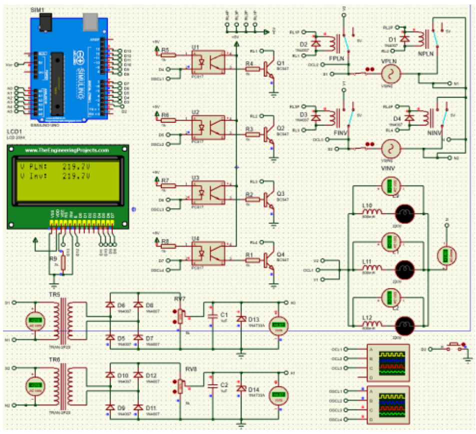


Fig 7. Inductive Load

B. *Hardware Design*

Hardware design utilizing relays to transfer power by separating phase and neutral from the PLN grid and inverter. The interlock system is implemented on the relay using the previously initiated programming. PZEM-004T, which serves as a current and voltage sensor as well as an LCD for displaying PLN and inverter voltages. The LED acts as a working notification relay. Regarding the use of the 1.5mm2 NYAF cable to support continuous power transfer.

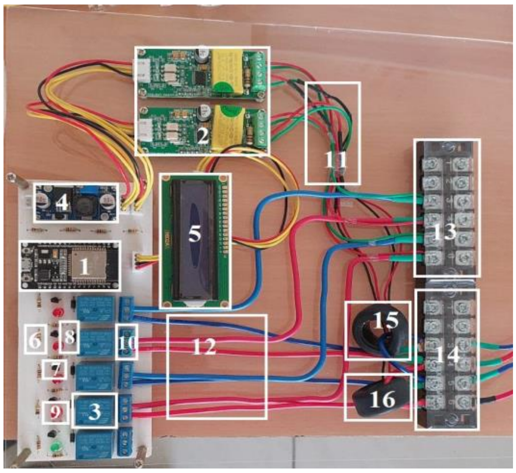


Fig 8. Hardware Design

Description:

1. ESP32
2. PZEM-004T
3. Relay
4. Buck Converter
5. LCD I2C 16x02
6. Resistor
7. Transistor
8. Diode
9. LED
10. Terminal Block 3 Pin
11. NYAF Cable 0,5 mm²
12. NYAF Cable 1,5 mm²
13. Terminal Block 6 Pin (Input)
14. Terminal Block 6 Pin (Output)
15. CT (Inverter)
16. CT (PLN)

C. *Software Design*

The IoT-based Blynk application is integrated into the ATS control and monitoring system by integrating ESP32, current and voltage sensors, and Blynk servers. Data transmission of voltage, current, and power occurs every 1 second. Furthermore, the interrupt feature transfers power without interfering with the main power supply.

Fig 9. User Interface Blynk Apps

Figure 9 displays the Blynk application's user interface, which includes PLN and inverter voltage gauges, current labels, interrupt switch buttons, and a power chart that is the multiplication of current and voltage.

IV. Result and Analysis

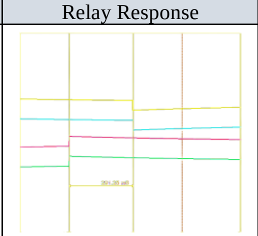
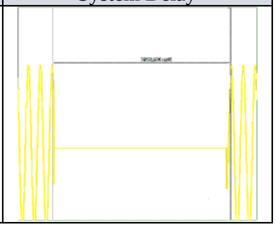
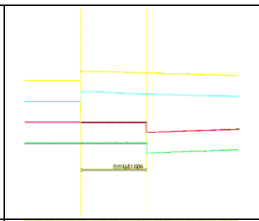
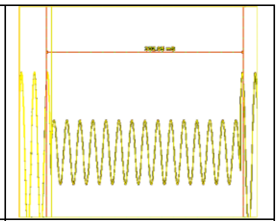
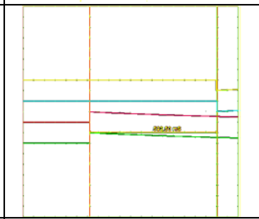
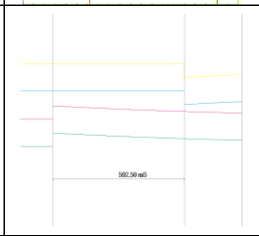
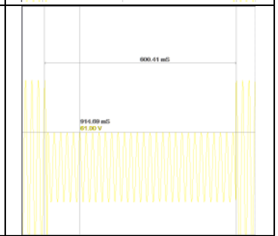
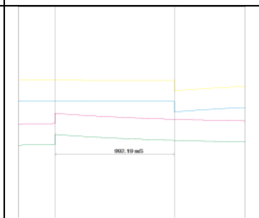
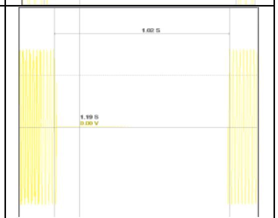
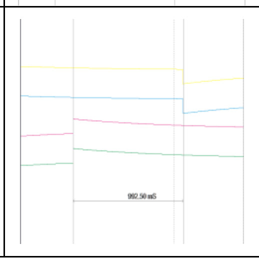
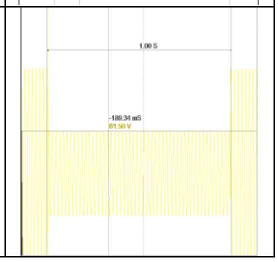
By using a fixed delay, this study differs from previous studies. The displacement was tested with the open delayed method for 300 ms, 600 ms, and 1000 ms, as well as the effect of linear (20 W) and non-linear (150 W) loading with a delay of 100 ms in this study.

A. Simulation Test

The simulation tests are divided into resistive and inductive loads. The purpose of the loading difference is to determine the effect of loading as a foundation for real-time testing. Furthermore, the accuracy of the delay during power supply switching serves as the foundation for real-time operation.

When the simulation occurs, there is a delay block on the vertical side so that each power supply shift can be seen accurately, beginning with the last wave before switching the power supply (power supply disconnection or cycle outage) and ending with the first wave after switching the power supply (steady condition). An impulse wave from the microcontroller is represented as a relay response on the horizontal side, and a voltage sinusoid wave from the ATS system is represented as a system delay.

Table 2. Sample of Simulation Switching

Sample	Relay Response	System Delay
300 ms (Resistive)		
300 ms (Inductive)		
600 ms (Resistive)		
600 ms (Inductive)		
1000 ms (Resistive)		
1000 ms (Inductive)		

There are relay response lines and system delay lines in table 2. The digital oscilloscope employs 20 mV volt/div with various time/div, namely 50ms and 100ms, as well as the function of wave widening and enlarging. The relay response line contains four impulse waves that represent the relay's response after the trigger is executed. The yellow impulse wave represents the Arduino response to relay 1, the blue impulse wave represents the Arduino response to relay 2, the red impulse wave represents the Arduino response to relay 3, and the green impulse wave represents the Arduino response to relay 4. The yellow oscillating wave represents the sinusoidal voltage waveform while the ATS system is operational.

1) ATS Simulation Testing using 300 ms Delay

The oscillation of the voltage wave when switching the power supply distinguishes resistive and inductive loading tests. The resistive load voltage wave oscillation is 0 V, according to table 2 column two. The voltage wave oscillation at the time of switching the power supply has an oscillation value of 60 V in the simulation of the inductive load in table 2 column three. Furthermore, when the main power supply is disconnected, the wave has an overshoot or transient for 0.1 ms. When the main power supply is turned off, the wave has an overshoot or transient for 0.1 ms.

TABLE 3. RESISTIVE – INDUCTIVE LOAD 300 MS DELAY

Nu	Resistive Load		Relay Respon Error (%)	Delay Error (%)	Inductive Load		Relay Respon Error (%)	Delay Error (%)
	Relay Respon (ms)	Delay Sistem (ms)			Relay Respon (ms)	Delay Sistem (ms)		
1	291,25	298,5	2,83	0,50	292,5	300	2,50	0
2	292,5	300,00	2,50	0	291,25	302,95	2,91	0,98
3	290,00	299,15	3,33	0,28	292,5	316,51	2,50	5,50
	Avg Error (%)		2,91	0,26	Avg Error (%)		2,64	2,16
	Percentage (%)		97,09	99,74	Percentage (%)		97,36	97,84

According to table 3, the relay response error represents the time difference between the response of the impulse wave to the relay and the system. This is due to the fact that the impulse wave passes through the control circuit, which includes an optocoupler, resistor, transistor, diode, and relay, resulting in a significant time difference between the impulse wave response and the system response. The high percentage accuracy value for inductive and resistive loads is due to the use of millis coding, which repeatedly runs the interval time every millisecond on the void loop system to reduce error.

2) ATS Simulation Testing using 600 ms Delay

The oscillation of the voltage wave when switching the power supply distinguishes resistive and inductive loading tests. The resistive load voltage wave oscillation is 0 V, according to table 2 column two. The voltage wave oscillation at the time of switching the power supply has an oscillation value of 60 V in the simulation of the inductive load in table 2 column three. Furthermore, when the main power supply is disconnected, the wave has an overshoot or transient for 0.1 ms. When the main power supply is turned off, the wave has an overshoot or transient for 0.1 ms.

TABLE 4. RESISTIVE – INDUCTIVE LOAD 600 MS DELAY

Nu	Resistive Load		Relay Respon Error (%)	Delay Error (%)	Inductive Load		Relay Respon Error (%)	Delay Error (%)
	Relay Respon (ms)	Delay Sistem (ms)			Relay Respon (ms)	Delay Sistem (ms)		
1	593,75	600,24	1,04	0,04	592,5	602,08	1,25	0,34
2	592,5	601,67	1,25	0,28	592,5	619,59	1,25	3,26
3	592,5	617,93	1,25	2,99	592,5	599,51	1,25	0,08
	Avg Error (%)		1,18	1,10	Avg Error (%)		1,25	1,22
	Percentage (%)		98,82	98,90	Percentage (%)		98,75	98,78

According to table 4, the relay response error represents the time difference between the response of the impulse wave to the relay and the system. This is due to the fact that the impulse wave passes through the control circuit, which includes an optocoupler, resistor, transistor, diode, and relay, resulting in a significant time difference between the impulse wave response and the system response. The high percentage accuracy value for inductive and resistive loads is due to the use of millis coding, which repeatedly runs the interval time every millisecond on the void loop system to reduce error.

3) ATS Simulation Testing using 1000 ms Delay

Table 2 column six shows the voltage wave oscillation at the time of displacement is 0 V in resistive load simulation. The voltage wave oscillation at the time of switching the power supply has an oscillation value of 61.5 V in the inductive load simulation, as shown in table 2 column seven. Furthermore, when the power supply is disconnected, there is a 0.1 ms overshoot or transient..

TABLE 5. RESISTIVE – INDUCTIVE LOAD 1000 MS DELAY

Nu	Resistive Load		Relay Respon Error (%)	Delay Error (%)	Inductive Load		Relay Respon Error (%)	Delay Error (%)
	Relay Respon (ms)	Delay Sistem (ms)			Relay Respon (ms)	Delay Sistem (ms)		
1	995	1000	0.5	0	995	1020	0,5	2
2	992,5	999,08	0,75	0,09	987,5	1020	1,25	2
3	992,5	1000	0,75	0	990	1020	1	2
	Avg Error (%)		0,67	0,03	Avg Error (%)		0,91	2
	Percentage (%)		99,33	99,97	Percentage (%)		99,09	98

According to table 4, the relay response error represents the time difference between the response of the impulse wave to the relay and the system. This is due to the fact that the impulse wave passes through the control circuit, which includes an optocoupler, resistor, transistor, diode, and relay, resulting in a significant time difference between the impulse wave response and the system response. The high percentage accuracy value for inductive and resistive loads is due to the use of millis coding, which repeatedly runs the interval time every millisecond on the void loop system to reduce error.

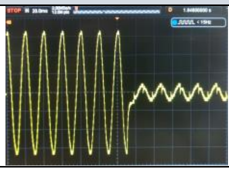
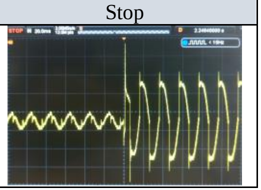
B. Real-time Test

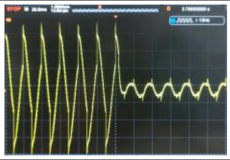
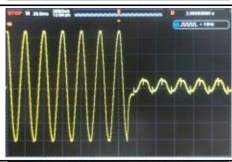
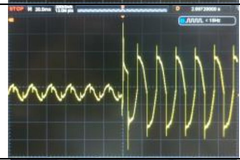
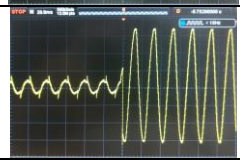
Equipment testing is performed to ensure that the tool will work properly based on the design. The test was conducted using the open delayed method, which involves delaying for each transition for 300, 600, and 1000 milliseconds. The switching PLN - inverter trial is performed by disconnecting the PLN supply (phase (RL2) and neutral (RL1)) and then triggering a backup response from the inverter grid (phase (RL4) and neutral (RL3) by activating RL5 to turn on the inverter. At the time of testing the inverter - PLN, the PLN supply is connected to the ATS system.

1) Switching Test

The number of experimental samples and the switching process are represented by sample lines, starting lines, and ending lines. The use of volts/div in various oscilloscopes, namely 50, 100, and 200 volts/div, aims to discover the details of the phenomena that occur by enlarging the voltage waveform during power supply discharge. The use of different time/div, specifically 20 ms and 50 ms, aims to broaden the voltage wave.

TABLE 6. REAL-TIME ATS SYSTEM TEST

Sample	Start	Stop
300 ms (PLN-INV)		

300 ms (INV-PLN)		
600 ms (PLN-INV)		
600 ms (INV-PLN)		
1000 ms (PLN-INV)		
1000 ms (INV-PLN)		

Description:

PLN - Inverter : Power is switched from the PLN grid to the Inverter grid (microgrid).

Inverter - PLN : Power is switched from the inverter grid (microgrid) to the PLN grid.

The voltage wave has an overshoot or transient based on the test in table 6. This is caused by a relatively quick change in the switch conditions from NO to NC, resulting in an unstable response from the backup network (grid inverter), but the voltage wave returns to a steady state quickly. The transient value of the 300 ms sample (PLN-INV) is 231 V, the transient value of the 300 ms sample (INV-PLN) is 229 V, the 600 ms sample (PLN-INV) is 231 V, the sample 1000 ms (PLN-INV) is 229 V, and the sample 1000 ms (INV-PLN) is 231 V.

a) Testing ATS using 300 ms Delay PLN - Inverter

This test is performed by changing the transfer of power from the PLN grid to the inverter grid for 300 milliseconds.

TABLE 7. TEST DATA ATS USING 300 MS DELAY PLN - INVERTER

Nu	Oscilloscope		Delay (ms)	Accuracy
	Start (s)	Stop (s)		(%)
1	1,3844	1,6912	306,8	97,73
2	2,5584	2,8588	300,4	99,87
3	1,9460	2,2484	302,4	99,20
4	-0,7424	-0,4376	304,8	98,40
5	2,4964	2,7900	293,6	97,87
RMSE (%)	1,60			
Accuracy (%)	98,40			

TABLE 8. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIOD (PLN – INVERTER) USING 300 MS DELAY

Nu	Vmax PLN – Inverter (V)	Vrms (V)
1	28,7	20,29
2	29,7	21
3	32,4	22,91
4	30,2	21,35
5	18	12,72
	Avg (V)	19,65

According to table 7 testing, the ATS system delay has an error value of 1.60%. This occurs because each component of the control circuit has an impedance that causes an error in the system, but it has no effect on the value of the voltage oscillation when the cycle goes out because the error value is relatively small.

According to the results of the test in table 8, the voltage wave oscillates with an average of 19.65 V during the outage cycle. The oscillation occurs because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and vice versa.

b) Testing ATS using 300 ms Delay Inverter - PLN

This test is carried out by determining the displacement of the power supply for 300 ms from the inverter grid to the PLN grid.

TABLE 9. TEST DATA ATS USING 300 MS DELAY INVERTER - PLN

Nu	Oscilloscope		Delay (ms)	Accuracy
	Start (s)	Stop (s)		(%)
1	2,0444	2,3412	296,8	98,93
2	1,2844	1,5892	304,8	98,40
3	0,9632	1,2676	304,4	98,53
4	-2,0184	-1,7100	308,4	97,20
5	0,5236	0,8288	305,2	98,30
RMSE (%)	1,82			
Accuracy (%)	98,18			

TABLE 10. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIOD (INVERTER – PLN) USING 300 MS DELAY

Nu	Vmax Inverter - PLN (V)	Vrms (V)
1	52	36,76
2	52	36,76
3	88	62,22
4	72	50,91
5	27,5	19,44
	Avg (V)	41,22

According to table 9 testing, the ATS system delay has an error value of 1.82%. This occurs because each component of the control circuit contains an impedance, which causes an error in the system but has no effect on the value of the voltage oscillation when the cycle fails because the error value is relatively small.

According to the results of the test in table 10, the voltage wave oscillates with an average of 41.22 V during the outage cycle. The voltage that oscillates when both supplies are inactive is the average value of the voltage during the blackout cycle. Oscillations occur because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and vice versa.

c) Testing ATS using 600 ms Delay PLN - Inverter

This test is carried out by determining the transfer of the power supply for 600 ms from the PLN grid to the inverter grid.

TABLE 11. TEST DATA USING 600 MS DELAY PLN - INVERTER

Nu	Oscilloscope		Delay (ms)	Accuracy (%)
	Start (s)	Stop (s)		
1	-7,7960	-7,1740	622,0	96,33
2	-4,6184	-4,0120	606,4	98,93
3	2,0956	2,6972	601,6	99,73
4	5,2700	5,8632	593,2	98,87
5	4,0952	4,6880	592,8	98,80
RMSE (%)	1,86			
Accuracy (%)	98,14			

TABLE 12. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIOD (PLN – INVERTER) USING 600 MS DELAY

Nu	Vmax PLN - Inverter (V)	Vrms (V)
1	25,1	17,74
2	25,8	18,24
3	27,7	19,58
4	23,8	16,82
5	23,3	16,47
	Avg (V)	17,77

Based on table 11 testing, the ATS system delay has an error value of 1.86%. This occurs because each component of the control circuit contains an impedance, which causes an error in the system but has no effect on the value of the voltage oscillation when the cycle fails because the error value is relatively small.

According to the results of the test in table 12, the voltage wave oscillates with an average of 17.77 V during the outage cycle. The voltage that oscillates when both supplies are inactive is the average value of the voltage during the blackout cycle. Oscillations occur because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. However, when the cycle is turned off, the value of the voltage oscillation decreases when compared to the experiment with a lag time of 300 ms. This is because the transfer time is longer (200%), resulting in a more stable oscillating voltage. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and vice versa.

d) Testing ATS using 600 ms Delay Inverter - PLN

This test is carried out by determining the displacement of the power supply for 600 ms from the inverter grid to the PLN grid.

TABLE 13. DATA TEST ATS USING 600 MS DELAY INVERTER - PLN

Nu	Oscilloscope		Delay (ms)	Accuracy (%)
	Start (s)	Stop (s)		
1	-9,3506	-8,7520	598,6	99,77
2	-6,1868	-5,5888	598,0	99,67
3	-0,4712	0,1364	607,6	98,73
4	3,6772	4,2812	604,0	99,33
5	3,1044	3,6996	595,2	99,20
RMSE (%)	0,75			
Accuracy (%)	99,25			

TABLE 14. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIOD (INVERTER – PLN) USING 600 MS DELAY

Nu	Vmax Inverter - PLN (V)	Vrms (V)
1	26,9	19,02
2	24,8	17,53
3	24	16,97
4	26,1	18,45
5	26,8	18,95
	Avg (V)	18,18

Based on table 13 testing, the ATS system delay has an error value of 0.75%. This occurs because each component of the control circuit contains an impedance, which causes an error in the system but has no effect on the voltage oscillation value when the cycle fails because the error value is relatively small.

According to the results of the test in table 14, voltage wave oscillations occur with an average of 18.18 V during the outage cycle. When both supplies are inactive, the average voltage value during the outage cycle is the voltage value that oscillates. Oscillations occur because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. However, when compared to the experiment with a lag time of 300 ms, the value of the voltage oscillation at the time of the outage cycle decreased. This is because the transfer time is longer (200%), resulting in a more stable oscillating voltage. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and conversely.

e) Testing ATS using 1000 ms Delay PLN - Inverter

This test is carried out by determining the transfer of the power supply for 600 ms from the PLN grid to the inverter grid.

TABLE 15. DATA TEST ATS USING 1000 MS DELAY PLN - INVERTER

Nu	Oscilloscope		Delay (ms)	Accuracy (%)
	Start (s)	Stop (s)		
1	-9,3610	-8,3660	995,0	99,50
2	-3,8100	-2,8180	992,0	99,20
3	1,7390	2,7300	991,0	99,10
4	7,2944	8,2928	998,4	99,84
5	-4,9718	-3,9690	1002,8	99,72
RMSE (%)	0,60			
Accuracy (%)	99,40			

TABLE 16. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIOD (PLN – INVERTER) USING 1000 MS DELAY

Nu	Vmax PLN – Inverter (V)	Vrms (V)
1	21,1	14,91
2	22,9	16,19
3	27,3	19,30
4	25,9	18,31
5	26,7	18,87
	Avg (V)	17,52

Based on table 15 testing, the ATS system delay has an error value of 0.60%. This occurs because each component of the control circuit contains an impedance, which causes an error in the system but has no effect on the value of the voltage oscillation when the cycle fails because the error value is relatively small.

According to the results of the test in table 16, the voltage wave oscillates with an average of 17.52 V during the outage cycle. The voltage that oscillates when both supplies are inactive is the average value of the voltage during the blackout cycle. Oscillations occur because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and conversely.

f)Testing ATS using 1000 ms Delay Inverter - PLN

This test is carried out by determining the displacement of the power supply for 1000 ms from the inverter grid to the PLN grid.

TABLE 17. DATA TEST ATS USING 1000 MS DELAY INVERTER - PLN

Nu	Oscilloscope		Delay (ms)	Accuracy (%)
	Start (s)	Stop (s)		
1	-6,5860	-5,5868	999,2	99,92
2	-1,0390	-0,0432	995,8	99,58
3	4,5076	5,5060	998,4	99,84
4	10,0550	11,0656	1010,6	99,94
5	-2,1888	-1,1952	993,6	99,36
RMSE (%)	0,59			
Accuracy (%)	99,41			

TABLE 18. VOLTAGE OSCILLATION VALUE DURING OFF CYCLE PERIODE (INVERTER – PLN) USING 1000 MS DELAY

Nu	Vmax Inverter - PLN (V)	Vrms (V)
1	27,4	19,37
2	27,2	19,23
3	28	19,79
4	32	22,62
5	34,3	24,25
	Avg (V)	21,05

Based on table 17 testing, the ATS system delay has an error value of 0.59%. This occurs because each component of the control circuit contains an impedance, which causes an error in the system but has no effect on the value of the voltage oscillation when the cycle fails because the error value is relatively small.

According to the results of the test in table 18, voltage wave oscillations occur with an average of 21.05 V during the outage cycle. When both supplies are inactive, the average voltage value during the blackout cycle is the voltage value that oscillates. Oscillations occur because the ATS system lacks a grounding system, causing the voltage to oscillate throughout the outage cycle. The lower the voltage oscillation value when the cycle ends, the more stable the power transfer made by ATS from two different supplies, and conversely.

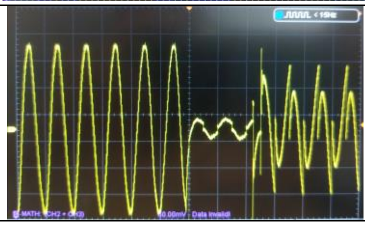
2) Load Testing

The loading test is carried out using delay 100 ms with linear and non-linear load.

a) Linear Load

This test is carried out using a 20 W lamp which represents a linear load.

TABLE 19. LINEAR LOAD PHENOMENA

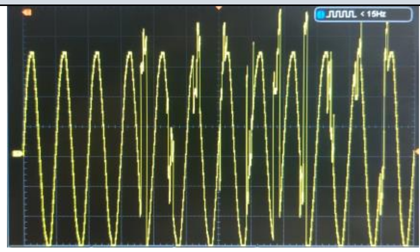
Nu	Phenomena
1	
2	

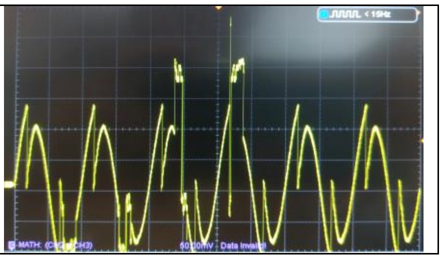
According to the results of the test in table 19, when linear loading occurs, the phenomenon of backup grid instability occurs when the electricity is transferred, causing transients in the voltage wave due to a relatively fast change in switch conditions from NO to NC, resulting in an unstable response from the backup grid, but the voltage wave returns to normal. in a short period of time The voltage wave in the first phenomenon is unstable for 12 ms and then stabilizes within 2 ms. The voltage wave is unstable for 40 ms and stable within 2 ms in the second phenomenon.

b) Non – Linear Load

This test is carried out using a 150 W charger which represents a non-linear load.

TABLE 20. NON – LINEAR LOAD PHENOMENA

No	Phenomena
1	

2	

Harmonic distortion occurs in the voltage wave in Table 20. This is the effect of non-linear loading, in which the voltage and current for different time views are never equal because of the non-constant impedance value, which causes waveform distortion. Harmonic distortion occurs for 9 periodic frequency cycles in the first phenomenon, and harmonic distortion occurs for 2 periodic frequency cycles in the second.

C. IoT System Test

The IoT system is tested in two stages, data transmission from hardware to the Blynk server and manual overrides or interruptions (manual override).

1) Manual Override Test

This test is performed with a transfer delay time of 1000 ms and without the PLN power supply by activating the interrupt feature via the Blynk application's button (shown in Figure 9).

TABLE 21. DATA TEST MANUAL OVERRIDE

Nu	Voltage Condition		Button Condition	Relay Condition					Maneuver
	PLN (V)	Inverter (V)		RL1	RL2	RL3	RL4	RL5	
1	219,7	225,4	On	0	0	1	1	1	Succeed
2	220	225,4	Off	1	1	0	0	0	Succeed
3	220,1	225,4	On	0	0	1	1	1	Succeed
4	221	224,7	Off	1	1	0	0	0	Succeed
5	220	224,7	On	0	0	1	1	1	Succeed

According to table 21, when there is no disturbance in the PLN grid, this feature can work with a working basis, namely the input voltage from two different power sources, with 100% success.

2) Data Transmission Test

This test is carried out by sending data every one second interval, as well as testing the suitability of the data with the serial monitor.

Table 22. Suitability of Transmission Data from Hardware to Blynk Server

Nu	Data Transmission	Delta Delay (ms)	Accuracy (%)
1	18:14:50.055	17	98,30
2	18:14:51.036	19	98,10
3	18:14:52.060	24	97,60
4	18:14:53.043	17	98,30
5	18:14:54.068	25	97,50
RMSE (%)	2,06		
Accuracy (%)	97,94		

Based on table 22 testing, the accuracy rate is 97.94%. The error value occurs due to the continuous programming loop system, both in ATS control and during data transmission.

Table 23.Data Hardware Voltage Compatibility with Blynk Application

Nu	Serial Monitor		Blynk Apps		Accuracy (%)
	VPLN (V)	Vinv (V)	VPLN (V)	Vinv (V)	
1	225,7	225,1	225,7	225,1	100
2	225,7	225,1	225,7	225,1	100
3	225,7	225,1	225,7	225,1	100
4	225,7	225,1	225,7	225,1	100
5	225,7	225,1	225,7	225,1	100
RMSE (%)	0				
Accuracy (%)	100				

Based on the test of table 23, the accuracy of the hardware voltage suitability with the Blynk application is 100%.

TABLE 24. DATA HARDWARE CURRENT COMPATIBILITY WITH BLYNK APPLICATION

Nu	Serial Monitor		Blynk Apps	Accuracy PLN (A)	Accuracy Inv (A)
	I PLN (A)	I Inv (A)	I Load (A)		
1	0,09	0,09	0,09	100	100
2	0,09	0,09	0,09	100	100
3	0,09	0,09	0,09	100	100
4	0,09	0,09	0,09	100	100
5	0,08	0,09	0,08	100	87,5
RMSE PLN (%)	0				
Accuracy (%)	100				
RMSE Inverter (%)	5,59				
Accuracy (%)	94,41				

Based on the test of table 24, there was an error of 0.01 A in the 1st experiment. This occurs due to the display of the loading current following the working supply. In the 1st experiment using the PLN supply so that the loading current is in accordance with the load from the PLN grid.

V. CONCLUSION

Based on the results of the research conducted, the following conclusions can be drawn.

1. The ATS system can function both automatically and manually by utilizing a relay as a switch with a working algorithm based on input voltage (+5% and -10%) via the Blynk application's interrupt feature. The delay time can be adjusted based on the installed load capacity. Light loads can use delays of 100 ms and 300 ms, while relatively large capacity loads can use delays of 600 ms and 1000 ms.
2. There are several phenomena when the power supply shift takes place, including overshoot or transients in the voltage wave when switching the power supply, voltage wave oscillations when the cycle goes out, and harmonic distortion when loading is non-linear. The value of the voltage oscillation when the cycle is terminated can be used as a reference for determining the optimal time lag in the ATS system based on the loading capacity and type of load.
3. IoT control and monitoring on the ATS system was successfully carried out with an interrupt success accuracy of 100% and a data transmission suitability of 97.94%.

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