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Development of a Mobile App for Inverter System Management

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Abstract: *In many developing nations, inconsistent power supply has led to a reliance on generators for residential energy needs, resulting in increased noise and air pollution. In response, the adoption of inverters has gained prominence as a cleaner and safer alternative. However, the lack of remote monitoring and control capabilities has limited the widespread application of traditional inverters. While previous research efforts have focused on mobile app development for inverter systems, the observed limitations in accuracy, precision, and response time have prompted the need for further advancements. This study addresses these challenges through the development of a mobile app for precise inverter system control and monitoring, leveraging the Blynk app's remote-control features. The user-friendly interface of the application enhances accessibility and usability. A specialized control device, integrated with the inverter system, utilizes the ESP32 microcontroller for efficient and low-power operation. Performance evaluation of the developed system yielded an impressive 94.15% accuracy and an optimal precision of 0.98%. The recorded average response time of 1.2 seconds highlights the system's efficient and prompt responsiveness. These findings demonstrate the suitability of the developed mobile application for robust monitoring and control of inverter systems. Furthermore, the identified scope for improvement includes enhancing the response time using 5G networks and ensuring the system's compatibility with evolving technological standards.*

Keywords: *ESP32 Microcontroller, Inverter systems, Mobile application, Remote monitoring, Renewable energy*

1. INTRODUCTION

Electricity is an indispensable part of modern human life, powering homes, businesses, and industries [1]. It enables everything from critical healthcare equipment, communication devices, and transportation systems to basic lighting and heating, underscoring its paramount importance in daily activities and the overall quality of life. However, the generation and consistent supply of electricity have posed significant challenges, particularly in developing countries [2]. In these regions, homeowners often resort to the use of generators as the primary alternative to the commercial generation and supply of electrical power. This involves the conversion of mechanical energy into electrical power using fuel. While it provides a solution to the problem of unreliable power supply, it comes with several drawbacks, including noise and air pollution as the primary concerns. Additionally, the cost of maintenance and fuel contributes to the secondary issues associated with this alternative.

A growing alternative to this is the use of inverters. Inverters utilize batteries and solar panels to harness the energy from the sun and convert it into electrical power. This system offers a notable advantage over the main alternative, as it eliminates the drawbacks associated with generators, such as noise and air pollution. The primary consideration with inverters is their initial cost, which may seem relatively higher [3]. However, in the long run, the efficiency and sustainability they provide make this initial investment inconsequential.

Monitoring and maintenance of the inverter systems have been generally done manually, which is stressful, sometimes inaccurate, and time-consuming. This necessitates the need for a system that can be used for the management of the inverter system. The alliance of mobile technology and energy management has led to the creation of mobile app-controlled inverters. This innovative move was driven by demands for improved energy management, amidst the inconsistent grid connections and an increasing interest in eco-friendly energy solutions. Mobile app-controlled inverters, unlike traditional inverters, provide users with an advanced way to monitor, manage, and optimize their energy usage [4]. They offer greater accessibility and flexibility to fulfill modern energy management requirements.

Recent advancements in the field of energy management have spurred extensive research into the development of inverter systems controlled by mobile apps and innovative solutions for efficient power control. Yang and Park's research emphasizes that user acceptance is crucial for the success of mobile app-controlled inverters [5]. Factors such as user education, simplicity of use, and perceived benefits significantly influence user adoption. Studies on user feedback have resulted in gradual improvements in app interfaces and functionality, boosting user satisfaction. The work reveals the importance of a user-centric design in ensuring that these innovations satisfy user needs and expectations. Brown *et al.* study highlighted the importance of UI and UX design in improving the usability of mobile apps controlling inverters [6]. They stress the value of visual clarity, simplified navigation, and interactive real-time data displays for effective design. These findings are geared towards making energy management more accessible to a wider audience through user-friendly interfaces. Nguyen *et al.* study focused on the use of data visualization techniques in mobile app-controlled inverters [7]. The research highlights the importance of real-time data insights for understanding energy production trends and usage patterns. By utilizing advanced analytics tools such as machine learning algorithms, the system can predict maintenance needs and optimize energy use. The evolution of inverters demonstrates the progress of energy management technology, now becoming more accessible through user-centered design and advanced data visualization techniques. Adams and Martinez ensured that the security and privacy of user data is a paramount concern, also it highlights the significance of end-to-end encryption in securing communication between the mobile app and the inverter system [8]. Regulatory compliance, especially regarding data protection and user consent. Jones *et al.*, proposed that numerous studies have highlighted the technical aspects of mobile app-controlled inverters, emphasizing the integration of communication protocols such as Wi-Fi, Bluetooth, and ZigBee [9]. These protocols enable real-time communication between the inverter and the mobile app interface, allowing users to remotely control and monitor the system's performance. Taylor *et al.*, introduce an intelligent load management algorithm that adapts to changing consumption patterns and optimizes energy distribution also explores Bluetooth Low Energy (BLE) connectivity for short-range communication between mobile devices and inverters [10]. Petersen and Kim discuss the potential of app-controlled inverters to influence user behavior and promote a culture of energy efficiency through the impact of Real-Time Energy Monitoring and the potential influence on user behavior like users finding an app-controlled inverter too complex to set up and use effectively, susceptible to technical glitches or connectivity problems and its reliability which is also a result of maintenance [11]. Johnson *et al.*, proposed a study that has shown that user interfaces designed with a focus on intuitive design and real-time data visualization enhance user experience and usability [12]. Martinez and Johnson postulate that literature underscores the role of mobile app-controlled inverters in enabling advanced energy management strategies [13]. Researchers have investigated algorithms for dynamic energy optimization based on factors such as user preferences, energy costs, and available renewable energy sources. These algorithms contribute to more efficient energy consumption and grid interaction, thereby promoting energy sustainability. Smith and Davies proposed a mobile app-controlled inverter serves as a valuable source of data for researchers and users alike [14]. Real-time data visualization and analytics provide insights into energy consumption patterns, system performance, and potential areas for optimization. Kumar *et al.* presented a review that moreover, the evolving landscape of smart technologies suggests opportunities for integration with emerging devices, such as smart appliances and electric vehicle chargers [15]. Smith and Garcia emphasize the need for robust encryption and authentication mechanisms to protect user data from unauthorized access and also underscore the ethical responsibility of app developers to safeguard user privacy and ensure compliance with data protection regulations [16]. Addressing these concerns is crucial for building trust among users and fostering wider adoption of the technology. Wang and Chen proposed research explores user preferences, concerns, and the factors influencing the adoption of this technology [17]. User-centric design and addressing usability challenges emerge as critical strategies for achieving higher adoption rates. Smith and Lee highlight that connectivity is a vital aspect of mobile app-controlled inverters comparing various communication protocols, demonstrating the superiority of Wi-Fi over Bluetooth in terms of data transfer speed and reliability [18]. Moreover, IoT protocols like MQTT are explored. Kumar *et al.* points out the need for seamless integration with diverse inverter models and the importance of addressing potential connectivity disruptions [19]. Future research could focus on refining energy optimization algorithms, exploring advanced visualization techniques, and integrating with emerging technologies like blockchain for enhanced data security and transparency.

While researchers have developed effective mobile apps, their accuracy seems to be somewhat low, and response time for online control is slow. To address these shortcomings, a mobile app was developed with a focus on achieving high accuracy and efficiency in terms of response time. The Blynk app was utilized to create the interface, resulting in a user-friendly design and real-time data visualization, thus increasing accuracy. To facilitate faster response time for online control and monitoring, the ESP32 microcontroller was adopted. This low-cost microcontroller is equipped with internet connectivity capabilities. The primary contributions of this article include:

i. Development of a user-friendly mobile app utilizing the Blynk platform, promoting simplicity and reducing ambiguity while ensuring lightweight performance on various devices.
ii. Implementation of an integrated control system that enables online control of inverter systems via the mobile app.

The remainder of this article is organized as follows: In Section 2, we present the methodology, providing a detailed list of the devices used in the development of the integrated control system, and we describe the mobile app building process. Section 3 presents and discusses the results of the testing of the mobile app with the control system. In Section 4, we offer a conclusion based on the objectives and results presented in this article.

2. METHODOLOGY

This section highlights the integrated components for the virtual monitoring and control of inverter systems, the specifications of the inverter system, and the development of the mobile app. The performance metrics are presented also.

2.1 Operating System Model

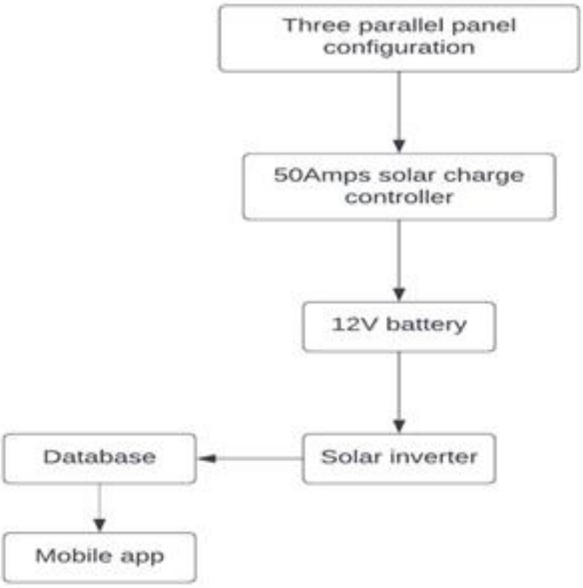


Figure 1: Block diagram showing the wiring of the inverter system

Figure 1 shows the block diagram connections of the system. The solar panel is connected to the PWM controller and the controller is connected to the 12 v dry cell battery. The ESP 32 is the controller that has the ZM3C103C current sensor connected to it, it measures the amount of DC/AC that is entering the system. The battery is connected to the buck converter that converts high DC voltage to lower Output DC voltage. The buck converter is also connected to the ESP32, as the 5v single channel relay, used for triggering the power of the inverter remotely. The ESP32 hosts the code for connecting to the database for Blynk app interaction to control the process. The mobile app-controlled inverter system consists of two basic units:

1) Hardware
    i. Monocrystalline Solar panel
    ii. Charge Controller – PWM
    iii. Inverter – Modified square wave
    iv. ESP32 microcontroller
    v. Dry Cell Battery -12volts
    vi. Buck converter
    vii. Current Sensor
    viii. Relay
    ix. Cables and Jumper wires
2) Software
    i. Blynk

2.1.1 Monocrystalline solar panel:

Monocrystalline solar panels stand at the forefront of solar energy technology, captivating the renewable energy landscape with their remarkable efficiency and sleek design. These solar panels are revered for their ability to efficiently convert sunlight into electricity, offering a sustainable solution to power generation while minimizing environmental impact.

A 24 V monocrystalline solar panel (Photovoltaic cell/PV cell) is selected for the conversion of solar energy to electrical energy. The PV cell is angled at 45 degrees to the sun. This angle is designed such that the sun's reflection hits the PN junction on the solar panel directly. In Figure 2, a single-diode circuit represents the solar cell. In the study, 24 volts / 200 watts is sufficient. The rating is determined by the total load applied to the solar panel. The system is assumed to be used in a standard home in a developing country such as Nigeria with four 60-watt light bulbs, a 300-watt fridge, a 60-watt fan, a

100-watt television, and three 10-watt phones. In watts, total load = (60 × 4) + 300 + 60 + 100 + (10 × 3) = 730 W = 0.73 KW.

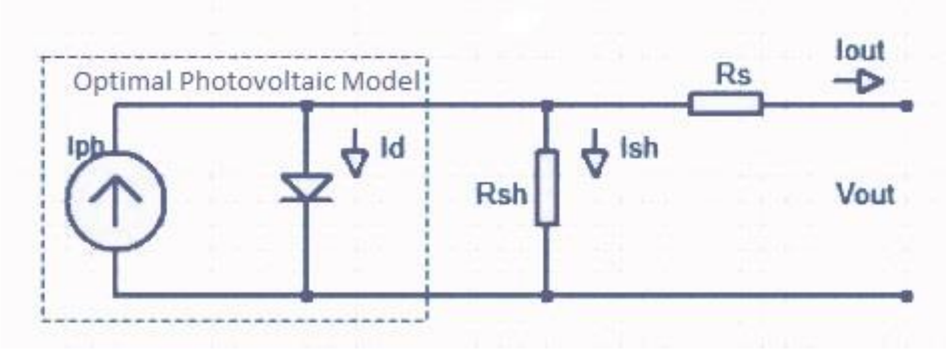


Figure 2: Equivalent circuit of the solar panel/cell

The output current of the circuit is calculated as shown in Equations 1 to 4 [4].

$$I_{out} = I_{ph} - I_{sat}\left(e^{\left(q\cdot V_{\text{cet}} + R_S I_{\text{cot}}\right)} - 1\right) - \left(\frac{V_{\text{out}} + R_S\cdot I_{\text{out}}}{R_p}\right) \tag{1}$$

$$I_{ph} = \left[I_{sc} + K_1\cdot(T - T_r)\right]\frac{G}{G_n} \tag{2}$$

$$I_{sat} = I_{rs}\cdot\left(\frac{T}{T_r}\right)^3\cdot\exp\left\{\frac{q\cdot E_{gap}}{K\cdot A}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right\} \tag{3}$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q\cdot V_{OC}}{N_{s.A.k.t}}\right) - 1} \tag{4}$$

In Equations 1 to $4, I_{sat}$ is the reverse saturation current, I_{ph} is the photocurrent source, A is the ideality factor, k represents Boltzmann constant $(1,3806503.10^{-23}\text{j}/\,^{\circ}\text{k})$, T is the solar cell surface temperature, R_s is the series resistance, R_p is parallel resistance, I_{sat} is short circuit current, k_i is a measure of open-circuit voltage, T_r is reference temperature of the solar cell, I_{rs} is reverse saturation current at a reference temperature, E_{gap} is the energy bandgap q is electron charge $(160217646.10^{-23}\text{C}), V_{\text{out}}$ is open-circuit voltage and N_s is the number of cells connected in series. Equation 5 describes the Maximum Power $(P_{\max})$ and the Parallel Resistance (R_p) of the solar cell is expressed in Equation 6.

$$P_{\max} = V_{\text{mp}}\cdot I_{\text{out}} \tag{5}$$

$$I_{\text{out}} = I_{ph} - I_{\text{sat}}\left(e^{\left(q\cdot\left(V_{\text{out}} + R_S I_{\text{out}}\right)\right.} - 1\right) - \left(\frac{V_{\text{out}} + R_S\cdot I_{\text{out}}}{R_p}\right) \tag{6}$$

Given that:

$$P_{\max} = V_{mp}\cdot\left\{I_{ph} - I_{\text{sat}}\left(e^{\left(q\cdot\left(V_{\text{out}} + R_S, I_{\text{out}}\right)\right.} - 1\right) - \left(\frac{V_{\text{out}} + R_S\cdot I_{\text{out}}}{R_p}\right)\right\} \tag{7}$$

$$R_p = \frac{V_{mp} + R_S\cdot I_{mp}}{\left\{V_{mp}\cdot I_{ph} - V_{mp}\cdot I_{sat}\cdot\left(\exp\left(\frac{q\cdot(V_{mp} + R_S\cdot I_{mp})}{N_S A\cdot k\cdot t}\right) - 1\right) - P_{\max}\right\}} \tag{8}$$

Figure 3: Monocrystalline solar panel

Specifications
Maximum power: 200 W
Rated voltage: 24 V
Open circuit voltage: 45.3 V
Short circuit current: 6.15 A
Voltage at max power: 37.8 V
Current at max power: 5.31 A
Dimensions: 1580 x 808 x 35 mm
Weight: 20.0 kg

2.1.2 Charge controller – PWM

A PWM (Pulse Width Modulation) charge controller is a device used in solar energy systems to regulate the charging of batteries from solar panels. Its primary function is to control the amount of voltage and current that flows from the solar panels to the batteries, ensuring efficient and safe charging.

The charge regulation is shown in Equation 9:

$$I_{\text{charge}} = \frac{V_{\text{battery}} - V_{\text{charge}}}{R_{\text{charge}}} \tag{9}$$

Where:

- I_{charge} is the charging current.
- V_{battery} is the battery voltage.
- V_{charge} is the desired charge voltage.
- R_{charge} is the charge resistance.

Figure 4: PWM charge controller

Specifications
Model: LD2450U
Rated Voltage: 12/24 V
Rated Current: 50 A
USB: 5 V 30 A

2.1.3 Inverter – modified square wave

A modified square wave inverter, also known as a modified sine wave inverter, is a type of power inverter that converts direct current (DC) from a battery source into alternating current (AC) that can be used to power various electronic devices and appliances.

Figure 5: 1000W inverter – modified square wave

Specifications
Power Input: 220 V-50 Hz
Output: AC -220 V
3.5 A
800 W
1000 W
Fuse: 4 A
Battery Input: 12 V

2.1.4 ESP32 microcontroller

The ESP32 is a versatile and widely used microcontroller module developed by Espressif Systems. It is known for its powerful capabilities, integrated Wi-Fi and Bluetooth connectivity, and a range of features that make it suitable for various applications.

Figure 6:ESP32 microcontroller

2.1.5 Dry cell battery -12volts

A dry cell battery with a voltage output of 12 volts can be used to power a 1kva (kilovolt-ampere) inverter. The inverter converts the 12-volt DC (direct current) from the battery to 110-220 volts AC (alternating current) for powering various household appliances or electronics. It is important to note that the capacity (in ampere-hours) of the dry cell battery should be sufficient to provide a continuous power supply for the desired duration.

Figure 7: Dry 12volts battery

2.1.6 Buck converter

A buck converter, also known as a step-down converter, is a type of DC-DC power converter that efficiently reduces the voltage from a higher level to a lower level. It's widely used in various electronic devices and power supply systems to regulate voltage and provide energy-efficient voltage conversion.

Figure 8: Buck converter

Specification
Module name: 12 A step-down version
Module Nature: Non-isolated step-down module (BUCK)
Input voltage:5-40 V Input voltage please do not exceed 40 V!!
Output voltage: 1.2-36 V continuously adjustable (default output 5 V)
1.2-36 V Fixed output (The default delivery is adjustable output)
Output current: 12A MAX (rated 8 A, peak 12 A) 100 W enhanced heat dissipation up to 200 W,
Operating temperature: -40~+85 degrees
Operating frequency: 180 KHz
Conversion efficiency: 95% higher
Module size: length 60 mm, width 51 mm, height 22 mm

2.1.7 Current sensor

The current sensor ZMCT 103C is a micro-precision current transformer that is commonly used in small current measurement, control, and protection. It adopts a novel magnetic circuit structure that effectively limits the magnetic leakage and makes it possible to obtain highly accurate, low-phase distortion linear output.

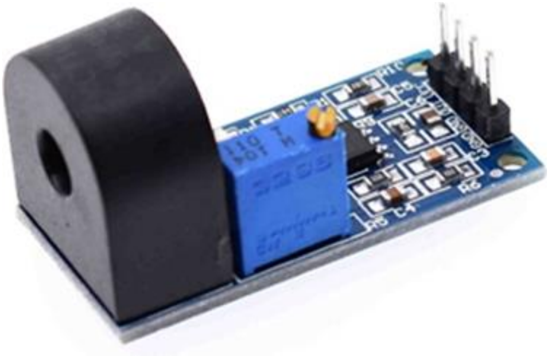


Figure 9: Current sensor

Specification
Operating Frequency: 50 Hz – 400 Hz
Rated Input: 5 A
Output Ratio: 2000: 1
Measuring Range: 5 A
Rated Output: 2.5 m
Accuracy Category: 0.2
Linear Accuracy: ≤±0.2% (5% - 120% rated input)
Phase Error: ≤5 min (at rated input)
Load Resistance: <8 Ω

It is often used in automation technology, new energy vehicle charging piles, inverters, power controllers, precision power meters, and other fields of power measurement, detection, and control.

2.1.8 Relay

A 5 V single-channel relay module is an electronic device that controls the flow of electricity to a connected circuit using low-voltage signals. It has a single channel and a three-pin interface, with normally open and normally closed contacts. These relay modules are commonly used in home automation, robotics, and industrial control systems to switch high voltage and current circuits.

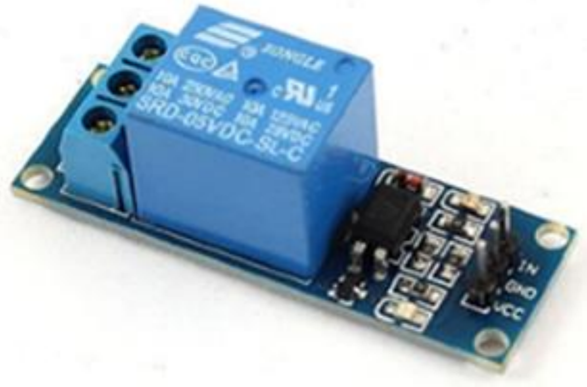


Figure 10: Relay module

Specification
Normal voltage: 5V DC
Normal current: 70 mA
Maximum load current: 10 A/250 V AC, 10 A/30 V DC
Maximum switch voltage: 250 V AC, 30 V DC
Operate time: ≤ 10 ms
Release time: ≤ 5 ms

2.1.9 Cables and jumper wires

The cables used in solar installations need to be durable, weather-resistant, and capable of carrying the generated power efficiently. Type of Cables and Jumper Wires

1) Solar PV Cables (PV Wire): These cables are specifically designed for connecting solar panels to combiner boxes, inverters, and other components. They are often double-insulated and UV-resistant to withstand outdoor conditions. PV cables come in various gauges (AWG sizes) to handle different levels of current. Those included in the system are of the types:
   i. PV Wire: Commonly used for outdoor interconnections in solar arrays.
   ii. DC Cable for Inverters: This cable connects the solar panels to the inverter, which converts the DC power generated by the panels into AC power for use in homes or businesses. These cables need to handle the DC voltage and current produced by the panels.
   iii. AC Cable: Once the inverter converts the DC power to AC power, regular electrical AC cables are used to distribute the electricity to the building's electrical system.
   iv. Battery Cables: For systems with energy storage (batteries), heavy-duty battery cables are used to connect the batteries to the inverter and other components.
   v. Communication Cables: Some solar installations may include communication cables that connect monitoring systems, data loggers, or other control equipment to the inverter or other components. These cables allow you to monitor and manage the system's performance.
   vi. Jumper wires: Jumper wires are a type of electrical wire with connectors at both ends that are used to create temporary connections between components on a breadboard, circuit board, or other prototyping platforms. They are a fundamental tool in electronics prototyping and are commonly used to build and test circuits without the need for soldering. Jumper wires come in various forms, and they play a crucial role in connecting components in a circuit quickly and efficiently.

2.2 Software Architecture

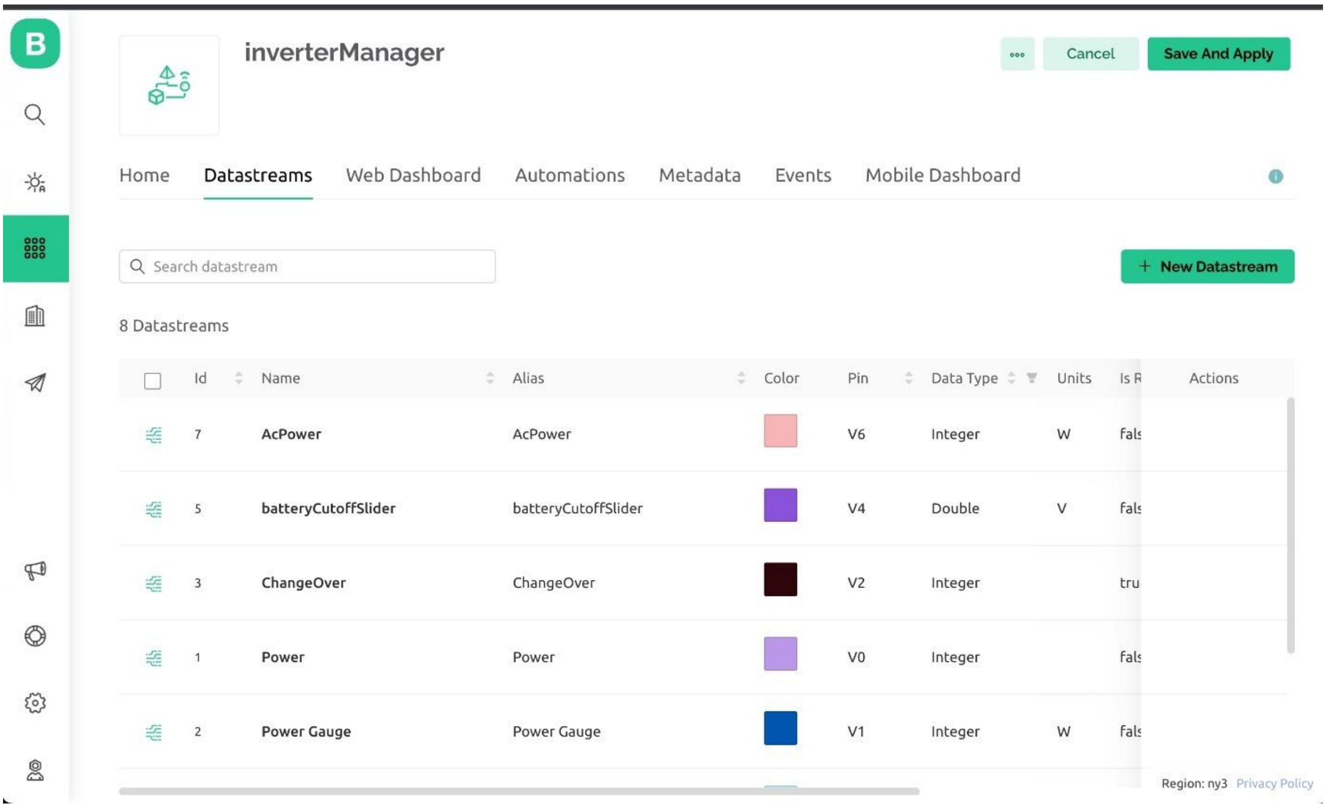
2.2.1 Blynk

Blynk is a popular Internet of Things (IoT) platform that allows users to easily create and control IoT projects using a smartphone app. It provides a simple and user-friendly way to build applications for various IoT devices, such as Arduino, Raspberry Pi, ESP8266, and more. Blynk is particularly well-suited for hobbyists, makers, and developers who want to create IoT projects without extensive programming knowledge.

2.3 Overview of Components and Materials Used

Table 1: Overview of materials used for implementation.

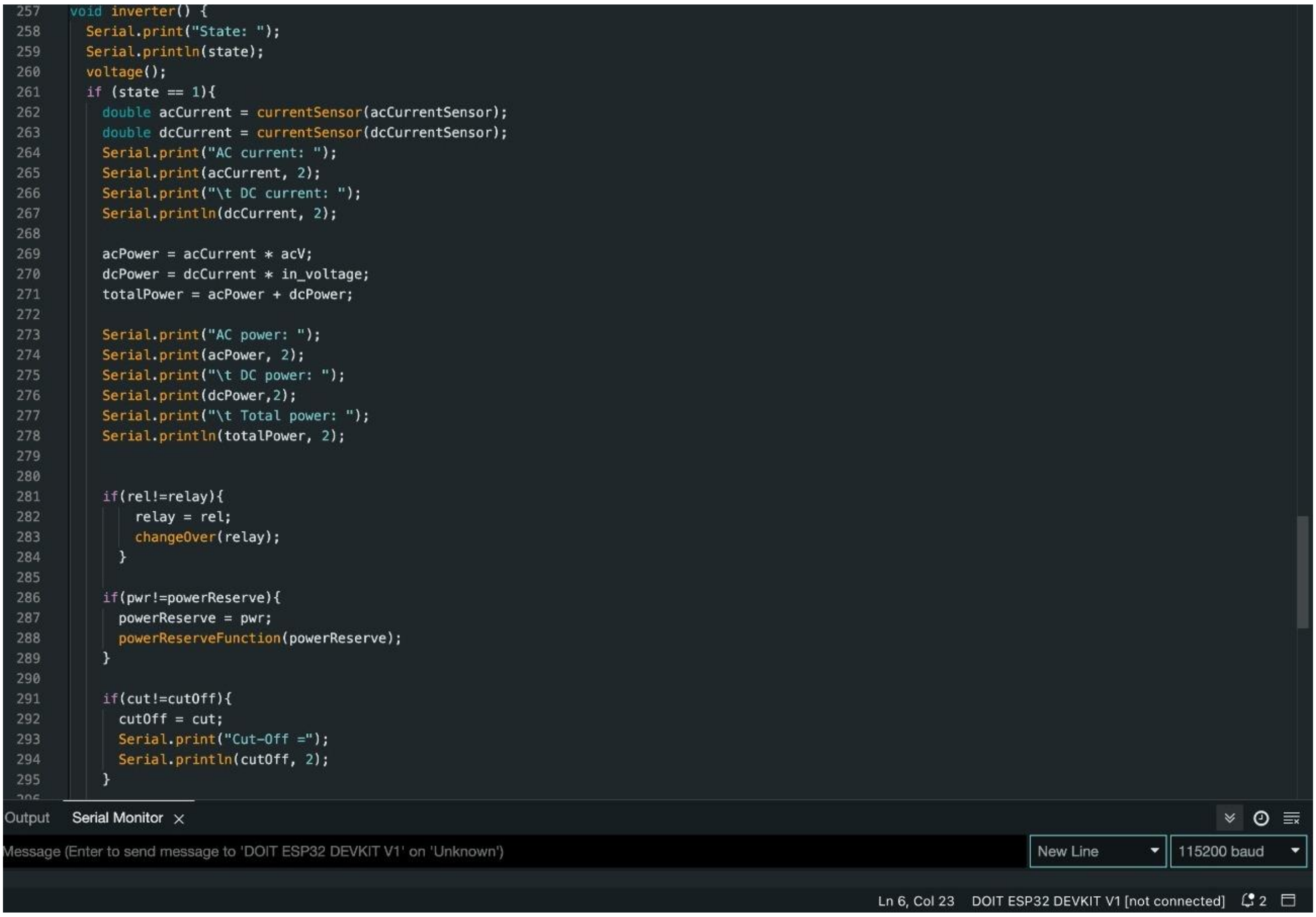
S/N	Component	Justification
1.	Monocrystalline Solar panel	To collect energy from the Sun in the form of sunlight and convert it into electricity
2.	Charge Controller – PWM	Regulates the amperage and voltage delivered to the loads
3.	Inverter – Modified square wave	To support household appliances
4.	ESP32 microcontroller	Utilized for processing-intensive applications requiring separate cores for high-speed data transmission.
5.	Dry Cell battery	To convert chemical energy into electricity
6.	Buck converter	To derive the required input voltage from a higher voltage source
7.	Current Sensor	To measure the flow of electric current and based on their usage
8.	Cables and Jumper wires	To connect two points in a circuit without soldering



8 Datastreams

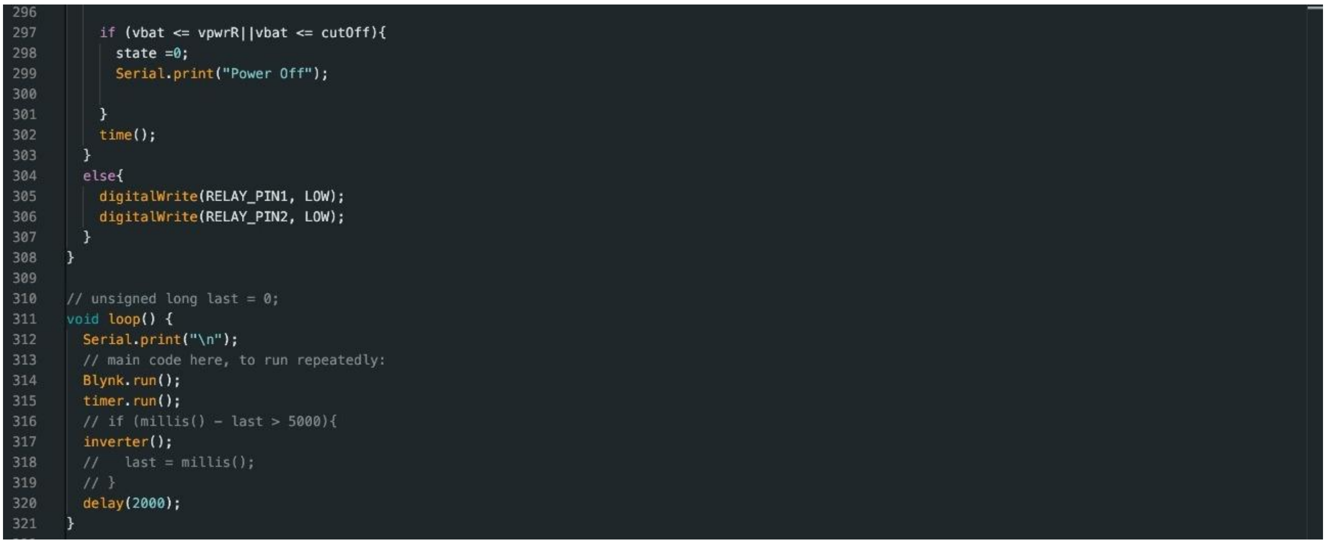
☐	Id	Name	Alias	Color	Pin	Data Type	Units	Is R	Actions
	7	AcPower	AcPower	🟥	V6	Integer	W	fals	
	5	batteryCutoffSlider	batteryCutoffSlider	🟪	V4	Double	V	fals	
	3	ChangeOver	ChangeOver	⬛	V2	Integer		tru	
	1	Power	Power	🟪	V0	Integer		fals	
	2	Power Gauge	Power Gauge	🟦	V1	Integer	W	fals	

Figure 11: Blynk



```
void inverter() {
  Serial.print("State: ");
  Serial.println(state);
  voltage();
  if (state == 1){
    double acCurrent = currentSensor(acCurrentSensor);
    double dcCurrent = currentSensor(dcCurrentSensor);
    Serial.print("AC current: ");
    Serial.print(acCurrent, 2);
    Serial.print("\t DC current: ");
    Serial.println(dcCurrent, 2);

    acPower = acCurrent * acV;
    dcPower = dcCurrent * in_voltage;
    totalPower = acPower + dcPower;

    Serial.print("AC power: ");
    Serial.print(acPower, 2);
    Serial.print("\t DC power: ");
    Serial.print(dcPower,2);
    Serial.print("\t Total power: ");
    Serial.println(totalPower, 2);


    if(rel!=relay){
        relay = rel;
        changeOver(relay);
      }

    if(pwr!=powerReserve){
      powerReserve = pwr;
      powerReserveFunction(powerReserve);
    }

    if(cut!=cutOff){
      cutOff = cut;
      Serial.print("Cut-Off =");
      Serial.println(cutOff, 2);
    }
```

Figure 12: Blynk IoT data streams



```

    if (vbat <= vpwrR||vbat <= cutOff){
      state =0;
      Serial.print("Power Off");

    }
    time();
  }
  else{
    digitalWrite(RELAY_PIN1, LOW);
    digitalWrite(RELAY_PIN2, LOW);
  }
}

// unsigned long last = 0;
void loop() {
  Serial.print("\n");
  // main code here, to run repeatedly:
  Blynk.run();
  timer.run();
  // if (millis() - last > 5000){
  inverter();
  //   last = millis();
  // }
  delay(2000);
}
```

Figure 13: Microcontroller code

Reserve
75

ChangeOver
dc

0 W

Ac Power
0 W Watts

Dc Power
0 W Watts

Auto startup/shutdown
07:00:00 - 16:00:00

Battery Cutoff
12.3 V

Figure 14: Inverter manager

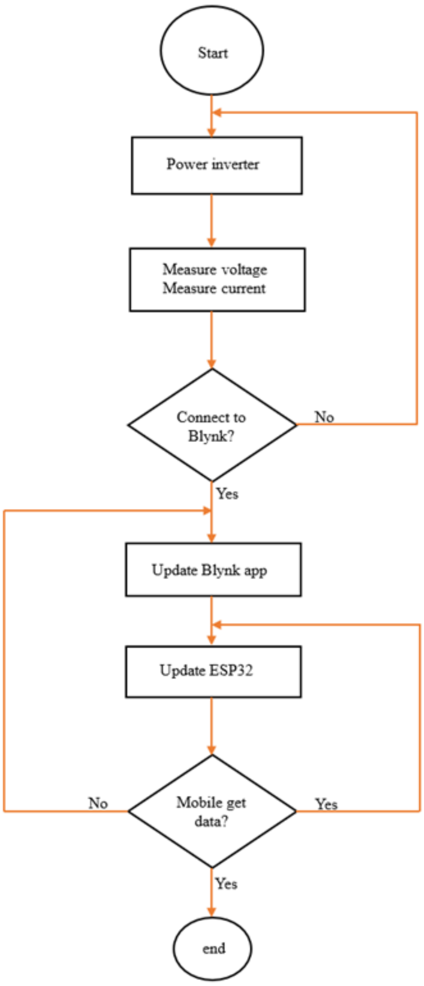


Figure 15: Flow diagram of the process

2.4 Performance Metrics

The accuracy, response time, and precision of the system were used to assess its performance. The time it takes for the input signal from the mobile device to produce an output at the inverter system. The precision rate is based on how closely the system repeats the values.

2.4.1 Accuracy

The accuracy of a system's computed and observed values pertain to their proximity to the true value of the measured quantity. Equation 10 is applied for the determination of the system's accuracy.

$$\%Err = \frac{TLV - SMV}{TLV} \times 100\% \tag{10}$$

Where %Err denotes the percentage error, TLV denotes the tested load value, and SMV is the system-measured value.

2.4.2 Precision

Precision refers to how close the readings are when they are repeated numerous times. It will be performed in the system to determine how precisely the system responds to the installed voltage and power consumption in the inverter. This is shown in equation 11. Equation 12 shows the standard deviation, to observe how skewed the readings are.

$$\text{Precision} = \frac{\text{Measured Value} - \text{Actual Value}}{\text{Actual Value}} \times 100 \tag{11}$$

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \tag{12}$$

Where:

σ = standard deviation
N = the size of the reading
x_i = each value from the reading

2.4.3 Response time

The assessment of system response time involves monitoring the duration required to transmit commands from the mobile app to the controller linked to the peripheral devices of the inverter system. Equation 13 outlines the computation of the response time, capturing the interval taken by the system to acknowledge input and generate the intended output in response to user instructions.

$$\text{Response time} = \frac{T_i}{T_o} \tag{13}$$

Where T_i is the amount of time it takes to process the input and T_o is the amount of time it takes to trigger the correct output. The processing time of the ESP32 and the mobile application is also factored into the response time.

3. RESULTS AND DISCUSSIONS

3.1 Accuracy test

Table 2 displays the tested load (w), system measured power (w), and absolute percentage error, while Figure 9 depicts the system's accuracy on the load. Figure 9 shows that the measured values are reasonably near to the actual value of the tested load, with a maximum estimated percentage error of 5.85%. As a result, the system operated flawlessly, with 94.15% accuracy.

Table 2: Accuracy test table

S/N	Tested load (Watts)	System displayed Load on mobile app (Watts)	Percentage error (%)
1	0	0.00	0
2	20	21.17	5.85
3	40	39.57	1.08
4	65	65.21	0.32
5	85	85.63	0.74

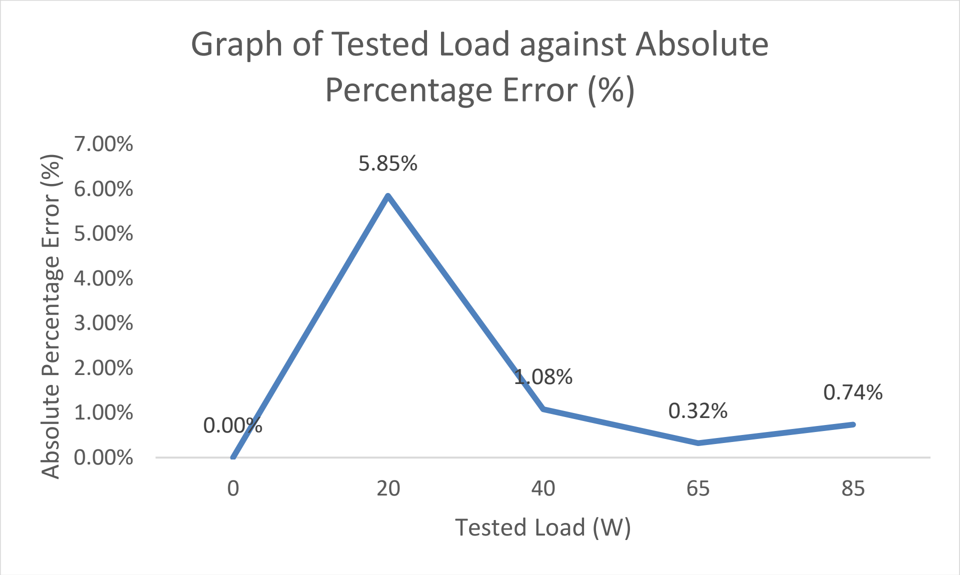


Figure 16: Graph showing the accuracy in terms of error percentage

3.2 Precision Test

Table 3 illustrates the findings obtained after repeating the readings up to 5 times for each load tested. As indicated in table 3, the minimum and maximum measurements, mean and standard deviation were tabulated. The graph of the tested load against the minimum and maximum power is shown in Figure 17. The readings are all within a very narrow range, with an optimal precision of 0.98%. This indicates that the readings are highly reliable and consistent.

Table 3: Precision test table

S/N	Tested load (W)	Testing readings taken (Watt)					Range (Watt)		Mean	Standard deviation	Prec. (%)
		Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Min. reading	Max. reading			
1	0	0.00	0.06	0.08	0.13	0.00	0.00	0.13	0.05	0.0555	-
2	20	18.56	21.23	19.67	20.90	18.98	18.56	21.23	19.87	1.1682	0.66
3	40	40.06	41.79	39.17	39.93	39.99	39.17	41.79	40.19	0.9650	0.48
4	65	65.24	65.24	65.67	65.47	65.89	65.24	65.89	65.50	0.2815	0.77
5	85	84.70	85.89	85.66	86.45	86.43	84.70	86.43	85.83	0.7165	0.98

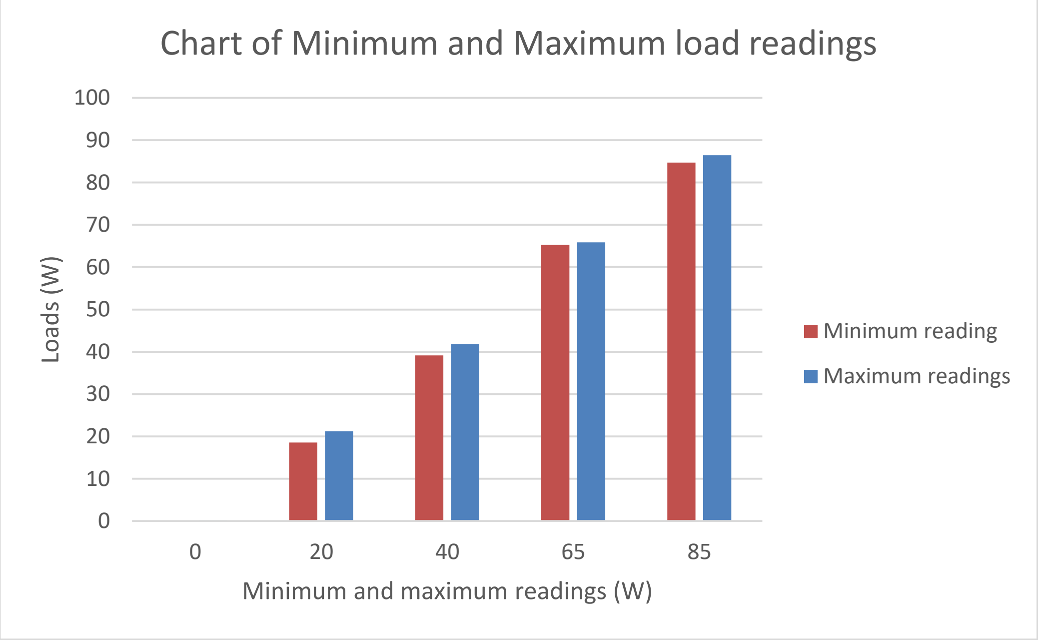


Figure 17: Minimum and maximum load readings

The readings increase slightly with increasing load, but the increase is very gradual. This suggests that the system t is very stable and does not show any significant nonlinearity over the load range tested.

The mean reading for each load condition is very close to the median reading, indicating that the data is not skewed. The standard deviation is also very low, indicating that the readings are very tightly clustered around the mean. The range is also very small, indicating that there is very little variation between the minimum and maximum readings.

The precision generally seems to be relatively low, ranging from 0.47% to 1%. This suggests that the readings are close to the actual values, indicating a good level of precision in the measurements.

3.3 Response Time Test

The system response time is a measurement of how long it takes the system to conduct the activities that have been imputed. This was tested by entering a command through the mobile app and timing how long it took for the system to react. The result of this is shown in Table 3. The average time of response was 1.20 seconds. Figure 18 shows a slight variation in the response time, this is due to network connection strength. With a good network connection, the response time will be faster and more consistent.

Table 4: Response time to mobile-app commands

S/N	All ON (sec)	All OFF (sec)	Other Commands ON (sec)	Other Commands OFF (sec)	Mean time of response
1	1.10	1.20	1.20	1.10	1.15
2	1.31	1.22	1.10	1.20	1.21
3	1.11	1.20	1.33	1.23	1.22
4	1.25	1.22	1.34	1.26	1.27
5	1.11	1.11	1.21	1.23	1.17

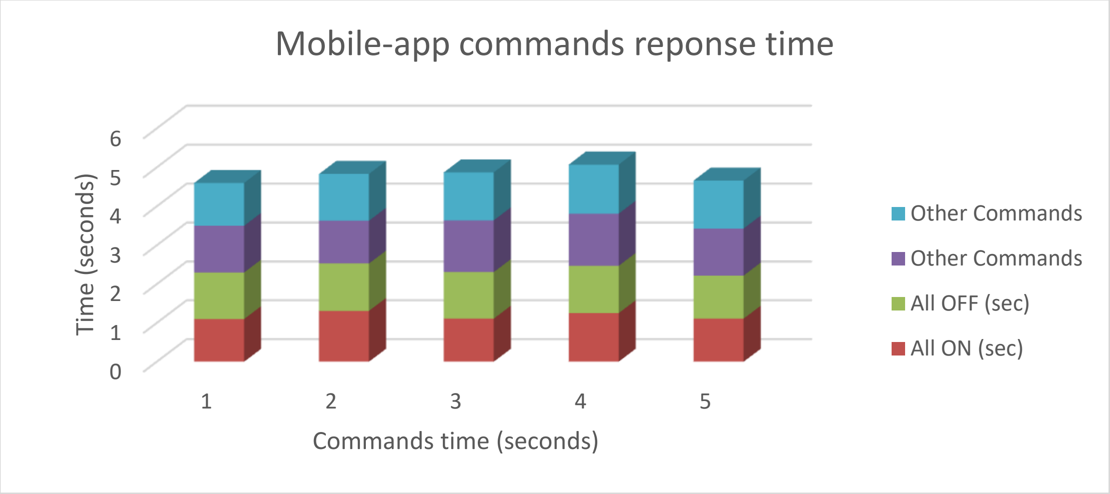


Figure 18: Mobile-app response time

Table 5: Comparison of accuracy

Author	Accuracy
Buhari *et al.* [4]	67%
Present study	94.15%

Table 5 shows comparison of accuracy with another existing study that developed a mobile app for monitoring and control of inverter systems. It can be observed that the present study's accuracy is higher.

4. CONCLUSION

This study developed a mobile app for the control and monitoring of an inverter system. The integration of a user-friendly interface in the mobile app enhances the overall user experience by providing a convenient platform for users to monitor and control their energy usage. This feature allows users to easily track the load, duration, battery depletion, and remaining battery levels, enabling them to optimize their energy consumption.

The test results demonstrate show that the accuracy and precision are high, showing that the system is reliable. The response time is fast. This study has successfully developed a mobile app for the control and monitoring of an inverter system. By integrating a user-friendly interface, the mobile app significantly enhances the overall user experience, providing a convenient platform for users to actively monitor and manage their energy consumption. The inclusion of features that enable real-time tracking of load, duration, battery depletion, and remaining battery levels empowers users to make informed decisions for optimizing their energy usage.

The test results affirm the high levels of accuracy and precision within the system, underscoring its reliability and robust performance. A maximum accuracy of 94.15% and an optimal precision of 0.98% were recorded. Furthermore, the fast response time of the system underscores its efficiency in promptly addressing user commands and ensuring seamless control and monitoring.

In light of these outcomes, future research endeavors may focus on integrating inverter systems with 5G wireless networks and developing algorithms that focuses on battery management, thereby further enhancing the capabilities and applicability of the developed system.

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