CONSTRUCTİON OF INTERNET OF THINGS BASED INVERTER SYSTEM

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Abstract: This work presents the design and construction of an IoT-based inverter system, aimed at monitoring level (rate) of backup power during electricity outage while enabling advanced control through Internet of Things (IoT) technology. Different IOT based inverter systems have been constructed in existing works but this system provides additional system of monitoring the level of backup store power and communicate in response to the use of the stored power. The developed system was tested and it was observed that the system successfully power loads up to 1800 watts with minimal voltage drops. The system was connected with network and demonstrated reliability in maintaining stable output and proper IoT functionality over extended periods of operation. The results of this project underscore the potential for IoT-enabled devices to revolutionize the energy sector by making energy systems more intelligent, responsive, and adaptable. Through prototype testing and real-world deployment, the system proved to be reliable and effective in managing energy flows in residential and commercial applications. The use of cloud-based data analytics further allowed for continuous optimization of energy usage, reducing waste and operational costs. The system indicates and displays the level of power usage when connected. The IoT-based inverter offers a robust and user-friendly solution, enhancing convenience and safety for users seeking dependable backup power with remote access and control; therefore, the developed system is recommended for its application.

Keywords: Alternating current, Direct current, Inverter, Internet of Things, Smart Device

Introduction

In recent years, the integration of the Internet of Things (IoT) into energy systems has led to significant advancements, particularly with the development of IoT-based smart inverters (Jia et al., 2024; Olusanya et al., 2024). These devices are essential in modern energy infrastructure, especially for optimizing power management from renewable sources such as solar energy (Agrawal et al., 2020; Rao, 2023). This study discusses the design and implementation of IoT-based smart inverters, focusing on their components, functionality, and applications**.** A smart inverter is an advanced version of a conventional inverter (Olaniyan et al., 2023; Olusanya et al., 2024; Pandiyan et al., 2024). Traditional inverters convert direct current (DC) from sources like solar panels into alternating current (AC) for use in homes and businesses. However, smart inverters incorporate additional intelligence and communication capabilities to monitor, control, and optimize energy use in real-time (Chowdhury et al., 2020). United States Department of Energy in the year 2021 stated that smart inverters are critical for enhancing grid stability by providing advanced functionalities such as voltage regulation, frequency support, and communication with energy management systems (Jia et al., 2024). IOT technology enhances the functionality of smart inverters by enabling communication with other devices and systems, allowing for real-time data collection on energy production, consumption, and storage (Bamgbade et al., 2018; Adetunji *et al*., 2024). This connectivity facilitates remote monitoring and control, which is essential for optimizing performance, reducing energy waste, and contributing to grid stability (Agrawal et al., 2020). IoT-enabled inverters significantly improve energy efficiency by dynamically adjusting power flows based on real-time data and predictive analytics (Pandiyan et al., 2024). The components of an IOT-Based smart inverter are, power electronic which makes up the inverter circuit. Power management unit, microcontroller which serves as the processor, sensor, internet access which all the user to control it remotely and the user interface which include the liquid crystal display (LCD), mobile application and the web interface (Ukoba et al., 2024). The increasing adoption of renewable energy sources, particularly solar power, has led to a greater need for efficient and intelligent energy management systems (Bourne et al., 2021). Traditional inverters, which convert the direct current (DC) from renewable energy sources into alternating current (AC) for residential or commercial use, are limited in their ability to manage energy dynamically, communicate with other devices, and optimize power distribution in real-time (Motlagh et al., 2020). These limitations result in inefficiencies, reduced grid stability, and minimal user control over energy systems (Kumar et al., 2024). As energy grids evolve toward a more decentralized model, with power generation distributed across various small-scale renewable energy sources, the demand for advanced inverters that can support grid stability and ensure efficient energy flow has become critical. Traditional inverters often fall short in meeting these new requirements, leading to potential energy losses, higher operational costs, and challenges in integrating with smart energy systems (Adetunji et al., 2023; Olaniyan et al., 2023; Pandiyan et al., 2024). This brings about the design of a smart inverter which can solve those problems to be monitored and controlled remotely. Recent studies have focused on various aspects of solar energy systems, particularly the integration of smart technologies and improvements in efficiency and reliability. Focus on the generation of variable D.C. voltage for daytime applications using solar energy and voltage regulation is generated directly from the solar panel, which is connected to the loads. Their design eliminates the need for an inverter and battery, thereby reducing costs (Bamgbade et al., 2018) and it is only applicable during the daytime (Nazir et al., 2021). Explored the generation of electricity through solar energy and the integration of wireless communication to monitor the solar power inverter using IOT (Nair et al., 2020). This system enables the monitoring of charge levels and consumption times based on different load usage (Krishna & Kumar, 2015). Explored the integration of the Internet of Things (IoT) with solar energy systems to enhance monitoring and control and the work demonstrated that IOT enabled solar systems can significantly improve energy management by providing real-time data on system performance, which can be used to optimize energy usage and reduce operational costs. They also highlighted the importance of cyber security in IOT-enabled solar systems to protect against potential threats. Investigation of the impact of solar tracking systems on the efficiency of solar photovoltaic (PV) installations. Their study showed that dual-axis tracking systems, which allow solar panels to follow the sun's path both horizontally and vertically, can increase energy output by up to 40% compared to fixed systems. A comprehensive review of hybrid solar energy systems, which combine solar power with other renewable energy sources such as wind or biomass was examined by (Pandiyan et al., 2024). They found that hybrid systems are particularly effective in providing a more reliable and stable power supply, especially in remote or off-grid areas (Ang et al., 2022; Rao, 2023). The study also discussed the challenges associated with the integration of multiple energy sources, including the need for advanced control systems and energy storage solutions(Chakravarty et al., 2023). Development of an advanced materials for solar PV cells was examined by (Shaikh, 2017). They introduced a new type of perovskite solar cell with enhanced stability and efficiency, which could potentially lower the cost of solar energy production. Their research also explored the scalability of these materials for commercial applications, addressing the challenges of mass production and durability under various environmental conditions. Examination of the use of artificial intelligence (AI) in optimizing the performance of solar energy systems was carried out by (Shaikh, 2017). Their work involved developing machine learning algorithms that predict energy production based on weather forecasts and historical data. The AI-driven approach resulted in more accurate predictions and better energy management, leading to higher overall efficiency of solar power systems. A smart photovoltaic inverter with an IoT-based maximum power point tracking (MPPT) system (Hanif & Ahmed, 2024). This system maximizes power transfer from solar panels and includes real-time monitoring and solar tracking capabilities. Development of a 3.5kVA pure sine wave IoT-based inverter system, which also incorporated IoT technology for enhanced remote monitoring and control was carried out by (Urbina et al., 2022). The system is designed for efficient power management, enabling users to remotely manage power loads, monitor battery levels, and control energy distribution across multiple AC output terminals. Their research demonstrates the value of IoT in optimizing power systems and achieving a more resilient, energy-efficient infrastructure, particularly for off-grid locations and areas with unreliable power supplies. The use of smart inverters in solar power systems, emphasizing the benefits of integrating advanced control mechanisms for more efficient energy management(Rao, 2023). Their work provided a comprehensive analysis of how smart inverters can support both household and industrial applications. However, this work involves internet of things-based inverter, aimed at providing reliable backup power during electricity outages while enabling advanced monitoring and control system.

Materials and Method

This section explains the proposed method employed to achieve the system as shown in the figure 1. The method involves gathering the required components for the project, programming and testing the functionality performance of the system. Embedded projects frequently utilize LCD modules due to their affordability, accessibility, and compatibility with programming. A popular choice among these combinations, such as 8x1, 8x2, 10x2, and 16x1, is the 16x2 LCD. This designation indicates that the screen has 16 columns and 2 rows, totalling 32 characters composed of 5x8 pixel dots each. This results in a total of 1280 pixels. The display of information on the screen is made possible through the implementation of a specialized IC, such as HD44780, integrated into the LCD module. This IC functions as a controller interface, receiving and processing commands and data sent from the microcontroller unit (MCU), which it then displays on the screen in an easily readable format. A current sensor detects and measures the electric current passing through a conductor. It turns the current into a quantifiable output, such as a voltage, current, or digital signal, which may be utilized in a variety of applications for monitoring, control, or protection. Voltage sensors can measure the voltage in various ways, from measuring high voltages to detecting low current levels. These devices are essential for many applications, including industrial controls and power systems. There are two main types of voltage sensors are available: capacitive type voltage sensor and resistive type voltage sensor. The application of these sensor includes measurement of AC and DC voltage. Typical applications include power demand control, power failure detection, and load sensing. Safety switching and motor overload control can also be managed with AC sensors. Node MCU is a powerful, open-source firmware designed specifically for the ESP8266 Wi-Fi chip. It is programmed using LUA and provides robust capabilities for users to explore and utilize the full potential of the ESP8266. The Node MCU Development board is an excellent platform to get started with, as it comes equipped with the Node MCU firmware pre-installed, providing a seamless experience for those looking to work with the ESP8266 chip. A push button shown in Figure 2 is a simple switch used to control electrical circuits. it is either completes or interrupts a circuit, and returns to its original state when released. Push buttons can be normally open (NO), where the circuit completes when pressed, or normally closed (NC), where the circuit breaks when pressed. They are commonly used in electronic devices, control panels, and appliances. Types include mechanical, capacitive, and illuminated buttons, often chosen for their simplicity and reliability in controlling various processes.

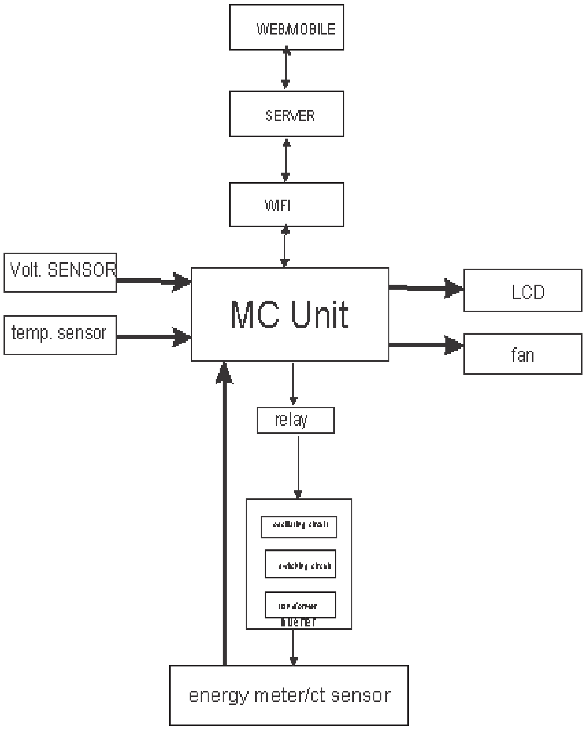


Figure 1: Proposed System Overview

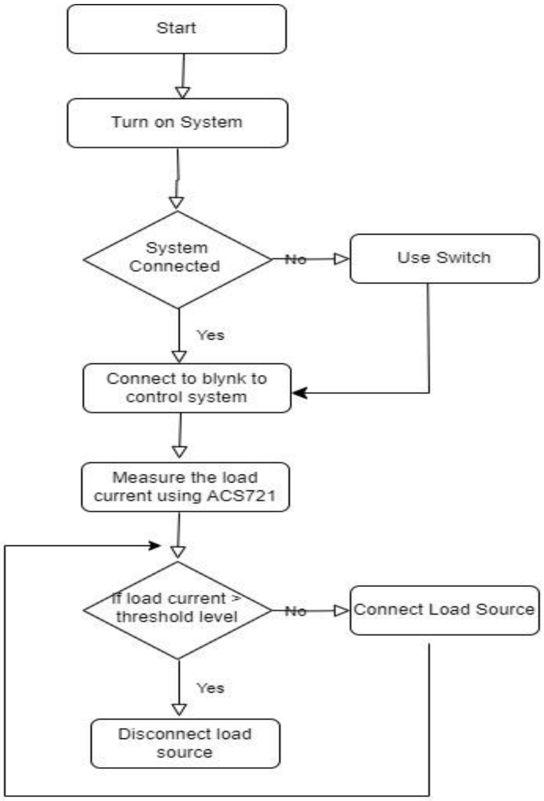


Figure 2: Flowchart of the System

Design Setup and Architecture

The propose system was developed using C++ programming language and Arduino IDE. Figure 2 shows the circuit diagram of the system designed using proteus. In this system, smartphones acting as wireless controllers are connected through Wi-Fi to control and monitor an inverter. ESP32 board was used as the microcontroller unit to communicate with the system. The microcontroller receives a signal from the sensor that captures the measurement. Using relay circuits acting as a switch for the load (appliances) outlet are connected to the controller. The relay module acts as a connection point affected by the signal sent from the phone and received by the microcontroller. The inverter and its output are controlled by a mobile app (Blynk) and a button. The system comprises a voltage sensor that precisely measures the ratings of the battery. ESP32 microcontroller is integrated with the sensor which captures the readings from the battery and the inverter environment and then transmits them to an internet module. The Internet module requires an Internet Service Provider (ISP) to establish a reliable connection to the World Wide Web using a SIM Card module, which creates an Internet gateway for the Internet module to connect. To provide a source of power for the ESP32 microcontroller and the internet module, a voltage regulator to regulate the output voltage from the Battery. The output of the voltage regulator is then connected to the Vin pin of the ESP32 microcontroller to provide a stable source of power. Once the ESP32 is connected to the internet and powered by the battery, it allows the use of control over the internet and can transfer the inverter data to the Blynk application, which is a user-friendly platform that enables users to obtain real-time updates on the Inverter. With the Blynk application, users can receive notifications when the inverter is running low on battery and can take necessary measures to replenish the water level. The system provides an efficient and user-friendly approach to monitoring the inverter, which ensures that users have a steady supply of electricity at all times while reducing the environmental impact. The hardware implementation of the system involves several sections, including the power supply unit, control unit, and display unit. The power supply unit consists of a 12V battery. The control unit comprises a ESP32 MCU which have a wireless module integrate on it, voltage sensor, current sensor, and a push button. The display unit consists of a liquid crystal display (LCD) interfaced with the ESP32 MCU to provide a user interface.

Circuit Layout

The designed circuit and schematic diagram were simulated using a simulation software called Proteus to validate the functionality, reliability, and correctness of the system. The circuit includes sequential circuit components such as LED indicators, switches, voltage regulators, ESP32 microcontroller, current and voltage sensor, LCD, and a 2-channel Relay module. Once the simulation was completed and the circuit was verified, the hardware components were assembled and tested in the actual system. The schematic diagram, simulation results and designed system are shown in Figure 3 and Figure 4. The system circuit diagram was design and simulated on the proteus before its integration with the inverter. Figure 4 shows the internal view of the system after the IoT has been integrated with the inverter. The integrated inverter was responsible for converting direct current (dc) to Ac) current that can be used to power electronic devices. It was also equipped with sensors such as temperature sensor, voltage sensor and current sensor.

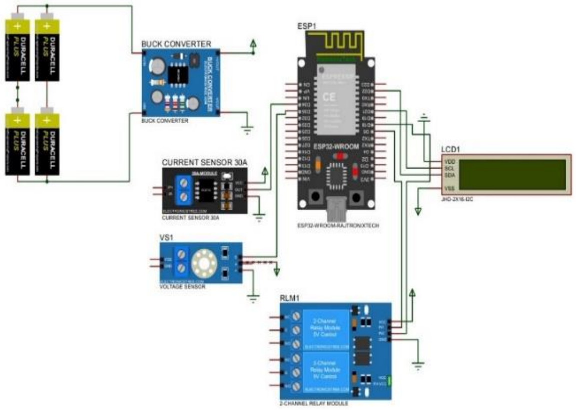


Figure 3: Circuit diagram of the system

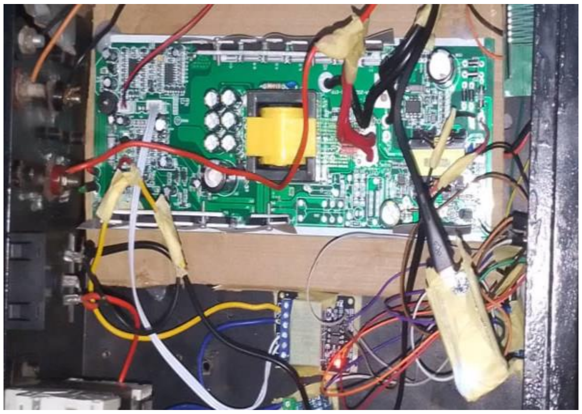
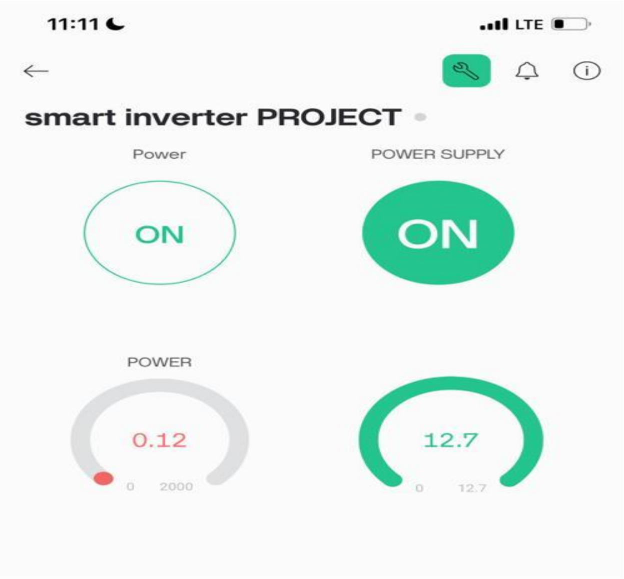


Figure 4: Internal View of the System

Results and Discussion

The sensor continuously collect data and send it to a central IoT gateway. The IoT gateway serves as a bride between the inverter and the cloud - based monitoring and control system. It enables real-time monitoring, data analysis and control of the system. The developed system was tested and it was observed that the system successfully power loads up to 1800 watts with minimal voltage drops.

The system was connected with network and demonstrated reliability in maintaining stable output and proper IoT functionality over extended periods of operation, indicates and displays the level of power usage when connected and notification for low battery as illustrated in the Figures 7, 8 and 9 respectively. A user interface is designed as illustrated in the Figure 6 for the log ins to the smart inverter project.



11:11 LTE

smart inverter PROJECT

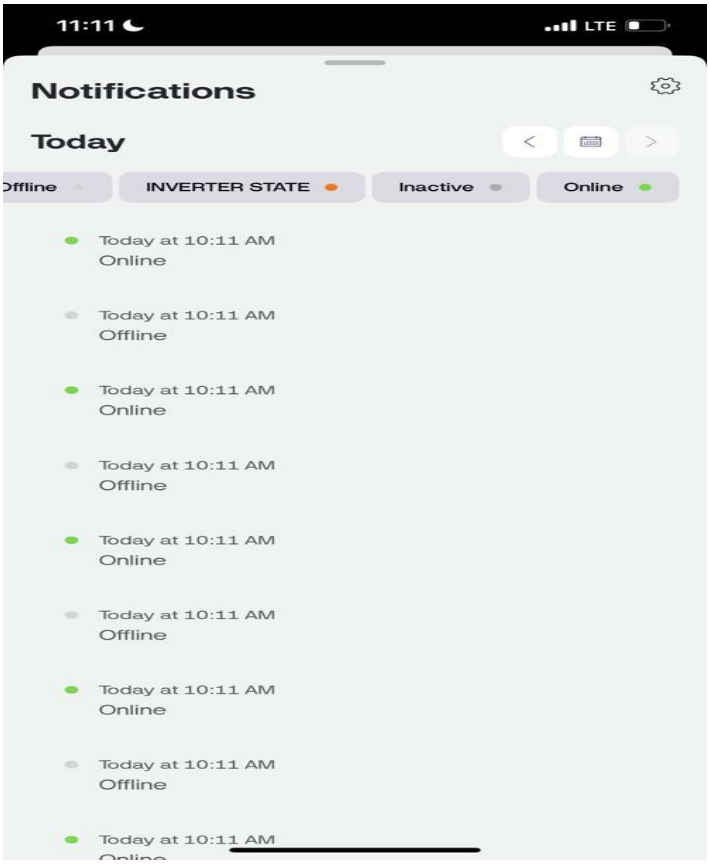
Power: ON

POWER SUPPLY: ON

POWER: 0.12 (0 – 2000)

12.7 (0 – 12.7)

Figure 5: Application Interface



11:11 LTE

Notifications

Today

ffline | INVERTER STATE | Inactive | Online

Today at 10:11 AM
Online

Today at 10:11 AM
Offline

Today at 10:11 AM
Online

Today at 10:11 AM
Offline

Today at 10:11 AM
Online

Today at 10:11 AM
Offline

Today at 10:11 AM
Online

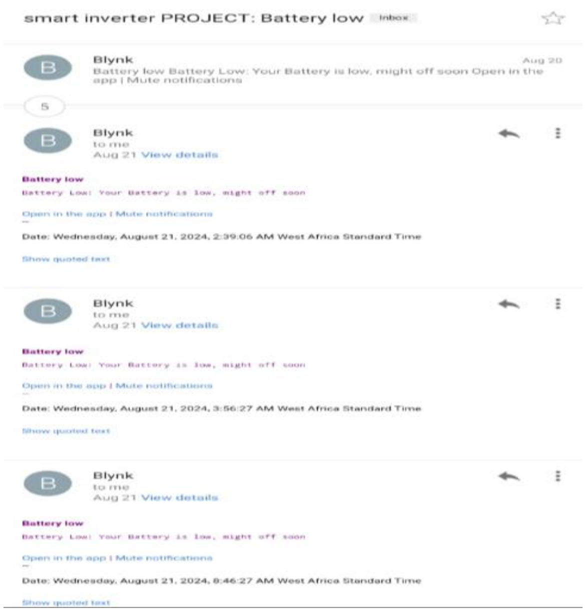
Today at 10:11 AM
Offline

Today at 10:11 AM

Figure 6: History Log-ins to the inverter

Figure 7: When the system is connected with load and network

Figure 8: Connected with load and battery level (%)



smart inverter PROJECT: Battery low

Blynk
Aug 20
Battery low Battery Low: Your Battery is low, might off soon Open in the app | Mute notifications

5

Blynk
to me
Aug 21 View details

Battery low
Battery Low: Your Battery is low, might off soon

Open in the app | Mute notifications

Date: Wednesday, August 21, 2024, 2:39:06 AM West Africa Standard Time

Show quoted text

Blynk
to me
Aug 21 View details

Battery low
Battery Low: Your Battery is low, might off soon

Open in the app | Mute notifications

Date: Wednesday, August 21, 2024, 3:56:27 AM West Africa Standard Time

Show quoted text

Blynk
to me
Aug 21 View details

Battery low
Battery Low: Your Battery is low, might off soon

Open in the app | Mute notifications

Date: Wednesday, August 21, 2024, 8:46:27 AM West Africa Standard Time

Show quoted text

Figure 9: Low Battery Notification

Conclusion

The development of an IoT-based smart inverter represents a significant leap in energy management technology, particularly for renewable energy applications. This project successfully demonstrated the design, implementation, and testing of a smart inverter controlled through a mobile app and web interface, which allowed for real-time monitoring and remote control of energy systems. The integration of advanced sensors, microcontroller, and communication modules enabled precise control and efficient power conversion, enhancing overall energy efficiency. This smart inverter not only contributes to more sustainable energy usage but also supports grid stability and user convenience. The results of this project underscore the potential for IoT-enabled devices to revolutionize the energy sector by making energy systems more intelligent, responsive, and adaptable. Through prototype testing and real-world deployment, the system proved to be reliable and effective in managing energy flows in residential and commercial applications. The use of cloud-based data analytics further allowed for continuous optimization of energy usage, reducing waste and operational costs. As renewable energy continues to grow in prominence, technologies like the IoT-based smart inverter will be pivotal in addressing the challenges of energy efficiency, grid integration, and decentralized power generation. This project serves as a foundational model for future advancements in this field, paving the way for more sophisticated, scalable, and commercially viable energy solutions.

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