

Smart Automatic Transfer Switch: ESP32-Based Power Changeover System with Android Monitoring and Real-Time Data Logging for Residential Power Systems

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Abstract: Dependable and efficient power management is essential for energy conservation, especially in areas susceptible to power interruptions. This study presents the design and implementation of an Android-based microcontroller-controlled automatic power switching system aimed at enhancing energy supply and facilitating smart automation in residential and small commercial structures. The suggested approach automatically transfers the load from the primary source to a secondary backup source, thereby eliminating the time delay and difficulty associated with manual switching. The system consists of a regulated power supply unit, a voltage measurement circuit, a microcontroller-based control unit with a relay driver module, a real-time clock (RTC), A DS3231 real-time clock time-stamps every event, forming the backbone of the system's data logging function, the integration of IoT technology for cloud monitoring; the incorporation of GSM connections for remote access; and Android mobile application used for remote monitoring and system operation. The MCU serves as the system's central processing unit (CPU) to accurately and swiftly detect power failures and provide seamless transitions between power sources. The next design element is the processing core, TSR, which is a crucial part of the overall system design. Improved control over system performance and administration can be attained through heightened contact between the monitoring system and the user via mobile phones and PCs. The application must enhance user experience and interface by enabling real-time monitoring and remote control of the system, ensuring usability and system accessibility. The system's functional description was delineated through a circuit and block diagram, as well as a process flowchart, to encompass all tiers of the functional architecture. The system's performance was empirically validated under various operational situations. The findings indicate that the system's response to power interruption is rapid, the load transfer is seamless and devoid of considerable delay, and the communication link between the mobile application and the system remains stable. The intended system design will ensure a cost-effective, highly reliable, and user-friendly. It also performs data logging while promoting energy efficient, intelligent, and responsive usage.

Keywords: Automatic Power Changeover, Microcontroller System, Android-Based Control, Smart Power Management Home Automation, Power Reliability, Embedded Systems.

1. Introduction

The availability of a stable and uninterrupted electric power supply is important to modern life, yet Africa is faced with inconsistent or epileptic power supply, particularly in Nigeria. The national power grid, operated by the Power Holding Company of Nigeria (PHCN), is frequently faced with outages that can last for hours or even days at a stretch, forcing homes, offices, and small businesses to depend on alternative power sources such as battery inverter, generators and other alternative power systems (Okafor et al., 2023). The used of manual process as always been the major means of switching between these power sources. These requires human availability and attention, introduces circuit breakers and delays, and can expose sensitive electronics and electrical equipment to damage during the transition period (Adeyemi & Ogunleye, 2022).

The use of automatic changeover systems have long been seen and employed as a practical solution to this problem. The incoming supply voltage is monitored and a relay is triggered to switch sources the moment one of the power source is down or a failure is detected, such systems eliminate the human involvement in the entire switching process (Ibrahim et al., 2023). Earlier designs and works depends on simple analogue circuitry or basic microcontrollers with limited communication capabilities. Moreover, these solutions lacked the ability to provide remote monitoring or user interaction beyond simple indicator lights or local displays (Chukwuemeka et al., 2022).

However, Internet of Things (IoT) technology has opened up new ways for smarter, more connected power management systems (Rajput & Sharma, 2023). Microcontrollers such as the ESP32, which come with built-in WiFi capability, make it straightforward to integrate remote monitoring and control features without significantly increasing the cost or complexity of the system (Nwosu et al., 2024). However, WiFi-based systems are limited by the range of the local network — a significant drawback in environments where the user may need to monitor the system from a distant location (Aliyu et al., 2023). The integration of GSM connectivity through modules

such as the SIM800L addresses this limitation by enabling SMS-based alerts and data transmission over the cellular network, ensuring the user remains informed regardless of location (Musa & Abdullahi, 2023). Furthermore, the incorporation of IoT cloud platforms such as ThingSpeak enables long-term storage and analysis of system data, providing valuable insights into power supply patterns and system behaviour over time (Kumar et al., 2024).

Android-based interfaces have been shown to significantly improve the usability and accessibility of embedded monitoring systems, particularly for non-technical users (Okonkwo & Ezeh, 2023). The use of MIT App Inventor for developing such interfaces has gained traction in research due to its low development overhead and ability to produce functional, user-friendly applications rapidly (Eze et al., 2022).

A. Problem Statement

Most automatic changeover systems used in Nigerian homes and small businesses only handle the physical switching and nothing else. They cannot notify the user when a changeover happens, they keep no record of outage frequency or duration, and they offer no way of monitoring the system remotely. The few systems that do include some form of communication rely on either WiFi or GSM alone, not both together, and none of them combines switching, data logging, cloud analytics, and a proper Android interface in one affordable package. This leaves the users with the option of not knowing what is happen to their power system when not in the premises. This design provides a

- Build an automatic changeover circuit using the ESP32 that switches between mains and battery inverter in under 250 milliseconds without any manual input.
- Monitor mains voltage and load current continuously using sensors with high accuracy.
- Provide a continuous data logging function for power management.
- Provide dual remote communication through both WiFi and a SIM800L GSM module, with GPRS as a fallback when WiFi is unavailable.
- Connect to the ThingSpeak IoT cloud platform for permanent data storage, real-time charting, and threshold-based alerting.
- Develop an Android app using MIT App Inventor with four screens covering live status, manual control, event log, and cloud analytics.
- Test and evaluate the complete system across switching speed, measurement accuracy, GSM reliability, data logging consistency, and app usability.

This paper presents the design and implementation of a system that combines automatic changeover, dual WiFi and GSM communication, IoT cloud analytics, continuous data logging and a dedicated Android interface into a single affordable solution. The rest of the paper is organized as follows: Section 2 presents the literature review, Section 3 describes the materials and methods, Section 4 presents the results and discussion, and Section 5 draws conclusions and

Table 1
Summary of related literature

Author(s) & Year	Microcontroller	Communication	Key Features	Limitations
Adeyemi & Ogunleye (2022)	Arduino Uno	None	Automatic voltage sensing and relay switching	No remote monitoring or mobile interface
Chukwuemeka et al. (2022)	PIC16F877A	None	Voltage stabilisation with changeover	No IoT integration, no user notification
Eze et al. (2022)	Arduino	Bluetooth (HC-05)	Mobile interface design and usability	Short-range only, no cloud logging
Ibrahim et al. (2023)	Arduino Mega	GSM (SIM900)	SMS alert on power failure	No Android app, no cloud logging
Aliyu et al. (2023)	NodeMCU ESP8266	WiFi	Real-time monitoring via web dashboard	WiFi only, no GSM fallback, no changeover
Musa & Abdullahi (2023)	Arduino Uno	GSM (SIM800L)	Remote monitoring via GSM	No IoT cloud, no Android app
Okafor et al. (2023)	ATmega328	None	Changeover analysis in Nigerian context	No communication module, no remote access
Okonkwo & Ezeh (2023)	Raspberry Pi	WiFi	UI design principles for embedded systems	Not a changeover system, no GSM
Rajput & Sharma (2023)	ESP32	WiFi + MQTT	ThingSpeak cloud logging, mobile app	No automatic changeover, no GSM fallback
Nwosu et al. (2024)	ESP32	WiFi	Energy monitoring and remote control	No changeover relay, no GSM module
Kumar et al. (2024)	ESP32	WiFi + HTTP	Real-time analytics and cloud logging	No switching function, no SMS alert
This study	ESP32	WiFi + GSM	Changeover + Android app + IoT cloud + SMS + data logger	—

low-cost solution that manages power switching automatically, notifies users when power is available, and keeps an historical record of power supply conditions for better decision-making.

B. Objectives

The objectives of this paper are:

outlines directions for future work.

2. Literature Review

A review of recent related works was carried out to identify existing approaches to automatic power changeover systems, remote monitoring, and IoT-based energy management, and to

position the contribution of this study within the current state of knowledge. Table 1 presents a summary of selected studies reviewed.

A. Research Gap

The review clearly identifies a gap in the existing literature: there is currently no widely reported system that combines automatic power changeover, dual WiFi and GSM communication, IoT cloud analytics, continuous data logging and a dedicated Android application interface into a single, affordable, and fully integrated solution. This study directly addresses this gap by presenting a system built on the ESP32 microcontroller that unifies all of these capabilities.

3. Materials and Methods

A. System Overview

The automatic power changeover system monitors the availability of mains power supply and switches the connected load to a battery inverter whenever the mains supply fails, and back again once it is restored. The ESP32 microcontroller serves as the central processing unit. The system comprises six main functional units: the voltage sensing unit, the microcontroller control unit, the relay switching unit, data logger, the GSM communication unit, and the Android

B. ESP32 Microcontroller

The ESP32 was selected due to its specifications such as: Operating at 3.3V logic with a clock speed of up to 240 MHz, dual-core processing capability, built-in WiFi and Bluetooth modules, and 34 GPIO pins (total usable pins, 18 analog input pins (ADC), 2 analog output pins (DAC) and 25+ digital I/O pins ESP32 handles simultaneous tasks of real-time voltage monitoring, relay control, WiFi communication, GSM coordination, and IoT cloud data transmission efficiently (Nwosu et al., 2024). ESP32 has an in-built WiFi features, such that no external WiFi module is needed. This makes the microcontroller compact and cost effective.

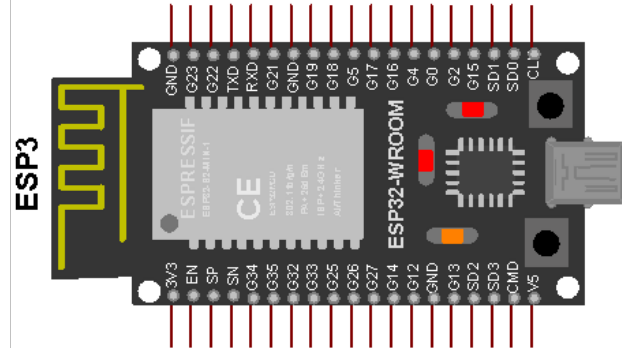


Fig. 2. ESP32 Microcontroller

Table 2
Summary of key system components

Component	Specification	Function
ESP32	240 MHz dual-core, built-in WiFi	Main controller and communication hub
Voltage divider/AC-DC2416	R1 = 82kΩ, R2 = 8.2kΩ	Scales mains voltage for ADC reading
SIM800L	Quad-band GSM/GPRS	SMS alerts and GPRS cloud uploads
DS3231 RTC	±2 ppm, I2C interface	Accurate event time-stamping for data logger
BC548 NPN transistor	hFE = 110, I _c max = 100 mA	Drives the relay coil
Relay module	5V SPDT, 10A contact rating	Physical load switching
1N4007 diode	1A, 1000V PIV	Relay flyback voltage suppression
LM2596 buck converter	Input up to 40V, output 3A	Powers the SIM800L at correct voltage
1000μF capacitor	16V electrolytic	Stabilizes GSM module supply
Buzzer	5V	Alarm

monitoring and control interface supported by IoT cloud integration.

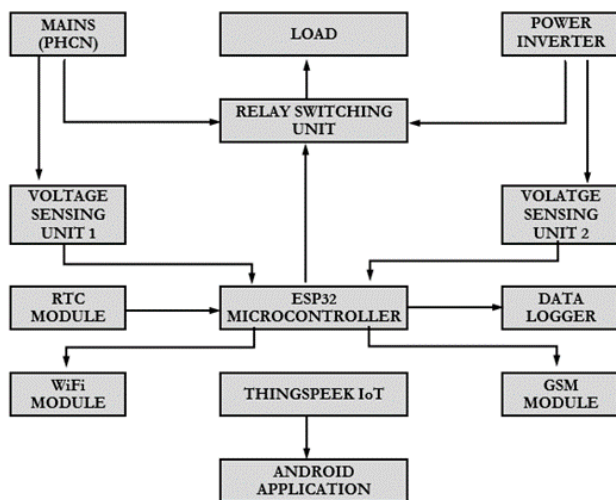


Fig. 1. Block diagram of the system

C. Voltage Sensing Unit

Mains voltage (240V AC) is stepped down using an AC-DC2416. A voltage divider comprising a 82kΩ and 8.2kΩ resistor pair scales the resulting DC signal to within the 0–3.3V ADC input range of the ESP32. The microcontroller continuously reads this voltage and compares it against a preset threshold of 180V. When the voltage drops below this threshold, the system interprets this as a mains failure and initiates the switchover sequence

$$V_{out} = V_{in} \times R_2 / (R_1 + R_2) = 36 \times 8.2 / (82 + 8.2) = 36 \times 8.2 / 90.2 \approx 3.27V (1)$$

D. Real-Time Clock Module

The DS3231 RTC module provides accurate time and date stamping of all switching events. Event records are stored locally and uploaded to ThingSpeak, where they can be reviewed through the Android application or a web browser (Kumar et al., 2024).

E. Relay Switching Unit

A relay module driven by a TIP120 NPN transistor switches the load between the mains supply and the battery inverter. The design and interfacing of a microcontroller-based relay driver circuit capable of switching a 20A, 220V AC load. The system uses a TIP120 NPN Darlington transistor to control a 12V relay, which then handles the high-current AC load. An Arduino microcontroller provides the control signal.

Components Used: (i) Arduino Microcontroller (5V logic) (ii) TIP120 NPN Darlington Power Transistor (iii) 2.2kΩ Base Resistor (iv) 12V Relay (Contact Rating: ≥ 20A @ 250V AC) (v) 1N4007 Flyback Diode (vi) High-Current AC Load (e.g., 20A, 220V) (vii) External 12V DC Power Supply for Relay

Base Current Required: $I_b = I_c / \beta = 150\text{mA} / 250 = 0.6\text{mA}$ (2)

Base Resistor: $R_b = (5\text{V} - 2.5\text{V}) / 0.6\text{mA} \approx 4.2\text{k}\Omega \rightarrow$ Choose 2.2kΩ for stronger saturation (3)

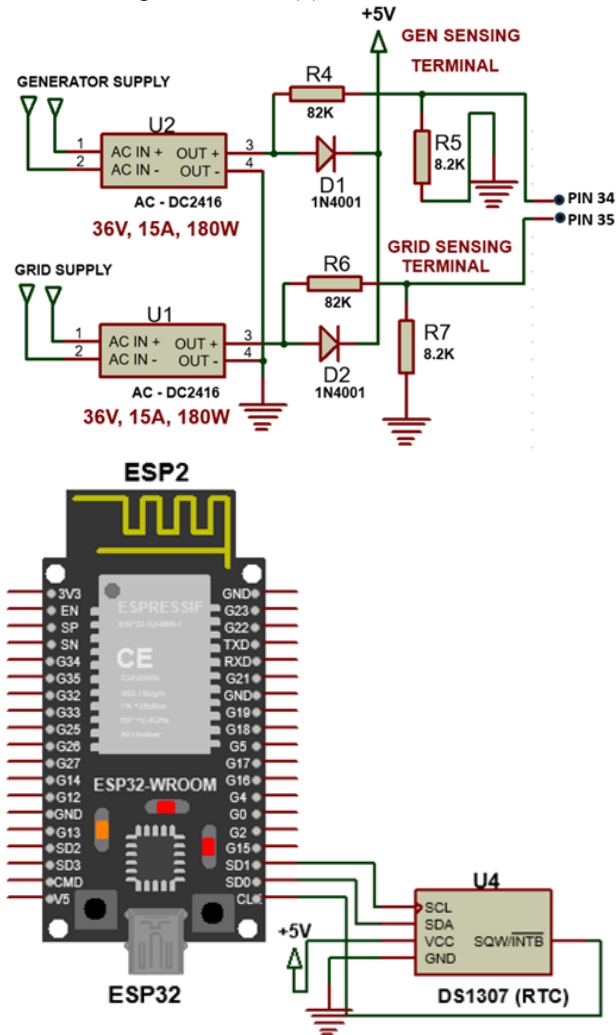


Fig. 3. (a) Voltage sensing interfacing (b) RTC interfacing for data logging activities

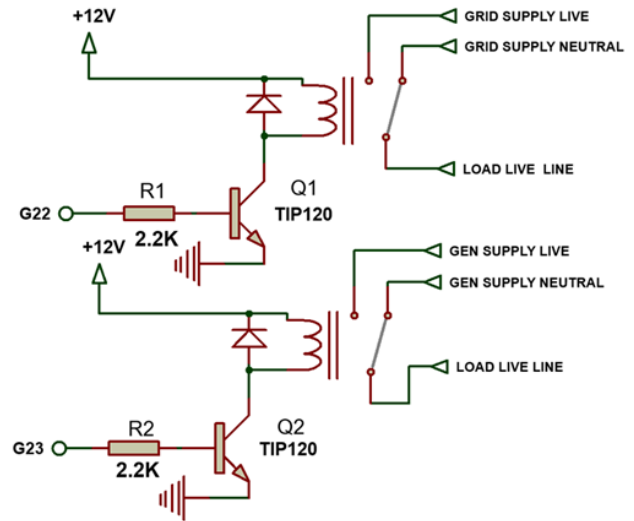


Fig. 4. Microcontroller interfacing with 20A relay Driver Interface for both Generator and grid

F. GSM Communication Unit

The SIM800L GSM module communicates with the ESP32 via serial UART and is powered through an LM2596 buck converter with a 1000μF stabilisation capacitor. When mains failure occurs, the ESP32 sends a signal to SIM800L, instructing it to send an SMS alert describing the event. When WiFi is unavailable, the GSM module handles ThingSpeak uploads via GPRS (Musa & Abdullahi, 2023).

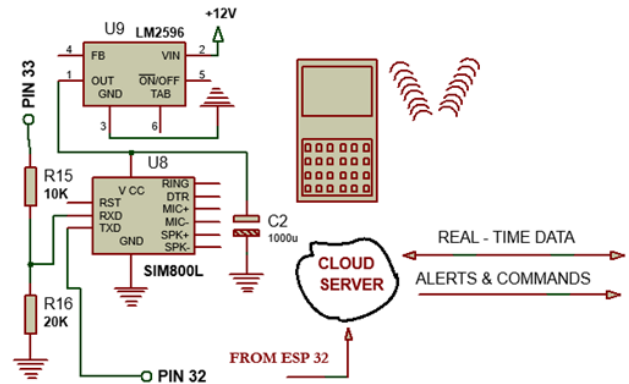


Fig. 5. SIM800L GSM module circuit

Table 3
Design calculations

Parameter	Typical Value
Load Current	20A @ 220V AC
Relay Coil Voltage	12V DC
Relay Coil Current	~150mA
Transistor Gain (β)	~1000 (safe base drive considered with $\beta = 250$)

G. IoT Cloud Platform Integration

ThingSpeak was selected for long-term data logging due to its ease of integration with the ESP32 and support for both HTTP and MQTT protocols (Kumar et al., 2024). Voltage readings, current readings, power source status, and switching event data are uploaded at 15-second intervals over WiFi, with

GPRS fallback through the SIM800L when WiFi is unavailable. ThingSpeak stores data and create interactive charts that can be accessed from any internet device. Threshold-based alerts configured on the platform complement the GSM SMS notifications (Rajput & Sharma, 2023).

H. Android Interface Design

The Android application was developed using MIT App Inventor and serves as the primary user interface for interacting with the system. The graphic user interface was design to enable those with poor technical background use them easily. (Okonkwo & Ezeh, 2023). The application is organised into four main screens.

The Home Screen displays the system status at a glance — the active power source, real-time mains voltage, and time of the last switching event. The green status indicator represents MAINS operation, Amber status for inverter battery active, and red for a faulty condition.

The Control Screen provides a manual override toggle that allows the user to switch the active power source through the application when required. A confirmation prompt appears before any switching action is executed to prevent accidental commands. This screen also displays WiFi connection status and GSM signal strength.

The Event Log Screen presents a chronological list of all switching events recorded by the RTC module, with each entry colour coded to distinguish between automatic and manual switching events. This log gives users visibility into the frequency and duration of power outages over time.

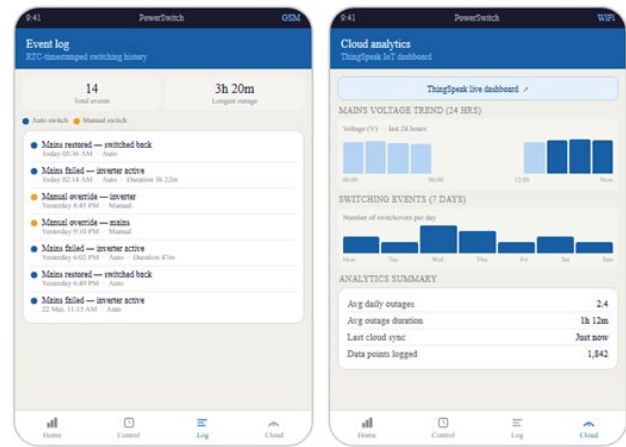


Fig. 7. Event log screen and cloud analytics screen GUI

I. System Operation

When powered on, the ESP32 continuously monitors mains voltage and the alternative power supply. Under normal conditions, the mains supply powers the load while the battery inverter system remains on standby. When mains voltage drops below 180V or power outage occurs, the ESP32 detects the failure, logs the event with an RTC timestamp, triggers the relay to switch the load to the battery inverter, sends an SMS alert via the SIM800L, and uploads event data to ThingSpeak — all within milliseconds. When mains power is restored, the system waits for a 3-second stabilization delay before switching back and notifying the user through both SMS and the Android application.

Table 4
Switching response time test results

Test Run	Failure Detection to Relay Closure (ms)	Restoration to Switchback (ms)
1	184	3,122
2	171	3,083
3	190	3,203
4	167	3,079
5	173	3,190
Average	177	3,140.8

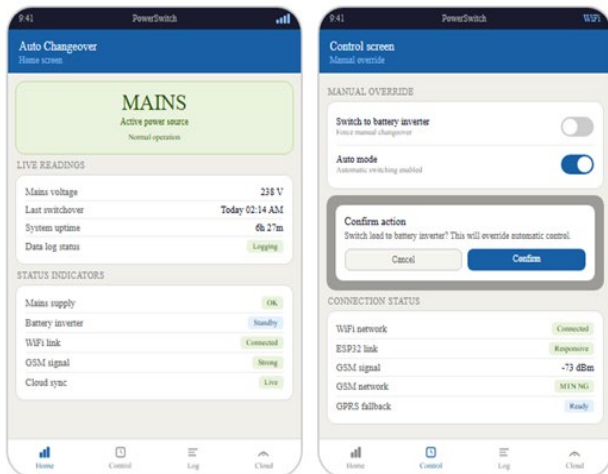


Fig. 6. Home display and control screen GUI

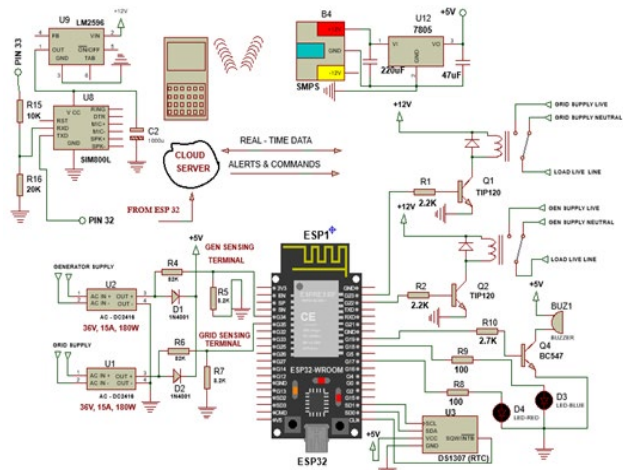


Fig. 8. Full circuit diagram of the System

4. Results and Discussion

A. System Performance

The system was tested under real-world operating conditions to evaluate switching speed, voltage sensing accuracy, GSM communication reliability, and cloud data logging consistency. Multiple test cycles were conducted simulating sudden mains failures, gradual voltage drops, and deliberate WiFi disconnection to test GSM fallback behaviour. In all the test carried out, the system was able to detect MAINS failure and was able to perform change over process to inverter mains

B. Switching Response Time

The response time — measured from voltage threshold breach to relay contact closure — was consistently below 200 milliseconds across all test runs, as shown in Table 3. This performance is well within the acceptable range for protecting sensitive electronic equipment and is comparable to response times reported in recent literature

C. Voltage Monitoring Accuracy

The voltage divider circuit provided accurate mains voltage readings, deviating by no more than $\pm 2V$ from values obtained using a calibrated digital multimeter. Readings were displayed in real time on the Android application and simultaneously uploaded to ThingSpeak for trending and analysis

D. GSM Communication Performance

The SIM800L delivered reliable SMS alerts in all test scenarios, with notifications received within 5 to 15 seconds of a switching event depending on network signal strength. The GPRS fallback for cloud uploads functioned correctly, with an average upload latency of 22 seconds over GPRS compared to 3 seconds over WiFi, consistent with findings

E. IoT Cloud Platform Performance

Data was logged to ThingSpeak throughout testing at 15-second intervals, with the dashboard clearly identifying transition points between power sources. Historical data provided a complete picture of power supply conditions during each test session, demonstrating the platform's usefulness for long-term monitoring and analysis

F. Android Application Performance

All four interface screens performed as designed throughout testing. Status updates, voltage and current readings, and event log entries were accurate and reflected with minimal latency.

The ThingSpeak integration within the Cloud Analytics screen loaded historical charts reliably. Informal user evaluation indicated that the colour-coded status indicators were particularly helpful in conveying system state at a glance, consistent with usability principles outlined by Okonkwo and Ezeh (2023).

G. Comparative Analysis

Table 4 compares the proposed system against selected related works across key performance and feature dimensions.

The comparative analysis shows that the proposed system offers a more comprehensive feature set than any single existing work, combining automatic changeover, dual communication channels, IoT cloud analytics, dedicated Android interface, and RTC-based event logging in a single integrated and affordable solution.

5. Discussion

The results confirm that the proposed system delivers fast, reliable, and automatic power changeover between mains supply and a battery inverter, with real-time remote monitoring through an Android application, GSM-based SMS alerts, and long-term data logging through ThingSpeak. The dual WiFi and GSM communication architecture proved particularly effective, ensuring the user remains reachable regardless of location and addressing a key limitation of purely WiFi-based designs highlighted by Aliyu et al. (2023). The system is a practical and

affordable option for households and small businesses in Nigeria and similar environments

6. Conclusion

This paper presented the design and implementation of an Android-enabled microcontroller-based automatic power changeover system capable of seamlessly switching between mains supply and a battery inverter without manual intervention. The system demonstrated fast and reliable switching with response times consistently below 200 milliseconds, accurate voltage and current monitoring, reliable GSM-based SMS alerting through the SIM800L module, and consistent long-term data logging on the ThingSpeak IoT cloud platform. The Android interface, developed using MIT App Inventor, provided an intuitive and accessible monitoring and control experience across four well-designed screens. The tabulated literature review and comparative analysis confirmed that the proposed system addresses a clear gap in existing work

Table 5

Comparative analysis of proposed system against related works

Feature	Ibrahim et al. (2023)	Aliyu et al. (2023)	Rajput & Sharma (2023)	Nwosu et al. (2024)	This Study
Automatic load switching	Yes	No	No	No	Yes
WiFi communication	No	Yes	Yes	Yes	Yes
GSM SMS alerts	Yes	No	No	No	Yes
Dedicated Android app	No	No	Partial	Yes	Yes
Data logger function	No	No	No	No	Yes
IoT cloud analytics	No	No	Yes	Yes	Yes
GPRS fallback logging	No	No	No	No	Yes
RTC timestamped events	No	No	No	No	Yes
Avg. switching time	~250 ms	N/A	N/A	N/A	~179 ms

by unifying automatic changeover, dual communication channels, IoT analytics, and a dedicated Android interface into a single affordable solution.

Future work could explore the incorporation of machine learning algorithms on the cloud platform for predictive fault detection, expansion to multi-node monitoring across several installations, and broader field deployment across multiple sites in Nigeria to generate real-world validation data.

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