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Design and Implementation of an IoT Microcontroller Power Protection and Control System

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Abstract :Unstable power supply is a persistent challenge in Nigeria, necessitating effective voltage regulation solutions. This study presents the design and implementation of an Internet of Things (IoT)-based microcontroller voltage stabilizer for power protection and control. The system automatically detects abnormal voltage levels—low, high, and over-voltage conditions—and corrects them to maintain a stable output of approximately 220 volts. Using a microcontroller and the Blynk application, the device enables real-time wireless monitoring of voltage levels. Experimental tests confirmed that the device could regulate input voltages ranging from 140 V to 250 V, ensuring a consistent output voltage near 220 V. The proposed solution offers a reliable, cost-effective, and efficient alternative to commercial stabilizers and demonstrates minimal thermal risk during operation.

Keywords: *IOT, Microcontroller, Low voltage, High voltage, 220 volts*

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1.0 Introduction

Unstable power supply remains a major challenge in Nigeria and other developing countries. The electricity supplied from the national grid is often characterized by irregular voltage levels, typically fluctuating above or below the standard 220–240 volts required for optimal operation of most electrical and electronic devices. These voltage fluctuations have detrimental effects on appliances such as televisions, refrigerators, air conditioners, computers, and sensitive industrial equipment. Inconsistent voltage not only reduces the performance and lifespan of these devices but also leads to frequent breakdowns and high maintenance costs for both domestic and industrial users.

To address this challenge, voltage stabilizers have traditionally been used to maintain a constant output voltage regardless of variations in input. These stabilizers function by boosting or bucking voltage to protect connected loads. However, conventional stabilizers are often bulky, expensive, and lack intelligent features that allow for remote control, real-time monitoring, or adaptability to varying power conditions. With the increasing demand for smarter and more efficient power control systems, attention has shifted to the integration of microcontrollers and Internet of Things (IoT) technologies in the design of voltage regulation systems.

Several researchers have proposed intelligent voltage stabilization techniques. For example, Akinlolu (2018) emphasized the role of microprocessor chip technology in achieving high-quality voltage regulation. Arthur et al. (2021) highlighted the compatibility of stabilizers with various sensitive appliances and their role in minimizing damage caused by voltage surges. More recent advancements have explored the incorporation of wireless communication and automation to enhance stabilizer performance. Hamidah (2021) and Adabara (2021) investigated the development of programmable automatic voltage stabilizers and systems with backup power and alarm integration. While these systems demonstrated improvements in performance, they often lacked IoT capabilities for real-time remote monitoring and feedback control.

Despite these efforts, there is still a noticeable gap in the availability of cost-effective, IoT-enabled microcontroller-based stabilizers that offer automatic detection, correction, and monitoring of voltage fluctuations, especially within the Nigerian context. Most available commercial products are either too expensive or not adequately tailored to local grid conditions, making them inaccessible to low-income households and small businesses.

The aim of this study is to design and implement an IoT-based microcontroller-controlled voltage stabilizer that can detect abnormal input voltage conditions—such as low, high, and over-voltage—and automatically correct them to deliver a consistent output voltage. The system will also enable wireless monitoring of voltage levels using the Blynk application to enhance user control and system diagnostics.

The significance of this study lies in its contribution to the development of smart, affordable, and energy-efficient power stabilization solutions. By leveraging microcontroller programming and IoT connectivity, the proposed stabilizer provides an innovative alternative to conventional systems. It addresses both technical and economic barriers by ensuring reliable voltage supply, reducing appliance damage, and supporting remote management, which is critical for modern households, offices, and small-scale industries in power-deficient regions.

1.0 Review of Related Literature

Power instability, including voltage fluctuations, sags, and surges, poses a significant threat to both household and industrial electrical systems. To address these challenges, researchers have developed various stabilizing technologies, ranging from basic automatic voltage regulators (AVRs) to more advanced programmable and IoT-enabled systems.

2.1 Traditional and Automatic Voltage Stabilizers

Several researchers have examined conventional stabilizer designs and their limitations. For instance, Hamidah (2021) emphasized that fluctuations in AC supply significantly affect sensitive electronic devices and contribute to long-term equipment damage. To mitigate such issues, practitioners often adopt automatic voltage stabilizers (AVS). Her study compared AVS with programmable AVS (PAVS), showing that the latter offers greater adaptability and protection against common power quality issues such as brownouts and surges.

Adabara (2021) focused on the development of an automatic high-performance voltage stabilizer capable of identifying and correcting improper voltage levels. The device incorporated a backup DC power source to maintain operation during outages and included an alert system for user awareness. This innovation, while effective, did not incorporate IoT-based remote monitoring, thereby limiting its control capabilities.

Hietpas and Naden (2000) addressed the challenges of voltage sags and sustained undervoltages in industrial settings. They proposed an AC voltage–voltage converter for voltage-sag correction using high-speed insulated gate bipolar transistor (IGBT) switching technology. The system demonstrated efficiency in simulations and showed potential for addressing voltage instability in large-scale applications. However, the system lacked real-time monitoring or adaptability via microcontrollers.

2.2 Power Quality in Distribution Networks

The issue of deteriorating power quality in distribution systems has also been discussed in recent studies. Statsenko (2017) noted that aging infrastructure and increasing electrical demand often cause frequent voltage fluctuations, leading to the malfunction of household and industrial appliances. He emphasized the need for reliable voltage regulators, and reviewed transformer-based designs with series-connected windings and tap changers. However, these systems remain bulky and inflexible, especially in fast-changing load environments.

Similarly, Karimov (2021) explored the use of optoelectronic voltage relays in stabilizers to switch transformer windings for boosting voltage. His study, supported by MATLAB R2014a simulations, showed that the output waveform closely resembled an ideal sinusoid. While the approach demonstrated technical soundness, it did not consider remote accessibility or automated feedback mechanisms enabled by IoT technologies.

2.3 Gaps in Existing Literature and Need for IoT Integration

From the reviewed studies, it is evident that while various stabilization techniques have been developed, most lack real-time monitoring, wireless control, and user interactivity, which are essential for modern smart power management systems. Furthermore, existing solutions are often cost-prohibitive or not tailored to address the highly unstable grid conditions observed in countries like Nigeria.

Although some progress has been made in incorporating automation into stabilizers, as seen in the works of Adabara (2021) and Hamidah (2021), there is still a lack of IoT-integrated, microcontroller-based designs that are both affordable and customizable. Additionally, current literature has focused more on the control aspect and less on user feedback mechanisms, cloud-based monitoring, and integration with mobile platforms such as the Blynk application.

This study aims to address these gaps by designing a voltage stabilizer that not only uses a microcontroller to regulate abnormal voltage levels but also incorporates IoT-based wireless monitoring. By doing so, it merges automation, user accessibility, and affordability into a single system, offering a more sustainable and efficient solution to voltage instability in both residential and small industrial settings.

3.0 Materials and Methods

This section outlines the components and processes involved in the design and implementation of the microcontroller-based Power Protection System. The approach focuses on cost-effectiveness, operational flexibility, and reliability. Both the materials and the methodology adopted are aimed at ensuring the final product performs within desired electrical and safety standards.

3.1 Materials

To actualize the system design, a combination of hardware and software components was assembled. The selection of components was influenced by performance requirements, availability, and cost efficiency.

3.1.1 Hardware Components

The key hardware components used in constructing the Power Protection System include:

- Power Supply Unit
- Microcontroller (Atmega328p)
- 7805 Voltage Regulator
- Auto-Transformer
- UNL2803A Darlington Pair Transistor (IC)
- Potentiometer Resistors (Variable Resistors, VR)
- 6V Relay
- Connecting Wires (Jumper Wires)

Each component was selected based on its compatibility with the control logic, voltage regulation requirements, and current handling capacity.

3.2 Methods

The implementation of the system is divided into two major categories: hardware design and software design. The overall methodology adopted integrates both analog and digital components to create a stable, responsive, and protective voltage regulation system.

3.2.1 Regulated Power Supply Design

The power supply circuit was designed (Fig. 1) to provide two levels of DC output: 5V and 12V. Using the Zener power regulation method, the circuit incorporates a current limiting capacitor, bridge rectifier, filter capacitors, a Zener diode, buffer transistor, and a three-terminal adjustable voltage regulator.

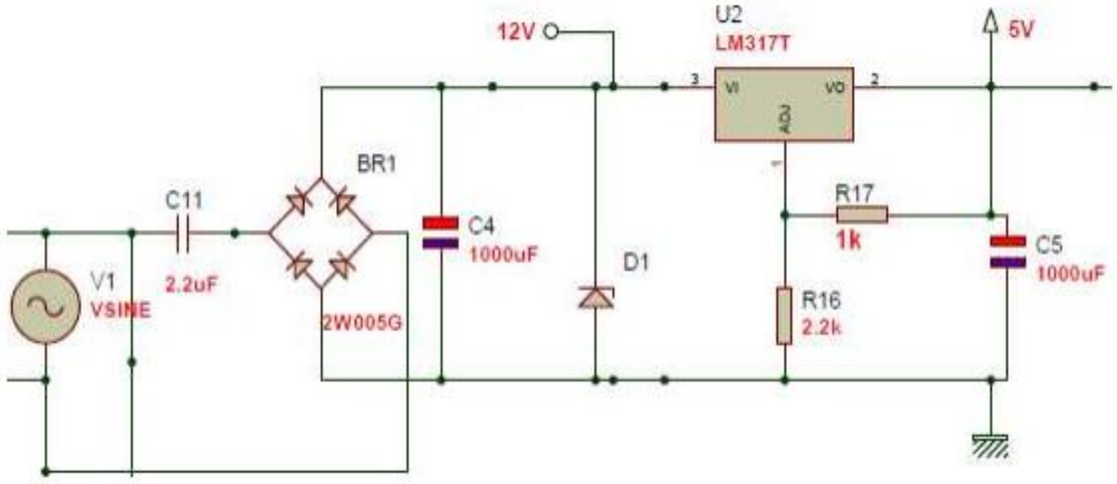

Fig.1: Regulated Power Circuit

3.2.2 Bridge Rectifier

A 2W005G bridge rectifier was used to convert AC to DC. It features a low forward voltage drop (1V), high current capability (50A), and an average rectified output current of 2A. This rectifier outputs a voltage of approximately 14.16V, which is then regulated to desired levels for other circuit components.

3.2.3 Filtering Capacitors

Capacitors C4 and C5 (each rated at 1000µF) were added to smooth the ripple produced by the rectifier. Their capacitance, voltage rating, and ripple tolerance were carefully selected to ensure consistent DC output.

3.2.4 Zener Regulator Design

The Zener diode (1N5242B) was used for voltage regulation. When reverse biased, it maintains a constant output voltage across the load, irrespective of fluctuations in input or load conditions. This ensures that the system is not affected by minor voltage changes on the grid.

3.2.5 Switching Circuit Design

A 12V relay forms the core of the switching circuit (Fig. 2). Relays are connected in parallel with their common terminals joined and normally open (NO) terminals connected to various taps of the autotransformer. The switching logic ensures that the output terminal always receives a steady 220V.

3.2.6 Referencing Voltage Circuit

To determine when a switch should operate, a reference voltage is required (Fig. 3). This was obtained from a voltage divider network comprising a fixed and a variable resistor. The output from the divider is fed into an Analog-to-Digital Converter (ADC) input pin on the microcontroller.

3.2.7 Flowchart of System Operation

The logic of the system is clearly represented in the system flow chart (Fig. 4). This outlines how the system processes input voltages, makes switching decisions, and protects connected loads.

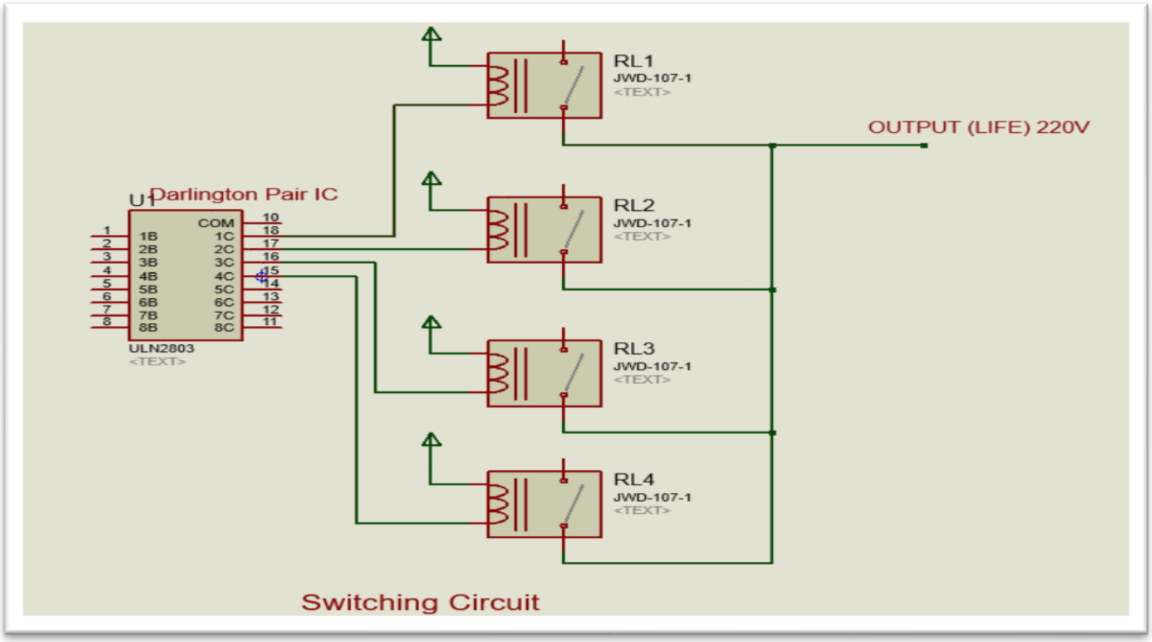

Fig. 2: Switching Circuit

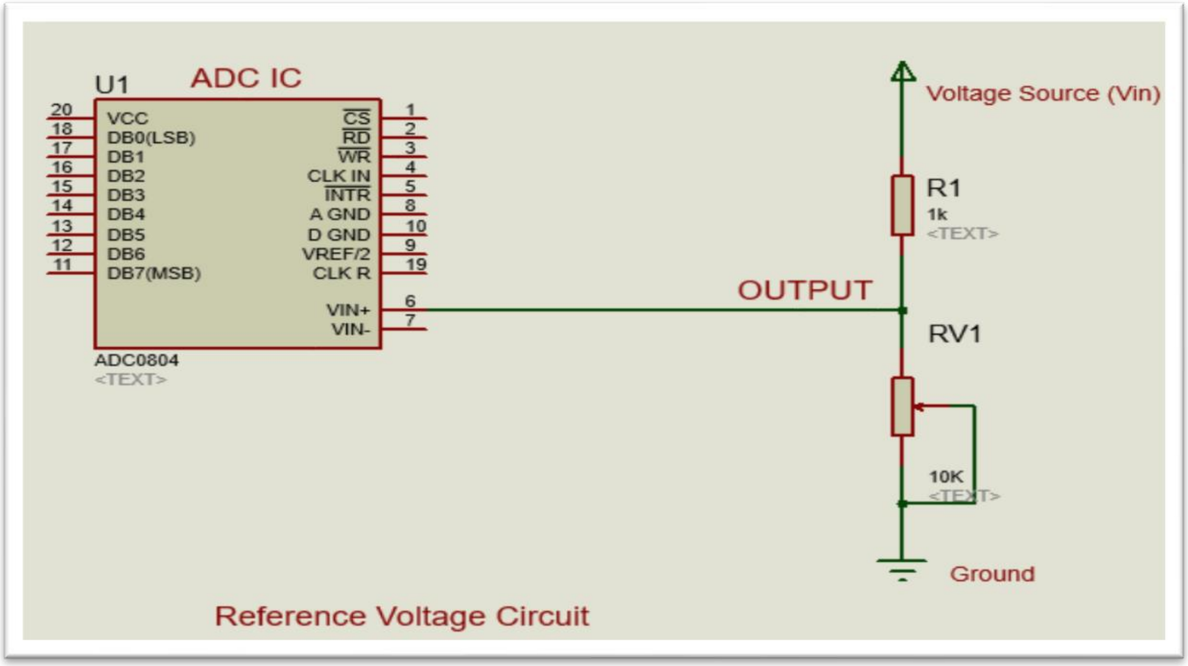

Fig .3: Referencing Voltage Circuit.

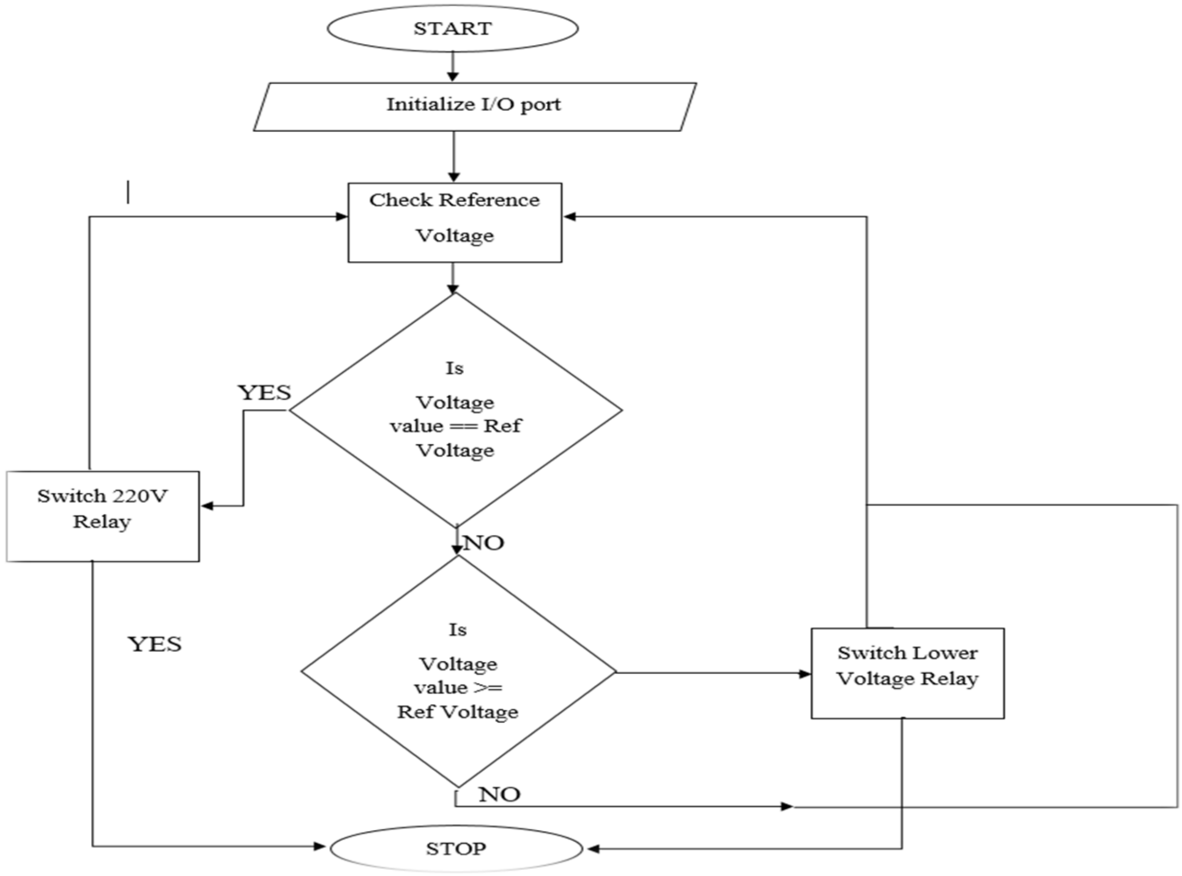

Fig.4: System Flow Chart

3.3 Block-Level and Circuit-Level Design

To understand the modular architecture of the system, a block diagram was developed as shown in Fig. 5. It illustrates the interaction between major components: power supply, reference voltage circuit, microcontroller, switching relays, and output terminal.

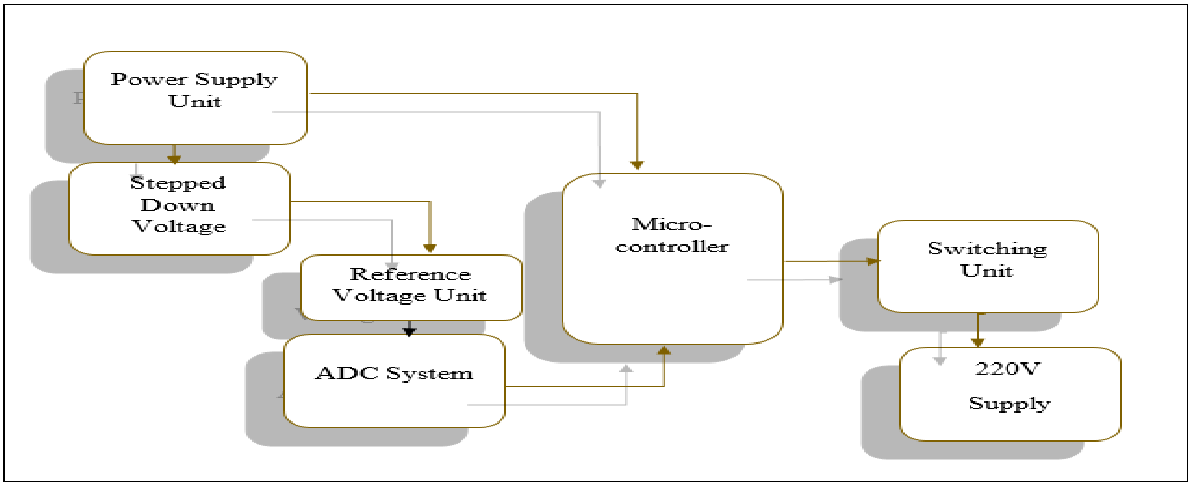

Fig. 5: Block Diagram of a micro-controller based Power Protection System

Additionally, a full system circuit was simulated using Proteus software (Fig. 6). . This allows for visualization of voltage flow, component interaction, and validation of logic before physical implementation.

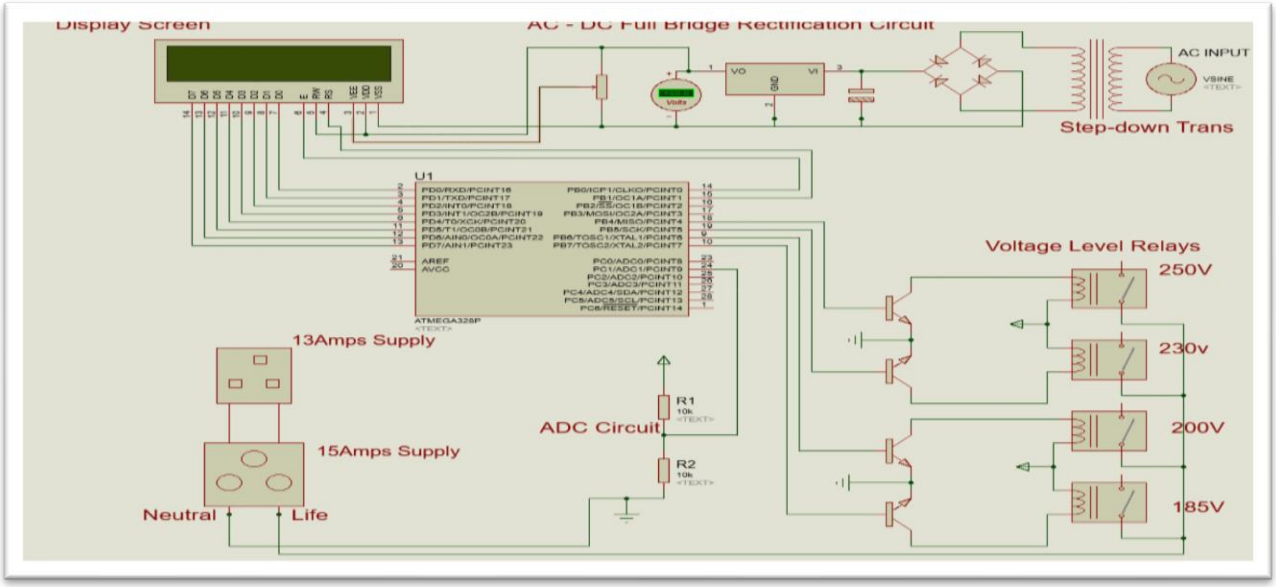

Fig.6: Proteus Simulation of the System

3.3.1 Full-Bridge Rectification

A 230V AC input is supplied to the 12V tap of the auto-transformer, stepping it down before rectification. The full-bridge rectifier then converts the AC into DC, which powers the control circuit. The autotransformer's secondary windings provide different voltage levels (0V to 250V), proportional to the input from the primary winding. This design ensures appropriate tap switching depending on voltage conditions.

3.4 Referencing, Supply, and Circuit Breaker Unit

An analog referencing unit, comprising a voltage divider, Zener diode, and ADC (ADC0804), was used to monitor input voltage levels. This reference voltage is digitized and compared within the microcontroller. Based on the comparison outcome, an appropriate relay is energized, allowing the system to stabilize the output to 220V.

Each relay switch is connected in parallel to the output voltage taps of the stabilizer. This configuration ensures quick response to input changes and maintains a constant output voltage. The Zener diode also plays a critical role in circuit protection by acting as a gate to a kill switch mechanism, activated when the output exceeds 230V, thus safeguarding connected appliances.

3.5 IoT-Based Automatic Voltage Regulator (AVR) Design

To modernize and expand the system's capability, an IoT-based AVR model was also designed (Fig. 7). This model integrates traditional voltage regulation with remote monitoring and control using an ESP32 microcontroller and online platforms such as Blynk or MQTT.

The schematic includes voltage and current sensors, relay modules for tap control, and communication links for real-time monitoring.

3.5.1 Operation of the IoT AVR

The voltage sensor (e.g., ZMPT101B) continuously monitors grid voltage (Fig. 8). If deviations are detected, the ESP32 adjusts transformer taps using a relay module. Data is transmitted over Wi-Fi for remote monitoring via a mobile or web-based dashboard. Optional local display units such as OLED or LCDs can provide on-site feedback.

3.5.2 IoT AVR Simulation in Proteus

Although real cloud interaction is not supported in Proteus, virtual terminals can simulate data transmission. The ESP32 is programmed externally using the Arduino IDE, with logic to:

- Read and compare voltage.
- Trigger relays based on thresholds.
- Simulate data logging or alerts.

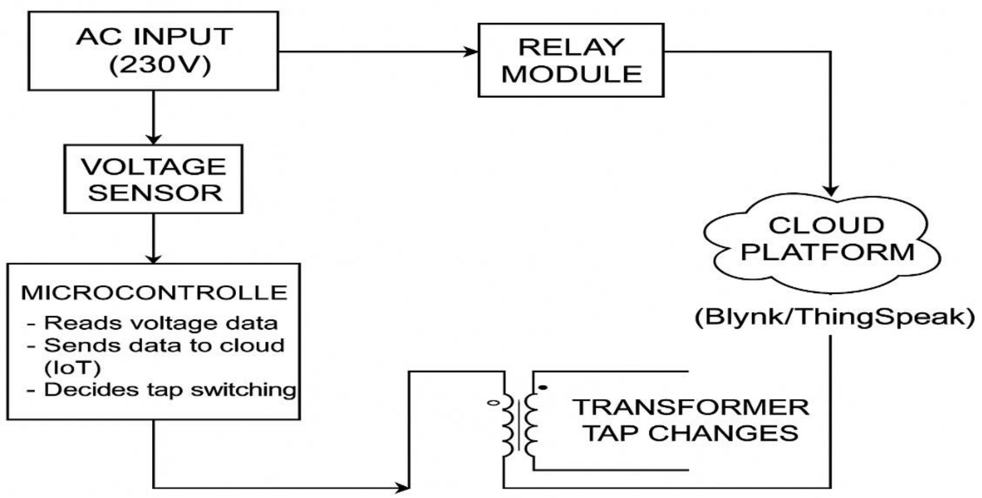

Fig. 7: Block Diagram of IoT-based Automatic Voltage Regulator (AVR)

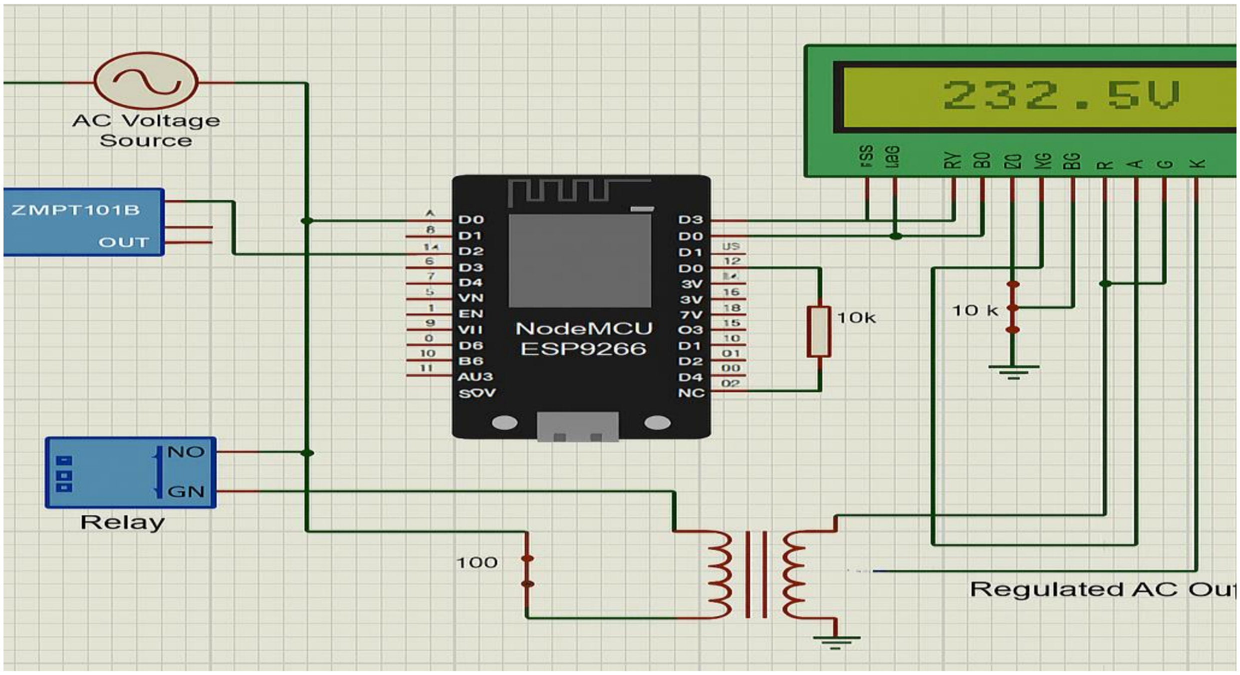

Fig. 8: Circuit Diagram of IoT-based Automatic Voltage Regulator (AVR)

4.0 Results and Discussion

To ensure the reliability, efficiency, and robustness of the developed Power Protection System, a series of performance tests were carried out. These tests were strategically designed to evaluate its ability to regulate voltage, protect against abnormal power conditions, and maintain operational stability under various electrical scenarios. Each test targeted specific functionality of the system, beginning with voltage regulation at different thresholds and extending to diagnostic checks that ensure system integrity.

4.1 Low Voltage Test

The first evaluation focused on determining the system's behavior under low voltage conditions. An input voltage of 170 V, which is at the lower threshold of the device’s operating range, was applied. The system successfully amplified this low input to a usable level of approximately 200 V. This demonstrates the system's ability to boost insufficient voltage to a safe and reliable level suitable for sensitive electrical appliances. The implication of this finding is that end-user equipment connected to this system will be protected from malfunction or damage due to voltage drops, which are common in unstable power grids.

4.2 High Voltage Test

Following the low voltage performance, the system was subjected to a high voltage condition. When 240 V was supplied at the input, the system efficiently regulated it down to 220 V at the output. This confirms the device’s voltage normalization feature. In regions where voltage fluctuations are rampant, such regulation ensures equipment longevity and operational consistency. The ability to bring high input voltage within standard tolerance levels highlights the effectiveness of the stabilizer's transformer and relay switching mechanisms.

4.3 Over Voltage Test

Further testing was conducted to assess how the system responds to dangerous over-voltage scenarios. According to IEEE standards, voltage exceeding 250 V ± 5% poses a risk to most electrical devices. In this test, a voltage of 260 V was input into the system. The Power Protection System activated its over-voltage cut-out mechanism, preventing any output from being delivered. This result is crucial, as it demonstrates the protective circuitry’s responsiveness and confirms that the design meets regulatory safety standards. Such functionality ensures that connected appliances are shielded from harmful voltage spikes that could result from lightning strikes or transformer faults.

4.4 Continuity Test

To complement the voltage regulation tests, internal circuit integrity was assessed via continuity testing. This test was conducted both during and after construction to ensure that there were no breaks in connectivity between components. The absence of discontinuities indicates sound construction practices and the reliability of electrical joints within the system. A lack of proper continuity could have led to partial system failure, compromised protection features, or increased resistance, resulting in inefficient power transfer.

4.5 Open Circuit Test

The open circuit test was conducted to assess core magnetic behavior and no-load losses in the transformer. During the test, the high-voltage winding was left open while the low-voltage winding was energized with a normal input. The setup included a voltmeter, ammeter, and wattmeter to record relevant data. As expected, iron losses were observed while copper losses were minimal due to the low current flow. The purpose of this test was to verify that the transformer core was magnetically functional and that all necessary windings were intact. This test ensures that energy losses within the system during no-load conditions are within acceptable limits, enhancing energy efficiency.

4.6 Short Circuit Test

To simulate fault conditions and evaluate the system’s response to them, a short circuit test was carried out. A low voltage was applied to the primary side of the transformer, while the secondary was short-circuited through a low-resistance path. The input voltage was gradually increased until full load current was achieved in both windings. This test helps determine the system's impedance and verifies that no component fails under stress. It also confirms that the system can handle current surges without compromising internal components such as relays and transistors. The short circuit test was particularly important for validating the protective design features against internal electrical faults.

4.7 Voltage Regulation Results and Graphical Interpretation

The data obtained from the tests across different input voltages and corresponding output voltages are presented in Table 1. This data set was used to evaluate the system's performance under real-world operational conditions.

Table 1: Input/Output Voltage Table

Input Voltage (V)	Output Voltage (V)
180	198
188	200
200	210
202	213
270	Cut-out

The table shows a consistent and progressive amplification of input voltage up to a threshold, beyond which the system shuts down output delivery (cut-out at 270 V). This behavior highlights a well-calibrated voltage regulation mechanism with appropriate safety margins.

A graphical representation of the input/output voltage relationship is provided in **Fig. 9**, further illustrating how the output voltage stabilizes within a safe operational range even as the input fluctuates.

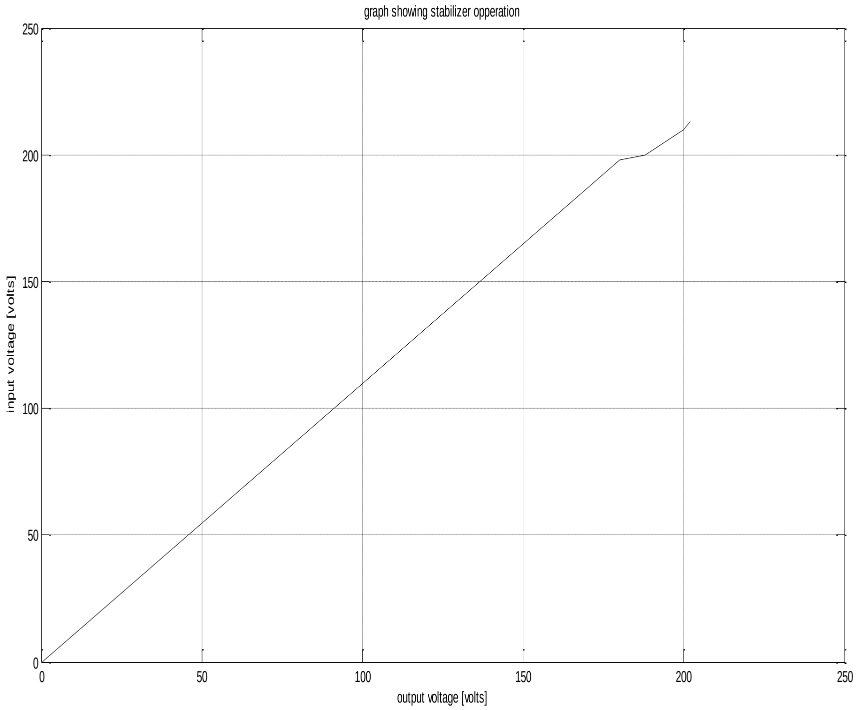

Fig. 9: Input/Output Characteristic Graph of the Power Protector

The graph shows a nearly linear response between 180 V and 202 V, beyond which the system ceases operation at 270 V, confirming the over-voltage protection circuit's efficacy.

Additionally, the waveform of the output voltage was observed using an oscilloscope to examine the quality and stability of the regulated output.

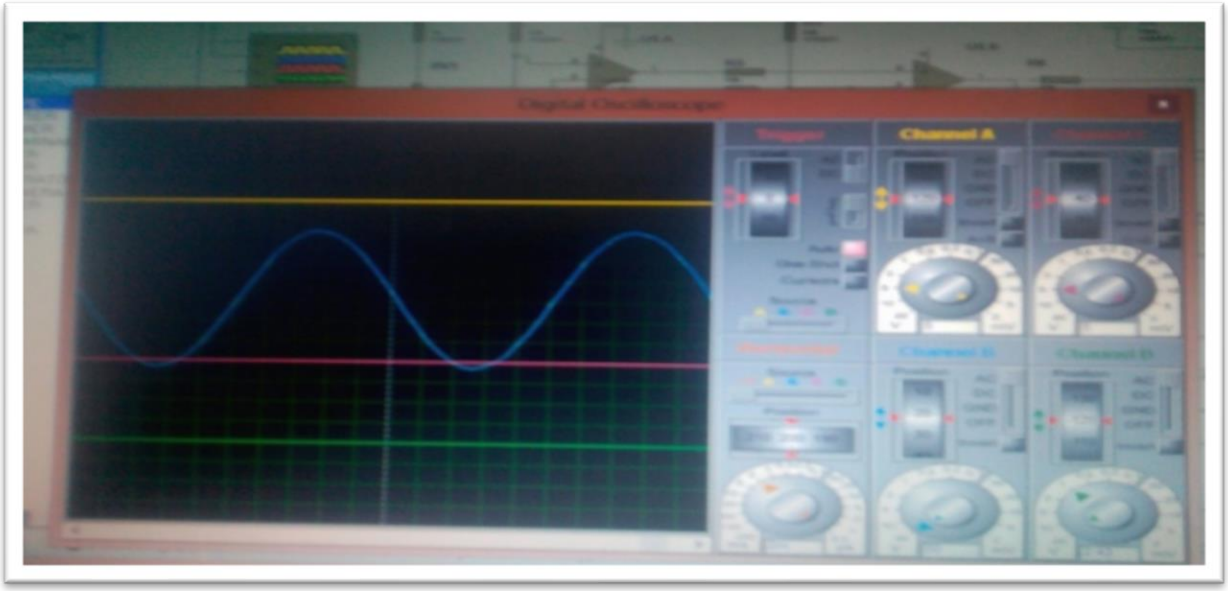

Fig.10: Oscilloscopic view of the stabilizer output

The waveform indicates a consistent and smooth output signal, which confirms that the system delivers stable voltage without significant fluctuations or harmonic distortion. Such output characteristics are vital for the safe operation of electronic appliances, especially those sensitive to waveform distortion.

4.8 Discussion and Implications

The integration of low voltage amplification, high voltage regulation, and over-voltage shutdown ensures that the Power Protection System provides all-round protection. The voltage stabilization characteristics shown by the graphical and oscilloscopic results affirm the system's real-time adaptability to input voltage fluctuations. The implication of these results is that users in low-power quality environments can confidently rely on this system to protect electronic assets.

Moreover, the continuity, open, and short-circuit tests confirm not just operational performance but also structural integrity and durability. The design demonstrates compliance with safety standards and supports ease of deployment in residential, commercial, or light industrial settings.

In summary, the comprehensive test results validate the overall design objectives. Each phase of the test provides clear evidence that the system can regulate, stabilize, and protect against harmful power anomalies, offering a reliable solution to power fluctuation challenges in developing regions.

5.0 Conclusion

Due to the challenges of unstable power supply in our country, the need for a stabilizer can never be overemphasized. This research is a solution to low voltage, high voltage and over voltage conditions in Nigeria. This design is more efficient, reliable and cheaper compared to its equivalent in the market.

In this research, we developed an effective strategy for minimizing volatility. The IoT-based method is used here which combines the concept of a microcontroller-based technology along with wireless monitoring application.

It is concluded that using IoT-based microcontroller-based method is the most optimal and least harmful method to run the stabilizer while maintaining an optimal temperature optimally.

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

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Authors' Contribution

Okoro Gladys Ihuoma and Nnochiri Ifeoma U. designed and implemented an IoT-based microcontroller voltage stabilizer. Their contribution lies in creating a reliable, cost-effective, and efficient solution for Nigeria's unstable power supply, enabling automatic voltage correction and real-time wireless monitoring for enhanced power protection.