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DESIGN AND DEVELOPMENT OF AN AUTOMATIC VOLTAGE STABILISER: AN EFFECTIVE APPROACH TO POWER STABILIZATION IN NIGERIA

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Abstract:
Voltage fluctuations in power distribution networks pose significant risks to domestic and commercial electrical equipment. This paper presents the design, construction, and experimental evaluation of a relay-based automatic voltage stabilizer that employs microcontroller-controlled transformer tap switching. The proposed system is rated at 5 kVA, operates at 50 Hz, and is designed to regulate input voltages ranging from 100 V to 250 V. The main components of the stabilizer include an autotransformer with multiple taps, voltage-sensing circuitry, relay switching units, and an Arduino microcontroller. The control algorithm continuously monitors the input voltage and selects the appropriate transformer taps to maintain a stable output voltage while protecting against overvoltage, undervoltage, and surge conditions. Experimental results demonstrate that increasing the number of transformer tapings significantly improves regulation accuracy and output stability. The developed prototype maintained an output voltage close to 220 V under varying load and input conditions, confirming its effectiveness as a cost-efficient and reliable voltage regulation solution.

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ey words: Automatic voltage stabilizer, relay-based tap changing, autotransformer, voltage regulation.

I. Introduction

In today's modern world, there is an increased need for and usage of various electrical and electronic devices for different purposes. Some are needed for the purpose of entertainment, and some for certain critical needs, as the case may be. The protection of such devices against varying electrical voltages is very important to the actualization of their purpose. Several factors account for the changes in voltage levels at different times. For instance, factors emanating from power supply generating equipment, faulty conditions, poor maintenance culture, surges as a result of lightning, electrical partial connections causing sparking and many others are responsible for the various electrical faulty conditions at homes (Fabiyi *et al,* 2018). Home used gadgets are designed to be used at a certain safe voltage level, depending on the country of usage. When the voltage level is too low, it makes the electronic devices work below their optimal point, and when too high, such devices are not safe for usage. In a bid to protect our electrical/electronic devices from both undervoltage and overvoltage faulty conditions, an automatic voltage regulator that operates within the range of usage was designed as a protective device to safeguard the connected load from damage by providing a constant voltage at any point in time when the input voltage varies (Ludin et al 2021). An automatic voltage stabilizer is essential in every home to protect electronic devices from unsafe, varying input power supply conditions.

Voltage surges, spikes and transients in excess of kilovolts, overvoltage, are the most common faults that lead to power equipment malfunction. These faults are largely due to the chaotic and problem-prone infrastructure of the Nigerian power generation sector. Willoughby A.A. et. al, (2014) in their research established that irreparable damages such as extremely high (>280V), low (< 160V) or unstable and noisy fluctuating mains supplies have caused permanent damage to a huge number of domestic and industrial appliances. High frequency interface, improper earthing are high contributors to unstable power supply. It is worth knowing that exposures to natural climatic conditions and disturbances like lightning have resulted in voltage spikes, which are common in the Nigerian power infrastructure (Willoughby A.A. et. al, 2014).

This paper aims to develop an automatic voltage stabilizer that will deliver a stable voltage suitable for most power appliances. It will operate within a voltage range of 100VAC to 250VAC, with an operating frequency of 50Hz and with the ability to deliver stable voltage and currents required for various electrical appliances. The design will incorporate an Arduino microcontroller, an Autotransformer for voltage tapping, also a design will incorporate a variable resistor for input voltage sensing. Switching between the transformer terminals will require an electromechanical relay connected to the autotransformer tapings, and the Transistors serve as a driver to the relay.

The research developed in this study details the design, development and implementation of an automatic voltage stabilizer for commercial and household use, utilizing a relay-type topology due to its simplicity, robustness, and cost-effectiveness in power applications.

II. Literature Review

Vikash, K *etal (*2025) designed, developed and implemented a 0.5kva relay-based automatic voltage regulator integrated with a bulk boost transformer to regulate the output voltage within desired limits. The performance evaluation showed that the proposed stabilizers effectively maintain output voltage within + -5% of the nominal voltage over a wide range of input voltage, ensuring safety and reliability for connected loads.

According to Ponnle, A. and Olajide, M, M.B. (2019), a wide input range between 30V and 240V stabilizer was developed and implemented for low voltage residential areas in Nigeria. The relay-type stabilizer adopted an input switching methodology in its operation with seven taps at the primary side of the autotransformer with a common output in all. It was noted that a lower input voltage range can be achieved with an input switching type, thereby having an advantage over output switching relay type stabilizers. However, the developed system lacked surge protective capabilities making it unsafe in an environment where surges is prevalent.

A microcontroller-based 5KVA Automatic stabilizer was implemented by Ofualagba, G. and Igbinoba, C. (2017) using a PIC16F877A microprocessor with an 80V-250V input range. The design included an under/over voltage device protection, which ensures that the device is inoperative when the supply voltage is above 250VAC. At voltages within the specific input voltage range, the stabilizer gave an output voltage of 220 VAC (±6%), but at voltages outside the specified input range, the over/under voltage protection prevents power from being supplied to the auto-transformer, thus making the stabilizer output 0 V. The implemented stabilizer monitored an input AC voltage range between 80V and 250V, but lacked the surge protective capability.

In a related development, another 7KVA voltage stabilizer using ATMEGA328 microcontroller was implemented by Ramraj, B *et.al.* (2021). In the framework, a variable tapping transformer, voltage sensor, current sensor, current sensor, relays and lightning detector were major components utilized in the design. The input voltage range was between 120V and 250V. The implemented system was first designed using Proteus 7.10 before practical demonstration. A steady output voltage of 225V was realized during testing. A program-based stabilizer is less maintenance free but in case of unusual error, it can be difficult for unprofessional personnel to maintain; thus, maintainability can pose a great challenge.

Chaudhary *et al* (2023) designed and fabricated a 1KVA, 190V-250V input voltage range with a constant output of 220V automatic voltage stabilizer using relay-based tap changing of the transformer. The implemented system utilized an Arduino microcontroller, a voltage sensor, a relay board and an autotransformer with fourteen (14) tapings as major components. The result showed that when tested in fourteen tapings, provided significant improvement in the control of the voltage level which was not obtained using fewer tapings. There was a greater level of precision and control over the output voltage. The fourteen tapings provided a wider range of voltage adjustments, allowing for finer control over the output voltage, which led to improved accuracy and maintained the desired output voltage level. The implemented system does not incorporate a surge protector in its design, and the input range is not wide enough to accommodate a much lower input voltage.

Hnin Hnin, A (2018) designed and constructed a 7KVA single-phase control system for an Automatic Voltage Stabilizer within a 120V to 250V fluctuating input range. In the work, a toroidal-type variable autotransformer was used for the regulating unit, and an electronic control circuit was used for the sensing unit. It was noted that if the input voltage is lower than 120V or higher than 250V, the system will be automatically shut down. This automatic voltage stabilizer was very suitable and economical for all electrical equipment, but surge protection devices were not incorporated in the design, and the input voltage range was not wide enough.

III. Methodology

The methodology for stabilizer design and construction involves systematic steps to ensure efficiency, durability, and reliability. First, the power requirements and load capacity are determined through analysis of input voltage fluctuations and output stability needs. Next, appropriate circuit components—such as transformers, relays, voltage regulators, and control units—are selected based on design specifications. A circuit diagram is developed and simulated to verify performance. After the simulation, the stabilizer is constructed on a suitable chassis, ensuring proper wiring, insulation, and cooling. The assembled unit is then tested under variable load and voltage conditions to evaluate regulation accuracy, response time, and overall stability. An AVR regulates voltage by sensing the output voltage and comparing it to a reference value. When the output voltage deviates from the desired level, the AVR adjusts the excitation of the generator or transformer to restore the voltage to its set point.

Key Components:

i. Sensing Circuit – Measures the output voltage

ii. Control Circuit – Compares output voltage to reference voltage

iii. Amplifier – Strengthens the error signal

iv. Actuator – Adjusts the excitation

v. Voltage Reference – Provides the desired voltage level.

This study uses semiconductor devices like diodes, transistors, relays, etc., for its control and tap switching methodology. It is designed for a band-pass voltage of 100 volts to 250 volts, with a Cut-off voltage of 251 volts and above (voltage surge) and 99 volts and below (voltage sag). The Automatic Voltage Stabilizer system is designed to comprise three major sections. These sections include the transformer design phase, sensing of the input and output AC voltages, and relay logic for transformer tap changing. The block diagram of the system is shown in Figures 1& 2

Block Diagram Representation

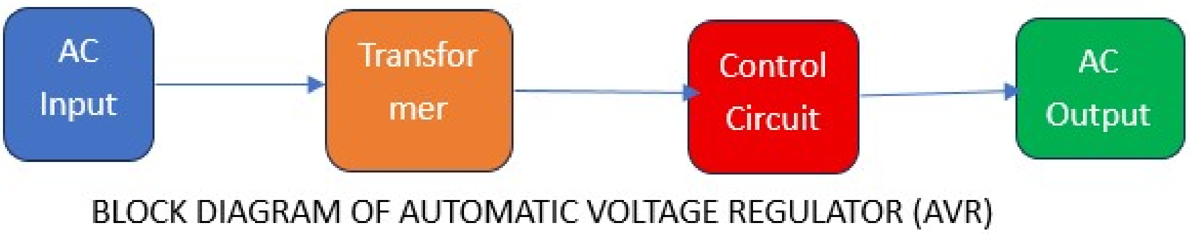


Figure 1: Design Block Diagram

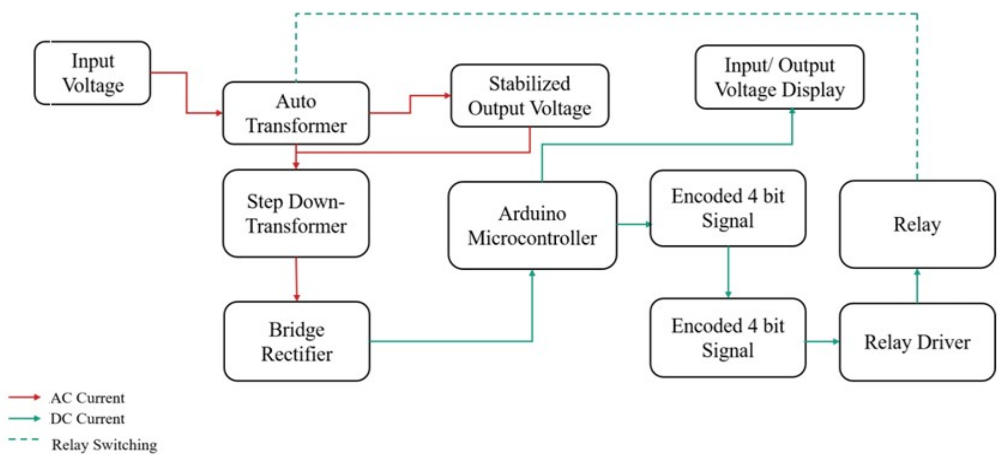


Figure 2: Detailed Block diagram

Design theory:

The AC Input Supply – Receives fluctuating mains or surge voltage and the sensing unit detects input voltage level. The Control Circuit – Compares the input voltage with reference voltage and triggers error correction by Voltage Regulating Unit which adjusts the output voltage via transformer tapping. The output voltage remains stable or cut-ff for the load.

Transformer Design for Stabilizer

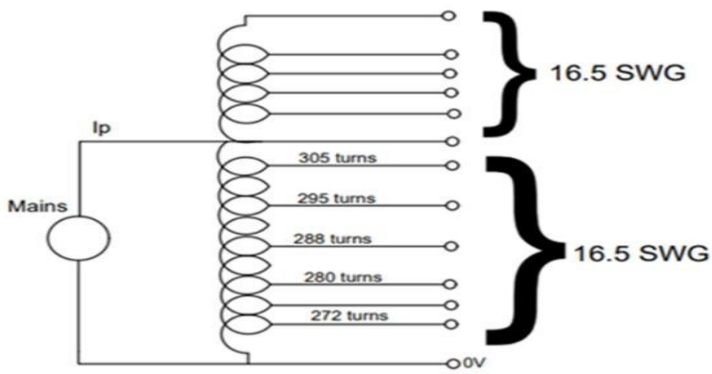
Design of Autotransformer: The autotransformer used in this experimentation was designed with a capacity of 5kVA and 14 tapings. The transformer was intended to operate in a frequency of 50Hz, and the input voltage range was between 100V to 250V. The autotransformer was constructed using high-quality materials and was tested to ensure it met the required specifications. To obtain different voltage ratios, the tapings on the autotransformer were adjusted accordingly.

The transformer is the core component of a voltage stabilizer. It is responsible for regulating and maintaining a constant output voltage despite input fluctuations. The design begins with determining the **input voltage range, desired output voltage,** and **load capacity (kVA or watt rating)**. Based on these parameters, the **turns ratio** is calculated to provide proper voltage correction (auto-transformer operations).

A ferrite or laminated iron core is used for efficient magnetic flux and minimal losses. **Copper or aluminum windings** are then designed according to current requirements, ensuring adequate wire gauge and insulation. **Tapping points** are incorporated in the secondary winding for voltage adjustment. Finally, the transformer is enclosed in a ventilated casing with proper cooling and tested for efficiency, voltage regulation, and thermal stability.

Transformer Calculations:
Parameters of Autotransformer Designed
S.N. Parameters Values

i. Calculated voltage per turn 0.72 V/turns
ii. Maximum magnetic flux in the Core 0.003243 Wb
iii. Cross Sectional Area 3621 mm2
iv. Magnetic Field Strength of Transformer 8.9 x 10-4 T
v. Net Window Area 1900 mm2
vi. Number o
vii. Minimum
viii. Ma
ix. Primary W
x. Secondary
xi. SWG for I
xii. SWG for S



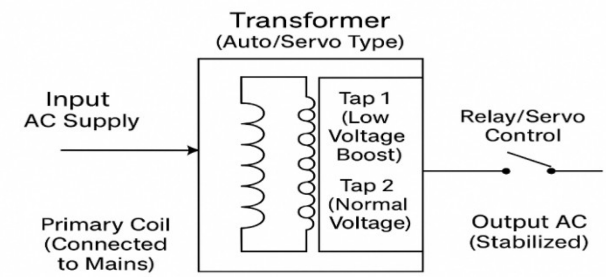


Figure 3: transformer design representation

1. Turns per Volt (TPV): $TPV = \frac{1}{4.44 \times f \times B_{max} \times A}$

Where: f = frequency in hertz (Hz), typically **50 Hz**

$B\,Max =$ maximum flux density in tesla \\\(T \\\),usually **1–1.2 T** for silicon steel

A = core cross-sectional area in square meters (m^2)

If your area is in cm^2, use: $TPV = \frac{1}{4.44 \times f \times B_{max} \times A \times 10^{-4}}$

Approximate form: $TPV \approx \frac{1}{B_{max} \times A_{cm^2} \times 0.00044 \times f}$

i. Number of Turns

Primary winding: $NP = TPV \times V_{primary}$

Secondary winding: $NS = TPV \times V_{secondary}$ ♦

3. Core Area (approximation): $A_{cm^2} = 1.152 \times \sqrt{Output\ \ Power\ \ \backslash\backslash\backslash(\ VA\ \backslash\backslash\backslash)}$

VA = transformer output power in volt-amps

4. Wire Size (Current Capacity)

You can estimate the wire cross-section area (mm^2) from the current: $A_{wire} = \frac{I}{3}$

or for finer design, use:

Copper wire current density = 2.5 to 3.5 A/mm^2

Aluminum wire = 1.5 to 2.5 A/mm^2

Then pick a wire gauge (SWG or AWG) close to that area.

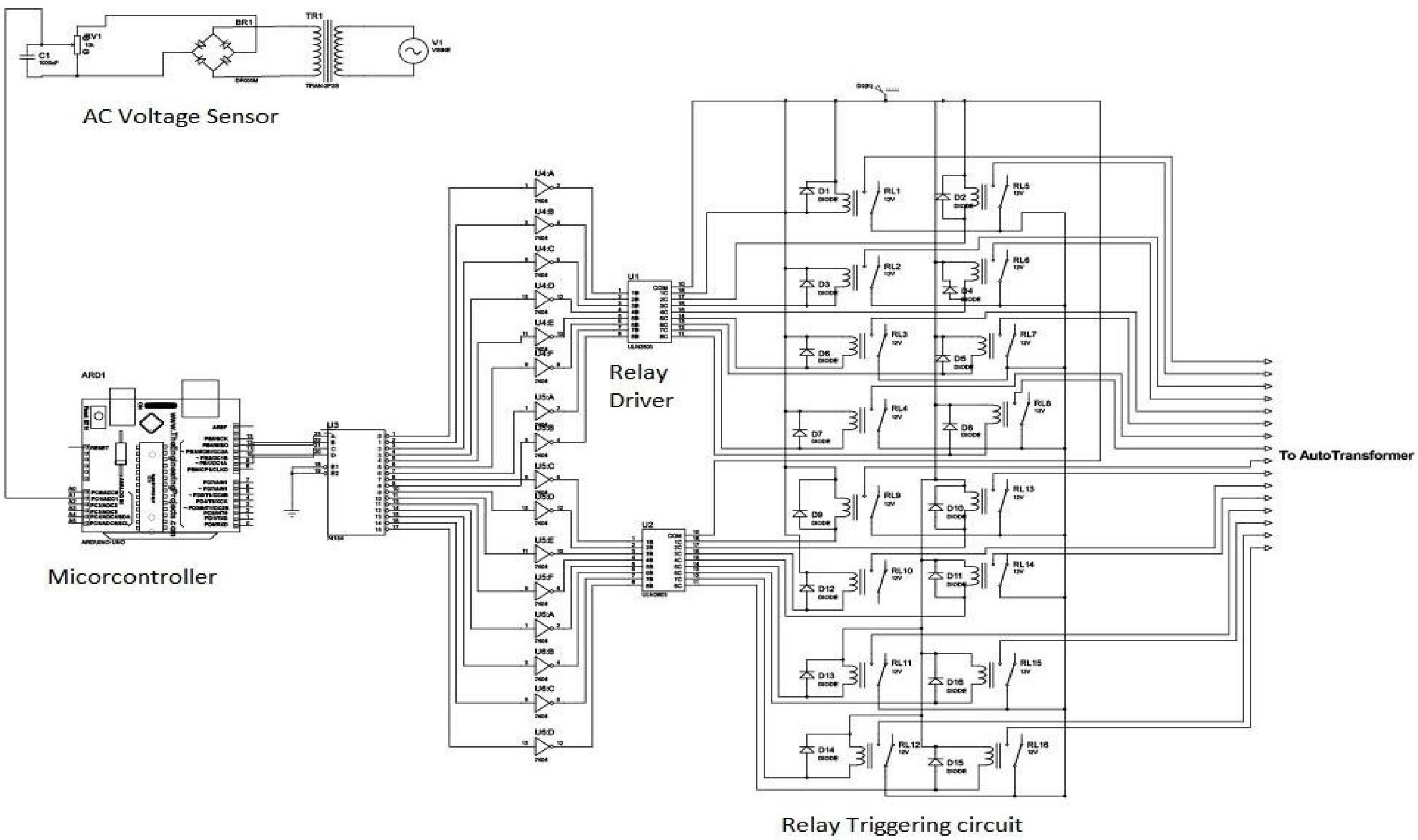


Figure 4: Circuit Diagram

IV. Design of Control Unit

The source voltage was first stepped down with a step-down transformer or potential transformer, and then rectified into a DC signal. The DC signal was conditioned to get a better signal using a capacitor and fed into the microcontroller. To filter any harmonics and protect the circuit, a capacitor rated at 1000 μF was added in parallel to the DC signal.
The DC signal is sent to the regulator to calibrate the input voltage, thus sensing and controlling the relay. The output from the comparator signals which were then demultiplexed to trigger the relay switches. The tapping of the transformer was then changed to achieve a stabilized output. The system was fabricated using an autotransformer with 14 tapings. The voltage difference between two adjacent tapings was 4 volts, providing precision to the system. The primary winding of the transformer was connected to the input voltage source and the input voltage measuring potential transformer. The voltage from the input potential transformer was conditioned and fed into the Arduino microcontroller. The secondary tapings of the transformer were connected to individual relays and the load, with the circuit designed to turn one relay on and turn all other relays off. The switching of the relay was controlled from the Arduino microcontroller through the demultiplexing of binary-coded signals generated from the Arduino.

The **Automatic Voltage Regulator (AVR)** operates in several key stages to ensure a stable output voltage regardless of load or input fluctuations. Here are the typical **stages of operation in an AVR**:

Voltage Sensing

The AVR continuously monitors the output voltage of the system. A voltage divider or sensor is used to scale down the voltage for processing. This sensed voltage is fed into a comparator or control unit.

Reference Comparison

The sensed voltage is compared with a preset reference voltage (usually from a zener diode, voltage reference IC, or microcontroller). The difference between the sensed voltage and reference voltage (called the error signal) determines whether adjustment is needed.

Error Amplification

The error signal is amplified using an operational amplifier. The amplified error is used to drive the controlling mechanism of the AVR.

Voltage Regulation/Correction

Based on the error signal, the AVR adjusts the voltage using tap changing in transformers and Power electronic circuits. This corrects the output to bring it back within acceptable limits.

Feedback and Stabilization

The corrected voltage is fed back into the sensing circuit for continuous monitoring. The loop repeats in real time to maintain a stable output voltage.

V. Results and Discussion

The performance of the developed automatic voltage regulator (AVR) was experimentally evaluated under varying input voltage conditions to assess voltage regulation accuracy, stability, and protection response. The system was tested using different numbers of relay-controlled transformer tapings, and the measured input–output voltage responses are presented in **Fig. 6–Fig. 9** and summarized in **Table I**.

Table 1: Stabilizer Response with four taping and fourteen taping comparisons

		Output Voltage	
S.N.	**Input Voltage**	**Six Relay**	**12 Relay**
0	90	0	0
1	190	221	220.87
2	194	226	220.67
3	196	213	220.9
4	200	217	220.15
5	205	221	221
6	220	220	220.08
7	225	225	220.34
8	230	218	221.32
9	235	223	220.87
10	240	227	220.56
11	245	218	221.32
12	250	220	223
13	251	0	0

Performance with Six Tapings

The voltage regulation characteristics of the AVR when configured with six transformer tapings are illustrated in figure **6**. Due to the limited number of tap positions, the correction step size was relatively large, resulting in coarse voltage regulation. As shown in **Table I**, the output voltage varied significantly with changes in the input voltage, with regulated values ranging approximately from 100 V to 230 V. This level of fluctuation indicates reduced regulation accuracy and limited control resolution, making the system less effective for maintaining a stable nominal output voltage under wide input variations.

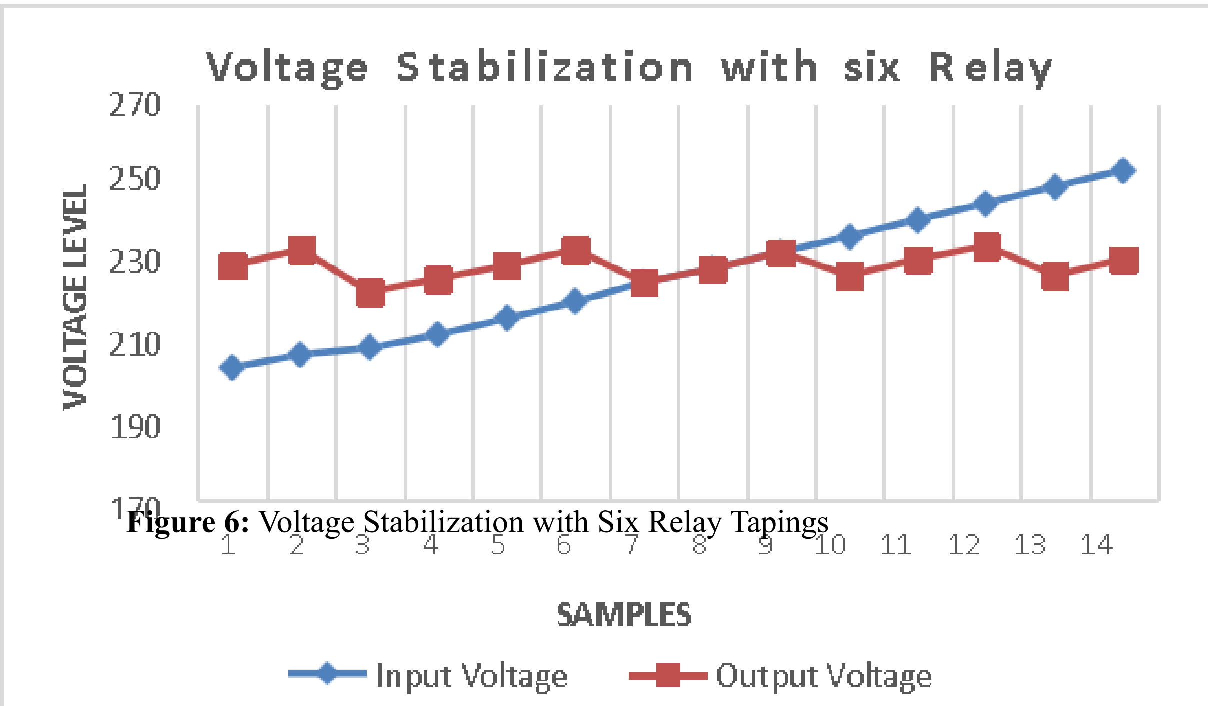
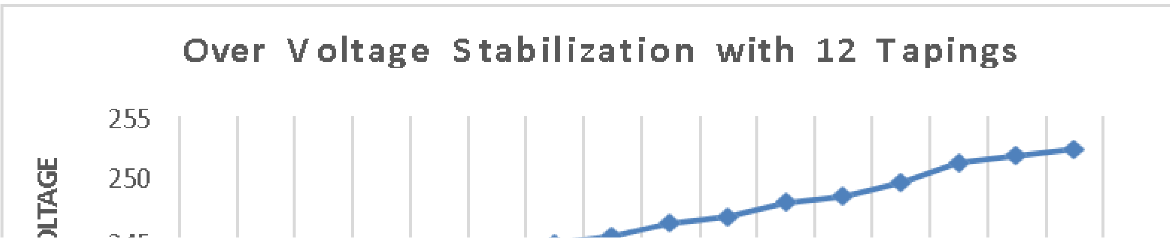


Figure 6: Voltage Stabilization with Six Relay Tapings

Performance with Twelve and Fourteen Tapings

Increasing the number of transformer tapings to twelve and fourteen Improved voltage regulation. The output voltage responses under over-voltage and under-voltage conditions are presented in **Fig. 7** and **Fig. 8**, respectively. As summarized in **Table I**, the output voltage was consistently maintained within a narrow range of approximately 220–221 V across the specified input voltage range. The finer tap resolution enabled more precise voltage correction, significantly reducing output deviations and improving overall stability compared to the six-tap configuration.



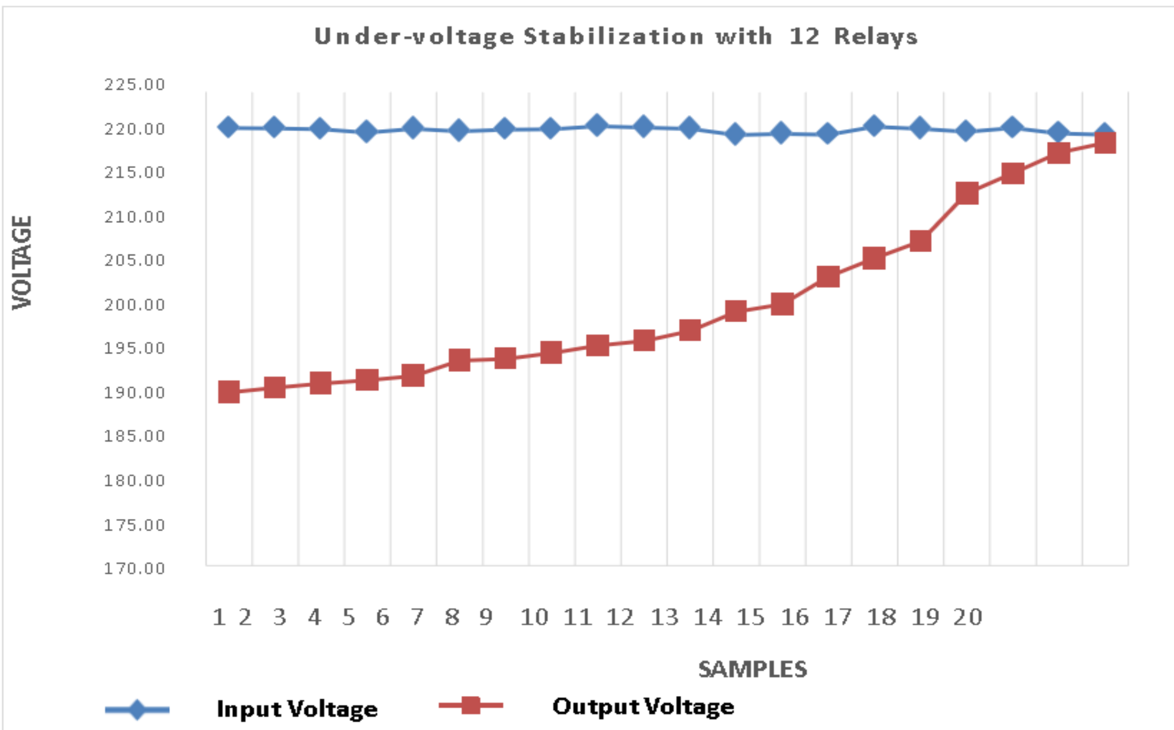


Figure 8: Over Voltage Stabilization with fourteen relays

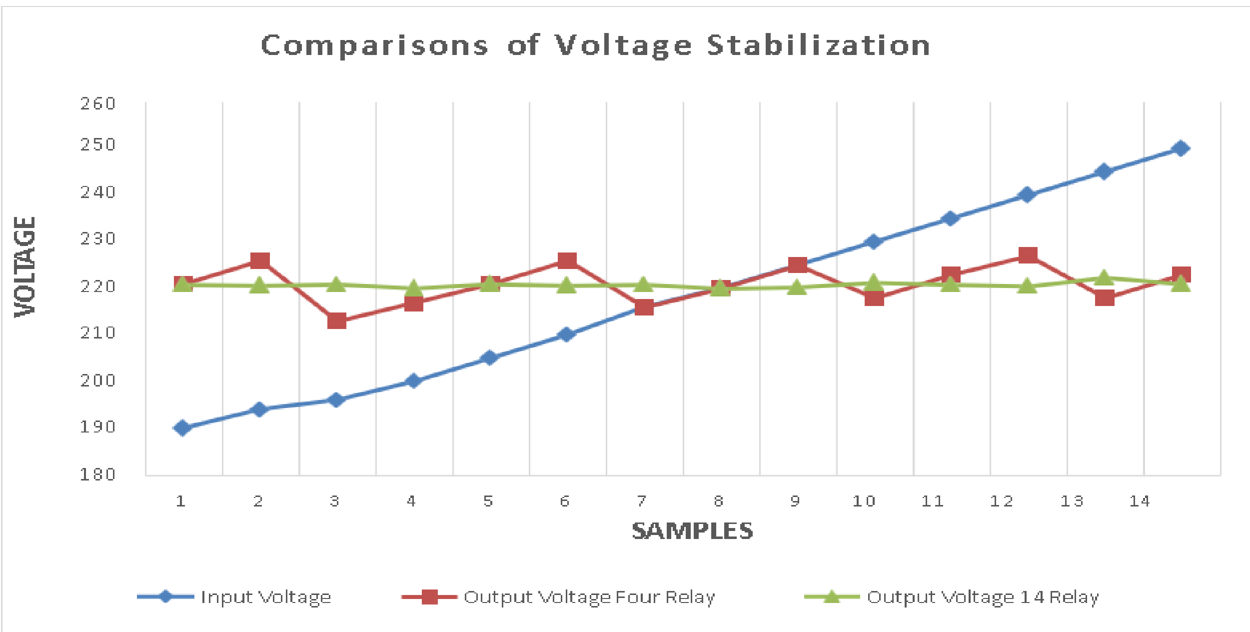
Over-Voltage and Under-Voltage Protection

The protective response of the AVR during abnormal operating conditions is also documented in **Table I**. When the input voltage exceeded 250 V or dropped below 99 V, the system automatically disconnected the load, resulting in zero output voltage. This behavior confirms the effectiveness of the implemented over-voltage and under-voltage protection mechanisms in preventing damage to connected loads during severe voltage disturbances.

Comparative Analysis

A comparative evaluation of the stabilizer performance with six or higher numbers of tapings is presented in **Fig. 9**. The results clearly indicate that systems employing twelve or more tapings exhibit superior voltage regulation accuracy, reduced voltage ripple, and improved response consistency. The comparison validates the design approach of increasing tap resolution to enhance voltage regulation performance in relay-based AVR systems.

Overall, the experimental results demonstrate that the proposed microcontroller-controlled tap-changing AVR delivers reliable voltage regulation and effective protection, making it suitable for domestic and commercial applications in unstable low-voltage distribution networks.



voltage protection, under-voltage protection, overload protection, and short-circuit protection.

The use of twelve or more tapings in the system has been experimentally verified to provide better control, accuracy, and stability compared to a system using six or fewer tapings. The results demonstrate the feasibility of this system as an economical and effective way to ensure consistent and stabilized voltage in a range of 100-250V.

References

Ali M. N, Soliman M; Mahmoud K; Guerrero J. M; Lehtonen M.; And Darwish M. F (2021), Resilient Design of Robust Multi-Objectives Pid Controllers for Automatic Voltage Regulators: D-Decomposition Approach, *Digital Object Identifier 10.1109/ACCESS.2021.3100415*

Ali, T.; Malik, S.A.; Hameed, I.A.; Daraz, A.; Mujlid, H.; Azar, A.T. Load Frequency Control and Automatic Voltage Regulation in a Multi-Area Interconnected Power System Using Nature-Inspired Computation-Based Control Methodology. Sustainability **2022**, 14, 12162. https://doi.org/10.3390/su141912162

Chaudhary, C; Kshetr, I A; Shresth, A; Bista, A and Bista, D (2023). "Design and Fabrication of Automatic Voltage Stabilizer using Relay-Based Tap Changing of Transformer" Journal of Physics Conference Series, November 2023. DOI: 10.1088/1742-6596/2629/1/012023

Hamidah I, Ramadhan D. F, Mustagisin I, Sriyono, Abdullah A. G, Solehudin A, (2020), The Performance Comparison Between Commercial Automatic Voltage Stabilizer and Programmable Automatic Voltage Stabilizer, Journal of Engineering Science and Technology Vol. 15, No. 2 1011 - 1017

Hnin Hnin Aye (2018), "Design and Construction of Control System for Automatic Voltage Stabilizer", International Journal of Trend in Scientific Research and Development (IJTSRD). ISSN NO: 2456-6470, Vol 3, Issue 1, NOV-DEC 2018.

Ludin, L; Derick, J; Jeswin, P; Fathmathul, Z and Sebin, Davis (2021)." Design and Evaluation of Voltage Control using Static Stabilizer" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol 10 Issue 06, June 2021.

Noco´ n; Paszek, S., (2023), A Comprehensive Review of Power System Stabilizers, Energies 2023, 16, 1945. https://doi.org/10.3390/en16041945

Ofualagba G and Igbinoba (2017), "Implementation of a Microcontroller-Based 5 KVA Automatic Voltage Stabilizer", International Journal of Latest Research in Engineering and Technology (IJLRET) ISSN: 2454-5031, Volume 03 - Issue 06, June 2017, PP. 01-08.

Ponle A and Olajide M (2019)," Development of a wide Input Range Automatic AC voltage stabilizer for Low Voltage Residential Areas in Nigeria". Journal of Multidisciplinary Engineering Science Studies (JMESS), Vol 5, Issue 2, February, 2019.

Ramraj, B; Nareshkumar, E; Rajkumar, K and Vijaykumar (2021), "Design of Automatic Smart Voltage Stabilizer for Domestic Loads" IJSART, Volume 7, Issue 3, March 2021. ISSN(ONLINE) 2395-1052

Vikash, K; Satyam, T; Sarvesh, Y, Piyush, K; Praval, M (2025), "0.5 KVA Automatic Stabilizer: Design, Implementation, and Performance Analysis", IJARIIE-ISSN (0) - 2395-4396, IJAR11E, Vol-11 Issue-3 2025.