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Design and Development of a Microcontroller-Based Triple Action Automatic Voltage Stabilizer (AVS) for Reliable Power Stabilization in Nigeria

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Abstract:

This paper presents the design and development of a microcontroller-based triple action automatic voltage stabilizer (AVS) for reliable power stabilization in Nigeria. The system is designed to provide stable output voltage, protect against voltage surges, and prevent damage from overloading, high voltage, and low voltage conditions. The AVS employs the AVR microcontroller, ATMEGA328P to monitor the input voltage and control the output voltage using power relays, ensuring a stable 220V AC output. The system features a triple action protection mechanism, which includes voltage stabilization, surge protection, and overload cutoff, as well as high and low voltage cut off. The system's performance was evaluated under various load conditions, demonstrating its ability to stabilize output voltage within ±5% of the nominal value, protect against voltage surges, and prevent damage from overloading and abnormal voltage conditions.

Key Words: Automatic Voltage Stabilizer, Microcontroller, Triple action, voltage surges, stabilization

I. Introduction

The increasing demand for reliable power supply in Nigeria has necessitated the development of efficient and effective power stabilization systems. Nigeria's power distribution network is characterized by voltage fluctuations and power surges , which can cause damage to electrical and electronic equipment, leading to significant economic losses and inconvenience to consumers (Adeyemo, 2018). Automatic Voltage Stabilizers (AVS) are designed to regulate voltage levels and provide a stable output voltage, protecting equipment from voltage fluctuations and surges.

The traditional AVS systems have limitations, including slow response time, limited accuracy, and lack of protection against surges and overloading (Kumar, 2017). To address these limitations, microcontroller-based AVS systems have been developed, offering improved performance, reliability, and flexibility (Rahman, 2019). However, these systems often focus on voltage stabilization alone, neglecting other important aspects of power quality, such as surge protection and overload protection.

This project presents the design and development of a microcontroller-based triple action AVS that provides voltage stabilization, surge protection, overload cutoff, and high and low voltage cut off. The system is designed to provide a stable 220V AC output, protecting equipment from voltage fluctuations, surges, and overloading.

II Related Works / Literature Review

The Nigerian Electricity Regulatory Commission reported that the power system stability indicator has fallen short of the accepted regulatory threshold, resulting in grid voltage fluctuations outside the acceptable range (Jimoh, M. A., & Raji, B. (2023). The economic burden of relying heavily on diesel and gasoline generators after the removal of fuel subsidy has made these alternatives unaffordable for so many small businesses. Sensitive electronics equipment is not immune to voltage spikes, power surges and low input voltage. The Nigerian power scenario is anything but smooth. Most power equipment malfunctions due to Voltage surges, spikes and transients in excess of kilovolts, overvoltage. Irreparable damages such as excessively high (>280V), low (< 160V) or unstable and noisy fluctuating mains supplies have caused irreparable damage to a huge number of domestic and industrial appliances (Willoughby A.A. et. al, 2014). It was reported that high-frequency interference and improper earthing have contributed to unstable power supply. Most power infrastructures in Nigeria are exposed to natural climatic disturbances like lightning, resulting in voltage spikes (Willoughby A.A. et. al, 2014).

Automatic voltage stabilizers (AVS) are essential for the protection of various industrial and domestic equipment from these power variations. The automatic voltage stabilizer regulates the input voltage by tap changing the step-up transformer winding to a suitable voltage. As the input voltage reduces, the sensing circuit of the stabilizer switches between the relays connected to different transformer windings to select the most suitable voltage and vice versa.

The triple-action microcontroller-based automatic voltage stabilizer designed and developed in this research will have an input voltage of 80V and 250V output. Other features include its overvoltage and undervoltage protection, voltage surge protection and stable output voltage of 220V±5%. For precision and durability of the system, microcontroller was introduced. The embedded system hardware functions as an electronics controller that helps to control the input and output voltage on the voltage stabilizer. The microcontroller actions are guided by the program, hence maintaining proper precision on the input and output voltage conditions (Hamidah I, et. al 2020).

The objective of this research is to develop an automatic voltage stabilizer that handles all input and output conditions, like a lower threshold for input voltage, power surge protection, and overload protection, low voltage, high voltage cutoff, while maintaining the required voltage of 220V at a frequency of 50Hz.

Aye H, H developed a control circuit for an automatic voltage stabiliser. The system compared the instantaneous input and output voltage. The electronic control circuit operated within the fluctuation range of 120V to 250V. The rating of the automatic voltage stabilizer was 7 kVA (single-phase), and its frequency range was 50Hz. The system produced an output sensitivity of ±%. The system will automatically shut down at an input voltage of 120V or an output voltage of 250V.

Ponnle and Olajide (2019) developed a 500VA ARS designed for extremely low voltages of 30V to 240V input voltage. The switching system employed is input switching, in which the autotransformer taps are switched at the input. The design used a 12 V rechargeable battery to power the control unit at 'switch-on' and when the input mains voltage is very low. They include a Delay function to delay the mains voltage from getting to the autotransformer for 24 seconds at 'switch-on' and also to prevent it from damage under abnormal high input voltages. The performance and results achieved during testing of the developed stabilizer were better than existing commercial stabilizers in the Nigeria market. However, this design is limited to a small load when compared to the design in this study, which handles larger voltages and currents and has wider applications.

G. Ofualagba and C.K. Igbinoba developed a microcontroller-based 5KVA AVS using a PIC16F877A microcontroller to monitor the input voltage. if voltage level is between 80 VAC and 250VAC, it gives a constant output voltage of 220VAC (±6%) required by the appliance. The design also constantly varies the turn's ratio of the Auto-transformer, initiating a step-up or step-down operation of the transformer so that a regulated voltage of 220 VAC (±6%) was obtained at the stabilizer output. The design also included an under/over voltage device protection, which ensured that the device is inoperative when the supply voltage is above 250VAC. The critical issue of surge protection of appliances was not addressed in this design when compared to the design in this proposed study.

A 0.5kVA relay-based automatic voltage regulator integrated with a bulk boost transformer to regulate the output voltage within desired limits was developed by Vikash, K *etal (*2025). The study performed an evaluation, which indicated 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.

Aye H H designed and developed a control circuit for automatic voltage stabilizers that compares the instantaneous input and output voltage. The system consisted of two units: the measuring unit and the regulating unit. A toroidal-type variable auto transformer was used for the regulating unit, and an electronic control circuit was used for the sensing unit. The additional features like surge control and overvoltage protection, were not included in this design, making it an obsolete design

According to Ramraj, B *et.al.* (2021), they developed a voltage stabilizer using an ATMEGA328 microcontroller. The design framework included a variable taping transformer, voltage sensor, current sensor, current sensor, voltage relays and lightning detector. The input voltage range was between 120V and 250V. The simulated design using Proteus 7.10 and the practical demonstration achieved a constant voltage of 225V. A program-based stabilizer has fewer maintenance options in case of unusual error, can be difficult for unprofessional personnel to maintain, and thus, maintenance can be a great challenge.

In a related research, Chaudhary *et al* (2023) designed and fabricated a 1KVA, 190V-250V input voltage range with a constant output of 220V automatic voltage stabilizer design using relay-based tap changing of transformer. The system utilized an Arduino microcontroller, voltage sensor, relay board and autotransformer with fourteen (14) tapings as major components. The results from the demonstration indicated significant improvement in the control of the voltage level when using more tapings, providing a greater level of precision and control over the output voltage. More tapings provided a wider voltage adjustment range, which led to improved accuracy while maintaining the desired output voltage level. The design did not incorporate surge protection, also its input voltage of 190V did not accommodate a lower input voltage.

III. Methodology

System Design

The system consists of a power supply unit, a microcontroller unit, a voltage sensing unit, a current sensing unit, and a switching unit. The microcontroller continuously monitors the input voltage and current, and controls the output voltage using a power relays arranged in such a way that no two taps of the auto transformer will ever clash. The system also features surge protection, overload cutoff, and high and low voltage cut off.

IV. System Design and Architecture

Designing an Automatic Voltage Stabilizer (AVS) system is a multidisciplinary engineering process that combines power electronics, control systems, embedded programming, and safety engineering. In this design, the following were the system definition/specifications:

Table 1: System Definitions/Specifications

Parameter	**Descriptions**
Input Voltage Range:	80V–250V AC
Output voltage:	220V ± 5%
Load capacity:	3KVA
Features:	Overvoltage, Under voltage, Fault, and Surge Protection
Visual Feedback Mechanism:	Digital AC Voltage display.

System Architecture/Block diagram

The AVR system comprises several subsystems, which can be grouped into the following blocks as shown in Figure 3.0:

i. AC Input
ii. Voltage Sensing/Divider Module (ZMPT101B)

iii. MCU/Controller Unit (ATmega328P Micro-Controller)
iv. Relay Driver Module (ULN2003)
v. Relay Control Logic (Tap Switch)
vi. Autotransformer Design block

Figure 3.0 illustrates the functional block layout of a microcontroller-based Automatic Voltage Regulator (AVR) that uses a tap-switching autotransformer. The system accepts a wide-range mains supply, which may fluctuate outside the desired 220V level. The AC input Mains is the overall supply voltage that serve as input voltage to the DC voltage regulator used in this work, and the autotransformer. The incoming AC is sampled through a voltage sensing module (ZMPT101B) and a divider network. This provides a scaled-down, isolated signal representing the actual line voltage. The measured signal is fed to an ATmega328P, which acts as the decision-making center. It continuously monitors the mains voltage and determines the correct transformer tap to maintain a stable 220 V output. In other words, it reads the sensed voltage, compares it to preset thresholds, and decides which transformer tap is appropriate. Because the ATmega328P's output current is too small to directly energize the relays, a ULN2003 driver interfaces between the microcontroller and the power relays supplying the current and voltage necessary to actuate the relay coils. The driver activates relays which in turns select the correct tap on the autotransformer to either boost, buck, or pass the input voltage so that the output remains close to 220V. The multi-tap autotransformer performs the actual voltage adjustment based on the relay selection to keep the output near 220 V. After tap selection and transformation, a regulated AC output within the stated tolerance is delivered to the load. A small auxiliary supply provides the regulated DC power supply required for the sensing module, ATmega328P microcontroller, and relay driver circuitry.

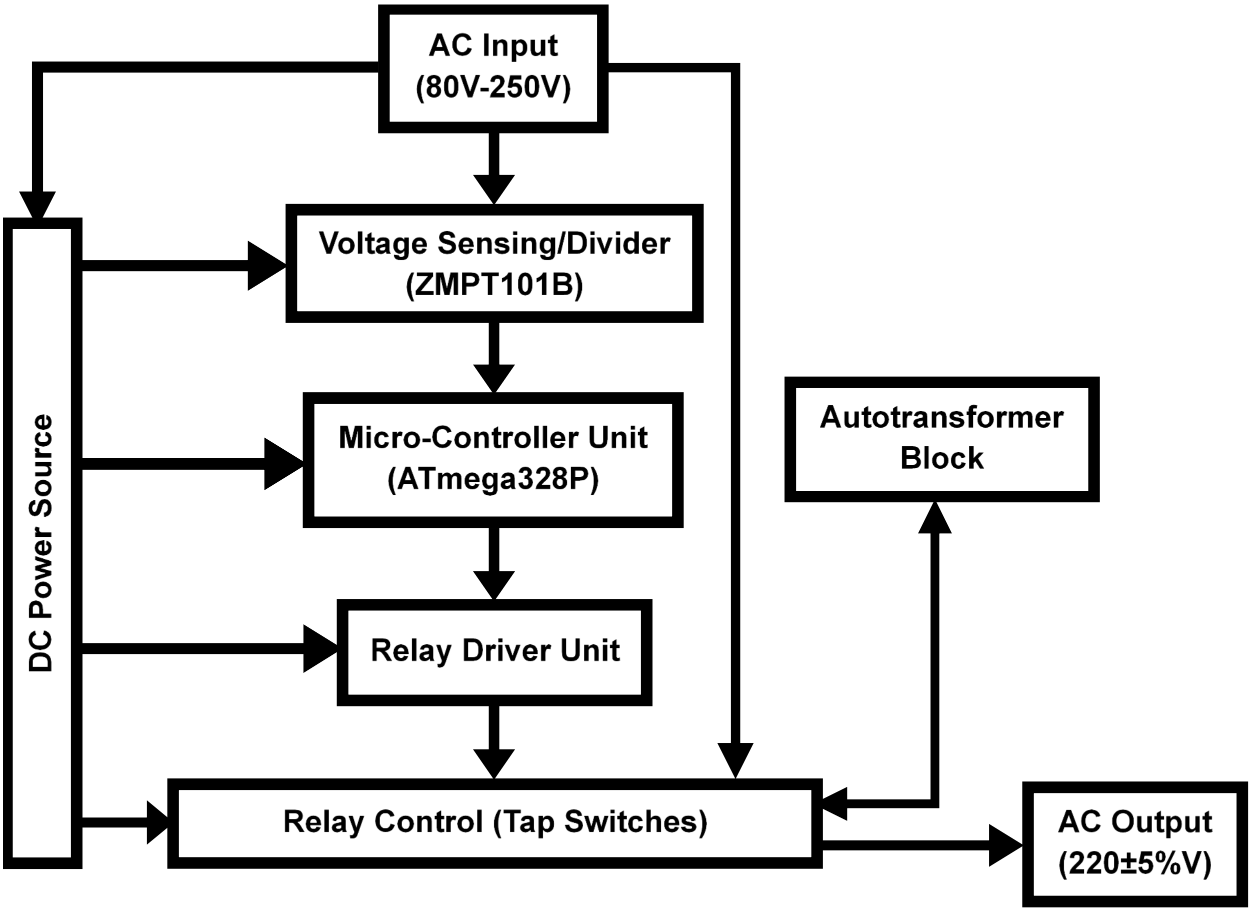
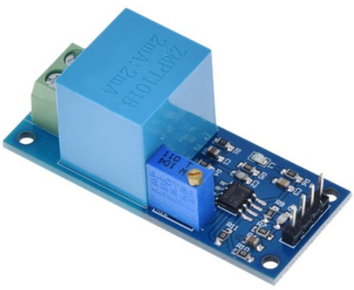


Figure 1: Block Diagram of A triple Action Gordian AVR

Voltage Sensing Unit

The ZMPT101B is a high-precision voltage sensor module that uses a voltage transformer to measure AC mains voltage. It provides a voltage signal that's proportional to the input AC voltage, which can be read by the Arduino using the ADC (analog-to-digital converter). It allows you to measure AC voltages up to 250 volts with analog output. As the input voltage changes, the output voltage of the sensor adjusts accordingly. The ZMPT101B library simplifies the process of reading true RMS voltage values from the sensor. It handles signal sampling, calibration offset, noise filtering, and RMS voltage computation. Figure 3.1 is a picture image of a typical ZMPT101B available in the market.



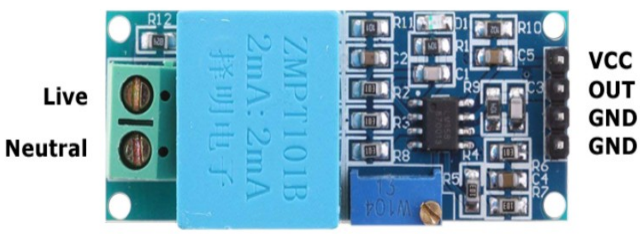


Figure 2: Pictorial View of available ZMPT101B used in this project.

It has a live and neutral pin that is connected to the AC mains, a VCC pin powered by a 5V DC circuit design, an OUT (A0) pin that is connected to the microcontroller's input pin, and two GND pin connected to the ground.

Table 2 shows the basic specification of a typical ZMPT101B module:

Table 2: ZMPT101B Specification

Max Input Voltage:	250V AC
DC Supply:	5-30V DC
Rated Input Current:	2mA
Dimensions:	50mm x 20mm
Net Weight:	20g

Figure 3.2 is a circuit design of 5V dc power supply/a signal conditioning circuit used to power the ZMPT101B voltage sensor, the microcontroller and to compliment ZMPT101B for noise and interference reduction. The circuit design comprises of an AN7805 Linear Voltage Regulator with a low pass filter circuit configuration for the purpose of filtering and noise reduction.

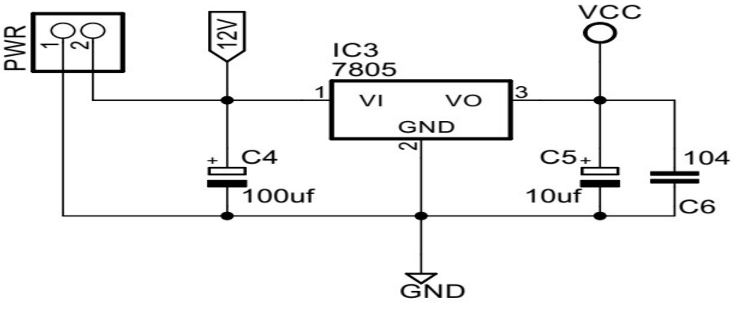


Figure 3.2: Signal Conditioning Circuit

Autotransformer Design

In the design of auto transformer, the average voltage of each input range was used as the reference for designing the transformer taps as shown in Table 3.2. The autotransformer was design using a single input multiple output approach; a situation whereby at every single input, it is expected that only one output should have a voltage value closer 220 $\mp 5\%$V, which will be selected eventually using the microcontroller – relay logic.

To divide the 100V – 250V input range into five subranges, we determine the average voltage for each range as follows:

Computing The Transformer Design Input Voltage V_{TDV}:

Input Voltage range = 100V to 250V

Where $V_{Lower}=100\,V=100\,V$; and $V_{Upper}=250\,V$

Difference in Input Voltage Range:

$V_{Diff}=V_{Lower}-V_{Upper}=(250-100)\,V=150\,V$

Midway Voltage: $V_M=\frac{V_{Diff}}{2}=\frac{150}{2}=75\,V$

To get the average Input Voltage for the design;

$V_{TDV}=V_{Lower}+V_M=100+75=175\,V$

Alternatively,

$V_{TDV}=V_{Upper}+V_M=250-75=175\,V$

Design Power, P_D**:**

$$P_D=P_O\left(1-\frac{V_{TDV}}{V_2}\right) \qquad (1)$$

Where the output power, $P_O=3000\,VA$

$V_{TDV}=175\,V$

Transformer secondary voltage, $V_2=220\,V$

$$P_D=3000\left(1-\frac{175}{220}\right)$$

$$P_D=P_O\left(1-\frac{V_{TDV}}{V_2}\right)\approx 614\,VA=0.614\,KVA$$

Using the EMF standard formula for transformer design:

$$V_{per\,turn}=4.44\,f\,B_{max}\,A_c \qquad (2)$$

Where,

$V_{per\,turn}=¿$ the Voltage per Turn

$f=¿$ the frequency (50Hz)

$B_{max}=¿$ chosen peak flux density (typ. 1.2–1.5 T), and

$A_c=¿$net core cross-sectional area in m², given by;

$A_c(cm^2)\approx 1.1-1.3\times\sqrt{P_D}(VA)\,cm^3$; which must be converted to m^2

Where P_D (VA) = 0.614KVA= 614VA

$A_c\approx 32\,cm^2=0.0032\,m^2, f=50\,Hz, B_{max}=1.3\,T$

$V_{per\,turn}=4.44\times 50\times 1.3\times 0.0030=0.930\,V/turn$

This implies that the number of secondary turns for each range of input voltage is given by $N_S = \frac{V_{avg}}{V_{per\,turn}}$.

Relay Control Switching Pattern

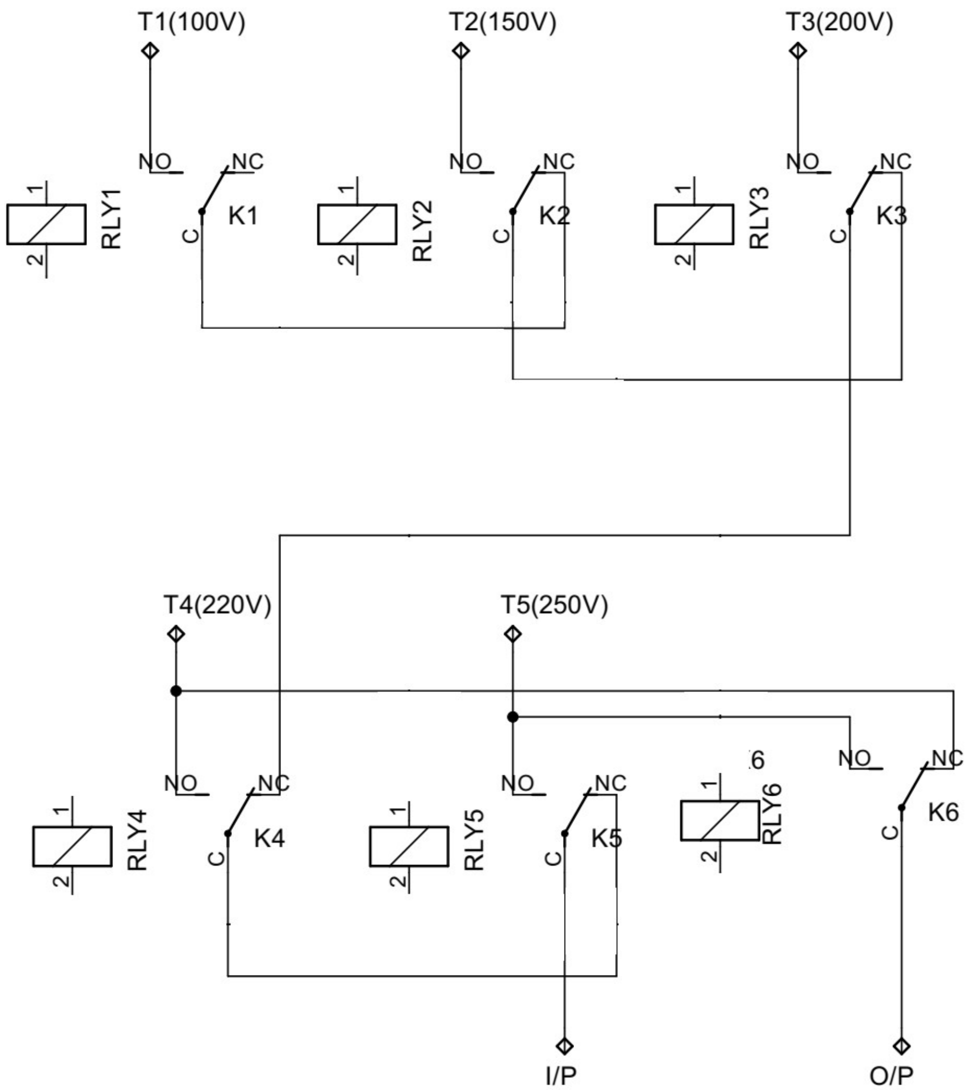


Figure 4: Relay Control Switching Design

Figure 4 shows six relays, (RLY1 to RLY6) tap selection terminals, (K1 to K6) switching between five transformer taps (T1 to T5) and ultimately controlling the connection between input and output lines. The relays are used to select appropriate voltage levels depending on the mains input voltage conditions. T1-T5 are transformer secondary taps delivering stepped voltage levels (e.g., 100V to 250V). RLV1–RLV5 are tap selection relays that choose the right tap based on sensed voltage based on the control program/code. RLV6 is output relay which controls whether power is delivered to the output terminal. Each tap connects to a specific relay's common terminal. The relay's Normally Open (NO) contact is used to route the selected tap toward the output line.

Table 4: Relay Control Switching Pattern

I/P (V)	I/P (TAP)	RELAY/OUTPUT	O/P (TAP)
100-108	T1	R1(ON), R6 (OFF)	T4
109-120	T2	R2(ON), R6 (ON)	T5
121-139	T2	R2(ON), R6 (ON)	T5
140-160	T2	R2(ON), R6 (OFF)	T4
161-186	T3	R3(ON), R6 (ON)	T5
187-210	T3	R3(ON), R6 (OFF)	T4
211-230	T4	R4(ON), R6 (OFF)	T4
231-250	T5	R5(ON), R6 (OFF)	T4

Table 4 describes the relay control switching pattern from which the logic of the design is drawn. The relay switching logic in correlation with the input AC voltage explains how the transformer taps (T1–T5) are used to regulate output voltage to ~220 V. For example, in Table 3.2 above, when the input voltage range is between100 and 108 V, relay R1 switches on and the value is connected to transformer tap, T1. At this same time transformer tap T4 becomes an output, while the output relay R6 controls connection of output tap to the load.

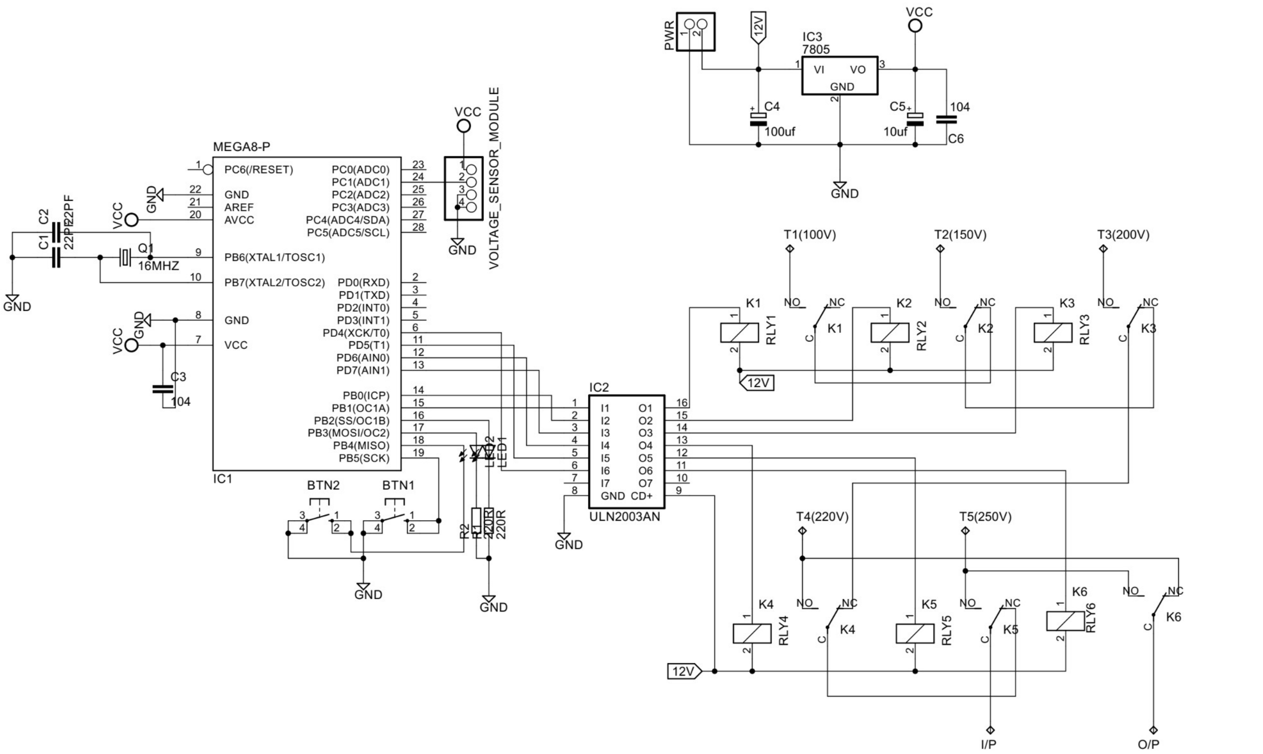


Figure 5: Schematic diagram of the AVS

V Discussion

This work discusses the design and development of a microcontroller-based triple action automatic voltage stabilizer (AVS) for reliable power stabilization in Nigeria. The system provides a stable 220V AC output and protects against voltage surges, overloading, high voltage, and low voltage conditions.

The AVS employs the AVR microcontroller, ATMEGA328P, to monitor input voltage and control output voltage using power relays. It features a triple action protection mechanism, including voltage stabilization, surge protection, and overload cutoff, as well as high and low voltage cut off. The system's performance was evaluated under various load conditions, demonstrating its ability to stabilize output voltage within ±5% of the nominal value.

The design addresses Nigeria's power distribution challenges, including voltage fluctuations and surges, which can damage electrical and electronic equipment. The system has a load capacity of 3KVA and operates within an input range of 80V-250V AC.

The paper highlights the importance of automatic voltage stabilizers in protecting equipment from power variations. It also reviews related works on microcontroller-based AVS systems and their limitations. The system's architecture includes a power supply unit, microcontroller unit, voltage sensing unit, current sensing unit, and switching unit. The ZMPT101B voltage sensor module measures AC mains voltage, and the autotransformer regulates output voltage. The relay control switching pattern ensures stable output voltage. The system's features, such as overvoltage and undervoltage protection, voltage surge protection, and stable output voltage, make it suitable for Nigerian power conditions.

Overall, the microcontroller-based triple action AVS offers a comprehensive solution for power stabilization, providing reliable protection for electrical and electronic equipment in Nigeria.

VI Conclusion

The designed and developed microcontroller-based triple action AVS provides a comprehensive solution for power stabilization, providing voltage stabilization, surge protection, overload cutoff, and high and low voltage cut off. The system's performance was evaluated under various load conditions, demonstrating its ability to stabilize output voltage and protect equipment from voltage fluctuations, surges, and overloading.

The system's performance evaluation demonstrates its ability to stabilize output voltage within ±5% of the nominal value, making it suitable for sensitive equipment. The use of a microcontroller (ATMEGA328P) and a triple action protection mechanism ensures reliability, flexibility, and better precision in stabilizing voltage levels.

This AVS design has the potential to mitigate the economic losses and inconvenience caused by voltage fluctuations and power surges in Nigeria. Its implementation can benefit households, businesses, and industries, promoting economic growth and development.

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