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DESIGN IMPLEMENTATION OF A 3 KVA OP-AMP BASED AUTOMATIC VOLTAGE STABILIZER FOR NIGERIA USAGE

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Abstract:

This paper is on the implementation details of automatic voltage stabilizer which can be used in Nigeria. Power problem in Nigeria is not limited to the epileptic nature of the supply but also the quality of the supply in term of acceptable voltage range which often become a challenge especially for sensitive equipment as can be found in hospitals and other areas of accurate electronic measurements. One of the ways forward is to design and implement a system that is capable of accepting low voltages to supply acceptable voltage to our equipment and also protect that equipment from overvoltage. The implementation of this automatic voltage stabilizer has processes or stages for the system to come out functional and rugged for Nigeria situation. The main sections of automatic voltage stabilizer are the autotransformer, the power supply, the switching and the control sections. Other circuit implemented are the overvoltage protection circuit, the overload protection circuit, the low voltage cutoff and the output voltage delay circuit. The implementation was achieved by first sourcing for electronic components based on the design specifications, making printed circuit board, populating the board and soldering the components to the board. The casing was also made to specifications with all the displays and switches well connected and properly fixed. The test carried out on No Load and on Load revealed proper functioning of the system. The stabilizer is rugged, user friendly and operates effectively within the specified voltage range.

Key Words: Stabilizer, Components, Switching, Transformer, Stabilizer, Operational Amplifier, Relay

I. Introduction

The power problems in Nigeria are numerous and can be traced to all areas of the power system in the country (Igwe 2021). Right from generation to distribution, the nation has always been in the state of unstable and epileptic power supply (Chinwuko, et al. 2011). The problems range from lack of good energy generation infrastructure, to unfriendly government policies about tariffs and privatization regulations (Princewill, et al. 2023) (Ponnle and Olajide 2019). The general concern of the populace when it comes to electricity is the erratic nature of our public power supply voltage whenever the power is available (Chinwuko, et al. 2011).

These problems have in many ways constitute difficulties to the people through crippling of the economy (Chinwuko, et al. 2011). They have impeded the growth of the nation. Many people that essentially depend on stable and reliable electricity have no choice but to spend exorbitantly on alternative source of supply to be able to fend for their families.

The need for voltage stabilization

The concern for stability in power supply for some people stems out of the sensitivity of some equipment to voltage variation (Oluwatoyin, Agbaje and Alabi 2015). Nigerians, in most cases, experience low voltage supply especially in rural areas and suburban centers. Often, the supply voltage goes below acceptable value for sensitive equipment and other household appliances. Some equipment such as Television, deep freezer, and pumping machine cannot operate at very low voltage (Ponnle and Olajide 2019). There is therefore the need to use voltage stabilizer for proper functioning of such equipment when using public power supply to power them.

A lot of effort has been made in the area of voltage stabilization and the resulting product are seen in the market all over the country (Ofualagba and Igbinoba 2017). There are also different types of stabilizers been used all around us. Some of these stabilizers perform satisfactorily, but some do not. Not only that, some stabilizers do not have some critical protection measures necessary to safeguard the appliances connected to them. Other stabilizers could not handle very low voltages; rather, they switch off their output when the input voltage is too low.

In the design of this stabilizer, some of these lapses have been put into consideration so as to have a very robust stabilizer that gives protection to the load and also make use of very low voltage in its operation instead of switching off its output.

Voltage Stabilization Concept

Most of the appliances we use in Nigeria are rated in voltage and power (Oshevire, Oladimeji and Mmonyi 2014). Other specification is the frequency. The usual voltage intake is between 220V to 240V. the reality of the power supply in Nigeria is that this voltage range cannot be expected always mainly due to distribution shortcomings. Most time, the consumers of electricity experience voltage of as low as 100V instead of 220V.

Therefore, the automatic voltage stabilizer is used to step up the voltage for the proper functioning of the load being placed on it (C. Chaudhary, et al. 2023). For necessarily high voltage from the public utility, the stabilizer has the capacity to step it down to the acceptable range so as to protect the load from damage (Kızılırmak, et al. 2024).

Generally, a stabilizer receives an input voltage, sense the voltage is higher than the acceptable range, it steps it down but if the voltage is lower than the acceptable range, it steps it up (Hoque 2014). If the input voltage is within the range the system gives out the output without altering it; this is the voltage stabilization concept.

Block diagram presentation

The diagram below is the block diagram of a typical stabilizer. It has an input cord for AC input. It also contains output port for stabilized output port for stabilized output voltage. The central component of the stabilizer is the autotransformer. The transformer works with the control and relay circuit. A power supply is usually needed to rectify the AC input voltage dc for specific use of voltage comparation.

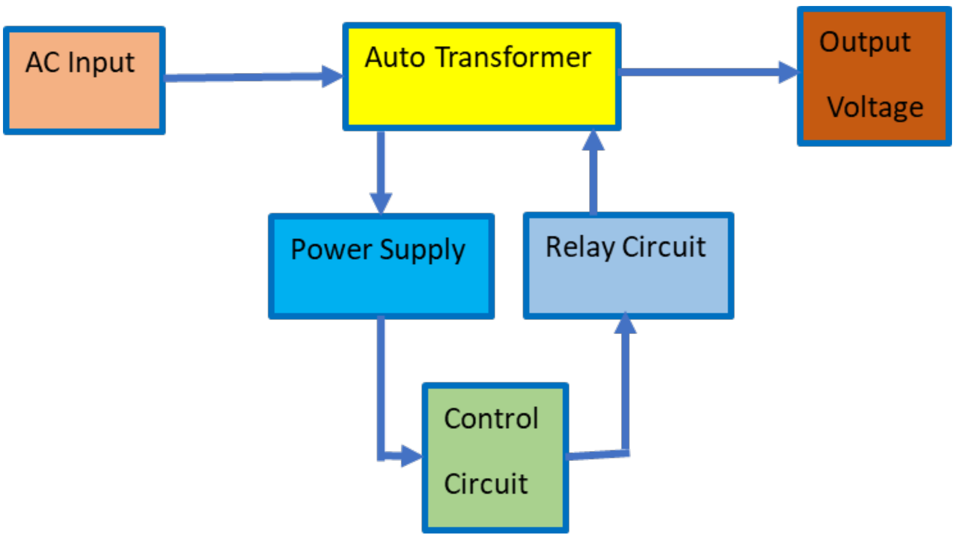

Figure 1: AVR Block Diagram

II. Literature review

Voltage fluctuations on distribution lines damage sensitive equipment and reduce power quality. Automatic Voltage Stabilizers (AVS, sometimes called Automatic Voltage Regulators (AVR)) are essential for maintaining stable output voltages by compensating for fluctuations in the power supply. They are devices that detect mains voltage fluctuations and automatically implement corrective measures so that the output voltage remains within tolerance. They are critical in protecting electronics gadgets from over- and under-voltages. Research on AVS spans electromechanical (servo), ferro resonant, static (power-electronic) and transformer tap-changing solutions, with an increasing trend toward high-speed static designs and digital control (Aung 2018).

The Purpose of AVR

The function of the Automatic Voltage Stabilizer (AVS) is to maintain a constant output voltage between 220V to 240V irrespective of the fluctuations in input voltage (C. Chaudhary, et al. 2023). The input voltage is designed to work in the range of 80V to 250V and still maintain the constant output voltage of 220V as well as the power rating. It protects electronics appliances from over-voltage, under-voltage, surge currents from the supply and protects itself from overload; by switching off the load.

Categorisation of AVS designs

Electromechanical/Servo (variac-based) stabilizers: They use a servo motor-driven autotransformer/variac to change turns ratio by moving a contact arm on a toroid. They are simple and robust but relatively slow and bulky.

Ferro resonant stabilizers: This uses resonance in a specially-designed transformer to absorb input swings. It is good for isolation and transient suppression but it is bulky and energy-inefficient at light loads (Mulchandani, et al. 2018).

Static (solid-state) stabilizers: It uses either electromechanical or solid-state components like comparators or relays to switch between different transformer windings to provide fast response time (Lawrence, et al. 2021). Devices like power electronic converters (SCRs, IGBTs, AC-AC choppers, buck–boost arrangements or series reactors) rapidly inject or remove voltage, giving fast correction and compact size (Sawant, et al. 2016). Static designs dominate recent research because of speed and control (Mulchandani, et al. 2018).

On-load tap-changing transformers (OLTC) / programmable tap changers: Change transformer tap under load to regulate voltage which is ideal for medium/large power ratings and distribution automation. They are slower than power-electronic static stabilizers but suitable at distribution/generator scale.

AUTOMATIC: They can be solid-state or electromechanically controlled and is usually automated by the use of integrated control circuits. They usually use comparators and microcontrollers to continually control, monitor and adjust the input voltages to produce a constant output voltage.

Control strategies and digital implementations

Early stabilizers relied on analog comparators and hysteresis. Modern work emphasizes digital controllers: microcontrollers, DSPs, and FPGA-based controllers implementing PID, hysteresis, SMC (sliding mode), fuzzy logic, fractional-order PID (FOPID), and hybrid controllers to improve stability, robustness and transient response. Research shows fuzzy/FOPID and cascaded/hybrid controllers can improve disturbance rejection and robustness to parameter changes. DSP- or microcontroller-based static AVS implementations enabling fast PWM control of IGBTs are common (Martin’s Electronic Devices & Instruments n.d.).

Hardware topologies and switching devices

SCR-based: Phase control (older static approach) - robust but can produce harmonic distortion and slower control of output amplitude.

IGBT-based: AC-AC converters or choppers that allow fast correction (tens of milliseconds), lower conduction losses and better controllability; many recent academic prototypes use IGBTs with DSP control.
Buck-boost transformer with power-electronic series chopper; a hybrid approach used to extend correction range while keeping transformer volume moderate (Sawant, et al. 2016).

Performance metrics

Common metrics to evaluate AVS include:

- Voltage regulation band / tolerance (e.g., ±1-5% at rated load)
- Correction speed / response time (static designs: ms-tens of ms; servo/tap changers: 100s ms to few seconds)
- Efficiency and power loss at no-load and full-load
- Total harmonic distortion (THD) introduced to the supply
- Reliability, MTBF, and cost per kVA

Comparative studies show programmable/static designs can outperform commercial servo units in regulation speed and accuracy, but THD and cost are trade-offs.

III. Circuit Implementation

Circuit Sections and Specifications

The various sections in the AVR are:

i. Transformer
ii. Power Supply
iii. Control circuit array
iv. Overvoltage Circuit
v. Overload Circuit
vi. Low Voltage Cutoff

Each of these sections is designed to specification based on the expected output power rating, the input voltage range, the current handling capacity, the load type and the responsiveness. The core area of the transformer is also determined based on the intended power handling capacity of the transformer.

Table 1: AVR SPECIFICATIONS

	Parameter	**Specification**
1	Input Voltage Range	100V – 250V
2	Expected Output Voltage	220V +/- 5%
3	Output Power	3000VA
4	Transformer Core Area	9cm x 5.5cm
5	Number of Turns	190 turns
6	Volt per Turn	1.32
7	Frequency	50Hz

As can be deduced from the table above, the system to be implemented will operate on 50Hz frequency with output voltage range between 109V and 231V. The rated output power is 3kVA
Among the components that are used for the implementation are: Diodes, Ceramic Capacitors, Electrolytic Capacitors, Transistors, Operational Amplifier, Resistors, Relays, Optocoupler, Integrated circuit, Fuse, MOSFET e.t.c.

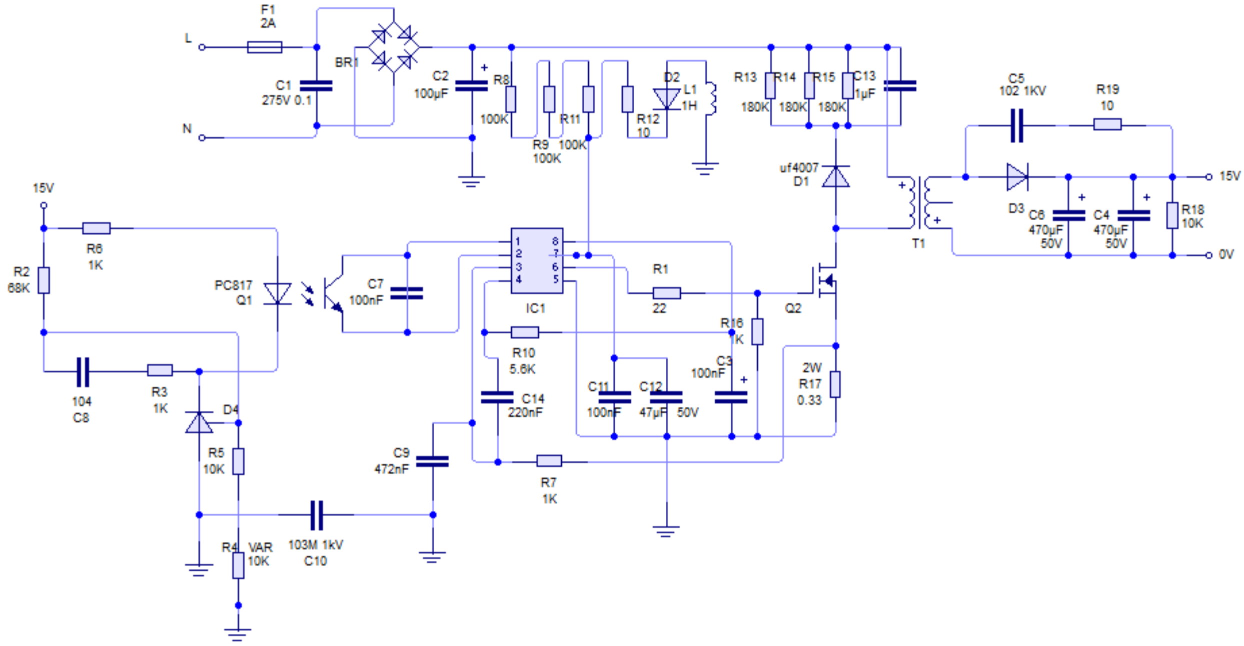

Figure 2: The Power Supply Unit

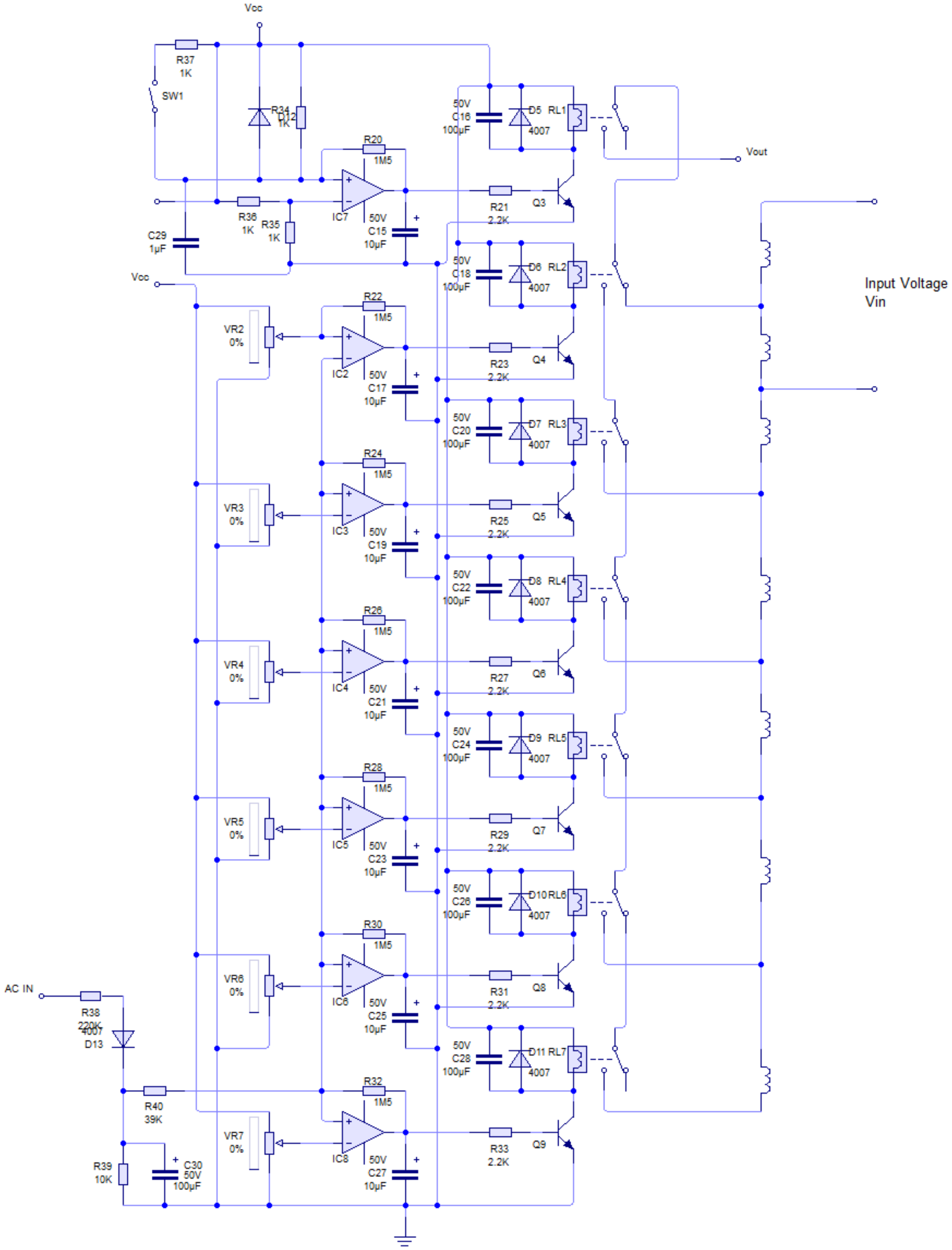

Figure 3: The Control Circuit

Implementation Stages

The steps involved in the implementation of the above circuit include

v. PCB production

vi. Population

vii. Soldering

PCB Production

The stage of PCB production is important in the implementation of AVR. It usually starts with the drawing or design of circuit diagram using software tool like eagle which has the capacity to give the best layout of the board. This is followed by printing the design and creation of substrate for it. The inner layer is then printed and there is an application of ultraviolet light for hardening photoresist. The unwanted copper is thereafter removed and the piece is inspected for consistency before laminating the layer. Drilling is later carried out followed by plating and final etching. The process is concluded by surface finishing and testing.

Population

The following are the steps necessary for the population of printed circuit board:

Preparation

There is need to gather necessary tools and materials: Ensure you have the bare PCB, all required electronic components, solder, a soldering iron with a stand, wire cutters/flush cutters, safety glasses, and a fume extractor or a well-ventilated area.

Next is to inspect and clean the PCB: Prior to starting population, it is good to visually inspect the bare board for any defects ensuring the surface is clean of dust, grease, or contaminants.

Organize Components: another important thing is to sort and organize components by type and value. It is better to populate the board starting with the lowest-profile components (like resistors and diodes) and working up to taller ones (capacitors, ICs, connectors) to make the assembly process easier.

Assembly

Component Insertion: the various components that have been sorted are inserted to the pre-drilled holes on the PCB based on the circuit diagram, following the layout indicated by the silkscreen markings.

Observe Polarity: there are polarized components such as electrolytic capacitors, diodes, LEDs, and integrated circuits (ICs), ensure the correct orientation by inserting based on markings (notches, stripes, or longer/shorter leads) with those on the PCB. For example, some LED have their positive terminal longer than negative. This should guide the correct positioning of such components.

Secure Components: Lightly bend the leads on the underside of the PCB to hold the components in place before soldering, or use a temporary adhesive/jig for heavier parts.

Soldering

Solder the component leads to the pads on the reverse side of the board. Heat both the component lead and the copper pad simultaneously with the soldering iron tip for a few seconds, then apply solder wire to the heated joint (not the iron tip) until it flows freely and forms a shiny, conical joint.

Trim Excess Leads: Use flush cutters to carefully trim the excess length of the component leads close to the solder joint for a neat finish and to prevent short circuits.

Cleaning: Clean any flux residues from the board using deionized water or isopropyl alcohol to maintain the board's reliability and appearance.

Inspection and Testing: Visually inspect all solder joints for quality (e.g., checking for cold solder joints or bridges). A multimeter can be used to check for continuity and to verify the circuit's functionality. The final step is functional testing to ensure the board operates as intended.

Rework (If Necessary): Use de-soldering braid or a solder sucker to correct any mistakes, such as misplaced components or poor solder joints.

Transformer and Control Circuit connection

The design of the auto transformer was done to conveniently power a load of 3kVA. All the specifications concerning the design have been mentioned earlier. A total number of 386 turns were

wound according to the design. There are two terminals with 190 turns which are designated input terminals. The terminals are to be connected to the input voltage which is meant to be stabilized. Other terminals are labeled T2 to T7 and are interconnected through a network of relays to the output. This is shown in figure 3 and figure 4. In figure 4, each terminal is labeled with the voltage range it is meant to supply. If the range is exceeded the relay transfers the output terminal to another terminal. Figure 3 also shows how the terminals, relays and operational amplifier are related.
While setting the voltage limit of each terminal as shown in figure 3, the 10kΩ variable resistor is used. These resistors help to have precision during calibration of the AVR. Also, in figure 3, there is low voltage cutoff for voltage input less than 100V. This helps to prevent the supply of too low voltage to the load. Another feature is the over voltage cutoff. The AVR was designed to cutoff if it detects any voltage higher than 250V. this is to protect the load from over voltage. The over voltage section of the circuit is fortified with selectable delay switch. The purpose is to choose whether to switch the input of the AVR immediately to the output or to wait a few seconds before doing so.

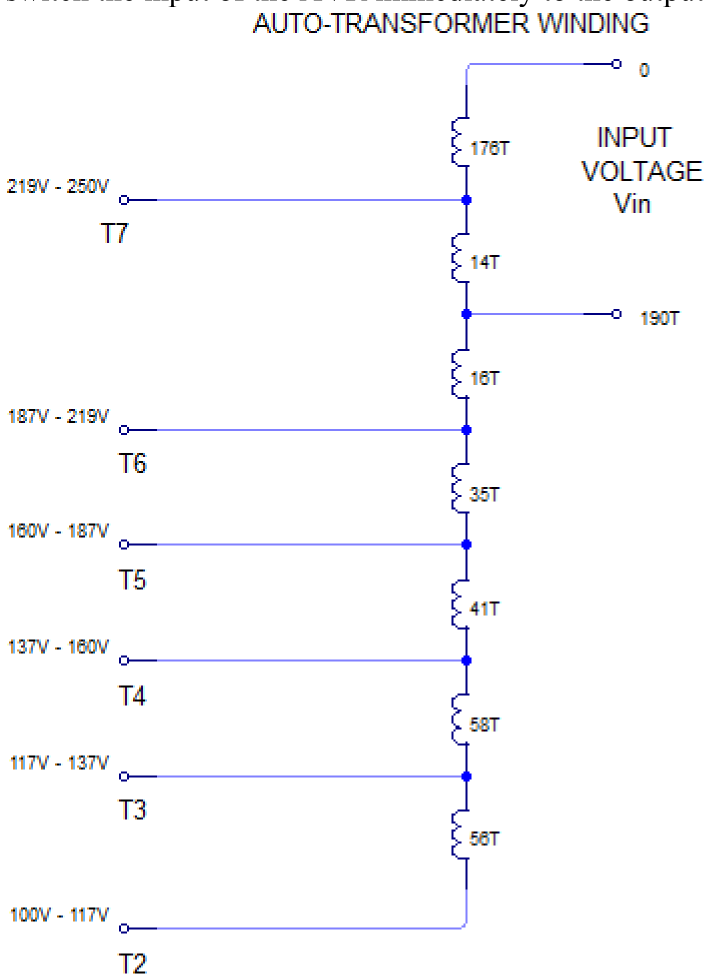

Figure 4: 3kVA Auto-Transformer Winding

Table 2: AVR Testing (No Load and On Load)

	No Load				On Load (330W, 232V)			
S/N	I/p Voltage	O/p Voltage	Input Current	Output Current	Output Voltage	Input Current	Output Current	Output Power
1	80	154	0.12					
2	90	169	0.09	0.04	165	4.01	2.05	338
3	100	187	0.09	0.05	185	4.25	2.17	401

4	110	205	0.09	0.05	203	4.44	2.27	461
5	120	223	0.09	0.06	222	4.65	2.38	527
6	130	191	0.15	0.05	190	3.49	2.21	418
7	140	206	0.15	0.05	204	3.61	2.30	468
8	150	187	0.16	0.05	219	3.74	2.38	519
9	160	200	0.18	0.05	199	3.06	2.26	448
10	170	213	0.18	0.05	211	3.15	2.34	494
11	180	224	0.18	0.06	190	2.60	2.22	422
12	190	202	0.23	0.05	201	2.67	2.28	457
13	200	213	0.24	0.05	212	2.74	2.34	497
14	210	224	0.30	0.06	222	2.82	2.40	532
15	220	201	0.34	0.05	201	2.36	2.28	460
16	230	211	0.40	0.05	210	2.46	2.34	491
17	240	220	0.48	0.06	219	2.53	2.38	522
18	250	0	0.60	0.00	0.00	0.00	0.00	0.00

IV. Casing

Casing Dimensions and Fabrication

The casing was fabricated from mild steel sheet metal, selected for its durability, ease of welding, and capacity to support structural integrity. Sheet thickness is approximately **1.214 mm**, adequate for holding the AVR internals while withstanding vibrations and external stress.

The casing components were **cut, bent, and welded** using standard sheet metal fabrication tools available in the workshop. Key tools used include:

i. PLASMA CUTTER (for sheet cutting)
ii. MANUAL FOLDING MACHINE (for bending)
iii. MIG welding setup (for joining parts)

Dimensions (approximate):

i. **Main housing:** 350mm (L) × 200mm (W) × 250mm (H)
ii. **Front panel:** Cut-outs made for:
   - Power switch (rectangular)
   - Display screen (square)
   - LED indicators or fuse holders (circular and rectangular holes)
iii. **Side panels:** Include 120 ventilation perforations (in circular patterns) for thermal regulation.

Rust has begun forming due to exposure, so final finishing (e.g., powder coating or anti-rust primer) will be essential before deployment.

External Body Features

The external body of the AVR casing has been designed with **utility and airflow** in mind. The notable external features include:

ii. **Ventilation Slots:** Laser-cut perforations in flower or floral-like patterns on the side panels aid in passive cooling and heat dissipation from the transformer and heat sinks inside.
iii. **Cut-outs & Ports:**
    i. Display and control interface on the front face
    ii. Cable entry/exit slots for AC input/output wiring
    iii. Provision for fuse holder, indicator LEDs, and circuit breakers
iv. **Mounting Holes:** Pre-drilled holes for wall or surface mounting
v. **Rustproof Coating (To Be Applied):** Final paint or anti-corrosive coating will improve the longevity of the unit

Equipment Final Outlook

The current state shows an **assembled but unfinished metal casing**, with all major cutouts and fabrication steps completed. The casing will house:

i. Main AVR PCB (Op-Amp based)
ii. Relay/Contactors
iii. Power Transformer
iv. Display Module
v. Heat sinks for power components

The expected final outlook after assembly and finishing includes:

iii. Fully enclosed metal box with:
    Painted finish (likely matte black or grey)
    Labelled front interface for user interaction
    Secure cable management
iv. Ventilation holes aligned with fan or passive airflow strategy
v. Easily removable top cover for maintenance and inspection

This casing design is rugged enough for deployment in harsh Nigerian environments where voltage instability is common, while also being user-friendly and serviceable.

This fabricated casing plays a crucial role in housing and protecting the internal components of the Op-Amp based 3.5kVA AVR. It was designed with attention to airflow, accessibility, and structural integrity. Final testing and implementation will ensure that the enclosure meets electrical safety and operational standards required for effective voltage stabilization in Nigeria.

V. Conclusion

In conclusion, this paper presents the successful design and implementation of an automatic voltage stabilizer tailored to address Nigeria's power challenges, providing a reliable voltage output solution for sensitive equipment in hospitals, laboratories, and other critical applications. The stabilizer's robust architecture, comprising an autotransformer, power supply, switching, and control sections, ensures efficient voltage regulation and protection against overvoltage and overload. The implementation's success is evident in its ability to accept low input voltages and produce a stable output, making it an effective and user-friendly solution for Nigeria's power needs.

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