An Improvement to the Line Voltage Regulation of Automatic Voltage Regulator in Meeting Voltage Fluctuation Problems in Nigeria

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Abstract
In Nigeria, household electrical and electronic appliances are most times under the threat of low voltage supply. This low voltage supply causes appliances to malfunction or get damaged. The existing automatic voltage regulators in the Nigerian market do not perform optimally under low voltage supply conditions. In this paper, the automatic voltage regulator is improved by smoothing the taps of the autotransformer which is usually used in automatic voltage regulators. The taps of a typical automatic voltage regulator in the Nigerian market are; 0V, 100V, 140V, 180V, and 220V, while the taps of the autotransformer used in this work are; 0V, 85V, 100V, 115V, 130V, 145V, 160V, 175V, 190V, 205V, 220V, and 235V. The mains power supply is sensed and used by comparators to control the relays in selecting the appropriate terminal of the autotransformer. The output voltage is also sensed and used by a comparator in controlling the output relay so as to ensure that voltages above 230V are cut off from the output. A voltage regulation of 212V ±8.5% (194V to 230V) was achieved for input voltage of 75V to 245V and this automatic voltage regulator is ideal for Nigeria.

1. INTRODUCTION

Every electrical and electronic appliance are designed and manufactured, based on the expectation that the input voltage would be at a certain value. Voltage fluctuations can be described as repetitive or random variations of the supply voltage envelope due to sudden changes in the real and reactive power drawn by a load. The characteristics of voltage fluctuations depend on the load type, size and the power system capacity.

Under-voltage might result into brownout, distortion or permanent damage while overvoltage in the form of spikes and surges could cause distortion, burn-out, melt-down, fire, electro-pulsing and permanent damage. Usually, under-voltage conditions are more prevalent than over-voltage conditions in Nigeria. Some of the causes of the extended or perpetual voltage sags are due to use of underrated cables from substations to homes and industries which result in massive voltage drops at every termination to buildings and industries thereby causing unnecessary loss of power at the customers point. Most substations have underrated transformers to what they are supposed to be as most of them were installed several years back when the energy demand of the area was still very low (Arobieke et al, 2012).

The Electricity Regulatory Commission said that the supply voltage from the supply authority is allowed to fluctuate between ± 6% of the declared nominal voltage if under system stress or following system faults (Nigeria Electricity Regulatory Commission, 2007). Any voltage below or above this is termed under-voltage or overvoltage conditions respectively.

Since the electric power distribution companies are unable to provide the consistent adequate voltage level (220V) demanded by appliances, the consumers are ultimately responsible for the safe operation of their appliances, hence automatic voltage regulator (AVR) are used in homes and industries.

AVR is required for two distinct challenges which are under-voltage and over-voltage conditions. The function of every AVR is to transform an input voltage into a specific, stable, output voltage and maintain that voltage over a wide range of load current and input voltage conditions. Many of the AVR used in Nigeria face situations beyond their design limit or specifications which renders them under-utilized in Nigerian homes (Akinlolu, 2015).

The function of the autotransformer is to produce the required output voltage with the help of the control unit (Gupta and Lyman, 1980). The voltage variations are accomplished by changing the ratio of transformation automatically (Pansini, 1983). The transformer turns ratio is varied accordingly by selecting one of the taps using relays.

There are many AVR in the Nigerian market, some are poor in performance and as such, not reliable. This is due to their inability to regulate low voltages, knowing that the major power quality problem experienced in most part of Nigeria is that of brown out and voltage sags. Even though voltage surge and spikes also occur, they are occasional and occur for a very short period of time as compared to brown out and voltage sags. About one and half decade ago, statistical data revealed that 22% of AVR purchased by consumers were not performing satisfactorily as a result of very low input supply voltage (Ogunlade, 1999).

2. ISSUES WITH THE EXISTING SYSTEMS

A survey study by Arobieke et al, 2012, in a city in South Western Nigeria revealed that voltages in most of the areas surveyed are between 120V and 175V due to overloading and voltage drop along the distribution networks.

A survey of supply voltage by Oluwole et al, 2014, in some selected areas of the city where the author resides in the South Western Nigeria revealed that about 30% of consumers receive voltages less than 80V while up to 50% receive less than 120V. The survey also revealed that almost all the substations studied, provide power supply to consumers that are quite far from the substation's transformer. Some consumers were being supplied electricity at about 4.5Km from the substation, with an average distance of 2.5Km for most of the selected areas of study. Average typical supply voltage at those areas that are far from the substation's transformer was about 78V at day time and 65V at night.

Akinlolu, 2015, presented a paper on the line and load regulation tests that were carried out on twelve (12) selected brands of commercially available domestic 1 KVA AVR used by consumers in Nigeria for the protection of appliances. The results showed that many of the AVR tested are unable to adequately meet the current low voltage situation experienced by consumers of electricity in Nigeria. With the input voltage range of 100V to 250V, The graph of the test carried out on the commercially available AVR (figure 1) shows that the AVR do not perform optimally at low voltages.

The major cause of the poor performance of the commercially available AVR in Nigeria is the number of taps in the autotransformer. The autotransformers used have five (5) taps for 0V, 100V, 140V, 180V, and 220V. The gap between the taps which is about 40V is not smooth and thus the AVR's output will have much deviation from the set target of 220V. A simple schematic diagram of the commercially available AVR is shown in figure 2.

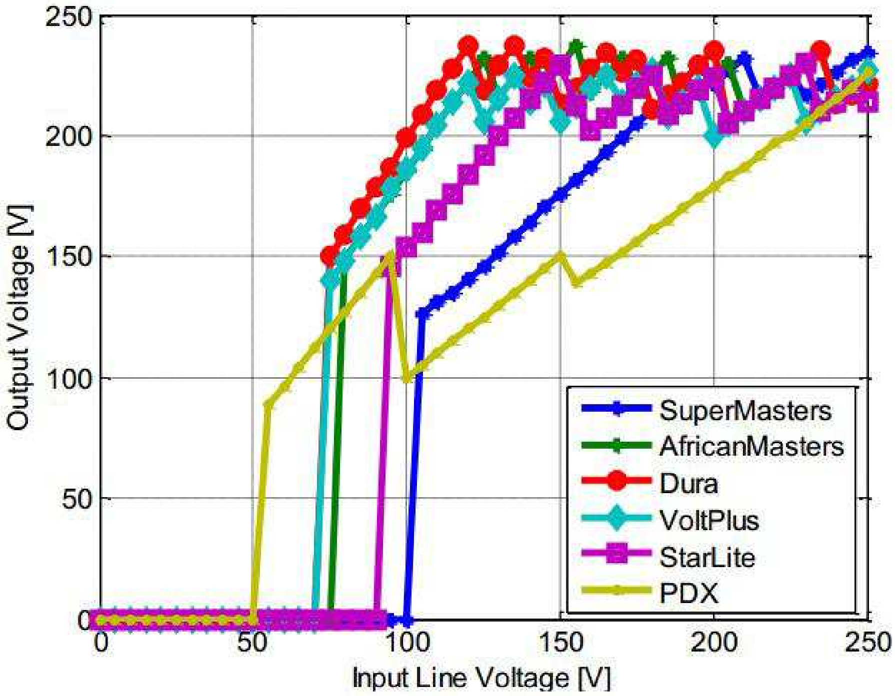

Figure 1: Output Voltage against Input Voltage for Super Masters, African Masters, Dura, Volt Plus, Star Lite and PDX AVR (Akinlolu, 2015).

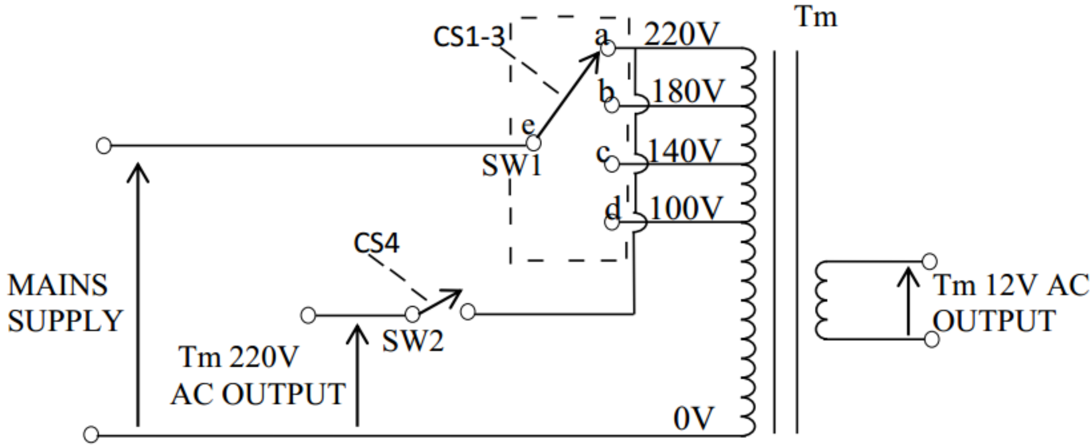

Figure 2: Simple Schematic Diagram of Commercially Available AVR in Nigeria.

From figure 2, if the output voltage is not to exceed 230V, then the maximum input voltages to be applied to each tap can be calculated as;

$$V_m = \frac{V_o \ * \ V_t}{220} \tag{1}$$

Where V_m is the maximum voltage to the taps, V_o is the AVR allowed maximum output voltage (230V), and V_t is the tap voltage.

With the maximum input voltage to the taps calculated, the minimum input voltages can be found to form the range of input voltages to the taps and the respective output voltage range as shown in table 1.

Table 1: The Autotransformer (Tm) taps voltage, Input Voltage Range and the Respective Output Voltage Rage.

Autotransformer Taps	Input Voltage Range	Output Voltage Range
220V Tap	189V – 230V	189V – 230V
180V Tap	147V – 188V	179V – 230V
140V Tap	105V – 146V	165V – 230V
100V Tap	75V – 104V	165V – 230V

From table 1, it can be seen that a typical commercially available AVR does not perform optimally as input voltage drops since the deviation from the minimum output voltage to the set target (220V) is 55V that is 230V – 165V.

3. STRATEGY FOR IMPROVING THE AVR

AVR consist of three main units: the sensing unit, the control unit, and the regulating unit. The sensing unit detects changes in the input and output voltages of the AVR and produces signals which the control unit reacts to, and adjust the output voltage of the AVR, by sending the appropriate control signals (CS) to the regulating unit. Relays in the regulating unit are used to select the correct terminal of the autotransformer for input.

Since the major limitation to the line voltage regulation of an AVR is the taps of the autotransformer, a smooth tapping interval is introduced and this does not increase the cost of the autotransformer though there will be increase in control and switching devices. The taps of the autotransformer used in this work are; 0V, 85V, 100V, 115V, 130V, 145V, 160V, 175V, 190V, 205V, 220V, and 235V, that is gap of 15V between the taps.

Figure 3 is a simple schematic diagram of the AVR where the utility supply is to be switched to the appropriate tap by the switch SW2. SW2 is a group of 10 relays controlled by the control signals CS1-10. The output is tapped from the 220V tap of the autotransformer and controlled with a relay responding to control signal CS11. The 12V output is to power the control and switching circuits.

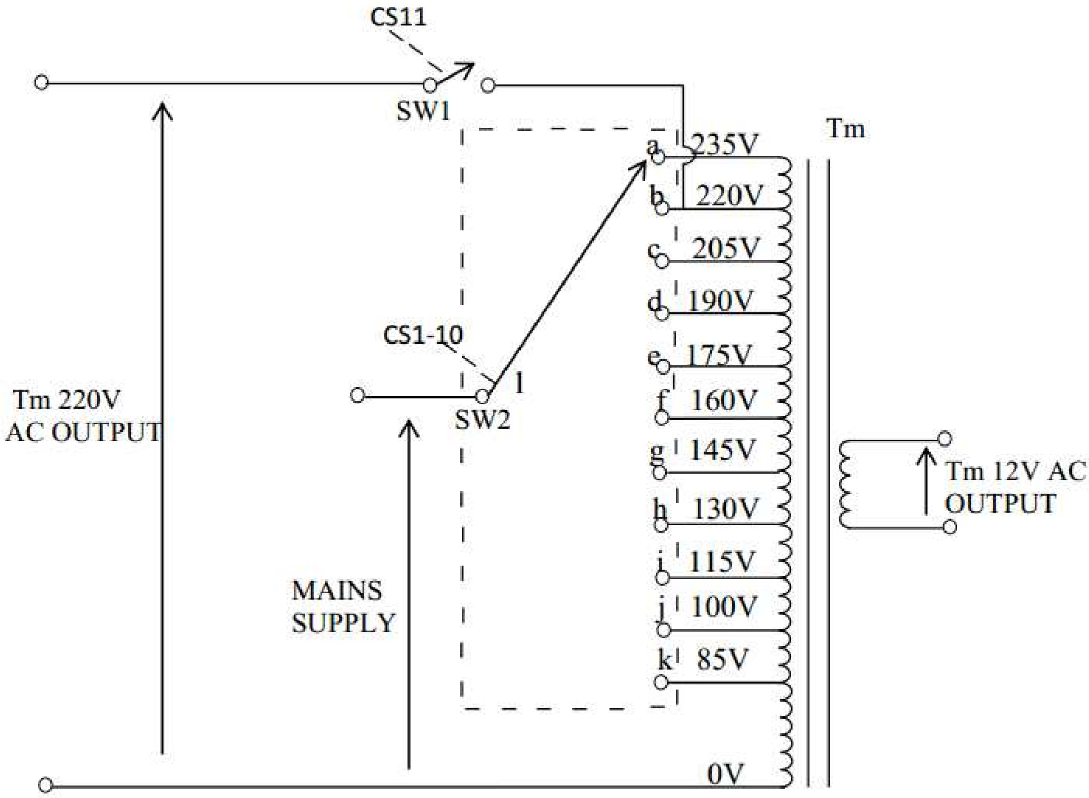

Figure 3: A Simple Schematic Diagram of the AVR.

In figure 4, the control signals CS1 to CS11 are used to control relays RL1 to RL11 respectively. RL1 to RL10 are used for voltage regulation while RL11 is used to control the power output of the AVR. Making any of the CS1 to CS11 5V will make the corresponding relay to switch thereby connecting the normally open and common contacts together while 0V will put it OFF. The output indicator will be ON when there is power output from the AVR. Low voltage or overvoltage indicator will also be ON when the input voltage to the AVR is below 75V or when the output voltage is above 230V. The relays are powered with 12V DC supply while the 5V DC supply is for the control unit.

A is the input switching circuit.
B is the output sensor circuit.
C is the output switching circuit.
D is the output indicator circuit.
E is the DC power supply circuit.
E is the low input voltage or over output voltage indicator.

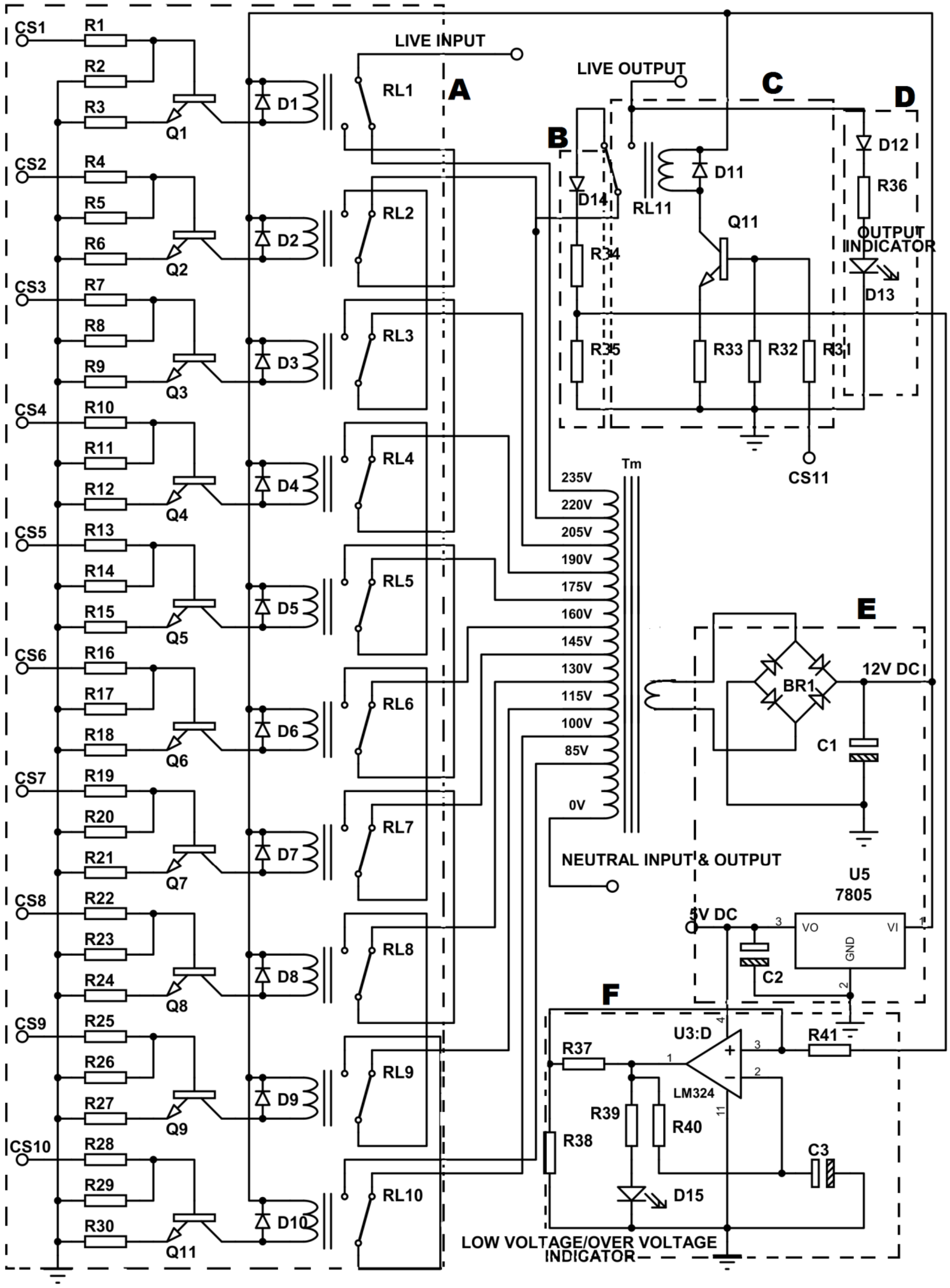

Figure 4 the Circuit Diagram of the regulating unit, indicators and DC power supplies.

In figure 5, the input and output voltages are sensed so as to control the regulating unit and the ouput. The input and output sensors are in voltage divider form generating DC voltages between 0V and 5V. The outputs of the sensors are delayed for 0.5sec by the resistor capacitor arrangement in the circuit. The output of the input voltage sensor is supplied to ten comparators to determine the state of CS1 to CS10 while the output of the output voltage sensor is supplied to a comparator which determines the state of CS11.

The comparators are set to a predefined voltage level for switching the relay and they will generate 5V output to switch a relay when the input voltage falls below the voltage level they are monitoring, otherwise their output will be 0V. U1:A to U1:D are set at 230V, 210V, 195V, and 180V which corresponds to 4.5V, 4.1V, 3.8V, and 3.5V respectively. U2:A to U2:D are set at 165V, 150V, 135V, and 125V represented by 3.2V, 2.9V, 2.6V, and 2.4V respectively. U3:A and B are set at 110V and 95V which is equivalent to 2.1V and 1.8V respectively. U3:C is set at 75V (1.5V) to detect low input voltage while U3:D is set at 230V (4.5V) to detect overvoltage supply to the output.

The input indicator will be ON if there is input power supply to the AVR, else it will be OFF.

G and I are the comparators.
H is the input sensor and indicator.
K is the output sensor.

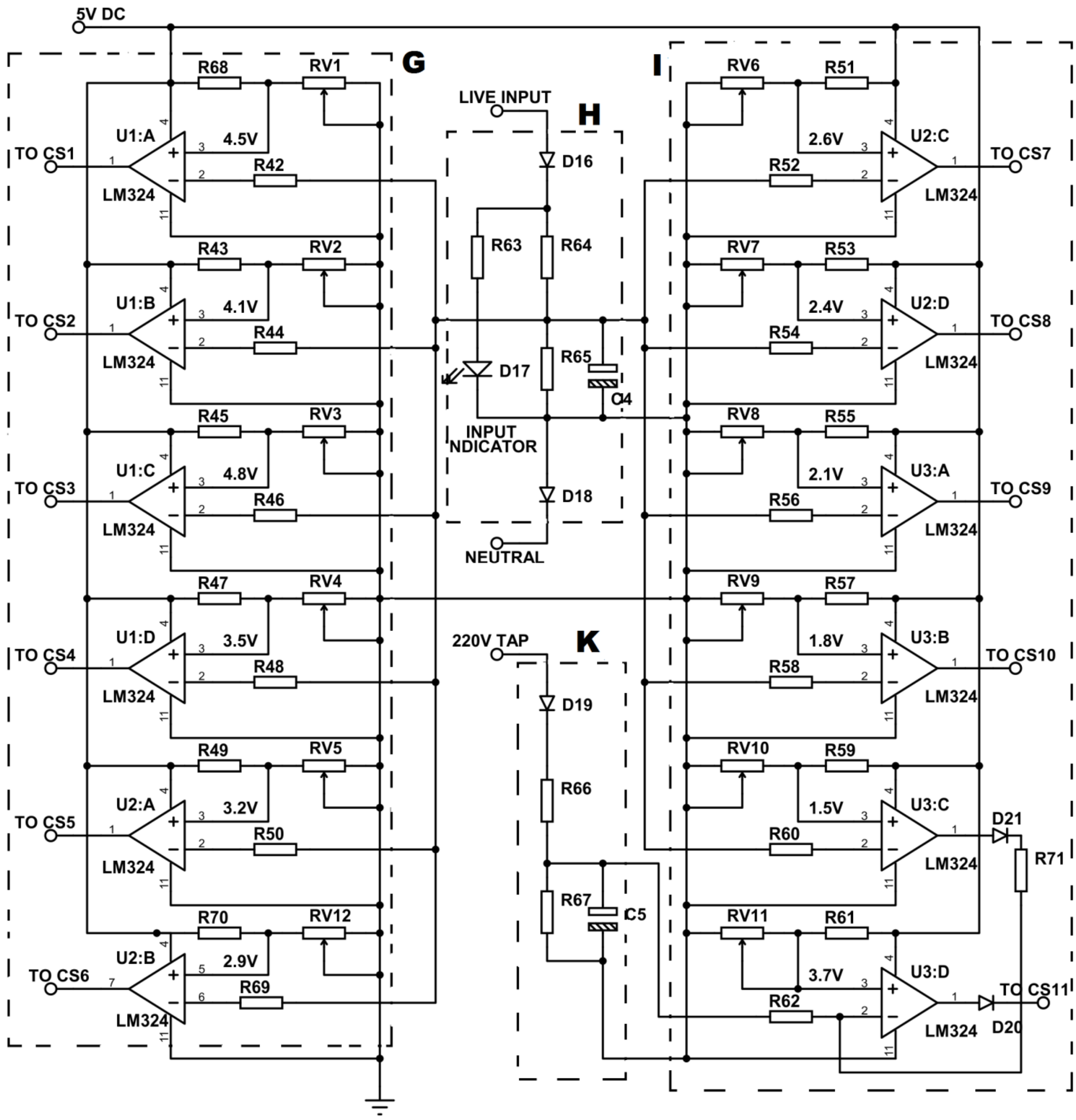

Figure 5: The Circuit Diagram of the Sensing Units, Control and input indicator.

4. EXPERIMENTAL RESULT

A voltmeter was attached to the output of a variac which serves as input to the AVR. The variac was used to vary the mains input to the AVR and the status of the switches monitored and tabulated as in table 2.

It was observed that when the input voltage is above 245V which implies an output voltage more than 230V, the system disconnects the output from the load while if the intput voltage is below 245V but above 74V, the system connects the output which is not more than 230V to the load. If the mains is below 75V, the output is disconnected because the input volyage is below the operating range of the AVR.

Table 2: The Mains Input (Vm), Control Signals CS1 to CS11, SW1, and SW2 Status at Various Input Voltage Ranges.

Mains Input (V)	CS1 (V)	CS2 (V)	CS3 (V)	CS4 (V)	CS5 (V)	CS6 (V)	CS7 (V)	CS8 (V)	CS9 (V)	CS10 (V)	CS11 (V)	Remarks	
												SW1	SW2
Vm > 245	5	0	0	0	0	0	0	0	0	0	0	0	1 o→o a (Default)
230 < Vm <245	5	0	0	0	0	0	0	0	0	0	5	5	1 o→o a (Default)
210 < Vm <230	5	0	0	0	0	0	0	0	0	0	5	5	1 o→o b
195 < Vm < 210	5	5	0	0	0	0	0	0	0	0	5	5	1 o→o c
180 < Vm < 195	5	5	5	0	0	0	0	0	0	0	5	5	1 o→o d
165 < Vm < 180	5	5	5	5	0	0	0	0	0	0	5	5	1 o→o e
150<Vm < 165	5	5	5	5	5	0	0	0	0	0	5	5	1 o→o f
135<Vm <150	5	5	5	5	5	5	0	0	0	0	5	5	1 o→o g
125<Vm <135	5	5	5	5	5	5	5	0	0	0	5	5	1 o→o h
110<Vm <125	5	5	5	5	5	5	5	5	0	0	5	5	1 o→o i
95<Vm <110	5	5	5	5	5	5	5	5	5	0	5	5	1 o→o j
75<Vm <95	5	5	5	5	5	5	5	5	5	5	5	5	1 o→o k
0<Vm <74	5	5	5	5	5	5	5	5	5	5	0	0	1 o→o k

In another experiment, a voltmeter was also attached to the output of the variac which serves as input to the AVR so that the ouput voltage of the variac can be monitored as the desired voltage levels are selected. A voltmeter was attached to the output of the AVR so that it can be monitored and readings taken. The output of the variac was increase at intervals of 5V from 0V to 250V and the corresponding output voltage of the AVR recorded as shown in table 3.

Table 3: Varied Input Voltage to the AVR and the Corresponding Output Voltage.

Input Voltage to AVR (Variac output voltage)	Output Voltage of the AVR
0V – 70V	0V
75V	194V
80V	207V
85V	220V
90V	198V
95V	209V
100V	220V
105V	200V
110V	210V
115V	220V
120V	229V
125V	211V
130V	220V
135V	228V
140V	212V
145V	220V
150V	227V
155V	213V
160V	220V
165V	226V
170V	213V
175V	220V
180V	226V
185V	214V
190V	220V
195V	225V
200V	214V
205V	220V
210V	225V
215V	215V
220V	220V
225V	225V
230V	230V
235V	220V
240V	224V
245V	229V
250V	0V

The graph of the output voltage of the AVR against the input voltage was plotted as shown in figure 6.

It was observed that for the input voltage of 0V to 74V, the AVR output was cut off. From 75V to 245V, the AVR's output is within 194V to 230V (212V $\pm$8.5%).

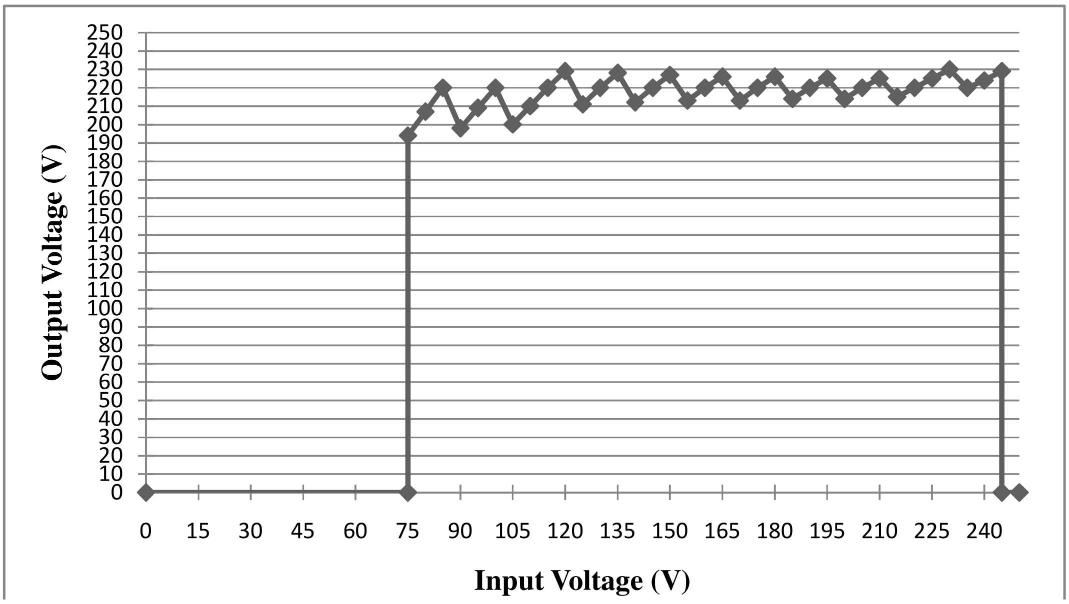

Figure 6: The Output Voltage of the AVR against the Input Voltage

5. CONCLUSION

The AVR will provide adequate voltage regulation for input voltage from 75V to 245V giving output voltages between 194V and 230V. The voltage regulation of the AVR which is 212V $\pm$8.5% shows that the AVR is optimized and thus will improve the services and life span of electrical and electronic appliances used in Nigerian.

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