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Implementation of a Microcontroller Based 5 KVA Automatic Voltage Stabilizer

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Abstract: Every electrical and electronic appliance is designed to work perfectly at a certain input voltage. In Nigeria, household electrical and electronic appliances are designed to work properly at 220VAC, 50Hz and most of the times the voltage supplied from distribution companies are as low as 80VAC making this appliances to work under threat of low voltage supply. This low supply voltage causes these appliances to malfunction and in most cases damage them. Since the electric power supply/distribution companies are unable to provide the consistent adequate voltage level (220VAC) demanded by these sensitive appliances, therefore there is need for consumers to protect the appliances from damage and ensure their safe operation, hence the use of automatic voltage stabilizers to improve the situation. In this research work, a PIC16F877A microcontroller was programmed to monitor the input voltage from distribution companies and if voltage level is between 80 VAC and 250VAC, it gives a constant output voltage of 220VAC (±6%) required by the appliance. In doing this, it 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%)is obtained at the stabilizer output. The design also includes an under/over voltage device protection which ensure that the device is inoperative when the supply voltage is above 250VAC. The system constructed was tested with a variable transformer. At voltages within the specific input voltage range, the stabilizer gave an output voltage of 220 VAC (±6%) and 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 to be 0 V. The system at this voltage alerts the user of the anomaly by displaying UNUSUAL VOLTAGE on the LCD Screen.

Keywords: Auto-transformer, PIC16F877A, stabilizer, over/under voltage, appliances

1. Introduction

The development of any country is largely hinged on the availability of undisturbed and regulated power supply. In Nigeria, electricity is generated by turbine driven synchronous generators at 50Hz at a standard minimum voltage of 11kV. The generated voltage is then stepped up to the primary or secondary Grid voltage of 330kV or 132kV to reduce power losses during transmission. The generated power then travels from the generating stations to the point of utilization via high voltage Transmission lines, most of which are suspended overhead. However due to the uneven power demand at the load end and the complexity of the consumer network, a third party is required to ensure that the generated electricity is properly distributed according to the load demand, while taking into consideration the necessary geographic and economic factors as they affect the overall socio-economic growth of the nation. In Distribution, electrical power is stepped down at distribution sub-stations of various levels to a final voltage of 415V (phase to phase) and 230V (phase to neutral) which is directly consumed by most electrical load.

Nigeria power system is a typical power system that is faced with several challenges, the most basic of which includes - Insufficient generated power, lengthy transmission lines, overloading of distribution Transformers, vandalization of Transmission lines, low power factor of distribution network, lack of infrastructure maintenance, lack of system planning, etc. all of which result in reduction of the voltage level of the electric power eventually received by the consumers.

The occurrence of faults within the power system could also result in surges that cause the flow of excessive short circuit current under extremely high voltages. Even though this condition lasts for a short period of time (because of the protective measures incorporated into the system) a lot of damage can be done to our connected loads in that very short period of time.

A growing market for automatic stabilizers and regulators rated between 0.5 kVA and 10 kVA for the domestic market has grown. The devices have various advertised performance limitations and employ a combination of electronics to select the tappings on transformers. In an ideal situation, voltages no less than 170 volts can be readily taken care of with outputs lying within the stipulated tolerance of the supply authority's values. Unfortunately, the unrestricted expansion of the distribution networks has led to extremely low voltages so that the typical commercially available voltage regulators are not effective for restoring some sort of acceptable operating voltage. A research work carried out reveals that the situation in practice is much worse with consumer voltages as low as 50 volts being quite possible [1]. Statistical data reveal that 22% of stabilizers purchased by consumers did not perform satisfactorily when the input supply voltage less than 160 volts. Products like Qlinks, Binatone, Philips, Super Masters, Century etc, regulate input voltage that falls within 160 volts and 260 volts, a range that does not cater for the Nigerian buyer [2].

The automatic voltage stabilizer presented in this paper aim at designing a suitable Automatic Voltage Regulator rated 5 KVA with output 220 VAC, when the input voltage is varying between 80 VAC and 250 VAC.

2. Literature Review

[5] designed and implemented a microcontroller-based single-phase automatic voltage regulator (AVR). The design is based on the principle of phase control of AC voltage using a triac. The trigger pulse for the triac is delayed by the microcontroller to provide the desired regulator terminal voltage. This voltage is always sensed and fed back to the microcontroller via a measuring unit to get a continuous control system. The target applications of this AVR design as stated in the publication is domestic heating and lighting controls. It can also be used as an adjustable voltage source by adjusting a variable resistor in the voltage sensing circuitry. It was also intended to introduce a compact AVR and to demonstrate the usefulness of the PIC microcontroller in power control field. The uniqueness of this design is that no moving part is present and as a result, no maintenance is required. Moreover, lack of mechanical devices enables the system not to encounter wear and tear of relay contact points, fatigue of the transformer taps, etc., which, can be found in some typical automatic voltage stabilizer.

This design was able to eradicate the use of components with moving parts, as such it is free from the adverse effects of wear and tear on such parts due to ageing.

In this design the minimum input voltagethat can give a regulated output of 220 VAC is 170 VAC, hence the system cannot be used when the input voltage level is between 80VAC and 169VAC.

3. Automatic Voltage Stabilizer

An Automatic Voltage Stabilizer is a device which uses a switched autotransformer to maintain an A.C. output that is close to the standard mains voltage as possible under conditions of fluctuations. It uses relays through negative feedback, to control the position of the tap switching of relays that reduces the output voltage towards the standard voltage [4, 9, 10]. Automatic voltage stabilizers consist of two units: the sensing unit and the regulating unit. The sensing unit detects changes in the input or output voltage of the stabilizer and produces a signal which the regulating unit reacts to, and acts in such a manner as to correct the output voltage of the stabilizer to, as near as possible, the standard predetermined value [4,10].

The functional block diagram of a stabilizer utilizing electromechanical transformer tap-changing with relays is shown in Figure 1. It makes use of relays connected in series with autotransformer taps. The function of the autotransformer is to produce the required output voltage with the help of the control unit [11]. The voltage variations are accomplished by changing the ratio of transformation automatically [12]. The transformer turns ratio is accordingly varied by selecting one of a fixed number of taps using relays

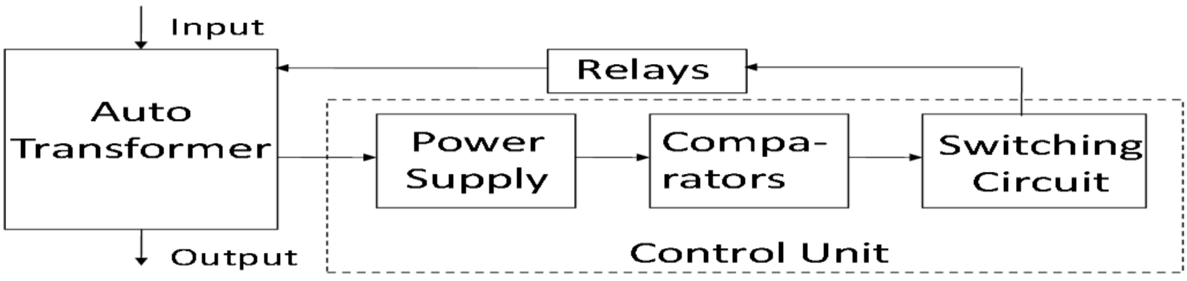

Fig. 1.Functional block diagram of an A.C. stabilizer using electromechanical transformer tap-changing with relays.

4. Methodology

The project work was designed and implemented using the top to bottom approach design method. This approach involves breaking down the design into core functional blocks to simplify the rest of the design and construction process. By allowing a more in-depth study of these functional blocks, the system as a whole can better be understood. This is often called the Input to output approach. The functional blocks are;

1. Power supply
2. Microcontroller

3. The Autotransformer
4. Display

The goal is generate and evaluate concepts for the execution and interfacing of the functional blocks, and after careful analysis of the available options, taking into proper consideration factors like component availability, cost, and others, select the most optimum design.The result of this phase was a simple low-cost microcontroller based design.

5. Design Analysis

5.1. Circuit Breaker

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect fault condition and interrupt current flow. Unlike a fuse which must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in different sizes and ratings. The Single pole miniature circuit breaker was used in this design. The circuit breaker must be able to carry the full load current without tripping the breaker and overheating, therefore the breaker rating must be equal to or above the full load current. Therefore;

$$I_B = I_{max} \quad (1)$$

Where; I_B – Breaker operating current

I_{max} – Maximum input current

I_{max}= (KVA rating /Minimum input voltage) = (5000 /80)

I_{max}= **62.5Amps**

5.2 Input Sensing

A 220 ACV/ 15 VAC step-down transformer designated as T_2 in the circuit diagram was used to step down the input supply voltage from the distribution network.

The turns-ratio of the transformer is given by the equation

$$\frac{Np}{Ns} = \frac{Vp}{Vs} \quad (2)$$

Where Vp = 220 VAC and Vs = 15 VAC

$$\frac{Np}{Ns} = \mathbf{14.7\ Volts}$$

Using the Turns-ratio of the transformer, the limits of the expected transformer secondary voltage for the operating range of the device is calculated at Vp_1 = 80 VAC and Vp_2 = 280 VAC.

(a) For Vp_1 = 80 VAC;

$$V_{S1} = V_{p1}\ x\ \frac{\text{Ns}}{\text{Np}} = \mathbf{5.5\ V_{rms}}$$

Peak secondary voltage (Vm_1) is given as;

$$V_{m1} = \frac{V_{s1}}{0.707} = \mathbf{7.8\ Volts}$$

(b) For Vp_2 = 280 VAC;

$$V_{S2} = V_{p2}\ x\ \frac{\text{Ns}}{\text{Np}} = \mathbf{19\ V_{rms}}$$

Peak secondary voltage (Vm_2) is given as;

$$V_{m2} = \frac{V_{s2}}{0.707} = \mathbf{26.9\ Volts}$$

The filtering capacitor used here is the same for that of transformer T_1. Since the microcontroller mode of operation is compatible only with dc voltage, the dc equivalent of Vm_1 and Vm_2 are calculated using the equation:

$$V_{dc} = \frac{2V_{m1} - 1.4}{\Pi} \quad (3)$$

For V_{p1} = 80 VAC and V_{m1} = 7.8 VAC

V_{dc} = **4.5 Volts**

For V_{p2} = 280 VAC and V_{m2} = 26.9 VAC

V_{dc} = **16.7 Volts**

5.2 Output Sensing

A 220 ACV/ 15 VAC step-down transformer designated as T_3 in the circuit diagram was used to step down the input supply voltage from the distribution network.

The turns-ratio of the transformer is given by the equation;

$$\frac{Np}{Ns} = \frac{Vp}{Vs} \tag{4}$$

Where Vp = 220 VAC and Vs = 15 VAC

$$\frac{Np}{Ns} = 14.7\ Volts$$

Since the expected regulated output is 220 VAC; Vp_3 = 220 VAC

$$V_{S3} = V_{p3}\ x\ \frac{Ns}{Np} = \mathbf{15\ V_{rms}}$$

Peak secondary voltage (Vm_3) is given as;

$$V_{m3} = \frac{V_{s3}}{0.707} = \mathbf{21.2\ Volts}$$

The filtering capacitor used here is the same for that of transformer T1. Since the microcontroller mode of operation is compatible only with dc voltage, the dc equivalent of Vm_1 and Vm_2 are calculated using the equation:

$$V_{dc} = \frac{2V_{m3} - 1.4}{\Pi} \tag{5}$$

For V_{p3} = 220 VAC and V_{m3} = 21.2 VAC

V_{dc} = **13 Volts**

In order to reduce this value to less than 5V, Eq (6) is applied.

$$\text{Vout} = \text{Vdc}\frac{R_1}{R_1 + R_2} \tag{6}$$

Thus to find the resistances of the voltage divider network that we require to rescale the input dc voltage, we equate the maximum expected value of $V_{out}$to 4V. If a fixed value for R1 is assumed as 1kΩ, we calculate using the following parameters;

R_2 = **444.4**□

5.3Autotransformer Design

Table 1. Table of Autotransformer Specifications

Maximum Input Voltage	250 V
Minimum Input Voltage	80 V
Output Voltage	220 V
Supply Frequency	50 Hz
kVA Rating	5 kVA
Number of Phases	Single Phase
Cooling Medium	Natural Air (AN)
Design Type	Shell Type
Conductor Material	Copper
Input Voltage Levels (Tap Voltages)	70 V, 100 V, 130 V, 160 V, 180 V, 210 V, 240 V,

5.3.1. Current Calculation

5.3.1.1 Maximum Input current (I_{max}) is given by;

$$I_{max} = \frac{kVA\ Rating\ X\ 10^3}{Minimum\ \ Input\ \ Voltage} \quad (7)$$

I_{max} = **62.5 Amps**

5.3.1.2 Minimum Input current (Imin) is given by;

$$I_{min} = \frac{kVA\ Rating\ \ X\ 10^3}{Maximum\ \ Input\ \ Voltage} \quad (8)$$

I_{min} = **20 Amps**

5.3.1.3 Output current (I_{out}) is given by;

$$I_{out} = \frac{kVA\ Rating\ \ X\ 10^3}{Output\ \ Voltage} \quad (9)$$

I_{out} = **22.7 Amps**

5.3.2 Core Design

5.3.2.1 The voltage per Turns (V_t) is given by:

$$Vt = C\ X\ \sqrt{kVA\ Rating} \quad (10)$$

C = A constant which depends on the material and Labour cost and is 0.6 V for shell type transformer.

Vt = **1.4 Volts/Turns**

5.3.2.2 Net Core Area

The induce E.M.F of the transformer is given by:

$$E = 4.44NB_mAF \quad (11)$$

$$\frac{E}{N} = V_t = 4.44B_mAF \quad (12)$$

Where, E = R.m.s value of the applied phase voltage

F = Supply frequency

N = Number of turns

B_m = Maximum value of flux density = 1.0×10^{-6} wb/mm^2

A = Net core area

A = **6306.3 mm^2**

The maximum flux (ϕ_m) for a given core is given by;

$$\phi_m = B_m x\ A \quad (13)$$

ϕ_m = **6.3×10^{-3}wb**

5.3.3 Calculation of Winding Area (A_w)

This parameter can be calculated using the relationship;

$$A_w = \frac{kVA\ Rating}{2.22\ F\ \phi_m k_w 10^{-3}} \quad (14)$$

k_w = Window space factor; and J = Current density

k_w can be calculated using the formula;

$$k_w = 0.1 + 0.08\ log_{10}\left\{\frac{kVA}{0.1}\right\} - 0.2log_{10}(0.23) \quad (15)$$

k_w = **0.36**

Current density (J) is given by;

$$J = \frac{I_{max}}{A_C} \quad (16)$$

Recall Imax = 62.5 Amps from Eq.(7)

With this current value, the corresponding Area of Copper (A_c) with this ampacityobtained from an SWG table is 21.15mm^2 which is gauge 4

J = **2.9 A / mm^2**

Therefore, A_w = **6848.7 mm^2**

5.3.4 Window Dimensions

Using the ratio of 2 to 4, the width and length of the window can be calculated as follows;

$$A_w = W_H \times W_w \quad (17)$$

Where, Window height (W_H) = 4L
Window width (W_w) = 2L
A_w = 4L x 2L = **$8L^2$**
L = **29.3 mm**
So that, W_H = 4 x 29.3 = **117.2 mm**
W_w = 2 x 29.3 = **58.6 mm**
A_w = **6867.9 mm**

5.3.4 Winding Calculation

The number of turns for each voltage is given by;

$$N = \frac{Voltage\ \ at\ tapping}{Voltage\ /Turn\ (V_t)} \quad (18)$$

At 70 V Tapping, N_{100} = (100 / 1.4) = **71 turns**

Table 2. Number of turns per voltage

S/N	VOLTAGE AT TAPPING (V)	NUMBER OF TURNS (TURNS)
1	100	71
2	120	85
3	150	107
4	180	129
5	210	150
6	240	171

5.3.5 Turns per Layer

$$\text{Turns per Layer} = \frac{Window\ \ Height}{Diameter\ \ of\ Conductor}$$

(19)

The height occupied by the winding is given approximately as;

H_w = Height of window (W_H) – 10% of window height (20)

Recall, W_H = **117.2 mm**
H_w = 105.5**mm**

At Imax = 62.5 Amps, J = 2.9 A/m^2 and A =21.15 mm^2

Area of a circular conductor is given by;

$$A = \frac{\Pi d^2}{4} \quad (21)$$

Given the above relationship the required diameter for I_{max} = 62.5A is calculated as
d = **5.2 mm**

Therefore Turns per layer of the autotransformer is calculated as;

$$\text{Turns per layer} = \frac{H_w}{d}$$

(22)

Turns per layer = **20 turns/layer**

Using the turns per layer and the total number of turns, the number of layers is given by;

$$Number\ of\ layers = \frac{Total\ Number\ \ of\ turns}{Turns\ \ per\ \ layer} \quad (23)$$

Total number of turns = 171 (from Table 2)
Number of turns = 8.55 (Approximately 9)
Number of turns = **9**

5.3.6 Stack Height

Window Area (A_w) = Stack Height x Window width (W_w) (24)
Stack Height = **117.2 mm**

6. Mode of Operation

Assuming the Input voltage is 170 VAC, when the mains switch is powered ON, transformer T1 and T2 receives the 170 VAC at their inputs and the voltage is stepped down, and rectified. The rectified output from T1 is regulated to 8 VDC and 5 VDC respectively. The regulated 8 VDC from transformer T1 is used to power Relay RL1 to RL7 and the 5 VDC is used to power the LCD and the Microcontroller.

Also, when the mains switch is powered ON, 170 VAC is fed to the Normally Close (NC) terminal ofan under/over voltage protection relay RL1 and to the Normally Open (NO) of RL2 to RL7. The COMMON pin of relay RL2 to RL7 is connected to the various taps of the Autotransformer.

Transformer T2 is used to sense the input voltage and T3 to sense the output voltage. When the Mains inputis within the workable voltage range 80 VAC to 250 VAC, the mains input is connected to the various tap of the Autotransformer. Also, when the mains input voltage falls below 80 VAC or Increases above 250VAC, relay RL1 is energized cutting off power supply to the autotransformer.

The microcontroller monitors the mains input voltage variation from the distribution network over the specified window (80 VAC-250 VAC) in categories of threshold voltages. A single category of threshold voltage will cover a specified voltage range, and at the detection of a new threshold voltage, the microcontroller energizes the appropriate relay by sending an output HIGH (equivalent to VCC) with the help of a Relay-driver IC, the ULN2003A. The 5V from the microcontroller starts a sequence of operations that energizes the relay which in turn makes the required contact, thus completing the circuit to the connected tap and varying the Turn-ratio of the Auto-Transformer, such that the output voltage falls within 220V±6%.

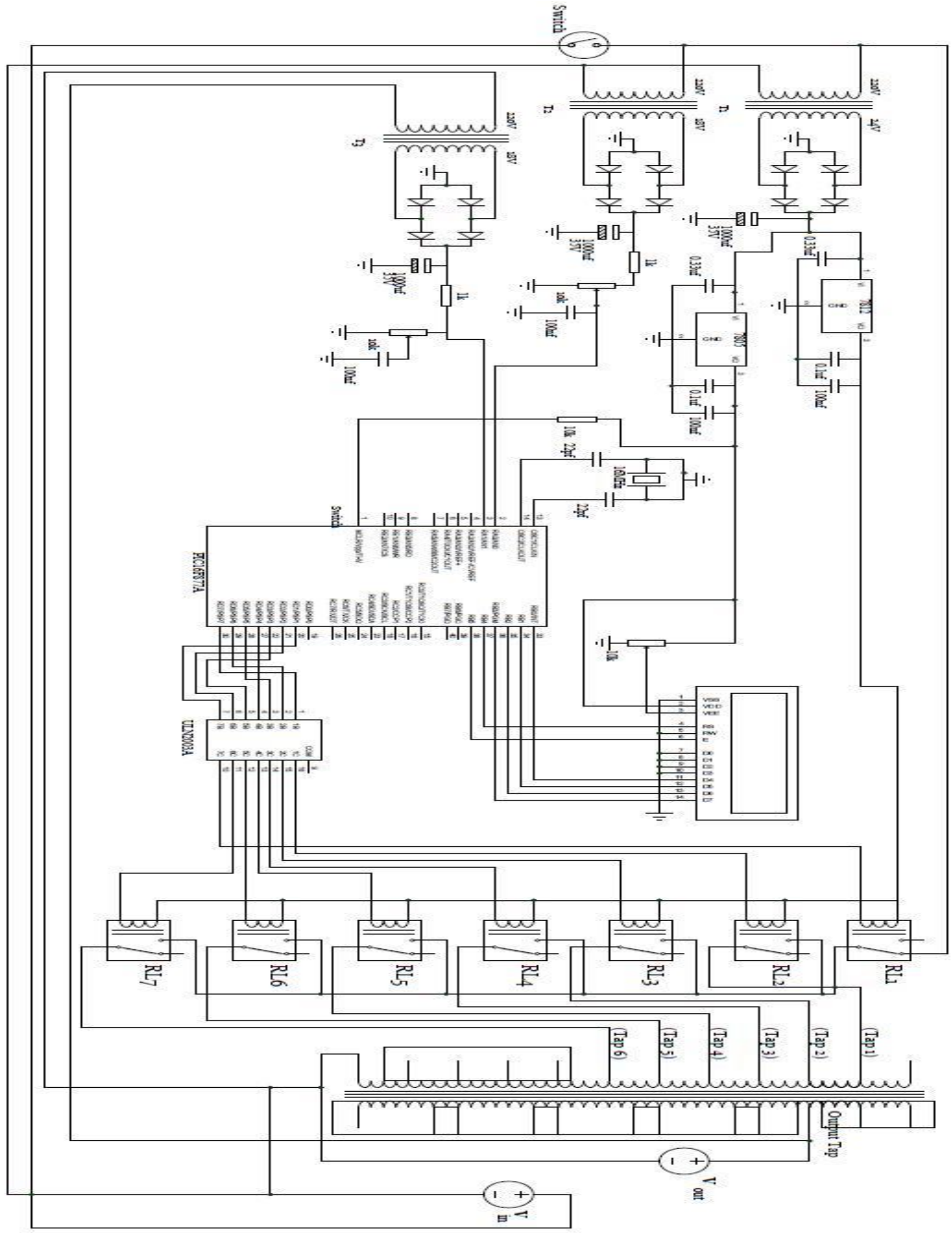

Fig. 2.Circuit Diagram of the 5 kVA Microcontroller Based Automatic Voltage Stabilizer.

7. Test and Results

7.1 Test

The system was connected to a Variac to observe the Output Voltage at selected input voltages and the following results were obtained.

Table 3. 5 kVA Stabilizer output at different input voltages.

Input From Variac (Volts)	Stabilizer Output (Volts)
70	0
80	216
100	217
120	217
140	218
160	218
180	220
200	220
220	222
240	222
250	225
270	0
300	0

8. Conclusion

This paper has covered the implementation of a microcontroller based 5 kVA Automatic Voltage Stabilizer. The system was design, constructed and tested using a variac to supply the various voltage range (80 VAC – 250 VAC) at the input and the output giving a stabilized 220 VAC ± 6% which is required for the satisfactory operation of electrical and electronics appliances. This system offers a better regulation because of some peripheral modules contained in the PIC microcontroller.

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