DEVELOPMENT OF A MULTI AC/DC POWER SUPPLY SYSTEM FOR DOMESTIC AND LABORATORY USE

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ABSTRACT

With today's technological advancement, new miniaturized electrical and electronic products continue to emerge and these products require either a very low AC source or DC source for their operation. Many of the existing power supply devices with various levels of complexities and sophistication can only give a single DC output which cannot serve the same purpose when a very low AC power output is greatly desired. Hence, the need for designing and developing a multi-output power supply that can serve a dual purpose of providing DC and AC outputs of different values for use in miniaturized electrical and electronic appliances as well as for various domestic and laboratory experimental purposes. In this work, a simple, cost effective and reliable power supply that produces AC outputs of 5V, 10V, 15V, 20V and 25V, variable DC outputs of 0-20V, regulated DC output of 5V and regulated dual DC outputs of $\pm$15V was developed. The system consists of two sections; AC and DC with DC section comprising three segmental subsections. A centre tapped transformer 220/30V (15V-0-15V) was constructed to produce the desired AC voltage range 0-30V at interval of 5V, For the DC section, 25V, 20V and 15V from the output of the transformer were rectified, smoothened and regulated using appropriate discrete components. The major components used include transistors, comparator LM393 and regulators LM317, LM7915 and LM7815. Short circuit test, open circuit test and earthing test were carried out on the developed power supply unit. The output measurements showed that the power supply was functional and the measured values gave minima variation from the nominal designed values. The developed multi output power supply is much useful in measurements, laboratory works and general applications requiring power supply.

Keywords: *miniature, AC source, DC source, multi-output power supply, accuracy.*

1. INTRODUCTION

In this golden age of technological advancement, the need to design and develop multi-output power supply units in most developing countries of the world, like Nigeria, has been on the increase and has remained one major area of an intense research. The electricity supply from the national grid is an alternating current (AC). At the consumers' end, after series of step-down processes, the walls' outlets carry a 50Hz, $220V_{rms}$ AC voltage supply. The energy from the wall outlet is practically limited; however, it must be converted from the alternating current (AC) to the direct current (DC) form and tailored towards providing the suitable levels of voltages for driving most electronic equipment. This can be achieved by using a DC power supply unit (PSU) [1,2]. The PSU is a device that supplies electrical power to a device or group of devices [1,3]. The term 'PSU' is commonly applied to units that are integrated with devices the supply power to such as computers and household electronic appliances. The PSU used in the laboratory for experimental purposes is called a laboratory bench supply [1]. It is usually a variable power supply unit which can either supply a uni- or bi- polar power to the load connected. Aside the aforementioned, there are cases when the need to power other electrical appliances using a very low AC source either for domestic use or laboratory experimentation arise. In these situations, the DC output is less useful. Hence, the need to design and develop a simple, cost effective, functional and reliable multi-output power supply that can serve a dual purpose of providing DC and AC outputs of different magnitudes for satisfying the desired need.

In this design, transistors, comparators and regulators have been used as the basic building blocks in order to facilitate a robust design to give the desired multi-output required. Hence, reducing the number of components used in circuit design and also increases the functionality of the power supply unit.

2. BASIC OVERVIEW OF THE DEVELOPED MULTI-POWER SUPPLY

The requirement of regulated DC and AC power supplies differ widely among the various electrical and electronic devices. The main characteristics that need to be considered in the design of a regulated power supply are the output DC voltage (V_{dc}), maximum current (I_{max}) required by the load, the tolerance level and the percentage regulation

(%Reg) allowable [1,2,4,5]. In addition, the AC output level needed by the load must also be considered for the case of a multi-output power supply. Figure 1 shows the generalized block diagram of the designed multi-output power supply unit. Each block in the diagram represents a section of the circuit that carries out a specific function. The functional block diagram of figure 1 also shows the interconnection between these blocks.

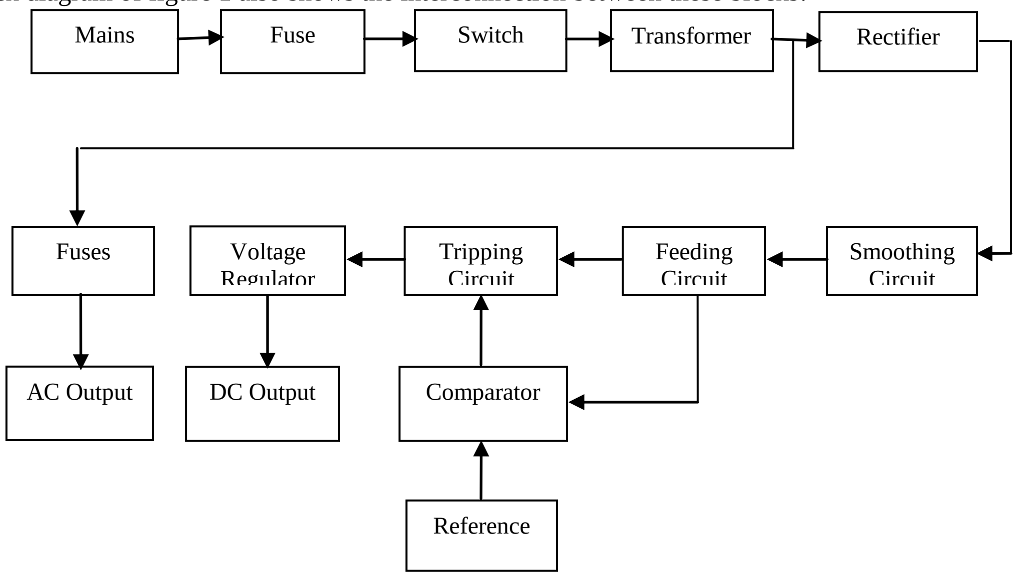

Figure 1: Block diagram of a multi-output power supply

The basic and integral components of the block diagram in figure 1 above are briefly described below.

- **The Transformer:** The centre-tap transformer initially takes the input supply from AC mains voltage of 220V and steps it down to a lower voltage level of 30V (15V-0-15V). However, after construction, the desired voltage range was obtained at the output.
- **The Rectifier:** The AC voltage from the transformer is rectified using half wave rectifier to give equal positive and negative voltages. The output is DC in a sense that it does not change polarity, but it has periodic variations in voltage about a steady value called ripples [6,7].
- **The Smoothing Circuit:** The ripples are smoothened using a low-pass filter in the form of a shunt capacitor. Choosing capacitors that are sufficiently large, the ripple voltage is reduced to a low level [4,7].
- **The Feeding Circuit:** This is the circuit that feeds in the rectified voltage after smoothing into the comparator for the purpose of comparison. It therefore serves as an input for the comparator.
- **The Comparators:** These are voltage sensors which compare two voltages and give an output, which tells if they are equal or not [8]. The comparator therefore serves as a controller for the tripping circuit to determine when it will be on or off. It compares the input from the feeding circuit with that of the reference and takes decision whether the switching circuit should be on or off.
- **The Tripping Circuit:** This control the voltage regulator by switching it off when there is an over-current. The source of this control is the comparator.
- **The Voltage Regulator:** This is the stage that delivers a stabilized DC voltage to the output as set by the control unit [7,9]. The regulator circuit provides a fixed voltage for stable calibrated DC output voltages. Usually zener diodes and transistors are used for voltage regulation purposes [7].
- **Fuses:** Fuses are over-current protection devices, therefore protecting the circuit and other components from damage due to excessive current.

3. DESIGN AND IMPLEMENTATION

This work involves the design of AC output circuit, variable DC circuit, regulated DC and regulated DC dual rectified circuit, construction of the designed circuit and testing of the power supply.

3.1. Design of AC Output Circuit

A centre tap transformer initially rated 15-0-15 was wound to give the output of 25V, 20V, 15V, 10V, 5V, 0V. This was done using equation (1) [7]. However, the 30V output was not used.

$$\frac{V_1}{V_2} = \frac{n_1}{n_2} \quad (1)$$

Where V_1= Primary voltage of the transformer

V_2= Secondary voltage of the transformer

n_1= Number of turns on the primary side of the transformer
n_2= Number of turns on the secondary side of the transformer

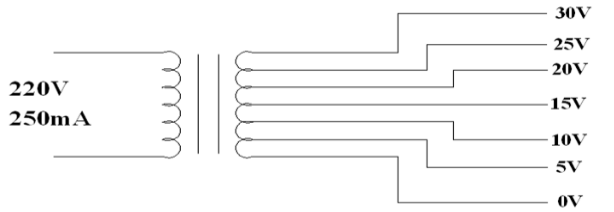

Figure 2: Circuit Diagram for AC Regulated Output

3.2. Design of 5V Regulated DC

The major sections of the regulated dc supply are rectification, smoothing, control and voltage regulation as shown in the block of figure (1) above. This applies to all the regulated power supplies that are designed in this work.
The rectification section employs bridge rectification that comprises of four (4) diodes IN4007 while the smoothing was carried out using two 1000µF 50V capacitors. Since the desired regulated output voltage is 5V, input of 10V was used in the design to cater for instance of low voltage in the 5V output design since at least 7V is required for the LM7805 regulator according to data sheet. Using equation (2) adapted from [7], we obtain the root mean square value of the maximum possible rectified voltage after smoothing as shown in equation

$$V_{rms} \;=\; V\sqrt{2} - V_d \tag{2}$$

Where $V =$ Input voltage to the rectifier
V_d = Forward voltage of the diode

In this case V=10V and V_d = 2 X 0.7 =1.4 (since there are two diodes involved in each cycle).
Therefore,

$$V_{rms} \;=\; 10\sqrt{2} - 1.4 = \; 12.74V$$

At 220V ac supply into the transformer, the maximum possible rectified voltage after smoothing is 12.78V. The limit of the input for maximum input voltage is 35V.
At the comparator section, R3 is the voltage dropper or current limiter. D5 is a zener diode = $5V_1$ as a reference. When the comparator input is high then, the output voltage of the comparator ($V_{control}$) is low and the switch is ON. When $V_{control}$ is high, the switch is OFF.
As shown in figure 3, a Darlington pair was used in the switching to boost the current R4 and R6 are the bias resistors. It turns ON if the V_{BE} is -0.6V at Q2 since PNP transistors were used.

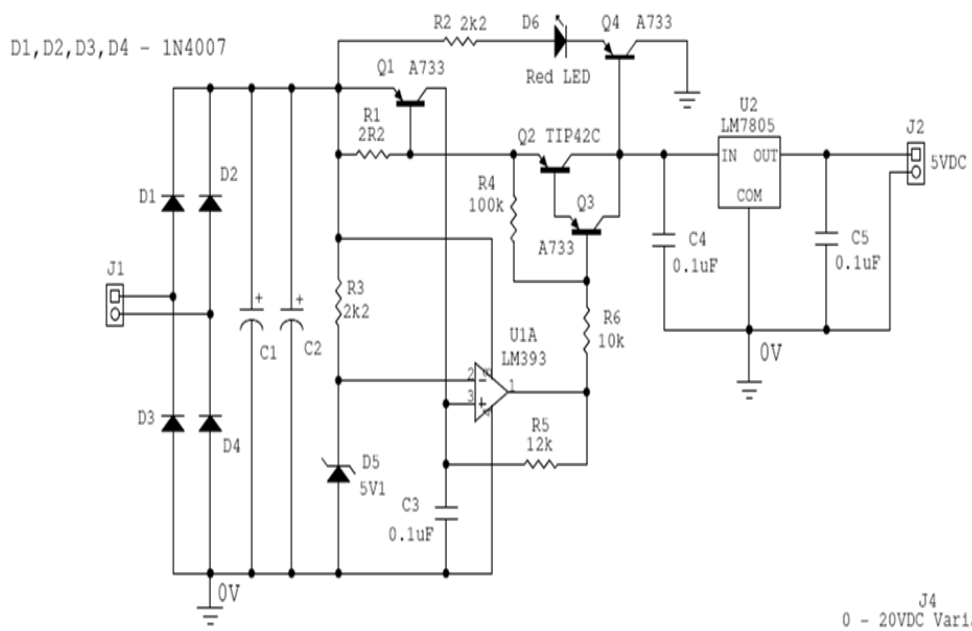

Figure 3: Circuit Diagram for Regulated DC Circuit

3.3. Design Current

Since it is desirable to have a design of 250mA, there is need to determine the resistor suitable for that at 0.6V using equation (3) [7]:

$$V = IR \qquad (3)$$

$$R = \frac{0.6V}{250mA} = 0.0024k\Omega = 2.4\Omega$$

2.4 Ω was not common in the market; therefore 2.2 Ω which was available was used

Therefore the new maximum current was calculated.

$$I_{\max(new)} = \frac{0.6}{2.2}\Omega = 0.2727A = 272.7mA$$

3.4. Tripping Circuit

The tripping circuit is incorporated in figure 3. The resistor R1(2R2) develops a voltage proportional to the amount of current flowing through it. This voltage is sensed by the comparator U1A(LM393) through transistor Q1(A733) and compared to the 5.1V zener voltage reference of D5. When the reference voltage is exceeded the output of the comparator switches high, with its voltage approaching the positive supply rail's voltage. This voltage then switches off the PNP Darlington circuit of Q2(TIP42C) and Q3(A733). At the same time, the low voltage that consequently appears at the collector of the Darlington pair switches on transistor Q4(A733) and thus, there is a current path through its emitter to its collector which results in the glowing of the indicator LED D6. The LED turns ON only when the switch is off that is, when the supply has tripped. R2 was used as current limiter for the LED. C4 and C5 were used to suppress transient effects on the input and the output respectively of the regulator. This tripping circuit is also incorporated in each of the DC segment of figures 4 and 5.

3.5. Design of Variable DC Circuit

In this segment of the power supply, it is desirable to design a variable dc supply ranging between 0V-20V. In this case V=20V and V_d = 2 X 0.7 =1.4 (since there are two diode involved in each cycle). Therefore, referring to equation (2),

$$V_{rms} = 20\sqrt{2} - 1.4 = 26.88V$$

At 220V ac supply into the transformer, the maximum possible rectified voltage after smoothing is 26.88V. C9 performs same function as C4 earlier explained.

According to the data sheet, the equation governing the output of LM317 regulator used is given by (4) [10]:

$$V_{out} = 1.25\left(1 + \frac{R13}{R14}\right) + I_Q R_{14} \qquad (4)$$

Where I_Q = 100µA

LM317 is a differential regulator with respect to its output. Hence, it can be used to regulate both high and low resistance.C10 improves ripple rejection. D12 and D13 protect the regulator against discharge of the capacitors C11 and C10. The D14 and D15 were included to enable the achievement of 0V in the variation.

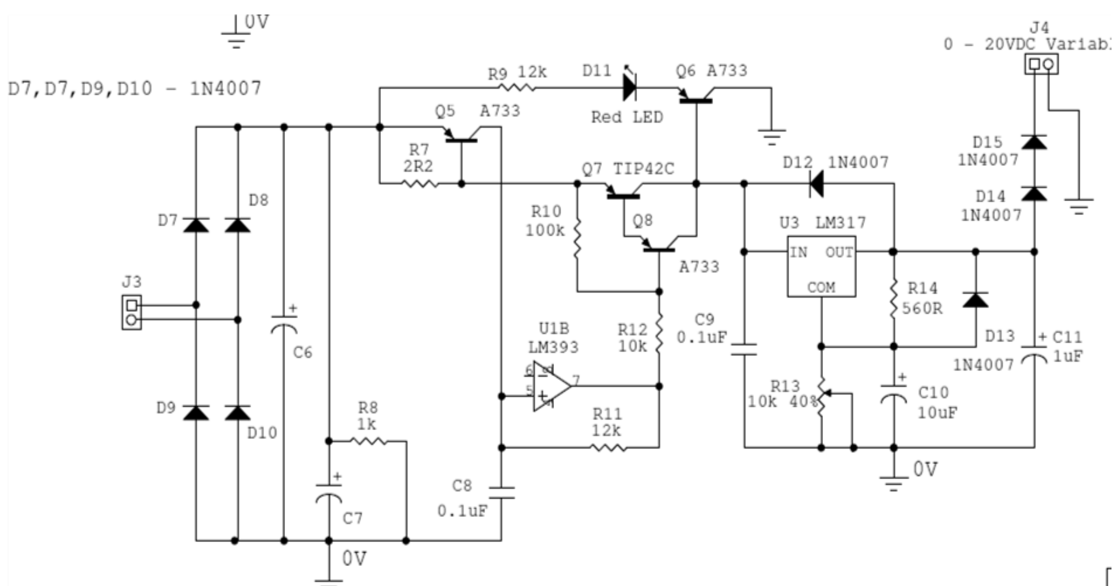

Figure 4: Circuit Diagram for Variable DC Circuit

3.6. Design of Regulated DC Dual Rectified Circuit

This dual rectified circuit is intended to produce $\pm\mathbf{15}\boldsymbol{V}$. Unlike the other regulated dc circuits , it makes use of two half wave rectification. One for the positive output and the other for the negative output as shown in figure (4).

In this case V=15V and V_d = 0.7 (since there is only one diode involved in each cycle). Therefore, referring to equation (2), we have:

$$V_{rms} = 15\sqrt{2} - 0.7 = 20.5V$$

At 220V ac supply into the transformer, the maximum possible rectified voltage after smoothing is 20.5V goes into LM7815 used as regulator. D22 and D18 protect the regulator against discharge of the capacitors C22 and C8.

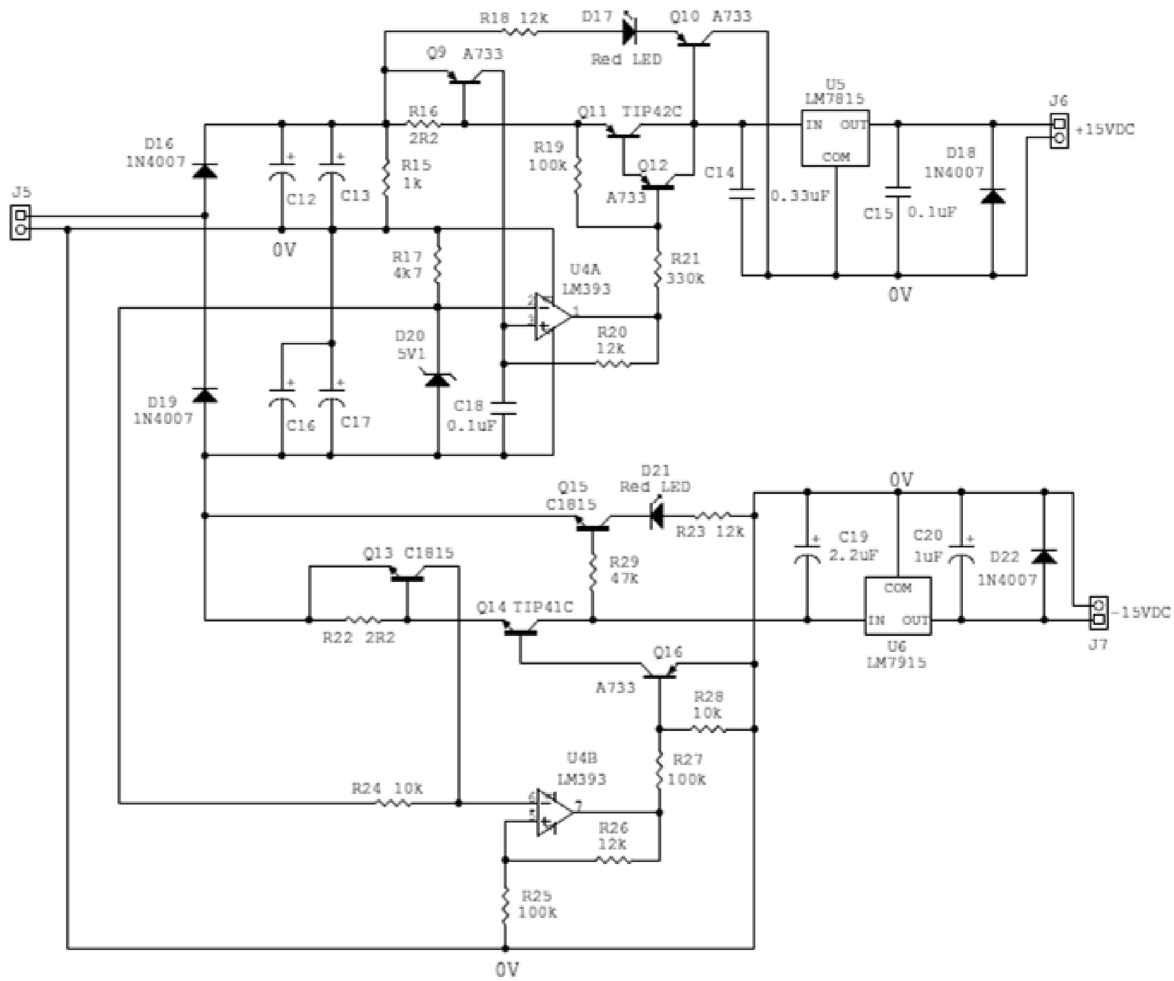

Figure 5: Circuit Diagram for Regulated DC Dual Rectified Circuit

4. DEVELOPMENT OF THE POWER SUPPLY

After drawing the circuit diagram using circuit maker, the circuit was converted to a PCB format and etched. The power supply unit was then constructed using circuit diagrams in figure2, figure3, figure4 and figure5 above. Having constructed the power supply unit according to the block diagram in figure1, the final construction of the power supply unit, showing major components is indicated in figure6.

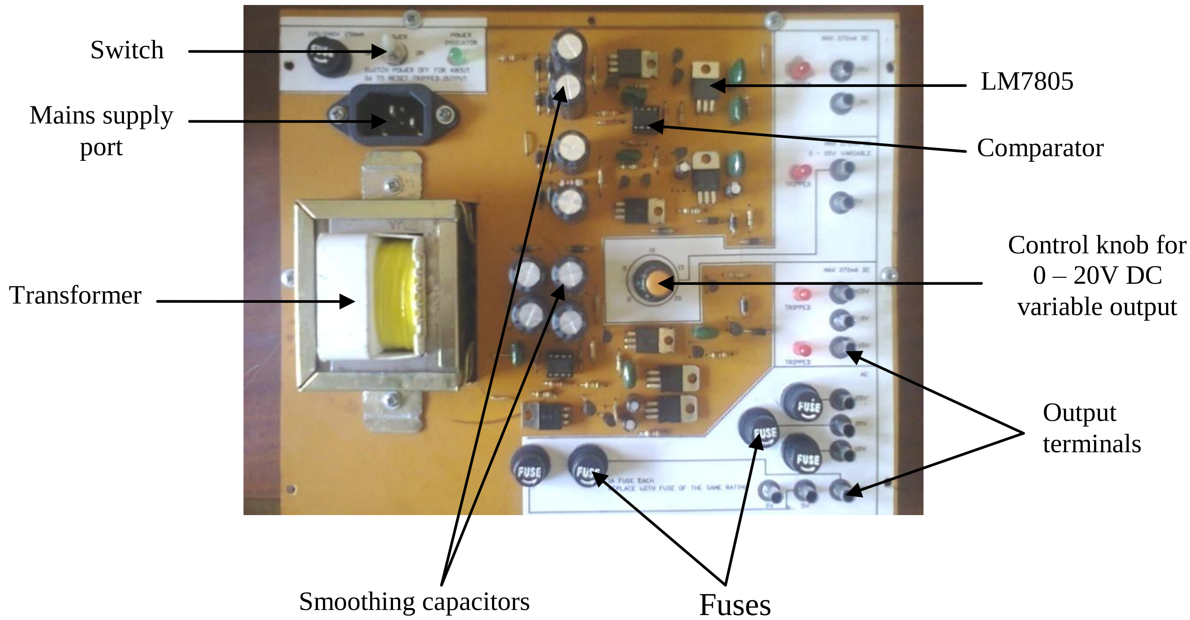

Figure 6: Final construction of the power supply unit

4.1. Input Connection

The input connection to the power supply unit is actually an ac supply of 220/240V which is supplied to the power supply unit using a cable. The specification of the cable is 10A 250V PVC.

4.2. Output Connection

Output connection to the load from the power supply unit is made possible by the use of banana wires which can be connected to the unit's terminals.

5. SAFETY MEASURES

The power supply unit was designed with keen attention given to protection of the unit and safety of the user. The measures include; the inclusion of fuses and tripping circuits. Earthing test is conducted to ensure that users are not unnecessarily exposed to electric shock. Furthermore, short-circuit test is carried out to ensure that the unit is protected from overloading arising from the excessive drawing of current by the external load.

6. RESULTS AND DISCUSSION

The developed power supply was tested and the output of each section was measured. The summary of the results are hereby discussed as follows.

6.1. Testing and Measurement

Tests were conducted on the developed power supply unit. These include short circuit test and earthing test. The output measurement was done using digital multimeter. In each segment, measurement of the output was made five times and the average of the measured values was obtained.

6.1.1. Short Circuit Test

Short circuit test conducted on the four sections of the power supply showed that the tripping circuit worked efficiently by tripping on the LED in each of the section specially designed to show short circuit.

6.1.2. Measurement

Measurements were carried out to determine the output voltages of the AC and DC sections. The obtained values were compared with the nominal values on the unit as shown in Table1 and Table 2.

Table 1: Tests and Results for AC Circuit Output

AC OUTPUT	AC OUTPUT VOLTAGE AT VARIOUS TERMINAL
25V	24.3V
20V	19.7V
15V	14.7V
10V	9.8V
5V	5V
25V	24.3V

Table 2: Tests and Results for DC Circuit Output

TEST	RESULT (Average of 5 measurements)
Regulated 5V output	4.97V output
Regulated 15V dual output 15-0-15	14.7V(positive0 -15,1(negative)
Variable DC output	0 – 21V

The results shown in Table1 and Table2 indicate that the output measurements at various sections gave values comparable to the nominal values of the terminal voltages. The 5V regulated output in particular was within $\pm$5% of the designed output as stipulated in the regulator's data sheet i.e. 4.75V-5.25V.

7. CONCLUSION

Due to the need for most domestic and laboratory equipment of small ratings to be powered by electricity in one form or the other coupled with the problem of insufficiency of number of specially designed power supply for the needed domestic application or laboratory experiment as well as electrical project design, a multi-output power supply unit was developed. The developed multi-output power supply consists of four segmental outputs; AC output, variable DC output, regulated dual rectified DC output and regulated single DC output. The AC outputs produced 5V, 10V, 15V, 20V and 25V. The variable DC output produced values ranging from 0-20V while the regulated and regulated dual outputs produced 5V and $\pm$15V respectively. Tripping circuit was incorporated with transistors TIP41C and TIP42C and comparator LM393 and was provided to guard against overloading and short circuit for the DC circuits while fuses were used to protect the AC circuit. Short circuit test and earthing test were carried out on the developed power supply unit. The output measurements showed that the developed power supply was effective and the measured values gave minima variation from the nominal designed values. The developed system is cheap, robust and very useful for domestic application and laboratory experimental purposes.

8. REFERENCES

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