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Design and Construction of 2A, 0 – 15 V dc Variable, Regulated Power Supply

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Abstract: *Basic household circuits use regulated dc power supplyfor operation. In this research work, locally sourced materials and components were used to implement a designed circuit of a variable dc regulated power supply. The step down transformer used has about 53 and 708 turns for its secondary and primary coils respectively. The ac output voltage of the transformer was 17 Vrms, while the dc output voltage was 24 V. The performance of the power supply revealed that the regulation of the power supply is good and the overload protection is active for the set range of operational current. This will protect the series-pass transistor from getting damaged easily.*
Keywords: *Voltage regulation, Overload protection, Power supply, Transformation*

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I. Introduction

Almost all basic household circuits need an unregulated alternating current (ac) to be converted to constant direct current (dc) in order to operate the electronic device. Also, all devices have a certain power supply limit and the electronic circuits inside these devices must be able to supply a constant dc voltage within this limit (Martin, 1985). This means that, all the active and passive electronic devices will have a certain dc operating point (Q point) and this point mustbe achieved by the source of dc power.

A regulated power supply aside for household usage, gains much usage in carrying out electronic practical for students in related professions. The national power grid comes in the form that needed to be stepped down, rectified and then regulated to be useful for such students' practical works.

The rectified pulsating dc output is filtered to virtually eliminate the large voltage variations. For capacitor-input filter for instance, when the diode is forward biased, it allows the capacitor to charge to within a diode drop of the input peak. When the input begins to decrease below its peak, the capacitor retains its charge and the diode becomes reverse-biased. During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the $R_L C$ time constant. The variation in the output voltage due to the charging and discharging of the capacitor (ripple) needed to be filtered. The smaller the ripple, the better the filtering action. The ripple factor is an indication of the effectiveness of the filter and it is defined as:

$$r = \frac{V_r}{V_{dc}}, where\ V_r\ is\ the\ rms\ ripple\ voltage\ and\ V_{dc}\ is\ the\ dc\ value\ of\ the\ filter's\ output\ voltage.$$

The lower the ripple factor, the better the filter (Theraja, 1996).

The filtered dc voltage is further regulated. It is usual for the voltage of a power supply to remain fixed independent of the load current. Some factors such as IR drops across the transformer, filter choke winding resistances, changes in the line voltage and even component aging may result in voltage variation in a power supply (Brophy, 1977). To maintain constant output voltage however, voltage regulator devices are made part of the power supply circuit.Zener diodes and transistors are widely used for this purpose. As the input voltage varies for instance, the zener diode maintains an essentially constant voltage across the output terminals (line regulation). Also, the zener diode maintains a constant voltage with a variable load resistor across the terminals (load regulation). The percentage regulation specifies the performance of a voltage regulator. The percentage-input regulation specifies how much change occurs in the output voltage for a given change in input. It is given as percentage change in V_{out} for a one volt change in V_{in}. The percent load regulation specifies how much change occurs in the output voltage over a certain range of load current values, usually from minimum current (no load) to maximum current (full load). It is expressed as:

$$Percent\ load\ regulation = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%,$$

$$where\ V_{nl}\ is\ the\ output\ voltage\ with\ no\ load\ and\ V_{fl}\ is\ the\ output\ voltage\ with\ full\ load.$$

This study provided a design and construction of a regulated power supply, which can supply voltage ranging from 0 – 15 V. This can then be used for a mass production of a variable regulated power supply for household and laboratory use.

II. Methodology

Different designing stages were made. The first was transformation stage. A 2 KWV transformer was opened up and the laminations removed so as to rewind the transformer. The number of primary and secondary turns was obtained from transformer equations:

$$E = 4.44Nf\emptyset$$

whereN is number of turns, f is the operating frequency (50 Hz for Nigeria mains supply) and $\emptyset = a \times \beta$, where a is the cross sectional area of the coil and β is flux density (given as 1.1 wb/m^2).

With primary voltage of 240 Vrms and the expected output voltage of 18 V, the number of turns for primary and secondary are calculated to be 708 and 53 turns respectively. The transformer was then accordingly rewound.Continuity test carried out on the coils showed that the internal resistances of primary and secondary coils are 11.5 Ω and 0.3 Ω respectively. The source and output voltage of the transformer was measured as 220 V and 16 V respectively.

The other designing stages involved are the rectifying, filtering and regulating stages. Integrating the four stages gave the circuit diagram of the constructed power supply.The circuit diagram was transferred to Copper Clamp Board in preparation to getting the Printed Circuit Board (PCB) using heat transfer method. Etching process was achieved using cupric chloride which was heated to accelerate the etching. The PCB was then exposed to drying and was followed by drilling for component installation.

III. Construction Analysis and Results

3.1 Design and Construction Analysis

The laminations of the transformer were removed to give way for rewinding of the secondary and primary turns. The Forma's dimensions were taken with the following values:

$$A = 4.3\ cm, B = 3.2\ cm, h = 1.7\ cm\ and\ L = 4.4\ cm.$$

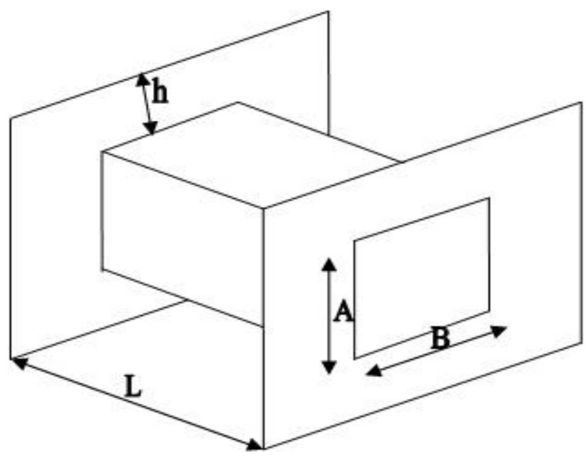

Fig. 1: The Transformer Forma

Let d_1 be the diameter of the primary coil and d_2 the diameter of the secondary coil. From the transformer equations,$E = 4.44Nf\emptyset\ and\ \emptyset = a \times \beta$,the numbers of turns of primary and secondary coils are obtained as follows:

From Fig. 1, $a = A \times B = 4.3 \times 10^{-2} \times 3.2 \times 10^{-2} = 1.376 \times 10^{-3} m^2$.

This gives the value of E to be: $E = 4.44N \times 50 \times 1.376 \times 10^{-3} \times 1.1 = 339 \times 10^{-3} N$.

It implies that $N = \frac{E}{339 \times 10^{-3}}$.

Now, using the primary voltage as 240 V (mains supply) and the expected output voltage as 18 V, the number of turns for primary and secondary turns are obtained.

For $E_1 = E_P = 240\ V, N_1 = \frac{240}{339 \times 10^{-3}} = 708\ turns$

Similarly, $N_2 = \frac{18}{339 \times 10^{-3}} = 53.08 \approx 53\ turns\ (E_2 = E_s = 18\ V)$.

The ac output of the transformer is 17 V. This was used to determine the output voltage of the dc power supply as follows:

$V_{out} = V_{dc} = 1.41V_{ac}$ (Rs component data book on transformers)

$$= 1.41 \times 17 = 23.97 \approx 24\,V$$

There was need to discharge capacitor when circuit is switched off, hence a choice of Bleeder resistor $R_1 = 3.3k\Omega$. The voltage specification of D_1(zener diode is 6.8 V, hence, $V_{R2} = 24 - 6.8 = 17.2\,V.$

Let $I_{R2} = 10\,mA$, then $V_{out} = \frac{17}{10mA} = 1.7\,K\Omega$

The value of R_2 was then taken to be 1.5 $K\Omega$ (standard value). Let R_3 be 100 Ω.

The resistorsR_6 and R_5 were obtained as follows: At a steady state condition, $V_{fb} = \frac{V_o \times R_6}{R_6 + R_5} = V_{D1} = 6.8\,V$ (breakdown voltage).$V_o = 15\,Vmax$

$$\therefore \frac{15 \times R_6}{R_6 + R_5} = 6.8$$

$$or\ \frac{R_6}{R_6 + R_5} = \frac{6.8}{15}$$

$$or\ 1 + \frac{R_5}{R_6} = 2.21$$

$$\therefore \frac{R_5}{R_6} = 1.21$$

If $R_6 = 2.2\,K\Omega, then,$

$$R_5 = 2.2K \times 1.21 = 4.85K\Omega$$

The value of R_5 was then chosen to be 4.7KΩ.

The choice of overload resistor R_4 was also made from the following design:

The$V_{BE} = 0.6\,V$ atroom temperature. Let maximum current (I_O) before the trigger of overload protection be 1 A. Then $V_{BE} = I_o \times R_4\ or\ R_4 = \frac{V_{BE}}{I_o} = 0.6\,\Omega$. To attain this current, the value of resistor R_4 is reduced to 0.25Ω, that is, four 1 Ω resistors in parallel.

The circuit diagram as shown in Fig.2 showed the different stages involved to accomplish a power supply and the components specifications while Fig. 3 is the art work in printed circuit board (PCB).

3.2 Performance of Power Supply with Load

The performance of the power supply with load was investigated. This was done by loading the power supply and the corresponding voltage and current measurements recorded. Table 1 and Fig. 3 show the variation of current with voltage and a plot of current versus voltage respectively. From the table, the variation of current with load revealed sharp increase in current from 0.348 to 1.457 A as the load decreased from 30 to 10 Ω. This observation could be the effect of the protective resistor and transistor, as contained in the circuit.When the voltage passing through the resistor is close to

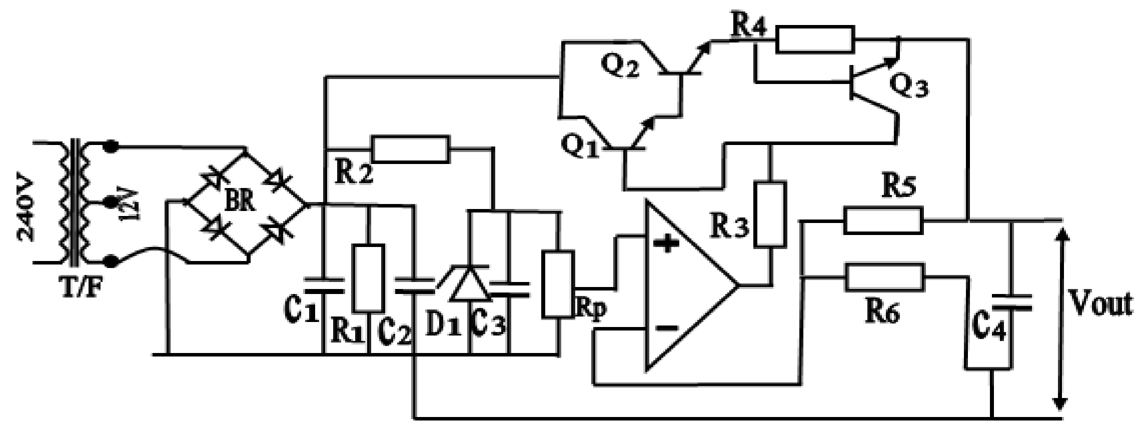

Fig. 2: Circuit Diagram of 0 – 15 V Variable Power Supply

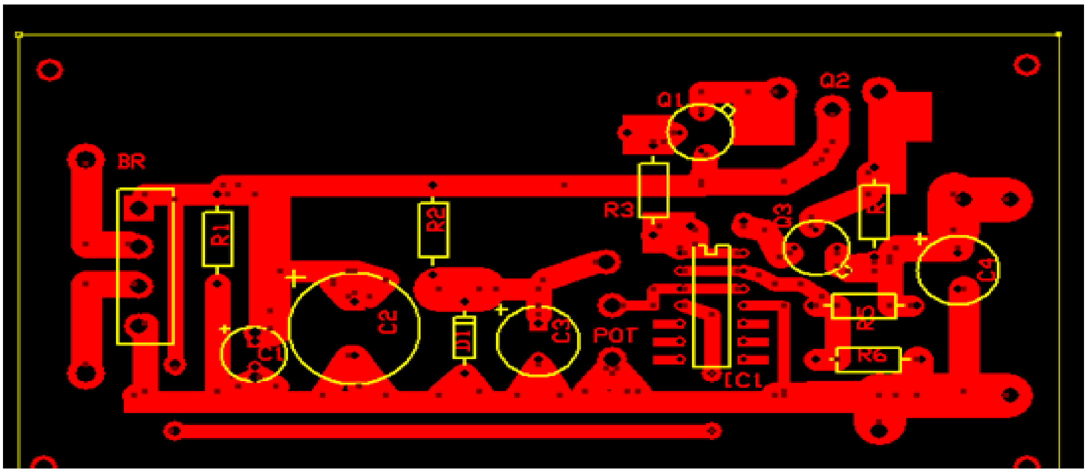

Fig. 3: PCB Art Work for 0 – 15 V Variable Power Supply

0.6 V (the base-emitter voltage), the transistor begins to conduct. This protects the circuit from overload.From the table also, the supposed constant voltage was seen dropping as the load decreases. This may have been as a result of ripple voltage. As the load decreases, the ripple voltage increases, leading to drop in the dc voltage.

The series resistor (Rs) value used in the circuit is 0.8 Ω. The base-emitter voltage (Vbe) at room temperature is 0.6 V. Current delivered by the series transistor (Q2) before the overload protection was activated is $\frac{Vbe}{Rs} = \frac{0.6}{0.8} = 0.75\,A$.From the graph, it was obvious that the voltage was almost constant at current of 0 to about 0.74 A (Imax). The current is able to regulate the output voltage, keeping it constant until overload protection comes into play.It can then be said that the regulation of the power supply is good and the overload protection is active for the set range of operational current.

Table 1: Variation of Current Versus Voltage with changing Load

Resistance, R (Ω)	Currrent, I (A)	Voltage, V (V)
100	0.145	15.08
90	0.161	15.07
80	0.159	15.06
70	0.180	15.04
60	0.204	15.04
50	0.237	15.04
40	0.282	15.03
30	0.348	15.03
20	0.749	14.98
10	1.457	4.60

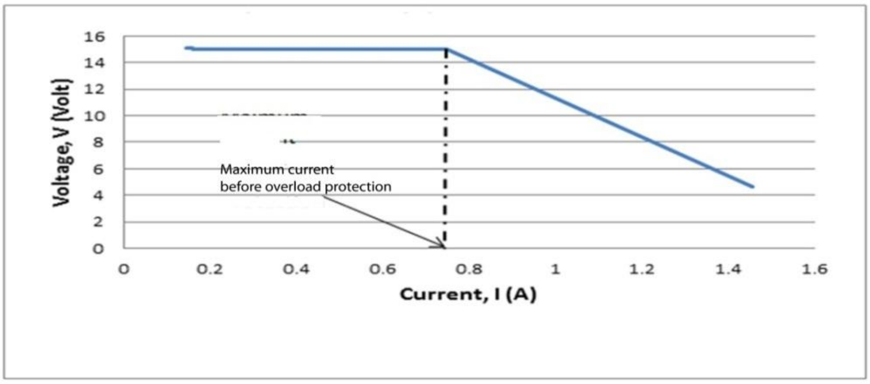

Fig. 3: Variation of Output Voltage with Load Current

IV. Conclusion

The following conclusions are made:

(1) A good transformation process was achieved by careful laminations after the rewinding. This made the transformer to be very efficient, as high as 90%.

(2) The power supply was protected from an overload, which will eventually results in longer life span of the instrument.

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