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A NOVEL SINGLE PHASE AC VOLTAGE STABILIZER USING AN AUTOMATIC TRANSFORMER TAP CHANGING

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ABSTRACT

By provisions of international regulations a power supply company is expected to furnish power to the consumer at a given nominal voltage ±6% variation. This variation is small enough and will give the optimum conditions for the consumers' equipments to perform at peak levels of reliability. In reality, however, especially in Nigeria, the variations in power supply voltage are far too wide and it is not uncommon to measure voltages as low as 90V from 220V or even less in some parts of our urban areas. This low value of voltage makes it impossible for equipments to operate and many homes stay in the peak period of the evening without operating their electronic equipments The stabilizer described in this work is capable of operating from voltages as low as 90V up to the full nominal value of 220V with a guaranteed output of 220V ± 10% variations. Measured value of the output voltage ranged from 170V at an input voltage of 80V to 250V at an input voltage of 230V, which is the maximum tolerable voltage that disconnects any appliance.

KEY WORDS: Stabilizer, voltage, power supply, variations.

1.0 INTRODUCTION

There are many types of voltage stabilizers, both local and foreign, in the market, which are primarily designed to meet the challenge of low voltages. A good number of them are typically characterized by a small input window of operation ranging from 160V-220V in order to produce a guaranteed output of 220V. It is thus seen that in a typical low voltage area these stabilizers have values only in the sense that they add to the ornaments in the home. The proposed system is capable of operating from voltages as low as 90V and also has provisions for disconnecting the load in the event of an over voltage.

2.0 System Block Diagram

The detailed block diagram of the system is given in Figure 1. The ac input from the mains is applied across the primary winding of transformer T_1 the secondary of which has multiple tapings a, b, c, and d. The mains input is also changed to a proportional dc voltage, which is sampled for its value by a sampling network. The various voltages from the sampling network are changed to the required logic levels by the interface network. Depending on the level of mains input the logic control network operates to close the contacts of the desired relay in order to maintain a stable voltage across the load terminals. If the input voltage reaches a level that will cause an excessive voltage across the load the protection network acts by disconnecting the load thus preventing any danger to the load. The dc power supply required to operate the relays and the logic network is derived from an auxiliary winding on the secondary of the transformer.

2.1 Specifications

The stabilizer is designed to operate from an input varying from 90V-230V. The output should be maintained at 220V ± 10%. At an input voltage of 235V the protection network should operate to disconnect the load. The power capability should be at least 1000VA and is upgradeable to other values depending on the parameters of the transformer and relays used.

2.2 Transformer Design

In this research the transformer is the core of operation around which the electronics control circuit is built. The quality of the output voltage is determined by the quality of the transformer. In particular the transformer must be designed to have excellent regulations at peak load (Elgard, 1983).

Power transformer design is pursued largely through the use of empirical formulae and tables. One set of such formulae is that of Armour Research Foundation which gives a step-by-step procedure for the estimation of core size and the wire gauge to be used for the winding. The choice of type of construction is that of scrapless series of E-I laminations of core (McLyman, 1978). The special transformer used has the secondary tapped at various points depending on the input voltage range as shown in Table 1.

Table 1: Voltage Ranges and Tappings of Power Transformer

Input voltage range (V)	Operating relay and transformer tapping for 220V output	Output voltage range (V)
90 – 120	$a: n_a = 2.1n_1$	189 – 252
120 – 140	$b: n_b = 1.8n_1$	216 – 252
140 – 170	$c: n_c = 1.5n_1$	210 – 255
170 – 230	$d: n_d = 1.1n_1$	187 – 253

It should be noted that in Table 1 n_1 is the number of turns in the primary circuit and n_a, n_b, n_c and n_d are respectively the number of turns at the tappings a, b, c, and d. The winding required to provide the dc power to the relays and logic network should provide at least 12V ac at 90V input to be able to power the 12V relays used. The winding will thus have 30V at 220V input and its number of turns should be $n_1/7$

3.0 System and other Design Considerations

3.1 Proportional Voltage Converter

The ac input voltage is converted to a proportional dc voltage using a full wave rectifier network shown in Fig. 2. The magnitude of the rectified dc voltage is related to the ac input voltage through equation (1) (Ryder 1967, 1976).

$$\frac{V_{dc}}{V_m} = \frac{1}{1 + \frac{\pi}{2wc_1R}} \quad \Lambda\ [1]$$

In equation (1) V_m is the peak value of the ac input voltage. If $2wc_1R >> \pi$ then

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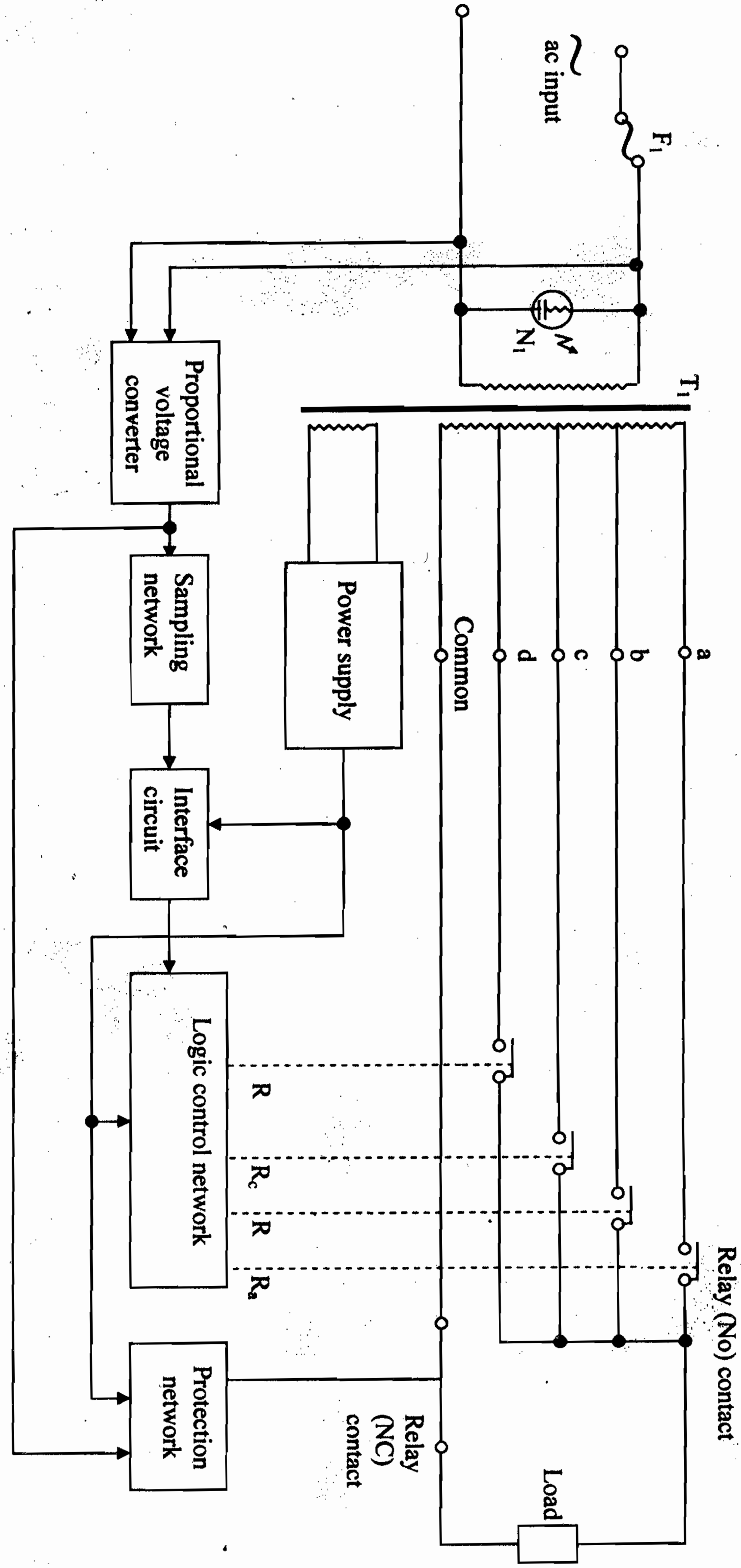

Fig. 1: Block Diagram of Voltage Stabilizer

$$V_{dc} \approx V_m \Lambda \, [2]$$

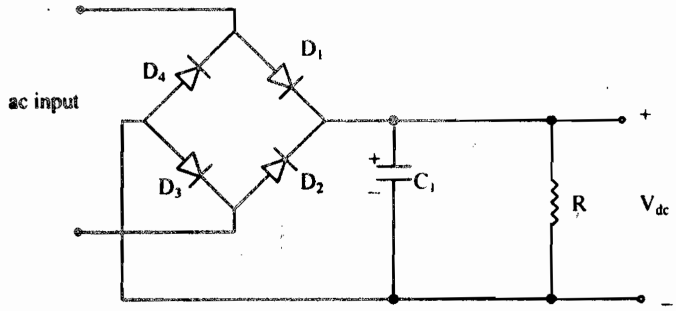

Fig. 2: Proportional Voltage Converter

The minimum value of V_{dc} is given by

$V_{dc} \min = \sqrt{2} \times 90 = 127.3V$ while its maximum value is $V_{dc} \max = \sqrt{2} \times 235 = 332.3V$.

3.2 Sampling, Interface, and Protection Networks

The combined sampling, interface and protection circuit is depicted in Figure 3. In order to meet the requirements of equation (2) the values of resistors R_1-R_9 should be high.

At the minimum voltage to be controlled i.e 90V, v_a' is required to be large enough to turn on Q_1. This is the minimum value of v_a' and it is given by:

$$v'_{a\min} = V_{dc\min} \frac{R_2}{R_1 + R_2} \Lambda \, [3]$$

$$= 127.3 \frac{R_2}{R_1 + R_2}$$

The maximum value of v_a' is obtained when V_{dc} is maximum

$$v'_{a\max} = V_{dc\max} \frac{R_2}{R_1 + R_2} \Lambda \, [4]$$

i.e

$$= 332.3 \frac{R_2}{R_1 + R_2}$$

The ratio $v'_{a\max}/v'_{a\min}$ is given by

$$\frac{v'_{a\max}}{v'_{a\min}} = \frac{332.3}{127.3} = 2.61$$

The value of R_2 is calculated from equation (3) to be

$$R_2 = \frac{R_1 \cdot v'_{a\min}}{V_{dc\min} - v'_{a\min}} \Lambda \, [5]$$

By reasoning in a similar manner the minimum and maximum values of v_b' vc' v_d' and the value R_4, R_6 and R_8 can be calculated.

A closer examination of these minimum and maximum values shows that while some are out of the permitted logic levels of TTL devices, others can easily cause the TTL devices to go into the forbidden band thus leading to an indeterminate behaviour. It is for these reasons that an interface network is required to precisely define the TTL levels (Greenfield, 1977 and Johnson, 1981).

When the ac input voltage is likely to cause over voltage across the load the protection network is required to switch off the load under this condition. The operating relay up to the point the input voltage reaches 235V is relay d and the secondary turns ratio of the transformer switched is 1.1 so that the load voltage equals $1.1 \times 235 = 258.5V$. This is obviously too high and the load should be switched off.

3.3 Logic Control and Relay Drive Networks

The four normally open (NO) relays a, b, c, and d are required to close their contacts one at a time in order to select the appropriate tap on the transformer that will provide the correct voltage for the load. Since more than one output of the interface network may be high at a time (for instance all outputs of the interface network are high if v_d is high) a logic circuit, which behaves like a code converter having the truth table shown in table 2 will provide the desired switching signals.

Due to the don't -care conditions, it turns out from the truth table that the corresponding logic equations can be obtained simply by observation and the intermediate minimization process can be skipped. The equations are:

$$R_a = v_a \cdot \bar{v}_b \cdot \bar{v}_c \cdot \bar{v}_d \Lambda \, (6)$$

$$R_b = v_a \cdot v_b \cdot \bar{v}_c \cdot \bar{v}_d \Lambda \, (7)$$

$$R_c = v_a \cdot v_b \cdot v_c \cdot \bar{v}_d \Lambda \, (8)$$

$$R_d = v_a \cdot v_b \cdot v_c \cdot v_d \Lambda \, (9)$$

The logic network corresponding to eqns. (6) to (9) is shown in Figure 4.

Table 2: Code Conversion for Interface-Relay Network.

Interface Voltages				Relay Contacts to be closed			
V_a	V_b	V_c	V_d	R_a	R_b	R_c	R_d
0	0	0	0	0	0	0	0
×	×	×	1	0	0	0	1
×	×	1	0	0	0	1	0
×	×	1	1	0	0	0	1
×	1	0	0	0	1	0	0
×	1	×	1	0	0	1	0
×	1	1	0	0	0	1	0
×	1	1	1	0	0	0	1
1	0	0	0	1	0	0	0

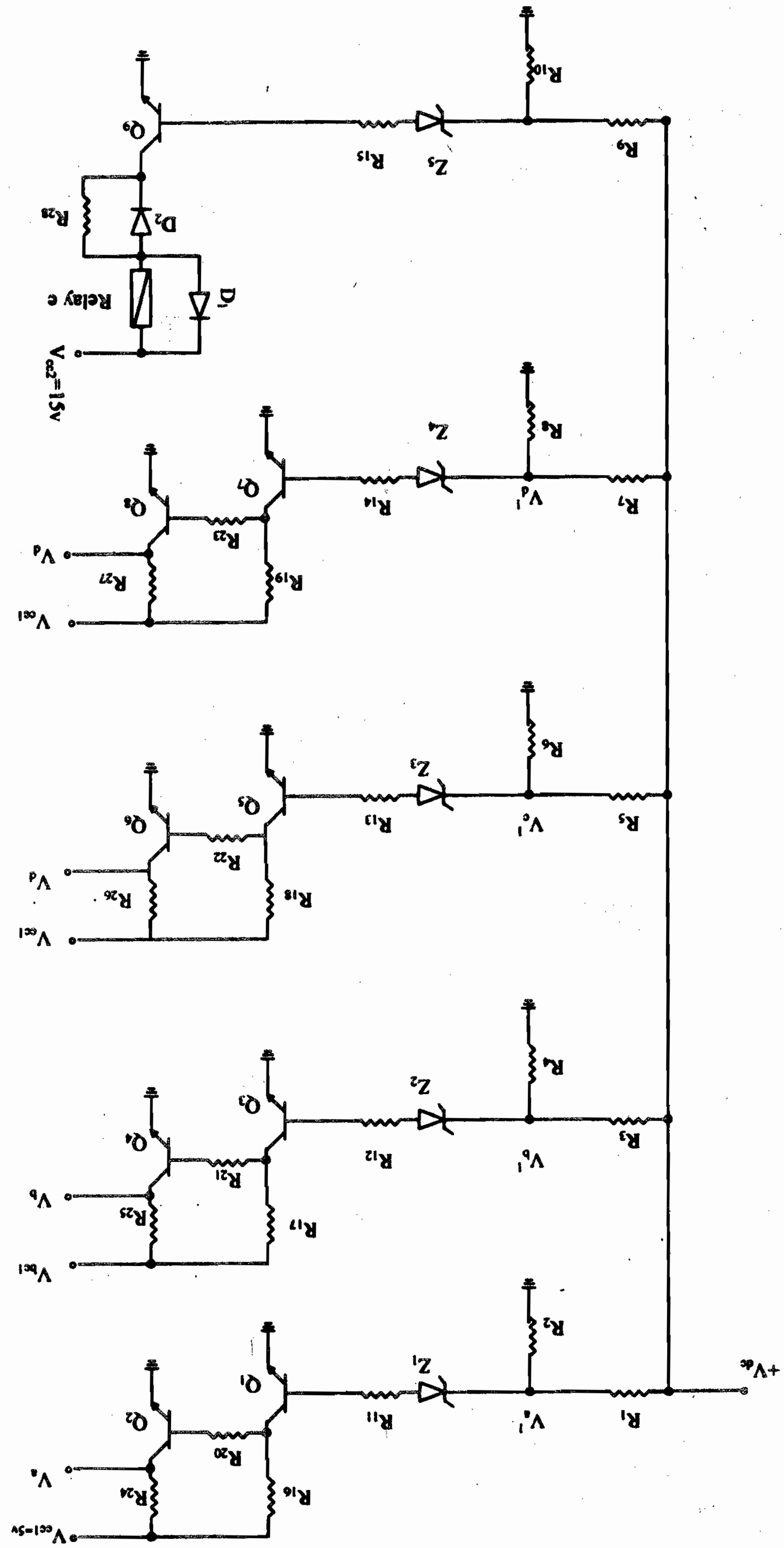

Fig. 3: Sampling, Interface, and Protection Networks

1	×	×	1	0	0	0	1
1	×	1	0	0	0	1	0
1	×	×	1	0	0	0	1
1	1	0	0	0	1	0	0
1	1	×	1	0	0	0	1
1	1	1	0	0	0	1	0
1	1	1	1	0	0	0	1

× is don't care condition.

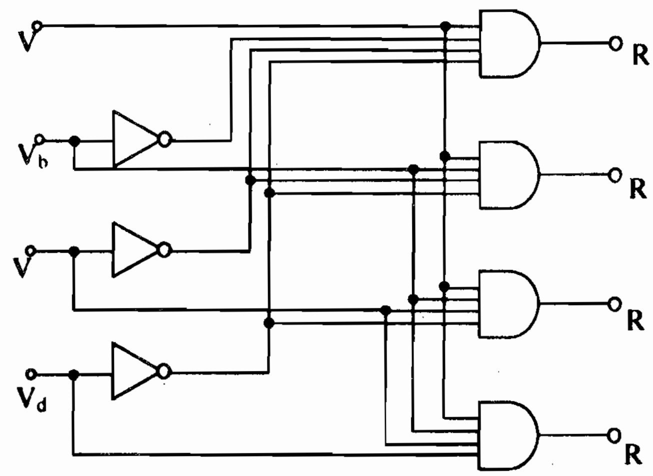

Fig. 4: Relay Switching Logic Network

The outputs R_a, R_b, R_c, and R_d of the logic network are required to drive the relays a, b, c, d through the transistors Q_{10}-Q_{13} as shown in Figure 5. The circuits are similar in all respects. Consider the drive network designed around Q_{10}.

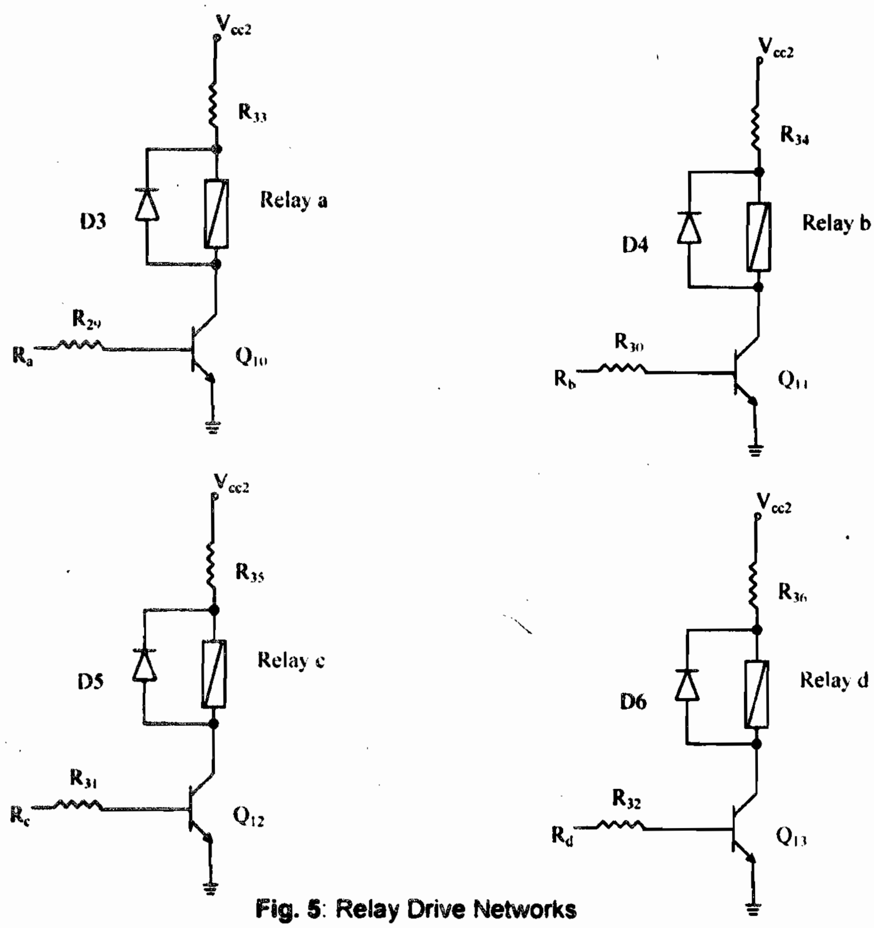

Fig. 5: Relay Drive Networks

When the transistor is turned on its collector current is given by

$$I_C = \frac{V_{cc2}}{R_{33} + R_{ra}} \Lambda \ [10]$$

where R_{ra} is the coil resistance of relay a. The base current is given by

$$I_B = \frac{V_{Ra} - V_{BE}}{R_{29}} \Lambda \ [11]$$

The condition for the BJT turning on is that $\beta_F I_B > I_C$ so that

$$R_{29} < \frac{\beta_F (V_{Ra} - V_{BE})(R_{33} + R_{ra})}{V_{cc2}} \Lambda \ [12]$$

3.4 Power Supply

There are two dc voltage levels in the circuit required to power the components: the V_{cc1} (+5V) needed for the logic components and the V_{cc2} (+15V) required for the relay drive networks. A separate 30VA winding at the transformer secondary will provide the dc supply. The ac from this winding is first rectified and the 7815 and 7805 regulators are used to provide V_{cc2} and V_{cc1} respectively. The diagram for the power supply is shown in Figure 6.

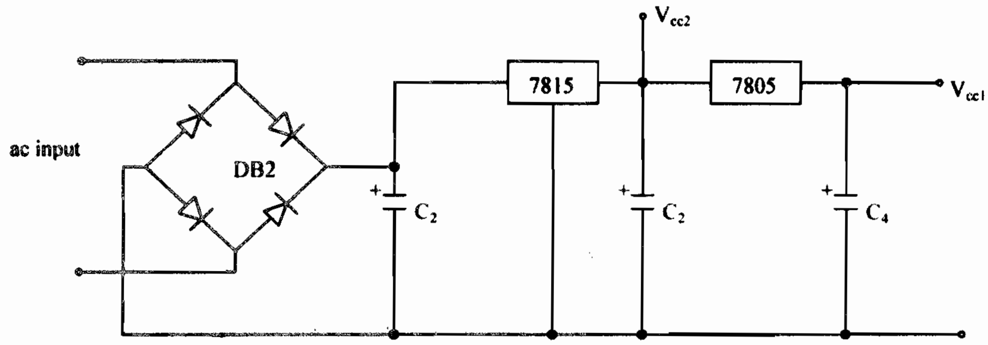

Fig. 6: Power Supply Circuit

4.0 Conclusions and Suggestions for Further Work

A system using multi-winding transformer and electronic control circuit to stabilize a load voltage has been described. This system was built and the performance was very satisfactory in terms of the range of output voltage for a given input voltage variations. Measured values are given in Table 3. This system could be modified to include more features. The input and output voltages can be displayed either in an analog or digital forms for the user to see. The logic control network can be made intelligent by using a micro controller to switch the relays.

Table 3: Measurement of Input and output Voltages

Input Voltage (V)	**Output Voltage (V)**	**% Variation fror**
80	170	-22.7
85	180	-18.2
90	191	-13.2
95	201	-8.6
100	212	-3.6
110	230	+4.5
120	217	-1.4
130	232	+5.5
150	223	+1.4
160	242	+10
170	245	+11.4
180	200	-9.1
190	210	-4.5
200	218	-0.9
210	228	+3.6
220	240	+9.1
230	250	+13.6
234	0 (disconnected)	-

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