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DUAL INPUT-OUTPUT VARIABLE DC POWER SUPPLY

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ABSTRACT

A variable "d.c power supply" is the type of power supply that gives the opportunity to vary its outputs. These types of power supply are usually found and used in laboratories for research and practical purpose. Usually bench power supplies use an a.c source for their inputs in order to operate, in the absence of power supply from the national grid another means of powering these power supplies is no doubt the gasoline or petrol generator. The disadvantages of these power sources are their contribution to the environmental pollution and economically pocket-drain. In the present work, a dual input–output variable dc power supply that uses **12VDC** or **220VAC** as an input and obtained variables **0-30VDC** and **0-15VDC** as the outputs is designed and constructed using **"Ac-link chopper"** and **"integrated circuit Regulator"** (LM317T). The produced equipment will contribute in avoiding absolute dependence on single power source for operating laboratory power supply, reducing pollution as it does not necessarily require *a.c* source for its operation and curtail the expenses of buying fuel for running the generator in order to provide the input source of the power supply in the absence of power from the national grid.

Keywords: Ac-link chopper, Ac source, Dc source, Integrated circuit Regulator.

1. INTRODUCTION

A power supply is a source of electrical power for operating electronic circuit devices and systems [1]. A dc power supply is the type of power supply that when connected to the power sources will provide at its output a required d.c values. The source that provides the input of a power supply can be *a.c* or d.c source, a power supply can be fixed or variable depending on the needs. A fixed power supply is the type in which the output remains constant, these types of power supply are found in most electronic devices such as radio, television, mobile phones e.t.c. a variable d.c power supply is the type that gives the opportunity to vary its output, these types of power supply is usually found in laboratories. Different technologies have been used to produce variable power supplies, if a d.c. source is used in the input of a power supply and d.c values are obtained at the output, we have DC-DC converter [2]. Although, this type of device is known as **'chopper'**. A chopper is basically a dc to dc converter whose main function is to create adjustable dc voltage from fixed dc voltage sources through the use of semiconductors [3]. The choppers are classified as Ac link chopper and Dc chopper. In the Ac-link chopper, first dc is converted to *ac* with the help of an inverter, after that, Ac is stepped-up or stepped-down by a transformer, which is then converted back to dc by a diode rectifier [3]. A dc chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly using a high speed static semiconductor switch [4].

Usually, bench power supplies use an a.c source for their inputs in order to operate, in the absence of power supply from the national grid another means of powering these power supplies is no doubt the gasoline or petrol generator. The disadvantages of these power sources are their contributions to the environmental pollution that include air and noise pollution. This is due to the carbon IV oxide release by the generator during combustion and the noise produced as a result of mechanical friction that occurs in the engine parts. Also, the a.c powering source is economically pocket-drain as fuel (Diesel or Petrol) must be used for operating the generator in the absence of power from the National Grid. Since laboratory session requires enough time usually 3 hours to above, a lot of fuel is consumed and in the process a lot of money is used for that. Financing of buying fuel is not as that easy for the schools management especially in under developed as well as some developing countries. As most of these laboratory power supplies (bench work) require *a.c* power sources for their operation, relying completely on a single power sources is the major limitation associated with such power supplies.

In the present work, a dual input–output variable dc power supply that can overcomes the limitation accompanied with those laboratory power supplies has been designed and constructed. This power supply uses **12VDC** or **220VAC** as an input and obtained variables **0-30VDC** and **0-15VDC** at the outputs, achieved using; **"Ac-link chopper"** and **"integrated circuit Regulator"** (IC: LM317T). One of the input source is a dc source which uses the principle of the *ac* link chopper to deliver the dc input to the regulator integrated circuit (lC:LM317T) for regulation of the output dc voltage. While the second input uses the a.c main source to deliver the a.c power to step-down transformer which is then input to the rectifier diode circuit for conversion into unregulated d.c and then to the IC regulator for regulation of the output d.c voltage.

2. MATERIAL AND METHOD

The materials used in this power supply consist of inverting circuit, mechanical switching circuit, conversion circuit and regulating circuit. These are represented in the block diagram in figure 1 and the schematic circuit diagram in figure 2.

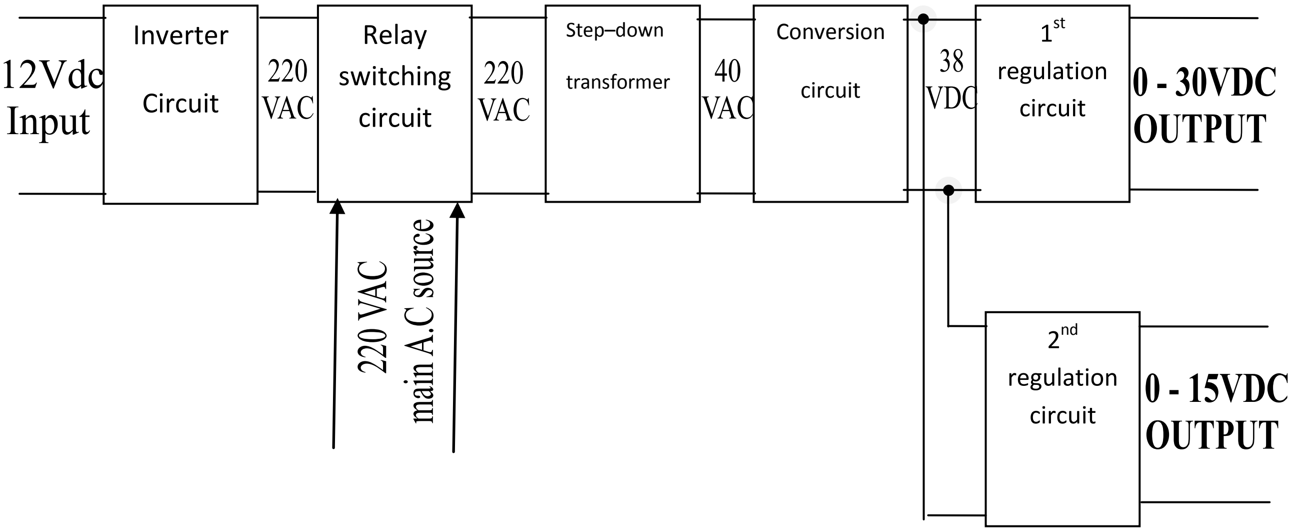

Figure 1: Block-diagram of dual input-output variable power supply

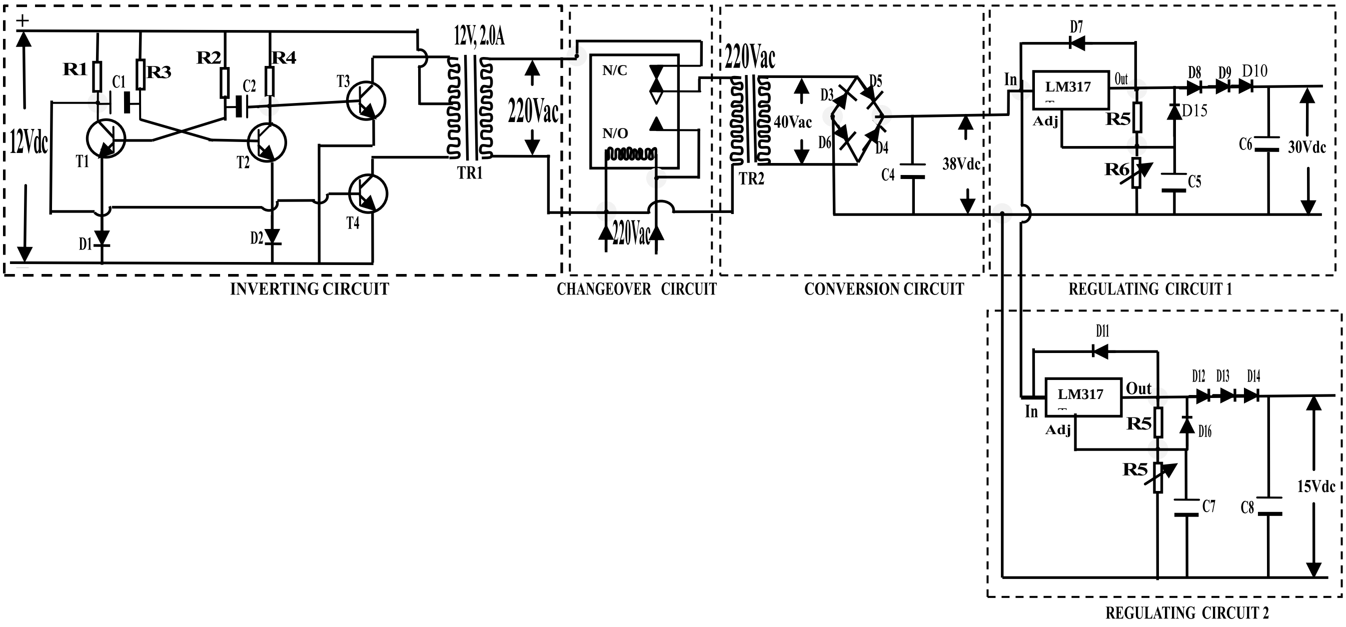

Figure 2: Schematic diagram of dual input-output variable dc power supply

2.1. Analysis of inverting circuit

The inverting circuit is that which changes the dc input signal into a.c signal with the help of discrete components that includes transistor, resistors and capacitors. An inverting circuit is also called an oscillator, when the dc input oscillates, it is fed to the input of step-up transformer in which an alternating current (a.c) is obtained at its output. The pulse shape of the output signal is a square wave which satisfies the requirement for this design. The inverter oscillator is made up of free-running astable multivibrator as seen in figure 3.

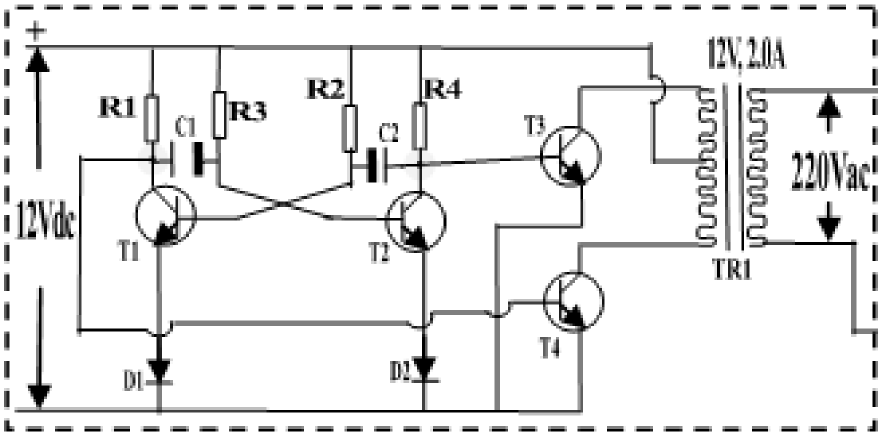

Figure 3: The Schematic diagram of the Inverting Circuit

The output requirement of this inverter is 220VAC and 2 ampere. The transistors T_1 and T_2 are D882 (TO-220). The output current of symmetric astable circuit in each part of the transistor T_1 and T_2 is given by; [5]

$$I_c = \frac{V_s}{R_c} \tag{1}$$

The base resistors R_2 and R_3 are selected to be 10kΩ, this makes the base current to be approximately 1.13mA, and this is obtained using the equation;

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \tag{2}$$

As V_{BB}=V_S= Supply voltage = 12Vdc, and V_{BE} is 0.7V (barrier voltage). This makes the I_C to be 113mA taking h_{fe} to be 100. i.e.

$$I_C = \beta I_B \tag{3}$$

Where β= h_{fe} = 100. Therefore, the collector resistor is selected using equation (1) as; $R_c = \frac{V_s}{I_c} = \frac{12}{113mA} = 106\Omega \approx 100\Omega\ (2\ Watts)$. Note that, R_1=R_4 = 100Ω.

The diodes D_1 and D_2 are protection against excess reverse breakdown voltage, C_3=250V, 50/60Hz is the protection against transients [3]. The frequency of switching symmetrical astable circuit is required to be 50Hz which is the frequency required by the step-up transformer T_{R1} for effective induction. This frequency is obtained by selecting the appropriate capacitor C_1=C_2 =C and R_2=R_3=R=10KΩ, using the relation;

$$C = \frac{1}{1.4Rf} \tag{4}$$

$$= \frac{1}{1.4\times10^4\times50} = 1.43\mu F.$$

The outputs of the astable circuit are connected to the base of transistors T_3 and T_4, these transistors are 2SC5200 which has $I_{C(max)}$ of 15A and $h_{fe(min)}$ of 35 [6]. It is capable of providing the required current use by T_{R1}. The collectors of T_3 and T_4 are connected to the input of T_{R1} while center-tap is connected to the $+V_S$. When the circuit (astable) is switched on, it makes T_1 and T_2 on and off with the frequency of 50Hz, the T_4 vibrates simultaneously with T_1 and T_3 with T_2 respectively. This oscillation causes the input of T_{R1} to induce in the secondary winding thereby stepping-up the 12Vdc input to 220Vac output.

2.2. Changeover circuit

The mechanical relay used in the changeover circuit of the power supply is an a.c single pole relay with input voltage of 220Vac/50Hz and 5 amperes current carrying capacity [9].

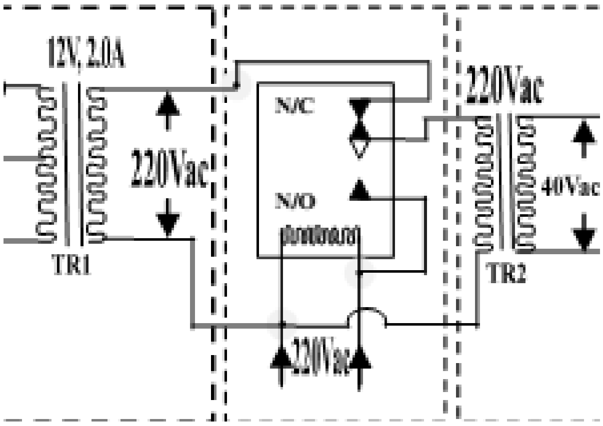

Figure 4: Schematic diagram of change-over circuit capable of switch-linking the output of inverting circuit to the input of converting circuit

2.3. Analysis of converter circuit

Conversion circuit is the one which converts the a.c into d.c. The conversion circuit comprises of step-down transformer 220Vac/40Vac, 4Amps. The rectifying diodes D3, D4, D5 and D6 are IN5408 which is capable of withstanding up to 3 amperes of current, and the C_4 is a filter capacitor with values of 2530µf and 50vdc.

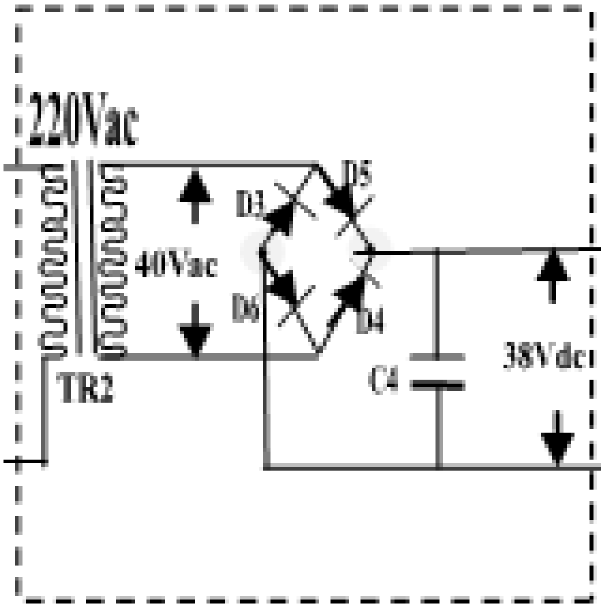

Figure 5: Schematic diagram of Conversion Circuit

The required rectified dc output voltage is 35Vdc while the output is 2.0A. These are obtained as follows [5]:

$$\boldsymbol{V_{dc} = V_{out(pk)}\left[1 - \frac{1}{2fR_LC}\right]} \qquad \textbf{(5)}$$

Where,

V_{dc} is the voltage at the output of the rectifier when there is load R_L and $V_{out\,(pk)}$is the voltage at the output of the rectifier when there is no load R_L.

Thus,

$$V_{out\,(pk)} = V_{s(pk)} - 2V_o$$

(6)

Where,

$V_{s(pk)}$ is the peak secondary voltage of the transformer, and V_o is the barrier voltage of the diode, as there are two diodes in series, then the V_o is doubled and for silicon diode V_o = 0.7V.

$$V_{s(pk)} = V_{rms} \times \sqrt{2}$$

(7)

V_{rms} is the voltage measured with voltmeter across the transformer secondary.

The f in (5) is the frequency of the rectified d.c signal and it doubled that of the input a.c signal (i.e. 60Hz).

Thus,

$$f = 2f_{\text{in}}$$

(8)

$$= 2\text{x}60 = 120\text{H}_\text{z}$$

The value of C_4 depends on R_L, it should be selected so that $\left[1 - \frac{1}{2fR_LC}\right]$ is very close to unity. As the $V_{s(pk)}$ is 40Vac and V_o = 0.7V, using the equation (2), $V_{out\,(pk)}$ = 38.6Vdc. Since the required V_{dc} is 35V and the load across the rectifier output is 17.5Ω which is the input impedance of the regulating circuit. Then, using the equation (1), $V_{dc} = 35V$. The average d.c output current is given by: [5]

$$I_{dc} = \frac{V_{dc}}{R_L}$$

(9)

$$= \frac{35}{17.5} = 2.0A$$

2.4. **Analysis of regulating circuit**

The regulating circuit consists of Lm317 integrated circuit (IC) regulator, variable, fixed resistors, capacitors and diodes.

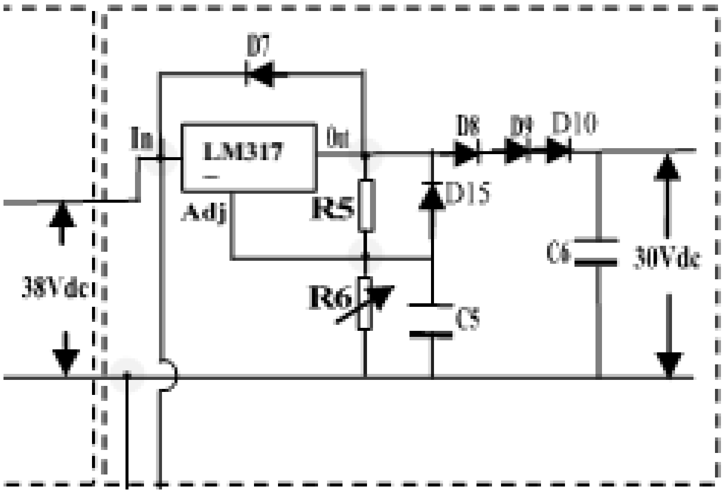

Figure 6: Schematic diagram of 0-30Vdc Output Regulating Circuit

According to the manufacturers of the IC regulator [7], it is a positive voltage regulator capable of supplying in excess of 1.5A over a 1.25V to 37V output range and a wide temperature range. For better regulation, the voltage difference between V_{in} to V_{out} should be at least$3V \leq (V_{in} - V_{out}) \leq 40V$. The Lm317 develops and maintains a nominal 1.25V reference (V_{ref}) between its output and adjustment terminals. This reference voltage is converted to a programming current (I_{prog}) by R_1 (i.e. R_5 in regulating circuit I and R_7 in regulating circuit II), and this constant current flow through R_2 [R_6 and R_8 in regulating circuits I and II respectively] to ground. The regulated output voltage is given by:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{Adj}\,R_2 \quad \textbf{(10)}$$

Since the current from the adjustment terminal (I_{Adj}) represents an error term in the equation, the Lm317 was designed to control I_{Adj} to less than 100µA and keep it constant. By doing this, all quiescent operating current is returned to the output terminal. This imposes the requirement for a minimum load current. If the load current is less than this minimum, the output voltage will rise. Since the Lm317 is a floating regulator, it is only the voltage differential across the circuit which is important to performance, and operation at high voltages with respect to ground is possible as long as the maximum input- to- output differential is not exceeded. That is, avoid short – circuiting the output. The Lm317 is capable of providing extremely good load regulation, but a few precautions are needed to obtain maximum performance. For best performance, the programming resistor R_1 should be connected as close to the regulator as possible to minimize line drops due to increased trace resistance which effectively appear in series with the reference, thereby degrading regulation. The ground end of R_2 should be returned near the load ground to provide remote ground sensing and improve Load regulation. In the design of this circuit, a 100Ω was used for R_1 and 2.5kΩ was used for R_2. Since I_{Adj} is very tiny (in a few microamperes). The error term in the equation (10) is neglected which approximated the equation to:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right)$$

(11)

$$V_{out} = 1.25\left(1 + \frac{2500}{100}\right) = 32.5V$$

Now, this gives the output voltage of the regulating circuit 1 which is control (i.e. varies) by variable resistor R_6 (i.e. R_2 in equation 7). Due to the fact that the regulating output required is in the range 0-30V, three silicon diodes D_8, D_9 and D_{10} were used in series so that a voltage drop of 2.1V exists. This makes the lowest output to be equal to zero volt (0 volt) while the highest output to be 30.5V.

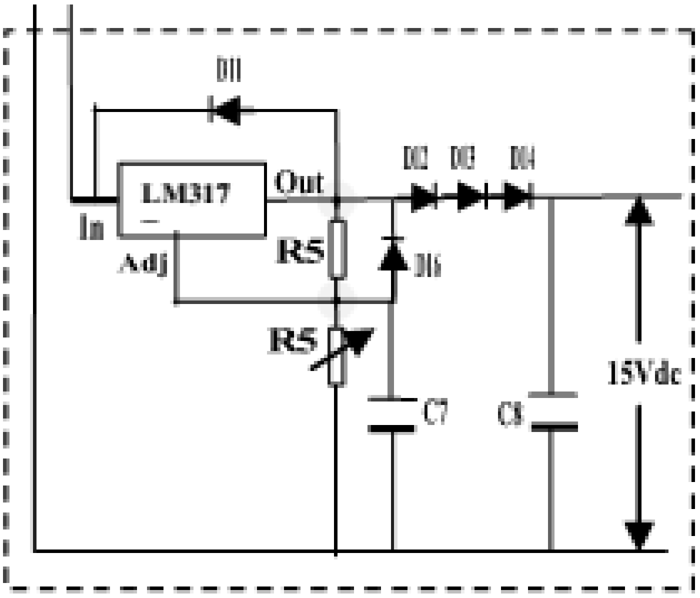

Figure 7: Schematic diagram of 0-15Vdc Output Regulating Circuit

The same techniques was used in regulating circuit 2 with the changing value of R_8, where 1.3kΩ was used, the diode IN5408 was used for D_8, D_9 D_{10}, D_{12},D_{13} and D_{14}. The output voltage of regulating circuit 2 is in the range *of* 0–15V. During operation, the IC regulator becomes hot, so a fairly large heat sink is used in both the IC's for dissipation of heat. In order to improve ripple rejection by the regulator, the adjustment terminal was by-passed to ground using capacitor C_5 and C_7 which have the value of $10\mu f$, 50v (electrolytic capacitor). These capacitors prevent ripple from being amplified as the output voltage is increased. An output capacitance C_6 and C_8 of values $25\mu f$, 50V were used to prevent excessive ringing by certain values of external capacitance and insures stability. When external capacitors are used with any IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low currents points into the regulator [7]. To overcome this, diodes D_7 and D_{11} were used to prevent C_6 and C_8 respectively from discharging through IC during an input short circuit. Diode D_{15} and D_{16} protect against capacitors C_5 and C_7 discharging through the IC during an output short circuit. The combination of diodes D_7, D_{15} and D_{11}, D_{16} prevent C_5 and C_7 from discharging through IC during an input short circuit. The diode IN4002 was used for D_7, $D_{15,}$ D_{11} and $D_{16.}$

3. CONSTRUCTION, TESTING AND RESULT

The schematic diagram of figure 2 is used in the construction of this equipment. The circuit was first constructed on a breadboard by pushing each component into an appropriate hole by following the circuit diagram after which the circuit diagram was then transferred and constructed on a Vero board. Continuity test was made on each stage to ensure continuity of conductive parts, insulation test was also made to ensure that nonconductive parts are properly insulated, after which results were observed and taken. For the inverter circuit, the output *a.c* signal of 200 to 220vac was observed for the conversion circuit an output dc signal of 35vdc obtained, while in the regulating circuit I an output dc voltage in the range 0-30v was obtained and in the regulating circuit II, the voltage output in the range 0-15vdc was also obtained.

3.1. Testing and Result

This equipment was tested for voltage regulation (load regulation) as given by the following tables [5], [8].

S/N	Load resistance $R_L(\Omega)$	Load voltage V_L(V)	Load current I_L(mA)
1.	1000	27.21	27.40
2.	800	27.25	34.00
3.	600	27.02	45.01
4.	400	26.65	65.50
5.	200	26.15	130.50
6.	100	24.21	245.13
7.	50	19.13	385.52

Table 1: The test result of the power supply for voltage regulation at different loads when the output voltage is 30Vdc

S/N	Load resistance $R_L(\Omega)$	Load voltage V_L(V)	*Load current* I_L(mA)
1.	1000	12.57	12.94
2.	800	12.42	15.34
3.	600	12.27	20.05
4.	400	12.07	29.37
5.	200	11.60	56.70
6.	100	11.21	111.80
7.	50	10.72	206.30

Table 2: The test result of the power supply for voltage regulation at different loads when the output voltage is 15Vdc

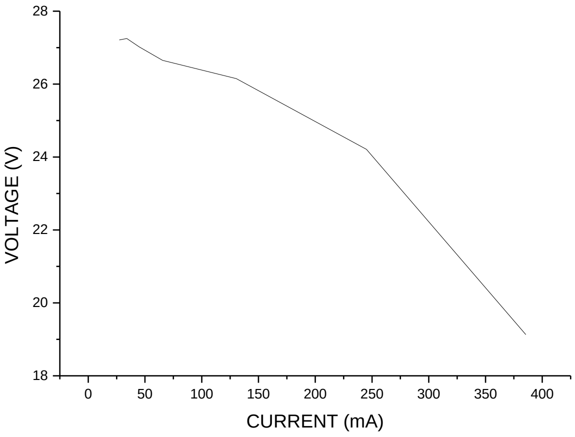

Figure 8: A curve showing the relationship between the output current and the output voltage in the 30VDC output range

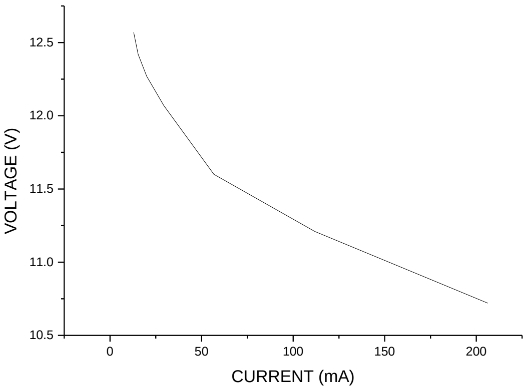

Figure 9: A graph showing the relationship between the output current and the output voltage with varying load in the 15VDC output range

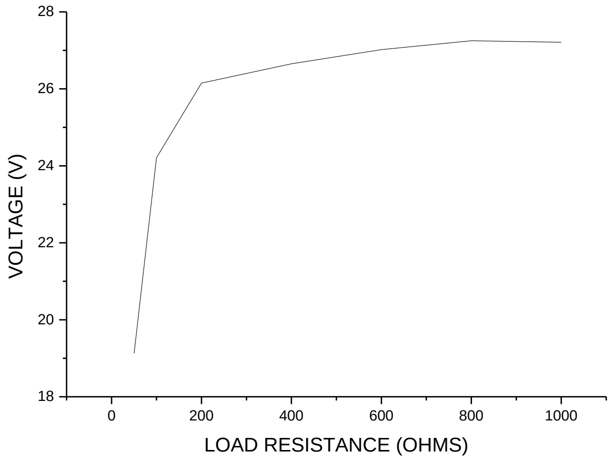

Figure 10: A curve showing the relation between the varying resistance of the applied load and the output voltage in the 30VDC range.

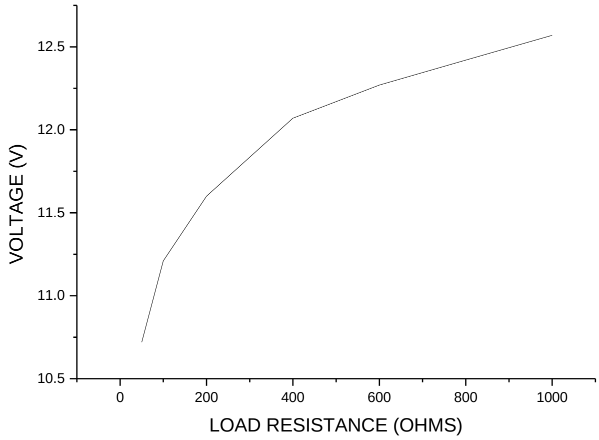

Figure 11: A curve showing the relation between the varying resistance of the applied load and the output voltage in the 15VDC range.

4. Discussion of the results

From the tables above, the values of the result of test were recorded. In table 1.0, in the first column, are the values of different load resistances (R_L) which were used to test the regulation stage of the regulating circuit, in the second column are the values of voltages at various load resistances. Moving to column three are the values of currents consumed by different load resistances. From this table, it clearly shows that, the regulation of regulating circuit 1 is somehow better at the load resistance ≥ 200Ω as the output voltage drop of the power supply at these loads is not much; it is between 3 to 4v. This indicates that, at higher loads >1000Ω the voltage drop will be reduced. This really shows that, this power supply will operate better with a circuit of higher impedance such as that of logic circuits. The table 1.0 and 2.0 has similar columns for the output range of

0-30V and 0-15V respectively. Regulation circuit 2 shows similar behavior to that of regulation circuit but with a fewer output voltage drop than that in circuit 1 in the load resistances ≥200Ω. Also, from the tables, it reveals that as the load resistance is decreasing, there is drastic drop in the output voltage. This shows that, the power supply should not be used with a circuit having the impedance lower than 200Ω. In Figure 8, a curve showing the relationship between the output current and the output voltage in the 30VDC output range, it is observed that there is gradual voltage drop with increase of output current. Also in Figure 9, is a curve showing the relationship between the output current and the output voltage with varying load in the 15VDC output range, this curve reveals the sudden voltage drop with increasing output current. This curve shows that the 0-30V output range has a better regulation than the 0-15V output range. Also another curve was plotted between the resistance of the applied loads and the voltage. This is to find out the level of stability of the voltage regulation of this power supply. In figure 10, is a curve showing the relation between the varying resistance of the applied load and the output voltage in the 30VDC range. Obviously, there is better voltage stability from the load of 400Ω to above. Moving to figure 11, is another curve showing the relation between the varying resistance of the applied load and the output voltage in the 15VDC range. This curve shows that, the stability of the output voltage in this range is not quite good as the curve decays exponentially which means that even at higher loads no better regulation is obtained. Finally, this power supply can be used as variable voltage battery charger with a charging current less than 1000mA through the two outputs of the regulation circuits 1 and 2.

5. WORKING PRINCIPLE OF THE EQUIPMENT

Initially, when an input dc sources of 12v is connected to the equipment, it is linked to the inverting circuit internally which inverts the input 12dcv to 220Vac. One of the output terminals of the inverting circuit is connected to one of the input terminal of the transformer TR_2 that supplies power to the conversion circuit while the other terminal is connected to the normally closed (N/C) terminal of the relay as seen in figure 2. The armature (A) terminal is always connected to the N/C and the other input terminal of the transformer T_{R2}. This shows that, provided there is 12vdc input then there should be a 220Vac across the TR_2 input, this enables the output of TR_2 which is a stepped down 40Vac to be deliver to the rectifier and the smoothing capacitor C_4, thereof, *a* 35vdc unregulated is delivered to the two regulation stages (i.e. circuit I and II) where regulation takes place.

The output voltages are taken across the two outputs of the power supply, one from the regulation circuit, 1 in the range 0-30Vdc while the other from regulation circuit 2 in the range 0-15Vdc. In the other hand, if an *a.c* line from the 220Vac source is required for use, the wire code of the equipment is connected to the relay a.c input. This input wire is also connected across the relay input coil, one of these terminals is connected to the TR_2 and the other connected to the normally open (N/O) terminal of the relay. By the moment, there is available power from the main *a.c* sources, the armature (A) of the relay will not be in contact with N/C but with N/O, this enables the TR_2 to be powered by the main *a.c* sources and then to the conversion circuit which proceeds to the two regulating circuits. As long as there is available ac power source the equipment will not be operated via the 12vdc input source, rather it will operate with the a.c supply. A *fuse* of 2.5 ampere rating can be used for protection of the TR_2 against high voltage from the main *a.c* source.

6. **CONCLUSION**

A dual input-output variable in the range 0-30vdc and 0-15vdc power supply is designed and constructed. The result obtained shows that the equipment voltage regulation is better with higher loads while at lower loads appears to be fairly good. The percentage regulation of this power supply is somewhat high. This shows that there is need to improve the regulation to a better level. However, this power supply can be used for laboratory experimental purpose with better performance when delivering power to the circuit with high input impedance such as logic circuits. Another great advantage of this power supply is that, it can be used as variable voltage battery charger with charging current less than 1000mA. The equipment is of economic advantage, as there is no more buying fuel for electric generator during the practical session with this power supply. A 12V battery or 220a.c can supply the source and yet the variable 0-30Vdc and 0-15Vdc was obtained at the output of the power supply. The benefit of this research is the avoidance of complete dependence on a single power source whenever it comes for the use of power supply for experimentation in a laboratory and it will also contribute in reducing environmental pollution thereby not necessarily operating the designed power supply on the gasoline or petrol generator.

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