DESIGN AND CONSTRUCTION OF TRANSFORMER WITH DISCRETE MULTIPLE OUTPUT VOLTAGE OF 15 VOLT INTERVAL

BY

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2003/15373EE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY,

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DEDICATION

This project work is dedicated to my beloved parents (Alh. Jibrin Bako, Late Hassanatu Bako and Hajiya Fatima Bako). Also to all my blood brothers, relatives and all that wish me success in life.

DECLARATION

I Hussaini Bako declare that this project work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinguish the copyright to the Federal University of Technology Minna.

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ABSTRACT

The project work is mainly the design and construction of a transformer with multiple output of 15V (Ac) step.

The main design employs the principle of operation of transformer consisting of two coils called the primary and the secondary windings wound on circular iron core (toroid). The primary winding is not connected the secondary winding in any way, but are coupled by magnetic flux set up by the alternating current through the core. The tappings out of the secondary winding are connected to switches mounted on wooden case. The switches are used to select the desired output voltage at a time.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

The discovery of electricity in nineteenth century by Michael Faraday has generated continuous design and construction of different types of electrical appliances/equipment having different voltages and power ratings. Different electrical appliances/equipments require different voltages, hence the need to vary the source voltage to the desired amount. In some cases the voltage of thousand or million volts is required while in other cases a low voltage of a few volts is sufficient. The need of an electrical device therefore arise to transform (increase or decrease) the supply voltage. This lead to the discovery of transformer which transform the voltage with almost no loss of energy. Michael faraday invented the first transformer "induction ring" on August 29, 1831, although Faraday used it only to demonstrate the principle of electromagnetic induction.

A transformer is an electrical device that transfers electrical energy from one circuit to another purely by magnetic coupling; relative motion of the parts of the transformer is not required for transfer of energy. The electrical energy is transferred without a change in frequency, but may involve changes in magnitudes of voltage and currents. Because transformer works on the principle of electromagnetic induction, it must be used with an input source voltage that varies in amplitude (AC voltage source). The magnetic field coupling the circuit can be in air but is usually in ferromagnetic material called the iron core in which the field can be thousand of time greater than it will be in air, making the transformer more efficient and small. Transformers are designed to give a specific output voltage which is determined by the number of turns of the coil (winding). Transformers come in different types depending on either step-down or step-up, it then implies that when different voltages are required for operation, multiple transformers with the required output voltages will be required. This of course had broken a new base for the necessity of an alternative device which can handle voltage variation for the various applications.

1.1 MULTIPLE OUTPUT (AC) TRANSFORMER

This device provides a voltage adjustable source of alternating current (AC). The primary is usually connected to a voltage source of 220V AC at 50Hz frequency in Nigeria and 120V (ac) at 60Hz in USA. The device has output control that can range from OV (ac) to any attainable voltage depending how the winding is connected. This project work mainly focus on the available voltage in Nigeria as the input voltage and a discrete variable output voltages ranging from OV (ac) to 200V (ac) with 15V (ac) intervals. The project work mainly has the ventilated shield with output control, an off/on switch, one (ac) outlet in this case but can be more.

1.2 SIGNIFICANCE OF THE STUDY

1. Due to different voltage requirement of different electrical appliances/Equipments, a device with multiple output voltage is necessary.

2. The device also play important role in the area of equipment testing, high Current generator control and many other engineering as well as Experimental applications.

3. It is also paramount to give the variation of the output power with respect to the change in input voltage, current and resistance.

1.3 AIMS AND OBJECTIVES

1. Due to the fact that much practical experiment in physics under electricity requires changes in voltage, the need of variable (ac) transformer become necessary.

2. To produce a device that will help in some domestic applications as a result of different power, current, and voltage ratings of the Appliance/equipment.

3. To produce a device that will help in some light duty industrial applications, like in operation of hot hire plastic foam, cutting control and many other operations like electric motor speed control. Etc.

1.4 SCOPE AND LIMITATION

1. The project work is basically the design and construction of a multiple output (ac) transformer with a variable output voltage of 15V interval.

2. The major limitation of the project work is the inability of it be used for any application other than the various output voltages it has been designed for.

3. It cannot be used above it maximum current and power supply

CHAPTER TWO

2.0 LITERATURE REVIEW

Multiple output AC transformer is a transformer designed to give multiple AC. output voltages to the desired amount, and has the same principle of operation as transformer, this should be well understood. Unlike most transfomers, the multiple AC transformer has a transformation ratio that can be continuously changed so that the output of the unit can be controlled from zero to the line voltage or even higher (2). This is achieved by tapping out each voltage required from the secondary winding, thus, the multiple output AC. transfomer can be described as tapped inductors. Unlike transformers with isolated input and output windings, this multiple AC transformer have single winding, which serve as both input and output source.

2.1 TRANSFORMER INVENSION

Many people are credited with the invention of transformer. The roll played by some of them is stated below:

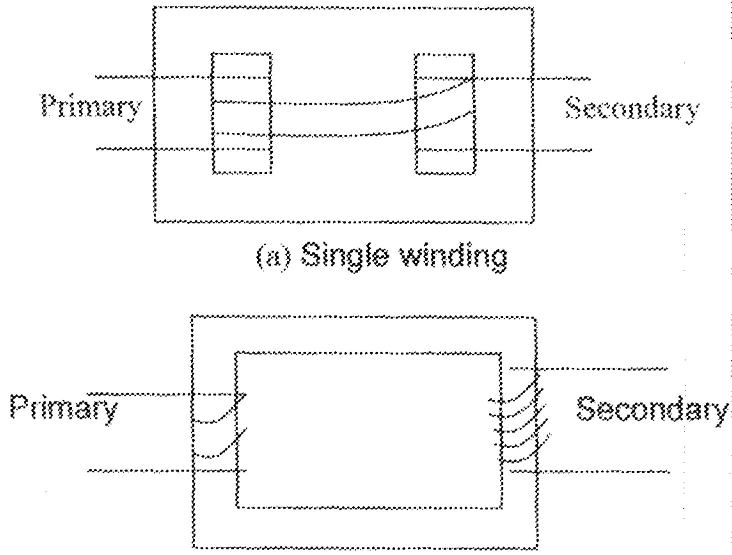
- The transformer principle was demonstrated in 1831 by Michael Faraday, although he used it only to demonstrate the principle of electromagnetic induction and did not foresee its practical uses [5].
- Russian engineer Pawel Yablochkor in 1876 invented a lighting system based on a set of induction coils, were primary windings were connected to a source of alternating current and secondary windings could be connected to several electric candles.

Evidently, the induction coil in this system operates as a transformer [8].

- Lucien Gaulard and John Dixon Gibbs, who first exhibited a device with an open iron core called a secondary generator in London in 1882 and then sold the idea to American company Westinghouse. They also exhibited the invention in Turin 1884, which was adopted for an electric lighting system [8].
- William Stanley, an engineer for Westinghouse, built the first commercial device in 1885 after George Westinghouse has bought Gaulard and Gibbs patent. The core was made from interlocking E-shaped iron plate. This design was first used commercially in 1886.
- Hungarian engineers Zipernowsky, Batty and Deri from the Gant Company in Budapest created the efficient "ZBD" model based on the design by Gaulard and Gibbs.
- Russian engineer, Mikhail Doliro-Dobrovolsky developed the first three-phase transformer in 1889.
- In 1891 Nikola Tesla invented the Tesla coil, an air cored, dual turned resonant transformer for generating very high voltages at high frequency.

Many others have patents on transformers, but to mention a few. While new technologies have made transformers in some electronics application obsolete, transformers are still found in many electronics devices because of its importance.

Generally, every transformer posses two coils called the primary and secondary windings (which are not connected to each other in any way) wound on the Faraday's iron core. Either one on top of the other as shown in figure 2.1 (a) or on a separate leg of the iron core as in figure 2.1(b).



(b) Double winding

Fig. 2.1(a and b). Transformer windings

If an alternating current is passed through the primary coil, a large alternating magnetic field is set up through the core to the secondary coil and an alternating emf is induced in it. The secondary induced voltage Vs is scaled from the primary voltage Vp by a factor ideally equal to the ratio of the number of turns of the coil in either respective windings and it is given by

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \text{(1)}$$

Where N_s=Number of turns of the secondary coil and N_p=Number of turns of the primary coil.

When a mutual inductance is used in this way, it is called a transformer (4).

By appropriate selection of the number of turns, a transformer thus, allows an alternating voltage to be stepped up by making the Ns more than Np or stepped down by making Ns less.

2.1.1 PRINCIPLE OF OPERATION OF TRANSFORMERS

A transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current. The physical basis of a transformers is mutual induction between two circuits linked by a common magnetic flux. In its simplest form, it consists of two inductive coils which are electrically separated but magnetically linked through a path of low reluctance. The two coils possess high mutual inductance. If one coil is connected to a source of alternating voltage, an alternating flux is set up in the laminated core, most of which is linked with the other coil in which it produces mutually-induced e.m.f. (according to Faraday's Laws of Electromagnetic Induction $e = Mdl/dt$). If the second coil circuit is closed, a current flows in it and so electric energy is transferred (entirely magnetically) from the first coil to the second coil. The first coil, in which electric energy is fed from the a.c. supply mains, is called primary winding and the other from which energy is drawn out, is called secondary winding. In brief, a transformer is a device that

1. Transfers electric power from one circuit to another
2. It does so without a change of frequency
3. It accomplishes this by electromagnetic induction and

4. Where the two electric circuits are in mutual inductive influence of each other.

2.1.2 MAGNETIC FIELD AND MAGNETIC FLUX (Φ)

The discovery by Prof. Oersted in 1819 at the university of copenhange that an electric current is accompanied by magnetic effect, saw the birth of electromagnetism [4], since then, the subject has been an extremely fruitful field of study for the imagination of scientists and creative genius of engineers. In electrical engineering the motor and transformers were the out come of Faraday's work because shortly afterward, Tesla invented the induction motor which does not require brushes to supply current to its motor and which is now the indispensable servant of industry [4].

Magnetic field due to a magnet is the space or region surrounding a magnet where magnetic force is experienced, experiment also reveal that current carrying conductor also generate magnetic field around it. This magnetic field is due to the current through the conductor. It is this fact that led to the believe that all magnetic effects are due to current in conductor. Magnetic field is represented by H and is given by magnetomotive force (mmf) per unit length (4). Magnetomotive force (mmf) is the effort exerted in creating a magnetic field which depends on the current in a coil and the number of turns, because increase in the current in the coil increases the mmf.

So, $H = \frac{mmf}{l}$ .... (2a).

Since mmf is also ampere-turns for base unit, but in the metric system mmf units is just the ampere, although, the ampere-turns is a more descriptive unit than ampere but the number of turns carrying current does not really matter. i.e.

$$H = \frac{mmf}{l} = \left(\frac{A-t}{m}\right) unit \ldots\ldots\ldots\ldots\ldots\ldots(2b)$$

Michael Faraday (1791-1897) noticed that the important quantity in all experiment is the magnetic flux [4]. Magnetic flux is the property of the magnetic field represented by magnetic lines. It is actually the measure of the strength of the magnetic field lines.

2.1.3 MAGNETIC FLUX DENSITY (B)

When referring to the strength of a magnetic field, use is made of the term magnetic flux density. It is an analogous quantity of the magnetic field and sometimes called magnetic induction. Magnetic flux density is defined as the force acting per unit length on a conductor carrying a unit current and it is at right angle to the direction of the magnetic field [4]. It is given by,

B=F/IL (N/AM)……………………(3),

Given a special Name 1Tesla (T)

Another unit is gauss (G) where IT= 10^4G but G is not an SI unit and therefore not always used.

F=BIL…………………… (4a)

This is the force on the conductor of length L, carrying a current I and lying at right angle (90^0) to the magnetic field of the flux density B.

But if the conductor and the field are not at right angle, but make an angle with another, then.

F = BIL sinθ......................(4b)

For θ=90^0 gives F = BIL

θ =0 gives F =0

Meaning when the conductor is parallel (along the field lines) there will not be any force as shown in the figure below.

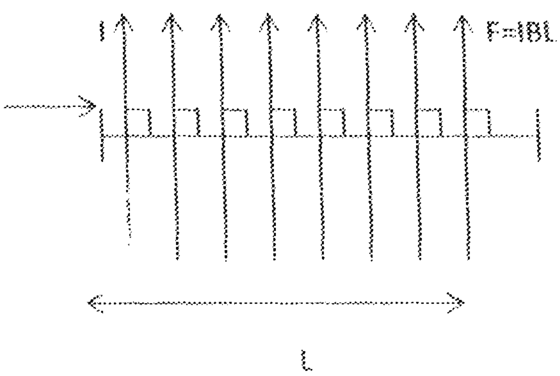


Fig 2.2 (a)

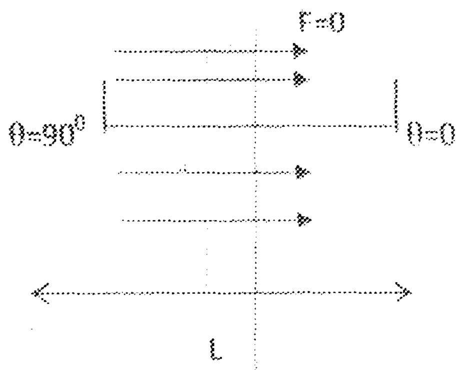


Fig 2.2(b)

For n numbers of charges moving with velocity V per unit length L, then from

$\frac{F}{L} = nBI \sin\theta$ .... (4c)

I can be simplified interns of charge motion as

I=q/t................................ (5)

But all the charges will pass through a cross sectional area of the wire in time t.

Since over time (t) free charges will move a distance

L=Vt........................(6), then

$$F = \frac{nqvtB\sin\theta}{t} = nqvB\sin\theta \quad ....(7)$$

In terms of transformer the strength of the magnetic field depends on the ability of the core to conduct flux. This ability of the material of the core is represented by μ called the permeability. This is given as the ratio of the magnetic flux to the magnetic field strength.

$$\mu = \frac{B}{H} \quad ....(8a)$$

$$B = \mu H \quad ....(8b)$$

2.1.4 INDUCED ELECTROMOTIVE FORCES (EMFS)

EMF are extremely important in modem day electricity, because they are the basis to the operation of electric generators, motors and transformers [4]. When two coils are wound on the same iron core, under certain circumstance one induces a current in the other. When an alternating current (ac) is passed through one coil a magnetic field is setup which has some properties called magnetic flux linking the other coil. Change in this magnetic field as a result of the alternating current in the first coil will induced electromotive force (EMF) in the second coil and it's magnitude is determined by the change in flux over time through a unit coil [1].

$EMF = \frac{-d\phi}{dt}$

The negative sign indicates that the emf opposes the magnetic flux. No emf is induce when no change in the magnetic field occur and there is no magnetic field without current.

If there is a flux through a coil with N number of turns changing at the rateΔΦ/Δt, the induced emf (according to the faraday's law of induced emf) in the coil is [2]

$Emf_s = -N_p \frac{d\theta}{dt}$ ....(9b)

and $Emf_s = -N_s \frac{d\theta}{dt}$

Since the flux linking the two coils is the same in both coils, dividing the two expressions above as

$$\frac{Emf_s}{Emf_p} = \frac{V_s}{V_p} = \frac{-N_s \frac{d\theta}{dt}}{-N_p \frac{d\theta}{dt}} = \frac{N_s}{N_p}$$

$\frac{V_s}{V_p} = \frac{N_s}{N_p}$ ....(10)

This is called the transformer ratio

2.1.5 ENERGY LOSSES IN TRANSFORMER

Although, transformers are very efficient devices, small energy losses do occur in them due to four main causes [11].

i. Hysteresis loss:- This is caused by residual magnetism which remains in a material after the magnetizing force has been removed. The magnetization of the core is repeatedly reversed by the alternating magnetic current (ac). The resulting expenditure of energy in the core appears as heat called (Hysteresis loss). This heat increases with the frequency of the primary alternating (ac). This is why laminated iron core transformers are not used above audio frequency range. The loss is narrowed by using a laminated iron-core made from silicon steel.

ii. Eddy current loss:- The changing magnetic flux in the core of a transformer induces voltage into any conductor which surround it (11). Since the core it self is a conductor there is induced voltage in it as well as the surrounding conductors. The voltage causes induced current to circulate in the core thereby producing heat as it flows though the resistance of the core. This current is called EDDY CURRENT. The Eddy current can be reduced by using a laminated core. since the heat is due to the induced voltage and current, the power.

$P = VI$ .... (11a)

The lamination will increase the resistance of the path through which the Eddy current will flow.

I = V/R.................... (11b) from Ohm's law [4]

iii. Copper Loss:- This is refers to as the power dissipated in the windings of the transformer. The copper wire used for the winding has a resistance and so ordinary heat loss occurred calculated as power.

$P=I^2 R$.................................(12)

In high-current, low Pd windings this minimized by using thick wire (II)

iv. Flux leakage:- The flux due to the primary may not all link the secondary if the core is badly designed or has air gaps in it which caused some flux been loss. This is reduced by designing the core properly to reduce the air-gap. Vary large transformers have to be oil-cooled to prevent over heating.

2.2 APPLICATIONS

Multiple output (ac) transformer has numerous applications in domestic, laboratory and industrial settings.

i. Many electronic service departments employ the transformer to check out equipment at low and high operating voltages.

ii. Engineering department often check designs to assure new products operate with e.qpected input power, here the transformer is useful.

iii. Quality control testing, electronic equipment burn-in and life tests utilize such transformer in testing procedures.

iv. Temperature and lighting control

v. Industrial motor speed control

vi. The transformer has numerous industrial, domestic, laboratory and electronic applications where different voltages are required for the operation of some devices.

CHAPTER THREE

3.0 DESIGN PROCEDURES

It is important not simply to design a transformer that will do, but one that is economical, efficient and makes the best use of available materials.

However, the size, shape and material of the core must be chosen, and the number of turns of the primary and secondary windings. The size of the wire and the insulation determines if the winding will fit the available space. The insulation determines the permissible temperature rise and means of cooling the energy loss under load. A complete design must include all these features.

The fundamental parameters are the core and the number of turns. Basically, two equations are used in transformer design. The first is essentially Faraday's law

$$E = \frac{d\phi}{dt} \times 10^{8} V \text{ .... } (13)$$

For transformer $B_{max} = \dfrac{\sqrt{2}E \times 10^{8}}{2\pi fNAK}$ .... (14)

Where E = rms voltage in a winding, N = number of turns, f = frequency (Hz), A =area of core (cm^2) and K = stacking factor.

B_{max} is generally assumed as a design parameter as well as a value for E/N in volt per turn. A typical value for a small transformer is E/N =0.1 V/turn.

The second equation is the Ampere's law

$H = 0.4\pi NI / L$ ....(15)

Where L= length of the magnetic circuit. From the value of B_{max}, the value of H_{max} can be found from the magnetization curve of the core material and this equation is used to determine N, when a reasonable value of I is assumed (say 5% of the full-load current).

3.1 SYSTEM SPECIFICATION

The specification of this variable (ac) transformer is to provide a regulated alternating current (ac) supply voltage within 0 to 200V ac with an output voltage step of 15V ac. This project is designed to be used by electronics and other applications within this voltage range.

3.2 CHOICE OF MATERIAL

The materials used in this project work were chosen with due consideration of their capability to serve the desired purposes. On the other hand, the properties of available materials rigidly limit the possibilities.

3.2.1 IRON CORE

A soft iron core was chosen for its good conductivity of electric current and high ability to conduct magnetic flux. The permeability of iron core increases with increase in flux density. The iron core used for this project was a circular iron core (toroid) of internal diameter of 10cm, external diameter of 15cm and 5cm height. The toroid was selected as against the interlocking E shaped cores so as to have as small as possible size of the transformer.

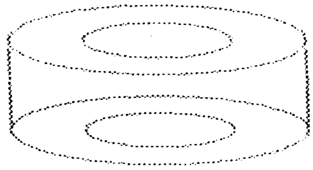


Fig. 3.1 A circular iron core.

3.2.2 THE COIL WIRE

As most transformers, laminated cupper wire was used for the windings, mainly due to its cheapness and its physical strength. Large number of turns of the primary was chosen to minimize the heat dissipated from the transformer as result of current flow. The size of the primary wire used was 22.5mm and 20mm for the secondary mainly to ensure efficiency and strength

3.2.3 THE CONTROL SWITCH

Ordinary switches were used to select each voltage required at a time. This was due to the unavailability of a perfect control knob that can be used for the selection of the output voltages. Switches which could be the easiest and less expensive alternative have disadvantage of having low heat resistance due to pure to poor quality control in Nigeria market.

3.2.4 COILING STAGE

The coiling was done manually and based on the transformer ratio principle. Since the voltage is linear variable, it then means that the length of the coil is directly proportional to the voltage, because each turn provides a proportion of the total voltage produced, thus there are number of turns in the primary winding (coil). The induced emf per turn is given by E/N, assuming that there are no losses of current and flux linkage, and if there are N_2 turns in the secondary winding (coil), the total induced emf is given as

E=N2E1/N2

Using equation 17, the coil wires of the secondary windings were tapped out after some number of turns which gives the required variation of the output voltage. Extra care was taken during the coiling in order to prevent the insulation of the coil wire being scrapped to avoid short circuit.

3.2.5 CASING

A rectangular wooden case of length 26cm and width 18.5, was used to housed and support the transformer. The case was perforated by the side to allow for ventilation and also dissipation of heat generated within.

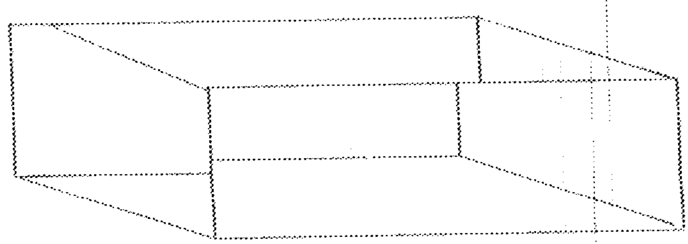
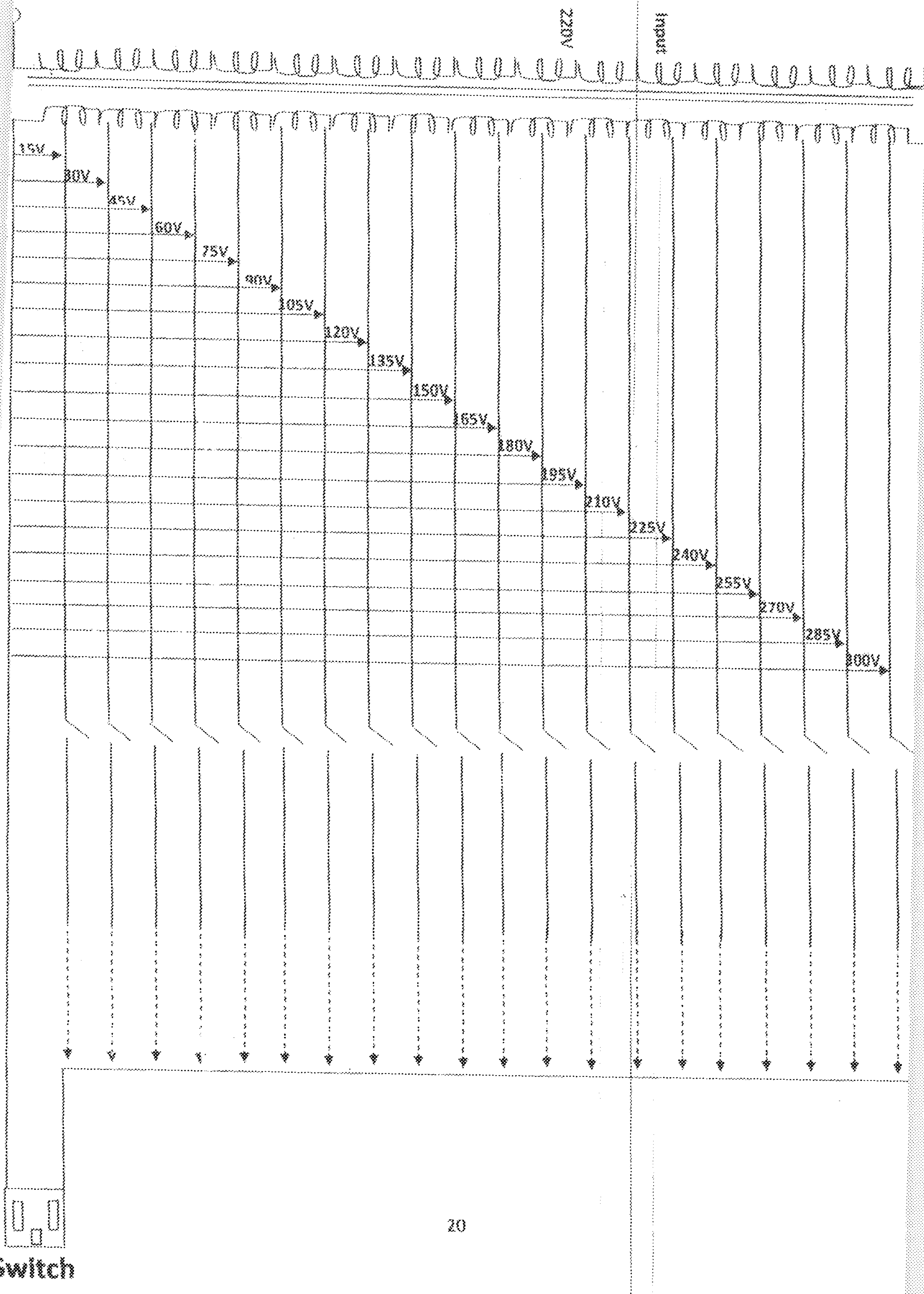


Fig. 3.2 A rectangular wooden case


220V
Input
15V
30V
45V
60V
75V
90V
105V
120V
135V
150V
165V
180V
195V
210V
225V
240V
255V
270V
285V
300V
Switch

CHAPTER FOUR

4.0 TEST RESULT AND DISCUSSION

After the completion of the construction work, the device was plugged to available source voltage in Nigeria (220v) and the multiple outputs were measured one at a time with the aid of a digital multimeter. The readings obtained were recorded and tablated as shown below.

Supplied voltage (v)	Designed voltage (v)	Measured voltage 1	Measured voltage 2	Measured voltage 3	Average voltage
220V	15v	14.71	14.69	14.67	14.69
	30v	29.6	29.7	29.6	29.63
	45v	44.6	44.3	44.5	44.47
	60v	60.7	60.6	60.5	60.60
	75v	74.9	75.2	75.4	75.17
	90v	90.6	91.2	90.0	90.6
	105v	105.5	105.3	105.7	105.50
	120v	120.8	128.7	120.6	120.70

	120v	120.8	128.7	120.6	120.70
	135v	136.3	135.9	136.1	136.10
	150v	150.9	152.1	151.3	151.43
	165v	168.3	168.6	168.4	168.43
	180v	184.4	183.5	184.0	183.97
	195v	192	193	195	193.33
	210v	211	211	212	211.33
	225v	226	226	226	226
	240v	240	240	239	239.67
	255v	254	255	254	254.33
	270v	266	266	266	266
	285v	280	280	279.9	277.99
	300v	292	294	295	293.67

Fig. 4.1 Table of results

During the test of the output voltages, it was found (discovered) that exact 15V intervals was not achieved, this may be due to losses and the position of tapping out wires. However its very interesting and encouraging that some were almost exact and a reasonable number rang fill between $\pm$ 3V of the expected voltage

4.1. PROBLEMS ENCONTERD AND SOLUTIONS

During the course of construction, some problems were encountered and solution proffered as follows:

1. Heat dissipation from the transformer and hence ventilation holes were perforated.
2. Its was difficult to attain the required voltage at the reference point after few number of tapped out is a result of voltage drup.
3. Another problem was the choice of size of the gange wires and the number of turns to ensure efficiency of d transfomer, $20^{1}/_{2}$mm and 20mm were chosen for the primary and secondary respectively.
4. Regular fluctuation of the input voltage.

CHAPTER FIVE

5.0 CONCLUSION

The main aim of the project work was to produce a regulated Ac voltage supply source of with 15v Ac output voltages which could be used in laboratory, domestic and industrial purposes. Most electronic device can not make use of the supply voltage directly from the main source (220V Ac) voltages. Therefore this device is very important device.

The result of this construction work shows a high performance voltage supply device with discrete output voltage of 15V Ac intervals ranging from 0 to 300V Ac. Like everything undertaken in life, is never absolute there must be some forms of errors and constraints. The major constraint encountered during this construction wok was in the design as well as the coiling of the secondary winding which requires tap out after some number of turns. However, the aim of the project is achieved.

5.1 RECOMMENDATION

This project can be further developed upon, by using any means of achieving a smooth variation of the output voltage, so that it can be used for any application that make use of both low and high voltage.

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