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Design and Construction of 0-500V 3KVA Variac with Digital Display

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ABSTRACT

The design and construction of 3KVA variac ranging from 0-500V with a digital display was carried out due to the fact that every electrical, electronic and laboratory appliances/equipments are designed and manufactured to operate based on the expectation that the input voltage would be at certain value. In Nigeria, household electrical/electronic appliances and also laboratory equipments are most time under threat of low voltage supply. Since the electric power supply/ distribution companies are unable to provide the consistent and adequate voltage level (220V) demanded by these sensitive appliances. The design and construction of a 3000VA variac (variable transformer) with an input voltage of 230V to give an output of 0-500V is aimed at providing solutions to this driving issue of low voltage and also to update in the growing trend of digitalization using a digital display. The method applied to achieve this project include faraday's law of induction, ohms law, e.m.f equation of transformer and voltage transformer ratio (k),where the number of turns in for the primary is 136turns and the secondary is 297turns (approx.). The major components used to achieve this work are the copper wires and the laminated steels (core) also known as the toroidal core. The designed and constructed variac was tested with an input of 230V and the output result of 500Vmaximum was confirmed ok. If designed and properly constructed with standard electrical components and materials it could be used in sub-stations as step up for distributions of electricity. It should be designed with heavy gauge coils, higher rated toroidal core and attached an indicator to indicate with beep sound when it is being overloaded above its capacity.

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***KEYWORDS:** Transformer, Toroidal, Design, Construction, Results*

INTRODUCTION

A transformer is a static piece of equipment used either for raising or lowering the voltage of an a.c. supply with a corresponding decrease or increase in current. It essential consists of two windings, the primary and secondary, wound on a common laminated magnetic core (Metha, 2012). A Toroidal transformer provides increased design flexibility, efficiency & compact design when compare to traditional shell & core type transformers. The design of most efficient toroidal transformer that can be built gives the frequency, volt ampere ratings, magnetic flux density, window fill factor and material which can be used. With the above all constant and only the dimension of the magnetic core is varied. The most efficient design occurs when the copper losses equal 60% of iron losses. When this criterion is followed, efficiency is higher(Harshit, 2018). In an auto-transformer, there are actually two coils, which are connected in series. In a step up application, the supply voltage is impressed across one while the magnetically induced voltage is created across the other winding. The sum of the two voltages is considered to be the output (Sujit, 2014).

AIM AND OBJECTIVES

The aim of this work is to design and construct a 3KVA variac (variable transformer) with a voltage ranging from 0 to 500volt with a digital display.

The specific objectives of this work are:

1. To power the electrical/electronic and laboratory equipments with a fixed input voltage
2. To be able to vary voltage from 0V to 500V
3. To construct the system stated in the aim above using locally available materials.

METHODOLOGY

In Designing and constructing of a Variac (variable transformer), there are procedure, laws and principles to be applied in order to achieve the aim and objectives of the project work. This also includes the scientific methods and laws applied in this work as well as the tools and materials used to actualized the aim of the project.

This topic deals with the steps and processes employed in design and construction of the work. It also explains the design concept, principles applied, data computation technique, simulation, assumptions of the work, construction and testing of the work.

Principles Applied

The principle applied for the execution of this work is basically an engineering principle. However the values of the parameters used were determined based on equations stated in the preceding sub topics;

Calculating the primary and secondary current

Joule's law is used to determine the primary and secondary current. Thus, mathematically express as:

$$P = IV \quad (1)$$

Where p = power in watts
I = current in Amperes
V = voltage in Volts

Calculating the core area (Ca)
The core area is calculated using the formulae
$Ca = Vde - Vdi$ (2)

Note that volume of external diameter, $Vde = \pi r_1^2 \times H$, and volume of internal diameter, $Vdi = \pi r_2^2 \times H$

Where,
Ca= cross sectional area of toroidal core
Vdi = volume of external diameter
Vdi = volume of internal diameter

r_1 and r_2 are external and internal radius respectively
H = height of core

Calculating turns per volt (TPV)
In calculating turns per volt the expression in equation (3) was use as thus;

$TPV = 1 / (4.44 \times 10^{-4} \times CA \times \text{Flux Density} \times \text{AC frequency})$ (swagatam, 2011) (3)

With equation (3), number of primary and secondary turns can be derived from equation (4)
Number turns in the primary; $N_P = TPV \times V_1$ (4)
Similarly for $N_S = TPV \times V_2$ respectively

Weight for the winding:
Weight = volume x density (5)
Volume of conductor, V = area of conductor x total number of turns
Area of conductor, A = πr^2

Design flow Chart
The design flow chart in figure shows representation in algorithms, workflow and process of this project. These processes are represented using boxes of various kind and shapes, and the various order performed in the work, by connecting them with arrows.

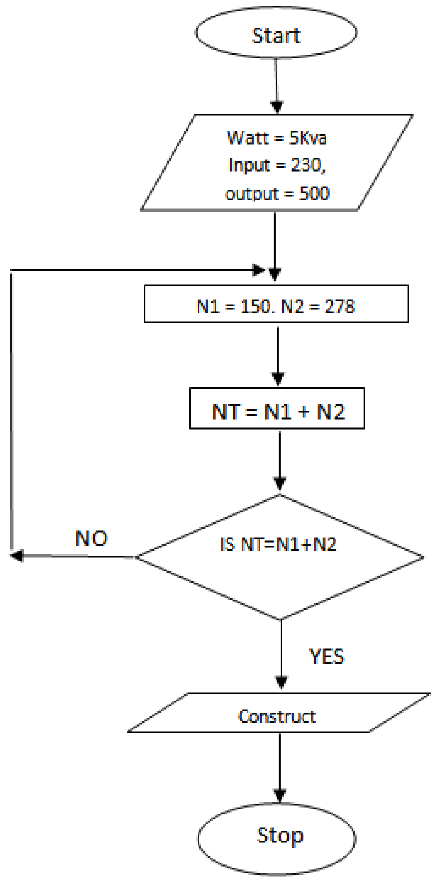

Figure.1: Design flow char

Block Diagram of the Project
The block diagram as shown in figure 2, shows in details the various parts or units of the entire project and every single stage of the project in block, which gives the interconnection between the first stages to the final stage, using arrows to indicate their directions. The input is fed with a 230volts (AC) supply, meanwhile the variac is a 3000VA variable transformer with a primary turns of 136T, and a secondary turn of 297T. This transformer produces an output of 0-500Volt, through the process called mutual induction and fed to the output terminal. Finally the digital display shows the exert value of the output voltage in discreet form on the screen.

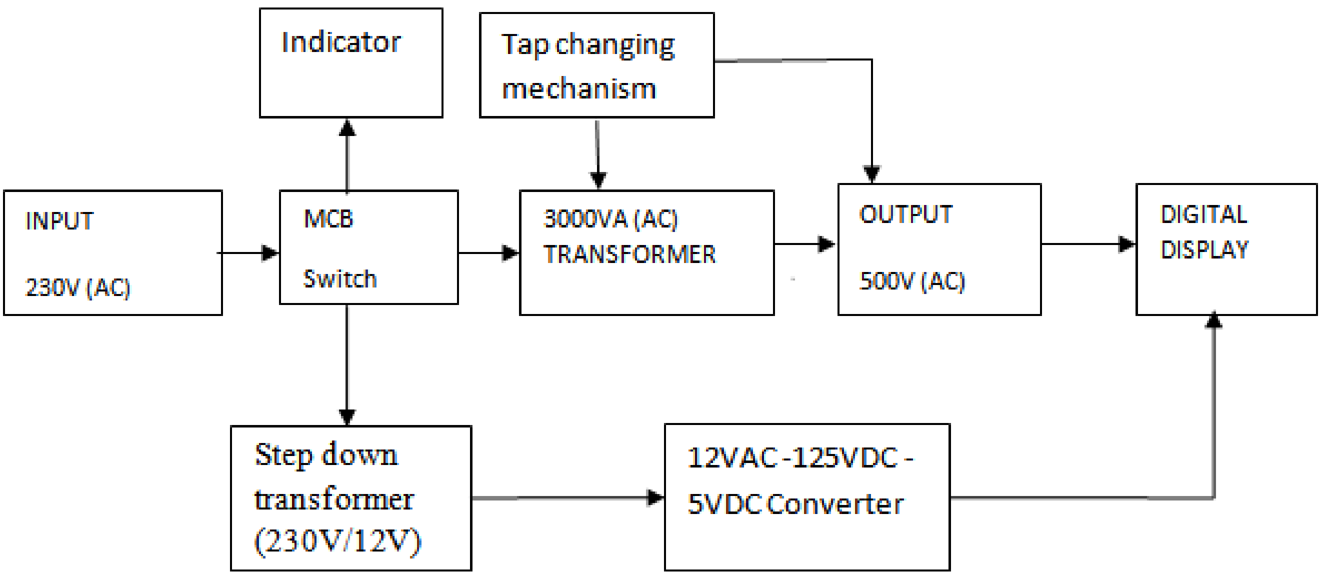

Figure 2: Block Diagram of a variable transformer (variac)

Procedure

Step one : Design calculation using a toroidal core

Step two : Preparation of core for winding (lamination of core).

Step three : Arrangement of the winding on laminated core.

Step four : Filing and varnishing of the winding.

Step five : Soldering of taps terminals on winding (input, neutral terminals)

Step six : Construction of casing

Step seven : Coupling of the transformer in a case with other accessories.

Step eight : Testing the transformer.

Design

The design is a process of bringing together technologies and ideas to meet human needs or to solve outstanding problems.

Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step-by-step approach.

Preliminary design assumptions

Assumptions considered when carrying out the preliminary design of the transformer include:

- Also to be able to archive 3KVA and a maximum of 500volt output, it is advisable to use a 5KVA core or above in the course of your design.

Designing calculation for a 3000watt variac with maximum output of 500volt

To do the design of this work the following parameters are to be considered

- Numbers of turns of both winding.
- Power rating of the transformer
- Core area
- Voltage levels (input and output)
- Current through both windings

From the data's given the wattage of the variac 3000VA while the input and output voltage are given as 230Volt and 0-500Volt.

Recall equation (1): P = IV

Step 1: Primary current $I_P = \frac{Power}{primary\ voltage}$

$$I_p = \frac{3000}{230} = 13.0A$$

Therefore, I_P = 13A with SWG of 12.5SWG/2.9mm (Appendix A)

Step 2: Secondary current I_S = $\frac{power\ rating}{secondary\ voltage}$

$I_s = \frac{3000}{500} = 6A$

Therefore, I_P = 13A with SWG of 15.5SWG/1.73mm (Appendix A)

Step 3: Calculating for the core area (Ca) from equation (2)

$$Ca = Vde - Vdi$$

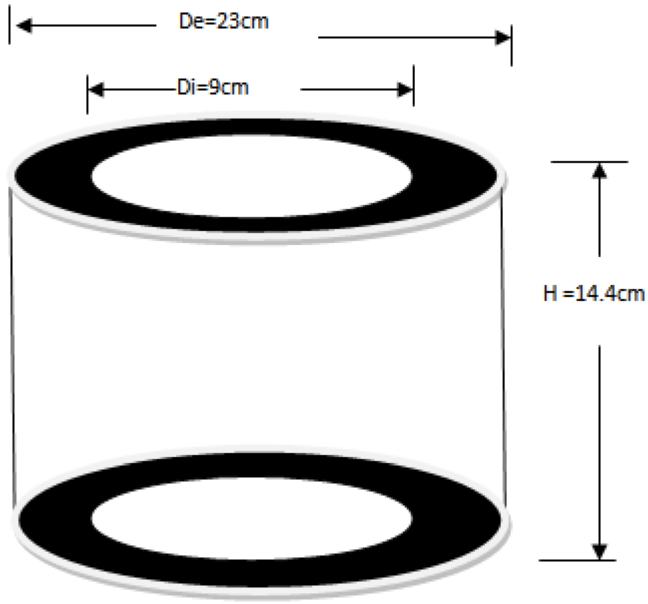

Figure 3: Toroidal core

Where

External diameter $(de) = 23cm$

Internal diameter $(di) = 9cm$

Height (H) = 14.4cm

Volume of external diameter $Vde = \pi r_1^2 \times H$, $Vdi = \pi r_2^2 \times H$,

Where

$$Radius\ (r_1) = \frac{de}{2}$$

$$\frac{de}{2} = \frac{23}{2} = 11.5cm$$

$$Radius\ (r_2) = \frac{di}{2}$$

$$\frac{di}{2} = \frac{9}{2} = 4.5cm$$

Hence

$Vde = \pi r_1^2 \times H$

$Vde = 3.142 \times 11.5^2 \times 14.4$

$Vde = 5983.6248cm$

$Vdi = \pi r_2^2 \times H$

$Vdi = 3.142 \times 4.5^2 \times 14.4$

$Vdi = 916.2072cm$

$Ca = Vde - Vdi$

$Ca = 5983.6248 - 916.2072$

$Ca = 5067.4176cm$

Step 4: Calculating turns per volt

Applying equation (3)

TPV = 1 / (4.44 × 10^{-4} × CA × Flux Density × AC frequency)

Bm is taken to be 1.5wb/m² = 1.5 x 10^{-2} (wb/cm²)

TPV = 1 / 4.44 x 5067.4176 x 10^-4 x 1.5 x 10^{-2} x 50 = 0.593turns per volt

Step 5: Primary numbers of turns = turns per volt x primary volt (equation 4).

N_p = 0.593 x 230 = 136 turns (approx.)

Step 6: secondary number of turns (Ns) = turns per volt x secondary voltage

N_s = 0.593 x 500 = 297 turns

Step 7: Weight for the winding:
Weight = volume x density (equation, 5).

Volume of conductor = area of conductor x total number of turns

Area of conductor = πr^2

Were d_p = 2.49mm diameter for a 12.5(SWG) standard size wire gauge with reference to appendix A

r = d_p/2 = 2.49/2 = 2.49mm

Area = 3.142 x 2.49^2 = 19.481

Volume of conductor for primary = 19.481x 136 = 2649.42mm (approx.)

Volume of conductor for primary = 2649.42 x 10^{-6} m^3

Recall; density of copper = 8960kg/m^3

Weight = 2649.42 x 10^{-6} x 8960

Weight of conductor for primary= 23.74gramm

Hence weight of winding = 0.024 kilo-grams (approx.).

Similarly for secondary;

Were d_s = 1.73mm diameter for a 15.5(SWG) standard size wire gauge with reference to appendix A

r = d_p/2 = 1.73/2 = 0.87mm

Area = 3.142 x 0.87^2 = 2.378

Volume of conductor = 2.378 x 297 = 706.266mm (approx.)

Volume of conductor = 706.266 x 10^{-6} m^3

Recall; density of copper = 8960kg/m^3

Weight = 706.266 x 10^{-6} x 8960

Weight of conductor = 6.33gramm

Hence weight of winding = 0.063 kilo-grams (approx.).

Total weight of winding = 0.024 + 0.0063 = 0.0303Kg

Schematic Diagram
The schematic diagram in figure 4 shows in details all the significant components, parts and their interconnections between one point to the other, omitting all details that are not relevant to the information, using a standard set of symbols, for preparing a preliminary cost estimate for the work.

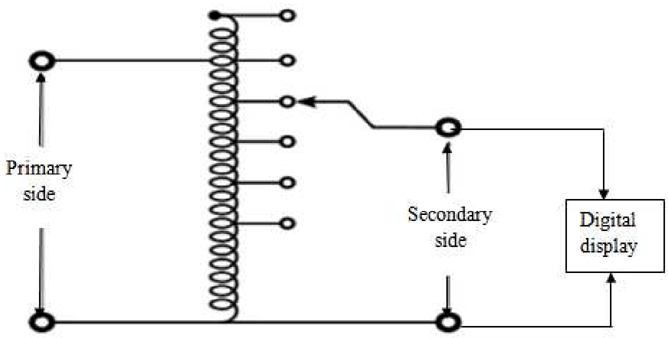

Figure 4: schematic diagram of the project

P_1 = primary input voltage terminals
N_1 = primary turn
N_2 = secondary turn
P_2 = Secondary output voltage terminal

Circuit Diagram
The diagram in figure 5 shows the circuit diagram of this work, showing in details a comprehensive design and arrangement of the construction of a step down or step up auto transformer with 230V input and 500V maximum output. It also describe with specification of the position, values and number of turns used on the primary and secondary winding of the transformer. Such that whenever a maintenance action is required, one can easily use the circuit diagram as a guide.

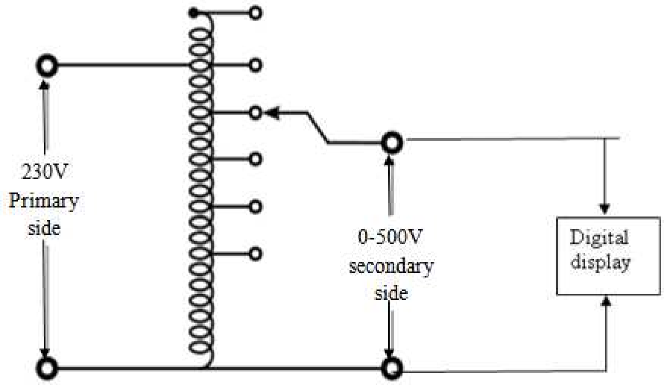

Figure 5: Circuit Diagram

CONSTRUCTION
The construction of a variable transformer (variac) consist of a winding being wound on a single core (toroidal) of soft iron from which provides the necessary magnetic circuit. The basic construction process includes:
- Identify the SWG for the winding
- Transformer core construction
- Transformer lamination preparation
- Transformer Winding arrangement
- Transformer filling and insulation (varnishing)
- Transformer Dot orientation

Design Assembly
This section describes the process and stages involved in the project construction including precaution and safety measure.

The project assembly procedures are as follows:
- Designing of variac
- Construction of variac
- Construction of former
- Winding of the former (core)
- Filing and varnishing of the winding
- Soldering of all the taps to the former terminals
- Construction of casing
- Coupling of the former, carbon brush and other accessories to the casing

Variac construction
The constructional parts of a variac are the conductors, winding, formers and carbon brush.

12.5 and 15.5 gauge copper wire was used in winding the core of the variac, where each copper is made to be well aligned with each other ensuring they do not be on top of each other for smooth calibration of each winding when the carbon brush is rotating.

The core (former): the core is circular in shape, it is also known as the toroid core. The copper wire is wound on the core which accommodates the required number of turns to produce the desired output voltage in respect to the desired specification.

Construction Winding

The design is 433turns in total wound on the former; it is a single coil variable transformer. The construction involves the winding of the coil on the former (core), ensuring the winding does not lap on each other especially on the surface that makes contact with the carbon brush. After which is properly varnish for good tightness.

Construction of casing

The casing was constructed with mild steel materials, air vet were provided by each side of the casing cover to allow inflow of air, with the sole aim of reducing the heat generated when in use.

Casing Dimensions:
- The height of the casing =45cm
- The width of the casing =25cm
- The length of the casing =30cm

Coupling of the Wounded Former and Other Accessories in the casing

The torodal core completely and successfully wound was mounted on the frame base on the casing with carbon brush well centralized on the core. All the top point soldered effectively to the core labeled terminals, digital display was as well mounted in the front panel according to the design specification.

Principle of Operation

Variac is a single inductive coil transformer which is electrically and magnetically linked through a path of low reluctance. The coil possesses inductance once it is connected to the source of alternating voltage, the whole coil is electrically connected and hence alternating flux is set up in the coil as well as in the core, there by produces\ self-inductance emf. According to faraday's law of Electromagnetic induction, if a load is connected, current flows in it and so electric energy is transferred magnetically and electrically in the coil. The winding ratio can be changed contentiously to change the output voltage from input voltage of 230volt smoothly to 500V when it regulator slides on the winding abrasive surface with the help of a knob main axis and brush stand. Variable transformer (Variac) is used where steady power is required to apply to the laboratory equipment, from the output voltage. The range of voltage according to design of variable autotransformer is calibrated at the top of the casing where the knob is situated for the user to know the level of the output applied to laboratory equipment to fit the voltage requirement.

Maintenance Prescription Manual

This manual is to show the steps on how to use the device and its safety precautions.

Safety precaution:
1. This work involve the use of dangerous voltage capable of causing hazard If not properly used.
2. You must make sure all high- voltage conductors are safely insulated from accidental contact.
3. During operations no bare wires should be seen anywhere on the conductors.
4. The variac should be used in a clean and well ventilation environment.
5. Units are designed to be used to a **maximum current,** not VA rating, so maximum current rating must not be exceeded at any point of operation.
6. The adjustment dial should be varied (increased or decreased) gradually, not fast or in jerky movements, rapid or rough dial movement may damage or break the carbon brush, necessitating replacement.
7. This will ensure long life of the variac, and reduce wear on the carbon control brush.
8. The unit is designed for regular movement of the adjustment dial, if being used continuously in one output position (no dial movement) the output current rating must be reduced or de-rated approx. 10% as outlined in the specifications.
9. The output dial includes a scale of voltage that provides general indication of voltage, it is not precise, for precise measurement, use an appropriate multimeter to measure the output voltage. Alternatively, some models are provided with output voltage and/or current meters for more accurate readings.
10. Loads such as LED lights, electronic switch mode power supplies may have a high harmonic content in them, therefore it is recommended to use a Variac that is double the load rating for such devices. (E.g. a 9 A load requires an 18 Variac).

Research prescription manual

Table1: Research prescription manual

S/N	Symptoms	Causes	Remedies
1	Shock	Leakage as result of induced EMF in the lamination.	Insulate the coil from the lamination.
2	Vibration	Too much load on the transformer and poor assembling of laminations	Reduce load from transformer and tighten lamination properly
3	Losses	Voltage induced in the iron core	Construct transformer core from tin steel lamination
4	Un usual smell from transformer	Short circuit and burnt windings	Check for bridged. burnt parts and rewind or change transformer completely
5	No display voltage level	Dead component or burnt component	Replace component with a new one or replace display with new one

ANALYSIS AND RESULTS

Analysis

This aspect is concerned with testing of constructed work (variac), results of the tests done and the discussion of the outcome of the tests carried out.

At the end of the constructed work, tests were carried out to determine the efficiency of the work. This test includes short circuit and continuity tests.

Short Circuit Test

The Short circuit test carried out is to ensure that there is no bridge between the wounded windings of the constructed system to achieve this, red probe of the multimeter was connected to a one point on the wounded windings and the black probe to the other end of the wounded winding.

Continuity Test

Continuity test carried out is to ensure that there is continuity between the autotransformer windings, this was achieved by using a file to remove the insulation on the copper conductor after which one probe of the multimeter was connected to a point on the winding and the other probe was connected to another point on the winding.

Determination of Output Voltage Value

Figure D shows the testing of the output voltage, final coupling of the work was carried out thereafter the test was done to verify that it was successful and to determine if the design specification was achieved. The device was plug to a power source of 240V and a multimeter was connected to the output terminals of the constructed variac to get the output voltage which eventually read 564V. This indicates that the output voltage in design specification was achieved i.e 500V.

Result

Table 2 Shows the results of the output voltage obtained to determine and know if the output voltages are within the specification of 0V — 500V.

Table 2: Input and Output Voltage Test Result

S/N	Input Voltage	Output Voltage	Remark
1	240V	564V	Normal input 230
2	200V	530V	Output 230 ±10%
3	190V	510V	Output 230 ±10%
4	180V	500V	Output 230 ±10%

Table 2 gives the input and output voltages obtained from the constructed system which ranges from 0V — 500V. The test result shows that the system is satisfactory and can perform it required function by producing different level of output voltages. The device can be used in laboratory to carryout experiment with electronic equipment's that requires to be fed with voltage of 2V, 3V, 6V, 50V and above as the case may be. From table 2, it shows that the work was successful.

CONCLUSION

Conclusion

The design and construction of 3KVA variable transformer (variac) was successfully executed to meet up to the aims of the work which include: eliminating the challenge of low voltage supply from the utility authority by using the variable transformer(variac) to either increase or decrease the voltage supplied to it. This design also aimed at producing ranges of voltage from 0-500volts for the purpose of powering electronic equipment's in the laboratories. Finally to provide desirable output voltage which can be displayed digitally hence adding to an improvement in technology which was a huge success in meeting human need.

Recommendation

At the completion of the work, it is of high level of reliability. The variable contact slide brush was adjusted and attains the desired output level from 0-500Volt. For the improvement of this work in nearest future, the following are recommended:

- That the design be used for domestic (homes and offices) purpose. Where appliances are limited to a desirable amount of voltage instead of fluctuation in voltage.
- If designed and well-constructed with electrical components of higher rating, it could be used for industrial purpose.
- Toroidal core of higher rating should be used, in order to have a higher output.

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APPENDIX A

Table A: Engineering Tables/Standard Wire Gauge (WIKIBOOKS, 2019)

Standard Wire Gauge	Diameter		Turns of wire		Cross-sectional area		Res. per length (for copper wire)		Mass per length		Current Capacity / A	
	in	mm	in^{-1}	mm^{-1}	kcmil	mm^2	Ω/km	Ω/kft	lb/ft	kg/m	750 kcmil/A	500kcmil/A
0000000 (7/0)	0.500	12.7	2.00	0.0787	250	127	0.136	0.447	0.759	1.13	333	500
000000 (6/0)	0.464	11.8	2.16	0.0848	215	109	0.158	0.519	0.654	0.973	287	431
00000 (5/0)	0.432	11.0	2.31	0.0911	187	94.6	0.182	0.598	0.567	0.844	249	373
0000 (4/0)	0.400	10.2	2.50	0.0984	160	81.1	0.213	0.698	0.486	0.723	213	320
000 (3/0)	0.372	9.45	2.69	0.106	138	70.1	0.246	0.807	0.420	0.625	185	277
00 (2/0)	0.348	8.84	2.87	0.113	121	61.4	0.281	0.922	0.368	0.547	161	242
0 (1/0)	0.324	8.23	3.09	0.122	105	53.2	0.324	1.06	0.319	0.474	140	210
1	0.300	7.62	3.33	0.131	90.0	45.6	0.378	1.24	0.273	0.407	120	180
2	0.276	7.01	3.62	0.143	76.2	38.6	0.447	1.47	0.231	0.344	102	152
3	0.252	6.40	3.97	0.156	63.5	32.2	0.536	1.76	0.193	0.287	84.7	127
4	0.232	5.89	4.31	0.170	53.8	27.3	0.632	2.07	0.163	0.243	71.8	108
5	0.212	5.38	4.72	0.186	44.9	22.8	0.757	2.48	0.137	0.203	59.9	89.9
6	0.192	4.88	5.21	0.205	36.9	18.7	0.923	3.03	0.112	0.167	49.2	73.7
7	0.176	4.47	5.68	0.224	31.0	15.7	1.10	3.60	0.0941	0.140	41.3	62.0
8	0.160	4.06	6.25	0.246	25.6	13.0	1.33	4.36	0.0778	0.116	34.1	51.2
9	0.144	3.66	6.94	0.273	20.7	10.5	1.64	5.38	0.0630	0.0937	27.6	41.5
10	0.128	3.25	7.81	0.308	16.4	8.30	2.08	6.81	0.0498	0.0741	21.8	32.8
11	0.116	2.95	8.62	0.339	13.5	6.82	2.53	8.30	0.0409	0.0608	17.9	26.9
12	0.104	2.64	9.62	0.379	10.8	5.48	3.15	10.3	0.0329	0.0489	14.4	21.6
13	0.0920	2.34	10.9	0.428	8.46	4.29	4.02	13.2	0.0257	0.0383	11.3	16.9
14	0.0800	2.03	12.5	0.492	6.40	3.24	5.32	17.4	0.0194	0.0289	8.53	12.8
15	0.0720	1.83	13.9	0.547	5.18	2.63	6.56	21.5	0.0157	0.0234	6.91	10.4
16	0.0640	1.63	15.6	0.615	4.10	2.08	8.31	27.3	0.0124	0.0185	5.46	8.19
17	0.0560	1.42	17.9	0.703	3.14	1.59	10.9	35.6	0.00952	0.0142	4.18	6.27
18	0.0480	1.22	20.8	0.820	2.30	1.17	14.8	48.5	0.00700	0.0104	3.07	4.61
19	0.0400	1.02	25.0	0.984	1.60	0.811	21.3	69.8	0.00486	0.00723	2.13	3.20
20	0.0360	0.914	27.8	1.09	1.30	0.657	26.3	86.1	0.00394	0.00586	1.73	2.59
21	0.0320	0.813	31.3	1.23	1.02	0.519	33.2	109	0.00311	0.00463	1.37	2.05
22	0.0280	0.711	35.7	1.41	0.784	0.397	43.4	142	0.00238	0.00354	1.05	1.57
23	0.0240	0.610	41.7	1.64	0.576	0.292	59.1	194	0.00175	0.00260	0.768	1.15
24	0.0220	0.559	45.5	1.79	0.484	0.245	70.3	231	0.00147	0.00219	0.645	0.968
25	0.0200	0.508	50.0	1.97	0.400	0.203	85.1	279	0.00121	0.00181	0.533	0.800
26	0.0180	0.457	55.6	2.19	0.324	0.164	105	345	984µ	0.00146	0.432	0.648
27	0.0164	0.417	61.0	2.40	0.269	0.136	127	415	817µ	0.00122	0.359	0.538
28	0.0148	0.376	67.6	2.66	0.219	0.111	155	510	665µ	990µ	0.292	0.438
29	0.0136	0.345	73.5	2.89	0.185	0.0937	184	604	562µ	836µ	0.247	0.370
30	0.0124	0.315	80.6	3.18	0.154	0.0779	221	726	467µ	695µ	0.205	0.308
31	0.0116	0.295	86.2	3.39	0.135	0.0682	253	830	409µ	608µ	0.179	0.269
32	0.0108	0.274	92.6	3.65	0.117	0.0591	292	957	354µ	527µ	0.156	0.233
33	0.0100	0.254	100	3.94	0.100	0.0507	340	1120	304µ	452µ	0.133	0.200
34	0.00920	0.234	109	4.28	0.0846	0.0429	402	1320	257µ	383µ	0.113	0.169
35	0.00840	0.213	119	4.69	0.0706	0.0358	482	1580	214µ	319µ	0.0941	0.141
36	0.00760	0.193	132	5.18	0.0578	0.0293	589	1930	175µ	261µ	0.0770	0.116
37	0.00680	0.173	147	5.79	0.0462	0.0234	736	2410	140µ	209µ	0.0617	0.0925
38	0.00600	0.152	167	6.56	0.0360	0.0182	945	3100	109µ	163µ	0.0480	0.0720
39	0.00520	0.132	192	7.57	0.0270	0.0137	1260	4130	82.1µ	122µ	0.0361	0.0541
40	0.00480	0.122	208	8.20	0.0230	0.0117	1480	4850	70.0µ	104µ	0.0307	0.0461
41	0.00440	0.112	227	8.95	0.0194	0.00981	1760	5770	58.8µ	87.5µ	0.0258	0.0387
42	0.00400	0.102	250	9.84	0.0160	0.00811	2130	6980	48.6µ	72.3µ	0.0213	0.0320
43	0.00360	0.0914	278	10.9	0.0130	0.00657	2630	8610	39.4µ	58.6µ	0.0173	0.0259
44	0.00320	0.0813	313	12.3	0.0102	0.00519	3320	10900	31.1µ	46.3µ	0.0137	0.0205
45	0.00280	0.0711	357	14.1	0.00784	0.00397	4340	14200	23.8µ	35.4µ	0.0105	0.0157
46	0.00240	0.0610	417	16.4	0.00576	0.00292	5910	19400	17.5µ	26.0µ	0.00768	0.0115
47	0.00200	0.0508	500	19.7	0.00400	0.00203	8510	27900	12.1µ	18.1µ	0.00533	0.00800
48	0.00160	0.0406	625	24.6	0.00256	0.00130	13300	43600	7.78µ	11.6µ	0.00341	0.00512
49	0.00120	0.0305	833	32.8	0.00144	730µ	23600	77500	4.37µ	6.51µ	0.00192	0.00288
50	0.00100	0.0254	1000	39.4	0.00100	507µ	34000	112000	3.04µ	4.52µ	0.00133	0.00200

Notes:	1. All values are rounded to three significant figures. Values less than 1×10^{-6} are shown with appropriate SI prefixes to avoid a large number of leading zeros. 2. The IACS value of 58.0 MS/m is used as the conductivity of copper. 3. These calculations do *not* take into account AC effects such as the skin effect - perform suitable calculations before using in a high-frequency application. Grid mains frequencies (50–60 Hz) should not have a noticeable effect, as the skin depth is over 8mm. 4. A density of copper of 8920 kg/m³ is used to derive the mass 5. An allowance of 750 kcmil/A is generally sufficient for calculating current capacity. The more relaxed 500 kcmil/A is an absolute maximum. 6. The values are guidelines – exact values will depend on the type of wire and operating conditions such as ambient temperature, thermal conductivity of the surroundings.
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APPENDIX B

Table B: Bill of Engineering Materials and Evaluation

S/N	Description	Quantity	Unit Price (₦)	Total Price (₦)
1	Toroid core	2	25,000	50,000
2	Copper wire	2kg	5,000	10,000
3	MCB switch	2	2,000	4,000
4	Casing	1	6000	6000
5	Varnish	2	600	1200
6	4mins dry gum	4	300	1200
7	Meter (display)	2	1200	2400
8	Indicator lamp	1	200	200
9	Knob (input and output)	4	300	1200
10	Bolt and Nut	20	30	600
11	2.5mm cable	3meter	300	900
12	Cord	1	500	00
13	Rod	1	500	500
	Total			**76,900**

APPENDIX C

Figure C1: pictures showing the core

Figure C2: picture showing the coiling process

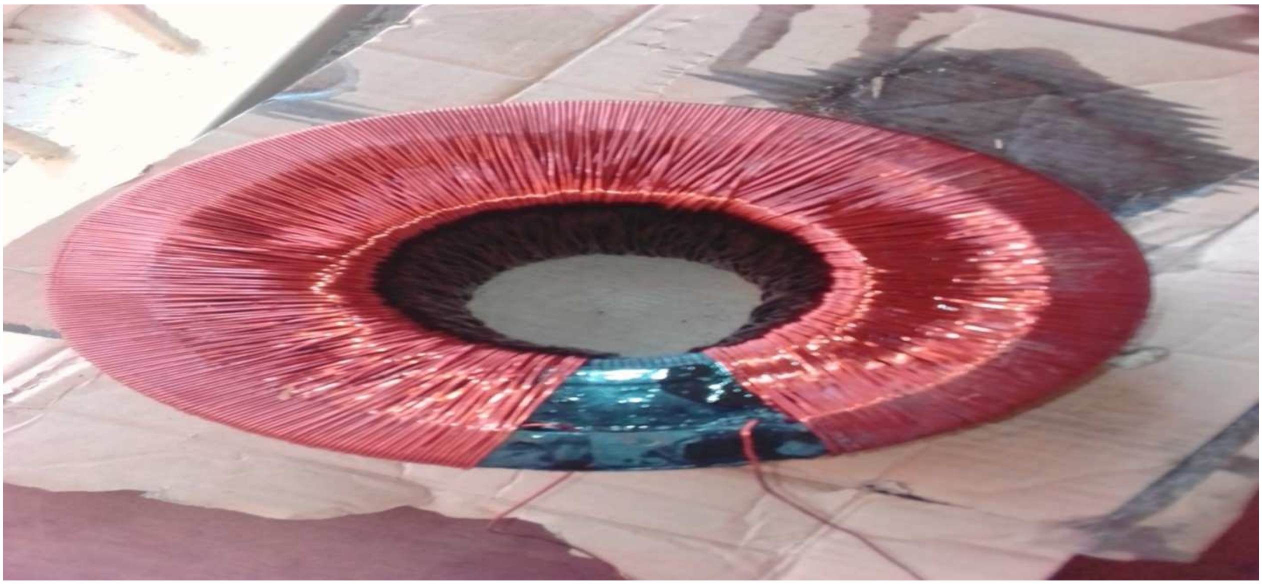

Figure C3: picture showing the completed coil and varnishing stag

APPENDIX D

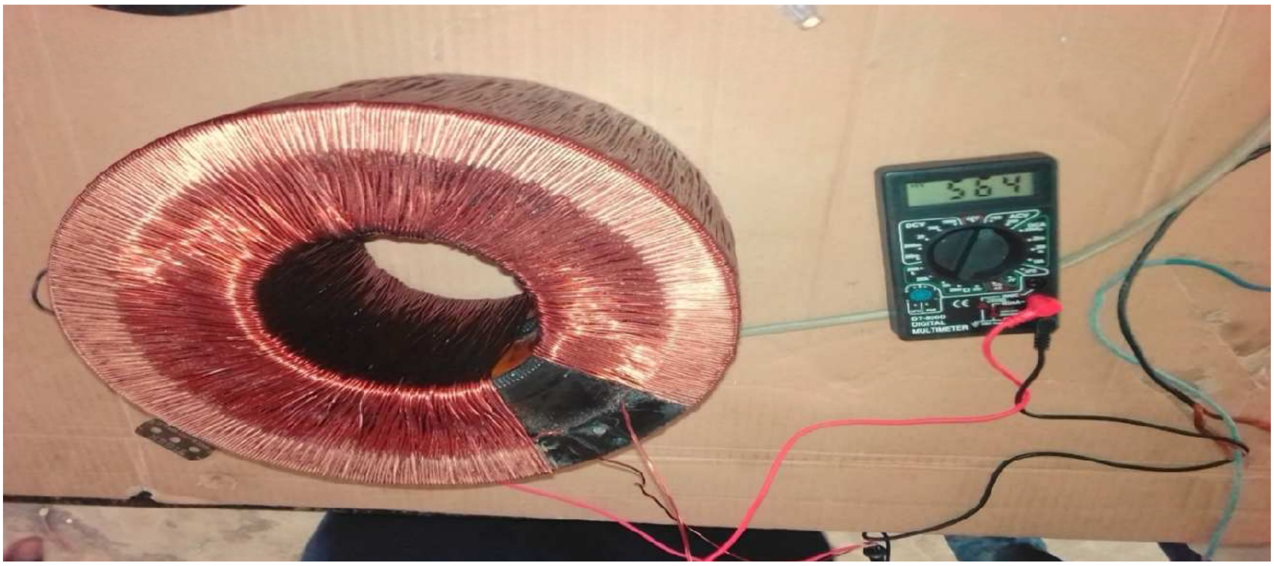

Figure D: picture showing the output voltage