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DESIGN AND CONSTRUCTION OF A 10KVA MULTI-RANGE ELECTRIC ARC WELDING MACHINE

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ABSTRACT

An electric arc welding machine was designed and constructed with a 10kVA, single phase multi-range alternating electric current. The machine was designed, fabricated and tested using locally made materials and tools available in Nigeria. This work was achieved through the design and construction of a core type of power transformer with an aluminum conductor and blast cooling medium, which step down the 230 volts main supply voltage to the appropriate voltage levels of 38 volts, 50 volts, 80 volts and 125 volts respectively. The welding machine on testing has efficiency of 89%, power factor of 71.4 and voltage regulation of 80%. This work will be of good significance to professionals and organizations involved in metal work and can also create job opportunities for our teeming youths if the methods are tremendously followed.

Keywords: Design, Construction, Arc welding Machine, Transformer, Efficiency

INTRODUCTION

Welding is an ancient art whose history could be traced back to the blacksmiths where two pieces of iron can be fused together by heating in fire until the iron are plastics followed by hammering or forging. Welding involves a wide range of scientific variables such as time, temperature, electrode, power input and welding speed (Soy et al, 2011). Electric Arc is formed when electric current is passed between two metallic electrodes which are separated by a short distance from each other (B.L Theraja and A.K. Theraja, 1997). However, newer welding processes have replaced these methods almost completely thereby making it difficult to trace the beginning of what we might call modern welding. The electric welding which is produced by electric arc welding machine operates exactly with the same principle as a step – down transformer which is a static electromagnetic device used for the transformation of sinusoidal varying quantities (voltage and current) from one value to another at the same frequency. It can raise or lower the voltage with a corresponding decrease or increase in current (Bharat heavy Electrical Limited, 2001). Hence, it is a fundamental fact that at lower voltages, we have higher current, it also follows that increase in current is directly proportional to the increase in heat energy. This heat energy is generated as a result of increase in current used in the welding of two ferrous metals (in case of A.C. welding machine) or non-ferrous metals (in the case of D.C. welding machine). Transformer importance in voltage and current transformation in our everyday life cannot be overemphasized. The invention of transformer has made it possible for long transmission of electrical power from its point of generation to it point of consumption (Akpojedje *et al*, 2017).The electric arc welding machine like the conventional step-down transformer consists of a core and insulated windings, which are wound on the limbs of the core.

Transformer forms the heart of electric welding machines when the voltage supply is from the mains. Transformers are veritable tools in electrical power system and their functions are significant especially in stepping up and stepping down (transformation) of voltages/currents for appropriate usage (Akpojedje *et al*, 2017). But in the industries today, the fusion and non-fusion of metals are keys in constructing or framing a design. These fusion and non-fusion of metals are done through welding processes with an apparatus called welding machine. Welding needs high starting voltage but low voltage to maintain an arc. Hence, welding machines are majorly step-down transformers which operate at low voltages with high leakage reactance.

The common type available in the market today is the arc with spot or single range welding voltage. The design and construction of transformers have been a problem because of the intricacies and difficulties in trying to achieve it, people only resort to rewinding burnt transformers, which may not give the desire power and satisfactory performance. This problem could be as a result of not using the appropriate core size, windings, insulating materials and cooling medium. Therefore, this research work aims at designing and implementing a 10kVA multi-range arc welding machine using local materials that will surpass the spot voltage arc welding machine currently available. To design, construct and analyse the harmonic effect of 10kVA, 240volts, 50Hz, multi range A.C. electric arc welding machine, there is need for voltage transformation which involved power transformer. The power transformer transforms the mains voltage from 240volts to 38volts, 50volts, 80volts, 100volts and 125volts, which are the range of voltages required for this A.C. electric arc welding. Tapping for 50volts is also provided. All material used for the construction were locally sourced since Nigeria is blessed with Iron, steel and the availability of copper and aluminum conductors for the windings.

The design and construction of 5kVA A.C. welding machine using locally available materials has been reported by (Evbogbai *et al.*, 2004). The stress involved in the cutting of the silicon steel sheets which forms the core was very high because it was manually done using scissor. Another major problem encountered in the previously designed welding machines was the rigor one has to go through in coiling the secondary winding using copper conductors due to its stiffness and the rectangular shape of the conductor. All this designed and constructed work has heavy weight. The 5KVA, A.C. welding machine reported by (Evbogbai *et al.,* 2001) weighed 100kg. Provision was made for at list two or more people to lift and transport the machine. The portability of this machine depends on the strength and energy possessed by those lifting it.

Principle Of Operation Of The Electric Arc Welding

An electric arc is formed when an electric current passed between two electrodes separated by a short distance from each other. In DC arc welding, one electrode is the welding rod or wire, while the other is the metal to be welded called the plate. The electrode and the plate are connected to the supply, one to the positive pole and the other to the negative pole. The arc is started by momentarily touching the electrode on the plate. When the electrode touches the plate, current flows, and as it is withdrawing from the plate current continuous to flow in the form of a 'spark' across the very small gap formed. This causes the air gap to become ionised and start conducting, as a result the current is able to flow across the gap, even when it is quite wide, in the form of an arc.

The arc is generated by electrons (small negative charged particle) flowing from the negative to positive pole and the electrical energy is changed in the arc into heat and light. The welding current may vary from 20 to 600A in the case of arc welding. When alternating current is used, heat is developed equally at the plate and rod, since the electrode and plate are changing polarity at the frequency of the supply.

The arc can be rendered easy to control and the absorption of atmospheric gases reduces to a minimum by shielding the arc. This is done by covering the electrode with one of the various types of covering and as a result gas such as hydrogen and carbon dioxide are released from the covering as it melts and form an envelope around the arc and molten pool, excluding the atmosphere with its harmful effect on the weld metals.

The electrode covering usually melt at a higher temperature than the wire core so that it extends a little beyond the core, concentrating and directing the arc stream, making the arc to be stable and easier to control.

A welding voltage of about 15–45 V and welding current in the range of 10–500A are generally utilized to produce an arc with a temperature range of about 4000- 6000°C (Huijie and Yanying, 2022,). Arc energy is usually expressed in kilojoules per millimeter length of the weld (KJ/mm)
Ea =Va x Iw/Cs x 100 ………(1.0)
Where Ea id the arc energy, Va is arc Voltage, Iw is welding current and Cs is welding speed

DESIGN ANALYSIS AND CALCULATIONS

The machine design procedures for core and shell types of power and distribution transformers have been reported by (Bharat Heavy Electrical Limited, 2001; Agarwal, 1992). The design differences lies on the specification of the machine to be design and the concept involved ((Akpojedje *et al*, 2017; Akpojedje *et al*, 2016).

Design Specifications

Table 1: Design Criteria

Power Rating, S	**10KVA**
Input voltage,V_1	240V
Output Voltages V_2	V_{2a} =38V V_{2b} = 50V V_{2c} = 80V V_{2d} =100V V_{2e} =125V
Frequency, *f*	50Hz
Maximum flux density, B_m	1.25Wb/m^2
Constant, K	0.55
Window Factor	0.33
Space Factor	0.3
Current density, δ	2.5A/mm^2
Type of construction	Core type
Cooling medium	Air Blast (transformer fan)

Design Calculations

Core Design

Calculating the voltage per turn, E_t

The voltage per turn $E_t = K\sqrt{S}$ (2.0)

$$E_t = 0.55\sqrt{10} = 1.74V \quad (2.1)$$

Calculating the core area, A_I

$$A_i = \frac{E_t}{4.44 f B_m} \quad (2.2)$$

$$A_i = \frac{1.74}{4.44x50x1.25} = 62.70cm^2 \quad (2.3)$$

Calculating the magnetic flux, ϕ_m

$$\phi_m = A_i B_m \quad (2.4a)$$

$$\phi_m = 62.70x1.25 = 78.38mWb$$

Calculating the diameter of circumscribing circle around the core, d
Since the transformer is a core type and assuming a three stepped core

$$A_i = 0.45d^2 \qquad (2.4b)$$

$$d = \sqrt{\frac{A_i}{0.45}} = \sqrt{\frac{62.70}{0.45}} = 11.80cm \qquad (2.5)$$

Calculating the gross core area, A_{gi}

$$A_i = K_s A_{gi} \qquad (2.6)$$

Assuming stacking factor $K_s = 0.9$

$$A_{gi} = \frac{A_i}{K_s} = \frac{62.70}{0.9} = 69.67cm^2 \qquad (2.7)$$

Calculating the width of lamination, a

Since, the core is to be square section, the width of lamination is

$$a = \sqrt{A_{gi}}$$

$$a = \sqrt{69.67} \qquad (2.8)$$

$$a = 8.35cm$$

Window - Design

Calculating the net window area, A_w

The expression for the output power of a single phase transformer is:

$$kVA_{1-ph} = S = 2.22fB_m A_i A_w K_w \delta x10^{-3} \quad (2.9)$$

$$A_w = \frac{Sx10^3}{2.22fB_m A_i K_w \delta} \qquad (3.0)$$

$$A_w = \frac{10x10^3}{2.22x50x1.25x0.3x6..270x10^{-3}x2.5x10^6} \qquad (3.1)$$

$$A_w = 0.01529m^2 = 152.9cm^2$$

Calculating the window dimensions, (H_w, W_w)

Assuming, $\frac{WindowHeight}{WindowWidth} = \frac{H_w}{W_w} = 3$ (3.2)

$$H_w = 3W_w \qquad (3.3)$$

Calculating the window width, W_w

$$A_w = H_w x W_w \qquad (3.4)$$

$$A_w = 3W_w x W_w \qquad (3.5)$$

$$W_w = \sqrt{\frac{A_w}{3}} \qquad (3.6)$$

$$W_w = \sqrt{\frac{152.9}{3}}$$

$$W_w = 7.14cm$$

Calculating the window height, H_w

$$H_w = \frac{A_w}{W_w} \qquad (3.7)$$

$$H_w = \frac{152.9}{7.14} = 21.41cm$$

Yoke – Design

The section to be 1.2x Limb section (3.8)

Calculating the net iron area of the yoke, A_y

$A_y = 1.2A_{gi}$ (3.9)

$A_y = 1.2x69.83$

$A_y = 83.80cm^2$

Calculating the gross area of the yoke, A_{yg}

Gross area of the yoke, $A_{yg} = \frac{A_y}{K_s}$ (3.10)

$A_{yg} = \frac{83.80}{0.9}$

$A_{yg} = 93.11cm^2$

Calculating the magnetic flux density in the yoke, B_y

$B_y = \frac{B_m}{1.2}$ (3.11)

$B_y = \frac{1.25}{1.5} = 1.042Wb/m^2$

Calculating the depth of the yoke, D_y

Assuming the yoke section is rectangular

Depth of the yoke, $D_y = a$ (3.12)

$D_y = 8.36cm$

Calculating the height of the yoke, h_y

Height of yoke, $h_y = \frac{A_{yg}}{D_y}$ (3.13)

$h_y = \frac{93.11}{8.36} = 11.14cm$

Design of Overall Core Dimensions

Calculating the distance between adjacent core centre, D

$D = W_w + d$ (3.14)

$D = 7.14 + 11.82$

$D = 18.96cm$

Calculating the overall core width, W

Overall core width, $W = 2D + a$ (3.15)

$W = 18.96 + 8.36$

$W = 27.32cm$

Calculating the overall core height, H

$H = H_w + h_y$ (3.16)

$$H = 21.41 + 2x11.14 = 43.69cm$$

Calculating the stack height, S_h

$$Stack = \frac{A_i}{0.9x0.71d} \qquad (3.17)$$

$$Stack = \frac{62.70}{0.9x0.71x11.82}$$

$$Stack, S_h = 8.32cm$$

Calculating the thickness of laminar
Thickness of Laminar = 2na (3.18)
Thickness of laminar = 0.05cm
Calculating the number of lamination, N_L

$$\text{Number of lamination} = \frac{stack\ heigh}{thickness\ of\ lamina} \qquad (3.19)$$

$$\frac{8.32}{0.05} = 167$$

Designing the High Voltage Winding

Calculating the number of turns for the primary circuit, N_1

$$N_1 = \frac{V_1}{E_t} \qquad (3.20)$$

The primary input voltage, V_1 = 240V

$$N_1 = \frac{240}{1.74} = 138 turns$$

Calculating the current of the primary circuit, I_1
Given that power, $S = 10kVA$
The input voltage, V_1 = 240V
Therefore, input current at the primary winding of the transformer is

$$I_1 = \frac{S}{V_1} \qquad (3.21)$$

$$I_1 = \frac{10{,}000}{240} = 41.7 Amps$$

Designing the Low Voltage Windings

Calculating the number of turns for the secondary circuit, given that the output voltages of the multi-range arc welding machine are:

$$V_{2a} = 38V, V_{2b} = 50V, V_{2c} = 80V, V_{2e} = 100V, V_{2f} = 125V$$

Calculating the number of turns for secondary side, N_1
The numbers of secondary turns for the various outputs are as follows:
For $V_{2a} = 38V$ output

$$N_{2a} = \frac{V_{2a}}{Et} = \frac{38}{1.74} = 22 \text{ turns} \qquad (3.22)$$

For V_{2b}= 50V output

$$N_{2b} = \frac{V_{2b}}{Et} = \frac{50}{1.74} = 29 \text{ turns} \qquad (3.23)$$

For V_{2c}= 80V output

$$N_{2c} = \frac{V_{2c}}{Et} = \frac{80}{1.74} = 46 \text{ turns} \qquad (3.24)$$

For V_{2d}= 100V output

$$N_{2d} = \frac{V_{2d}}{Et} = \frac{100}{1.74} = 57 \text{ turns} \qquad (3.25)$$

For V_{2e}= 125V output

$$N_{2e} = \frac{V_{2e}}{Et} = \frac{125}{1.74} = 72 \text{ turns}$$

Calculating the currents of the secondary circuit, given that power, $S = 10kVA$
Calculating for the multi-range output currents
For $V_{2a} = 38V$

$$\frac{S}{V_{2a}} \qquad (3.26)$$

$$\frac{10000}{38} = 263.16 \text{ Amps}$$

For $V_{2b} = 50V$

$$\frac{S}{V_{2b}} = \frac{10000}{50} = 200 \text{ Amps} \qquad (3.26)$$

For $V_{2c} = 80V$

$$\frac{S}{V_{2c}} = \frac{10000}{80} = 125 \text{ Amps} \qquad (3.27)$$

For $V_{2d} = 100V$ output

$$\frac{S}{V_{2d}} = \frac{10000}{100} = 100 \text{ Amps} \qquad (3.27)$$

For $V_{2e} = 125V$ output

$$\frac{S}{V_{2e}} = \frac{10000}{125} = 80 \text{ Amps} \qquad (3.28)$$

Calculating the conductor sizes of the circuit a, we select a value of the current density δ to be 2.5Amp/mm^2

Note that $I = \delta a$ (3.29)

Calculating the conductor size of the primary side, a_1

$$a_1 = \frac{I_1}{\delta} \qquad (3.30)$$

$$a_1 = \frac{41.7}{2.5} = 16.68mm^2$$

Calculating the conductor size of the secondary, a_2

In calculating the conductor area of the secondary side, the 263.16Amps was used since it is the highest among the five (5) currents available

$$a_2 = \frac{I_{2a}}{\delta} \qquad (3.31)$$

$$a_2 = \frac{263.16}{2.5}$$

$$= 105.26mm^2$$

Calculating the diameter of the copper conductor for the primary and secondary side, d_1, d_2

$$a = \frac{\Pi d^2}{4} \qquad (3.32)$$

Calculating the diameter of the primary circuit, d_1

$$d_1 = \sqrt{\frac{4a_1}{\Pi}} \qquad (3.33)$$

$$d_1 = \sqrt{\frac{4x16.68}{\Pi}} = 4.61mm$$

d_1 Corresponds to standard wire gauge of 6

Hence, the new area and diameter is $a_{1new} = 18.68mm^2$ and $d_{1new} = 4.88m$ respectively

Calculating the diameter of the secondary circuit, d_2

$$d_2 = \sqrt{\frac{4a_2}{\Pi}} = \sqrt{\frac{4x105.26}{\Pi}} = 11.58mm \ (3.34)$$

d_2 Corresponds to standard wire gauge of 6/0

Hence, the new area and diameter is $a_{2new} = 109.09mm^2$ and $d_{2new} = 11.79mm$ respectively

Calculating the total copper area in a window, A_t

$$A_t = 2(a_1N_1 + a_2N_2) \qquad (3.35)$$

$$A_{t2} = 2(a_{1new}N_1 + a_{2new}N_2) \qquad (3.36)$$

$$A_t = 2(16.68x138 + 105.26x72)$$

$$= 19761.12mm^2$$

$$A_{t2} = 2(18.68x138 + 109.09x72)$$

$$= 20864.64mm^2$$

Calculating the mean length per turn (lmt) for both primary and secondary coils

$$L_{mt} = \Pi[d + W_w/2] \qquad (3.37)$$

$$L_{mt} = \Pi[11.82 + 7.14/2]$$

$$= 15.39cm \approx 0.1539m$$

Calculating the length of primary turns, L_1

Length of primary coils, $L_1 = L_{mt}xN_1$ (3.38)

$$L_1 = 0.1539x138$$

$$= 21.23m$$

Calculating the length of the secondary turns, L_2

For N_{2a} turns, $L_{2a} = L_{mt}xN_{2a}$ (3.39)

$$L_{2a} = 0.1539x22 = 3.38m$$

For N_{2b} turns

$$L_{2b} = 0.1539x29 = 4.46m \qquad (3.40)$$

For N_{2c} turns

$$L_{2c} = L_{mt}xN_{2c} \qquad (3.41)$$

$L_{2c} = 0.1539x46 = 7.07m$

For N_{2d} turns

$L_{2d} = L_{mt} N_{2d}$ (3.51)

$L_{2d} = 01539x58 = 8.93m$

For N_{2e} turns $L_{2e} = L_{mt} x N_{2e}$ (3.52)

$L_{2e} = 0.1539x72 = 11.08m$

CONSTRUCTION AND TESTING

Material Considerations

The materials used in the construction of multi-range arc welding machine include the followings.

i. Hot rolled laminated steel
ii. Enamelled copper conductors
iii. Hard board and wooden plank
iv. Insulation materials such as vanish, card board paper and masking tape.
v. Bolts and nuts and angle bar cut to size for clamping.
vi. Switches
vii. Transformer fan
viii. Snips cutter
ix. Metallic casing

Construction of Active Parts

Core

The magnetic core of the transformer is constructed from laminated steel sheet (I shape manually cut using the snipe cutter) assembled together to provide a continuous magnetic path with a minimum air gap. In assembling the core, the insulated laminar were joined in such a way that, they overlap each other in regular order, that is they were staggered. This method of assembling was adopted in order to avoid the presence of narrow gaps through the cross – section of the core and also to avoid high reluctance at the joints where laminations are bolted against each other

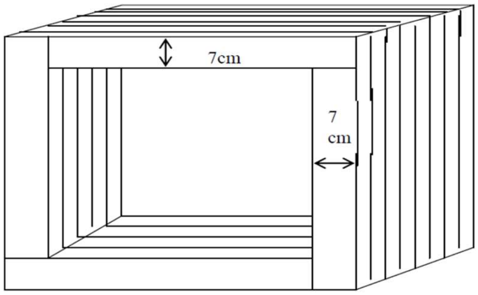

Fig2: Laminated Core of Transformer with Window Dimension

Assembling The Winding And Core

The bobbins on which the windings have already been wound are slotted on the limbs of the core. The rectangular opening of the bobbin was dimensioned relative to the core size; it fit firmly to the core limbs. In assembling both windings and the core as seen in plate 1, the primary and the secondary windings were interleaved so as to reduce leakage flux. That is half the primary winding and half the secondary were placed concentrically on each limb.

Plate 1: Pictorial View of Assembled Windings

3.2.3 Cooling

Plate 2: Pictorial View of Fixed Air Blast Cooling System

Transformers losses are due to mainly the core and the windings of the transformer, which produces significant quantities of heat and is transferred via a cooling system.

The cooling system employed in this work as shown in plate 2 is the AB (Air Blast) cooling medium. The assembled windings and cores were mounted with a cooling system using AB system in closed structure and forced air are filtered before circulating to the system in order to prevent dust.

Casing

This housed the core and the windings of the transformer. In constructing the casing steel sheet of gauge 14mm thickness was used. The casing is cubic in shape with size of 46cm x 40cm x 46cm. This size was chosen so as to have an appropriate heat radiation area without unnecessarily increasing the cubical capacity of the tank and to prevent the transformer oil from splitting in the cause of transporting the welding machine. At the top of the casing is a small opening called-vent, which is used for evaporation purpose. The transformer oil could equally be topped through this vent. The machine is fitted with rollers for ease of movement.

Plate 3: Pictorial View of Front Side of the Model Casing

Testing

The designed and constructed machine was subjected to testing at no load and Load test to ascertain its functionability, efficiency and reliability. Current at open and short circuit current were also determined. The following parameter was obtained from the test.

No-load primary current (Ammeter reading), Input voltage (voltmeter reading at primary), Output voltage (voltmeter reading at secondary), Wattmeter reading for Power P

$$P = V_1 I_1 Cos\theta \qquad \textbf{(3.53)}$$

$$\left(I_m\right) = I_o S_{in}\theta \qquad \textbf{(3.54)}$$

$$\eta = 1 - \frac{Losses}{Power\ input} \qquad \textbf{(3.55)}$$

Regulating the voltage of Transformer

$$\frac{E_{2-V_2}}{E_2}\ x\ 100 \qquad (3.56)$$

Equation 3.53 and 3.54 was used in the determination of power factor and the magnetizing current values in all the multi ranged tapping using the values obtained from the ammeter, voltmeter and wattmeter readings as indicated. The efficiency of the machine was determined using equation 3.55 while the transformer voltage regulation was determined by equation 3.56

RESULTS AND DISCUSSION

The result of the open and short circuit test carried out on the electric arc multi ranged welding machine is seen in Table 2 and 3 respectively. It can be seen that at short circuit test. The machine needs more current to carry out the welding operations. The power factor was calculated to be 71.4%. The efficiency of the machine computed as 89%.The transformer voltage regulation in percentage was calculated to be 80%

Table 2: Open Circuit (No-Load)

V_1(volt)	I_1 (A)	No-load iron losses (P_L)	V_0(volt)	I_m (Amp)
200	5.77	1134W	125V	3.05A
200	6.98	1,280W	100V	2.78A
200	5.68	1,100W	80V	1.43A
200	5.57	1,080W	50V	1.38A
200	5.46	1,060W	38V	1.31A

Table 3: SHORT CIRCUIT TEST

V_1	Short circuit current (I_{sc})	P_{Isc}	Vo	P_{in}
200	236 Amps	5.16kW	125V	10.24kVA
200	158Amps	4.95kW	100V	8.32kVA
200	215Amps	4.16kW	80V	6.68kVA
200	200Amps	4.12kW	50V	5.56kVA
200	180Amps	3.56kW	38V	4.86kVA

CONCLUSION

The test results showed that the machine performed satisfactorily. The successful completion of this research work revealed that power transformer can be constructed using locally made material and if this is done, it will create job opportunities for the teemed youths if the design and construction processes in this research work are harness religiously by the three tiers of government in Nigeria. The cost of producing the multi-range alternating current arc welding machine will fall drastically when mass production is embarked upon by the government.

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