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Realization of a 3kVA, Single Phase, Electric ARC Welding Machine with Facilities for Charging Batteries

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Abstract: This study present a 3kVA, single-phase alternating current, electric are welding machine and a battery charger in one unit. The device was designed, fabricating and tested using material and tools available locally in Nigeria. The work was achieved through the design and construction of a core type power transformer, which step down the 220 Volt main voltages to the appropriate voltage levels of 14 Volt, 26 Volts and 90Volts respectively. The 14 and 26 Volts were rectified using bridge rectifies (MBR1060) to produce the direct current needed for charging the 12 and 14 Volts batteries respectively while the 90Volt terminal is for alternating current welding. The welding transformer on testing has efficiency of 97%, voltage regulation of 80% and a power factor of 79%. The research will be pertinent to Engineers, Technologies, Technicians, Artisan and every one or organizations involved in metal works and battery charging business. It will provide job opportunities and reduces the over dependence of third world countries on imported goods.

Key words: Transformer, welding ferrous metal, bridge rectifier, battery charger

INTRODUCTION

The importance of transformer in voltage transformation in our everyday life cannot be over emphasized. Transformers and other electrical machines or devices are based on the basic principle of electromagnetic induction, which Michael Faraday discovered in 1813 (Theraja, 1997).

Transformer form the basis for the design, construction and operation of many electrical and electronics devices. The design and construction of small power transformers using locally available materials has been reported (Evbogbai *et al*., 2003).

The study showed that transformers and other electrical machines could be constructed locally since Nigeria is blessed with Iron, steel and the availability of copper and aluminum conductors for the windings.

Also reported is the design and construction of A. C. Welding machine using locally available materials (Evbogbai *et al*., 2002). This product finds wide applications in the fabrication of ferrous metal. Power transformer forms the heart of the A.C welding machine.

The battery charger helps to restore the depleted energy in storage battery and transformer equally form the basis for which the batter charger operates (Evbogbai *et al*., 2004).

In this study, an attempt has been made to design and construct an. A.C. welding machine and battery charger using the same transformer. The welding of the ferrous metal takes place during the daytime, but at night when welding had stopped the transformer can then serve as battery charger. That is the transformer can be used as a welding transformer or for battery charging depending on the setting, in this way the power transformer is fully utilized just like a power transformer in the distribution or transmission network in Electric power system which operates on continuous duty cycle.

For the transformer performing this dual role of welding and charging, the cost implication is low compared to having separate welding machine and battery charger.

MATERIALS AND METHODS

A 3 kVA, 220 Volts, single-phase transformer, transforms the mains voltage to the appropriate voltage level at the secondary of the transformer for welding and battery charging. The transformer was constructed locally

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using laminated silicon sheets and copper conductors for the windings. The 90 V terminal of the transformer is used for AC welding, while the other terminal are rectified, using bridge rectifier to produce the DC voltage required for battery charging. The design and constructional procedures are shown below.

Design specifications: The design procedures for core type power transformer has been reported (Bharat Heavy Electrical Limited, 2003) the difference lies within the design specifications.

The following are the specifications which the deign work strives to achieve:

Power rating, S = 3kVA
Input voltage V_1 = 220V
Output voltages, V_2 = 14V, 26V, 90V
Frequency, f= 50Hz
Max, flux density, $B_m = 1.25 \text{Wb m}^{-2}$
Current density, $j = 3.2 \text{A mm}^{-2}$
Constant, c = 0.8
Space factor kw=0.3

Design calculations: The voltage per turn

$$V_t = C\sqrt{S} \quad (1)$$
$$= 1.4\text{v}$$

Calculation for core area, A_I

$$Vt = 4.44fBm\ Ai \quad (2)$$
$$A_I = 50\text{cm}^2$$

Calculating for flux, Φ

$$= 6.25\text{m Wb}$$
$$\Phi_m = A_i B_m \quad (3)$$

Calculating for the diameter or circumscribing circle: Since the core is square section:

$$A_{gross} = 0.5d^2 \quad (4)$$

$$A_i = 0.9 \times A_{gross} \quad (5)$$

Assuming 0.9 as the stacking factor, we have

$$d = 10.5\text{cm}$$

Calculating for the width of lamination: Since, the core u of square section, the width of lamination is

$$0.71d = 7.5 \text{ cm} \quad (6)$$

Calculating for window area: $(A)_w$: The expression for the output power of a single phase transformer is

$$A_w = 45\text{cm}^2$$
$$\text{But } A_w = L \times W \quad (7)$$

$$KVA_{1-ph} = 4.44f\Diamond\frac{(K_w A_w J)}{2} \times 10^{-3} \quad (8)$$

Calculating for core dimensions: The centre-centre distance of the core is twice three the core width. This will be equal to 2.0.71d.

$$= 2 \times 0.71 \times 10.5 = 15\text{cm} \quad (9)$$

Center center distance between

$$\text{limb} = w + d \quad (10)$$

W = 4.5cm
L = A_w/W = 10cm

$$\text{Overall core height} = L + 2\,(0.71d) \quad (11)$$
$$\text{Overall core with} = W + d + 0.71d \quad (12)$$
$$= 22.5\text{cm}$$

Calculating for the stack height

$$S = \frac{A_i}{0.9 \times 0.71d} \quad (13)$$
$$= 7.5\text{cm}$$

Calculating for the number of laminations:

$$\text{Number of laminations} = \frac{\text{Stack height}}{\text{Thickness of lamina}} = 214 \quad (14)$$

Calculating for both primary and secondary circuit (windings)

Output power, S = 3kVA,
Primary voltage, V_1 = 220V
Current flowing at the primary winding is
= 13.6A

$$I_1 = P/V_1 \quad (15)$$

$$I_2 = P/V_2 \quad (16)$$

Current flowing at the secondary winding is given
Therefore,

At V_2 = 90V for A.C welding, the current at the secondary winding is
I_2 = 33.3A

Calculating for both primary and secondary number of turns

Volt per turn, V_t = 1.4V
= 220/1.4 = 157 turns.

$$N_1 = V_1 / V_t \quad (17)$$

$$\text{At 14V output, } N_2 = 14/1.4 = 10 \text{ turns} \quad (18)$$

$$\text{For secondary turns, } N_2 = \frac{V_2}{V_t}$$

At 26V output, N_2 = 26/1.4 = 18.6 turns = 19 turns
At 90V output, N_2 = 90/ 1.4 = 64.3 turns = 64 turns

Calculating for the conductor section of the primary ad secondary windings: The cross sectional area of the copper conductor at the primary winding from

$$I = aJ \quad (19)$$

Eq. 19 is $a_1 = I_1/J = 4.25 mm^2$.

Similarly, from Eq. 19, the cross sectional area of the copper conductor at the secondary winding is, $a_2 = I_2/J$ in calculating for the area and diameter of the secondary section, 54.51 Amps were used since it is the highest among the four available currents.

$$a_2 = 17.03 \text{ mm}^2$$

Calculating for the diameter:

$$\text{Area, } a = \pi d^2 / 4 \quad (20)$$

$$\text{Therefore, } d = \sqrt{4a/\pi} \quad (21)$$

Where d = diameter

$$d_1 = \sqrt{4 \times 4.25/\pi} = 2.33 \text{ mm}$$

Similarly,

$$d_2 = \sqrt{4 \times 17.03/\pi} = 4.66 \text{ mm}$$

Calculating for window space factor, Kw

$$= 0.19$$

$$Kw = \frac{N_1 a_1 + N_2 a_2}{Aw} \quad (22)$$

Calculating for the mean length per turn for both primary and secondary coils. L_{mt}:

$$I_{mt} = \left[dmb + w/2 \right] \quad (23)$$

$$I_{mt} = 0.4005 m$$

Calculating for the total length of the primary turns:

$$\text{Total length of primary} = I_{mt} \times N_1 \quad (24)$$

$$L_1 = 62.9 \text{ m}$$

Total length of secondary turns

$$I_2 = 25.6 \text{ m}$$

$$= I_{mt} \times N_2 \quad (25)$$

Calculating for the resistance of the secondary

$$R_1 = 0.2516\Omega$$

$$R_1 = \frac{eI_1}{a_1} \quad (26)$$

$$R_2 = \frac{eI_2}{a_2} \quad (27)$$

Calculating for the resistance of the secondary

$$R_1 = 25.6 \times 10^3 \Omega$$

Calculating for the weight of the core:

Weight for the core = (iron volume)×(iron density)
Volume of iron in core = Im in cm×Ai in cm^2
Where Im is the total mean flux path, including that limbs and yokes
In the case of a single phase transformer

$$L_m = 2(W+d) + 2\,(L + \text{Max, lamination width}) \quad (28)$$
$$= 64 cm$$

Therefore, volume of iron = $3200 cm^3$

Therefore, weight of core = $(3200\times7.8\times10^{-3})$ kg (29)
= 25 kg

Design of rectifier unit: For the 14 volts terminal

= 39.60 Volts

$$\text{Diode PIV} = 2\sqrt{2}\ V_{rms} \quad (30)$$

$$V_m = \sqrt{2}\ V_{rms} = 19.80\text{Volts} \quad (31)$$

= 12.6 Volts

$$V_{dc} = V_{R.M.S.} - 2\times0.7(\text{threshold voltage of diode}) \quad (32)$$

The capacitance of the filtering capacitor is
= 28,000 µf.

$$C = \left(\frac{I_{dc}}{4f\ (V_m - V_{dc})}\right) \quad (33)$$

Similarly, for the 26Volt terminal, using equations 30, 31, 32 and 33.

Diodes
PIV = 73. 53 Volts
V_m = 36.80 Volts
V_{dc} = 24. 6 Volt
C = 28, 000 Volt

Construction: The procedures for the construction of the core type transformer has been reported (Bhafat Heavy Electrical Limited, 2003; Chapman, 1997).

The laminated I sheet was cut to the design specification and assembled. Copper conductor of standard gauge 12, having a current capacity of 16.44A, diameter 2.640 mm and cross sectional area of 5.48 mm^2 was used for the primary windings, while for the secondary, gauge 6 having a current carrying capacity of 56A, diameter 4.876mm and cross sectional area of 18.7 mm^2 was used. Transformer oil was used for cooling. The bridge rectifier (MBR1060), having current carrying of 10A and peak inverse voltage of 80 V was used for rectifying the 14 and the 26 V of terminals B and C of the secondary of the transformer respectively. An electrolytic capacitor was used for filtering the ripple voltage present at the output of the rectifier so as to get pure DC voltages needed for charging batteries. Figure 1 show the complete circuit diagram while, Fig. 2 shows the photograph of the completed work.

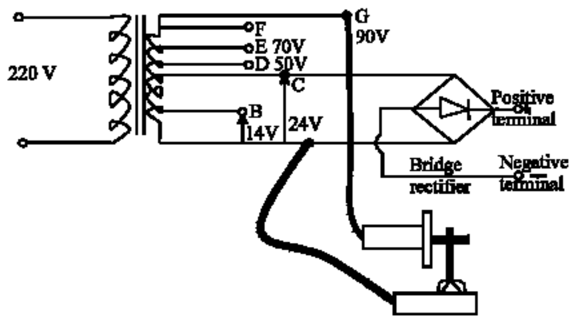

Fig. 1: Complete circuit diagram of the 3 kVA A.C welding machine and battery charger

Fig. 2: Photograph of the 3 kVA A.C welding machine and battery charge

RESULTS AND DISCUSSION

After the construction, open circuit and short circuit tests were carried out (Gourishankar, 1965). The physical working of the machine was also carried out.

The open and shorts circuits tests enables us to determine the efficiency, power factor and voltage regulation of the transformer, which are 97, 79 and 80%, respectively.

The tongs of the electrode holder grip the electrode tight for different job position; hence no arcing effect was observed on the tong.

Arc production with the deferent gauge of electrodes was satisfactory for the ferrous metal works, with 20 V drop across the arc.

When the rectifier circuit is connected to terminal A and B output voltage of rectifier 12.5 V for charging 12 V battery. When connected terminal A and C the output of the rectifier is about 24.8 V for charging a 24 V battery. It has a good performance and high operation efficiency and test showed that the design specified the anticipated requirement when compared to conventional battery.

Table 1: Bills for engineering measurement and valuation

Metal cost description	Specification	Quantity	Unit cost (N)	Total cost (N)
Metal sheet	1.6 mm sheet	½ full size	1,500.00	1,500.00
	0.5 mm sheet	2 full size	1,700.00	3,400.00
Varnish		2 litres	1,000.00	1,000.00
Copper	Gauge 6	7 kg	950.00	6,600.00
Conductor	Gauge 12	4kg	950.00	3,800.00
Bobbin	Wooden	4	100.00	400.00
Masking tape	Abro	4	100.00	400.00
Cord		1 metres	100.00	100.00
Insulating				200.00
Wrapper.	Card board	4	50.00	
Angle iron	50×50 mm	2.5 metres	600.00	600.00
Bolts	Θ 12mm	4	120.00	480.00
Nut and washer	θ 8 mm	14	40.00	560.00
Screw	θ 5mm	6	10.00	60.00
Paint	Medium tin	1	100.00	100.00
Cables	3 mm	4 metres	125.00	500.00
Electrode older	600 A	1	700.00	700.00
Cooling oil	Transformer oil	26litres	100.00	2,600.00
Cable lock	10 mm	2	100.00	200.00
Cable sleeve	22 mm, 15 mm, 10 mm, 5 mm	13	50.00	800.00
Ammeter	1-60A	1	2,000.00	2,000.00
Voltmeter	0-300 V	1	1,500.00	1,500.00
Switch		1	100.00	100.00
Diode		4	250,00	1,000.00
Transport				2,000.00
Labour				5,400.00
Miscellaneous				1,500.00
Total				₦40,000.00

The battery charger can successfully charge batteries from different manufacturers for safety of batteries, 12 V output should be used to charge 12 V battery and 24 V for 24 volts battery. The depleted chemical energy in the storage batteries would be replenished (Manahar, 1987).

Bills for engineering measurement and valuation: Table 1 shows that bill of Engineering measurement and valuation for the manufacture of 3kVA welding machine.

The total cost of producing the 3k VA. A.C Electric are welding machine and battery charger in one unit is N40,000.00.

CONCLUSION

The design and construction of a 3kVA, single phase, 50 Hz, step down power transformer capable of been used for alternating current welding machine and a battery charging for 12 and 24 Volts batteries has been successfully presented in this research. The use of transformer oil as a cooling medium enables the transformer to operate on a continuous duty cycle.

The successful completion of this research has broken the mystery behind transformer construction hence, larger capacity transformer can equally be manufactured locally using the same approach. The cost of construction will reduce drastically if mass-produced and if our iron, steel and copper conductor industries are given the desired attention by he government, cooperate bodies and individuals entrepreneurs.

It is pertinent to note that the successful realization of this work will provide job opportunities and improve the standard of living of our teemed population. It will equally reduce the over dependence of third world countries on imported goods.

In Nigeria, it will assist the Government in its poverty alleviation programme under the National Directorate of Employment.

The study will be of great importance to Engineers, Technologies, Technicians, Artisans and those involved in metal work battery charging business.

List of symbols and abbreviations:

V_1 : Input voltage applied tot he primary circuit
V_2 : Output/secondary voltage
A.C : Alternating Current
D.C : Direct Current
PIV : Peak Inverse Voltage
AH : Ampere Hour
D : Diode rectifier
C_f : Electrolytic capacitor
I_{dc} : Direct current

I_1	:	Input current (Primary current)
I_2	:	Secondary current
W	:	Watts
F	:	Frequency (Hertz)
C	:	Constant
J	:	Current density, amperes per square metre
K_w	:	Window
B_w	:	Flux density (Tesla)
N	:	Turns
N_1	:	Primary turns
N_2	:	Secondary turns
A_w	:	Windows area, m^2
A_I	:	Net core section, m^2
a_1	:	Primary conductor section, m^2
a_2	:	Secondary conductor diameter, m^2
d_1	:	Primary conductor diameter, mm
d_2	:	Secondary conductor diameter, mm
v_t	:	E.M.F. per turn

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