COVER PAGE

DESIGN AND FABRICATION OF AN INVERTER (ELECTRIC HYBRID) ARC WELDING MACHINE

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TITLE PAGE

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BEING A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGINEERING, FACULTY OF ENGINEERING TECHNOLOGY, UNIVERSITY OF BENIN.

IN FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER IN ENGINEERING MANAGEMENT (MS.c) IN PRODUCTION ENIGINEERING.

MARCH, 2025.

CERTIFICATION

We the undersigned certify that this project work titled "**DESIGN AND FABRICATION OF AN INVERTER (ELECTRIC HYBRID) ARC WELDING MACHINE**" was carried out by **AKPOREHE ERUS LUCKY** with MAT. No. **PG/ENG1410627** of the department of Production Engineering, University of Benin. We also certify that it is adequate in scope and quantity in the fulfilment for the award of Master in Engineering Management (M.Sc) in Production Engineering.

______________________	______________________
Prof. P.E. Amielomhen **(Project Supervisor)**	**Date**
______________________	______________________
Dr. F. Inegbedion **(P.G coordinator)**	**Date**
______________________	______________________
Prof. P.E. Amielomhen **(Head of Department)**	**Date**

DEDICATION

This Project work is dedecicated first to God- Almighty and to my lovely Wife and Children who have supported me on this journey.

ACKNOWLEDGEMENT

I am most grateful to GOD Almighty, the sole provider of knowledge, wisdom, love, mercy and grace for his protections throughout the period of this program. I sincerely appreciate my HOD and Supervisor Prof. P.E. Amiolemhen, who offered timely criticism and corrections that led me through the various stages of this project, I also want to appreciate my wife, Mrs. Bridget Akporehe for her financial support, encouragement, continuous prayers and moral support that make this project a success.

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ABSTRACT

Nigeria's unreliable power supply is a well-documented challenge that creates one of the most difficult business environments globally, undermining the country's competitiveness. The consequences are evident. To cope with the erratic electricity supply, individuals and businesses are forced to resort to expensive self-generated power solutions. One of ths Business adversely affected by the state of Power Generation and Distribution in Nigeria is the manufacturing industry. Most welders rely on the epileptic nature of power to carry out their jobs and meet consumer demands. In most instances, the business loss the goodwill/confidence of her customers as job completion schedules are not met.

This project focuses on the design, development, and optimization of an inverter-based arc welding system. This work aims at helping small scale Welders Busneses Meet their need for power. Inveter Welding Systems can be deployed in rural and semi urban areas that are off-grid. With this improvement, skilled workers can carry out their job near the target use location with minimal transportation cost. With proper funding, this project can be expanded for large industial use.

The optimized system demonstrates potential for applications in various industries, including automotive, aerospace, and construction.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Project

Arc welding is a fabrication technique that utilizes the intense heat generated by an electric arc to join metals. This process typically involves melting the edges of the workpieces and introducing a filler material, which combines to form a pool of molten metal that solidifies into a robust joint. Due to its exceptional strength, arc welding is widely employed in construction to join beams and fabricate critical structures, such as buildings and bridges.Welding can also be used to join pipes in pipelines, power plants at the construction sites and in home appliance. Furthermore, welding is used in shipbuilding, automobile manufacturing and repair, aerospace applications. There are many kinds of welding which include arc welding, resistance welding, gas welding among others.

Emphasis however will be laid on arc welding because it is the most common type of welding as well as the main aim of this project.

Arc welding is the process of welding that utilizes an electrical discharge (arc) to join similar materials together. Equipment that performs the welding operation under the observation and control of a welding operator is known as welding machine.

In order to solve the problem of work being handicapped during power outages which is very common in this part of the world, there is now the need to design a “hybrid” system. This ensures that in the event of power outages work can still continue.

The design involves an inverter that works at low frequency (50Hz); using IGBTs (Insulated Gate Bipolar Transistor) for the switching.

IGBTS are preferred in this case for switching the output because the welding process would involve shorting the output for extended periods and IGBTs are suitable due to their high current density.

It incorporates a control circuit used to adjust the PWM (Pulse Width Modulation) that switches the IGBTS and consequently the output voltage / current at the said frequency.

1.2 Statement of the problem

Epileptic power supply is a prevalent problem in this part of the world, therefore there is need to design a hybrid arc welding machine that can run off alternative and clean power sources. This is the idea behind this design.

When there is power outage, the machine would run off a battery. In this case a 24V 100AH battery, this battery capacity can be upgraded if a longer run time is desired.

The beauty of this project is that the alternative power source is clean and do not emit gases that are harmful to the environment or people around as against gasoline or diesel generator alternative sources.

1.3 Aims/Objectives of the Project

The aim of this project is to design and fabricate an electric hybrid arc welding machine which operate on an input voltage of range of 180 - 260Vac or 24VDC source with a current range between 40-80 amperes which could be used in both industrial and domestic sector for quick and joining of metals.

The objectives of the research work are as follows:

i. Design the electric hybrid arc welding machine (for AC and DC supply system).
ii. Fabricate the electric hybrid arc welding machine.

iii. Testing and modification of the electric hybrid arc welding and also maintaining safety standards in the process.

1.4 Significance of the Project

The significance of this project is that it seeks to develop an arc welding machine that is cost effective, strong, reliable and utilizes both AC and DC sources of power

1.5 Limitations of the Project

The project has certain limitations which are mentioned

i. The welding time when using the DC source of power depends on the battery capacity.
ii. The rectifier circuit is exposed to stress when using the AC power source to weld because the current delivered to charge the battery bank will be limited.
iii. Due to the fact that the charging system is a low frequency design, the transformer used for charging is quiet large. This would also make the project very bulky.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of Arc Welding Machine

The history of joining metals goes back several millennia, examples of forge welding go back to the Bronze Age and the Iron Age, arc welding did not come into practice until much later. In 1800 Humphry Davy discovered the short pulsed electric arcs (Anders, 2003). Independently, a Russian physicist named Vasily Petrov discovered the continuous electric arc in 1802 (Anders, 2003; Great Soviet Encyclopedia; lazarev, 1999; Shea, 1983) and subsequently proposed its possible practical applications, including welding (Scribner, 2008). Arc welding was first developed when Nikolai Benardos presented arc welding of metals using a carbon electrode at the International Exposition of Electricity, Paris in 1881, which was patented together with Stanisław Olszewski in 1887(Beginnings of submerged arc welding, 2016). In the same year, French electrical inventor Auguste de Méritens also invented a carbon arc welding method, patented in 1881, which was successfully used for welding lead in the manufacture of lead–acid batteries (Houldcroft, 1973). The advances in arc welding continued with the invention of metal electrodes in the late 19th century by a Russian, Nikolai Slavyanov (1888), and an American, C. L. Coffin. Around 1900, A. P. Strohmenger released in Britain a coated metal electrode which gave a more stable arc. In 1905 Russian scientist Vladimir Mitkevich proposed the usage of three-phase electric arc for welding. In 1919, alternating current welding was invented by C. J. Holslag but did not become popular for another decade (Cary & Helzer, 2005).

Competing welding processes such as resistance welding and oxyfuel welding were developed during this time as well (Cary & Helzer, 2005); but both, especially the latter, faced stiff competition from arc welding especially after metal coverings (known as flux) for the electrode, to stabilize the arc and shield the base material from impurities, continued to be developed (Weman, 2003).

During World War I welding started to be used in shipbuilding in Great Britain in place of riveted steel plates. The Americans also became more accepting of the new technology when the process allowed them to repair their ships quickly after a German attack in the New York Harbor at the beginning of the war. Arc welding was first applied to aircraft during the war as well, and some German airplane fuselages were constructed using this process (Lincoln, 1994). In 1919, the British shipbuilder Cammell Laird started construction of a merchant ship, the *Fullagar*, with an entirely welded hull (Royal Naval & World Events time line, 1919) she was launched in 1921 (Case study on shipbuilding, 2009).

During the 1920s, major advances were made in welding technology, including the 1920 introduction of automatic welding in which electrode wire was continuously fed. Shielding gas became a subject receiving much attention as scientists attempted to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres (Cary & Helzer, 2005). During the following decade, further advances allowed for the welding of reactive metals such as aluminium and magnesium. This, in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the 1930s and then during World War II (Lincoln, 1994)

During the middle of the century, many new welding methods were invented. Submerged arc welding was invented in 1930 and continues to be popular today. In 1932 a Russian, Konstantin Khrenov successfully implemented the first underwater electric arc welding. Gas tungsten arc welding, after decades of development, was finally perfected in 1941 and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases. Using a consumable electrode and a carbon dioxide atmosphere as a shielding gas, it quickly became the most popular metal arc welding process. In 1957, the flux-cored arc welding process debuted in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly increased welding speeds. In that same year, plasma arc welding was invented. Electroslag welding was released in 1958 and was followed by its cousin, electrogas welding, in 1961(Cary & Helzer, 2005).

Arc welding is a welding process that is used to join metal to metal by using electricity to create enough heat to melt metal, and the melted metals, when cool, result in a binding of the metals. It is a type of welding that uses a welding power supply to create an electric arc between a metal stick ("electrode") and the base material to melt the metals at the point of contact. Arc welding power supplies can deliver either direct (DC) or alternating (AC) current to the work, while consumable or non-consumable electrodes are used.

The welding area is usually protected by some type of shielding gas (e.g. an inert gas), vapor, or slag. Arc welding processes may be manual, semi-automatic, or fully automated. First developed in the late part of the 19th century, arc welding became commercially important in shipbuilding during the Second World War. Today it remains an important process for the fabrication of steel structures and vehicles.

2.2 Process of Arc Welding

- Gas metal arc welding (GMAW)
- Flux-cored arc welding (FCAW)
- Submerged arc welding (SAW)

2.2.1 Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) and metal active gas (MAG) is a welding process in which an electric arc forms between a consumable MIG wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to fuse (melt and join). Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from atmospheric contamination.

The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed in the 1940s for welding aluminium and other non-ferrous materials, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of moving air. A related process, flux cored arc welding, often does not use a shielding gas, but instead employs an electrode wire that is hollow and filled with flux.

To perform gas metal arc welding, the basic necessary equipment is a welding gun, a wire feed unit, a welding power supply, a welding electrode wire, and a shielding gas supply (‘Gas metal arc welding’, 2023).

2.2.2 Flux-Core Arc Welding (FCAW)

Flux-cored arc welding (FCAW or FCA) is a semi-automatic or automatic arc welding process. FCAW requires a continuously-fed consumable tubular electrode containing a flux and a constant-voltage or, less commonly, a constant-current welding power supply. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere, producing both gaseous protection and liquid slag protecting the weld.

One type of FCAW requires no shielding gas. This is made possible by the flux core in the tubular consumable electrode. However, this core contains more than just flux. It also contains various ingredients that when exposed to the high temperatures of welding generate a shielding gas for protecting the arc. This type of FCAW is attractive because it is portable and generally has good penetration into the base metal. Also, windy conditions need not be considered. Some disadvantages are that this process can produce excessive, noxious smoke (making it difficult to see the weld pool). As with all welding processes, the proper electrode must be chosen to obtain the required mechanical properties. Operator skill is a major factor as improper electrode manipulation or machine setup can cause porosity.

Another type of FCAW uses a shielding gas that must be supplied by an external source. This is known informally as "dual shield" welding. This type of FCAW was developed primarily for welding structural steels. In fact, since it uses both a flux-cored electrode and an external shielding gas, one might say that it is a combination of gas metal (GMAW) and FCAW. The most often used shielding gases are either straight carbon dioxide or argon carbon dioxide blends. The most common blend used is 75% Argon 25% Carbon Dioxide.[1] This particular style of FCAW is preferable for welding thicker and out-of-position metals. The slag created by the flux is also easy to remove. The main advantages of this process is that in a closed shop environment, it generally produces welds of better and more consistent mechanical properties, with fewer weld defects than either the SMAW or GMAW processes. In practice it also allows a higher production rate, since the operator does not need to stop periodically to fetch a new electrode, as is the case in SMAW. However, like GMAW, it cannot be used in a windy environment as the loss of the shielding gas from air flow will produce porosity in the weld (‘flux-core arc welding’, 2023).

2.2.3 Submerged Arc Welding (SAW)

Submerged arc welding (SAW) is a common arc welding process. The first SAW patent was taken out in 1935. The process requires a continuously fed consumable solid or tubular (metal cored) electrode. The molten weld and the arc zone are protected from atmospheric contamination by being "submerged" under a blanket of granular fusible flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds. When molten, the flux becomes conductive, and provides a current path between the electrode and the work. This thick layer of flux completely covers the molten metal thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes that are a part of the shielded metal arc welding (SMAW) process.

SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available. The process is normally limited to the flat or horizontal-fillet welding positions (although horizontal groove position welds have been done with a special arrangement to support the flux). Deposition rates approaching 45 kg/h (100 lb/h) have been reported — this compares to ~5 kg/h (10 lb/h) (max) for shielded metal arc welding. Although currents ranging from 300 to 2000 A are commonly utilized currents of up to 5000 A have also been used (multiple arcs).

Single or multiple (2 to 5) electrode wire variations of the process exist. SAW strip-cladding utilizes a flat strip electrode (e.g. 60 mm wide x 0.5 mm thick). DC or AC power can be used, and combinations of DC and AC are common on multiple electrode systems. Constant voltage welding power supplies are most commonly used; however, constant current systems in combination with a voltage sensing wire-feeder are available.

The flux starts depositing on the joint to be welded. Since the flux is not electrically conductive when cold, the arc may be struck either by touching the electrode with the work piece or by placing steel wool between electrode and job before switching on the welding current or by using a high frequency unit. In all cases the arc is struck under a cover of flux. Flux otherwise is an insulator but once it melts due to heat of the arc, it becomes highly conductive and hence the current flow is maintained between the electrode and the workpiece through the molten flux. The upper portion of the flux, in contact with atmosphere, which is visible remains granular (unchanged) and can be reused. The lower, melted flux becomes slag, which is waste material and must be removed after welding.

The electrode is continuously fed to the joint to be welded at a predetermined speed. In semi-automatic welding sets the welding head is moved manually along the joint. In automatic welding a separate drive moves either the welding head over the stationary job or the job moves/rotates under the stationary welding head.

The arc length is kept constant by using the principle of a self-adjusting arc. If the arc length decreases, arc voltage will increase, arc current and therefore burn-off rate will increase thereby causing the arc to lengthen. The reverse occurs if the arc length increases more than the normal.

A backing plate of steel or copper may be used to control penetration and to support large amounts of molten metal associated with the process ('submerged arc welding', 2023).

2.3 Arc Welding Power Supplies

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant voltage power supplies.

In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. Constant current is used in manual welding because it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current. Constant voltage power supplies are most often used for automated welding processes such as gas metal arc welding.

The direction of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration and as a result, changing the polarity of the electrodes has an impact on weld properties. If the electrode is positively charged, it will melt quickly, increasing weld penetration and welding speed.

Alternatively, a negatively charged electrode results in more shallow welds. Non-consumable electrode processes such as gas tungsten arc welding, can use either type of direct current as well as alternating current (AC). With direct current however, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrodes makes deeper welds.

Alternating current rapidly moves between these two, resulting in medium penetration welds. One disadvantage of AC is that arc must be re-ignited after every zero crossing. This disadvantage has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, eliminating low-voltage time after the zero crossings and minimizing the effect of the problem. Shielded metal arc welding and gas tungsten arc welding will use a constant current source. Constant voltage source is preferred in gas metal arc welding and flux-cored arc welding (Nasir, 2005; Larry, 2011).

The welding power supplies most commonly seen can be categorized within the following types.

2.3.1 Transformer

A transformer style welding power supply converts the high voltage and low current electricity from the utility mains into a high current and low voltage (typically between 17 to 65 volts and 55 to 590 Amps). A rectifier is used to convert AC into DC to obtain DC output.

By moving a magnetic shunt in and out of the transformer core helps to vary the output current. A series reactor to the secondary controls the output voltage from a set of taps on the transformer’s secondary winding. This type of power supply is least expensive but bulky. It is a low frequency transformer which must have as high magnetizing conductance to avoid wasteful shunt currents. The transformer may also have significant leakage conductance for short circuit protection in the event of a welding rod becoming stuck to be workforce. The leakage inductance may be variable so the operator can set the output current (Nasir, 2005; Larry, 2011).

2.3.2 Generator and Alternator

Welding power supplies may also use generators or alternators to convert mechanical energy into electrical energy. Modern designs as usually driven by an internal combustion engine but older mechanics may use an electric motor to drive an alternator or generator. In this configuration the utility power is converted first into mechanical energy to achieve the step-down effect similar to a transformer. Because the output of the generator can be direct current or even a higher frequency AC current, older machines can produce DC from AC without any need for rectifiers (Nasir, 2005; Larry, 2011).

2.3.3 Inverter

Since the advent of high-power semiconductors such as insulated gate field effect transistor (IGFET); with a variant - MOSFET (Metal Oxide Semiconductor Field-Effect Transistor), it is also now possible to design power supplies capable of coping with the high current demand required for arc welding (Nasir, 2005; Larry, 2011).

This design is fully automatic. It checks for mains power and switches the welding to mains while simultaneously charging the battery (ies). When battery goes below a set threshold, it shuts the system down to prevent harmful deep discharge, hence prolonging the battery life span.

It also incorporates a feedback system to ensure the output voltage is stable even while battery level is dropping and while welding is going on. The charging system checks for battery full condition and switches to float charging. This helps to compensate for the trickle discharge that's inherent in batteries.

There are other types of arc welding machines; as highlighted above, however our emphasis is on the not so common "hybrid" type arc welding machine, since it is the topic of the project.

2.4 Arc Welding Hazards

Normally operations are not hazardous but a completely safe work-place is something non-existent in the world. Because welding generally requires the use of electric current (including high frequency high voltage current) and compressed gases as well as it involves burning of fluxes, coatings, and gases therefore it may lead to accidents due to negligence and thus prove hazardous (Parmar, 2007). The profession is regarded as the most hazardous and not all welders are aware of all the Hazards. The hazards which are more or less peculiar are: fumes and gases; arc radiation; fire and explosion; electric shock; and compressed gases (Parmar, 2007; Amza et al, 2010).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Research Design

The research design was implemented by carrying out preliminary test on of the electrical components of the hybrid arc welding machine. Test carried out include conductivity and resistance testing using a multi-meter. The value and parameters used were determined based on mathematical logics and formulae which include the followings;

i. Ohm's law of resistance, mathematically expressed as V=IR as applied in selection of the size of conductor and determination of current carrying capacity. V is the voltage, I is the current and R is the resistance.

ii. Turn's ratio of a transformer for determination of induced e.m.f. It is expressed as the ratio of primary coil winding N_1 to secondary coil winding N_2. It is also a function of the ratio of emf at primary coil E_1 to secondary coil E_2 or ratio of current in primary coil I_1 to secondary coil I_2.

iii. Kirchoff's law of current in a circuit where current enters and leaves a point designated, it is given as EI = 0 i.e. I1 + (-I2) + (-I3) + (-I4) = 0 as applied in the point of arcing.

iv. Mutual induction principle in electromagnetic coupled coils in the transformer. It is mathematically expressed as; $M = \frac{N2\theta1}{I_1}$

Where; N is number of turns of coil, I is current.

3.2. Conceptual design

Concepts of welding machine were considered and a choice was made out based on suitability of purpose and design variables that were considered using a decision matrix. Two concepts were significantly viable for consideration as follows;

3.2.1 Concept 1: High Frequency Arc Welding Machine

The high frequency arc welding machine shown in Figure 3.1 comprises of main cable that receives energy from the source, usually a 3 phase 220 or 440 Volts AC, starter or switch, transformer, rectifiers, controls of tension (Voltage) and current (Amps-or-Amperage), two secondary wires. An electric arc from the AC power supply creates an intense heat of around 6500°F which melts the metal at the join between two work pieces.

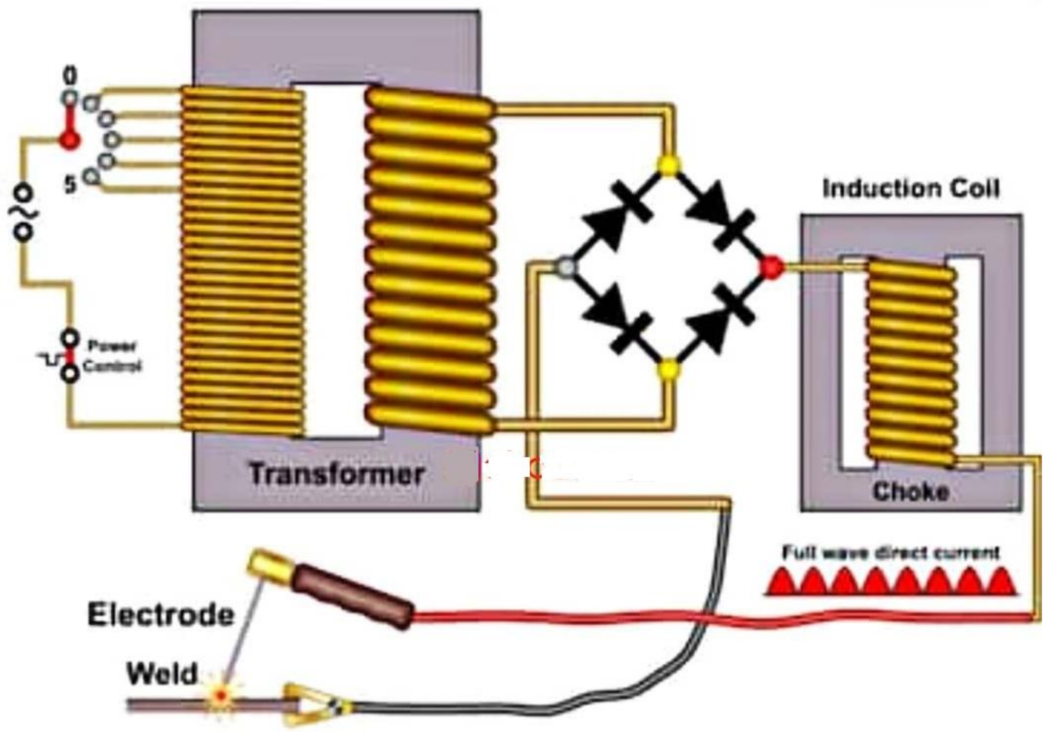

Figure 3.1: High frequency arc welding machine

3.2.2 Concept 2: The Hybrid Welding Machine

The concept 2 hybrid welding machine shown in Figure 3.2 comprises of rectifier, MOSFETS, microprocessors, transformer. The machine takes standard 50Hz AC power and runs it through an initial rectifier, turning it into high-voltage DC power. A microprocessor using extremely high-speed transistor switching turns the DC power off and on again at a very high rate (in Miller welders, for example, 60,000 times a second), which then simulates the waveform of AC power, but at 1,000 times the frequency. That high-frequency AC power then passes through a transformer to another rectifier that converts the power back to DC on its way to the tip of the welding wire.

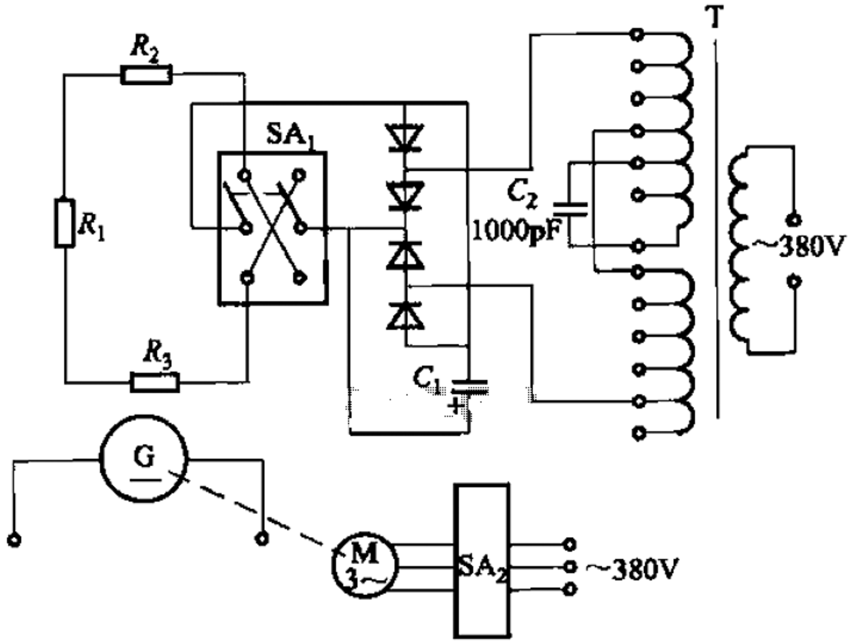

Figure 3.2: Hybrid Inverter Arc Welding Machine.

3.2.3 Decision Matrix

A decision matrix was used to select the most viable design amongst the two concepts based on some critical design inputs of the machines as shown in the Table 3.1. First the design inputs and considerations have to be itemized, tabulated and scaled on a decision matrix.

Table 3.1: Decision matrix for arc welding machine concepts

Selection criteria	**Weighting**	**Concept 2**		**Concept 1**	
		Score	Total	Score	Total
Low current utilization	5	5	25	4	20
Ease AC output conversion.	4	4	16	3	12
Ease of heat dissipation	3	3	9	2	6
Simplicity and light weight	2	2	4	1	2

Low cost of production	1	1	1	0.5	0.5
Total			55		40.5

From the decision matrix in Table 3.1, the concept 2 which is the hybrid arc welding machine has the highest weighted score of 55 based on the design factors considered. The concept 1 (high frequency arc welding) machine had grade points of 40.5. The concept 2 was therefore selected for detail design and fabrication.

3.3 Detailed design

Input design criteria for the hybrid welding machine include some known and assumed variables listed as follows;

i. Input (primary) Voltage 180-220V

ii. Output (secondary) Voltage 24V

iii. Output Current 75A

iv. Transformer 1 power rating 5KVA

v. Transformer 2 power rating 5KVA

vi. Frequency F 50Hz

vii. Secondary current I_2 10A-50A

viii. DC input current 20A

ix. Volts per turn factor K 0.45

x. Current density J 6 A/M

xi. Stocking factor kS 0.95

xii. Maximum flux density Bm 1.2 Tesla

xiii. Window space factor kWs 0.4

xiv. Lamination thickness D 0.012

xv. Iron space factor Ko 0.65

The block diagram of the hybrid welding machine is shown in Figure 3.3.

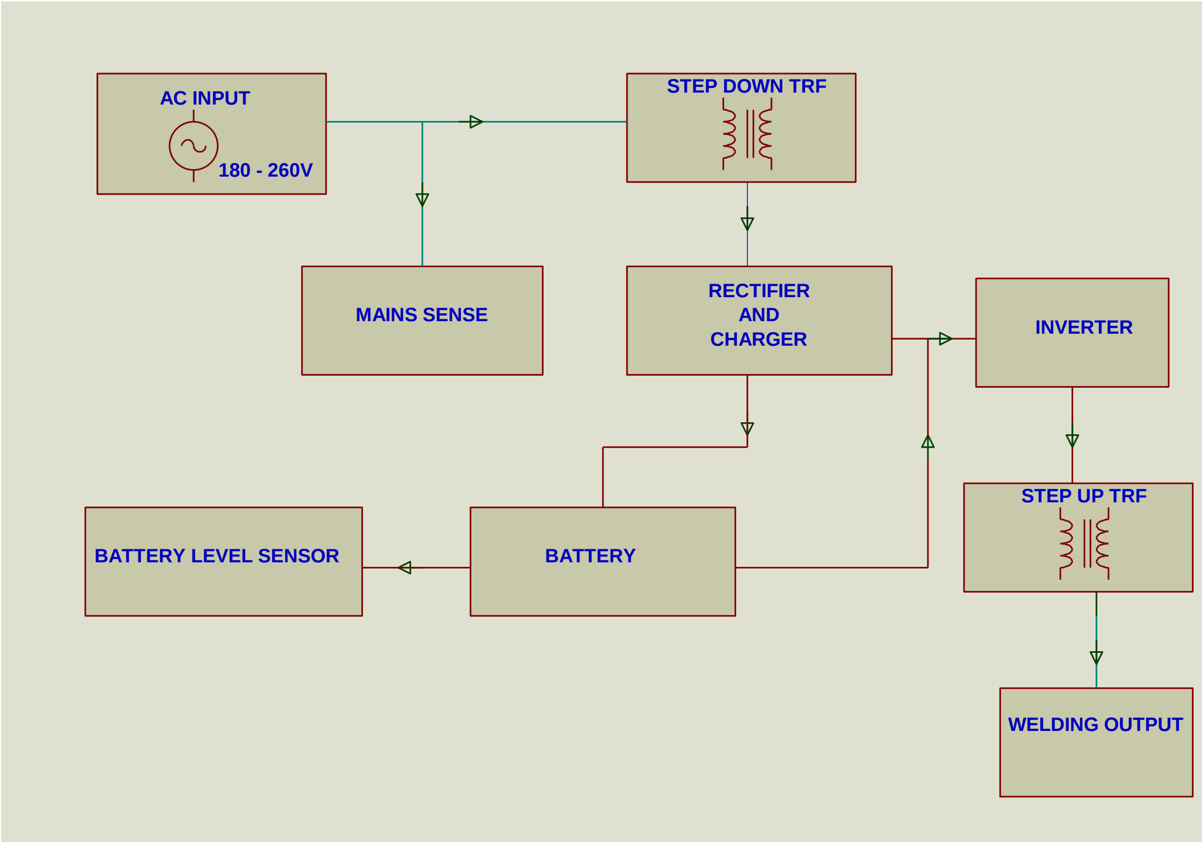

Figure 3.3: Block diagram of hybrid arc welding machine

From the block diagram in Figure 3.3, the oscillator which is an IC SG3524 was used to generate pulse required to drive the IGBT'S (K50T60) to convert the DC supply. The output of the oscillator was amplified using mosfet gate drivers (TLP250). The frequency at which the circuit operates is determined with the oscillator stage. This is followed by the inverter unit which converts the DC input to the required AC voltage. The transformer converts the high voltage and low current electricity from the utility mains into a high current and low voltage (typically between 21volt AC and 10 to 20Amps). The rectifier converts the AC into DC to obtain dc output. This DC output supplies both the charging current and the current required to keep the welding running smoothly. There is another transformer which is at the output of the inverter. This is the transformer that is responsible for the welding.

Determination of volt per turn

The KVA rating (S) of hybrid weld machine = 5KVA

E.M.F per turn (E_t) = k√S = $\frac{V_1}{N_1}$ (3.1)

Where; k = constant, N_1 = number of primary winding turns, V_1 = primary voltage.

Therefore, E_t = 0.45√5 = 1.006v/turn

3.3.1 Number of Turns per winding

From equation (1),

$N_1 = \frac{V_1}{E_t} = \frac{220}{1.006}$ = 218 turns

Since, $N_2E_1 = N_1E_2$, it follows that;

$$\frac{N_2}{N_1} = \frac{E_2}{E_1} \quad (3.2)$$

Expected E_2 = 29V

$N_2 = \frac{E_2\ xN_1}{E_1} = \frac{29\ X\ 218}{220}$ = 29 turns

3.3.2 Cross section area of primary winding conductor

$$G_1 = \frac{L_1}{j} \quad (3.3)$$

Where;

L_1 = the lower bound of the secondary current

J = the current density

Therefore; equation (3) = 25/6 = 4.17mm^2

The conductor diameter Dc is expressed as;

$$\sqrt{\frac{G\ X\ 4}{\pi}} \quad (3.4)$$

$= \sqrt{\frac{4.17\ X\ 4}{3.142}}$ = 2.38mm

Therefore, the standard wire gauge (SWG) which is the equivalent gauge of the primary copper winding is 13 (given). The cross section of the secondary winding conductor is G_2 also expressed as;

$G_2 = \frac{L_2}{j}$ (3.5)

Where;

L_2 = the upper bound of the secondary current.

Therefore, G_2 = 45/6 = 7.55mm^2

And the diameter of the secondary conductor will be= $\sqrt{\frac{7.5 X 4}{3.142}}$ = 3.09mm

The equivalent gauge of the secondary winding copper wire, i.e standard wire gauge (SWG) 8 gauge

3.3.3 Core design

The selected core material is mild steel scavenged from an old transformer which is still in good working condition and also have the capacity of absorbing heat.

From eq (2), using $\frac{E_1}{N_1}$ = 4.44F$B_m$$A_T$

i.e 220/157 = 4.44 x 50 x 1.24A_T

1.4 = 4.44 x 50 x 1.24A_T

Therefore, $A_T = \frac{1}{4.44 X 50 X 1.2}$ = 3.8cm2

Where;

A_T = cross-sectional area of the mild steel core

The cross section area of the core is directly proportional to the square of the stock length i.e. Where Q is the constant proportionality and is about 0.15 for a single phase transformer.

i.e. $A_T \alpha QL^2$

(3.6)

Where;

Q = constant of proportionality. It is about 0.15 for single phase transformer.

From eq (6)

$L = \sqrt{\frac{A_T}{Q}}$ = √(3.8/0.15) = 5m

$A_T = \frac{K_O \, x \, K_S \, x \, \pi D_O^2}{4}$ (Suleiman et al, 2019). (3.7)

Where; Do = core circle diameter.

$Do = \sqrt{\frac{4A_T}{K_O K_S \pi}}$ = √[(4 x 3.8)/(0.65 x 0.95 x 3.142)] = 8.9cm

The transformer circuit diagram is shown in Figure 3.4

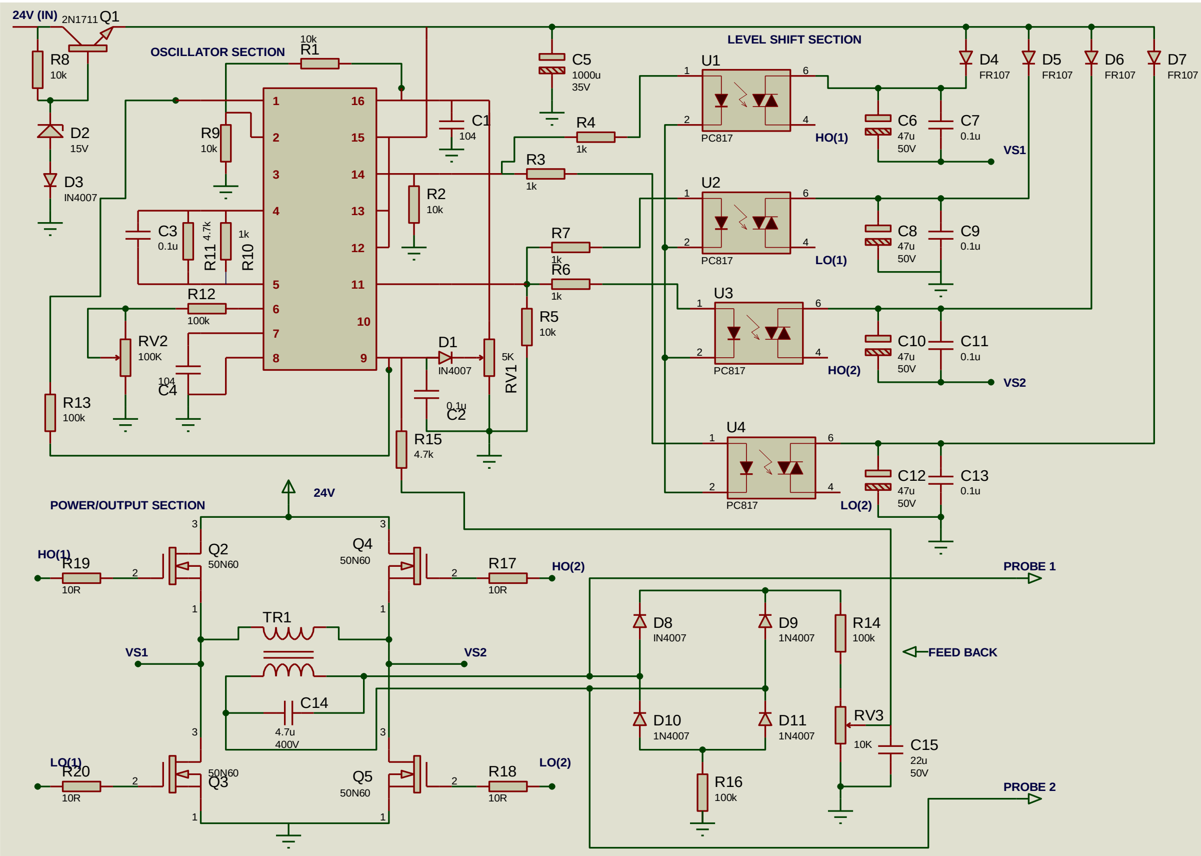

Figure 3.4: Transformer/Oscillator circuit diagram

3.3.4 Area of Window

$E_1 = 4.44F_mN = 4.44FB_mA_T \, AWKW_s \, J$ (3.8)

Where;

A_T = cross sectional area of the core

AW= window area

BM = maximum flux density

F = frequency

KWs = window space factor

J = current density

From eq (8), AW = $\frac{KVA\ X\ 10^{-3}}{2.22FB_M A_T KW_S J}$ = $\frac{5\ x\ 1000\ x\ 0.0001}{2.22\ x\ 50\ x\ 1.2\ x\ 0.0038\ x\ 0.4\ x\ 6}$ 41.2cm^2

3.3.4.1 Stack Height

The cross-section area of the core is directly proportional to the square of stack length or height. This follows from eq (6).

Where; L = $\sqrt{\frac{A_T}{Q}}$ = $\sqrt{\frac{3.5}{0.15}}$ 5M

3.3.4.2 Number of Lamination

Number of laminations is expressed as

No of Laminations = $\frac{Height\ of\ stack}{thickness\ of\ a\ lamination}$ (3.9)

= (5/0.012) = 419.

3.3.7 Design of Oscillator

RT (The timing resistor); comprising of (R12 andRV2) and C4 are connected at pin 6 and pin 7 of the IC SG3524 respectively. IC SG3524 is used in the inverter to generate the 50Hz frequency required by the inverter. The frequency produced by the IC depends on the value of the capacitor and resistor connected at these pins. The capacitor and resistor decides the 50Hz frequency output by the IC. The resistance at a selected pin keeps the oscillator frequency constant. A preset resistor (100K) connected between pin 1 and the compensation pin 9 of the IC keep the output stable. Preset is necessitated so that the value of the output current can be adjusted to a constant (40-50amps). The oscillator circuit diagram is shown in Figure 3.5.

R_{12} , RV2 and C_4 of the IC SG3524 respectively determine the frequency of oscillator. Using the equation expressed by Ovbiagele and Obaitan (2015) as;

f = $\frac{1.17}{R_T C_2}$ (3.10)

Assume C_2 = 104 x 10^{-12}F and the require frequency F=50Hz

Therefore $C_1 = \frac{1.18}{104 \, x \, 50 \, x \, 10^{-4}} = 226933F$

If; $R = R_T$ and $C_2 = C_T$

A fixed resistance of 220K is connected in series with the variable resistor by the relation:

$$f = \frac{1.30}{C_1 C_2} \quad (3.11)$$

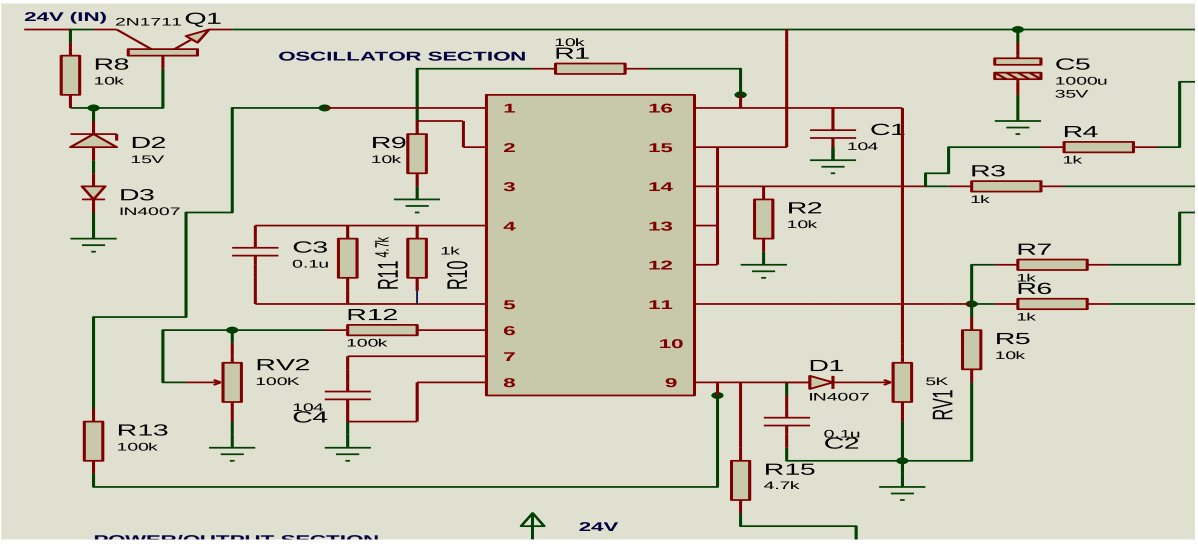

Figure 3.5: Oscillator circuit design diagram

Where F is the frequency in Hz, R_T is the total resistance at pin 6, and C_T is the total capacitance at pin 7. Therefore, to obtain a frequency of 50Hz,

Given $C_T = 0.1\mu F$

Where f is the frequency in Hz, R_T is the total resistance at pin 6, and C_T is the total capacitance at pin 7.

Therefore, to obtain a frequency of 50Hz

Given $C_T = 104pf$

$R_T = (1.30/\ 104 \text{ x } 10^{-12}) = 250000k\Omega$

R_T should be varied at 100k to obtain a frequency of 50Hz.

Signals generated at the oscillator section of converts the incoming signals into signals with changing polarity. Therefore, to achieve a frequency of 50Hz, this process should repeat every

50 times per second i.e. a pulsating signal with 50Hz frequency is generated inside the flip-flop section of the IC.

The 50Hz frequency alternating signal has an output at pins 11 and 14 of the IC. It is the MOS drive signals at pins 11 and 14. Its value lies between 4.6 - 5.4V

3.3.8 Design of Charger Section

The input of the charger section is switchable between voltage ranges of; 0-180VAC and 181-260VAC. This makes provision for the charger to still operate within a wide voltage range. The output of the transformer (TR1) is about 20VAC which after rectification (made up of D1-D4) and filtration (made up of C1-C3) would give a DC voltage of about 28.28Vdc. This would supply a current of about 70A making provision for losses. This is expected to charge the batteries and at the same time keep the welding machine running smoothly.

Overcharging the batteries would in the long run damage the battery cells. Therefore, a charge monitoring system is included. This is made up of R1-R3, Z1,Z2,U1,D5,Q1 and RL1.

Z1,Z2 and R1 are connected to the positive terminal of the battery under charge. Z1 is a 24V Zener diode and Z2 is a 5V Zener diode. They are both connected in series, their sum gives 29V hence when the battery under charge reaches about 27V current would flow through Z1 and Z2 to illuminate the internal LED of U1 (PC817), this inturn would cause current to flow from the 12V source through the collector of U1 (PC817); ultimately sending to the base of Q1; thereby switching on Q1. This would activate the relay RL1 and thereby disconnect the battery from charge. If the battery drops below this voltage, the relay deactivates and as such connects the battery bank to its charging source.

The battery bank used for this project is made up of 24Nos battery cells of 2V 100AH connected in serious.

The charge section circuit diagram of the hybrid arc welding machine is shown in Figure 3.6.

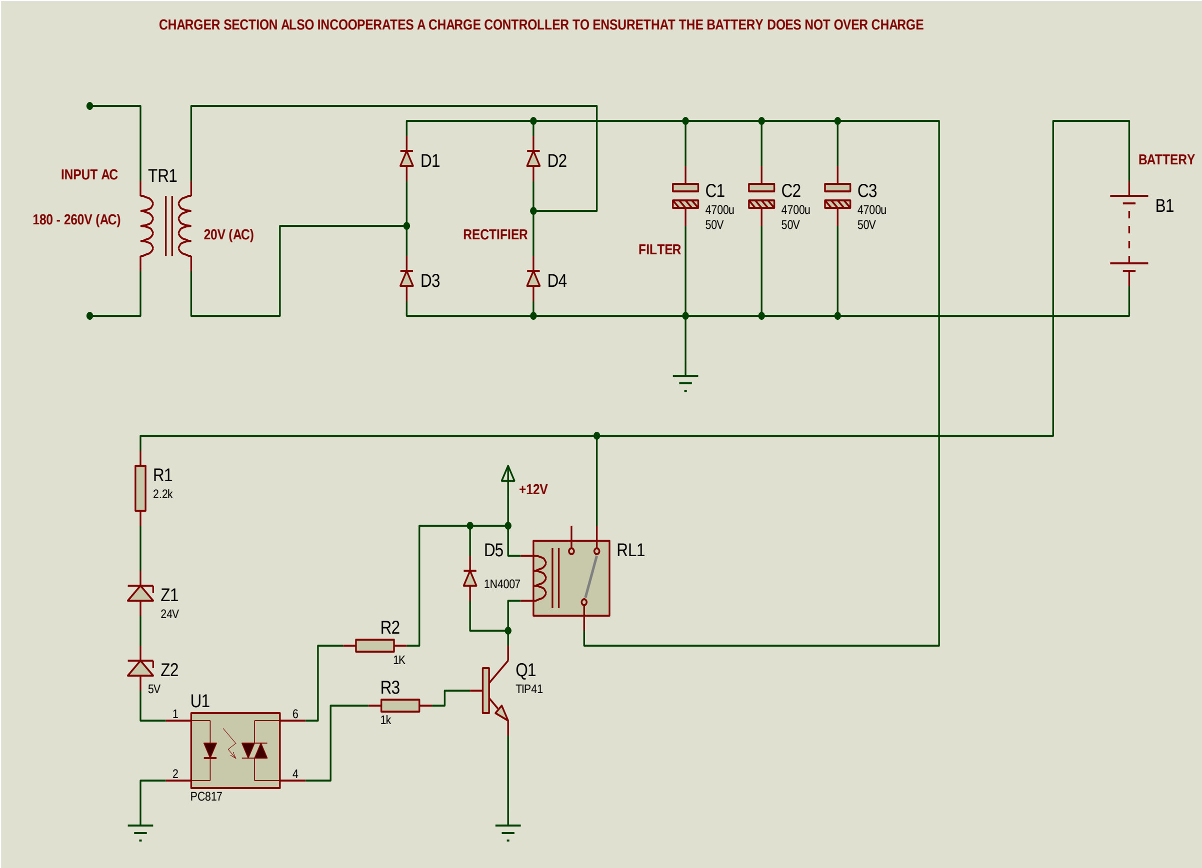

Figure 3.6 charger section of hybrid arc welding machine.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Results

The result obtained from testing of the hybrid arc welding machine is shown in Table 4.1.

Table 4.1 Test results for the operated hybrid arc welding machine

Runs	Power supply	Input voltage (V)	Output voltage (V)	Input current(A)	Output current(A)	Time Duration (sec)
1st run	DC Battery	24.0V	73.4V	21.1A	63.4A	30
	AC Mains	220V	80.1V	25.2A	69.22A	30
2nd run	DC Battery	23.7V	71.4V	21.1A	61.4A	30
	AC Mains	216V	80.1V	25.2A	66.23A	30
3rd run	DC Battery	24.3V	73.4V	21.1A	60.8A	30
	AC Mains	200V	80.1V	25.2A	65.02A	30

4.2 Discussion

Open and short circuit tests were carried out. The physical working of the machine was also carried out. In the course of welding with the produced arc welding machine, no arcing effect was noticed on the tong. Arc production with different gauge 10 of electrode used was very satisfactory for the metal works. From the three runs of test carried out with the welding machine, there was consistency in its production of output voltage and current. Thus insignificant drop was notice in the output currents of the second and third runs of the tests. This may have been due to the battery discharge over time and usage.

Power absorbed by the DC system was observed to be higher than that absorbed by the AC system. In the DC system, the source of the greatest power losses was the output rectifier, operating with entire output current. In the AC spot welding system, the regulator could only provide the adjustment of root mean-square voltage, as a result of which, current flowing through the transformer and electrodes has network frequency. The transformer operation at network frequency restricts the possibility of increasing energy density transmitted by the transformer.

4.3 CASING

Having satisfied the project aim and objective from the test carried out on the circuit operations, the project was then mounted into casing made with wood and fibre. The input AC voltmeter, battery voltmeter and welding output voltmeter were also incorporated into the casing. A low battery LED indication and the device on/off switch was also incorporated as well.

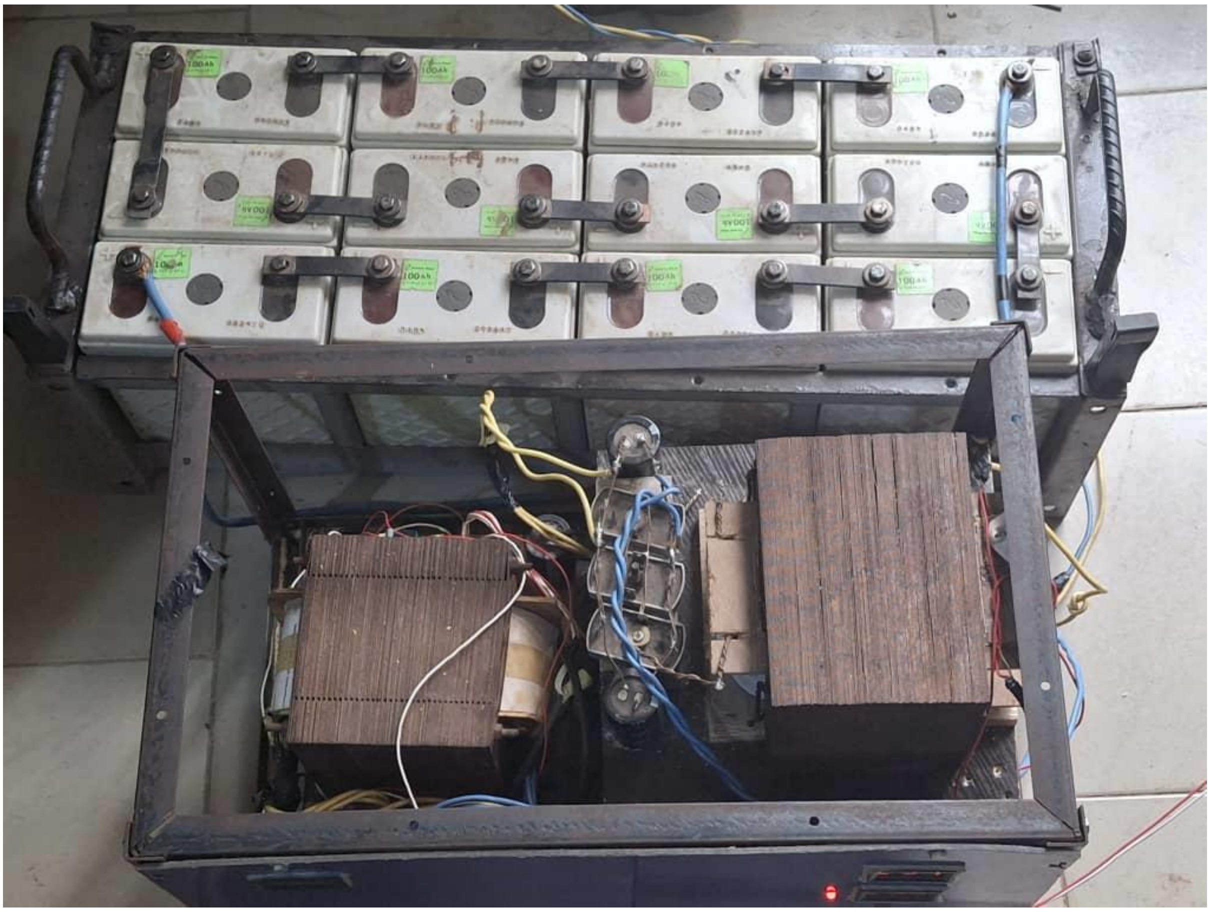

Figure 4.1: Hybrid Arc Welding Machine interior view showing the welding and charging transformers.

Figure 4.2: Hybrid Arc Welding Machine front view showing the voltmeters and contacts

Figure 4.3: Hybrid Arc Welding Machine

4.4 Bill of Engineering Materials and Evaluation

The bill of engineering materials and evaluation of the hybrid arc welding machine is shown in Table 4.2.

Table 4.2: Bill of Engineering materials and evaluation for hybrid arc welding machine

S/No	Item	Quantity	Unit Price(₦)	Amount (₦)
A	**Charging Transformer**			
1	Primary copper wire(guage 18)	0.5kg	*14,000.00*	*7,000.00*
2	Secondary copper wire (guage 15)	0.5kg	*14,000.00*	*7,000.00*
3	Lamination Core	1	*9,500.00*	*9,500.00*

4	Bobbin (13x5.5x8cm)	1	*6,000.00*	*6,000.00*
B	**Welding Transformer**			
1	Primary Copper wire (guage 9)	1kg	*12,000.00*	*12,000.00*
2	Secondary Aluminium Wire (guage 11)	1kg	*12,000.00*	
3	Bobbin (13x5.5x8cm)	1	*6,000.00*	*6,000.00*
4	Lamination Core	1	*9,500.00*	*9,500.00*
C	**Other Materials**			
1	PSG3524	1	*300.00*	*300.00*
2	Buck converter	1	*2500.00*	*2500.00*
3	Capacitor (1000µF/25V)	1	*150.00*	*150.00*
4	Capacitor (100µF/50V)	3	*70.00*	*210.00*
5	Capacitor (10µF/50V)	2	*50.00*	*100.00*
6	Capacitor (0.1µF non polarized)	6	*50.00*	*300.00*
7	Capacitor (10,000µF/100V)	6	*2500.00*	*15,000.00*
8	Capacitor (10µF/350V non polarized)	1	*1500.00*	*1500.00*
9	IC sockets	5	*150.00*	*750.00*
10	Heat Sinks	4	*5,000.00*	*20,000.00*
11	IGBTS(K50T60)	12	*1,500.00*	*18,000.00*

12	Resistor(10Ω)	12	*30.00*	*360.00*
13	Resistor(22KΩ)	4	*30.00*	*120.00*
14	Resistor(100KΩ)	2	*30.00*	*60.00*
15	Resistor(150KΩ)	1	*30.00*	*30.00*
16	Resistor(10KΩ)	3	*30.00*	*90.00*
17	Resistor(4.7KΩ)	5	*30.00*	*150.00*
18	Resistor(2.2KΩ)	5	*30.00*	*150.00*
19	IN4007 Diodes	7	*30.00*	*210.00*
20	Zener Diode	2	*50.00*	*100.00*
21	TLP250 (MOSFET/IGBT Driver)	4	*350.00*	*1,400.00*
22	80A Diode Bridge	3	*2,500.00*	*2,500.00*
23	Welding Tongue	1	*5,500.00*	*5,500.00*
24	Welding Output Terminals	2	*3,000.00*	*6,000.00*
25	10mm Flexible Wire	6 yards	*1,500.00*	*9,000.00*
26	2.5mm Flexible wire	10 yards	*850.00*	*8,500.00*
27	Soldering lead	1 roll	*8,000.00*	*8,000.00*
28	Screws	1pkt	*4,000.00*	*4,000.00*
29	Battery (2V 100AH)	12	*20,000.00*	*240,000.00*
30	Casing	lot	*25,000.00*	*25,000.00*
	Sub-total			***438,980.00***
	Labour Cost / Miscellaneous Expenses (15% of Sub - total cost)			***65,847.00***
	GRAND TOTAL			***504,827.00***

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The present research explored the use of an inverter system to aid the operation of the electric arc welding machine. The inverter welding machine works at low frequency (50Hz), using IGBTs (Insulated Gate Bipolar Transistor). The use of the inverter system promotes seamless working condition in arc welding where conventional power outage could be a disruption to work. The present research was able to meet its objectives which include design of the electric hybrid arc welding machine (for AC and DC supply system), its fabrication and testing. Results gotten from the test showed that the hybrid inverter arc welding machine performed to its designed capacity. The incorporation of a control circuit for adjusting the PWM (Pulse Width Modulation) that switches the IGBTS and the output voltage / current at the said frequency was also carried out to make the system user friendly and easy to operate. The system emphasizes the design of clean energy and energy saving systems to meet the present day clamor for non-environmental polluting systems as there are no harmful emissions from the machine.

5.2 RECOMMENDATIONS

Following the conclusion of the present research, the following recommendations are made

i. Further studies can be carried on the hybrid inverter electric arc welding machine to incorporate self-actuating controls to meet energy savings, current fluctuations, and automatic voltage regulator.

ii. The present study could further be developed to include a solar PVC system to facilitate its battery storage capability, extended working time and use of renewable and alternative energy source from the sun.

iii. The design can also be improved on to make it less bulky and easy to move around.

REFERENCES

Amza, G. Rontescu, C. Cicic, D. – T. Apostolescu, Z. Pică, D. Research on Environmental Pollution When Using Shielded Metal Arc Welding (SMAW). 72(3), 2010, pp. 73-88.

Anders, A. (2003). "Tracking down the origin of arc plasma science-II. early continuous discharges". *IEEE Transactions on Plasma Science*. **31** (5): 1060-9. Bibcode:2003ITPS...31.1060A. doi:10.1109/TPS.2003.815477. S2CID 11047670

Beginnings of submerged arc welding (PDF). Archived from the original (PDF) on 2016-03-04

Cary, Howard B., Helzer Pg 5-7, 9 (2005).”*Modern Welding Technology*”: upper saddle river, New Jersey.

Case Studies on Shipbuilding Archived February 3, 2009, at the Wayback Machine

Case Studies on Shipbuilding Archived February 3, 2009, at the Wayback Machine

Great Soviet Encyclopedia, Article “*Electric Arc*”

Houldcroft, P. T. (1973) [1967]. "Chapter 3: Flux-Shielded Arc Welding". *Welding Processes*. Cambridge University Press. p. 23. ISBN 978-0-521-05341-9.

Http: // www.miller welds. Com/ education/ articles/ article 31.html

Kalpakjian, Serope,Steven R. (2001). “*Manufactuering Engineering and Technology*”: Prentice hall

Lazarev, P.P. (December 1999), "Historical essay on the 200 years of the development of natural sciences inRussia" (Russian), *Physics-Uspekhi*, **42** (1247):1351-1361, Bibcode:1999PhyU...42.1247L, doi:10.1070/PU1999v042n12ABEH000750, S2CID 250892442, archived (PDF) from the original on 2011-02-11.

Lincolin E., pg 1.1- 6 (1994). “*the Procedure Handbook of Arc Welding*” : Cleveland, Ohio

Parmar, R. S. Welding Processes and Technology. Second Edition. Delhi: Khan Publishers, 2007, pp. 760.

Royal Naval & World Events time line

Shea, William R., ed. (1983). *Nature mathematized: historical and philosophical case studies in classical modern natural philosophy*. Dordrecht: Reidel. p. 282. ISBN 978-90-277-1402-2.

Weman Klas, pg 16, 26 (2003). "*Welding Process Handbook*": New York, CRC press