DESIGN AND DEVELOPMENT OF A 2 $\times$ 0.7KW ARC WELDING MACHINE USING MICROWAVE OVEN TRANSFORMER

BY

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(EES/16/17/0491)

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING

SUBMITTED TO

THE DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING,

COLLEGE OF ENGINEERING AND ENVIRONMENTAL STUDIES,

OLABISI ONABANJO UNIVERSITY,

IBOGUN, IFO LGA, OGUN STATE.

2021

DECLARATION

I hereby declare that this is my work and that it has not, to the best of my knowledge, been submitted before anywhere for the purpose of awarding a diploma or degree.

OTESILE, KEHINDE OLUWANIFEMI **DATE**

(EES/16/17/0491)

DEDICATION

To you, dad and mum. Thank you for your love, patience and the sacrifices made in sponsoring my education this far.

CERTIFICATION

This is to certify that the project was carried out by OTESILE, KEHINDE OLUWANIFEMI with the matriculation number, EES/16/17/0491, under the supervision of Engr. OLAJIDE, M.B., in partial fulfillment of the award of Bachelor of Engineering (B.Engr.) from the department of Electrical/Electronics Engineering Department, Faculty of Engineering, Olabisi Onabanjo University, Ibogun, Ifo LGA, Ogun State.

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ACKNOWLEDGEMENTS

I acknowledge God Almighty, the Giver of knowledge and inspiration for helping me through my study and the execution of the project for which this report is written.

In rendering my appreciations, I can in no way overlook my parents, Hon. And Mrs. Otesile. My father particularly encouraged me through the years of my study, seeing to it many times that I didn’t give up when I wanted to. Every child needs a father like mine – he is *too* sacrificial and loving. He inspires me to want to be a great father too. I cannot be more grateful to him and my mother.

A man I am also very grateful to is my mentor, Niyi Makinde. He is in fact more than a mentor to me. He too encouraged me many times through the years of my study, when I was burned out as a result of many responsibilities and my extracurricular involvements.

My sincere appreciation goes to my favorite lecturer in the department who happened to also be my project supervisor, Engr. Olajide, M.B. I respect him for his sincerity and intentionality with training his students.

I acknowledge other members of staff of Olabisi Onabanjo University.

These acknowledgements would not be complete if I do not mention some of my relatives and friends who had direct impact on me during my study. My friend, someone old enough for me to call an uncle, Emmanuel Olorunlowo, regularly checked on me, motivated me, and provided me with funds during the course of my study even though he was several thousand miles away from me. My cousin, Damola Adeleye, too bore some of my costs. My friend and colleague in the department, Ayorinde Alase, supported me in many ways – he, at different times, provided me with learning resources, and supported me in executing a few extracurricular projects targeted at the students of our campus. Emmanuel Raimi, Folahanmi Olugbemi, Emmanuel Edward, Praise Adeleke and a few other colleagues at one time or the other made an input into my study, mostly by providing me with learning resources. Oluwakemi Omoyeni had a significant impact in my study in the first semester of my final year. I could say that if not for her intentional support, I might have failed a particular course.

ABSTRACT

This report details the project, **Design and Development of a 2 × 0.7KW Arc Welding Machine using a Microwave Oven Transformer.**

Welding is the process of fabricating two or more pieces of metal together.

Some types of welding are less efficient than others, and they produce less neat results. Others which produce good results are mostly difficult to carry out and are expensive.

Arc welding is a type of welding process that uses an electric arc to create heat of as much as 6,500°F which melts metal pieces held together thereby causing them to stick after being cooled. Upon cooling, the molten metals form a metallurgical bond.

Microwave oven transformers are used because they are mobile and effective.

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CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Welding is the process of fabricating two or more pieces of metal together. Arc welding is a type of welding process that uses an electric arc to create heat of as much as 6,500°F which melts metal pieces held together thereby causing them to stick after being cooled. Upon cooling, the molten metals form a metallurgical bond. A power supply creates the electric arc between a consumable or non-consumable electrode and the base material using either direct (DC) or alternating (AC) current.

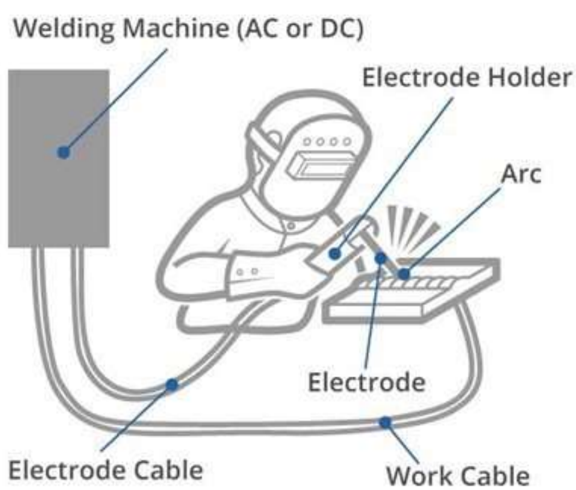

Figure 1.1: Welding Process

Electric Arc: Also referred to as arc discharge, it is an electric discharge that is caused between two electrodes—metallic conductors through which current enters and leaves—when a normally non-conductive medium such as air is ionized by electric current. The process produces plasma which may give visible light. The discharge relies on thermionic emission—the liberation of electrons from the electrodes supporting the arc due to the thermal energy supplied to the electrode overcoming its work function.

Electrode: It is used to supply electric current into non-metallic solids, into liquids, gases, plasmas and vacuums. Electrodes are good electric conductors but they need not be metals.

1.2 PROBLEM STATEMENT

Some types of welding process are less efficient than others and they produce less neat results. Others which produce good results are mostly difficult to carry out and expensive.

1.3 TYPES OF ELECTRIC ARC WELDING

There are different types of Electric Arc Welding classified into Consumable Electrode Methods and Non-Consumable Electrode Methods. Under Consumable Electrode Methods, there are Shielded Metal Arc Welding, Gas Metal Arc Welding, etc. Gas Tungsten Arc Welding and Plasma Arc Welding are two types of Electric Arc Welding classified under Non-Consumable Electrode Methods.

1.3.1 SHIELDED METAL ARC WELDING (SMAW)

One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding (MMAW) or stick welding. An electric current is used to strike an arc between the base material and a consumable electrode rod or *stick*. The electrode rod is made of a material that is compatible with the base material being welded and is covered with a flux that gives off vapors that serve as a shielding gas and provide a layer of slag, both of which protect the weld area from atmospheric contamination. The electrode core itself acts as filler material, making a separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment. However, weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding. Furthermore, the process is generally limited to welding ferrous materials, though specialty electrodes have made possible the welding of cast iron, nickel, aluminum, copper and other metals. The versatility of the method makes it popular in a number of applications including repair work and construction.

1.3.2 GAS TUNGSTEN ARC WELDING (GTAW)

Gas tungsten arc welding (GTAW), or tungsten/inert-gas (TIG) welding, is a manual welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all metals that can be welded, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and marine applications.

1.4 APPLICATION OF ELECTRIC ARC WELDING

The electric arc welding is applicable in different manufacturing industries for generating powerful joints worldwide because of its benefits like ease of operation and superior welding efficiency. It is most broadly used in different sectors and industries such as automotive, construction, shipbuilding, and aerospace, for protection and to renovate works.

1.5 AIM AND OBJECTIVES

Aim: The aim of this project is to design and develop a 2×0.7KW arc welding machine using a microwave oven transformer.

Objectives: The objectives of this project are as follows:

- To design a model of the arc welding process;
- To determine the most reliable specifications of an arc welding machine;
- To design and develop the arc welding machine; and
- To test the machine for maximal efficiency.

1.6 BENEFITS OF THE PROJECT

The benefits of an electric arc welding machine include the following:

- Speed and Efficiency: Arc welding has high speed and welding efficiency. The welding is a quick and consistent process and produces very little distortion such that smooth welding is produced.
- Apparatus: The machine is a simple welding apparatus.
- Portability: This is as a result of the simple equipment; the materials involved and the machine are simply moveable
- Cost: The process often requires less equipment. The equipment used and the power source are affordable.
- Accessibility: Common domestic current can be utilized for the welding process. It operates well with both alternating current and domestic current.

CHAPTER TWO: LITERATURE REVIEW

2.1 MICROWAVE OVEN TRANSFORMER

A transformer is a simple static (or stationary) electromagnetic passive component that converts electrical energy from one value to another and transfers the energy from one electrical circuit to another or multiple circuits.

The transformer operates on Faraday's law of induction which describes the induced voltage effect in any coil due to a changing magnetic flux encircled by the coil. A varying current in any one coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force across any other coils wound around the same core. Electrical energy can be transferred between separate coils without a metallic (conductive) connection between the two circuits.

Figure 2.1: A Typical Voltage Transformer

Transformers can be classified in many ways, such as the following:

- Power rating,
- Duty,
- Frequency range,
- Application,
- Voltage class, etc.

The high voltage transformer is essentially employed into home appliances such as a microwave oven which generates microwave to cook the foods, or the like, in order to supply the high voltage thereto.

2.1.1 DESIGN

A single phase voltage transformer basically consists of two electrical coils of wire, one called the "Primary Winding" and another called the "Secondary Winding". It could be said that the "primary side" of the transformer is the side that usually takes power, and the "secondary side" is the side that usually delivers power. In a single-phase voltage transformer, the primary is usually the side with the higher voltage.

These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the "core". This soft iron core is not solid but made up of individual laminations connected together to help reduce the core's losses.

The two coil windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other. When an electric current passed through the primary winding, a magnetic field is developed which induces a voltage into the secondary winding as shown.

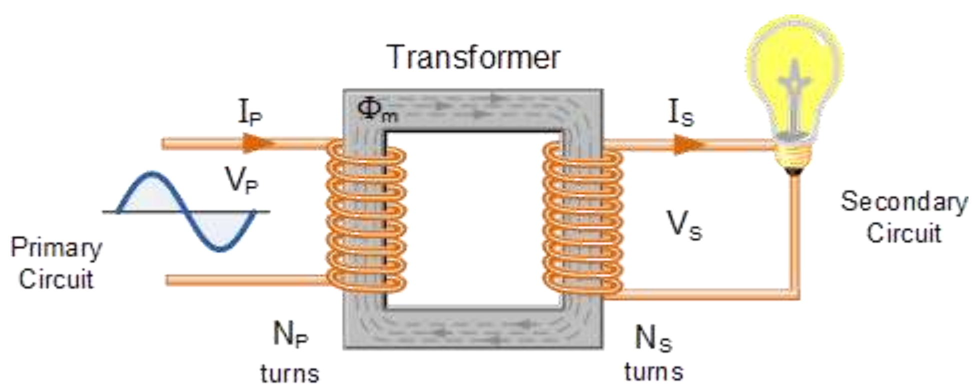

Figure 2.2: Single Phase Voltage Transformer Design

Where:

- V_p = Voltage in primary winding
- V_s = Voltage in secondary winding
- I_p = Current in primary winding
- I_s = Current in secondary winding
- N_p = Number of turns in primary winding
- N_s = Number of turns in secondary winding
- $\Phi_{max.}$ = Maximum flux in core

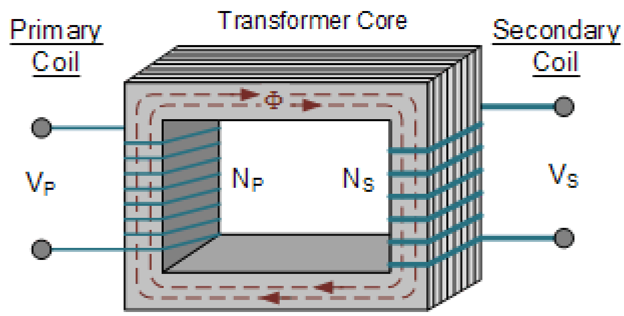

Figure 2.3: Transformer Construction

Where:

- $\Phi = \Phi_{max.}\text{Sin}\omega t$ = Flux in core

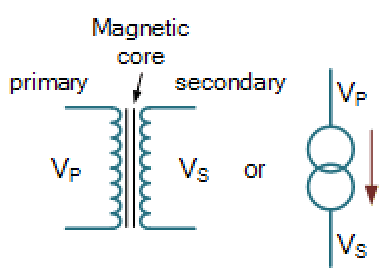

Figure 2.4: Transformer Symbols

2.1.2 EQUATIONS

Turns Ratio

The turns ratio of an ideal transformer ($\Phi_P \equiv \Phi_S$) is given by the equation below.

$$n = \frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{E_p}{E_s}$$

Where:

- n = Turns ratio
- E_p = EMF induced in primary winding
- E_s = EMF induced in secondary winding

Transformation Ratio

The voltage transformation ratio of an ideal transformer is given by the equation below.

$$K = \frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{E_s}{E_p}$$

Where:

- K = Transformation ratio

Number of Turns

Number of turns on one side of a transformer is the product of turns/volt in that winding and the total voltage in it. It is expressed mathematically below as:

$$N_p = \text{turns/volt} \times V_p$$

$$N_s = \text{turns/volt} \times V_s$$

EMF Induced in Primary and Secondary Windings

The EMFs induced in the primary and secondary windings of a transformer are given by the equations below.

$$E_p = 4.44fN_p\Phi_{max.} = 4.44fN_p\beta_{max.}A \text{ (Note: } \Phi_{max.} = \beta_{max.}A)$$

$$E_s = 4.44fN_s\Phi_{max.} = 4.44fN_s\beta_{max.}A \text{ (Note: } \Phi_{max.} = \beta_{max.}A)$$

Where:

- f = Line frequency
- $\beta_{max.}$ = Maximum flux density
- A = Area of core

Power in a Transformer

$$P = I_pV_pCos\Phi_p = I_sV_sCos\Phi_s$$

Where P = Power rating of transformer

Note that power in primary winding = power in secondary winding. Therefore, power ratio is unity.

Efficiency

The efficiency of the transformer is given by the output power divide by the input power. Some of the input power is wasted in internal losses of the transformer.

$$\text{Efficiency, } \eta = \frac{\text{Output Power}}{\text{Input Power+Total Losses}} \times 100\%$$

$$= \frac{\text{Input Power}-\text{Total Losses}}{\text{Input Power}} \times 100\%$$

$$= \left(1 - \frac{\text{Total Losses}}{\text{Input Power}}\right) \times 100\%$$

When a magnetic flux flows in the steel core of a transformer, two types of losses occur within the steel. One termed “eddy current losses” and the other one termed “hysteresis losses”.

Hysteresis Losses are caused because of the friction of the molecules against the flow of the magnetic lines of force required to magnetise the core, which are constantly changing in value and direction first in one direction and then the other due to the influence of the sinusoidal supply voltage.

Transformer Eddy Current Losses on the other hand are caused by the flow of circulating currents induced into the steel caused by the flow of the magnetic flux around the core.

2.2 WELDING ELECTRODES

Welding electrodes are lengths of wire that are connected with your welding machine to create an electric arc. Current passes through this wire to produce an arc, which generates a lot of heat to melt and fuse metal for welding.

Depending on the function, electrodes can be classified into:

- Consumable electrodes
- Non-consumable electrodes

2.2.1 CONSUMABLE ELECTRODES

Consumable electrodes get melted during welding operation. They are low-melting-point electrodes, that is, when an arc is produced, they start to melt at the end, and is transferred to the job in form of metal droplets.

Consumable electrodes are the key to stick, MIG, and flux-cored arc welding. The consumable electrodes used for stick welding are called stick electrodes. These include heavy-coated electrodes, shielded arc, and light coated electrodes.

2.2.2 NON-CONSUMABLE ELECTRODES

Non-consumable electrodes do not melt during melting process.

There are two types of non-consumable electrodes namely:

- Carbon electrodes
- Tungsten electrodes

2.3 ELECTRIC ARC WELDING

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 welders can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes.

The welding area is usually protected by some type of shielding 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.

CHAPTER THREE: METHODOLOGY

3.1 DESIGN SPECIFICATION

For this project, the transformer would have 230V as its input voltage, and 14 to 10V as its output voltage. The voltages depend on the power capacity of the microwave oven. It also has a higher current when short-circuited.

- Transformer rating = 0.7KW (700W)
- Input voltage = 230V
- Output voltage = 10V with deviation of +4V
- AC frequency = 50Hz

Note that the transformer shall be free from deficiencies such as deformation. The machine framework shall be well perforated to provide for ventilation into the engine. The material shall have enough tensile strength to support the load of the machine’s engine.

3.2 DESIGN METHODOLOGY

The project is a simple system which comprises of different components as seen in the block diagram below. A 230V power supply will be connected to the main switch through AC or DC which will then power the different components – fan, transformers, etc. The welding holder will be connected to two transformers. The secondary sides of each transformer will then be wound in turns in a number of turns that will give the required output voltage and current. The output voltage is required to be very low while the current is very high.

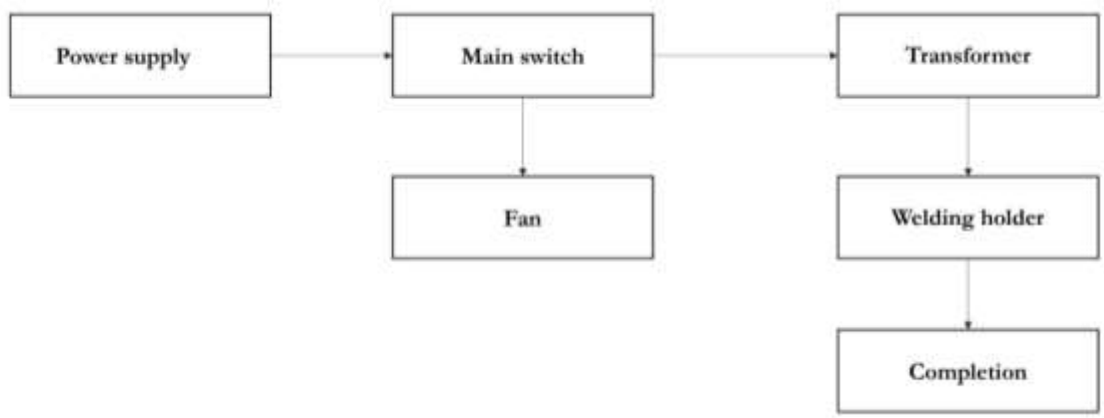

Figure 3.1: Project Block Diagram

3.3 DESIGN ANALYSIS

Power Supply

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 current power supplies and 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. This is important because in manual welding, 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, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

Transformer

High voltage electricity is provided by some types of transformers. These transformers are powered by 230V of electricity, and can create between 2KV and 1.5KV of output voltage. The type of transformers needed for this project is the microwave oven transformer (MOT).

The microwave oven transformer is being used due to its low voltage output and high current capacity which is built up enough to melt metals of fuse them together.

Cooling

Heat generated in the machine requires that it is cooled by some sort of system. In this project, a fan will be used to dissipate heat from the machine.

Machine Housing

The project will be housed in a strong metallic framework, 1.5mm thick.

3.4 DESIGN CALCULATIONS

Turns per Volt

Turns per Volt, TpV = $\frac{1}{4.44 \times 0.001 \times A \times \beta \times f}$

Primary Winding Calculations

Since power rating, P = 700W and input voltage = 230V,

Current at primary winding, $I_p = P/V_p = 700/230$

$\mathbf{I_p = 3.04A}$

The number of turns = TpV × V_p

= 1.2 × 230

= 276 turns

Secondary Winding Calculations

Since power rating, P = 700W and required output voltage is 10V,

Current at secondary winding, $I_s = P/V_s = 700/10$

I_s = 70A

The number of turns required for this = TpV × V_s

= 1.2 × 10

= 12 turns

3.5.1 CALCULATIONS TABLE

Table 3.1: Primary Winding Calculations Table

Variable	**Formula**	**Value**
Power rating	$P = I_p V_p$	700W
Voltage	$V_p = P/I_p$	230V
Current	$I_p = P/V_p$	3.04A
Number of turns	TpV × V_p	276 turns

Table 3.2: Secondary Winding Calculations Table

Variable	**Formula**	**Value**
Power rating	$P = I_s V_s$	700W
Voltage	$V_s = P/I_s$	10V
Current	$I_s = P/V_s$	10A
Number of turns	TpV × V_s	12 turns

CHAPTER FOUR: DEVELOPMENT PROCEDURE

A typical microwave oven transformer provides around 2.5KV as its output voltage. In order to achieve the required voltage of 12V, the secondary winding will be rewound thereby giving a higher current needed for the project. The microwave oven transformer is being used due to its low voltage output and high current capacity which is built up enough to melt metals of fuse them together.

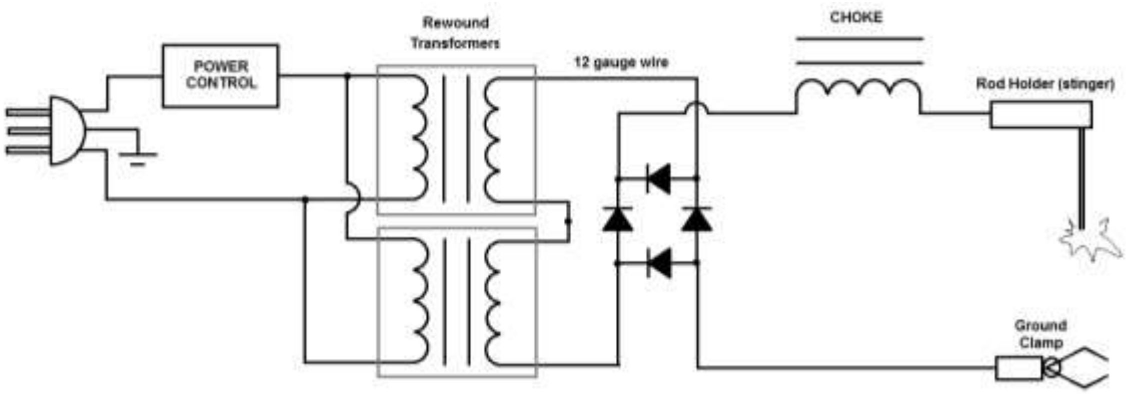

Figure 4.1: Project Schematic Diagram

The following were the procedures taking during the developmental phase of the project:

- The transformers to be used were sourced for and tested to ensure they met the stated specifications.
- The transformers were then modified by wounding the secondary sides to give required voltage outputs.
- The secondary windings of the transformers were then connected in series to achieve the same voltage with higher current.
- The primary windings of the transformer too were connected together but in parallel.
- An electric holder was connected to the secondary winding of the transformer and grounding clamp.
- A plug and a fan were then connected to the primary winding of the transformer.
- Lastly, the whole connections were coupled in a housing.

4.1 SYSTEM TESTING

The components used in the development of the system were also tested. This includes the testing of the transformers, cables, fans, etc.

The overall system built was also tested for durability, efficiency and effectiveness so as to determine if there was need to modify the design. After all tests carried out and slight modificatons, it was concluded that the system satisfied all requirements.

4.2 COST ANALYSIS

Table 3.3: Project Cost Analysis

Variable	**Quantity**	**Price**
13mm copper wire	1/4kg	₦3,000.00
700W MOT transformer	2	₦15,000.00
Electrode holder	1	₦3,000.00
Fan	2	₦1,000.00
Cable	4 yards	₦3,000.00
13A fuse	1	₦800.00
Transformer housing	1	₦5,000.00
Voltmeter	1	₦500.00
10A circuit breaker	1	₦1,000.00
Plug cable	2 yards	₦1,000.00
Miscellaneous		₦5,000.00
Total		₦38,300.00

CHAPTER FIVE: SUMMARY, RECOMMENDATION, AND CONCLUSION

The details contained in this section of this report are a summary of the project, problems encountered while undertaking it, and recommended line of actions for engineering students in order to further improve the design.

5.1 SUMMARY OF ACHIEVEMENT

This project spans the design of an effective arc welding machine and its development. I carried out extensive studies on the different aspects of the project – arc welding process, transformers, electrodes, etc. – and accompanying calculations. I then went on the mission to actually develop the machine, sourcing for materials and components, and making necessary fabrications and connections.

5.2 PROBLEMS ENCOUNTERED AND SOLUTIONS

One major problem I encountered during the course of this project is the need of professional mechanical skills, particularly metal working, as the project involved not just the connecting of electrical components but also constructing the framework for the machine. Being a student of electrical/electronics engineering, having very little knowledge of mechanical engineering, I needed support in this regard. This suggested that delay would occur, but with my supervisor’s guidance, I was able to find a workshop technician with enough skill to support me carry out the project effectively.

5.3 RECOMMENDATION

I would recommend to anyone undergoing a project as this to gain proficient understanding of high voltage transformers used in constructing a welding machine, and how to modify one or more pieces to achieve desired results. The project could also be improved upon by adding some type of control switch to regulate output of electrical variables, and some manner of automation system to improve its ease of operation.

5.4 CONCLUSION

Welding electrode is a piece of wire or rod, which can be of metal or alloy and has a flux with or without flux and carries an electric current to obtain sufficient heat for welding. At one end, it is fastened to a holder and an arc is installed at the other.

Altogether, 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 welders can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes.

REFERENCES

1. Fundamentals of Arc Welding (https://pdfcoffee.com/fundamentals-of-arcwelding-pdf-free.html)
2. Arc welding machine.docx – PDFCOFFEE.COM (https://pdfcoffee.com/arcwelding-machinedocx-pdf-free.html)
3. Electric Arc Welding: Meaning, Procedure and Equipment (http://engineerexperiences.com/design-calculations.html)
4. What Are Welding Electrodes (and What You Should Know)? - Welding Headquarters (https://weldingheadquarters.com/welding-electrodes/)
5. Transformer Basics and Transformer Principles (https://www.electronics-tutorials.ws/transformer/transformer-basics.html)
6. Transformer Construction and Transformer Core Design (https://www.electronics-tutorials.ws/transformer/transformer-construction.html)
7. Transformer Formulas and Equations - Electrical Technology (https://www.electricaltechnology.org/2020/10/transformer-formulas-equations.html)
8. Power Transformers Basics| Types and Design Formulas of Transformers (https://www.elprocus.com/transformer-design/)
9. Homemade Stick Welder - From Microwave Parts! : 8 Steps (with Pictures) - Instructables (https://www.instructables.com/Homemade-Stick-Welder-From-Microwave-Parts/)
10. Designing_Your_Own_Transformer (http://www.idc-online.com/technical_references/pdfs/electrical_engineering/Designing_Your_Own_Transformer.pdf)
11. US5954988A - High voltage transformer of a microwave oven having a structure for radiating heat - Google Patents (https://patents.google.com/patent/US5954988A/en)
12. (PDF) Designing the high voltage transformer of power supplies for DBD: Windings arrangment to reduce the parasitic capacitive effects (https://www.researchgate.net/publication/259745444_Designing_the_high_voltage_transformer_of_power_supplies_for_DBD_Windings_arrangment_to_reduce_the_parasitic_capacitive_effects)

13. Transformer – Wikipedia (https://en.wikipedia.org/wiki/Transformer#Classification_parameters)
14. Arc welding - Wikipedia (https://en.wikipedia.org/wiki/Arc_welding)
15. Shielded metal arc welding – Wikipedia (https://en.wikipedia.org/wiki/Shielded_metal_arc_welding)