DESIGN AND IMPLEMENTATION OF SPEED CONTROL DC MOTOR USING THYRISTOR.

BY

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A Thesis written in partial fulfilment for the award of a Bachelor Degree in Engineering and submitted to the Department of Electrical and Computer Engineering, School of Engineering and Engineering Technology, Federal University of Technology Minna, Niger State.

December, 2009

DECLARATION

I, Clarence Abram, declare that this work was done by me and has never been presented elsewhere for the award of a degree.

.... 17/03/2010 ....

CLARENCE ABRAM Date

CERTIFICATION

This is to certify that the project work titled "Design and Implementation of Speed Control D.C Motor using Thyristor" was carried out by Clarence Abram with the Registration Number 2004/18764EE, under the supervision of Engr. (Dr.) M.N. Nwohu and submitted to the Electrical and Computer Engineering Department, Federal University of Technology, Minna in partial fulfilment for the award of Bachelor of Engineering (B.Eng.) in Electrical and Computer Engineering.

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I want to express my heartfelt gratitude to my heavenly father Jehovah for giving me the life to accomplish this project. I also want to thank my parents Late Engr. and Mrs. Nathaniel Abram for their moral and financial support, and their patience in all the stress and demands I placed on them during my undergraduate programme. I won't forget to mention my lovely siblings, Claribel, Nina, Helga, Leila and Henry for their prayers.

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DEDICATION

I dedicate this project work to the Almighty God Jehovah for his protection, knowledge, guidance and wisdom throughout my course of study and who is the source of my inspiration.

ABSTRACT

This project is focused on the design and implementation of a DC motor speed control using a thyristor at different firing angles.

This is achieved by sending pulsating signals to the gate of the thyristor to trigger the thyristor into conduction and therefore puts the DC motor in motion. The firing angle of the thyristor is then varied afterwards to attain a desirable control for the DC motor.

This system is made up of thyristors, voltage regulators, bridge rectifier, transformer and a 555 timer connected to the input terminals of the DC motor to realize the required speed control of the DC motor.

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CHAPTER ONE

INTRODUCTION

Electric machines vary widely in appearance, functions, construction and operational principles. Thus, examples of electric machines are generator, motor, transformer, reactor, etc. These categories of machines operate on the fundamental principles of electromagnetic induction capable of converting or transferring energy from one form to another. The generator converts mechanical energy to electrical energy by the interaction of moving conductors across magnetic field in the air gap to produce an induced Electromotive Force (emf). While an electric motor is a device using electrical energy to produce mechanical energy by the interaction of magnetic fields and current-carrying conductors. Traction motors used on vehicles often perform both tasks.

Electric motors have wide applications such as industrial fans, blowers and pumps, machine tools, household appliances, power tools and computer disk drives. Electric motors may be operated by direct current from a battery in a portable device or motor vehicle or by alternating current from a central electrical distribution network. Medium-size motors of highly standardized dimensions and characteristics provide convenient mechanical power for industrial uses. The very largest electric motors are used for propulsion of large ships, and for such purposes as pipeline compressors, with ratings in thousands of kilowatts. Electric motors may be classified by the source of electric power, by their internal construction and by application [1].

The thyristor d.c drive remains an important speed-controlled industrial drive, especially where higher maintenance cost associated with the d.c motor brushes (induction motor) is tolerable. The rectifier provides a low-impedance adjustable direct current voltage for the motor armature, thereby providing speed control [2].

Until the 1960s, the only really satisfactory way of obtaining the variable-voltage d.c supply needed for speed control of an industrial d.c motor was to generate it with a d.c generator. The generator was driven at fixed speed by an induction motor, and the field of the generator was varied in order to vary the generated voltage [5,12].

For a brief period in the 1950s, the dc generator was superseded by grid-controlled mercury arc rectifiers but these were soon replaced by thyristor converters.

The disadvantages of rectified supplies are that the waveforms are not pure d.c, that the overload capacity of the converter is very limited, and that a single converter is not capable of regeneration. Though no longer pre-eminent, study of the d.c drive is valuable for several reasons:

The structure and operation of the d.c drive are reflected in almost all other drives, and lessons learned from the study of the d.c drive therefore have close parallels to other types. The d.c drive tends to remain the yardstick by which other drives are judged.

Under constant-flux conditions, the behavior of the d.c drive is governed by a relatively simple set of linear equations, predicting both steady-state and transient behavior. When we turn to the successors of the d.c drive, notably the induction motor drive, we will find that things are much more complex, and that in order to overcome the poor transient behavior, the strategies adopted are based on emulating the d.c drive [8,12].

THYRISTOR D.C. DRIVES - GENERAL

For motors up to a few kilowatts, the armature converter can be supplied from either single-phase or three-phase mains, but for larger motors three-phase is always used. In thyristor D.C drives, thyristor or diode rectifier is used to supply the field of the motor; the power is much less than the armature power so the supply is often single-phase.

The arrangement shown in Figure 1 is typical of the majority of d.c drives and provides for closed-loop speed control. The function of the two control loops will be explored later.

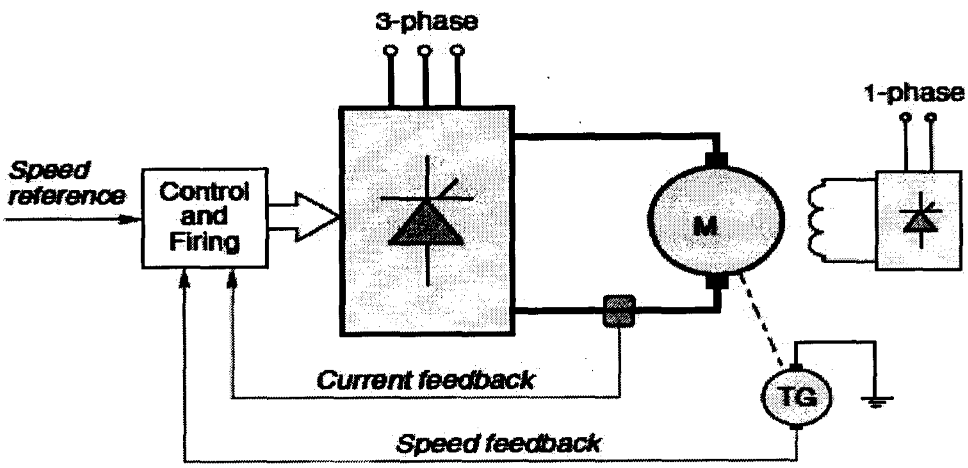

Figure 1: Schematic diagram of speed-controlled d.c motor drive.

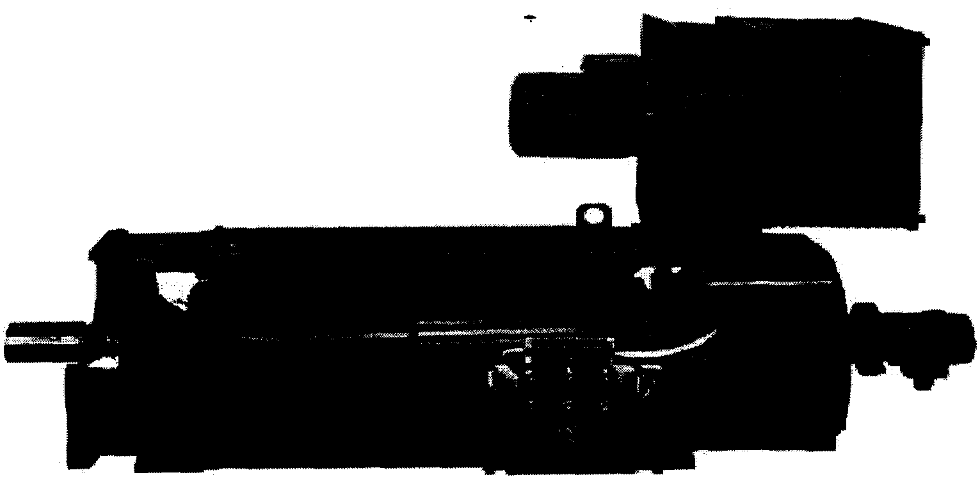

Plate 1: High performance forced-ventilated d.c motor.

The motor is of all-laminated construction and designed for use with a thyristor converter.

motor to maintain full torque at low speed without overheating [12].

The physical principle of production of mechanical force by the interaction of an electric current and a magnetic field was known as early as 1821. Electric motors of increasing efficiency were constructed throughout the 19th century, but commercial exploitation of electric motors on a large scale required efficient electrical generators and electrical distribution networks [3,4].

Due to its advantages, the electric motor has largely replaced other power both in industries, transport, business firms and homes. Electric motors are convenient, economical to operate, safe, environmental friendly and comparatively silent.

They operate in wide range of applications such as starting, accelerating, running, breaking, holding and stopping a load. They are also available in variety of sizes from small fraction of horse power to many thousands of horse power and in wide range of speed. The speed may be fixed (synchronous) constant for even load conditions, adjustable or variable [2,7].

For uniformity and interchangeability, motors are standardized in size, types and speed. Electric motors can operate in alternating current (A.C) or direct current (D.C). Although A.C motors are more common, D.C motors are preferred for applications requiring simple, inexpensive, speed control or sustained high torque under low voltage conditions [7].

1.1 THYRISTORS

A thyristor is a PNPN 4 layer semi-conductor device which is widely used as a switching device. It can control load by switching current OFF and ON up to many thousand times, thereby delivering selected amount of power to the load. Compared to the transistor, it has a very fast response, very high efficiency, very high reliability and very long life.

The applications of thyristors are found in Phase control, Inverter, Relay control, Battery charger, Heater control and more importantly, d.c motor speed control. In motor speed control, the thyristors control the means of energizing the motor.

1.2 MOTIVATION

It's often observed that the speed of a DC motor without speed control system is directly proportional to the input voltage level which makes its speed uncontrollable during high voltage condition, hence leading to overheating, reduced efficiency and reliability of the motor. Therefore, the need for a reliable and effective electronic speed control system comes into mind and brings about the need for the project.

1.3 AIMS AND OBJECTIVES

The aim of this project is to provide motor speed control system which exhibits small velocity variation as a result of variation of power supply and frequency.

1.4 SCOPE OF PROJECT

The project covered the construction and implementation of D.C motor speed control using thyristors at different angles of firing from the power supply unit to the commutation unit.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

A brief general discussion of the historical background and also the theoretical background of electric motors is highlighted in this chapter to give a picture of what has been in existence and various developmental stages of electric motors.

2.2 HISTORICAL BACKGROUND

The principle of conversion of electrical energy into mechanical energy by electromagnetic means was demonstrated by the British scientist, Michael Faraday, in 1821 and consisted of a free-hanging wire dipping into a pool of mercury. A permanent magnet was placed in the middle of the pool of mercury. When a current was passed through the wire, the wire rotated around the magnet, showing that the current gave rise to a circular magnetic field around the wire. This motor is often demonstrated in school physics classes, but brine (salt water) is sometimes used in place of the toxic mercury. This is the simplest form of a class of electric motors called homopolar motors. Subsequently, homopolar motors metamorphosized to Barlow's Wheel. These were demonstration devices, unsuited to practical applications due to limited power [12].

The first real electric motors

European writers asserted that in 1827, Hungarian Ányos Jedlik started experimenting with electromagnetic rotating devices which he called "electromagnetic self-rotors". He used them as illustrative instruments in the universities, and he demonstrated the first real electric motor using electromagnets for both stationary and rotating parts in Hungary in 1828. He built an electric motorpropelled vehicle that same year. There is no evidence that this experimentation was communicated to the wider scientific world at that time, or that it influenced the development of electric motors in the following decades [8].

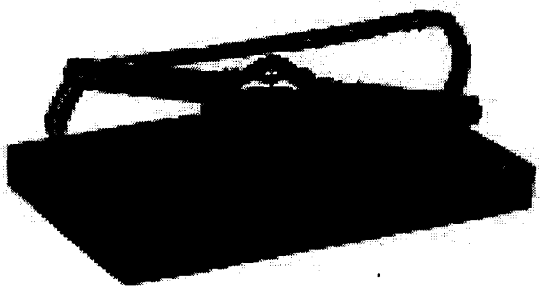

Plate 2: Jedlik's first successful electromagnetic "self-rotor" in 1827 (Museum of Applied Arts, Budapest)

The first English commutator-type direct-current electric motor capable of a practical application was invented by the British scientist, William Sturgeon, in 1832.

Following Sturgeon's work, a commutator-type direct-current electric motor made with the intention of commercial use was built by the American Thomas Davenport and patented in 1837. Although several of these motors were built and used to operate equipment such as a printing press, due to the high cost of primary battery power, the motors were commercially unsuccessful and Davenport went bankrupt. No electricity distribution had been developed at the time. Like Sturgeon's motor, there was no practical commercial market for these motors [5].

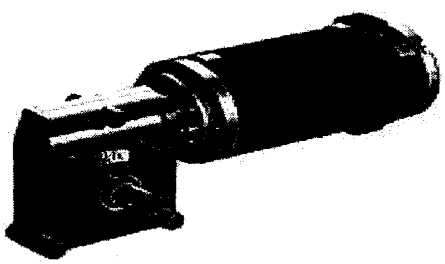

Plate 3: Typical DC electric motor with worm-wheel gearbox.

The modern DC motor was invented by accident in 1873, when Zénobe Gramme connected the dynamo he had invented to a second similar unit, driving it as a motor. The Gramme machine was the first electric motor that was successful in the industry [7].

The development of electric motors of acceptable efficiency was delayed for several decades by failure to recognize the extreme importance of a relatively-small air gap between rotor and stator. Early motors, for some rotor positions, had comparatively huge air gaps which constituted a very high-reluctance magnetic circuit. They produced far-lower torque than an equivalent amount of power would produce with efficient designs. The cause of the lack of understanding seems to be that early designs were based on familiarity of distant attraction between a magnet and a piece of ferromagnetic material, or between two electromagnets. Efficient designs are based on a rotor with a comparatively-small air gap, and flux patterns that create torque.

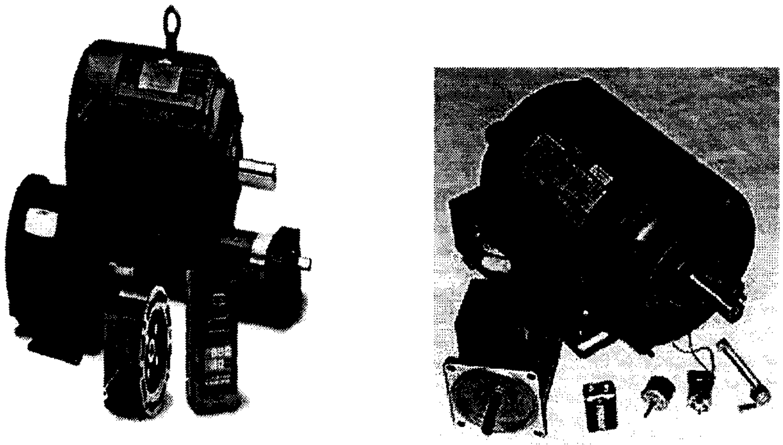

Plate 4: Electric motors.

Application of electric motors revolutionized industry. Industrial processes were no longer limited by power transmission using shaft, belts, compressed air or hydraulic pressure. Instead every machine could be equipped with its own electric motor, providing easy control at the point of use, and improving power transmission efficiency. Electric motors applied in agriculture eliminated human and animal muscle power from such tasks as handling grain or pumping water. Household uses of electric motors reduced heavy labour in the home and made higher standards of convenience, comfort and safety possible. Today, electric motors consume more than half of all electric energy produced.

2.3 THEORETICAL BACKGROUND

A variety of thyristor controlled circuitry has been devised for use in motor control depending upon the type of supply i.e AC or DC, and the type and size of the motor.

For DC motor control, controlled DC power from a constant voltage AC supply is obtained by means of controlled rectifiers or converters employing thyristors and diodes. The control of DC voltage is achievable by firing the thyristor at an adjustable angle with respect to the applied voltage. This angle is known as the firing angle and the scheme of control is called phase control.

Control of DC motors fed from DC supply is achieved by means of a Thyristor - switching circuit called a chopper. The chopper controller periodically opens and closes wherein the control of the average voltage is achieved by varying on and off durations. This gives an efficient control of DC motors.

The motor can also be made to operate in the regenerating / braking mode where the chopper controller would require forced commutation of the thyristor.

The speed characteristic of a motor usually represents the variation of speed with input current or input power. The speed of a D.C motor can be altered by varying either the flux or armature voltage or both. The methods which are commonly employed include:

- Variable Resistors
- Resistive controller
- Thyristor control

2.3.1 VARIABLE RESISTORS

A variable resistor called a field regulator is connected in series with the shunt winding in shunt and compound motors. When the resistance is increased, the hold current and the flux generated are reduced. Consequently, more currents through the armature and the increased torque enables the armature to accelerate until the generated Electromotive Force (emf) is again nearly equal to applied voltage. With this method, it is possible to increase the speed three or four times than at full excitation but it is not possible to reduce the speed below the value. Also with any given setting of the regulator, the speed remains approximately constant on no-load.

2.3.2 RESISTIVE CONTROLLER

This method of controlling the speed of D.C motor involves the use of resistor called controller which is usually connected in series with the armature. The electrical connections for the controller are exactly the same as a starter, the only difference being that in a controller, the resistor elements are designed to carry the armature current indefinitely whereas in a starter they can only do so for a comparatively short time without getting excessively hot.

For a given armature current, the larger the controller resistance in the circuit, the smaller the potential differences across the armature and the lower the speed.

2.3.2.1 ADVANTAGES OF RESISTIVE CONTROLLER METHOD FOR SPEED CONTROL

- Speeds from zero upwards are easily obtainable by this method.
- The method is majorly used for controlling the speed cranes, hoists, trains etc. where the motors are frequently started and stopped, and where efficiency is of secondary importance.

2.3.2.2 DIS-ADVANTAGES OF RESISTIVE CONTROLLER METHOD

- High cost of controller.
- High percentage of input energy may be dissipated in the controller and the overall efficiency of the motor reduced.
- The speed may vary with variation of load due to change in the potential difference across the controller.

2.3.3 THYRISTOR CONTROLLER

This method involves the application of the available a.c supply to the thyristor which controls the voltage applied to the armature of the motor. The thyristor is a solid state rectifier which is normally non-conducting in the forward and reverse directions. It is provided with an extra electrode, called the gate such that when a pulse current is applied to the gate circuit, the thyristor begins to conduct in the forward direction. Once the thyristor is fired, it continues to conduct until the current falls below the holding value of the current [6].

As compared to other methods of controlling the speed of a motor, the thyristor method of controlling motor speed have higher accuracy, greater reliability, quick response and also higher efficiency, as there are no I^2R losses in moving parts.

Thyristor control speed of motor can be achieved by adjusting either;

- The voltage applied to the motor armature.
- The field current
- By varying the firing angle of the thyristor

As stated above, the average output of a thyristor controlled rectifier can be changed by varying its firing angle, and hence, the armature voltage of the D.C motor can be adjusted to control its speed.

CHAPTER THREE

DESIGN AND IMPLEMENTATION

3.1 METHODOLOGY

This system (DC motor speed control using thyristor) is made up of thyristors, voltage regulators, transformer, bridge rectifier, 555 Timer and DC motor.

The primary part of the transformer is connected to an AC power supply and its secondary part is connected to the bridge rectifier's input terminals. A capacitor (C1) connected across the rectified DC power supply serves as a filter, i.e., it filters the AC ripples left after rectification of the AC supply into DC supply. A voltage regulator (LM317) is a 15V voltage regulator which regulates the filtered DC voltage output used by the motor and a 5V voltage regulator (78L05) through a 100kΩ variable resistor is used to regulate the voltage level required for use by the 555 timer which is 5V. Resistor (R1) is a 33kΩ resistor which limits the current that flows through a light emitting diode (LED1) so as to prevent the lighting indicator from damaging. LED1 is a light display indicator that shows the presence of power in the system when turned ON.

When the circuit is turned ON, the 555 timer receives a voltage signal from the voltage regulator (78L05) which sets it to a standby mode. As the potentiometer is being varied, the state of the 555 timer changes to an active mode and a signal is sent to the gate of the thyristor (SCR1) which triggers the thyristor ON and consequently charges the commutation capacitor (C3). Once the commutation capacitor (C3) is fully charged, it then begins to discharge through thyristor (SCR1) thereby acting as a shunt over the thyristor and then thyristor (SCR2) switches ON and begins to conduct until the commutation capacitor (C3) is fully discharged.

The full discharge of the commutation capacitor (C3) then turns OFF thyristors SCR2 and switches ON thyristor SCR1 while the capacitor (C3) goes back to its charging state.

The rapid switching ON and OFF of both thyristors keeps the speed of the DC motor constant even though the mechanical load changes which is assisted by the 555 timer. The free-wheeling diode (D3) located in the commutation circuit serves as a tool for blocking the unwanted DC voltage supply flowing towards the commutation circuit. Capacitor (C2) which is connected to the discharge and threshold pins of the 555 timer is a discharge capacitor which facilitates discharge from the 555 timer with the help of a 1kΩ resistor (R3).

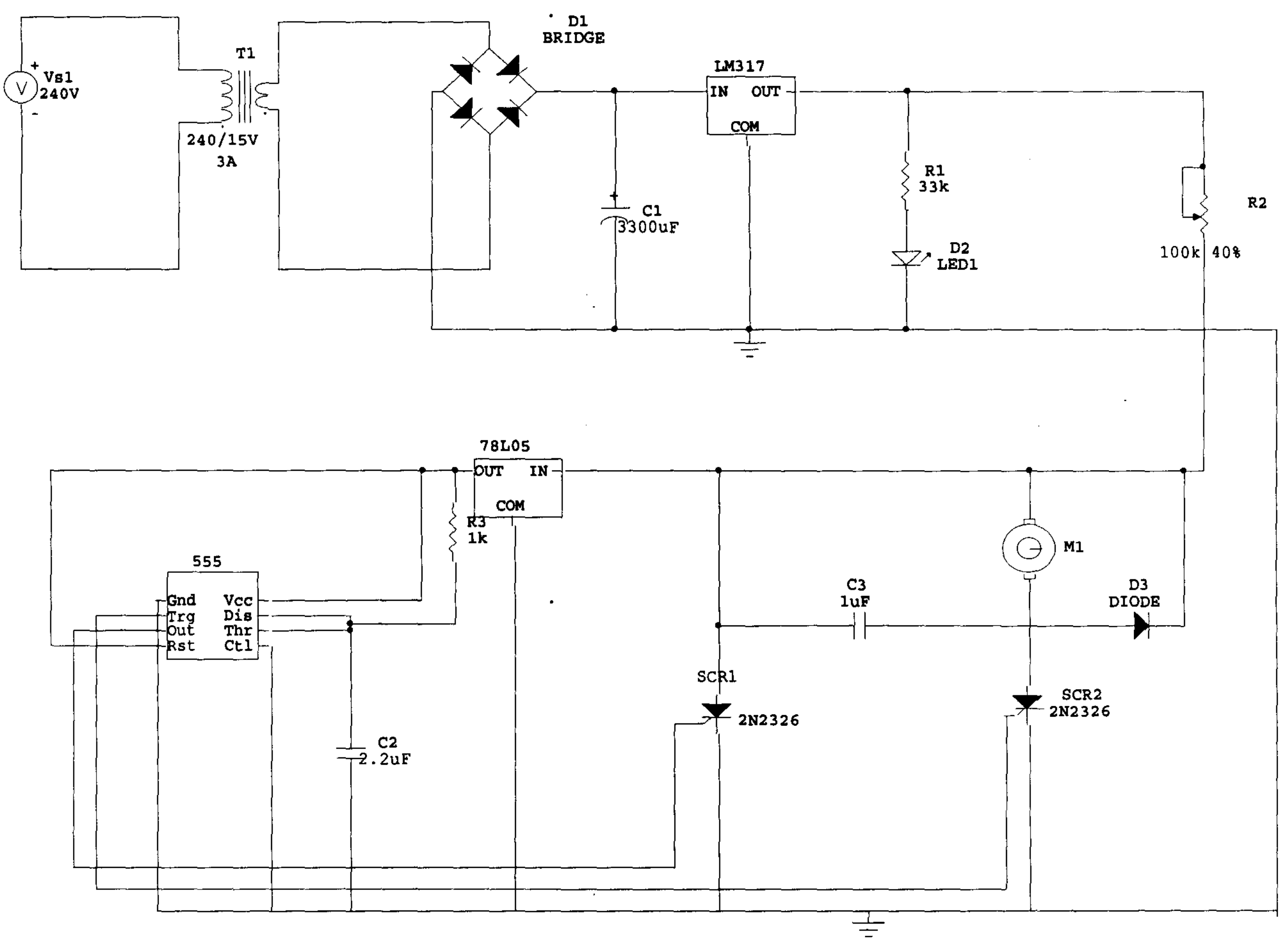

Fig. 2: DC motor speed control circuit using thyristors.

3.2 DESIGN AND CONSTRUCTION OF A DC MOTOR SPEED CONTROL

The construction of this project work was done in two parts, that is, the circuit construction on veroboard and the casing construction. The circuit construction was done using veroboard and soldering lead to solder components according to the design as shown in circuit diagram after which preliminary tests were carried out. The casing construction was done using plywood and the dimension of the casing is 32 × 15 × 12 cm which housed the circuit construction.

The design and construction of a DC motor speed control using thyristors at different firing angles involves the following stages:

- The construction of the power supply unit
- The configuration of the Astable multivibrator
- The construction of the commutation circuit unit and the mounting of the motor

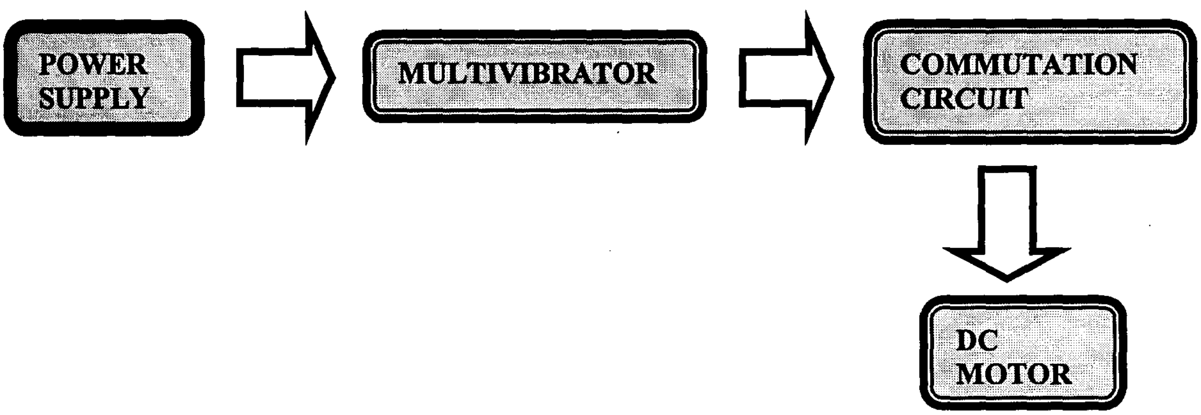

Fig. 3: Block diagram of D.C motor speed control circuit.

3.2.1 CONSTRUCTION OF THE POWER SUPPLY UNIT

The power supply unit comprises a step-down transformer (rated 240/15-0-15V, 3A), a full-wave bridge rectifier, 3300μF 50V capacitor and LM317T voltage regulator.

3.2.1.1 THE TRANSFORMER (STEP DOWN)

A transformer is a static device consisting of coils couple through a magnetic medium connecting two ports at different voltage levels in an electric system allowing the interchange of electric energy between the ports in either directions via the electric field. The most important task performed by transformers are changing voltage and current levels in electric power system matching source and load impedances for maximum power transfer in electronics, control circuitry and electrical isolation (isolating one current from another or isolating DC while maintaining AC continuity between two circuits)[6]. In this project work, a transformer of 240V a.c is used to step down the input voltage to the required output voltage value.

3.2.1.2 FULL WAVE BRIDGE RECTIFICATION

Rectification is the process of converting an alternating current into a unidirectional one which requires some form of unidirectional switch between the supply and the load. Thus an electrical component which only permits current to flow in one direction is diode [9]. Here, a single phase, full-wave bridge rectifier (four semi-conductor diodes) is connected across the output of the transformer to achieve rectification in the project work (see Figure 3 below).

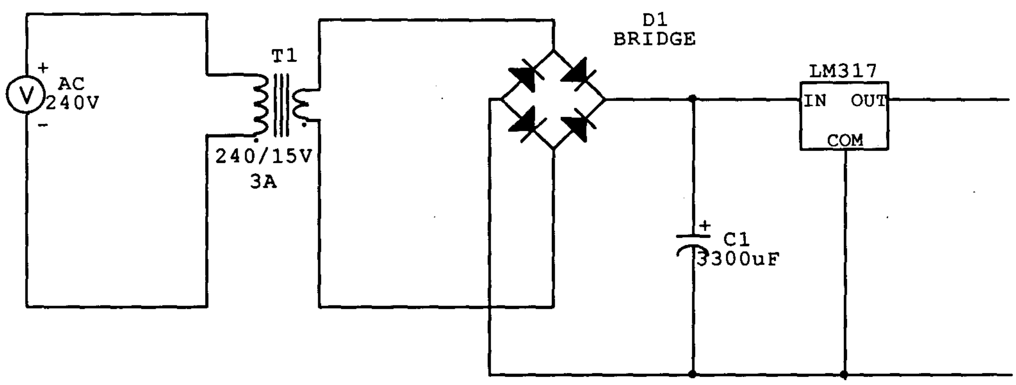

Fig. 4: Full- wave Bridge Rectifier

3.2.1.3 CAPACITOR (3500μF, 50V)

The capacitor used in the construction of the power supply unit of this project is an electrolytic capacitor which has a rating of 3500μF, 50V. It serves as a power supply filter which filters off a.c ripples and stores charges needed to moderate the output voltage and current fluctuation in the rectifier circuit.

3.2.1.4 VOLTAGE REGULATOR (LM317T)

The voltage regulator (LM317T) is a standard integrated three-terminal linear voltage regulator which supports input voltage of 3V - 40V and output voltage of 15V.

It is mostly used for high precision fixed voltage applications and for this construction; it regulates the rectified input voltage fed into it from the bridge rectifier and renders a fixed voltage at its output terminal.

3.2.2 CONFIGURATION *OF THE ASTABLE MULTIVIBRATOR*

The 555 timer IC in Astable mode is used to generate pulse signals of variable width to trigger the thyristors into conduction. The figure below shows pin configuration of the 555 timer IC.

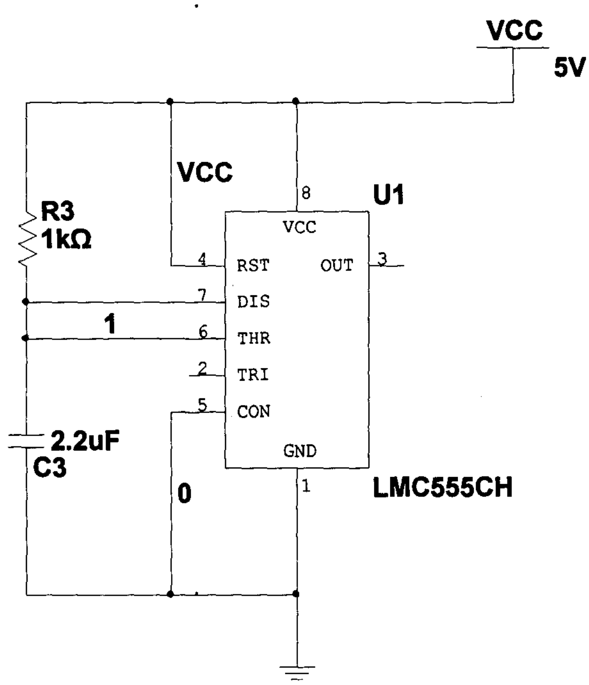

Fig. 5: Pin layout of an NE555 timer in astable mode.

In the configuration of the 555 timer, Pin 2 is connected to SCR2 which is responsible for triggering the thyristor into conduction by sending pulse signals to its gate which must be equal or greater than the holding current at the gate of SCR2. Pin 3 is also connected to SCR1 and it switches ON and OFF the thyristor at intervals where SCR2 switches OFF as a result of the switching ON of SCR1. Pin 7 discharges off the floating current through a capacitor as soon as the 555 timer IC resets.

3.2.3 THE CONSTRUCTION OF THE COMMUTATION CIRCUIT

When a thyristor is fired into conduction, the gate loses control and the thyristor continues to conduct. The commutation circuit is used for switching OFF. Thus, enabling it to perform ON-OFF switching function.

From the diagram below, when thyristor SCR2 is fired into conduction by the 555 timer control circuit, current is set up between the load and the commutation capacitor that gets charged during the ON period of thyristor SCR1. For switching OFF, the second thyristor SCR1 is triggered into conduction allowing commutation capacitor C3 to discharge by it (since it acts like a shunt circuit while conducting) which reverse- biases thyristor SCR2 thus turning it OFF. The discharge from capacitor C3 leaves SCR1 with reverse polarity so that it is turned OFF whereas SCR2 triggered into conduction again.

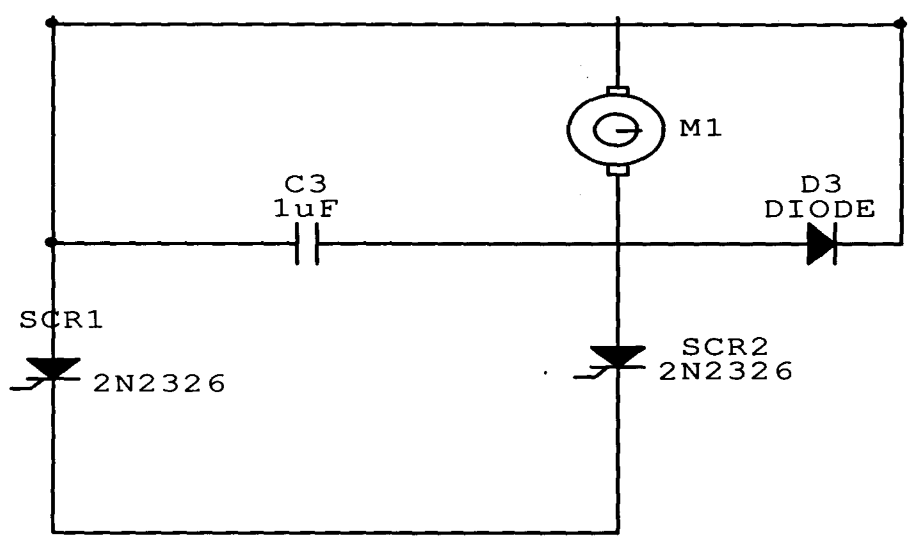

Fig. 6: Commutation circuit

CHAPTER FOUR

TESTS AND RESULTS

4.1 TESTING

After the design analysis, the project was constructed and tested to ensure that it was working. The process of testing involved the use of a digital multimeter. At various stages of the construction, tests on voltage measurements were taken and visual inspection for dry joints were also done.

4.1.1 Visual inspection of dry joints

After the circuit construction, it was visually inspected and continuously checked for defective soldering. From the checks, all board links that require opening were broken to avoid short circuits.

4.1.2 Measurement of voltages

Measurement of voltages was conducted using a digital multimeter for accuracy and reliability.

4.2 RESULTS

The following results were obtained at the end of the construction and testing:

- The output voltage from the transformer was measured to be 15V AC.
- The unregulated rectified DC output was measured to be 21.2V.
- The regulated DC output from voltage regulator LM317T was also measured to be 15V.

Figures 7, 8 and 9 below show the wave forms of the un-rectified AC output, unregulated DC output and regulated DC output voltages respectively.

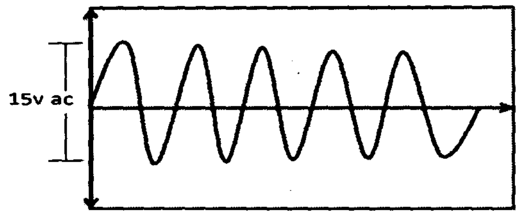

Fig. 7: Un-rectified AC output waveform

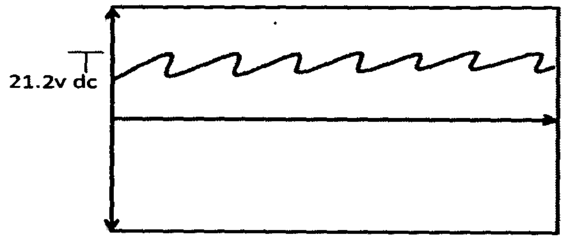

Fig. 8: Unregulated DC output waveform

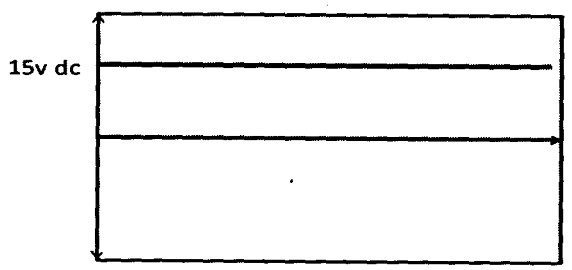

Fig. 9: Regulated DC output waveform

4.3 DISCUSSION OF RESULTS

The following are the results obtained in the tests carried out:

1. Power Supply Unit:

   A 15V regulated DC power supply needed to operate the control circuit was achieved leading to proper operation of the individual components.

2. DC motor test:

   The results gotten from this test shows how the incoming DC voltage is related directly to the speed of the DC motor. In essence, the higher the voltage, the higher the rotating speed of the motor and vice versa.

3. Thyristor Control test:

   This result shows the necessity of an external circuit for switching OFF the thyristor when in conduction. The thyristor conducts once its voltage barrier is broken down.

4. Commutation circuit test:

   The test shows that thyristors can be switched OFF using an external circuit such as the commutation circuit that brings about effective operation of the thyristor in terms of controlling the speed of the DC motor.

4.4 Problem Encountered

While carrying out this project work, some problems were encountered. Amongst these problems include

- Difficulty encountered while sourcing for components
- Irregular power supply during construction
- Unavailability and cost of components
- Wastage of resources, time and energy resulting to damage of some components during soldering

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The objective of this project was to design a simple circuit that can be used to control the speed of a D.C motor and this aim was achieved. The general operation and performance of this project work depends on the thyristors and the commutation unit that enhances rapid switching of the thyristors, thereby controlling the speed of the DC motor. The various units that constituted the whole system were individually tested and coupled together.

5.2 RECOMMENDATION

Future improvements of this project work recommended include

1. Use of a microcontroller chip to improve the switching time of the thyristors.
2. Use of a BCD 7-segment display can be incorporated into this device to display the precise angle at which the thyristor is being fired and also the speed of the motor.

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