DESIGN AND IMPLEMENTATION OF A SOFT START TO START A SINGLE PHASE INDUCTION MOTOR.

BY

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CERTIFICATION

This is to certify that this project, “Soft starter for a single phase induction motor” was carried out by Omoge Oluwatosin Victor (ENG1708907) a student of the department of Electrical and Electronic Engineering, University of Benin, Benin city, Nigeria, for the award of bachelor of Engineering under the supervision of Engr. Edohen O.M.

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Engr. Omoge Vincent and Mrs. Moyosola Omoge whose words of encouragement and push for tenacity ring in my ears. My brothers Taiwo, Kehinde and Oluwatobiloba have never left my side and are very special and also my very beautiful sister, Oluwaferanmi. I also dedicate this dissertation to my many friends and church family who have supported me throughout the process. I will always appreciate all they have done.

I'm dedicating this project to God Almighty, who made me and gave me strength, ideas, wisdom, knowledge, and understanding. He has strengthened me throughout this program, and I have only flown on His wings.

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ABSTRACT

The use of induction motor in various facet of engineering manufacturing and production sector to power various equipment have gained stability and thereby creating huge starting current which in turn contribute to the unbalance loading of network giving rise to high energy and economic loss. This research work therefore seeks to reduce the starting current of the connected single phase induction motor.

A smooth and soft start is employed in a single phase induction motor to eliminate the surge in current and electromagnetic torque during starting. The surge in current and torque are eliminated using soft starter at the time of starting. The soft starter also eliminates the unwanted effect in electric cables and distribution network. This project work provides an in depth description of sentimental and smooth start to an induction motor.

The smooth start of the motor is predicted by the firing angle of the TRIAC circuit. The firing angle is delayed during starting and the delay angle reduces as the motor picks up to speed. This proposed technique provided reduced voltage at the starting and the rated voltage when the motor is up to speed. By using soft starter, the performance and efficiency of the induction motor is improved and it also improves the load torque characteristics. This project consists of 6 anti-parallel SCR connected in each series with an induction motor to the main supply, wherein two to each phase. During starting the firing angle is heavily delayed by receiving a delayed triggering pulses.

The supplied voltage is gradually increased and the torque also in same manner. By this process the inrush current is drastically reduced making the motor start smoothly. The induction motor of 0.56KW, frequency of 50Hz, maximum voltage 230V, receives little or no surge using the soft

starter device. The startup ramp is about 4s to 7s depending on the power of the induction motor. The firing angle is gradually decreased from 80˚ by interval of 20˚ until 0˚ max of the full half A.C voltage.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

A soft starter for an induction motor is a device that gradually increases the voltage and current supplied to the motor. Its purpose is to decrease mechanical vibration and stress on the motor, shaft, and any connected components. Additionally, it helps prevent overheating of the motor coils or conductors.

The conventional method of starting an induction motor, known as direct on line (DOL) starter, involves supplying full voltage to the motor without any reduction. In a DOL starter, the starting current typically ranges from five to ten times the motor's full load current rating, but it can be even higher.

According to a study by Habyarimana et al. in September 2017, the initial current drawn by an induction motor when it starts is referred to as inrush current. This inrush current can have negative implications for an electrical power system. It is directly associated with the mechanical stress experienced by the motor's bearings and belt, as noted by Cohen et al. in 1995. Research has shown that this inrush current has significant detrimental effects on the induction motor, including overheating, mechanical stress, and damage to the machine.

To address this issue, various methods have been developed to mitigate the inrush current during motor startup. Examples of these methods include autotransformer starters and star-delta starters. These techniques have been somewhat successful in reducing the magnitude of the inrush current supplied to the motor, as discussed in a study by Larabee et al. in 2005.

With the assistance of a soft starter, it becomes possible to effectively regulate the flow of inrush current, minimizing it and thereby enabling the motor to operate efficiently and smoothly, resulting in an extended lifespan. In essence, controlling the current is achievable by managing the supplied voltage, a task accomplished through the utilization of a thyristor.

A thyristor is a semiconductor device comprising four layers of alternating p-type and n-type materials (PNPN). Typically, a thyristor consists of three cathodes: the gate, the anode, and the cathode. The silicon-controlled rectifier (SCR) is the most commonly employed type of thyristor. When the cathode bears a negative charge relative to the anode, no current flows until a pulse is applied to the gate. Subsequently, the SCR conducts until the voltage between the cathode and anode is reversed or reduced below a specific threshold or holding value. By utilizing this type of thyristor, a significant amount of power can be switched or controlled using a small trigger current or voltage. Moreover, devices operating with alternating current can be activated or deactivated by sending signals to the control gate, known as gate-turned off thyristors.

The concept behind a soft start is to gradually increase the motor current until it reaches a steady state. This approach reduces the initial surge of current during startup, but it also diminishes the motor's starting torque. Soft starters regulate motor voltage by employing back-to-back thyristors or triacs in each AC supply line connected to the motor. During the startup phase, the thyristors are activated in a progressively delayed manner, with each AC half cycle experiencing less delay. This delayed switching effectively ramps up the average AC voltage supplied to the motor until it reaches the full line voltage. Once the motor attains its rated speed, the thyristor switching circuit can be bypassed.

Certain soft starters offer a soft-stop function, which is beneficial in applications where an abrupt stop can lead to issues. For instance, pumps may experience water hammering if stopped abruptly, and conveyor belts can sustain damage if they halt too quickly. The soft-stop sequence utilizes the same power semiconductors employed during soft starting.

In a soft starter, thyristors permit a portion of the voltage to pass through at the start of the sequence, gradually increasing it according to the set ramp time. Moreover, these thyristors typically facilitate a soft stop by reducing the motor voltage according to a predefined ramp time.

1.2 PROBLEM STATEMENT

When the induction motor is connected to a power supply, it undergoes a substantial surge of current known as inrush current. This surge leads to mechanical vibrations and puts stress on both the motor and the attached equipment. Additionally, it causes the induction motor to overheat and contributes to unbalanced loading, resulting in energy loss. Ultimately, these factors shorten the lifespan of the machine. However, by utilizing a soft start mechanism, the inrush current can be substantially decreased. This reduction in inrush current has the effect of minimizing its negative consequences and ultimately extending the lifespan of the machine.

1.3 AIM OF THE PROJECT

The aim of this project is to use a soft starter to control gradually supply voltage of the induction motor thereby giving the motor a smooth start.

1.4 OBJECTIVES

The following are objectives of this work.

1. To reduce the inrush current supplied to the induction motor.
2. To gradually increasing the applied voltage to the motor.
3. To gradually increase the firing angle of the thyristors.
4. To delay the firing angle from the zero crossing point of the AC signal.
5. To reduce heating in the stator as well as to reduce mechanical stress of the induction motor damages associated with the equipment.

1.5 METHODOLOGY

1. The inrush current is reduced by gradually increasing the supplied voltage to the induction motor
2. Deployment of thyristor, to reduce the supplied voltage to the stator winding of the induction motor.
3. Deployment of a microcontroller to control and vary the firing angle of the thyristor also aiding the gradual increase in the voltage process.
4. Deployment of zero crossing detection circuit, in determining the zero crossing point for appropriate delaying of the A.C signal by the microcontroller

5. By the reduction in the inrush current, the heating of the stator winding and the mechanical stress of the motor is mitigated.

1.6 SCOPE

The scope of this project deals with starting of an induction motor with a soft start device. The induction motor entails a three phase induction motor or a single phase induction in order to reduce cost effectiveness of the project. The control of the system of the project entails the soft starter device, contactor and overload relay.

1.7 RELEVANCE OF WORK

The soft start of an induction motor finds application in the industry where large electric motor is used. Like in the oil and gas industry where pumping action is required to move crude over a long distance, a high power induction motor is required and there comes the need of soft starter to:

1. Reduce the energy used. Reducing the amount of energy, the motor requires is the ideal goal and the main aim of a soft starter. With the convectional starting, the motor immediately begins to expends it maximum amount of energy and continues to run. But with soft starter, the voltage increases gradually so that the amount of energy expended is reduced.
2. Low risk of power surge: when the maximum voltage rushes in the motor to start it running, the motor circuit experiences overloading resulting to power surge in the induction. Studies has proved that soft starter is an effective protective measure against surge, in the sense that, it does not allow much voltage to be thrown into the circuit but rather gradually increasing the voltage.

3. Reduced risk of overheating: the large surge associated with the conventional startup can lead to the overheating of the motor. The soft start helps to reduce the surge thereby also reducing the risk of the motor overheating.
4. Increasing the operating efficiency.
5. Extending lifespan.

CHAPTER TWO

LITERATURE REVIEW

2.0 GENERAL OVERVIEW

2.0.1 SOFT STARTER.

The induction motor is highly durable and has a characteristic of drawing a significant inrush current during startup. To address the impact of this large inrush current, a soft starter is employed. The soft starter allows for a controlled reduction in the starting current while ensuring a smooth and gradual increase in torque. It can also be used to softly stop the induction motor by reducing the voltage.

The soft starter operates on the principle that the torque is directly proportional to the square of the starting current, which, in turn, is dependent on the applied voltage. By decreasing the voltage during motor startup, both the torque and current can be adjusted accordingly.

The reduction of motor voltage is achieved through phase control. To accomplish this, two thyristors, also known as silicon controlled rectifiers (SCRs), are connected in anti-parallel for each phase. One SCR controls the positive half-wave, while the other controls the negative half-wave. The duration of conduction is determined by the firing angle of the thyristors, allowing for precise control of the effective voltage.

There can be two types of control of soft starter

1. The open loop type: In this configuration, the starting voltage is applied over time without considering the current drawn or the speed of the induction motor. In this system, the SCRs for each phase are connected in an anti-parallel arrangement. Initially, the SCRs are triggered to conduct at a delay of 180 degrees during the corresponding half-wave cycle. As time progresses, this delay is gradually reduced until the applied voltage reaches the supplied voltage. This method is also referred to as the voltage ramp system.

2. The closed loop type: In this system, continuous monitoring of the motor's output characteristics, such as speed and current, is carried out. The starting voltage is adjusted accordingly to achieve the desired performance. Additionally, the current in each phase is closely observed.

The core principle of a soft start lies in controlling the conducting angle of the SCRs, which enables regulation of the applied voltage. Once the start time (t Start) has passed, the thyristors are fully activated, leading to the application of complete half-wave sine voltages to the motor. This results in reaching the maximum ramp value known as the Top of Ramp (TOR). The thyristors only function during the motor's startup and shutdown phases. Once the startup phase is completed, mechanical contacts can bypass the thyristors, allowing for continuous static operation. This bypassing mechanism reduces power loss in the soft starter by taking advantage of the significantly lower contact resistance of the mechanical switching contacts.

Accumulatively, the soft start system consists of two main major components.

The components are:

1. The power switch like the SCRs that needs to phase control the applied voltage for each part of the cycle.
2. The control unit which involves control logic like the PID controllers, microprocessor or microcontroller or any other logic to control the application of the gate SCR i.e. to control the firing angle of the SCRs to make the SCR conduct at the required time.

2.0.2 INDUCTION MOTOR

An electric motor is a device that transforms electrical energy into mechanical energy. In the case of an induction motor, it utilizes alternating current as the electrical energy input. The motor operates by harnessing a rotating magnetic field. It comprises two main components, namely the stator and the rotor. The rotor obtains the necessary electrical current to generate torque through electromagnetic induction induced by the magnetic field generated by the stator winding.

2.0.2.1 STATOR

The stator of an induction motor consists of a sturdy steel frame enclosing a hollow cylindrical core. The core is layered with thin laminations to minimize losses caused by hysteresis and eddy currents. Additionally, evenly spaced slots are strategically placed along the inner periphery of the laminated core. In a three-phase induction motor, the stator is designed with a specific number of slots to accommodate a three-phase circuit winding. The winding is made up of insulated conductors and can be configured in either a star or delta connection. The winding is carefully wound to achieve a desired number of poles, which directly impacts the motor's speed requirements. Generally, a motor with fewer poles will operate at a higher speed, while a motor with more poles will run at a lower speed. When a three-phase power supply is connected to the stator, it generates a rotating magnetic field of constant magnitude. This rotating field induces an electric current in the rotor through the phenomenon of electromagnetic induction, thus giving rise to the name "induction motor."

2.0.2.2 ROTOR

The rotor of a three phase induction motor consists of a cylindrical laminated core with a parallel slot that carries conductors on the outer peripheral. The rotor is of two types which are;

- squirrel cage type
- wound type.

I am currently involved in a project that focuses on the squirrel cage type of induction motor. In this design, the rotor consists of heavy copper or aluminum bars, known as conductors, which are placed in the core. These conductors are short-circuited at each end by end rings. To optimize performance, the slots within the rotor are intentionally skewed rather than being parallel to the shaft axis. This arrangement aims to reduce magnetic humming noise and prevent motor stalling. The rotor is then mounted on the motor's shaft.

2.0.3 TYPES OF INDUCTION MOTOR

Induction motor can be grouped into two main and common types, which are:

- Single phase induction motor
- Three phase induction motor

Single-phase induction motors are typically connected to a single-phase power supply. Unlike three-phase induction motors, they usually require an auxiliary winding to start efficiently since they are not inherently self-starting. On the other hand, three-phase induction motors are connected to a three-phase power supply and are generally self-starting in nature.

2.0.3.1 SINGLE PHASE INDUCTION MOTOR

A three-phase motor has the ability to be operated using a single-phase power supply, but it will not start on its own. It can be manually started in either direction and will reach full speed within a few seconds. However, when running on a single-phase power supply, it will only generate approximately two-thirds of its rated power, as one of the windings remains unused.

In contrast, a single-phase motor, due to having only one coil, does not produce a rotating magnetic field, which is also the reason why it is not self-starting. Instead, it generates a pulsating magnetic field that reaches its maximum at 0 and 180 degrees.

The pulsating magnetic field is a strong electromagnetic field that is powered by short pulses of electric current in the windings, rather than a continuous current, resulting in a brief but strong magnetic field pulse. When an AC current passes through the single coil, it produces two counter-rotating magnetic field phasors, coinciding at 0 and 180 degrees.

However, if the motor operates at slightly less than the synchronous speed, it will achieve maximum torque at around a 10% slip compared to the forward rotating phasor. Torque developed above or below this 10% slip will be lower. The rotor will experience a slip ranging from 200% to 10% with respect to the counter-rotating magnetic field phasor. The counter-rotating phasor generates little torque, except for a double-frequency ripple. Consequently, the single-phase coil does not develop torque during motor startup.

2.0.3.2 THREE PHASE INDCTION MOTOR

In a three-phase induction motor, the stator windings are arranged in an overlapping manner and connected to a balanced three-phase power supply. This arrangement generates a rotating magnetic field (RMF) within the motor. The RMF passes through the air gaps and cuts across the stationary rotor conductors. Due to this relative motion, an electromotive force (EMF) is induced in the rotor conductors. Typically, the rotor conductors are closed or short-circuited at their ends (end rings are used for squirrel cage rotors).

According to Faraday's law, the induced EMF in a circuit is a result of the rate of change of magnetic flux through that circuit. As a result, current flows through the short-circuited rotor conductors. Since these conductors carry current within a magnetic field produced by the stator winding, the rotor experiences a mechanical force. The sum of these mechanical forces acting on all the rotor conductors generates a torque that causes the rotor to rotate in the same direction as the rotating magnetic field.

This phenomenon is in line with Lenz's law, which states that the direction of the rotor current will be such that it opposes the cause that produces it.

2.4 METHODS FOR STARTING AN INDUCTION MOTOR.

There are other methods used in starting an induction motor. They include:

- Direct on line starter
- Star delta starter

- Auto transformer starter
- Stator resistance/reactance starter
- Rotor resistance control

2.4.1 DIRECT ON LINE STARTER.

The induction motor, as its name suggests, is directly connected to the line supply. However, it is important to note that it also incorporates additional components such as a fuse, contactor, protective device, and overload relay. These components are utilized during motor starting operations. This particular motor starting method is commonly employed for motors with a power rating of less than 5HP.

CONSTRUCTION OF DIRECT ON-LINE (DOL)

The direct on-line (DOL) configuration consists of two buttons: a start button and a stop button. The start button is typically colored green, while the stop button is often colored red. Pressing the green start button connects the terminals and closes the circuit, allowing current to flow. Conversely, pressing the red stop button disconnects the terminals and interrupts the circuit, halting the current flow.

In addition to the buttons, the DOL setup includes various protective components. These include the MCCB (Molded Case Circuit Breaker) or fuse, which safeguards the motor coils against short circuit currents. The overload relay is also present to protect the motor from excessive loads. Furthermore, a contactor is incorporated to facilitate the switching operations, and it is connected to the start and stop buttons. Thus, the contactor enables the motor to be started or stopped by using the respective green and red buttons.

The parts of a Direct On Line (DOL)

The direct on line (DOL) starter is made of the following parts:

- Circuit breaker or Fuse: The circuit breaker is directly linked to the primary power source, serving as a safeguard for the motor in the event of a short circuit. It automatically activates a trip whenever it detects a short circuit, effectively preventing any potential hazards to the system.

- Magnetic contactor: The contactor is an electromagnetically operated switch that controls the power supply to the motor. It facilitates convenient connection and disconnection of multiple contacts, enabling remote control over the motor's operation. The contactor generates a magnetic field through its coil, which is responsible for switching the terminals. When current passes through the coil, it magnetizes the iron core that surrounds it. The resulting magnetic field attracts the armature, causing the contacts to close. The magnetic contactor typically consists of three normally open (NO) main contacts for supplying power to the motor, as well as auxiliary contacts (both NO and NC) used for the control unit. The coil is connected to a voltage source through the auxiliary contacts.
- Overload relay: The overload relay is the final component utilized in the direct on-line (DOL) starter. Its primary function is to safeguard the motor against overloading. The overload relay operates by tripping when the current flow surpasses a specific limit, while still allowing for toleration of high starting currents. Consequently, it is crucial to carefully select the rating of the overload relay to ensure that the tripping current limit remains above the range of starting currents. The overload relay plays a vital role in preventing excessive current from causing damage to the insulation of electrical wires and motor windings. Unlike a simple fuse, which is designed to protect against overcurrents such as short circuits, the overload relay is specifically designed to address overloading situations. In essence, the overload relay incorporates a sensor that differentiates between overcurrent and overloading conditions.

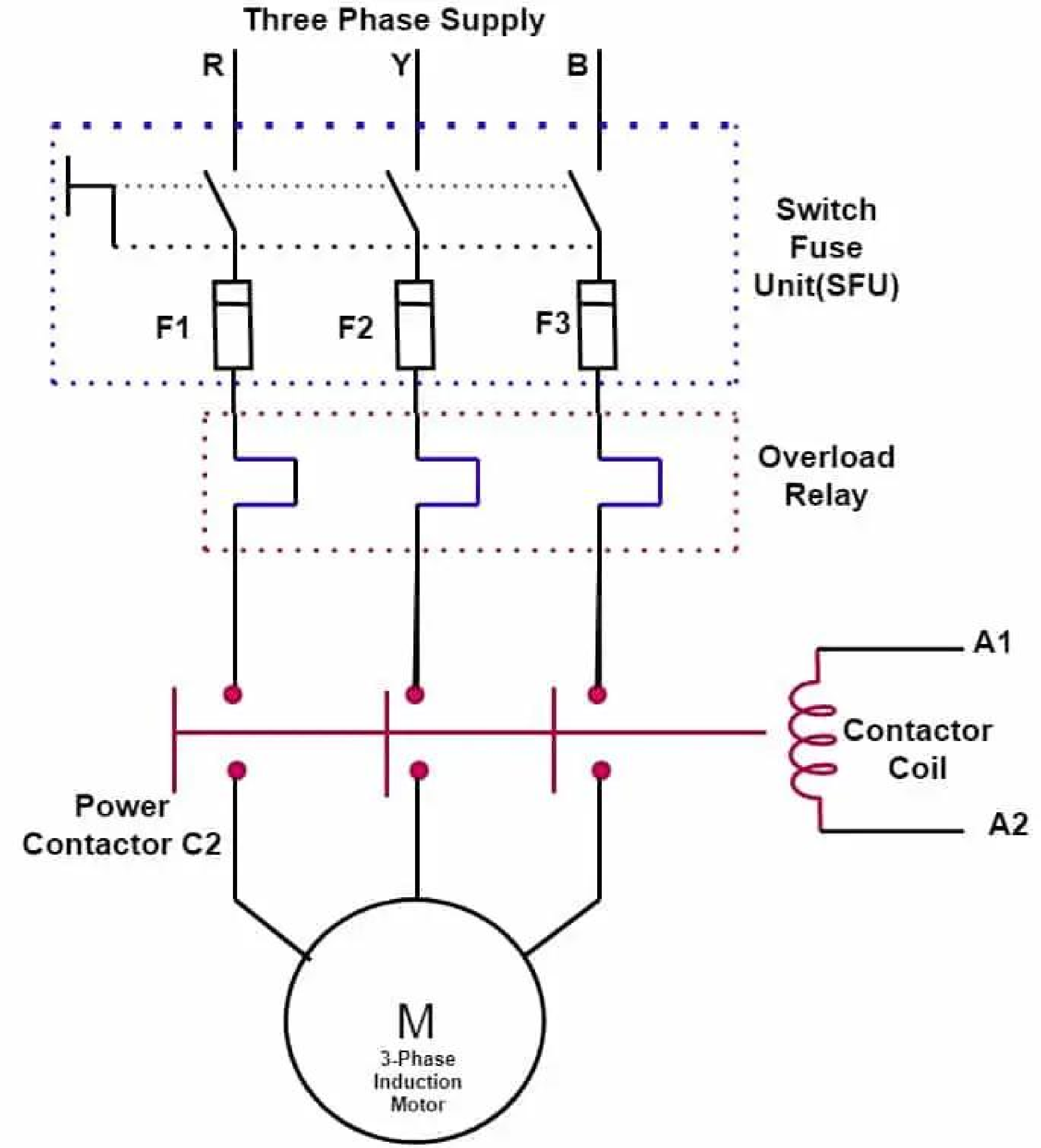

Figure 2.1: Direct On Line starter circuit

2.4.2 STAR DELTA STARTER.

A star-delta starter is an electromechanical device used to start and control the speed of an induction motor. It works by initially connecting the motor in a star configuration to reduce the high starting current, then switching to a delta configuration as the motor reaches a certain speed for efficient operation. The control circuit includes a timer, contactors, and overload relays. Commonly used in industries with high-power motors, the star-delta starter reduces starting current and stress on motor windings, but it also has drawbacks like increased cost, complexity, longer starting time, and reduced initial torque.

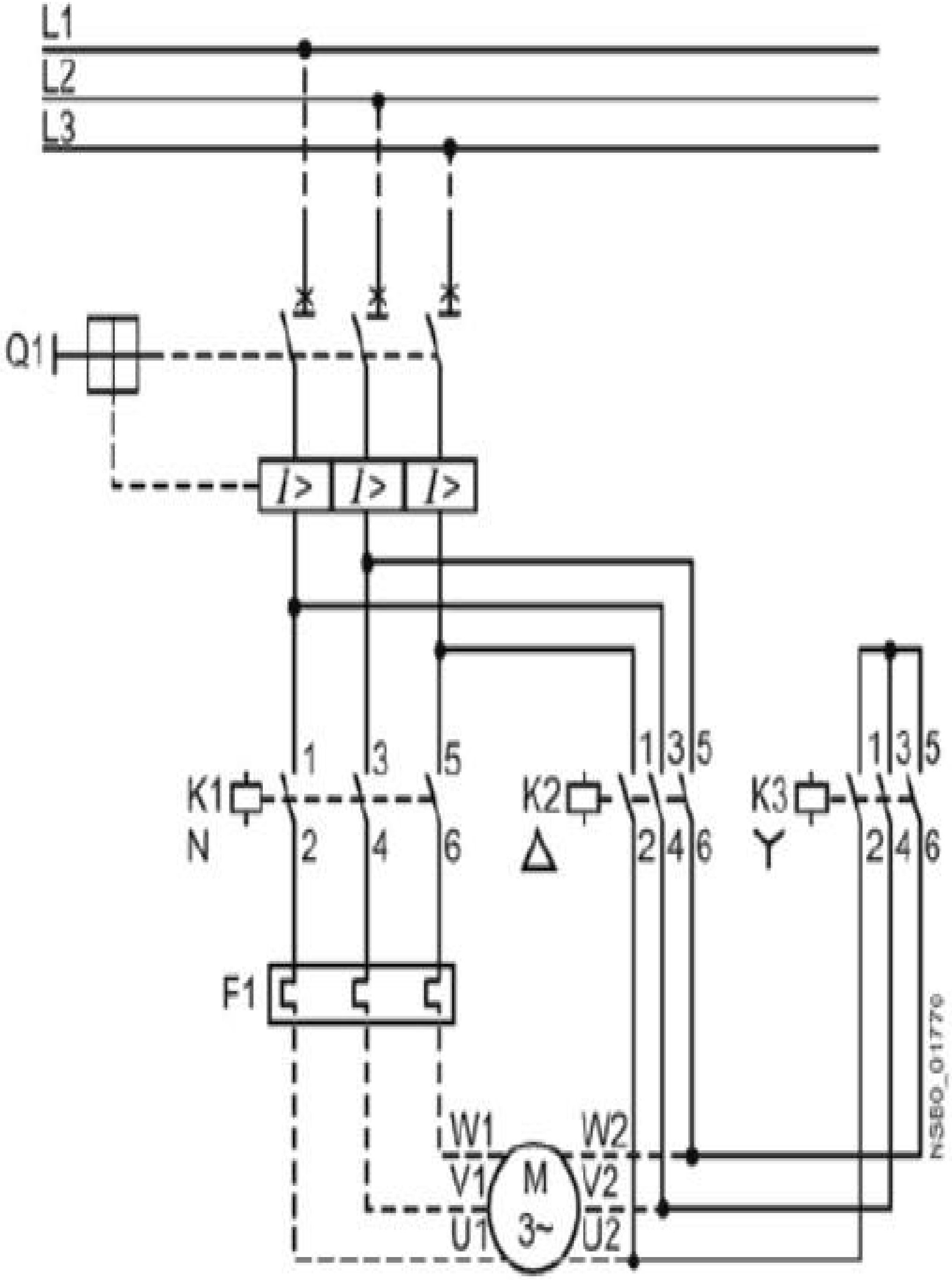

Figure 2.2: Star-delta circuit connections

Operation & Working of Automatic Star Delta Starter

The phase current starts at L1 and passes through an MCB/MCCB or general fuse before reaching the thermal overload contact. From there, it continues through the OFF push button, on push button interlocking contact 2, and finally reaches K3, completing the circuit and energizing both the contactor coil C3 and the timer coil (T) simultaneously. This action connects the motor winding in a star configuration. When K3 is energized, its auxiliary open contacts close, while the close contacts open.

As a result, contactor K1 is powered, allowing the three-phase supply to reach the motor. With the winding in a star configuration, each motor phase receives a voltage that is √3 times lower than the line voltage, ensuring a safe startup. The closed contact of K3 in the delta line opens, preventing the activation of contactor 2 (K2).

After releasing the push button, the timer coil and coil 3 remain powered through the timer contact (Ia), holding contact 3, and the closed contact 2 of K2. When contactor 1 (K1) is energized, the two open contacts in the line of K1 and K2 close.

The motor remains in the star configuration for a set duration (typically 5-10 seconds). After this time, the timer contact (T) opens (the duration can be adjusted by rotating the timer knob), turning off contactor 3 (K3). The open link of K3 in the K2 line closes, activating K2. When K3 turns off, the star connection of the winding opens, and K2 closes, switching the motor winding to a delta configuration. Contact 2 in the K3 line also opens, preventing the activation of coil 3 (K3).

Now that the motor is connected in a delta configuration, each phase receives the full line voltage (400V), allowing the motor to run at full speed.

2.4.3 AUTOTRANSFORMER STARTER.

The autotransformer starter is employed to initiate both star and delta connected 3-phase induction motors. In this method, the stator current of the motor is regulated by connecting it to a

3-phase autotransformer, which reduces the initial starting voltage supplied to the stator. The autotransformer is equipped with multiple tapings to achieve variable voltages.

In this approach, the stator winding is linked to a specific tapping of the autotransformer to obtain an appropriate starting voltage. In the provided circuit illustration, the switchgear or changeover switch S is utilized to incorporate the autotransformer into the circuit for starting.

When the handle H of switch S is in the start position, the primary winding of the autotransformer is connected to the power supply, while the secondary winding is connected to the induction motor. As the motor accelerates to about 80% of its rated value, the handle is switched to the run position, directly connecting the motor to the line supply and providing it with its rated voltage. The handle remains in the run position, held by the under-voltage relay. If the supply voltage fails or drops below a certain threshold, the handle is released and returns to the OFF position.

To ensure overload protection for the motor, a thermal overload relay is employed in the motor circuit.

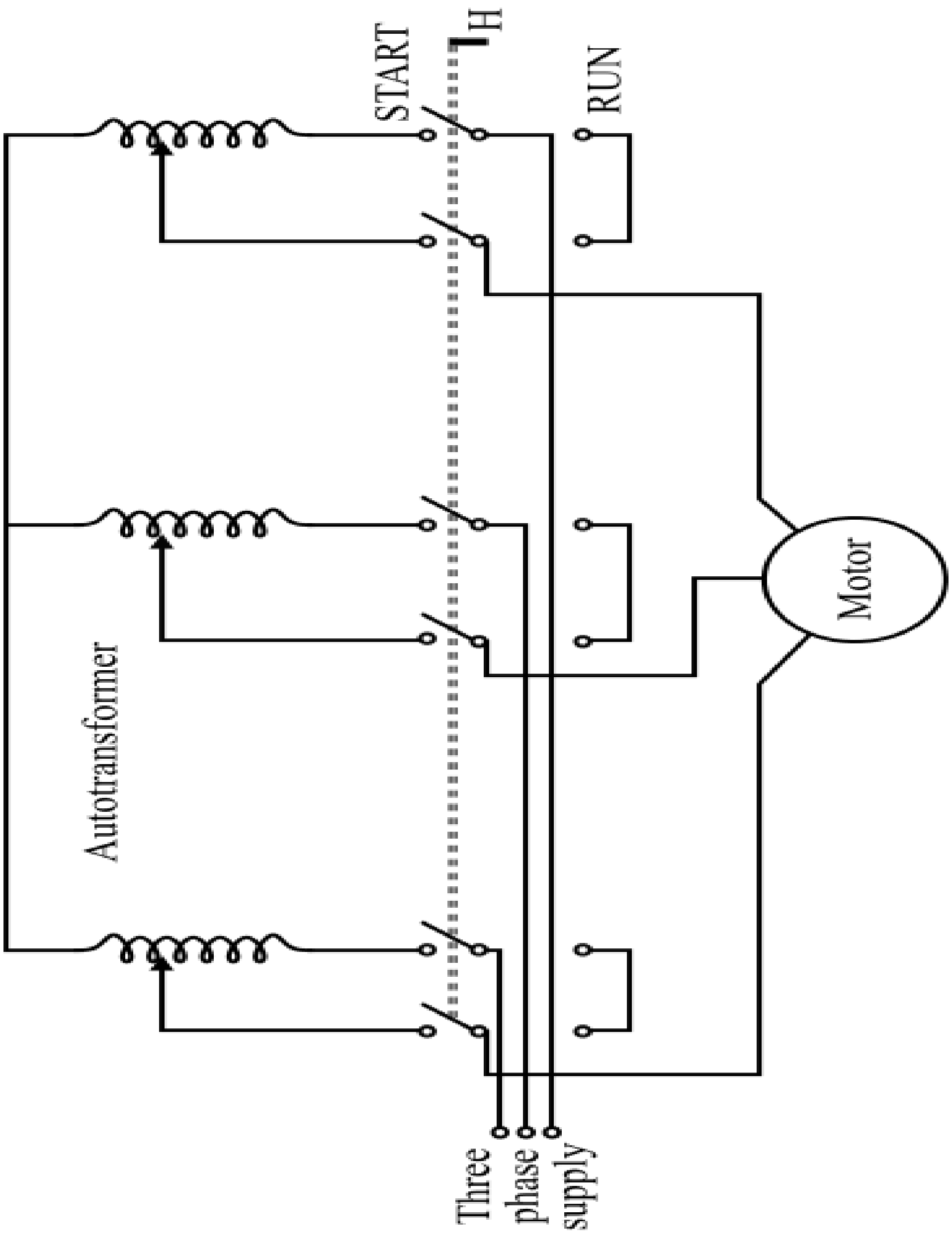

Figure 2.3: Autotransformer circuit connection.

2.5 REVIEW OF RELATED PREVIOUS WORKS

Borkar, P., in the research titled "SOFT STARTING OF INDUCTION MOTOR WITH IMPROVEMENT GATE PULSE TECHNIQUES AND ITS COMPARATIVE EVALUATION," highlights that induction motors are widely used in industries due to their robustness, affordability, and ease of maintenance. However, the starting current for an induction motor can be about ten times the rated current and lasts for a few cycles, which can be harmful to the machine. Therefore, starters are necessary to limit this high starting current. Traditionally, mechanical starters like star-delta, direct online, and autotransformer starters were used. Thyristor-based soft starters are now available at a lower cost.

Chang et al. (2023) introduced a novel starting method for induction motors in their research titled “A novel starting method with reactive power compensation for induction motors.” The method uses an autotransformer and a magnetically controlled reactor (ATMCR) to address the large starting current and reactive power, which can cause significant voltage drops and potential damage to motors and other devices on the same grid. They also developed a reactive power dynamic compensation strategy to enhance power factor and effectively mitigate voltage drops. The key benefit of this approach is its ability to reduce starting current and simultaneously compensate for reactive power.

Jolhe et al. (2023), in their research titled “SOFT STARTING OF THREE PHASE INDUCTION MOTOR,” discuss a method for smoothly starting an induction motor using SCR ignition. The process begins with a significant ignition delay angle, which gradually decreases until zero voltage is reached. This approach provides low voltage at startup, gradually increasing to full voltage, allowing the motor to start and then slowly accelerate to full speed. The project involves six counter-parallel SCRs, two for each phase, with the output connected to a group of lamps representing the windings of a three-phase induction motor.

Prapurt et al. (2022), in their research titled “Single-Phase Grid Connected Induction Generator with Soft Starting and Power Quality Improvement,” presented at the 25th International Conference on Electrical Machines and Systems (ICEMS), proposed a soft starting method and power quality enhancement for a single-phase grid-connected induction generator. They utilized a phase control thyristor converter and an active filter. The SCR soft starter reduces inrush current and electromagnetic oscillations during startup, while a shunt active filter addresses harmonic issues and reactive power, resulting in a near-sinusoidal grid current waveform and improved power factor. Simulation results demonstrate system performance.

Tunyasrirut et al. (2010), in their research titled “Phase Control Thyristor Based Soft-Starter for a Grid-Connected Induction Generator for Wind Turbine System,” presented a strategy using power thyristors to create a soft starter for wind turbine systems with induction generators. The soft starter is designed to reduce inrush current and ensure proper synchronization between the generator and the grid.

CHAPTER THREE

SYSTEM DESIGN AND METHODOLOGY

3.1 SYSTEM OVERVIEW

Starting an electric drive involves transitioning from rest to a steady rotational speed, making it a critical phase in the operation of an induction motor. The key to controlling this process is managing the motor's acceleration. A soft starter, like other starters, offers enhanced functionality and protects the motor from damaging voltage spikes. By limiting voltage and current during startup, the soft starter prevents large inrush currents, allowing the motor to gradually ramp up to speed safely and efficiently. However, depending on the model design of the soft starter, it can be incorporated to shut down the induction motor but in the case of this project it does not apply. Unlike variable frequency driver (VFD), soft starter does not change the frequency of the supplied power, instead it ramps up the voltage applied to the motor from the initial applied voltage to the final applied or full applied voltage.

The gradual increase of the voltage during the motor startup allows the motor to slowly gain speed and acceleration thereby preventing mechanical tear and jerking. Moreover, the torque of the induction motor is directly proportional to the square of the current, which in turn depend on the supply voltage. Hence, the supply of voltage can be used to control the starting torque achieving soft start.

Although, the main component used for the regulation of voltage in a soft start is a semiconductor switch (i.e. SCR). Adjusting the trigger or the firing angle of the thyristor regulates the voltage that goes the semiconductor. Other component such as overload relay, fuse and contactor are used for protection and switching purposes.

Hence, the outline bellow sums up the system that makes up the soft starter for the induction motor.

1. The power supply system
2. The switching and protection system
3. The soft starter system
4. The electric drive system.

3.1.1 THE POWER SUPPLY SYSTEM

The power supply system entails the source, where power is generated form which could either be from electricity distribution line or from a generator set. Although at the point of use, they are terminated at the bus bar so as to serve as many equipment as required. The power drawn at the bus bar could either be a single phase or a three phase depending on the design of the motor with it specifications and rating. Usually in big industries, three phase induction motors are widely use and for large varieties of operations.

For the sake of cost effectiveness of this project a single phase induction motor was used, implies a single phase power supply has to be drawn as required.

3.1.2 THE SWITCHING AND PROTECTION SYSTEM

This includes the contactors and the overload relay. The contactor and the overload relay work hand in hand serving as a switch and protection to the motor.

A contactor is an electromagnetic control device that is used to make or break connection between the load and the power supply. The device is used for high current carrying application. A contactor has several contacts as per the application and load. Generally, the contacts are normally open contacts and hence load is shut off when the coil of the contactor is de-energized. However, the contactor becomes normally close whenever the coil of the contactor is energized. In other words, the contactor is designed to be normally close and normally open.

A contactor consists of three main parts:

- The coil or electromagnet
- Enclose or frame
- Contacts

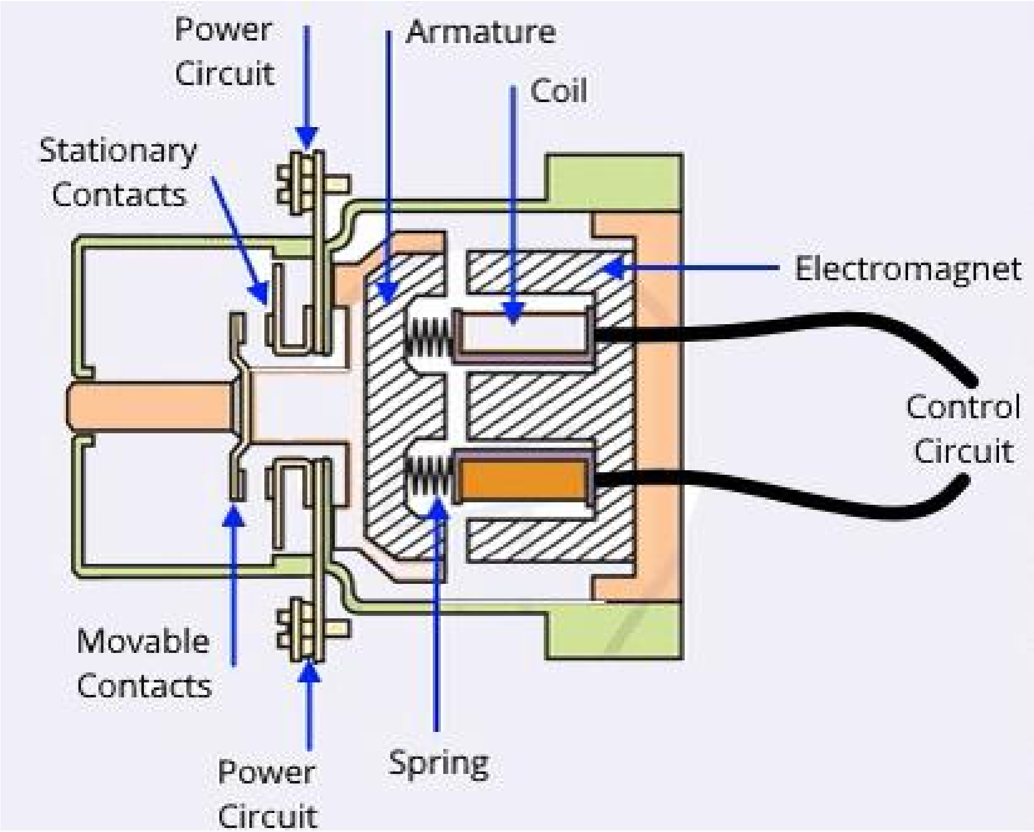

Figure 3.1: Schematics of a contactor parts.

An electromagnetic field is generated when the electromagnetic coil is energized by signals, which can be AC, DC, or both. A coil that accepts both types of signals is called a universal coil. The contactor's moving contact is connected to the electromagnet's armature. When the magnetic field is created, the armature is pulled toward the fixed contact, overcoming the spring's force, keeping the contacts in position until the coil is de-energized. When de-energized, the armature returns to its initial position. A contactor, similar to a relay but with a higher current rating, is used for switching power circuits, often in motors up to 150HP.

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3.1.3 THE SOFT STARTER SYSTEM

This is most important part of the design as it is the system that aids the control of the supplied voltage having it main component as the thyristor (SCR). As already established, it is a controlled rectifier that starts conduction of the flow of current in only one direction when gate pulse is applied, this pulse is also known as firing pulse.

Since AC supply is sinusoidal signal which has a complete cycle of 360˚ (i.e. maximum and minimum peak forming a complete cycle). For half of the cycles is 180. With the help of thyristor to control the amount of voltage to be inputted to the motor, the time or rather the angle of trigger known as firing angle is used to control the volume of voltage supplied. The firing pulse can vary between 0 to 180.

Using a single SCR, we are able to control half the signal while the other half is not conducting.

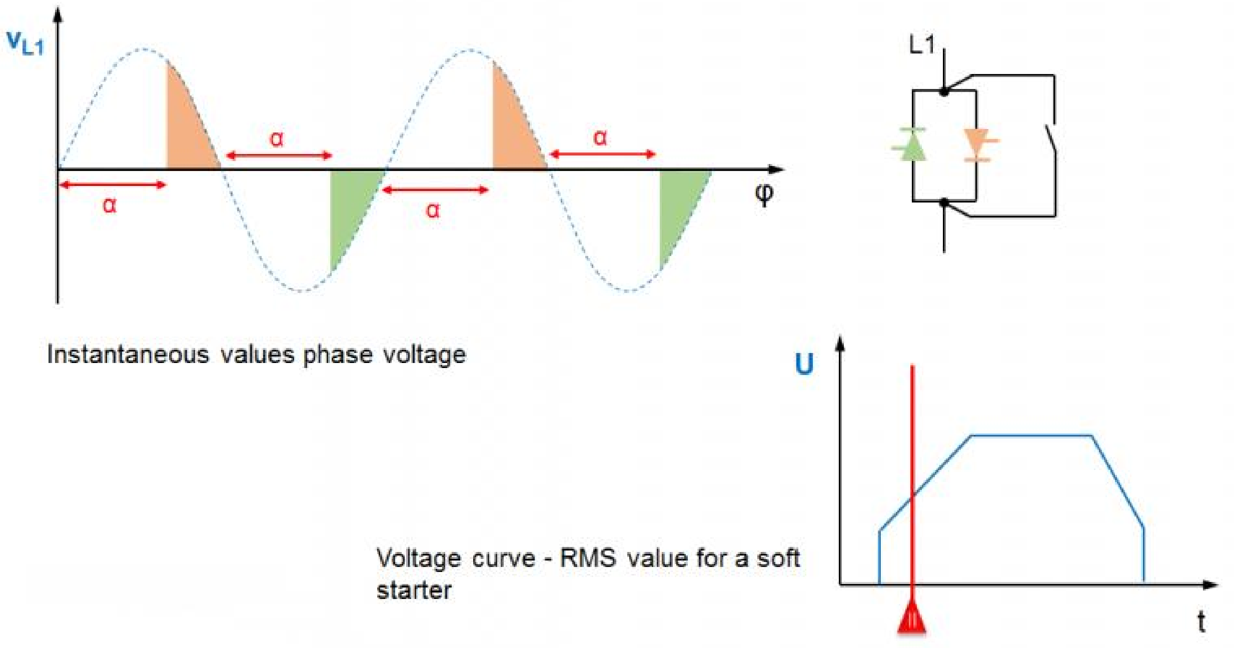

Figure 3.2: Illustration of triac circuit back to back configuration

Using two SCR, such that they are connected back to back formation for each phase (i.e. for the three phase), so that it can control the current in both directions. Each half cycle, the firing angle.

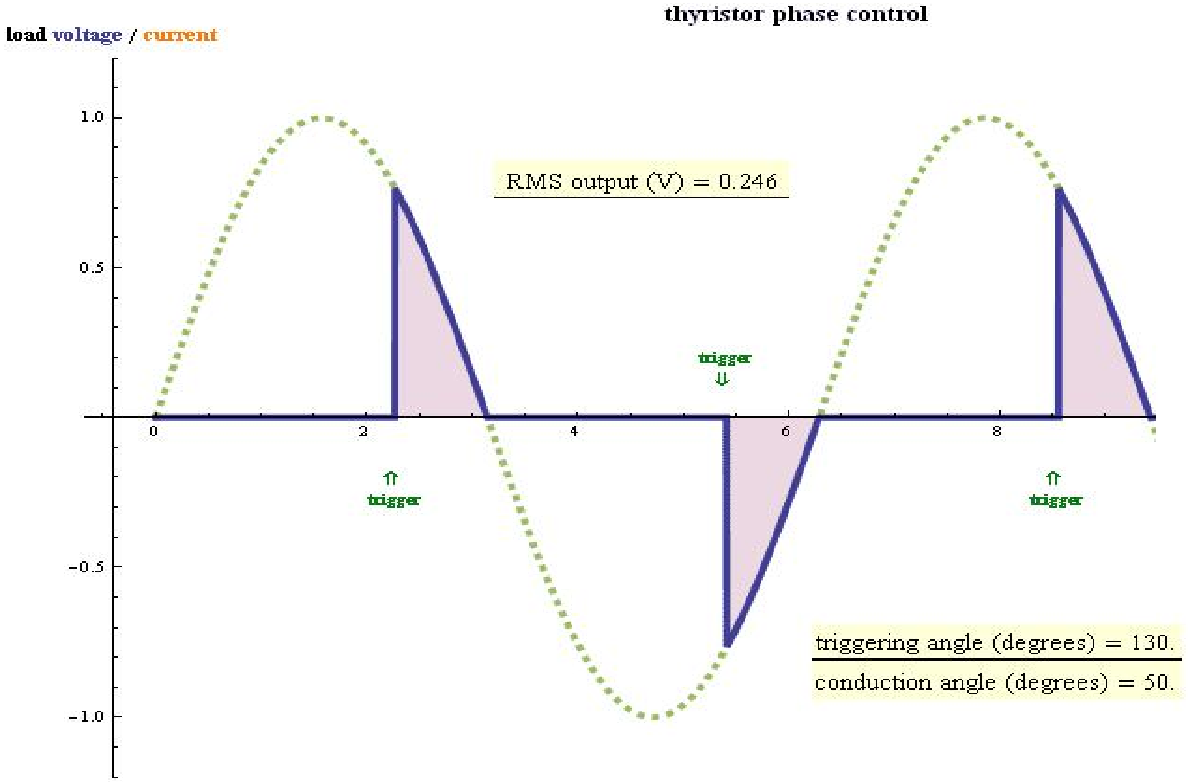

Figure 3.3: signal wave form indicating firing angle

The decrease in the firing angle, the increase in the conduction period of the thyristor, thus the amount of voltage that flows through.

The triggering is controlled by a zero crossing detection circuit; it is a logic circuitry that contains a simple microcontroller programed to generate pulse, although there are varieties of micro controller that can be used. The controller is isolated from the mains using an opto-isolator and a full bridge rectifier provides the DC power supply. The microcontroller generates pulses that are fed into a thyristor firing circuit, which amplifies them to trigger the SCR. During motor startup, the controller sends pulses to each SCR based on zero-crossing detection. Initially, the firing angle is set near 180 degrees to minimize voltage and conduction period. As zero-crossing detection continues, the firing angle decreases, increasing the thyristor's conduction period and consequently raising the motor's speed.

3.2 SOFT STARTER PRINCIPLE AND CONSIDRATION

The induction motor is started with a soft starter until the motor start to run at full speed, the bypass to run directly on the full supplied power. Just like every other starter, the power supply is first connected to the fuse, which serves as an overcurrent protection to the induction motor and soft starter. Then after are connected to the mains contactor, which serves the purpose of ON and OFF to the entire system.

The soft starter device is connected the mains contactor. The soft starter consists of the zero crossing detection device, the microcontroller, the thyristor.

The zero crossing detection circuit involves a full bridge rectification and an optocoupler. In the full bridge rectification, a step down transformer is connected to the supply to bring down the voltage as low as about 12volts, this is then connected to the 4 diode bridge that helps to convert AC power to DC power. Although, the signal produced is not smooth yet, the use of filters like capacitor voltage regulator and sometimes inductors are used to get a smooth wave. The rectification circuit is connected to the otpocoupler. The optocoupler helps to safely send signal between devices or circuit which operates on different voltage level, this is called galvanic isolation because there is no direct electrical connection between the input and the output. The LED in the optocoupler shines light on the phototransistor, which then draws current proportional to the LED current. As the rectifier voltage drops close to zero, the LED gets less current and the transistor draws low current and the voltage at the output rises which tell the micro controller the cycle moves close to the zero crossing point.

The microcontroller receives the signals from the zero crossing detection circuit, based on the preset logic programmed into the microcontroller, which are the ramp up time and the delay angle of the firing angle, are used to trigger the thyristor. As soon as the motor kicks up to speed, the bypass contactor is triggered and the motor continues to run directly on the main supply.

3.3 COMPONENTS AND CIRCUIT DESIGN.

1. **Regulated Voltage Supply:** The 12-volt DC regulated voltage supply is created using a specific circuit. Initially, a step-down transformer (230V/12V AC) reduces the voltage. This is followed by a bridge rectifier circuit that converts the AC to DC. The DC output from the rectifier is then fed to a regulating IC7812, which provides a stable 12V DC regulated supply. An LED is included for indication purposes.

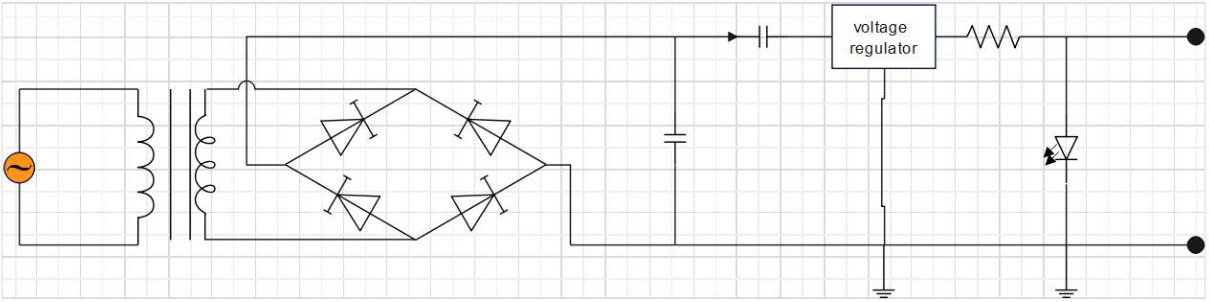

Figure 3.3: full bridge rectification

2. **Opto-coupler (4N25):** The 4N25 family, including models 4N26, 4N27, and 4N28, is a standard set of phototransistor couplers used in industry. Each optocoupler features a gallium arsenide infrared LED and a silicon NPN phototransistor. The LED’s light is

reflected onto the phototransistor, causing current proportional to the LED's current. When the LED current decreases, the transistor draws less current, causing a near-zero voltage drop and a rise in voltage at pin 2 (ZVC). This indicates to the Arduino that the mains are approaching the zero crossing point.

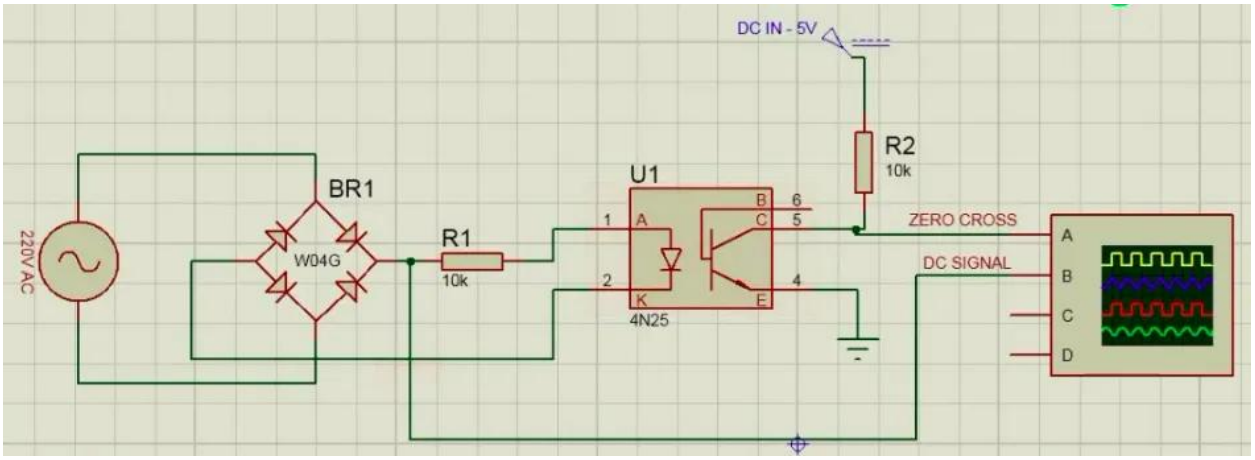

Figure 3. 4: circuit illustration of Opto-coupler (4N25)

3. **Opto-coupler (MO3021):** MO3021 is an optocoupler designed for triggering TRIAC. By using this we can trigger anywhere in the cycle, so can call them as non-zero opto-coupler. MO3021 are very widely used and quite easy to obtain. It comes with 6 pin DIP as shown in the figure bellow.

   Features:

- 400V photo-triac driver output.
- Gallium-arsenic diode infrared source and optically-coupled silicon TIRAC diver output
- High isolation 7500V peak
- Output Driver design for 220V AC
- Standard 6- terminals plastic DIP.

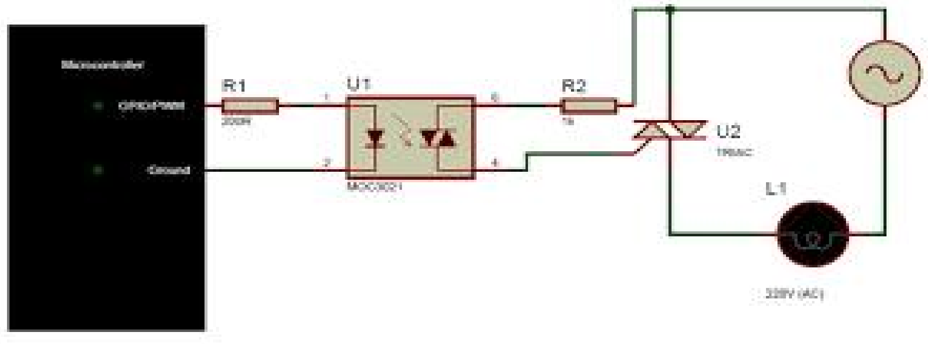

Figure 3.5: circuit for opt coupler (MO3021)

4. **Voltage sensor:** A digital voltage sensing device is a device that can measure and convert the voltage of an electrical signal into a digital format. A digital voltage sensing device can be used for various applications, such as monitoring, logging, or controlling the voltage of a circuit or a power source.

5. **Current sensor:** A digital current sensing device is a device that can measure and monitor the electric current flow in a circuit or system. A digital current sensing device can generate a signal that is proportional to the current and can be converted into a digital format. The digital signal can be used for various purposes, such as displaying, storing, analyzing, or controlling the current.

COMPONENTS

1. RESISTOR (560R, 1K, 2.2K, 3.3K, 4.7K, 10K, 22K, 27K, 100K, 2.2M, 100R/2W).
2. CAPACITORS (470M$_F$ / 35V, 10µF / 63V, 2.2µF / 25V, 0.47µF (470nF) polyester, 0.1µF / 400V polyester)
3. DIODES (IN4007, IN4148)
4. INTEGRATED CIRCUIT (7812, LM339, LM324, MOC3021)
5. IC BASE (14 PIN BASE, 06 PIN BASE)

6. TRANSISTOR (BC558/BC557, BC547)
7. MISCELLENEOUS PUSH BUTTON 2 PIN
8. TRANSFORMER
9. LED RED
10. LED YELLOW
11. LED GREEN
12. MALE BURGE TWO PIN
13. FEMALE BURGE PIN
14. HEAT SINK
15. SCREW NUT FOR HEAT
16. SCR (TYN616 OR TYN612)
17. PCB CONNECTOR 3PIN

3.3.1 CONTROL ALOGRITHM AND LOGIC DESIGN

First, a full supply AC to the induction motor has a frequency of 50Hz and the voltage supply of approximately 240volts. The AC voltage supply is considered a sine wave, with this we can establish the actually RMS voltage supplied at full supply and when the SCR is used to control the signal at a particular firing angle.

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V_p^2 \, sin^2\,(wt)\,dt} \qquad (3.1)$$

Frequency of the AC supply is 50Hz, which implies the amount of cycles made.

In relation to the time taken to complete a cycle, which implies period T, it is given as the inverse of frequency. $T = \frac{1}{F}$

Implies, $T = \frac{1}{50}$

$$T = 0.02s \ = 20ms$$

Thus, it takes 20ms for the AC signal to complete a cycle. For half a cycle, it takes 10ms.

Now, at every point where the SCR is triggered, there is a delay time and the average voltage output which all depends on the firing angle.

As known, voltage with respect to time angle, $V = V_m \sin{(wt)}\, dt = V_m \sin{\theta} \ d\theta$.

(3.2)

Using Fourier series, we can solve the average output voltage of the SCR at every point it is triggered.

Thus,

$$V_o = \frac{1}{2\pi}\int_{-\theta}^{\theta} V_m \sin{\theta} \ d\theta \qquad (3.3)$$

Assume the SCR is triggered at a firing angle α. The average output voltage for half the cycle will be

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} sin\theta \ d\theta \qquad (3.4)$$

$taking\ the\ integral, we\ have,$

$$V_o = \frac{Vm}{2\pi}[-cos\theta]_{\alpha}^{\theta} \qquad (3.5)$$

$$V_o = \frac{V_m}{2\pi}[-cos\theta + cos\alpha] \tag{3.6}$$

$$V_o = \frac{V_m}{2\pi}[cos\alpha - cos\theta] \tag{3.7}$$

Where α is the firing angle and for the half cycle $\theta = \pi\ (i.e.\, 180°)$

Therefore,

$$V_o = \frac{V_m}{2\pi}\left[cos\alpha - \cos\,(180°)\right] \tag{3.8}$$

$$V_o = \frac{V_m}{2\pi}[cos\alpha + 1] \tag{3.9}$$

Equation 3.9 is the expression for the average value of the DC output voltage.

For a 230-line voltage connected to the SCR, applying a firing angle of 90˚. Hence the delay by the SCR will be about 5ms and the average output voltage will be

$$V_m = 230 * \sqrt{2} = 325.27volt$$

$$V_o = \frac{325.27}{2\pi}[cos90° + 1]$$

$$V_o = 51.768\ volt$$

Now, for an AC output control of the SCR, it is important to the OFF state and the ON state.

Consequentially, the time period when the SCR is OFF and when it is on.

$f = input\ supply\ frequency$

$t_{ON} = controller\ on\ time = n \times T$

$t_{OFF} = controller\ off\ time = m \times T$

$n = two\ input\ cycles, thyristors\ are\ turned\ \boldsymbol{on}\ during\ t_{ON}\ for\ two\ input\ cycle$

$m = one\ input\ cycles, thyristors\ are\ turned\ \boldsymbol{off}\ during\ t_{OFF}\ for\ one\ input\ cycle$

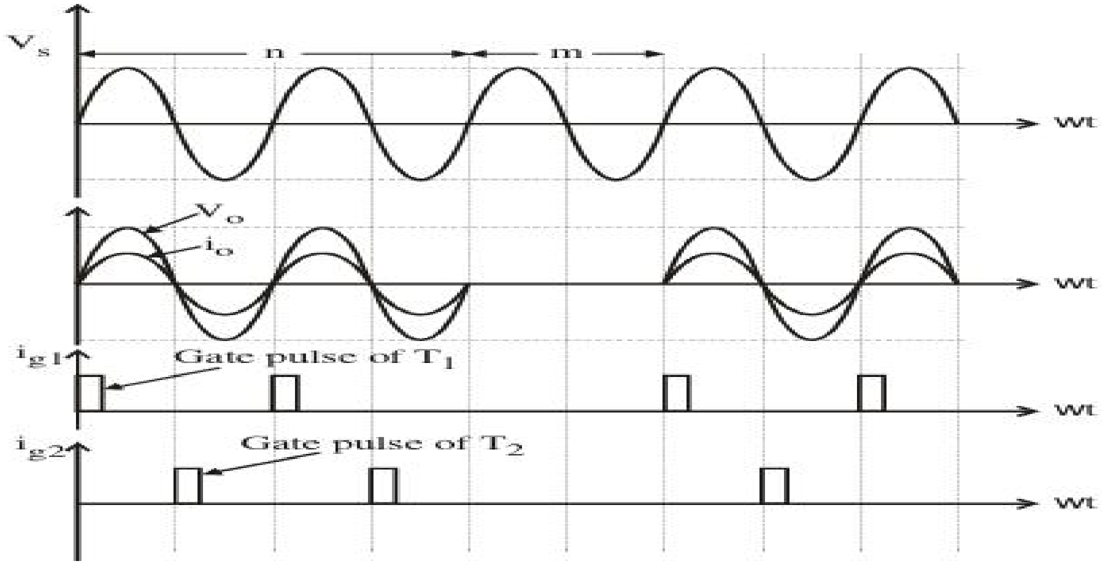

Figure 3.6: the firing angle pulse

$$T_o = output\ time\ period = t_{ON} + t_{OFF} = nT + mT$$

We can show that,

$$output\ RMS\ voltage\ V_{o(rms)} = V_{i(rms)}\sqrt{\frac{t_{on}}{T_o}} = V_s\sqrt{\frac{t_{on}}{T_o}} \qquad (3.10)$$

Where $V_{i(rms)}$ is the RMS input supply voltage = V_s.

To derive the expression for the RMS value of the output voltage on-off control method,

$$output\ RMS\ voltage\ V_{o(rms)} = \sqrt{\frac{1}{\omega T_o}\int_{\omega t=0}^{\omega t_{ON}} V^2{}_m sin^2\omega t.\,d(\omega t)} \qquad (3.11)$$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{\omega T_o}\int_{\omega t=0}^{\omega t_{ON}} sin^2\omega t.\, d(\omega t)} \tag{3.12}$$

Substituting for $\sin^2\theta = \frac{1-\cos 2\theta}{2}$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{\omega T_o}\int_{\omega t=0}^{\omega t_{ON}} \left[\frac{1-\cos 2\omega t}{2}\right] d(\omega t)} \tag{3.13}$$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\omega T_o}\int_{\omega t=0}^{\omega t_{ON}} [1-\cos 2\omega t] d(\omega t)} \tag{3.14}$$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\omega T_o}\int_{\omega t=0}^{\omega t_{ON}} d(\omega t) \int_{\omega t=0}^{\omega t_{ON}} \cos 2\omega t\, .\, d(\omega t)} \tag{3.15}$$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\omega T_o}\left[\omega t\Big|_0^{\omega t_{ON}} - \frac{sin\omega t}{2}\Big|_0^{\omega t_{ON}}\right]} \tag{3.16}$$

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\omega T_o}\left[(\omega t_{ON} - 0) - \left(\frac{sin2\omega t_{ON} - sin0}{2}\right)\right]} \tag{3.17}$$

$$Now, t_{ON} = an\ integral\ number\ of\ input\ cycle; Hence,$$

$$t_{ON} = T, 2T, 3T, 4T, 5T, \ldots and\ \omega t_{ON} = 2\pi, 4\pi, 6\pi, 8\pi, 10\pi, 2\pi.$$

Where T is the input supply time period (T = input cycle time period).

Thus we note that, $sin2\omega t_{ON} = 0$.

$$V_{o(rms)} = \sqrt{\frac{\omega t_{ON} V^2{}_m}{2\omega T_o}} \tag{3.18}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{t_{ON}}{T_o}} \tag{3.19}$$

Recall, $\frac{V_m}{\sqrt{2}} = V_{i(rms)} = V_s$

$$V_{o(rms)} = V_s\sqrt{\frac{t_{ON}}{T_o}} \tag{3.20}$$

$$\frac{t_{ON}}{T_o} = \frac{t_{ON}}{t_{ON}+t_{OFF}} = \frac{nT}{nT+mT} = \frac{n}{n+m} = k = duty\ cycle(d) \tag{3.21}$$

$$V_{o(rms)} = V_s\sqrt{\frac{n}{n+m}} = V_s\sqrt{k} \tag{3.22}$$

Performance parameter of AC controller.

- RMS output load voltage

$$V_{o(rms)} = \sqrt{\frac{n}{2\pi(n+m)}\int_0^{2\pi} V_m^2 sin^2\omega t\,.\,d(\omega t)} \tag{3.23}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{n}{n+m}} = V_s\sqrt{\frac{n}{n+m}} = V_s\sqrt{k} \tag{3.24}$$

Where $V_{i(rms)}(RMS\ of\ input\ supply\ voltage) = V_s = \frac{V_m}{\sqrt{2}}$

- Duty cycle

$$k = \frac{t_{ON}}{T_o} \tag{3.25}$$

$$k = \frac{t_{ON}}{t_{ON}+t_{OFF}} = \frac{nT}{nT+mT} = \frac{nT}{(n+m)T} = \frac{n}{n+m} \tag{3.26}$$

Where k is the duty cycle.

- RMS load current

$$I_{o(rms)} = \frac{V_{o(RMS)}}{Z} = \frac{V_{o(RMS)}}{R_L} \qquad (3.27)$$

- Output AC (Load) Power

$$P_o = I^2_{O(RMS)} \times R_L \qquad (3.28)$$

- Input power factor

$$PF = \frac{P_o}{VA} = \frac{output\ load\ power}{input\ supply\ volt\ amperes} = \frac{P_o}{V_S I_S} \qquad (3.29)$$

$$PF = \frac{I^2_{O(RMS)} \times R_L}{V_{i(rms)} \times I_{in(rms)}};\ I_S = I_{in(rms)} = RMS\ input\ supply\ current \qquad (3.30)$$

The input supply current is the same as the load current ; $I_o = I_{in} = I_L$

Hence,

$$PF = \frac{I^2_{O(RMS)} \times R_L}{V_{i(rms)} \times I_{in(rms)}} = \frac{V_{o(rms)}}{V_{i(rms)}} = \frac{V_{i(rms)} \times \sqrt{k}}{V_{i(rms)}} \qquad (3.31)$$

$$= \sqrt{k} \qquad (3.32)$$

- The average current of thyristor

$$I_{T(Avg)} = \frac{n}{2\pi(n+m)} \int_0^{\pi} I_m sin\omega t \,.\, d(\omega t) \qquad (3.33)$$

$$I_{T(Avg)} = \frac{I_m n}{\pi(n+m)} = \frac{k.I_m}{\pi} \qquad (3.34)$$

Where $I_m = \frac{V_m}{R_L} = maximum\ or\ peak\ thyristor\ current.$

- RMS current of thyristor $I_{T(rms)}$

$$I_{T(rms)} = \sqrt{\frac{n}{2\pi(n+m)} \int_0^{\pi} I_m^2 sin^2 \omega t \,.\, d(\omega t)} \qquad (3.34)$$

By solving the integration in the above equation we result to:

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{k} \tag{3.35}$$

- The derivation of expression for RMS output voltage

$$V_{o(rms)} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{2\pi} V^2{}_m sin^2 \omega t. d(\omega t)} \tag{3.36}$$

Bringing out the constant voltage ($V^2{}_m$) and substituting the alternate trigonometry solution we have,

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\pi}\int_{\alpha}^{2\pi} \frac{1-cos2\omega t}{2}. d(\omega t)} \tag{3.37}$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\int_{\alpha}^{2\pi} d(\omega t) - \int_{\alpha}^{2\pi} cos2\omega t. d(\omega t)} \tag{3.38}$$

$solving\ the\ integartion\ value$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\int_{\alpha}^{2\pi} d(\omega t) - \int_{\alpha}^{2\pi} cos2\omega t. d(\omega t)} \tag{3.39}$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}}\sqrt{(2\pi - \alpha) - \left[\frac{sin2\omega t}{2}\right]\Big|_{\alpha}^{2\pi}} \tag{3.40}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(2\pi - \alpha) + \frac{sin2\alpha}{2}\right]} \tag{3.41}$$

Remember $\frac{V_m}{\sqrt{2}} = V_{i(rms)} = V_s$

Therefore,

$$V_{o(rms)} = V_S\sqrt{\frac{1}{2\pi}\left[(2\pi - \alpha) + \frac{sin2\alpha}{2}\right]} \tag{3.42}$$

Equation (3.42) is the output AC voltage for a half-wave control.

For a full wave AC controller, it can be observed that the two half cycles of output voltage waveforms are symmetrical and the output pulse time period is $\pi\, radian$. Hence, the RMS output voltage can be determined by the expression below.

$$V_{o(rms)}^2 = V_{L(rms)}^2 = \frac{1}{2\pi}\int_0^{2\pi} v_L^2 d(\omega t) \tag{3.43}$$

$$V_{L(rms)}^2 = \frac{1}{\pi}\int_0^{\pi} V_m^2 \, sin^2\, \omega t \, . d\omega t \tag{3.44}$$

$$V_{L(rms)}^2 = \frac{1}{2\pi}\int_0^{2\pi} v_L^2 . d(\omega t) \tag{3.45}$$

$$v_L^2 = v_o = V_m^2 \sin \omega t\, ; for\ \omega t = \alpha\ to\ \pi\ and\ \omega t = (\pi + \alpha)\ to\ 2\pi$$

Hence,

$$V_{L(rms)}^2 = \frac{1}{2\pi}\left[\int_\alpha^{\pi} V_m^2 \, sin^2\, \omega t \, . d\omega t + \int_{\pi+\alpha}^{2\pi} V_m^2 \, sin^2\, \omega t \, . d\omega t\right] \tag{3.46}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{2\pi}\left[\int_\alpha^{\pi} sin^2\, \omega t \, . d\omega t + \int_{\pi+\alpha}^{2\pi} sin^2\, \omega t \, . d\omega t\right] \tag{3.47}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{2\pi}\left[\int_\alpha^{\pi} \frac{1-cos2\omega t}{2} . d\omega t + \int_{\pi+\alpha}^{2\pi} \frac{1-cos2\omega t}{2} . d\omega t\right] \tag{3.48}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{2\pi \times 2}\left[\int_\alpha^{\pi} d\omega t - \int_\alpha^{\pi} cos2\omega t. d\omega t + \int_{\pi+\alpha}^{2\pi} d\omega t - \int_{\pi+\alpha}^{2\pi} cos2\omega t. d\omega t\right] \tag{3.49}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[\omega t \Big|_\alpha^{\pi} + \omega t \Big|_{\pi+\alpha}^{2\pi} - \left[\frac{sin2\omega t}{2}\right]_\alpha^{\pi} - \left[\frac{sin2\omega t}{2}\right]_{\pi+\alpha}^{2\pi}\right] \tag{3.50}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[(\pi - \alpha) + (2\pi - (\pi + \alpha)) - \frac{1}{2}(sin2\pi - sin2\alpha) - \frac{1}{2}(sin4\pi - sin2(\pi + \alpha))\right]$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[2(\pi - \alpha) - \frac{1}{2}(0 - sin2\alpha) - \frac{1}{2}(0 - sin2(\pi + \alpha))\right] \tag{3.51}$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[2(\pi - \alpha) + \frac{1}{2}(sin2\alpha) + \frac{1}{2}(\sin{(2\pi + 2\alpha)})\right] \quad (3.52)$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[2(\pi - \alpha) + \frac{1}{2}(sin2\alpha) + \frac{1}{2}(\sin 2\pi . cos2\alpha + cos2\pi . sin2\alpha)\right] \quad (3.53)$$

Where $\sin 2\pi = 0 \quad and \quad cos2\pi = 1$

Therefore,

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}\left[2(\pi - \alpha) + \frac{1}{2}(sin2\alpha) + \frac{1}{2}(sin2\alpha)\right] \quad (3.54)$$

$$V_{L(rms)}^2 = \frac{V_m^2}{4\pi}[2(\pi - \alpha) + sin2\alpha] \quad (3.55)$$

$$V_{L(rms)}^2 = \frac{V_m^2}{2\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right] \quad (3.56)$$

$$V_{L(rms)} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]} \quad (3.57)$$

Recall, $V_{I(rms)} = \frac{V_m}{\sqrt{2}} = V_S$

$$V_{L(rms)} = V_S\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]} \quad (3.58)$$

Equation (3.58) is the output load voltage for a full wave AC controller to the induction motor.

3.3.2 DESIGN OF A SINGLE PHASE INDUCTION MOTOR

The specific electric loading factor

$$Q = \frac{I_{ph}Z_c}{\pi D} \quad (3.59)$$

The specific magnetic loading factor

$$B_{av} = \frac{\emptyset P}{\pi D L} \tag{3.60}$$

The output equation for a single phase induction motor

$$P_i = I_{ph} E_{ph} \times 10^{-3} \tag{3.61}$$

But, $E_{ph} = 4.44 f \emptyset K_w T_{ph}$ (3.62)

$$P_i = 4.44 f \emptyset K_w T_{ph} I_{ph} \times 10^{-3} \tag{3.63}$$

Form equation (3.59) and equation(3.60) we can make $\emptyset$ and $I_{ph} Z_c$ the subject of the formula and substitute into equation (3.63)

Hence, equation (3.59) becomes

$$I_{ph} Z_c = Q \pi D \tag{3.64}$$

$$but,\ Z_c = 2 T_{ph} \tag{3.65}$$

$$I_{ph} T_{ph} = \frac{Q \pi D}{2} \tag{3.66}$$

Also equation (3.60) becomes,

$$\emptyset = \frac{B_{av} \pi D L}{P} \tag{3.67}$$

Therefore, equation (3.63) becomes;

$$P_i = 4.44 f \times \frac{B_{av} \pi D L}{P} \times K_w \times \frac{Q \pi D}{2} \times 10^{-3} \tag{3.68}$$

$$= 4.44 \times \frac{n_s P}{2} \times \frac{B_{av} \pi D L}{P} \times K_w \times \frac{Q \pi D}{2} \times 10^{-3} \tag{3.69}$$

$$= 1.11\pi^2 n_s B_{av} K_w Q D^2 L \times 10^{-3} \tag{3.70}$$

$$C_o = 1.11\pi^2 n_s B_{av} K_w Q \times 10^{-3} \tag{3.71}$$

$$P_i = C_o D^2 L \tag{3.72}$$

Where,

B_{av} = Average value of flux density

$K_w = winding\ factor$

$n_s = speed\ of\ the\ induction\ motor\ in\ rps$

$D = diameter\ of\ the\ inductor\ motor\ stator, the\ inner\ core$

$L = length\ of\ the\ stator\ core$

$P = numbers\ of\ pole$

$Q = ampere - conductor\ per\ meter\ of\ armature\ \ periphery$

$C_o = coefficient$

$f = frequency$

$\emptyset = flux\ per\ pole$

$I_{ph} = current\ per\ phase$

$E_{ph} = applied\ voltage\ per\ phase$

$T_{ph} = number\ of\ turn\ per\ phase$

$Z_c = total\,number\,of\,conductor$

$\eta = efficiency$

$\tau = pole\,pitch$

Pole pitch $\tau = \frac{\pi D}{P}$ (3.73)

Speed $n_s = \frac{2f}{P}$ (3.74)

Pitch constant $K = \frac{L}{\tau} = \frac{LP}{\pi D}$ (3.75)

CALCULATIONS

We can determine the minimum rating of the contactor and the overload relay.

The rating of the contactor is calculated, thus;

output power = 0.75HP = 0.56KW,

maximum applied voltage = 230V,

efficiency =50% and

power factor = 0.85.

$$\eta = \frac{output\,power}{input\,power}$$

$$input\,power = \frac{output\,power}{\eta} = \frac{0.56KW}{0.5}$$

$$= 1.12KW$$

$$KW = cos\emptyset \times KVA$$

$$KVA = \frac{KW}{cos\emptyset}$$

$$KVA = \frac{1.12KW}{0.86}$$

$$KVA = 1.302KVA$$

$$KVA = 1.302KVA = E_{ph} \times I \times 10^{-3}$$

$$I = \frac{1.302}{E_{ph} \times 10^{-3}} = \frac{1.302}{230 \times 10^{-3}} = 5.66A$$

The maximum current consumed by the induction motor is about 5.66A. therefore, the rating of the contactor should not be less than 5.66A.

The rating of the overload relay is usually about 130% or 140% of the maximum load current of the induction motor (by Wes Gubitz. July 2018. jade learning). Which implies, the overload relay rating will be:

$$130\% \ of \ 5.66A = 7.358A \ overload \ relay \ rating$$

$$140\% \ of \ 5.66A = 7.924A \ overload \ relay \ rating$$

Calculating the applied voltage supplied by the thyristor of successive firing angle to the induction motor.

Using the above derived formula,

$$V_{L(rms)} = V_S \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Where, $\alpha = the \ firing \ angle \ and \ V_S = the \ input \ supplied \ voltage$

The output voltage of the thyristor of firing angle at 80˚ and 0˚ , $V_S = 230V$ is determined below:

At , α =80˚

In radian, $\alpha = \frac{80\times\pi}{180}$

$$V_{L(rms)} = V_S \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Therefore,

$$V_{o(rms)} = 230 \sqrt{\frac{1}{\pi}\left[\left(\pi - \frac{80 \times \pi}{180}\right) + \frac{sin2 \times 80^{\circ}}{2}\right]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[(1.745) + 0.1710]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[1.91633]}$$

$$V_{o(rms)} = 230\sqrt{0.6100}$$

$$V_{o(rms)} = 179.63V$$

At , α =0°

In radian, $\alpha = \frac{0\times\pi}{180} = 0$

$$V_{o(rms)} = V_S\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Therefore,

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}\left[\left(\pi - \frac{0\times\pi}{180}\right) + \frac{sin2\times 0°}{2}\right]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[(\pi - 0) + 0]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[\pi]}$$

$$V_{o(rms)} = 230\sqrt{1}$$

$$V_{o(rms)} = 230V$$

3.4 HARDWARE IMPLEMENTATION

The hardware that makes up the soft starter includes the cables, the contactors for the switching and bypass of the supplied voltage, the microcontroller (Arduino UNO) for the control of pulse to the SCR gate, overload relay for overcurrent protection of the system, the panel that encloses the electronic devices.

3.5 SOFTWARE DESIGN

The software consists of a program for the Arduino UNO microcontroller, which is programmable using the Arduino IDE. The Arduino UNO is an open-source board based on the Microchip ATmega328P MCU and developed by Arduino.cc.

The term "UNO," meaning "one" in Italian, was chosen to signify a major redesign of Arduino hardware and software. The Uno board, which succeeded the Duemilanove and was the 9th USB-based Arduino board, introduced Version 1.0 of the Arduino IDE. The ATmega328 chip on the board comes preloaded with a bootloader, enabling code uploads without needing an external programmer.

The Uno communicates via the original STK500 protocol but differs from previous boards by not using an FTDI USB-to-UART serial chip. Instead, it employs the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

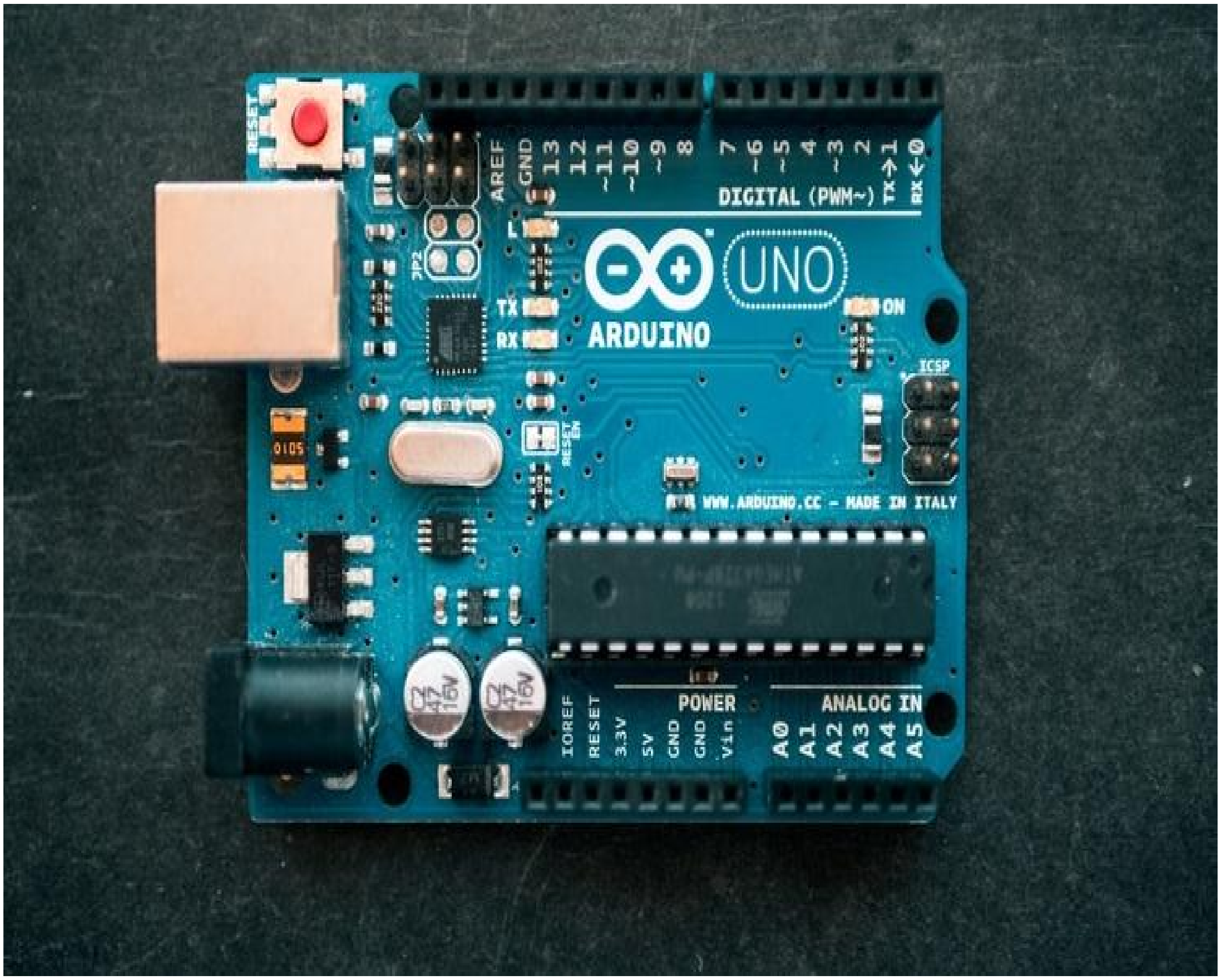

Figure 3.7: the UNO Arduino microcontroller

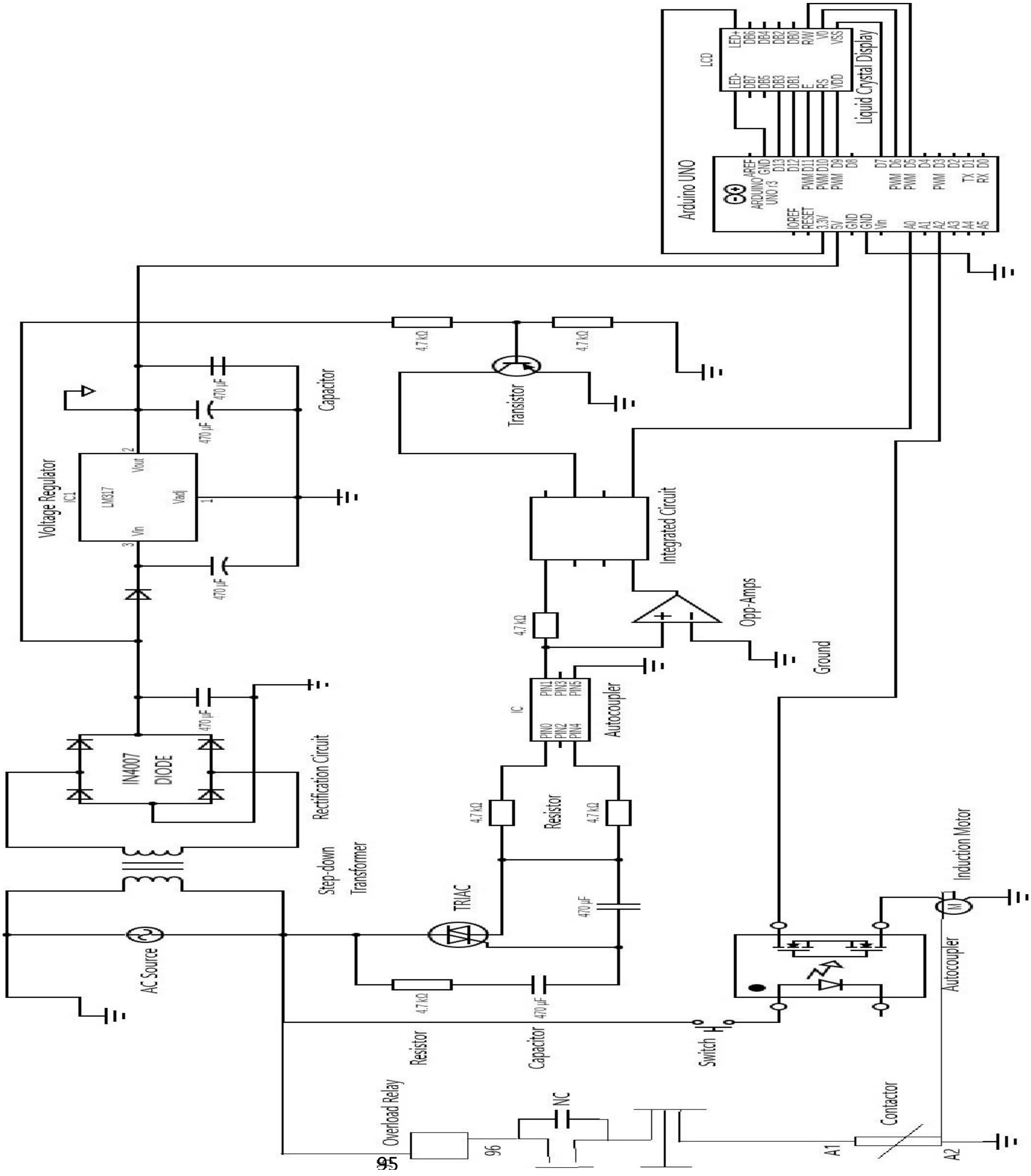

Figure 3.7: The complete circuit diagram of the soft starter

3.6 COMMON SETTINGS OF THE SOFT STARTER.

Common settings involve common parameters available on most soft starter. Although other settings are dependent on the type of soft starter or manufacturer. The parameters go as follows:

Start ramp: this the time from where the soft starter starts its ramp (initial voltage) until the full voltage is reached. Although the ramp time should not be too long as this could result to overheating of the motor winding.

Stop ramp: this when the soft stopping of the motor is required. The stop ramp is the time it takes from full voltage to zero voltage or initial voltage. Which is required to bring the motor to stop.

Initial voltage: this is the voltage point where the motor starts or stops it ramps. The torque of the motor will drop the square of the voltage which is directly proportional to the current. Experimentally, it is important to determine the initial voltage of the motor that will be high enough to start the motor ensuring the motor does not go overheating.

3.7 EXPERIMENTAL SETUP

- Provision of a single phase power supply (probably with power extension)
- Connecting the terminal of our device to the power supply and ensuring a firm connection
- The green button on the soft start is initiated, the contactor is energized to close the circuit.
- After the motor start. to run to stop the motor the red button is used.

CHAPTER FOUR

RESULT AND DISCUSSIONS.

4.1 TEST AND RESULT ANALYSIS

The output voltage simulation when the soft starter thyristor device is active.

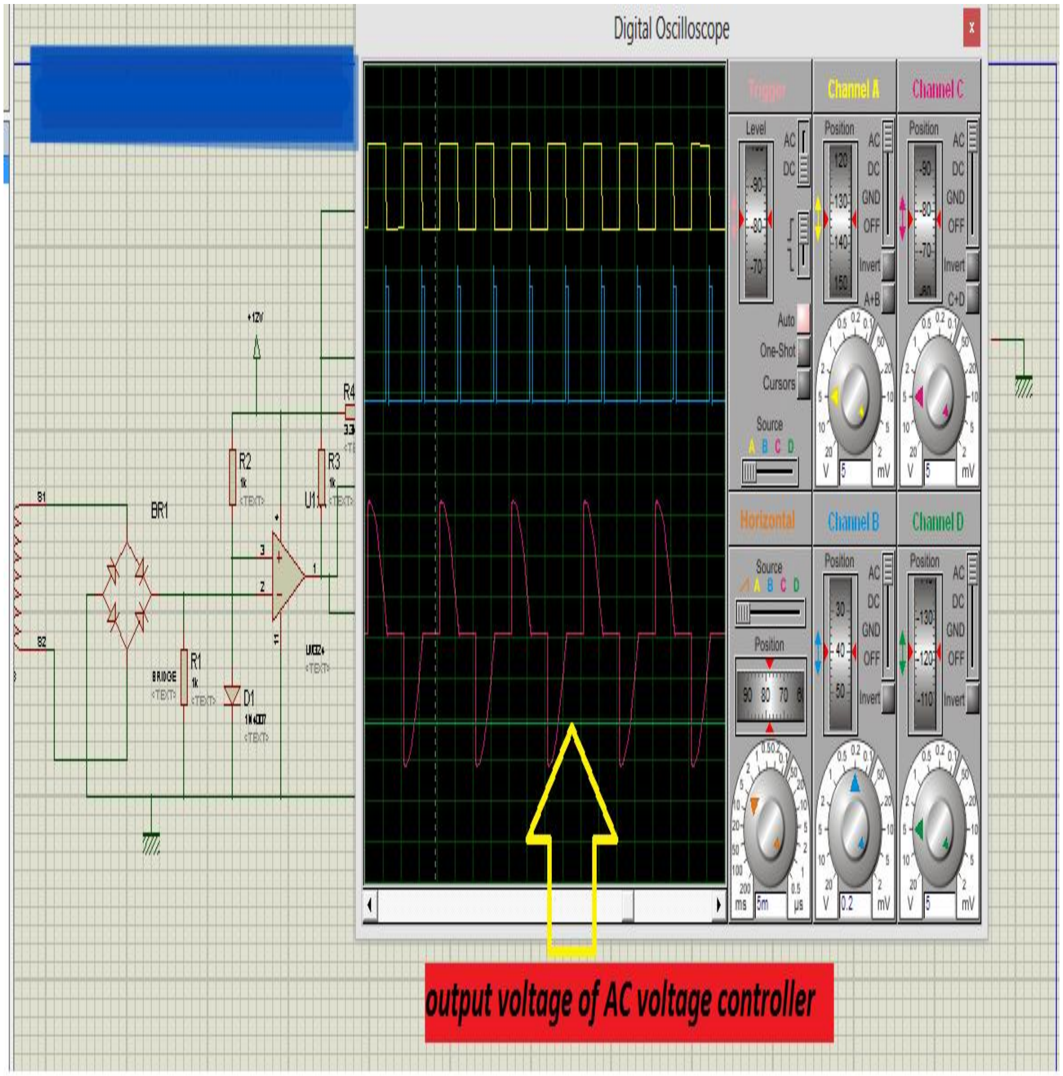

Figure 4.1: Simulation of the output voltage of the soft starter on proteus professional application.

The output voltage of the thyristor of firing angle at 80˚, 60˚, 40˚, 20˚, 0˚ is calculated in the table below

Firing angle (α)	80˚	60˚	40˚	20˚	0˚
Number of cycle during ramp	50	100	150	200	continues
Ramp interval (s)	0 -1	1 - 2	2 - 3	3 -4	continues
Output voltage, $V_{o(rms)}$ (V)	179.63	206.30	222.34	228.99	230

Thus, the greater the firing angle, the lesser the applied voltage.

Starting torque vs speed curve

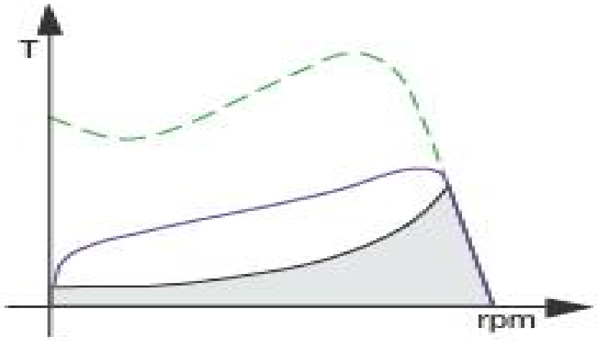

Figure 4.2: Torque/speed curve when using a soft starter

Starting current vs speed

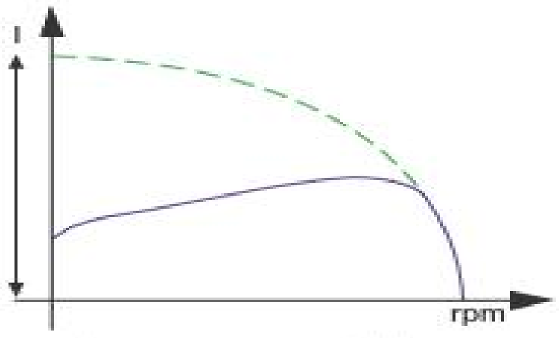

Figure 4.3: Current/speed when using a soft starter

4.2 COMPARISON WITH EXISTING SOFT STARTER TECHNOLOGIES

Soft starter vs DIRECT ON-LINE (DOL)

- A soft starter reduces the voltage to the motor gradually, reducing the starting current and torque but also allowing the motor to start and stop smoothly. On the other hand, the direct on line (DOL) starter connect the motor to the full line voltage, allowing maximum current and torque, but also increasing the risk of mechanicals stress.
- Soft starter is suitable for high power motors that needs to avoid high starting and mechanical stress while a direct on line (DOL) is suitable for low power motor as they need a high starting current and torque also relatively cost effective.

Soft starter vs autotransformer

- A soft starter can provide a smooth acceleration and deceleration of the motor while the autotransformer starter can cause voltage and current surge to the motor while changing tap
- A soft starter ca ramp up voltage gradually to a desire value, while an autotransformer can switch between fixed voltage tap.
- A soft starter can adjust starting torque according to the load, while an autotransformer has a constant torque to speed curve.

Soft starter vs variable frequency drive (VFD) soft starter

- A soft starter is simple and cheaper than a variable frequency drive (VFD) soft starter but can cause voltage dip in the system and cannot save energy or reduce demand charge on electricity bill, while variable frequency drive (VFD) soft starter is complex and quite expensive, but can improve the power quality and efficiency of the system.

- A soft starter can only control the speed and torque of the motor at starting and stopping while a variable frequency drive (VFD) soft starter can control the speed and torque not only during starting but also during the running cycle.

Soft starter vs star-delta starter

- With a soft starter there is a gradual increase in the voltage supplied to the motor, while the star-delta starter reduces the voltage supplied to each winding when starting.
- A soft starter allows the control of the starting time while star-delta does not.

4.3 DISCUSSION AND FINDINGS

The single phase induction motor is rated 0.56KW. For this reason, the starting current required is not high but for experimental purposes to demonstrate the effectiveness of the soft starter. The starting ramp time is estimated to be about 4sec before the full applied voltage is supplied to the motor.

It is worthy of note that the motor running current has been determined to be 5.66A which implies that the maximum current consumed by the induction motor under investigation is 5.66A. Therefore, the contactor rating should not be less than 5.66A. it was established that the overload relay should be about 130% or 140% of the maximum load current of the induction motor. From the running current (loading current) the overload should be about 7.358A or 7.924A (130% of 5.66A or 140% of 5.66A)

Further established result shows that the applied voltage decreases with increase in the firing angle.

The past chapter have highlighted the principle that entails the soft starter system and also the design chapter explain the steps involved in the process. These principles worked as shown by the test that has be carried out successfully after the construction. This results did not come out without some problem. The problem encountered includes the sensor errors and the heating issues in the device.

CHAPTER FIVE

CONCLUSION, SUMMARY AND RECOMMENDATION

5.1 CONCLUSION

This project presents the design and construction of a soft starter for a single phase induction motor. The aim of the project is to reduce the starting current also known as the inrush current during starting of the induction motor. This was achieved by gradually increasing the applied voltage to the induction motor, by this means, the thyristors performs this function as the major component to these cause. As established already, the thyristors is a one directional flow of current and was connected in a back to back configuration to control both half of the of the voltage signal making an averagely smooth signal and achieving a smooth starting as well. The circuits that makes up the soft starter includes the zero crossing detection circuit, the microcontroller circuit, the controlling circuit that consist of thyristors and opt coupler the switching component, the contactor and the overloading relay. Collectively all this was put together and the aim of this project proved successful.

The gradual increase in voltage was achieved and the motor was observed to start smoothly. The voltage increased from 206V to 230V. by this, the inrush current is reduced and mechanical vibrations was minimized to a bearable effect. Compared to other starter, like the direct on line starter, the soft starter starting current was marginalized and it is safe to say that when starting an induction motor, a soft starter is more efficient.

On a very large scale, this soft starter can be used to reduce the initial starting current of a large induction motor in the industry. This can be employed in large industries, although will be more efficient by using more sophisticated designs and component to withstand the high power capacity and requirement.

5.2 SUMMARY OF THE PROJECT

The soft starter is a device that is used to start an induction motor by reducing the initial starting current. As it is known the initial starting current of an induction motor is very high and can in the case of large electric induction motor, it can lead to mechanical stress and cause damages. To take out all this problem, a soft starter comes into play. A soft starter primary aim is to gradually increase the voltage applied to the induction motor thereby reducing the startup current. The soft start system is basically achieved with the help of an important power electronic device known as the thyristors.

The thyristors is a component like a two semiconductor transistor connected together. It consists of three terminals, the cathode, the anode and the gate. The thyristors device is can be used to control the flow of an ac signal with the gate terminal, although with a single device we can only control just half wave of the signal. In other for the full wave of the ac signal to be controlled, the thyristors are connected in a back to back configuration. With this configuration we can control the supply voltage at any varied interval by applying the required triggering pulse to the device. The point at which the triggering pulse is sent to the thyristors is known as the firing angle. It is denoted by the symbol $\boldsymbol{\alpha}$.

In order to give a definite, orderly and controllable signal pulse to the gate of the thyristors, a zero crossing detection circuit is used. This circuit primarily consist of bridge rectification and a transistor usually an opt coupler or an operational amplifier in a comparator configuration. This device is used to detect the zero crossing point on an ac signal. In other word, the point on the ac signal where the sinusoidal ac voltage crosses from the positive half to the negative and from negative again back to the positive half.

Although, the triggering pulse is not sent directly to the thyristors. The pulse generated is controlled by delaying using a microcontroller. The microcontroller is used to control the firing angle by gradually reducing the pulse from the zero crossing detection circuit. The microcontroller is programmed to discrete manner to delay the pulse gradually for a given period of time.

5.3 ACHIEVEMENT AND CONTRIBUTIONS

In this project we are able to achieve the gradual increase in the supply voltage to the induction motor with all the necessary component like the TIRAC contactor, overload relay, microcontroller. In a big sense, this can be used in industries where large induction motor is used to drive heavy loads resulting in a large amount of starting current to be controlled.

5.4 LIMITATIONS AND CHALLENGES

The limitation and challenges face in the actualization of this project are stated bellow:

- Time taken to actualize the project is quite short, which has resulted in giving out some minor error that could have been corrected if the time was permitted.
- Lack of some testing equipment like the oscilloscope that could have been simulate the generated signals for better understand of the circuits.
- Availability of the of some component contributed to the delaying of the project.
- Cost of some component and equipment.

- The heat generated by some component leads to some heat loss in turn loss in energy in the system

5.5 FUTURE DIRECTIONS FOR IMPROVEMENT AND ENHANCEMENT

The following stated below are the areas of the project that I consider for the improvement:

- A larger LCD screen for a better view of all required parameters.
- A more accurate sensing device to reduce the marginal errors in the system.
- A more sophisticated component is should be used to reduce heating.
- A smooth rectification circuit would have been helpful by reducing the cost of adding an external battery for the power of the control system and the LCD display.
- A high power rated transformer should be used to sustain the thyristor circuit and to reduce the heat lost by the device.
- A bypass contactor would be a better improvement for the soft starter by taking off load form the soft starter after starting to minimize the heat generated by the soft starter.

APPENDICES

- **Source Code**

  Programming Language: C++

  Programming Software: Arduino IDE Software.

```
#include <Wire.h>

#include <Adafruit_MCP4725.h>  // Library for digital-to-analog converter (DAC)

#include <LiquidCrystal_I2C.h>  // Library for I2C LCD display

// Define sensor pins

const int currentSensorPin = A0;   // Connect current sensor to analog pin A0

const int voltageSensorPin = A1;   // Connect voltage sensor to analog pin A1

// Define softmode and other control pins

const int softmodePin = 7;   // Connect relay control pin to digital pin 7

const int dacPin = 9;     // Connect DAC control pin to digital pin 9

// Define LCD parameters
```

```
LiquidCrystal_I2C lcd(0x27, 16, 2);  // Set the LCD address
and dimensions
// Define threshold values
const float currentThreshold = 5.0;  // Set your current
threshold value (in Amps)
const float voltageThreshold = 220.0;  // Set your voltage
threshold value (in Volts)
// Create instances of the sensors
Adafruit_MCP4725 dac;
void setup() {
  pinMode(relayPin, OUTPUT);
  digitalWrite(relayPin, LOW);
  dac.begin(0x62);  // Initialize the DAC at address 0x62
  lcd.init();                      // Initialize the LCD
  lcd.backlight();                 // Turn on the backlight
  lcd.setCursor(0, 0);
  lcd.print("Current (A):");
  lcd.setCursor(0, 1);
```

```
  lcd.print("Voltage (V):");

}

void loop() {

  // Read current and voltage values

  float current =
currentSensorValueToAmps(analogRead(currentSensorPin));

  float voltage = analogRead(voltageSensorPin) * (5.0 /
1023.0) * 220.0; // Assuming a 5V reference and a voltage
divider for voltage measurement

  // Calculate power (P = VI)

  float power = current * voltage;

  // Display values on the LCD

  lcd.setCursor(14, 0);

  lcd.print("      ");  // Clear previous value

  lcd.setCursor(14, 1);

  lcd.print("      ");  // Clear previous value

  lcd.setCursor(14, 0);

  lcd.print(current, 2);
```

```
  lcd.setCursor(14, 1);
  lcd.print(voltage, 2);
  if (current < currentThreshold && voltage >
voltageThreshold) {
    // Ramp up motor voltage using the DAC
    for (int i = 0; i < 4096; i++) {
      dac.setVoltage(i, false);
      delay(10);  // Adjust the delay for the desired ramp-
up speed for softstart automatically
    // Turn on the motor relay
    digitalWrite(softmode Pin, HIGH);
        // You can add delay or monitoring logic here
  } else {
        digitalWrite(softmode Pin, LOW);
    dac.setVoltage(0, false);
        // You can add fault handling or notifications here
  }
}
```

```
// Function to convert ADC value to current in Amps
(assuming ACS712 sensor)

float currentSensorValueToAmps(int sensorValue) {

  // Convert sensor value to voltage

  float voltage = (sensorValue / 1023.0) * 5.0;

    // Convert voltage to current using sensor
specifications

  float current = (voltage - 2.5) / 0.185;  // Change this
formula based on your ACS712 model

  return current;

}
```

- **Supporting calculations**

$$V_{o(rms)} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{2\pi} V^2{}_m sin^2 \omega t . d(\omega t)}$$

Bringing out the constant voltage ($V^2{}_m$) and substituting the alternate trigonometry solution we have,

$$V_{o(rms)} = \sqrt{\frac{V^2{}_m}{2\pi}\int_{\alpha}^{2\pi} \frac{1 - cos2\omega t}{2} . d(\omega t)}$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{\int_{\alpha}^{2\pi} d(\omega t) - \int_{\alpha}^{2\pi} cos2\omega t.\, d(\omega t)}$$

$$solving\ the\ integartion\ value$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{\int_{\alpha}^{2\pi} d(\omega t) - \int_{\alpha}^{2\pi} cos2\omega t.\, d(\omega t)}$$

$$V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{(2\pi - \alpha) - \left[\frac{sin2\omega t}{2}\right]\Bigg|_{\alpha}^{2\pi}}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{1}{2\pi}\left[(2\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Remember $\frac{V_m}{\sqrt{2}} = V_{i(rms)} = V_s$

Therefore,

$$V_{o(rms)} = V_S \sqrt{\frac{1}{2\pi}\left[(2\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$