DESIGN AND FABRICATION OF 8/6 SWITCHED RELUCTANCE MOTOR WITH DRIVE SYSTEM

A Project Report

Submitted by

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CERTIFICATE

This is to certify that this report entitled **DESIGN AND FABRICATION OF 8/6 SWITCHED RELUCTANCE MOTOR WITH DRIVE SYSTEM** submitted by **Mr.ABHIJITH NAIR EP(LKTE21EE066)**, **Mr.GOVIND P(LKTE21EE069)**, **Mr.GOVIND SAJEEV(LKTE21EE070)**, **Mr.RAHUL S(LKTE21EE072)** to APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of Degree of Bachelor of Technology in Electrical Electronics Engineering, is a bonafide record of the project presentation carried out by him under our guidance and supervision. This report has not been submitted in any form to any other university or institute for any purpose.

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Prof. Peter K Abraham	Prof. Veena L	Dr. Aryanandiny B
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Acknowledgement

The contentment and euphoria that accompany the successful completion of any task would not be complete without the mention of people who have helped to make it possible. First and foremost, we thank God Almighty for his abundant blessings without which we would not be able to complete this project.

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Abstract

This project focuses on the design, fabrication, and control of an 8/6 Switched Reluctance Motor (SRM) and drive system. SRMs, known for their robust construction, high efficiency, and fault tolerance, have gained significant attention in various applications. The 8/6 SRM configuration offers a favorable trade-off between torque density and switching losses. The design process involves detailed electromagnetic and thermal analysis to optimize the motor's performance and ensure efficient heat dissipation. The fabricated motor is meticulously assembled, incorporating precision machining techniques to achieve accurate dimensions and alignments. The control system, implemented using a microcontroller, plays a crucial role in generating precise switching signals to energize the stator windings at appropriate instants, thereby regulating the motor's torque and speed. Experimental results validate the effectiveness of the designed and fabricated SRM drive system, demonstrating its potential for various industrial and automotive applications.

Keywords- Switched Reluctance Motor (SRM),Electric Vehicle(EV), Torque ripple, permanent magnet assisted, Brushless DC Motor(BLDC).

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ABBREVIATIONS

1. **SRM** - Switched Reluctance Motor
2. **HESM** - Hybrid Excitation Switched Reluctance Motor
3. **PMSM** - Permanent Magnet Synchronous Motor
4. **BLDC** - Brushless DC Motor
5. **PM** - Permanent Magnet
6. **AF-HSRM** - Axial Flux High Speed Reluctance Motor

NOTATION

- ϕ_{0g2} - Air gap flux linkage of magnetic leakage circuit on both sides
- R_{m1} - Equivalent reluctance (main magnetic circuit)
- R_{m2} - Equivalent reluctance (magnetic leakage circuit)
- N_s - Number of stator poles
- N_r - Number of rotor poles
- T_{req} - Torque required (in Newton-Meter)
- P_{kw} - Power output in watts
- β_s - Stator pole angle
- β_r - Rotor pole angle
- D_0 - Outer diameter of the machine

- D - Frame size
- A_s - Stator pole area
- A_{sc} - Stator core area
- Φ - Flux in the stator pole
- ϕ_y - Flux in the yoke
- H_s - Stator pole height
- A_r - Rotor pole area
- B_g - Air gap flux density
- T_{ph} - Turns per phase

Chapter 1

INTRODUCTION

Electric vehicles (EVs) are experiencing rapid adoption worldwide due to the demand for sustainable transportation and the reduction of fossil fuel dependency. The electric motor is a fundamental component of EVs, providing the necessary torque and efficiency for propulsion. Traditional EV motors, such as Permanent Magnet Synchronous Motors (PMSM) and Brushless DC Motors (BLDC), have dominated the market due to their high efficiency and performance. However, these motors often rely on rare-earth materials, which drive up costs and create supply chain vulnerabilities. Consequently, there is growing interest in alternative motor technologies that deliver similar performance while reducing dependence on rare-earth materials.

The Switched Reluctance Motor (SRM) has emerged as a promising alternative. Unlike conventional motors, SRMs operate on reluctance torque, a principle where the rotor aligns itself with the minimum magnetic reluctance position within a magnetic field. This structure results in a motor that is cost-effective, robust, and highly efficient. Notably, SRMs do not require permanent magnets or brushes, which significantly reduces the cost and complexity of the motor while enhancing its lifespan and ease of maintenance.

This project explores the design and fabrication of an 8/6 Switched Reluctance Motor (SRM), focusing on applications within the EV industry. The 8/6 configuration (8 stator poles and 6 rotor poles) is particularly suited for EVs due to its balance of torque, efficiency, and compact design. Additionally, the project includes the development of a custom driver circuit with feedback sensors, which allows for precise control over speed and torque. This integration is critical in EV applications where high performance and reliability are required.

The project objectives center on both the theoretical design and practical implementation of the SRM, assessing its performance through magnetic field analysis, winding configuration, and switching control strategies. The SRM's advantages—such as no reliance on rare-earth magnets, high efficiency, and simple construction—position it as a viable candidate for the next generation of EV motors. While some challenges remain, including torque ripple and noise at high speeds, the SRM's potential benefits in cost reduction and efficiency make it a compelling focus for further research and development.

In summary, this project contributes to ongoing research efforts in sustainable motor technology, demonstrating that SRMs can offer a competitive alternative for EVs. By refining SRM design and integrating advanced driver systems, this work aims to provide insights into scalable and cost-effective motor solutions for the future of electric mobility.

1.1 PROJECT BACKGROUND

The transition to electric vehicles (EVs) has accelerated the search for efficient, cost-effective motor technologies that can meet the rigorous demands of automotive applications. Traditional EV motors, such as Permanent Magnet Synchronous Motors (PMSMs) and Brushless DC Motors (BLDCs), have been widely used due to their high torque density and efficiency. However, these motors often rely on rare-earth materials, making them expensive and vulnerable to supply chain disruptions. This dependency has led to a growing interest in alternative motor technologies, especially those that can deliver comparable performance without relying on these costly materials.

Switched Reluctance Motors (SRMs) present a promising alternative due to their unique design, which eliminates the need for rare-earth magnets. Instead, SRMs generate torque through reluctance, or the tendency of magnetic flux to follow a path of least resistance. This results in a simple yet robust structure, making SRMs more cost-effective and suitable for high-performance applications. Despite their advantages, SRMs have certain limitations, such as increased noise and torque ripple at high speeds. These drawbacks have historically limited SRM adoption, but recent advances in control and drive systems have helped mitigate these issues, making SRMs increasingly viable for automotive use.

This project focuses on the design and fabrication of an 8/6 SRM (featuring eight stator poles and six rotor poles) specifically for EV applications. By developing a custom driver circuit and implementing feedback mechanisms, this project aims to enhance control precision and optimize SRM performance, even under demanding conditions. The project not only seeks to demonstrate the practical benefits of SRMs in EVs but also to contribute to ongoing research efforts aimed at reducing the automotive industry's reliance on rare-earth materials, thereby supporting a more sustainable future in electric mobility.

1.2 PROBLEM STATEMENT

The demand for efficient and sustainable motor technology in the electric vehicle (EV) industry has brought attention to the limitations of traditional motor types, such as Permanent Magnet Synchronous Motors (PMSM) and Brushless DC Motors (BLDC). While these motors provide high torque density and efficiency, they are heavily dependent on rare-earth magnets, which are costly and environmentally challenging to source. This reliance on rare-earth materials not only increases the overall cost of EV production but also raises concerns about long-term sustainability and the security of supply chains. The result is an urgent need for alternative motor technologies that can offer high performance without such dependencies.

Switched Reluctance Motors (SRMs) present a potential solution, as they do not require permanent magnets and can be designed to operate with high efficiency and reliability in EV applications. However, SRMs have historically been underutilized in the EV industry due to certain drawbacks, including increased operational noise, torque ripple at high speeds, and the need for precise control systems to manage speed and torque output effectively. These challenges must be addressed to make SRMs a viable alternative to conventional motors in automotive applications.

This project addresses the above problem by designing and fabricating an 8/6 SRM, specifically optimized for EV use. The project will also develop a custom driver circuit with integrated feedback mechanisms to enhance control precision and mitigate issues like torque ripple. By focusing on both the design and practical implementation of the SRM and driver system, this project seeks to demonstrate the feasibility of SRMs as a cost-effective, sustainable alternative for the EV industry, contributing to the broader goal of reducing dependency on rare-earth materials.

1.3 PROJECT OBJECTIVE

This project focuses on the design and construction of an 8/6 switched reluctance motor (SRM) and its corresponding driver circuit.

Currently in the EV industry use of the higher power density magnetic motors with high torque and less cost such as BLDC motor and the PMSM-permanent magnet synchronous motors had become primary preferred choice for electric vehicles.

But in the near future, the PMSM(Permanent Magnet Synchronous Motors) will be getting replaced by SRM -Switched Reluctance Motor for the applications of electric vehicle(because of the potential advantages)

Chapter 2

LITERATURE REVIEW

2.1 DESIGN PROCEDURE FOR SRM

Switched-reluctance motors have gained attention in the variable-speed drive market. The savings in manufacturing cost of the motor due to its simplicity of construction and use of minimum number of switching devices in the drive circuit are two important factors in its favor compared to any other motor drive. The presented concern is with some of the design aspects of the switched-reluctance motor for non-servo applications. Towards this objective, a step-by-step procedure is developed for the design of switched reluctance motors.

Switched-reluctance motors have been developed for electric propulsion, fan, pump, and even servo applications. They have simple constructional features of concentrated windings but with no windings on the rotor itself. They have some of the operational features of a synchronous motor and lend themselves to programming of their torque and speed profiles. Due to the unidirectional current requirement in the switched-reluctance motor, its converter has a minimum number of switching devices compared to a conventional inverter-fed synchronous or induction motor drive.

2.2 SWITCHED RELUCTANCE MOTOR APPLICATIONS TO EV AND HEV: TORQUE CONTROL ISSUES

Switched reluctance motor (SRM) is being used by many automotive companies around the world as the drive motor for EV (Electric Vehicle) and HEV (Hybrid Electric Vehicle) applications. Torque pulsations are inherent in SRMs due to the doubly salient structure of the machine and its sequential excitation. Minimized torque ripple design of a SRM in an EV will certainly lead to a comfortable drive. Torque ripple in SRM is simulated utilizing both the bulk saturation model as well as the complete model, considering the local saturation in addition to the bulk saturation and a comparison of these two methods is presented. A novel method of torque ripple reduction that can be used is also presented. It is based on the optimal current profiling technique. But instead of phase current, unsaturated current obtained from phase current minus current required to overcome saturation is compared with current from static torque-unsaturated current-rotor position data table as reference which was generated using torque linearization and decoupling technique and the error is used to minimize the torque ripple.

2.3 DESIGN OF TWO-PHASE 8/6 SWITCHED RELUCTANCE MOTOR FOR TWO-WHEEL ELECTRIC VEHICLE

There is a strict space constraint for accommodating the hub motor in a two-wheel electric vehicle. Permanent magnet motors are widely used in these applications as they have high flux density and magnetic loading. Hence, they can meet high torque requirements at low speed. The two-phase switched reluctance motor offers an advantage over the three-phase motor in terms of torque density. A two-phase SRM is designed with higher torque density to meet the space constraints and typical torque-speed requirements of an electric two-wheeler. A two-phase 8/4 motor is designed to demonstrate the advantages of a two-phase switched reluctance motor over the three-phase motor. Simulation results are presented for the designed motor compared to a commercial 3 kW brushless DC permanent magnet motor used in a two-wheel electric vehicle. Comparison is drawn in terms of torque-speed characteristics for a fixed battery voltage and current rating. The results show the suitability of a two-phase switched reluctance motor for the application.

Chapter 3

INTRODUCTION TO SRM

Switched Reluctance Motors (SRMs) represent a unique category within the realm of electric motors, characterized by their simple construction and robust operation. Their design revolves around the principle of variable reluctance, where the stator windings are sequentially energized to attract the rotor. This interaction between the stator and rotor results in the generation of rotational torque. SRMs stand out due to their inherent simplicity. Compared to other motor types, they feature a less complex design, reducing manufacturing costs and enhancing reliability. This simplicity translates into a more robust and durable motor, capable of enduring harsh operating conditions such as high temperatures and vibrations.

One of the defining characteristics of SRMs is their ability to deliver high torque at low speeds. This makes them particularly suitable for applications that require substantial starting torque, such as robotics, material handling, and heavy machinery. The inherent torque density of SRMs allows them to efficiently generate the necessary force for demanding tasks. Another notable advantage of SRMs is their potential for sensorless operation. Unlike some other motor types that rely on position sensors for accurate control, SRMs can be designed to operate without them. This eliminates the need for additional components, reducing complexity and cost. Sensorless operation also enhances the motor's reliability and durability.

However, SRMs are not without their limitations. One common drawback is their tendency to produce higher acoustic noise levels compared to some other motor types. This can be attributed to the inherent switching and magnetic interactions within the motor. Additionally, SRMs may exhibit torque ripple, which can cause vibrations and reduce overall smoothness of operation. To address these challenges, researchers and engineers have been actively exploring various techniques and materials to improve the performance of

SRMs. Advancements in control strategies, winding designs, and rotor geometries have contributed to mitigating torque ripple and reducing noise levels. Furthermore, the development of new magnetic materials has enhanced the efficiency and power density of SRMs.

In conclusion, Switched Reluctance Motors offer a unique combination of simplicity, robustness, and high torque output. Their potential for sensorless operation and ability to withstand demanding conditions make them attractive for a wide range of applications. While SRMs may face certain challenges, ongoing research and development efforts are continually addressing these limitations, paving the way for their broader adoption in various industries. [1]

3.1 HISTORY AND EVOLUTION

The concept of SRMs dates back to the 1830s, but significant developments occurred in the 1960s and 1970s. Innovations in power electronics and control systems enabled SRMs to become competitive with traditional motors. Key milestones include:

- 1830s: Initial experiments by W. F. Hoyt and E. M. Hopkins
- 1960s: Development of thyristor-based SRM drives
- 1970s: Introduction of microprocessor-controlled SRM drives
- 1980s: Advancements in SRM design and materials
- 1990s: Widespread adoption in industrial and automotive applications
- 2000s: Emergence of advanced control strategies and sensorless control

3.2 BLOCK DIAGRAM

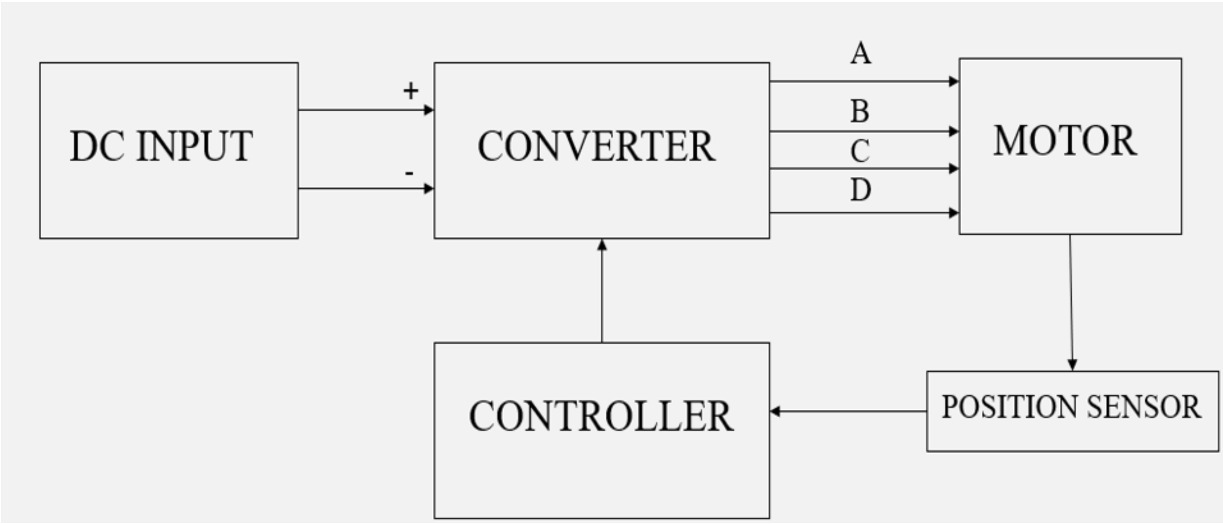

Figure 3.1: Basic block diagram of a srm motor

This block diagram illustrates the basic control and power flow in an 8/6 Switched Reluctance Motor (SRM) drive system, designed for applications like electric vehicles (EVs). The system begins with a DC Input source, which supplies the required direct current to power the motor. This input is then fed into a Converter, which converts the DC power into a form that can be used to drive the motor by sequentially energizing the motor phases. The converter output is divided into multiple connections (labeled A, B, C, and D) that represent different phases of the SRM, each connected to a specific winding in the motor.

A Controller governs the operation of the converter, sending control signals to determine the timing and sequence of phase activations. This precise control is necessary for producing smooth rotational motion, as SRMs operate based on the principle of reluctance torque, which requires that the magnetic field aligns the rotor with the stator poles in a controlled sequence.

A Position Sensor is integral to the system, providing real-time feedback to the controller regarding the rotor's position. This feedback enables the controller to accurately align the magnetic fields and minimize issues like torque ripple, which is crucial for maintaining efficiency and stability, especially in high-speed operations. The integration of these components — DC input, converter, controller, motor, and position sensor — allows for precise and efficient operation of the SRM, making it suitable for demanding environments such as electric vehicles.

3.3 WORKING PRINCIPLE

Switched Reluctance Motors (SRMs) operate on the principle of variable reluctance. This means that the magnetic resistance between the stator (stationary part) and rotor (rotating part) changes as the rotor moves.

The stator contains multiple windings arranged in a specific pattern, while the rotor has salient poles or teeth that interact with the stator's magnetic field. A controller manages the switching of the stator windings to produce the desired torque and speed.

The working process involves energizing a stator winding, which creates a magnetic field that attracts the rotor's salient pole. Once aligned, the stator winding is de-energized, and the rotor's momentum carries it to the next position. This process is repeated with the next stator winding, resulting in continuous rotation.

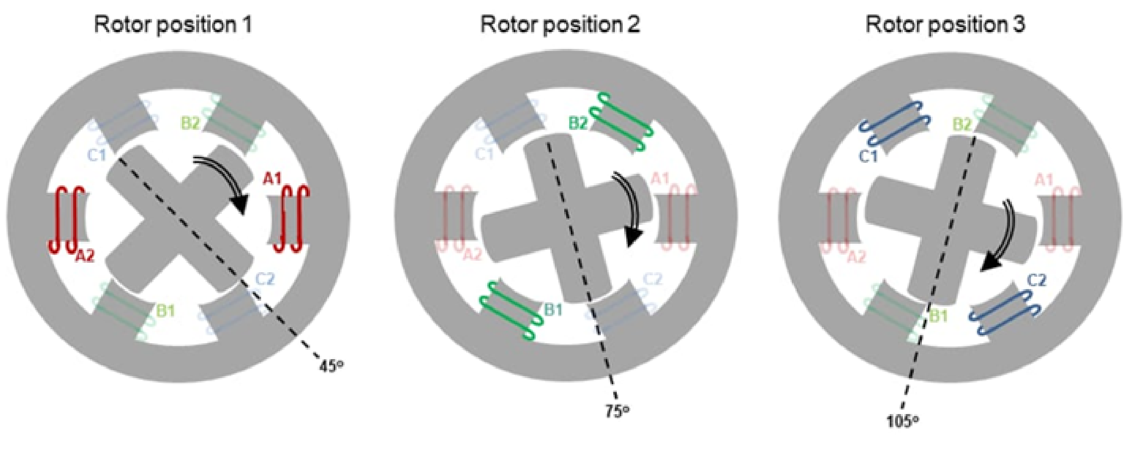

Figure 3.2: Modes of operation of a 6/4 SRM

A 6/4 SRM is a specific type of SRM with six stator poles and four stator windings.

The rotor typically has four salient poles or teeth. This configuration offers a balance between simplicity and torque ripple performance. The reduced number of stator windings can potentially lower manufacturing costs and complexity, while the 6/4 arrangement helps to minimize torque ripple, resulting in smoother operation.

SRMs in general, and 6/4 SRMs in particular, are widely used in various industries due to their advantages such as simple construction, high torque density, robustness, and potential for sensorless operation. They are well-suited for applications requiring high starting torque, such as robotics, material handling, and electric vehicles. [2]

3.4 ADVANTAGES OF SRM

* Simple Construction: SRMs have a simpler design compared to other motor types, reducing manufacturing costs and improving reliability. This simplicity also makes them more robust and tolerant to harsh operating conditions.

* High Torque Density: SRMs can produce high torque at low speeds, making them ideal for applications that require substantial starting torque. This characteristic is particularly beneficial in industries such as robotics, material handling, and heavy machinery.

* Robustness: SRMs are relatively rugged and can withstand harsh operating conditions, such as high temperatures and vibrations. This makes them suitable for demanding environments where other motor types might fail.

* Sensorless Operation: SRMs can be operated without position sensors, reducing complexity and cost. Sensorless control can also enhance the motor's reliability and durability.

* Scalability: SRMs can be designed and manufactured in various sizes and configurations to meet different power requirements. This scalability makes them versatile for a wide range of applications

3.5 APPLICATIONS OF SRM

* Industrial Automation: Robotics, material handling, machine tools, and factory automation systems.

* Automotive Industry: Electric vehicles, hybrid vehicles, power steering systems, and traction control systems.

* Aerospace: Actuators, control systems, and flight control surfaces.

* Consumer Electronics: Power tools, washing machines, air conditioners, and fans.

* Renewable Energy: Wind turbines, solar trackers, and wave energy converters.

* Medical Equipment: Surgical robots, rehabilitation devices, and medical imaging systems.

3.6 LIMITATIONS OF SRM

* Higher Acoustic Noise: SRMs tend to produce higher noise levels compared to some other motor types due to the inherent switching and magnetic interactions. This can be a concern in applications where noise reduction is critical.

* Torque Ripple: SRMs may exhibit torque ripple, which can cause vibrations and reduce overall smoothness of operation. This can be mitigated through careful design and control techniques.

* Efficiency: SRMs can have lower efficiency compared to some other motor types, particularly at high speeds. However, advancements in materials and control strategies have helped to improve the efficiency of SRMs.

* Complexity of Control: The control of SRMs can be more complex compared to other motor types, as it requires precise switching of the stator windings to achieve optimal performance.

* Limited Speed Range: SRMs typically have a limited operating speed range compared to some other motor types, which can be a constraint in certain applications.

Chapter 4

DESIGN PROCEDURE

4.1 INTRODUCTION

Designing various parameters of the SRM motor involves optimizing key elements like pole configurations, winding specifications, and magnetic flux paths to achieve desired performance. This process ensures efficient torque production, minimal losses, and suitability for high-demand applications such as electric vehicles.

4.2 MACHINE SPECIFICATIONS

- Treq=Php*745.6/(2N/60) NM . . . . (1)
- Where Pkw is the power output in watts.

4.3 POLE SELECTION

- 6/4,8/4,10/6,12/6,4/2,2/2 etc configurations are possible
- but 6/4 8/6 are most common and easy to construct compared to other complex combinations

4.4 SELECTION OF POLE ANGLES

- Condition 1: stator pole angle must be lesser than the rotor pole angle

- $\beta s < \beta r$

- Condition 2: $\beta s < (2/Nr) - \beta r\ \beta S + \beta r 60$

- Stroke Angle =($2\pi/(Ns * Nr/2)$)…..(2)

  Ns= number of stator poles

  Nr = number of rotor poles

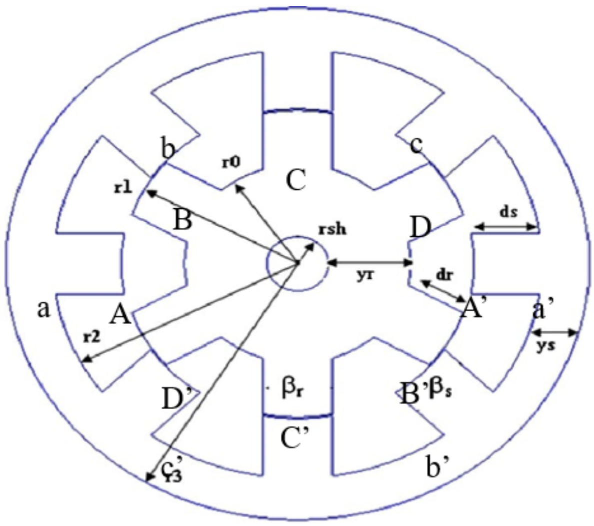

Figure 4.1: cross sectional area of stator

4.5 STATOR DESIGN

- Outer diameter of the machine (D0) = peripheral length/π…..(3)

  - Frame size (D)=(D0/2)+49……….(4)

- Stator pole area (As)=((D/2)-g)L βs……(5)

  - Stator core area (Asc)=As/1.6……(6)

- Flux in the stator pole (Φ) = $Bs * As$………(7)

- Flux in the yoke (ϕy) = $\phi/2$……….(8)

  - Stator pole height (Hs)=(D/2)-(g)-(Dsh/2)-(Asc/L)…..(9)

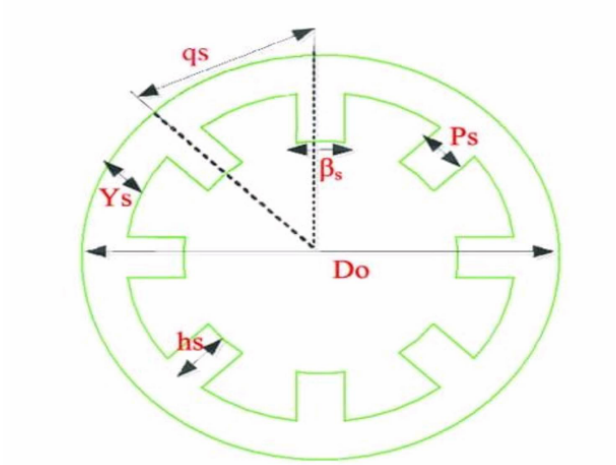

Figure 4.2: Stator

4.6 ROTOTR DESIGN

- Rotor pole area (Ar) =(D/2)L r. . . . . . (10)
- Flux in the rotor pole (ϕ) = Br/Ar. . . ..(11)
- Rotor pole height (hr) =(D0/2)-(Ar/L)-(D/2). . . . . . (12)
- Air gap area (Ag)=(D/2)-(g/2)*((r+ s)/2)*(/180)*75*$10^{-}6$..(13)
- Air gap flux density (Bg)=As Bs/Ag. . . ..(14)

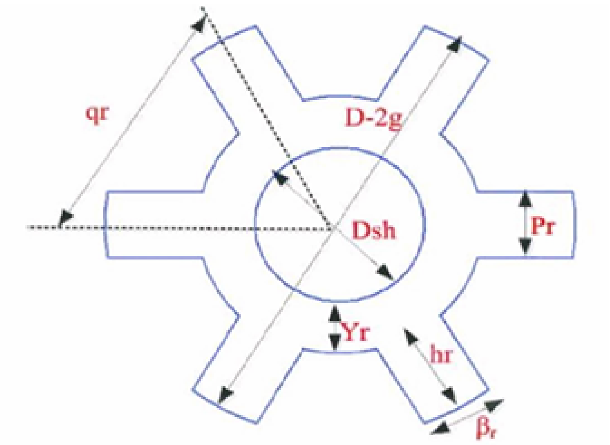

Figure 4.3: Rotor

4.7 WINDING DESIGN

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- Turns per phase $(T_{ph}) = \frac{S}{I_p}$ .....(15)
- MMF drop $(S) = 2\left(H_s I_s + H_r I_r + H_g I_g\right) + \left(\frac{H_{sc} I_{sc}}{2}\right)$ .....(16)
- Stator pole magnetic field intensity $(H_s) = \frac{B_s}{\mu}$ .....(17)
- Rotor pole magnetic field intensity $(H_r) = \frac{B_r}{\mu}$ .....(18)
- Stator core magnetic field intensity $(H_{sc}) = \frac{B_{sc}}{\mu}$ .....(19)
- Air gap magnetic field intensity $(H_g) = \frac{B_g}{\mu}$ .....(20)
- Stator core magnetic flux density $(B_{sc}) = \frac{\Phi_{sc}}{A_{sc}}$ .....(21)

Chapter 5

MODELLING AND SIMULATION OF SRM

ANSYS RMxprt is a powerful tool designed for the rapid design and analysis of electric machines, particularly focused on rotating machinery like motors and generators. It provides users with a streamlined interface for modeling and simulating electromagnetic performance, enabling engineers to quickly evaluate various design parameters and optimize for efficiency, performance, and cost.

In our project, RMxprt is specifically utilized to model the Switched Reluctance Motor (SRM), allowing us to analyze its electromagnetic characteristics and optimize its design. With integrated capabilities for electromagnetic field analysis, thermal management, and structural assessment, RMxprt facilitates a comprehensive approach to electric machine design. Its ability to generate detailed reports and integration with other ANSYS software enhances collaboration and ensures robust, reliable designs. Whether for academic research or industrial applications, ANSYS RMxprt is an invaluable resource for engineers working on electromechanical systems like our SRM project.

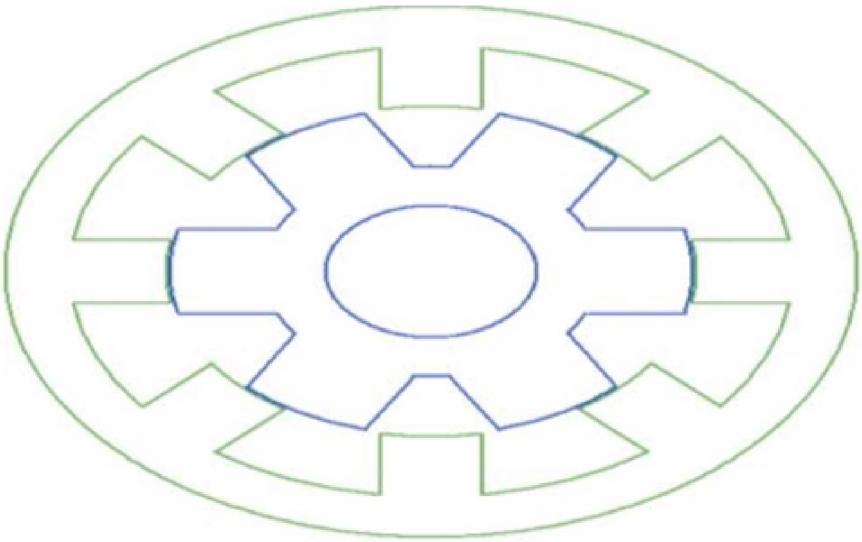
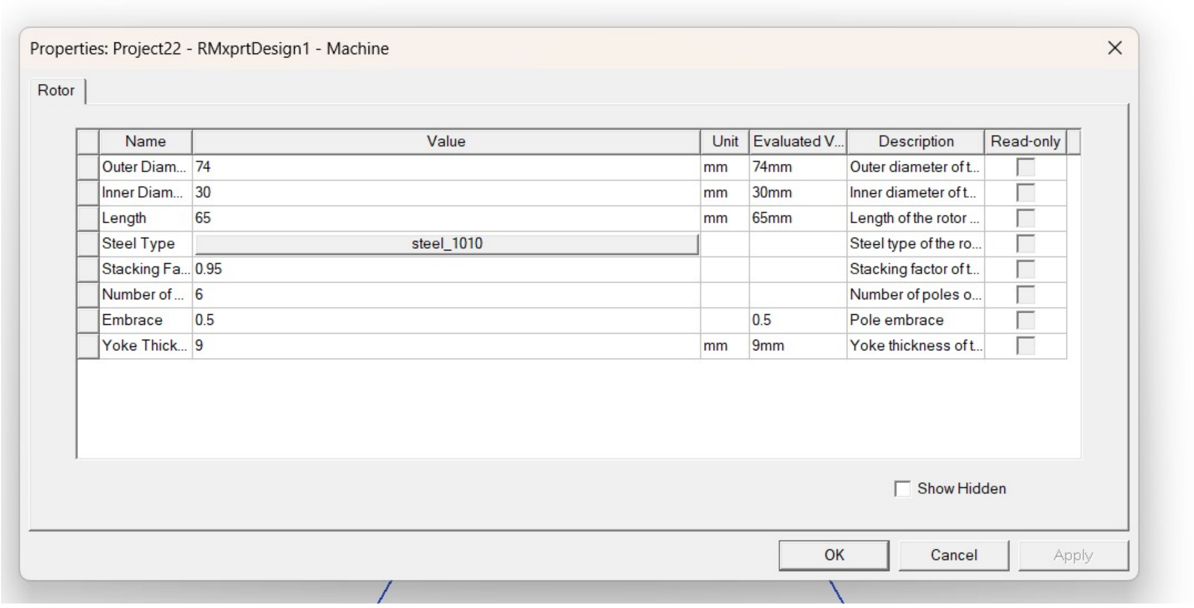


Figure 5.1: RMxprt model of the SRM

Leveraging RMxprt Model for SRM Design The RMxprt Model provides a versatile platform for designing and analyzing 8/6 switched reluctance motors (SRMs). By adjusting motor parameter values within this model, engineers can tailor the motor's characteristics to meet specific performance requirements. In this particular study, the motor parameters were initialized using default values from the Maxwell program. These parameters, as illustrated in upcoming Figures , establish a starting point for the design process. To access and modify these parameters, users can navigate to the RMxprt model in the machine tree and select the desired stator and rotor geometric values. It is important to note that the choice of rotor steel type significantly impacts the motor's performance.

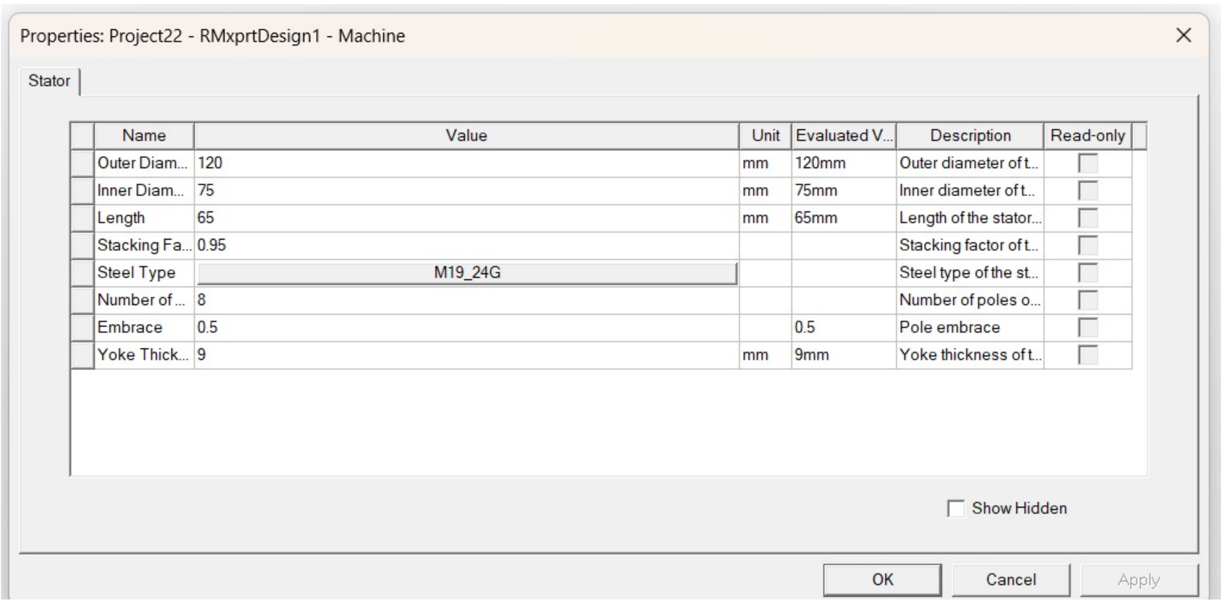
By effectively utilizing the RMxprt Model and carefully selecting motor parameters and materials, engineers can optimize the design of 8/6 SRMs for various industrial and commercial applications.

After designing the RMxprt model shown in Fig. 4.1, one can design the transient model with which to analyze the motor. To create the transient model, the RMxprt model is analyzed from the analysis section under the RMxprt project tree. After the finishing the analysis with aright click on the setup section under the analysis tab and selecting the create Maxwell 2D design



Name	Value	Unit	Evaluated V...	Description	Read-only
Outer Diam...	74	mm	74mm	Outer diameter of t...	
Inner Diam...	30	mm	30mm	Inner diameter of t...	
Length	65	mm	65mm	Length of the rotor ...	
Steel Type	steel_1010			Steel type of the ro...	
Stacking Fa...	0.95			Stacking factor of t...	
Number of ...	6			Number of poles o...	
Embrace	0.5		0.5	Pole embrace	
Yoke Thick...	9	mm	9mm	Yoke thickness of t...	

Figure 5.2: Rotor Parameter



Name	Value	Unit	Evaluated V...	Description	Read-only
Outer Diam...	120	mm	120mm	Outer diameter of t...	
Inner Diam...	75	mm	75mm	Inner diameter of t...	
Length	65	mm	65mm	Length of the stator...	
Stacking Fa...	0.95			Stacking factor of t...	
Steel Type	M19_24G			Steel type of the st...	
Number of ...	8			Number of poles o...	
Embrace	0.5		0.5	Pole embrace	
Yoke Thick...	9	mm	9mm	Yoke thickness of t...	

Figure 5.3: Stator Parameter

5.1 ANSYS MAXWELL 2D DESIGN AND SIMULATION

The results of the analysis can be seen under the Maxwell 2D design (transient) project tree under results and the field overlays tabs. For the magnetic analysis results we have examined in this study, with the right-click on the field overlays tab and select the results we want to see from the fields' option.

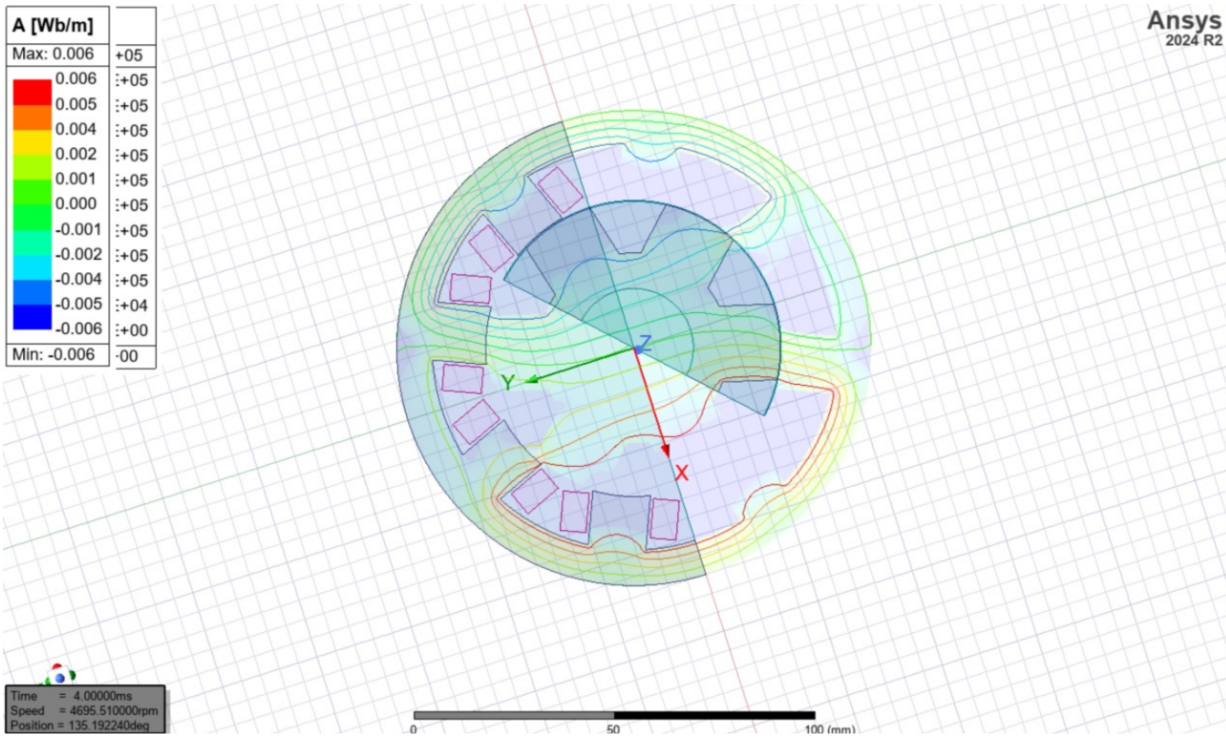


Figure 5.4: SRM Flux density Ansys Maxwell 2D design

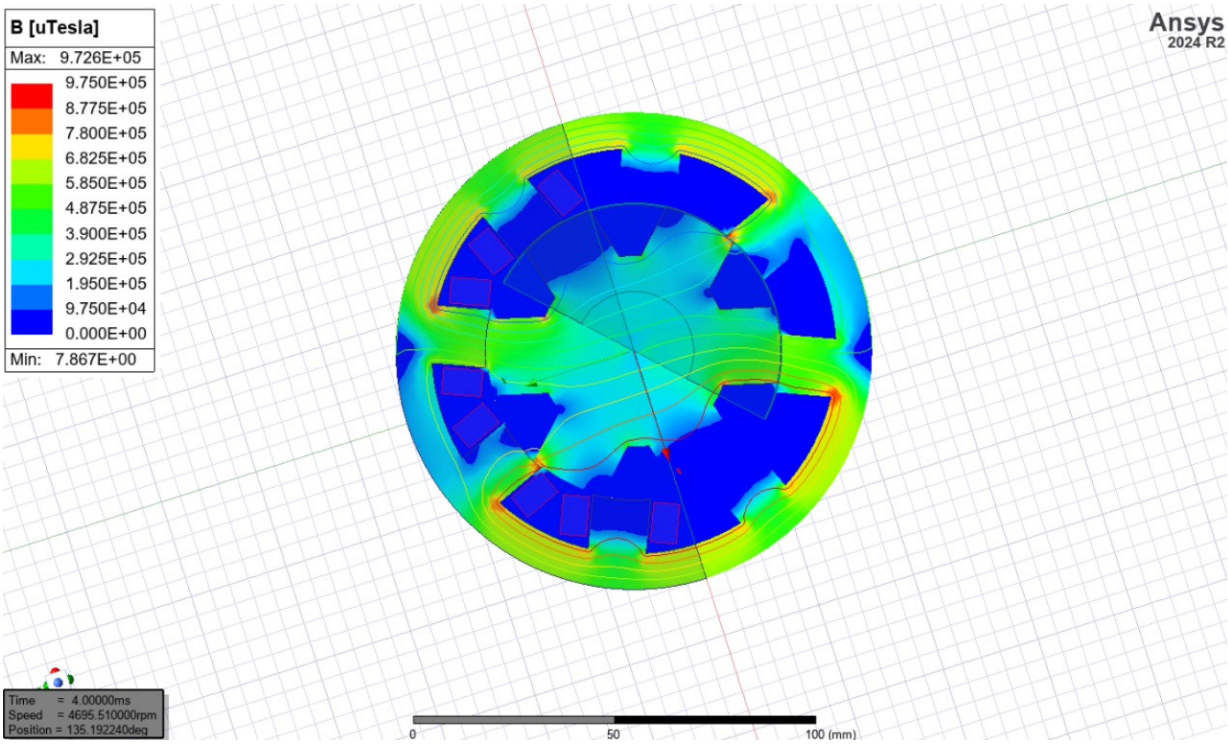


Figure 5.5: SRM Field intensity Ansys Maxwell 2D design

As the flux density vector graph (B), and field intensity (H-vector potential) obtained from the analysis are given in Fig. 4.4, Fig. 4.5, respectively. The graphs show the motor position at which phase B is energized. In Fig. 4.4, the B-phase magnetic flux vectors move through the rotor to the B-phase and then complete the circuit through the stator. In Fig. 4.4, the B (magnetic flux density) value of the motor is maximum on the B-phase poles with the color green and yellow, although the other poles are seen as blue. In Fig. 4.4, the B (magnetic flux density) value of the motor is maximum on the B-phase poles with the color green and yellow, although the other poles are seen as blue. The last graph of the analysis is Fig. 4.4 that shows the flux lines of the motor on the rotor poles, the stator poles, and the rotor core.

Chapter 6

SIMULATION OUTPUT AND RESULTS

Following are the results we obtained from Ansys software depicting various parameters such as magnetic flux lines, winding current, power voltage, torque, current etc. Apart from that 2-dimentional design of magnetic flux lines and magnetic density of the designed switched reluctance motor were found out. We found that the above design considerations of SRM were acceptable and obtained 3D view of SRM. [3] With the help of Ansys software we were able to run it without any error.

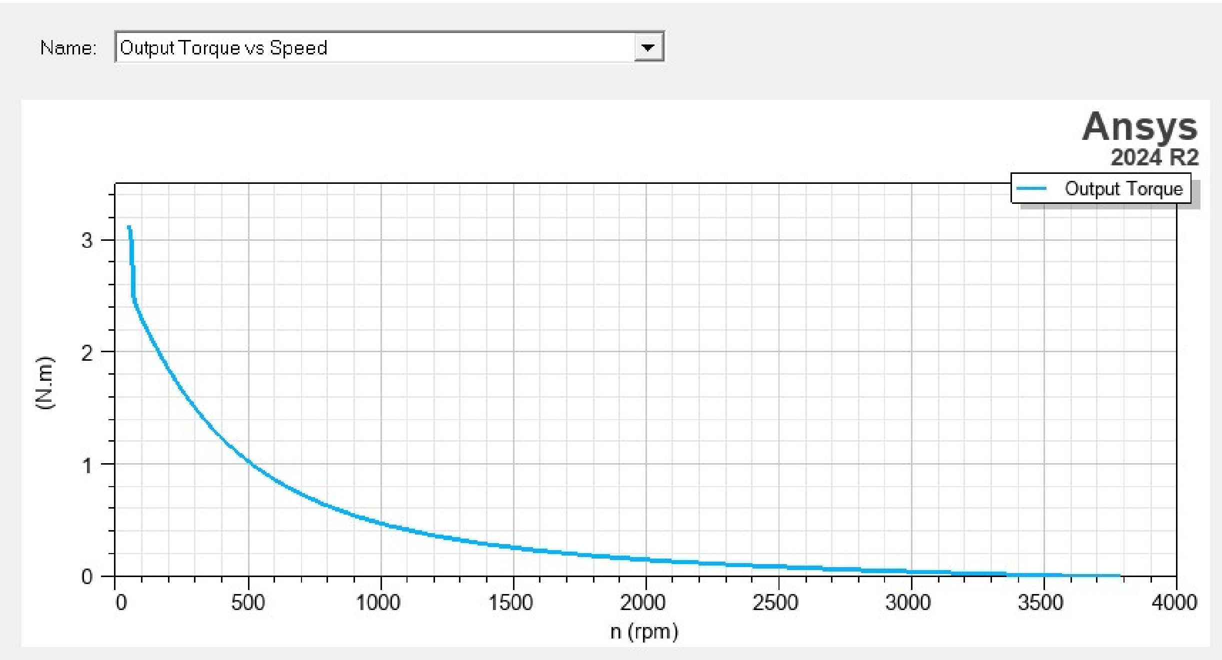


Figure 6.1: Output Torque

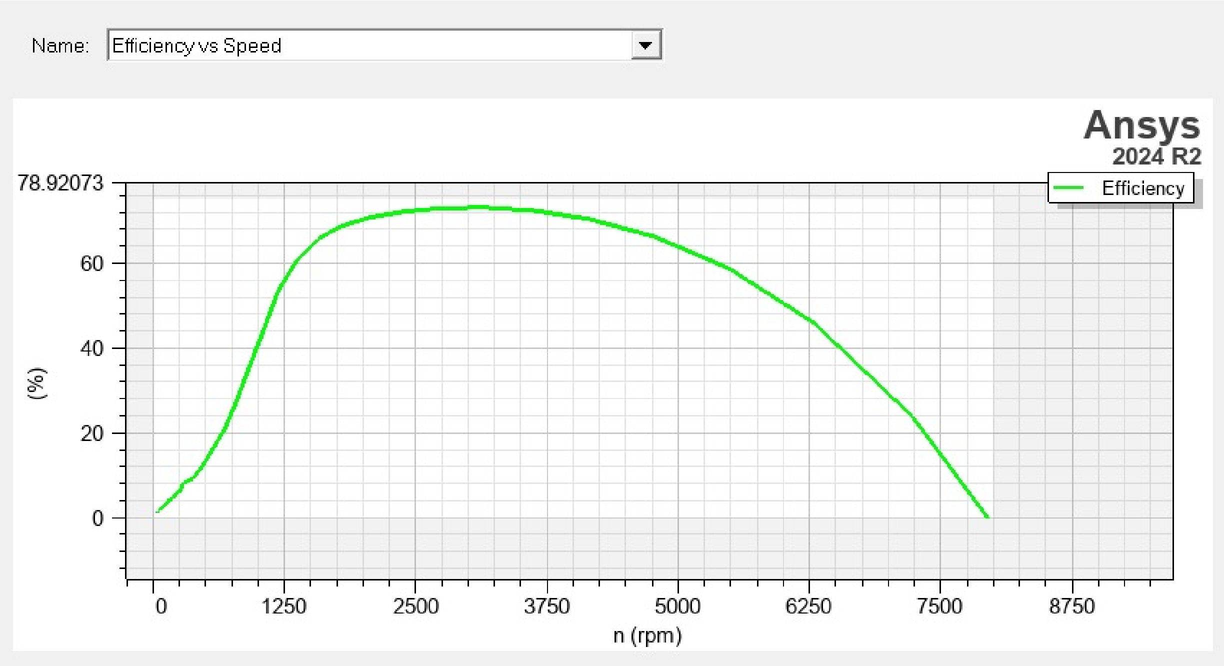


Figure 6.2: Efficiency

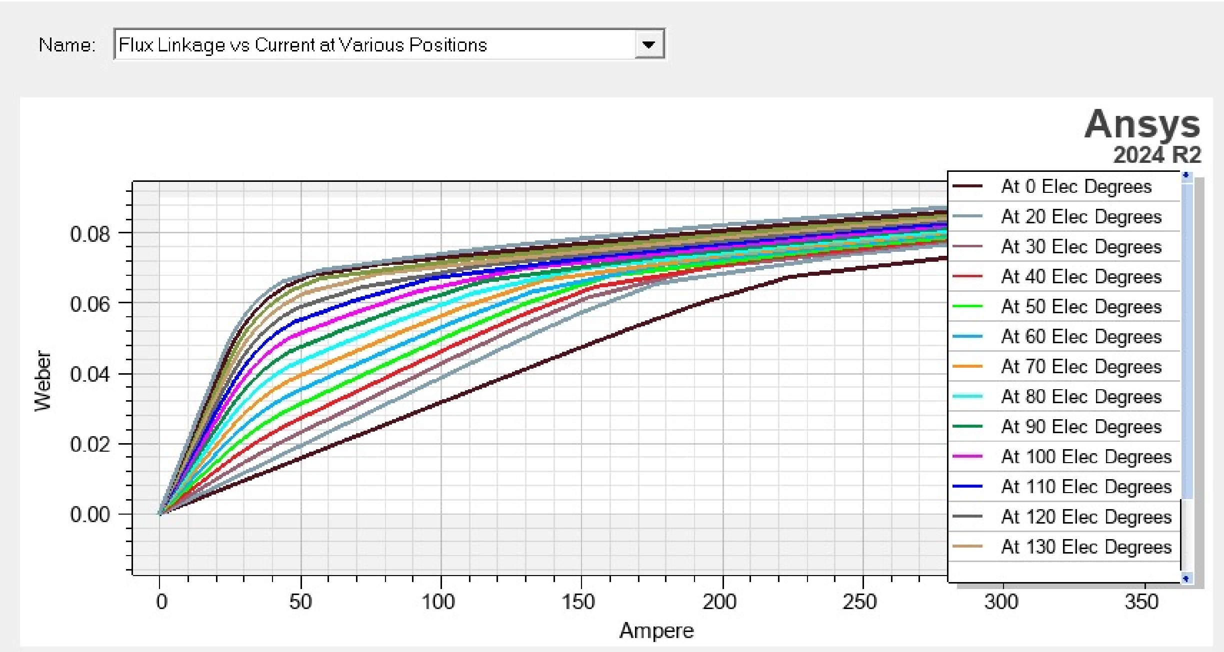


Figure 6.3: Flux linkage vs current

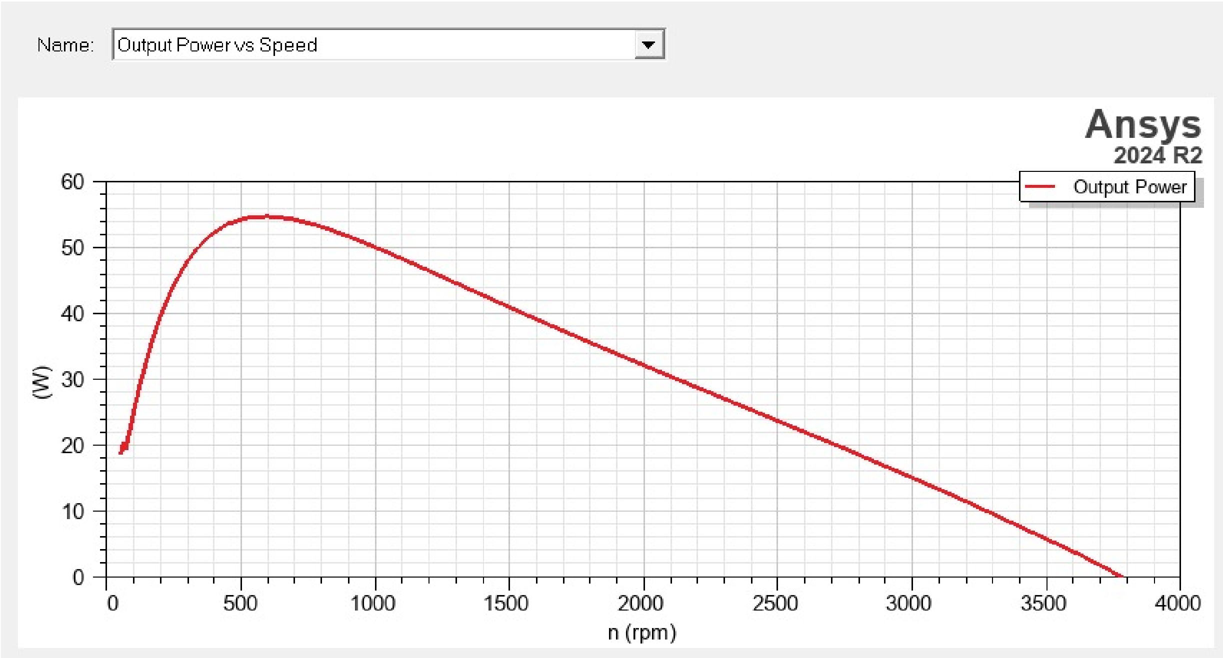


Figure 6.4: Torque

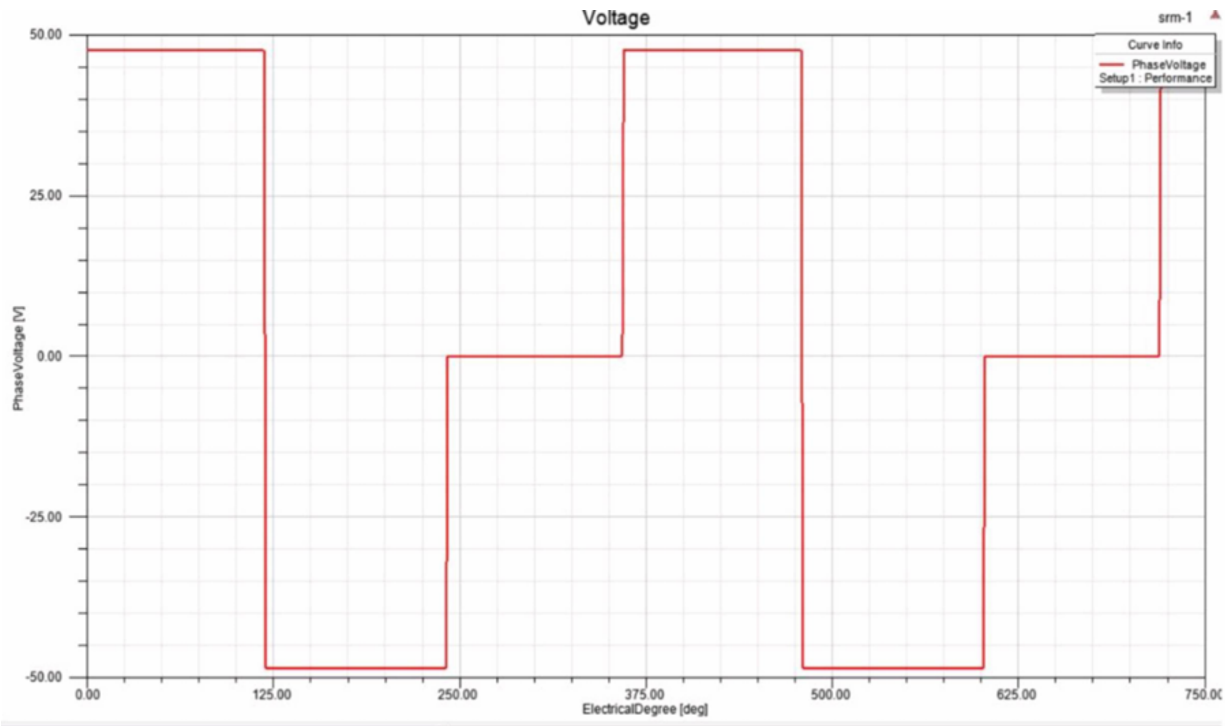


Figure 6.5: Voltage

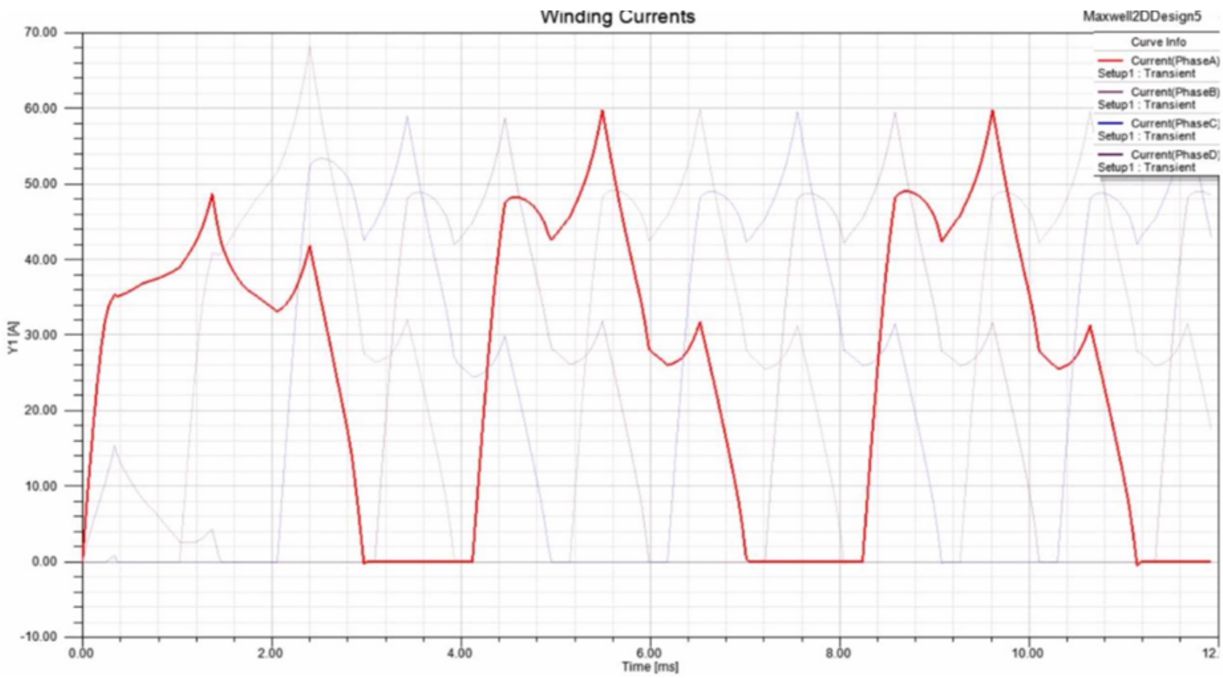


Figure 6.6: Winding current

Chapter 7

CONSTRUCTION

To construct the switched reluctance motor with the specified parameters, we utilized a previously built BLDC motor with an 8/6 configuration. The stator and rotor were separated, and the necessary components were gathered.

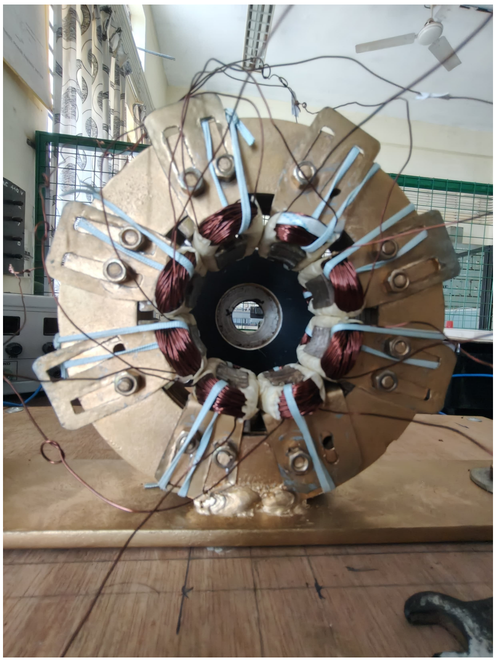


Figure 7.1: Stator

The 8/6 switched reluctance motor stator is constructed using laminated silicon steel, which helps reduce core losses and improve efficiency. Additionally, U-brackets made from GI (galvanized iron) sheets are used to provide structural support and enhance the mechanical stability of the stator.

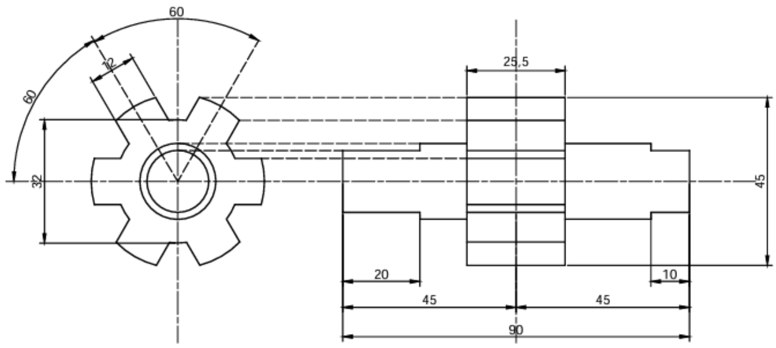


Figure 7.2: AutoCAD of rotor

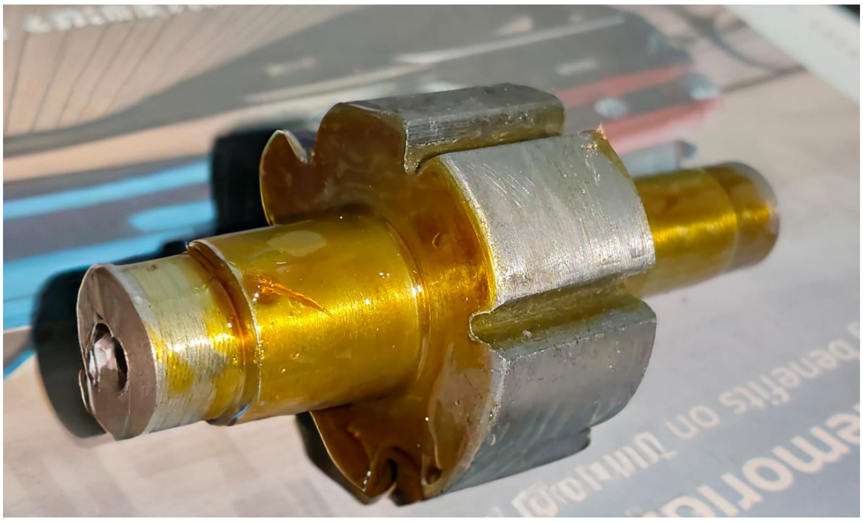


Figure 7.3: Rotor

The rotor made from a single piece of soft iron, which helps in reducing magnetic reluctance and improving the motor's performance. The rotor is designed with an air gap range of 2mm, ensuring efficient magnetic flux interaction between the stator and rotor.The specific air gap is essential for optimizing the motor's torque generation and overall efficiency.With the help of AutoCAD, we design a rotor as shown figure 7.3. beginfigure[H]

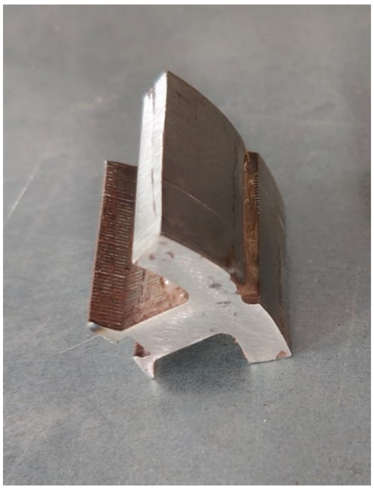


Figure 7.4: Stator pole

The stator pole shoe made of aluminum. The pole shoe is designed to guide the magnetic flux efficiently and enhance the performance of the motor. A 100-turn 22 SWG copper winding is wrapped around the pole shoe to generate the necessary magnetic field for motor operation. To ensure electrical insulation and prevent short circuits, the pole shoe is coated with electrical insulation varnish. This varnish coating also enhances durability and protects the winding from environmental factors.The stator pole shoe is essential for the operation of the switched reluctance motor, as it helps efficiently convert electrical energy into mechanical motion.

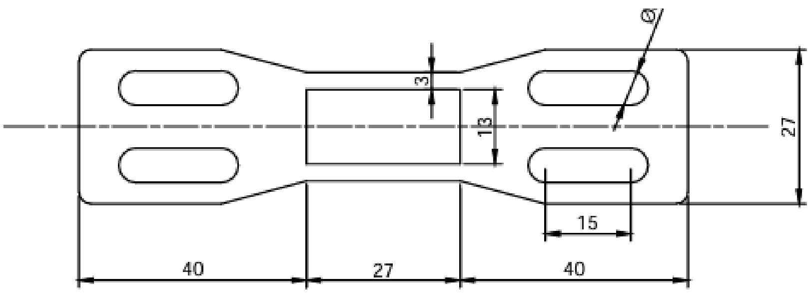


Figure 7.5: AutoCAD of bracket

Figure 7.6: U-Brackets

U-bracket is constructed to serve as the structural support for the stator pole shoes. The pole shoes are carefully positioned on the U-bracket to ensure proper alignment and efficient magnetic flux distribution. This setup helps in guiding the magnetic field effectively, contributing to the motor's overall performance. The U-bracket is made from a galvanized iron (GI) sheet, which provides durability, corrosion resistance, and mechanical strength.This bracket was designed using AutoCAD as shown in the figure 7.5 . The use of GI sheet ensures that the bracket can withstand operational stresses while maintaining the stability of the stator assembly.

Voltage	12v
Current	3.5A
Speed	1000rpm
Output power	150w

Table 7.1: Motor Specifications

Chapter 8

ELECTRONIC DRIVE

A drive is necessary for a Switched Reluctance Motor (SRM) as it manages sequential switching of stator windings, which is needed for proper operation. As there are no permanent magnets or rotor windings in the SRM, the drive ensures accurate phase energization timing based on feedback from the rotor position. In the absence of a drive, the motor will not be able to produce continuous torque effectively. The drive also manages current to reduce torque ripple and enhance efficiency. Besides, it facilitates variable speed control by varying the switching frequency and voltage. It provides bidirectional functionality, where the motor can be made to rotate in either direction according to demand. On use in electric vehicles, the drive also allows for regenerative braking, returning energy to the power source. It utilizes complex control techniques to optimize performance, minimize noise, and improve overall system reliability. The motor drive serves as the SRM's brain that guarantees the motor works smoothly and efficiently. Without this, the motor would not effectively work.

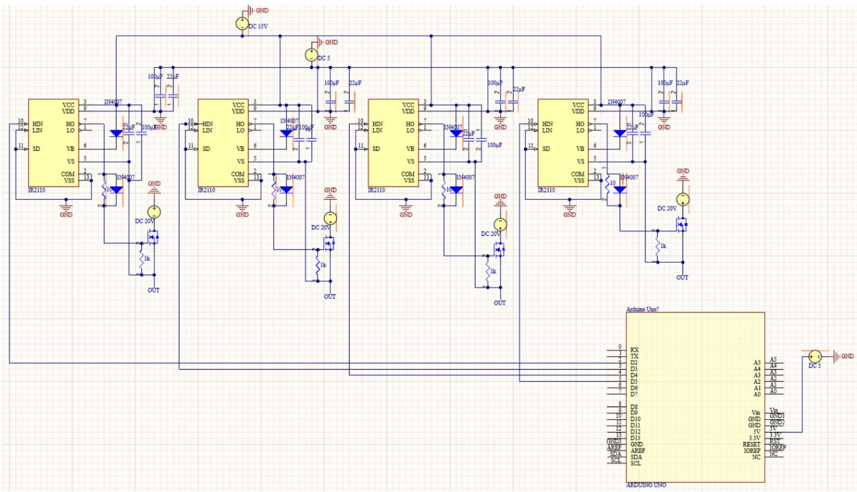


Figure 8.1: Drive circuit

The figure 8.1 shown drive circuitis designed for controlling a Switched Reluctance Motor (SRM) with an 8/6 configuration using an Arduino Uno as the controller. The circuit uses IR2110 gate driver ICs to drive the power transistors, which switch the SRM windings. The Arduino provides pulse signals to the high-side and low-side inputs (HIN, LIN) of the IR2110 ICs, ensuring proper phase excitation. Flyback diodes (IN4007) are used to protect the circuit from voltage spikes caused by inductive switching. The bootstrap capacitors (10µF, 22µF) help provide the required gate drive voltage for the high-side transistors. The DC 20V supply powers the motor windings, and a DC 15V and 5V supply powers the control circuit.

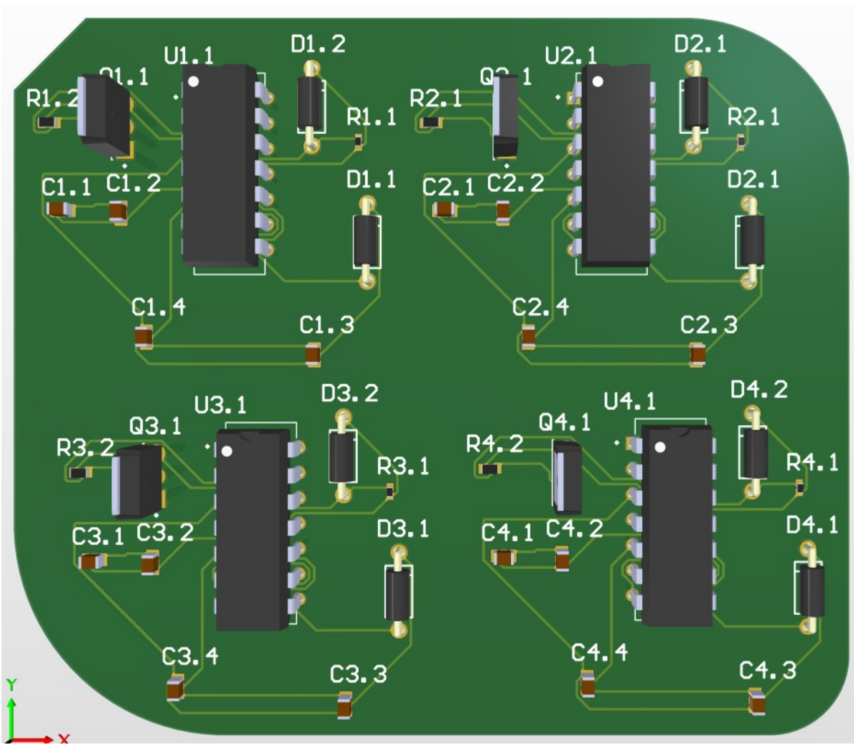


Figure 8.2: Drive circuit using PCB

The motor's phases are sequentially energized based on rotor position feedback, ensuring the proper switching sequence for continuous rotation. This circuit ensures efficient motor operation with controlled switching and protection mechanisms.Design the electronic PCB board as shown in the figure 8.2 using Altium software.

Chapter 9

SOFTWARE'S USED

9.1 ANSYS MAXWELL

A Switched Reluctance Motor (SRM) operates based on variable reluctance, where the rotor aligns with the stator poles to minimize magnetic reluctance. The 8/6 configuration consists of 8 stator poles and 6 rotor poles, ensuring efficient torque production. ANSYS software is widely used for designing and simulating SRMs, providing tools for electromagnetic, thermal, and mechanical analysis. The design process involves defining motor geometry, selecting magnetic materials, and placing windings on the stator. ANSYS Maxwell helps analyze magnetic flux distribution, torque production, and losses through finite element analysis (FEA). Thermal analysis ensures safe operating temperatures, while mechanical stress analysis evaluates structural durability. Multi-physics simulations integrate these factors for a comprehensive performance assessment. Virtual prototyping in ANSYS reduces development time and cost by optimizing pole shape and winding distribution. The final design ensures improved efficiency, reduced losses, and enhanced motor performance.

9.2 ALTIUM DESIGNER

Altium software is a very capable program applied for designing and simulating electronic circuits, especially power electronics and motor drives. Altium was employed in this project to design a drive circuit for an 8/6 Switched Reluctance Motor (SRM). The drive system is responsible for the operation control of the motor by effectively switching the phase windings to produce the necessary torque. The design process starts with the schematic creation, in which power electronics components like MOSFETs, gate drivers, and microcontrollers are chosen. The circuit is then placed on a printed circuit board (PCB) to provide efficient signal flow and power distribution. Altium's sophisticated PCB design tools optimize component placement, reduce electromagnetic interference, and enhance thermal performance. The software provides real-time rule checking, providing a solid and stable PCB design

9.3 AutoCAD

AutoCAD is an efficient 2D drafting application commonly applied to mechanical design and engineering purposes. In this project, we prepared a 2D design of an 8/6 Switched Reluctance Motor (SRM) rotor and U-bracket utilizing AutoCAD. The rotor comprised of 6 poles is well-drawn so that it remains accurately aligned in relation to the stator. The U-bracket is positioned to offer strength support and stabilize the motor assembly. AutoCAD's accurate dimensioning features facilitate the production of detailed drawings for fabrication. Layer control facilitates the easy distinction of motor components, enhancing clarity in the design. The software makes it possible to make rapid changes and ensure the design is technically compliant. We can produce an optimized 2D model of the rotor and U-bracket using AutoCAD, minimizing errors prior to fabrication.

AutoCAD is a market-leading 2D computer-aided design (CAD) software application by Autodesk. It is extensively used for the creation of technical drawings with intricacies in mechanical, electrical, and civil engineering. AutoCAD offers tools for accurate line work, annotations, and dimensioning that can be effectively used to create mechanical components. It has multiple file formats available to provide ease in modification, thereby ensuring seamless efficiency in the manufacturing and designing process. Its precision and range make it a valuable resource in engineering design and documentation.

Chapter 10

ESTIMATE

10.0.1 ELECTRONIC DRIVE

SL.NO	DESCRIPTION	QTY	UNIT PRICE	AMOUNT
1	ARDUINO UNO R3-CLONE (ADIY) CP2102	1	527.63	630.01
2	EL CAP 1000/25 KEL	4	7.63	36.01
3	JUMPER WIRE STRIP M/M (SET OF 40)	1	120.53	133.07
4	6A10 3NIX DIODE	8	5.93	56.00
5	10K 0.25W CFR 5%	8	0.85	8.00
6	IC IR 2110	5	140.22	840.0
7	PCB 6X4 KS-64 DOT	2	33.00	77.8
8	IRFB 4110 100V/180A (N) MFET	10	49.15	580.01
9	H SINK HS 49 16X12X20MM	8	6.36	60.01
10	COPPER WINDING WIRE	95m	–	868
11	10Ω RESISTOR	5	1.1	7
12	1KΩ RESISTOR	5	1.3	7.2
13	100μF CAPACITOR	4	5.4	24.2
14	22μF CAPACITOR	5	5.1	27.3
15	DIODE 1N4007	8	2.9	27.66
16	SINGLE CORE WIRE 21SWG (Al)	3m	13.5	44.8
17	HEAT SINK	5	12	62.11
18	IC HOLDER	5	16	88.1
–	**TOTAL**	=	=	**3577.27/-**

Table 10.1: Bill of Materials (drive)

10.0.2 Motor

SL.NO	DESCRIPTION	QTY	UNIT PRICE	AMOUNT (+GST)
1	COPPER WINDING WIRE 23SWG	95m		300
2	LABOUR COST	—	—	1200
3	GI SHEET	1	100	100
4	NUT AND BOLT			80
5	MISCELLANEOUS			600
6	OTHER EXPENSIVE			750
7	ELECTRICAL VARNISH	1	189.56	199.12
	TOTAL			**3229.12/-**

Table 10.2: Bill of Materials (Motor)

Chapter 11

CONCLUSION

In conclusion, this project successfully designed, fabricated, and simulated an 8/6 switched reluctance motor (SRM) with a drive system, demonstrating its potential as a cost-effective and efficient alternative to conventional electric motors. Through detailed electromagnetic and thermal analysis using ANSYS Maxwell 2D, we validated the SRM's performance, highlighting its advantages such as robustness, high efficiency, and the elimination of rare-earth magnets. The fabricated prototype, along with its custom drive system, exhibited promising results, confirming the feasibility of SRM technology in various industrial and automotive applications. The next step was optimizing the motor's performance by refining the winding configuration, minimizing torque ripple, and enhancing the control strategy to improve efficiency and operational smoothness. The insights gained from this project contribute to the ongoing development of sustainable and high-performance electric motor solutions, paving the way for broader adoption of SRMs in electric vehicles and other energy-efficient applications. [4]

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[3] A. Chiba and K. Kiyota, "Review of research and development of switched reluctance motor for hybrid electrical vehicle," pp. 127–131, 2015.

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