Design of Energy-Efficient Switched Reluctance Motor Using ANSYS Software

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Abstract: This research presents the design of an energy-efficient Switched Reluctance Motor (SRM) using ANSYS software, aiming to optimize performance and reduce energy consumption. The SRM is recognized for its robust construction and high efficiency, making it suitable for various applications in electric vehicles and industrial automation. Switched reluctance motor (SRM's) are particularly gaining attention in the EV world for their advantages over traditional motors, such as higher reliability, low material cost, high motor-drive efficiency. Electric Vehicles (EVs) driven by electric motor reduces the usage of fossil fuel. The model shows considerable improvement in efficiency and reduction in torque ripple.

1 INTRODUCTION

The Switched Reluctance Motor (SRM) has gained significant attention in recent years due to its inherent advantages, such as simplicity, robustness, and high torque-to-weight ratio. With the growing demand for energy-efficient solutions in various sectors, including electric vehicles and renewable energy systems, optimizing the design of SRMs has become crucial. Traditional electric motors often face challenges related to energy losses, inefficiencies, and thermal management.

This study focuses on enhancing the performance of SRMs through innovative design strategies using ANSYS software, a powerful tool for finite element analysis (FEA). By simulating electromagnetic fields and analyzing thermal and mechanical stresses, we aim to refine motor parameters such as rotor shape, stator configuration, and winding techniques. The goal is to minimize energy losses, improve efficiency, and ensure reliable operation across a range of applications.

In this paper, a phase radial force shaping method is proposed by using harmonic content analysis. A generic function for the radial force shape is identified, whose parameters are calculated by an optimization algorithm to minimize the torque ripple for a given average torque. From the phase radial force profile, a current reference is obtained. The proposed methodology is experimentally validated with a four-phase 8/6 SRM through acoustic noise measurements at different speed and load conditions (Emadi A, 2019).

A new method to detect the initial rotor position of switched reluctance machine (SRM) is presented in this article. Unlike most conventional position estimation methods, the proposed method does not need any extra premeasurement and only the data with finite element method (FEM) are required. First, a linear regression model (LRM) is presented to describe the relationship between FEM and measured inductance characteristics.

Then, to detect the position, the residual sum of squares of the proposed LRM is considered as an objective function, which is a convex function with rotor position. The rotor position can be estimated by minimizing the objective function with the golden-section search method. Finally, the accuracy of the proposed estimation algorithm is validated by the experimental results on a three-phase 12/8 pole SRM prototype (Bilgin, 2019).

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2 DESIGN OF SWITCHED RELUCTANCE MOTOR

This design approach outlines the steps necessary to create a 4-phase, 8-pole switched reluctance motor tailored to your specifications. Each aspect, from geometry to control strategies, is critical to ensure efficient operation and desired performance characteristics.

Here's a detailed design outline for a 4-phase switched reluctance motor (SRM) with the given specifications.

2.1 Design Specifications

The following is the design specification of the SRM motor.

- Phase Count: 4
- Stator Poles: 8
- Rotor Poles: 6 (common choice for 8 stator poles)
- Phase Resistance (R): 0.96 Ω
- Aligned Inductance (L_aligned): 120 mH
- Unaligned Inductance (L_unaligned): 14 mH
- Phase Current (I_phase): 8 A
- Maximum Phase Voltage (V_max): 400 V
- Torque Inertia (J): 0.053 kg· m^2
- Viscous Damping Coefficient (b): 0.008 N· m· s
- Maximum Speed: 1500 RPM
- Power Output: 5.5 HP (approximately 4.1 kW).

2.2 Motor Geometry

Rotor Configuration is set to 6 poles so to maintain a good balance with 8 stator poles. Stator and Rotor Dimensions: The stator is designed with 8 evenly spaced teeth. The rotor has 6 corresponding poles, shaped to minimize air gap and enhance magnetic interaction. The outer diameter, inner diameter, and length of the stator and rotor based on the power requirements and thermal considerations are determined.

2.3 Magnetic Circuit Design

Core Material: Laminated silicon steel for both stator and rotor to minimize eddy current losses is used.

Air Gap: Air gap is designed so as to optimize torque production while minimizing losses.

Winding Configuration: Each stator pole will have a winding. The number of turns can be calculated based on the desired inductance and phase current.

Turn Calculation:

$$L = (N\char`^2.\mu.A)/g \quad (1)$$

Where L = inductance (H)
N = number of turns
μ = permeability of the core material
A = cross-sectional area of the core (m^2)
g = air gap (m)

2.4 Torque Calculation

The average torque can be calculated using the following formula:

$$T = P/\omega \quad (2)$$

Where:
T = torque (N-m)
P = power (W) = 4.1 kW
ω = angular speed (rad/s)

$$\omega = (2\pi \times RPM)/60 \quad (3)$$

For a maximum speed of 1500 RPM:

$$\omega = \frac{2\pi \times 1500}{60} (4)$$

$$\approx 157.08\, rad/s$$

2.5 Control Strategy

Commutation: Use a microcontroller or FPGA to manage the switching of phases based on rotor position. This requires feedback mechanisms like encoders or resolvers for precise rotor position sensing.

Current Control: Implement a PWM strategy to control the phase current, ensuring it stays at 8 A while avoiding saturation.

2.6 Thermal Management

Ensure adequate cooling by either natural convection or forced air cooling methods. Calculate the heat dissipation based on power losses using:

$$P_{loss} = I^2.R.t \quad (5)$$

2.7 Simulation and Prototyping

Finite element analysis (FEA) software to simulate magnetic fields, torque production, and thermal behaviour is used and the design is validated with a prototype and refining the design can be done as necessary.

2.8 Testing and Optimization

The efficiency is evaluated by performing the tests and thermal performance, torque ripple is also obtained. The design can be optimized based on the test results.

2.9 Geometry Specifications

The SRM motor geometry specifications are given in Table 1.

Table 1: Summary of Geometry Specifications.

PARAMETER	VALUE
Stator outer diameter	150mm
Stator inner diameter	100mm
Stator height	50mm
Rotor outer diameter	100mm
Rotor inner diameter	50mm
Rotor height	50mm
Air gap	1mm
Tooth Width	5mm
Tooth height	20mm
Slot depth	10mm
Phase resistance	0.96Ω
Aligned inductance	120 mH
Unaligned inductance	1204 mH
Phase current	8amps
Maximum phase voltage	400V
Torque inertia	0.053 kg.m^2
Damping coefficient	0.008 nms
Maximum speed	1500 rpm
Power	5.5 Hp 4.1 kw

This geometric outline provides a solid foundation for designing and building the switched reluctance motor, ensuring optimal performance and efficiency based on the specified operational parameters.

3 SIMULATION PROCEDURE

The proposed system aims to design an energy-efficient Switched Reluctance Motor (SRM) utilizing advanced simulation capabilities offered by ANSYS software. The design process will encompass several key stages, beginning with the selection of optimal rotor and stator geometries to enhance torque density and efficiency. By employing finite element analysis (FEA), we will simulate the electromagnetic performance, focusing on minimizing losses associated with magnetic hysteresis and eddy currents. The system includes the following features:

1. **Geometric Optimization**: Iterative design adjustments to rotor and stator configurations to achieve the best performance metrics.

2. **Electromagnetic Analysis**: Comprehensive simulations to evaluate the motor's magnetic field distribution and torque characteristics under various operating conditions.
3. **Thermal Management**: Assessment of thermal behavior through heat dissipation analysis, ensuring reliable operation and longevity of the motor.
4. **Performance Validation**: Comparison of simulation results with experimental data to validate the design's efficiency and effectiveness.

By integrating these elements, the proposed system aims to produce a high-performance SRM that meets the growing demands for energy efficiency while addressing the challenges faced by traditional motor designs. This innovative approach is expected to lead to significant advancements in motor technology.

3.1 Motor Design Procedure

These steps can be used to design a motor in ANSYS. It is explained using the following flowchart shown in Figure 1.

This method makes use of ANSYS Maxwell, which is especially well-suited for motor design and electromagnetic field simulation. Define the project in step 1.

Create a new project in ANSYS Maxwell. Depending on your motor design requirements, select between the 2D or 3D model. More complex geometries require 3D design, while most motors are often developed in 2D.

To set up the workspace for motor design, choose the "Electromagnetic" or "Motor template". Establish the Design Environment

Step 2: Specify the unit of measurement is mm cm, inches etc.

Select each motor component's material from the ANSYS library, or import your own if necessary. Set up any extra parameters, like temperature, if thermal analysis

Create the motor geometry in Step 3.

Draw your motor's fundamental geometry using the sketch tools, beginning with the stator, rotor, and slots.

For simpler modifications, parameterize important dimensions (such as the slot geometry, rotor diameter, and stator inner and outer diameters).

Make sure the components are properly aligned and spaced apart.

Assign Material Properties in Step 4.

Assign materials to each component of the motor, such as copper for the windings and steel for the stator and rotor.

Use characteristics such as conductivity and magnetic permeability, which are essential for precise electromagnetic analysis.

Step 5: Establish Boundary Conditions and Excitations. Define the stator's coil windings and configure voltage or current excitations as necessary.

Set boundary constraints such as "Periodic" or "Symmetry" to streamline the model and cut down on computation.

Configure the simulation setup in Step 6.

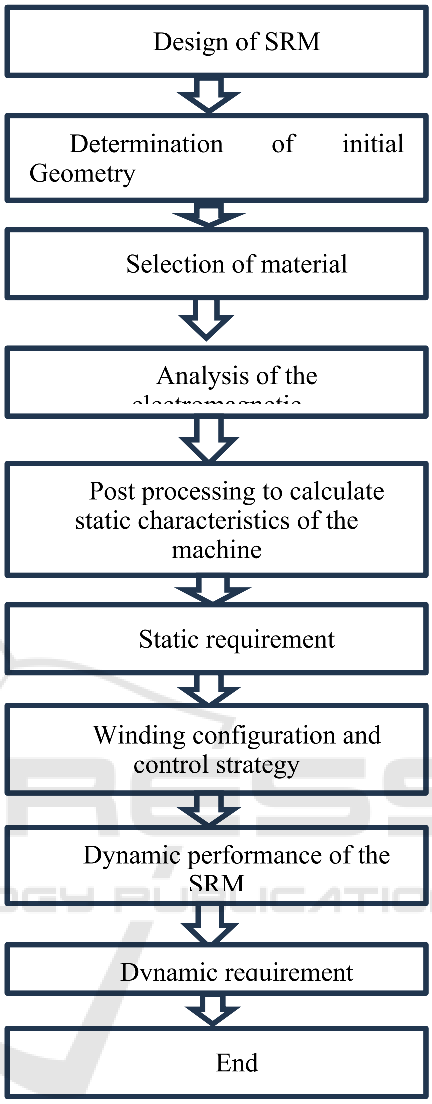

Figure 1: Motor design in Ansys.

Configure the type of solver. Because it takes time-dependent magnetic fields into account, the Transient Magnetic Solver is frequently used for motor design. Establish the rotor's motion parameters, such as its starting position and rotating speed.

Mesh the model in step 7.

To guarantee fine meshing in crucial regions, particularly close to the air gap between the stator and rotor, use automatic or manual meshing. Verify the mesh quality because a finer mesh produces more accurate results but requires more computing time.

Step 8: Execute the Simulation Launch the simulation and track its development.

After the simulation is finished, look for any faults or warnings in the solution configuration.

Step 9: Examine the Outcomes

To comprehend the electromagnetic behaviour, go over vector plots, flux lines, and magnetic field distributions.

To assess motor performance and efficiency, measure torque, back-EMF, core losses, and other performance metrics.

Modify the design parameters and execute the simulation again if the motor does not satisfy performance requirements.

Step 10: Design Optimization (Optional)

Automate parameter sweeps with ANSYS's optimization tools to increase torque or motor efficiency.

Establish goals and limitations for the design, then allow the software to suggest the best changes.

Step 11: Complete the Model

Complete the motor design if the results are satisfactory.

Export the simulation results, mesh, and geometry for use in physical prototyping or additional analysis.

This procedure ought to provide ANSYS motor design a solid basis.

3.2 Motor Structure

The motor designed in Ansys is shown in Figure 2.

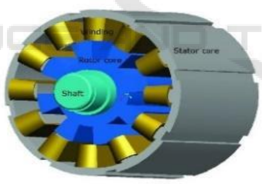

Figure 2: Motor structure.

3.3 Results and Discussion

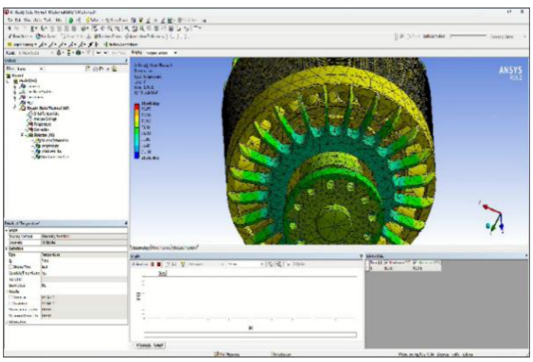

Figure 3: Mesh distribution.

The finite element analysis and mesh distribution is shown in Figure 3.

The simulation process typically involves creating a detailed geometric model of the motor, defining material properties, and setting up boundary conditions. Using ANSYS Maxwell, engineers can perform electromagnetic analysis to visualize flux distributions and predict performance metrics such as torque ripple and efficiency

By integrating these analyses, users can optimize the design of SRMs for specific applications, balancing factors like cost, performance, and reliability. The ability to simulate various operating conditions also aids in troubleshooting and improving existing motor designs.

With an emphasis on crucial parameters including magnetic flux density, torque output, back-EMF, losses, and efficiency, the motor simulation in ANSYS Maxwell offered a thorough examination of the electromagnetic and thermal performance. The main conclusions are summarized as follows:

Performance of Electromagnetics:

Magnetic Flux Density: To prevent saturation and guarantee effective magnetic coupling, the flux distribution in the stator and rotor stays within the core material limits. On the other hand, minor fluctuations close to the stator poles point to possible regions for flux uniformity optimization.

Torque Output: The motor operates smoothly by achieving a maximum torque within the design parameters with little torque ripple. Any slight torque ripple that is seen falls within the application's permitted bounds.

Back-EMF: By matching the intended speed and control parameters, the back-EMF profile verifies that the motor will operate effectively under the intended conditions.

Losses and Efficiency:

Core and Copper Losses: Core losses remain moderate, attributed to optimized material selection and design geometry. Copper losses are controlled, though minor adjustments in winding resistance may further reduce these losses.

Efficiency: The motor achieves a high efficiency rate, indicating a well-balanced design with minimal energy loss. This efficiency aligns with project specifications and sustainable operation goals.

Temperature Distribution: The temperature profile indicates a few hotspots near the windings, but they are manageable within the designed cooling system. Ensuring robust cooling or adjusting winding material may further enhance thermal stability.

Structural Integrity: Force density analysis shows the rotor and stator are structurally sound under expected loads, confirming mechanical stability and durability.

4 CONCLUSIONS

In this paper, the design and simulation of an energy-efficient Switched Reluctance Motor using ANSYS demonstrate significant improvements in performance. ANSYS provided valuable insights into the motor's magnetic characteristics and efficiency through detailed FEA, while MATLAB allowed for the validation of the motor's dynamic behavior under real-world conditions.

The findings indicate that with optimized design parameters, the SRM can achieve high torque with low energy losses. The control strategies developed enhance the efficiency further, making SRMs a viable option for various applications, including electric vehicles and industrial drives. Future work could involve refining the design based on experimental data and exploring advanced control algorithms for improved performance.

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