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RESEARCH PAPER ON 100 KW INTERIOR PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVES

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ABSTRACT

This thesis modeling, and performance assessment of a 100 kW Interior Permanent Magnet Synchronous Motor (IPMSM) for high-performance uses such industrial drives and electric cars are presented in this thesis. The motor's buried magnet design improves overall torque ripple performance, lowers cogging torque, and increases reluctance torque. To increase torque density and efficiency, the design approach concentrates on rotor geometry, stator winding configuration, and magnet placement optimization. Mechanical stress, thermal properties, and electromagnetic behavior are all assessed using finite element analysis (FEA) in both steady-state and dynamic scenarios. To guarantee accurate torque and speed control across a broad speed range, sophisticated vector control techniques such as flux weakening and Field-Oriented Control (FOC) are used. System-level performance is validated and the dynamic response is simulated under different load conditions using MATLAB/Simulink. The results of the simulation and analysis demonstrate that the suggested IPMSM produces strong torque output, dependable thermal management, and over 95% efficiency under rated settings. This motor has a higher power density, better torque performance, and enhanced field-weakening capabilities when compared to traditional surface-mounted PMSMs. All things considered, the study validates the suggested 100 kW IPMSM as a small, effective, and high-performing solution appropriate for demanding industrial applications and next-generation electric propulsion systems.

1. Introduction

1.1 Background of Study

Electric drive systems have advanced significantly as a result of the increasing need for ecologically friendly and energy-efficient industrial and transportation solutions worldwide. The Interior Permanent Magnet Synchronous Motor (IPMSM), one of the many varieties of electric motors, has become well-known because of its high power density, superior efficiency, and broad constant-power speed range. These attributes make it ideal for high-performance applications like wind energy conversion, electric vehicles (EVs), aerospace systems, and industrial automation. The IPMSM uses both magnet torque and reluctance torque because, in contrast to Surface Permanent Magnet Synchronous Motors (SPMSMs), it has permanent magnets implanted in the rotor. Increased torque per ampere, a longer speed range through field weakening, and better thermal properties because magnets inside the rotor core are protected are only a few benefits of this structural design. IPMSMs are particularly sought-after in systems that demand excellent reliability, dynamic performance, and compactness because of these characteristics. With the goal of providing excellent performance across a range of load circumstances, this thesis focuses on the design, analysis, and optimization of a 100 kW IPMSM. The selection of 100 kW is in line with applications for industrial motors and mid-sized electric vehicles, where control stability, efficiency, and thermal management are crucial.

1.2 Problem Statement

The need for high-performance electric motors keeps growing as companies throughout the world shift to more environmentally friendly and energy-efficient technology. Particularly, industries like industrial automation, renewable energy, and electric mobility need motors that are compact and have low operating costs while delivering great torque density, efficiency, and dependability. While the Permanent Magnet Inside

1.3 AIM & OBJECTIVE OF THE STUDY

As industries shift toward sustainable technologies, there is a growing need for efficient, high-performance electric motors in sectors like electric transport, renewable energy, and automation. Interior Permanent Magnet Synchronous Motors (IPMSMs) offer high torque density and efficiency but face challenges—especially at higher power levels like 100 kW—including thermal management, torque ripple, magnet demagnetization, and limited field weakening. This study aims to design, model, and optimize a 100 kW IPMSM with improved torque density, speed range, and thermal and mechanical stability, targeting next-generation electric mobility and industrial applications.

1. 4 IMPORTANCE OF THE STUDY

Building a powerful and efficient electric motor, like a 100 kW Interior Permanent Magnet Synchronous Motor (IPMSM), is very important. It helps meet the increasing global need for clean energy and sustainable transportation. As more industries switch to electric power, it's important to have motors that are powerful, dependable, and small.

This study is important for a few main reasons:

1. Helps Move to Clean Energy

Creating and improving a 100 kW IPMSM helps lessen the reliance on fossil fuels. It encourages the use of electric engines in vehicles and industrial machines.

2. Improves Understanding of Motor Design

The research contributes to our understanding of advanced motor design techniques. It focuses on important areas like improving torque, studying heat effects, and controlling field weakening, all of which are crucial for high-power uses.

3. Boosts Efficiency and Performance

This study looks at problems like torque ripple, core losses, and magnet demagnetization. By finding solutions to these issues, it helps make electric drive systems work better and last longer.

4. Allows for Different Uses of the Application

A well-made 100 kW IPMSM can be used in many different areas, like electric cars, industrial machines, and renewable energy systems. This flexibility helps engineers design better solutions.

1. 5 STUDY SCOPE

Creating a powerful and efficient electric motor, like a 100 kW Interior Permanent Magnet Synchronous Motor (IPMSM), is very important for meeting the increasing need for clean energy and eco-friendly transportation. As industries shift to using electricity more, there's a growing need for motors that are powerful, reliable, and small.

This study is important for a few main reasons:

1. Type and Rating of the Motor

The study focuses on an IPMSM that has a power output of 100 kW. Other types of motors, like surface-mounted PMSMs or induction motors, are used only to compare performance.

2. Design Features

The design work involves creating the electromagnetic layout, choosing magnetic materials, optimizing the shapes of the rotor and stator, arranging the slot and pole setup, and planning the winding based on performance goals.

3. Analyzing Performance

The motor is analyzed based on important performance factors like torque output, power density, efficiency, torque ripple, and thermal behavior, using simulation tools like the finite element method (FEM).

4. Using Simulations

The research is done using analysis and computer simulations. Practical work on making motors and testing them isn't included here, but it's suggested for future projects.

5. Things to Think About for Control

We look at basic ways to reduce field strength and control torque to evaluate performance, but creating detailed hardware or software for the controller is not included.

6. Focus on the Application

The motor is made to be flexible, focusing mainly on electric vehicle systems and industrial automation. It's important for it to be small and able to work well at different speeds.

7. Constraints

The study does not look at the costs of materials, supply chain issues, or making prototypes. Thermal analysis is based on common ideas without designing an active cooling system.

1. 6 LIMITATIONS OF THE STUDY

This study offers useful information about designing and analyzing a 100 kW Interior Permanent Magnet Synchronous Motor (IPMSM), but it has some limits because of time, resources, and scope.

1. No Testing to Prove It

The study mainly uses simulations and analytical models. No physical model was made or tested, so we couldn't check how it performs, how it handles heat, or how strong it is when in use.

2. Easy Thermal Analysis

The thermal performance is assessed when conditions are stable, based on ideas about material characteristics and heat loss. We do not consider temporary heat effects and active cooling systems.

3. Removing Manufacturing Limitations

The design process does not consider important factors like how precise parts need to be made, if materials are available, how much things will cost, and how difficult it will be to put everything together.

4. Limited Development of Control Systems

This work looks at field-weakening and torque control ideas, but it doesn't go into detail about creating control algorithms or implementing controllers in real time.

5. Force and Movement

The topic of structural dynamics, which includes things like mechanical stress from fast spinning, shaft bending, and vibration analysis, isn't explained in detail.

6. Integration for Specific Applications

The motor is built with general instructions in mind, but it isn't specifically made or improved for any one system, like an electric drivetrain or an industrial process setup.

7. No cost or money study.

The study does not include a cost-benefit analysis, magnet cost estimates, or life-cycle assessment, all of which are important for commercial use.

1.7 RELEVANCE OF THE STUDY

The increasing global emphasis on energy efficiency, electrification, and sustainable development has led to a growing demand for advanced electric motor technologies. In this context, the Interior Permanent Magnet Synchronous Motor (IPMSM) has emerged as one of the most promising solutions for high-performance electric drive systems. This study is highly relevant for the following reasons:

1. Alignment with Clean Energy Goals

By focusing on the design and optimization of a 100 kW IPMSM, the study contributes to the development of clean and efficient alternatives to internal combustion engines and traditional industrial motors, supporting global efforts to reduce carbon emissions.

2. Support for Electric Mobility

The findings of this study are directly applicable to the growing electric vehicle (EV) industry, where high-efficiency, high-power motors are critical for extending driving range and improving overall system performance.

3. Industrial and Renewable Applications

A 100 kW IPMSM is not only suitable for EVs but also for industrial automation, robotics, and renewable energy systems such as wind turbines, where reliable and efficient motor operation is essential.

4. Advancement in Motor Design

This study enhances academic and practical knowledge in the fields of electromagnetic analysis, finite element simulation, and torque optimization, providing a strong foundation for further research and innovation in electrical machine design.

5. Contribution to Engineering Education and Research

The methodology and findings presented serve as a valuable resource for engineering students, researchers, and professionals, fostering deeper understanding of motor performance optimization and interdisciplinary application of simulation tools.

6. Foundation for Future Development

The work can serve as a stepping stone for future projects involving motor prototyping, experimental testing, controller design, and commercialization, enabling continued progress in high-power motor technologies.

1.8 OVERVIEW OF THE STUDY

This study focuses on the design, analysis, and optimization of a 100 kW Interior Permanent Magnet Synchronous Motor (IPMSM), aiming to meet the demands of high-performance, energy-efficient electric drive applications such as electric vehicles, industrial machinery, and renewable energy systems.

The study begins with a comprehensive review of existing literature, discussing the principles of IPMSM operation, advantages over other motor types, and challenges in high-power applications. This provides the theoretical foundation for the design approach.

Following the literature review, the study moves into the electromagnetic design phase, where the rotor and stator geometries, winding configurations, and magnetic materials are selected. The motor design is then evaluated using finite element analysis (FEA) to assess magnetic flux distribution, torque output, efficiency, and cogging torque.

Next, the motor's field-weakening capabilities are analyzed to ensure reliable operation across a wide speed range—an essential requirement for applications like electric vehicles. Thermal analysis is also conducted to verify that the motor can operate within safe temperature limits under continuous and peak loading conditions.

The designed motor is then compared with conventional motor types (e.g., surface-mounted PMSMs and induction motors) in terms of torque performance, efficiency, and size. The results confirm the suitability of the IPMSM design for high-demand applications.

1.9 BATTERY CHARGING

A battery charger is an essential component in any electric system that uses rechargeable batteries, particularly in electric vehicles (EVs), energy storage systems, and industrial backup power supplies. It converts AC or DC input power into controlled DC output to safely charge the battery pack while maintaining optimal performance and battery lifespan.

Types of Battery Chargers

1. AC to DC Chargers (On-board or Off-board)

Converts grid AC power to DC to charge battery packs.
Used in most EVs, with power levels from 3 kW to 22 kW (Level 1 & 2), and up to 350 kW (DC fast charging).

2. DC to DC Chargers

Used in systems where a DC source is already available (e.g., solar panels or DC microgrids).
Also used for bidirectional charging or to charge 12V/48V auxiliary batteries from a high-voltage traction battery.

1.10 METHOD OF CHARGING THE LEAD ACID BATTERY

Lead-acid batteries require controlled charging to maximize performance and lifespan. The charging method depends on the application, battery type (flooded, AGM, gel), and the charger used.

1. Constant Current (CC) Method
Description: The battery is charged with a fixed current, while voltage gradually increases as the battery charges.
Steps:
1. Apply a steady current (e.g., 0.1C to 0.25C).
2. Monitor voltage until it reaches a preset maximum (typically ~14.4V for a 12V battery).
3. Stop charging or switch to another method.
Use Case: Simple chargers, initial stage charging.

2. Constant Voltage (CV) Method
Description: The charger maintains a fixed voltage, and the charging current gradually decreases as the battery approaches full charge.
Typical Voltage: 13.8 V–14.4 V for a 12 V battery.
Use Case: Float or standby applications (UPS, telecom)

3. Constant Current–Constant Voltage (CC-CV) Method
Description: Combines both CC and CV charging:
Phase 1: Charge with constant current.
Phase 2: When voltage limit is reached, switch to constant voltage.
Benefits: Safer and more effective charging; prevents overcharging.
Use Case: Automotive and industrial battery charging.

4. Trickle Charging
Description: Supplies a very low current continuously to maintain full charge without overcharging.
Voltage: Around 13.2 V–13.5 V (for 12V battery).
Use Case: Battery maintenance, standby systems, long-term storage.

5. Taper Charging
Description: Charging current naturally tapers (reduces) as the battery voltage increases.
Common in: Simple transformer-based chargers without active control.
Disadvantage: Less efficient, risk of undercharging or overcharging.

6. Boost Charging (Equalization Charging)
Description: High voltage charging (15–16 V for 12V battery) for a short period to remove sulfation and balance cell voltage.
Frequency: Typically done periodically (e.g., monthly).
Use Case: Flooded lead-acid batteries (not recommended for sealed types).
Warning: Can cause gassing and overheating if not carefully monitored.

7. Float Charging
Description: A form of CV charging used to maintain full charge after the battery is fully charged.
Voltage: ~13.2 V (12V system).
Use Case: Telecom, UPS systems where the battery is always on standby.

1.10.1 CONSTANT CURRENT CHARGING
Constant Current (CC) Charging refers to the method where the charging current remains fixed throughout the charging period, while the battery voltage gradually increases as it accumulates charge.
Working Principle: A regulated current source supplies a constant current (typically 0.1C to 0.25C, where C is the battery's Ah rating). As the battery charges, its terminal voltage rises. Charging is terminated or reduced once the battery voltage reaches a predefined level (usually ~14.4V for a 12V battery). If not controlled, overcharging can occur, especially in the later stages.

1.10.2 Tapping Constant Charging
Taper Charging is a semi-automatic charging method commonly used for lead-acid batteries, especially in older or simpler systems where precise regulation is not essential.
Taper Charging: In taper charging, the charging current naturally decreases (tapers) as the battery voltage rises during charging. It is not controlled electronically, but rather depends on the characteristics of the transformer and rectifier used in the charger.
Works: The charger initially provides high current when the battery is deeply discharged (low voltage).As the battery charges, its internal voltage increases.
This increase causes a voltage drop across the charger's internal resistance, which reduces the charging current.
Eventually, the current tapers off to a very low value as the battery becomes fully charged.

1.10.3 Stage of Charge
A modern battery charger (especially for lead-acid batteries) typically operates in 3 to 4 key stages to ensure safe, efficient, and complete charging while maximizing battery life.

1. Bulk Stage (Constant Current Charging)
Purpose: Restore 70–80% of the battery's capacity quickly.
Process: Charger delivers a constant current, and battery voltage gradually increases.
When it ends: When battery voltage reaches a pre-set threshold (e.g., 14.4V for a 12V battery).
Key Feature: Fastest charging stage.

2. Absorption Stage (Constant Voltage Charging)
Purpose: Charge the remaining 20–30% of the battery.
Process: Voltage is held constant (e.g., 14.4V), while current gradually decreases.
When it ends: When current falls to a low value (e.g., <2% of Ah rating), or a timer expires.
Key Feature: Ensures full charge without overcharging.

3. Float Stage (Maintenance or Trickle Charging)

Purpose: Keep the battery fully charged without overcharging.
Process: Voltage is reduced to a safe float level (e.g., ~13.2–13.6V for a 12V battery).
Key Feature: Ideal for standby/backup batteries (UPS, telecom).

4. Equalization Stage (Optional for Flooded Batteries Only)
Purpose: Balances cell voltages and removes sulfate crystals from plates.
Process: Brief overvoltage charging (~15–16V) for a set period.
Frequency: Once every few weeks or after deep discharges.
Warning: Not suitable for AGM or Gel batteries.

1.11 BATTERY CONSTRUCTION

The LEAD ACIDE BATTERY is one of the oldest and move widely used type of rechargeable batteries, especially in automotive, UPS & solar energy system.

LITERATURE REVIEW

The Interior Permanent Magnet Synchronous Motor (IPMSM) has emerged as a leading technology in the field of high-performance electric drives due to its high power density, efficiency, and torque characteristics. This literature review explores the foundational work, recent advances, and research gaps related to the design, control, and application of 100 kW IPMSMs.

1. Introduction to IPMSM Technology

IPMSMs are a subclass of permanent magnet motors where magnets are embedded within the rotor, providing reluctance torque in addition to magnet torque. Early studies by Boldea and Nasar (1997) established the theoretical underpinnings of IPMSM operation, emphasizing flux-weakening capabilities and field-oriented control (FOC).

2. Design and Modelling

Several researchers have contributed to the design optimization of IPMSMs for traction and industrial applications: Staton et al. (2002) explored finite element analysis (FEA) for electromagnetic design of permanent magnet machines, highlighting the importance of rotor geometry and magnet placement in torque performance.
Rahman et al. (2004) presented a high-speed IPMSM design for hybrid vehicles and analyzed the thermal and mechanical stresses at high operating speeds (~10,000 rpm). Recent studies focus on multi-objective optimization of rotor slots, magnet volume, and airgap structure (e.g., Li et al., 2016).

3 .Control Techniques

Advanced control strategies are critical for effective IPMSM operation: Field-Oriented Control (FOC) and Direct Torque Control (DTC) are the most used methods for IPMSM speed and torque regulation (Krause et al., 2001). Maximum Torque per Ampere (MTPA) and Flux Weakening Control (FWC) strategies are widely used to improve efficiency at both low and high speeds. Sensor less control using back EMF and model reference adaptive systems (MRAS) is gaining importance for reducing cost and complexity.

4. Applications in Electric Vehicles (EVs)

IPMSMs are extensively used in electric and hybrid vehicles due to their superior torque-to-weight ratio and efficiency: Toyota Prius and Nissan Leaf use IPMSM technology. Studies by Habetler et al. (2010) and Chen et al. (2015) demonstrated the suitability of IPMSM in EV drive trains, especially in high-speed and variable load conditions.
Research is ongoing into cooling systems and power electronics integration for compact motor-inverter units.

5. Performance and Efficiency Studies

Efficiency maps and loss modeling (core loss, copper loss, magnet loss) have been central in evaluating 100 kW IPMSM systems.
Studies show that IPMSMs can reach efficiencies >95% under optimized load and speed conditions (IEEE Transactions, 2020). Use of rare-earth magnets (NdFeB) improves power density but raises cost and thermal management concerns.

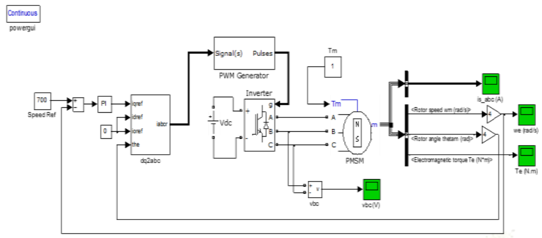
6. Recent Trends and Research Gaps

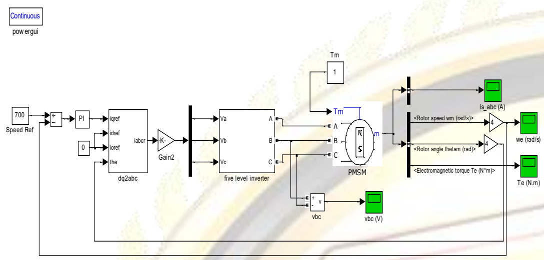
Focus is shifting toward rare-earth-free designs, fault-tolerant structures, and machine learning–based control algorithms. There is limited open-access research specifically detailing 100 kW-class IPMSMs, especially with regard to cost-effective materials, real-time control algorithms, and thermal optimization under variable operating environments.

Conclusion of Literature Review

The literature reveals that 100 kW IPMSMs are highly viable for traction and industrial applications, offering an excellent balance between power density, control accuracy, and efficiency. However, research continues to evolve around material cost reduction, thermal management, and real-time adaptive control. The reviewed studies provide a strong foundation for the present research into optimized 100 kW IPMSM design and application.

METHODOLOGY: BLOCK DAIGRAM





3 Level Inverter fed 100kw PMSM

WORKING

The Interior Permanent Magnet Synchronous Motor (IPMSM) works by using electromagnetic induction and rotating in sync with the electrical signals. It has permanent magnets inside the rotor and is powered by alternating current (AC) from an inverter. Here's an explanation of how the motor works:

1. How Power Supply and Inverters Work
The motor gets its power from a DC source, which is usually a battery or the power grid. A power inverter changes direct current (DC) into a three-phase alternating current (AC) supply. The speed and power of the motor are controlled by the frequency and strength of this AC.

2. Stator Function
The stator has three sets of wires that connect to the inverter. When AC passes through the wire coils, it creates a rotating magnetic field in the space around them.

3. Rotor Movement
The rotor has permanent magnets placed inside it (not on the surface). These magnets align with the rotating field of the stator. The motor runs at synchronous speed, which means the rotor turns at the same speed as the magnetic field of the stator. The reluctance torque, caused by the rotor's magnetic features, increases the magnetic torque. This means it produces more torque density than surface permanent magnet motors.

4. Making Torque
Total torque is made up of:
Magnet torque comes from the interaction between the stator's magnetic field and the magnets on the rotor. Reluctance torque is the torque that comes from changes in magnetic reluctance as the rotor spins. Control methods such as Maximum Torque Per Ampere (MTPA) help improve torque output and efficiency.

5. System for Control
A Field-Oriented Control (FOC) algorithm checks and changes the current and voltage to carefully control how fast the motor spins and how much power it has.
Sensors (or sensorless estimators) help determine the position of the rotor for better control.

6. Ongoing Functioning
As the magnetic field of the stator spins, the rotor moves along with it in sync. Changing the inverter frequency changes how fast the motor runs. The system keeps changing the voltage and current depending on how much work it has to do to stay efficient.

conclusion

Using Interior Permanent Magnet Synchronous Motor (IPMSM) drives greatly improves efficiency, reliability, and performance in many industries, such as electric vehicles, industrial automation, and renewable energy systems. This leads to less energy use, lower greenhouse gas emissions, and better sustainability. With high power density, low maintenance, and great speed control, IPMSM drives are a good choice for companies looking to operate more efficiently and reduce their environmental impact, resulting in better and more sustainable outcomes.

Result

In summary, Interior Permanent Magnet Synchronous Motors (IPMSM) are becoming an efficient and dependable option for many industries. They have many advantages, such as being powerful, needing little maintenance, and providing great speed control. This makes them a popular choice for businesses looking for high-performance and sustainable solutions. As technology advances, IPMSM motors are likely to become even more important in creating energy-efficient systems, helping industries like automotive, industrial automation, and renewable energy grow, and leading to a greener future.

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