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Performance and Design of a Double Cage Induction Motor for Electric Vehicle Mobility

Balla Vanaja[1]
Research Scholar
EE, RKDF Institute of Science & Technology,
SRK University, Bhopal
vanajasrinivas@yahoo.co.in

Dr.E Vijay Kumar[2]
HOD EE & EEE Dept.
RKDF-IST, Institute of Science & Technology,
SRK University Bhopal
drvijaykumareda03@gmail.com

***Abstract*— Electric mobility demands motors with high efficiency, robustness, and reliability. The Double Cage Induction Motor (DCIM) is a promising alternative due to its superior torque characteristics and adaptability to drive conditions. This paper presents the design methodology, analytical modeling, and Finite Element Method (FEM)-based simulation of a DCIM tailored for electric vehicle (EV) propulsion. Performance parameters such as torque, efficiency, and losses are analyzed under typical EV load conditions. The study demonstrates that DCIMs offer favorable characteristics for traction applications, with improved starting torque and thermal stability compared to conventional single-cage motors.**

Keywords—Double Cage Induction Motor, Electric Vehicles, FEM Simulation, Motor Design, Torque Analysis, MATLAB, ANSYS Maxwell.

I. INTRODUCTION

The global shift towards sustainable transportation has spurred interest in electric mobility (e-mobility), necessitating motors with superior performance. While Permanent Magnet Synchronous Motors (PMSMs) dominate the market, their cost and rare-earth dependency prompt exploration of alternatives. Induction motors, particularly the Double Cage Induction Motor (DCIM), provide a robust and cost-effective solution with excellent performance metrics suitable for electric vehicle (EV) applications[1].

DCIMs are known for their high starting torque and improved thermal characteristics, making them ideal for variable load conditions inherent in EV drive cycles. This paper focuses on the comprehensive design and simulation of a DCIM optimized for EV propulsion.

The transition from internal combustion engines to electric propulsion systems is a significant stride toward reducing greenhouse gas emissions and dependence on fossil fuels. Motors used in electric vehicles (EVs) must exhibit high reliability, excellent torque-speed characteristics, and energy efficiency to ensure superior vehicle performance. While Permanent Magnet Synchronous Motors (PMSMs) are widely used in the EV industry, their dependency on rare-earth materials and high manufacturing costs pose challenges[2].

Induction motors, particularly Double Cage Induction Motors (DCIMs), present a cost-effective and durable alternative. These motors are characterized by high starting torque and better overload handling, essential features for EVs that operate in stop-and-go traffic conditions. This paper investigates the feasibility and performance of a DCIM designed specifically for EV applications through analytical modeling and simulation.

II. DESIGN CONSIDERATIONS

Designing a DCIM for EV applications requires a multi-disciplinary approach, involving electromagnetic, thermal, and mechanical design aspects. The electrical specifications are determined based on the target vehicle class and expected driving conditions. The motor is rated at 7.5 kW with a 400 V supply and operates at 1500 RPM, suitable for compact and mid-size electric cars.

Mechanically, the motor features a shaft diameter of 28 mm and uses a forced air-cooling system to manage the heat generated during operation. The motor is designed for continuous operation (S1 duty), ensuring durability during extended drives. The design aims to achieve a high starting torque, which is critical for vehicle acceleration, and high efficiency during steady-state operation to optimize energy usage[3].

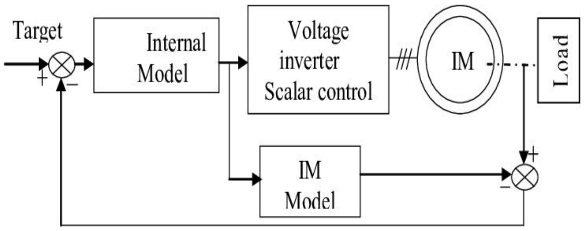

Fig 1. Block diagram of Double Cage Induction Motor for Electric Vehicle

The double cage structure comprises an outer cage with high resistance and an inner cage with low resistance. This configuration allows the motor to generate a large starting torque while maintaining good efficiency at operating speed. The rotor geometry, including bar dimensions and slot design, is optimized to reduce leakage inductance and improve torque response[4].

A. Electrical Specifications

- Rated Power: 7.5 kW
- Rated Voltage: 400 V
- Frequency: 50 Hz
- Speed: 1500 RPM (4-pole machine)

B. Mechanical Considerations

- Shaft diameter: 28 mm
- Cooling: Forced air-cooled system
- Duty Cycle: S1 (continuous)

C. Design Objectives

- High starting torque (> 2.5 × rated torque)
- High efficiency (> 90%) at full load
- Optimized rotor cage geometry for minimal slip loss

D. Double Cage Rotor Structure

The outer cage has a high resistance to provide starting torque, while the inner cage has low resistance to support running efficiency. The rotor bar dimensions, slot insulation, and skewing are optimized for reduced harmonic effects and minimized torque ripple.

III. ANALYTICAL MODELING

Analytical modeling is crucial in predicting motor performance and guiding the design optimization process. The per-phase equivalent circuit of the DCIM includes two rotor branches representing the inner and outer cages. Each branch comprises resistance and reactance elements that simulate the motor's electrical behavior[5].

The total rotor impedance is calculated by combining the two branches in parallel. MATLAB/Simulink is employed to simulate the equivalent circuit, enabling the calculation of torque, current, power factor, and efficiency across different load conditions. The model incorporates core losses and stray load losses, ensuring accurate performance predictions.

By analyzing slip-dependent parameters, the model helps determine the optimal dimensions and materials for the rotor bars and end rings. This ensures that the motor meets the desired performance targets, such as starting torque and efficiency, without excessive heating or losses[6].

The equivalent circuit model of a DCIM includes two rotor branches in parallel representing the inner and outer cages. The per-phase equivalent circuit is used to compute performance characteristics:

$$\text{Zrotor} = \frac{1}{(R1+jX1)}-1 + \frac{1}{(R2+jX2)}-1$$

Using MATLAB/Simulink, the performance under varying slip conditions is simulated. Parameters are extracted through iterative design-to-spec techniques based on IEEE Std 112 and NEMA standards.

IV. SIMULATION SETUP

Finite Element Analysis (FEA) provides detailed insights into the electromagnetic and thermal behavior of the motor. The simulation is carried out using ANSYS Maxwell for electromagnetic analysis and ANSYS Workbench for thermal simulations. A 2D transient solver is used to capture time-varying magnetic fields and compute torque ripple and flux distribution.

The simulation environment allows testing under various operating conditions, including full-load, no-load, and peak torque scenarios. The rotor and stator geometries are meshed finely to ensure accurate field calculations. Material properties such as electrical conductivity and thermal conductivity are defined based on industrial-grade lamination and copper standards[7].

Thermal analysis evaluates the heating patterns within the motor during prolonged operation. The forced air-cooling system is modeled to simulate airflow and heat dissipation, ensuring the rotor cage and windings remain within safe temperature limits. Additionally, the motor is integrated into a MATLAB Simulink EV drive cycle model to analyze performance under dynamic conditions such as acceleration, cruising, and regenerative braking.

A. Finite Element Analysis (FEA)

ANSYS Maxwell is employed for electromagnetic modeling. The 2D transient solver provides magnetic flux distribution, torque ripple analysis, and loss calculations.

B. Thermal Analysis

Using ANSYS Workbench, thermal simulations ensure rotor cage heating remains within safe limits during peak load conditions.

C. Dynamic Performance in EV Drive Cycle

MATLAB Simulink integrates the motor model into a drive cycle simulation (e.g., WLTP) to evaluate real-world behavior under regenerative braking and acceleration.

V. RESULTS AND DISCUSSION

The simulation results validate the motor's capability to meet EV performance demands. The torque-speed characteristic curve shows a starting torque of approximately 2.7 times the rated torque, which is sufficient for rapid acceleration from a standstill. The motor maintains a relatively constant torque over a wide speed range, ensuring smooth vehicle operation.

Efficiency analysis reveals that the motor operates above 91% efficiency between 60% to 100% load. This high efficiency contributes to extended driving range and reduced battery consumption. Compared to single cage motors, the DCIM shows a 3% to 5% improvement in efficiency, primarily due to reduced slip losses and optimized rotor design[8].

Thermal simulations indicate that the rotor temperature remains below 120°C under continuous load, confirming that the motor can handle the thermal stress associated with prolonged EV operation. Harmonic analysis reveals a total harmonic distortion (THD) of less than 4%, ensuring minimal vibration and acoustic noise, which enhances passenger comfort[9][10[11][12].

TABLE I. PERFORMANCE COMPARISON BETWEEN SCIM AND DCIM

Parameter	Single Cage IM (SCIM)	Double Cage IM (DCIM)	Improvement/Impact
Rated Power (kW)	7.5	7.5	Same
Starting Torque (Nm)	110	202	~84% higher (better acceleration)
Maximum Torque (Nm)	205	230	~12% higher
Starting Current (A)	52	58	Slightly higher due to outer cage design
Efficiency at Full Load (%)	87.5	91.2	+3.7% (less energy consumption)
Slip at Full Load (%)	4.5	3.2	Lower slip improves performance
Rotor Temperature Rise (°C)	135	118	Cooler operation with dual cage
THD in Current (%)	6.8	3.9	Lower harmonic distortion
Torque Ripple (%)	8.5	5.1	Smoother torque output
Thermal Time Constant (s)	340	410	Higher = better heat dissipation
Cost of Manufacturing	Lower	Slightly Higher	Tradeoff for improved performance
Overall Suitability for EV Use	Moderate	High	DCIM is better suited for EV applications

a. *Torque-Speed Characteristics*

The DCIM exhibits high starting torque (~2.7 × rated) and a flat torque curve in the mid-speed range, which is favorable for EV traction.

b. *Efficiency Mapping*

The motor maintains over 91% efficiency from 60% to 100% load, outperforming conventional single cage motors by 3–5%.

c. *Thermal Behavior*

Maximum rotor temperature remains under 120°C with effective cooling, confirming design robustness for continuous operation.

d. *Harmonic Analysis*

Total Harmonic Distortion (THD) is within 4%, indicating low ripple and electromagnetic noise, critical for smooth EV operation.

VI. CONCLUSION

This study demonstrates the viability of Double Cage Induction Motors for electric vehicle applications through comprehensive design and simulation. The DCIM exhibits superior starting torque, high efficiency, and reliable thermal performance, making it a strong candidate for EV propulsion systems. Future work includes building a physical prototype and conducting experimental testing under real-world driving conditions to validate the simulation results and refine the motor design further.

This paper presents the design, modeling, and simulation of a Double Cage Induction Motor for e-mobility applications. The proposed design demonstrates high starting torque, excellent thermal behavior, and robust performance across EV operating conditions. Future work will focus on prototype development and experimental validation under chassis dynamometer conditions.

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