Energy efficient induction motor for EV application

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Abstract— **As electric vehicles (EVs) gain popularity as sustainable transportation solution, the need for efficient and reliable propulsion systems becomes paramount. One critical component of the EV drivetrain is the induction motor. This study focuses on the development of energy-efficient induction motors for electric vehicle (EV) applications. With the increasing demand for sustainable transportation solutions, improving the efficiency of EV drivetrains is crucial. Key areas of investigation include the selection of suitable materials and core designs to minimize core losses and improve magnetic flux density. Additionally, the study evaluates the application of advanced control techniques, such as model predictive control (MPC), to optimize motor performance across different operating conditions. Through theoretical validations, the proposed energy-efficient induction motor designs are assessed for their performance, power density, and overall impact on vehicle range. The outcomes of this study provide valuable insights and guidelines for designing induction motors that contribute to improved efficiency and sustainability in EVs. Implementing these advancements can help accelerate the adoption of electric transportation and contribute to a greener future.**

Keywords—Induction motor, energy efficient, standards, efficiency class, electric vehicle.

I. Introduction

A. *Role of induction motor on electric vehicle application*

An induction motor is a type of AC (alternating current) electric motor that uses electromagnetic induction to produce rotational motion. It consists of a stator, which is the stationary part of the motor, and a rotor, which is the rotating part of the motor. The stator is made up of a series of windings that are supplied with AC power, while the rotor is typically made up of conductive bars or coils that are not connected to any external power source. When the AC power is applied to the stator windings, it creates a rotating magnetic field that induces a current in the rotor, which in turn creates its magnetic field. The interaction between the stator magnetic field and the rotor magnetic field causes the rotor to rotate, resulting in the generation of mechanical power. Induction motors are widely used in a variety of industrial, commercial, and residential applications due to their reliability, durability, and relatively low cost. They are commonly used in applications such as pumps, fans, compressors, conveyors, and many others.

In an electric vehicle, an induction motor is used as the main traction motor to convert electrical energy from the battery into mechanical energy to drive the wheels. The motor is connected to the wheels via a transmission system, which allows the motor to transfer torque to the wheels at different speeds. Induction motors are commonly used in electric vehicle applications due to their high reliability, low maintenance requirements, and ability to operate at high efficiency over a wide range of speeds. They also have a relatively simple design, which makes them easy to manufacture and repair. One of the main advantages of induction motors is that they do not require any brushes or commutators, which are commonly found in other types of electric motors.

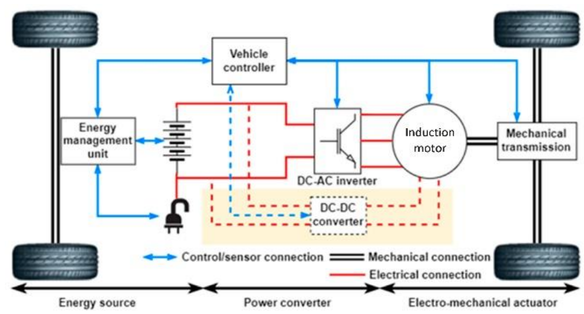

Figure 1. Use of an induction motor in an Electric vehicle drive train.

the design of a battery electric vehicle (BEV) powertrain, which essentially comprises a mechanical gearbox, a high voltage battery, a vehicle controller, a power converter, and an induction motor. The highlighted components show the external excitation supply needed for some controllable rotor excitation devices. This eliminates the need for regular maintenance and reduces the risk of failure due to wear and tear. Additionally, induction motors can operate at high speeds with low noise and vibration, which makes them well-suited for electric vehicle applications. Overall, the induction motor plays a critical role in the operation of an electric vehicle, providing the necessary torque and speed to propel the vehicle forward while also contributing to the vehicle's overall efficiency and reliability.

Overall, the induction motor is a critical component of electric vehicles, helping to deliver high performance, efficiency, and reliability while also contributing to the overall sustainability of the transportation sector.

B. *Motor technologies in EV*

Sl.no	Motor	Pros	cons	application
1	BLDC	High efficiency, good torque, good speed control, low maintenance	Complex design, limited power	2W and 3W
2	PMSM	High power, good efficiency, good speed control	Cost, control system	3W, 4W and heavy
3	Induction motor	Low cost, good efficiency	Poor low-speed torque, complex control systems	3W, 4W and heavy
4	SRM	Simple design, good torque	Poor efficiency, complex control systems	4W and heavy

Table 1. Comparison table for types of motor for electric vehicle

BLDC, PMSM, induction motors, and SRM are all types of electric motors that are commonly used in various applications, including electric vehicles. Here are the key differences between these types of motors. BLDC (Brushless DC) Motor: BLDC motors are like conventional DC motors but do not have brushes. Instead, they use electronic controllers to switch the current flow to the motor windings. BLDC motors are typically more efficient than conventional DC motors and can operate at high speeds with low maintenance requirements. PMSM (Permanent Magnet Synchronous) Motor: PMSM motors use permanent magnets in the rotor, which helps to improve efficiency and reduce the need for complex control systems. PMSM motors are commonly used in electric vehicles because of their high efficiency and ability to operate at high speeds. Induction Motor: As mentioned earlier, induction motors use electromagnetic induction to produce rotational motion. They do not require any brushes or commutators, which helps to reduce maintenance requirements and improve reliability.

Induction motors are commonly used in electric vehicles because of their high efficiency and ability to operate over a wide range of speeds. SRM (Switched Reluctance) Motor: SRM motors use the principle of magnetic reluctance to produce rotational motion. They do not have permanent magnets in the rotor and instead rely on the interaction between the rotor and stator magnetic fields. SRM motors are typically less expensive than other types of motors and can operate at high efficiencies. The type of motor has its advantages and disadvantages, and the choice of the motor depends on the specific application requirements. When it comes to electric vehicle applications, the most used motor types are PMSM (Permanent Magnet Synchronous Motor) and Induction Motor. The choice between these two motor types depends on the specific requirements of the electric vehicle application. Here are some factors that can influence the choice between PMSM and Induction Motor. Efficiency: PMSM motors typically have a slightly higher efficiency than induction motors, especially at higher speeds. Cost: Induction motors are generally less expensive than PMSM motors, mainly due to the lower cost of their rotor construction. Torque: Induction motors have a higher starting torque than PMSM motors, which can be advantageous for some electric vehicle applications. Regenerative Braking: Both PMSM and induction motors can be used for regenerative braking, which is an important feature for electric vehicles. Control: PMSM motors require more complex control systems than induction motors, which can increase their cost and complexity. Operating Temperature: PMSM motors are typically more sensitive to temperature changes than induction motors, which can affect their performance and reliability.

Overall, the choice between induction motors and PMSMs depends on the specific requirements of the electric vehicle application, including factors such as efficiency, cost, starting torque, overload tolerance, design simplicity, and temperature sensitivity. While PMSMs have their advantages, induction motors can offer a cost-effective and robust solution for many electric vehicle applications.

II. ENERGY-EFFICIENT MOTOR

A. *EESL roles in energy-efficient motors*

EESL stands for Energy Efficiency Services Limited, which is a joint venture company of four public sector enterprises under the Ministry of Power, Government of India. EESL is a leading energy service company that works towards implementing energy efficiency projects in India and other countries. Some of the key activities of EESL include Implementing large-scale energy efficiency projects across various sectors like public lighting, agriculture, buildings, and industry. Providing energy-efficient solutions to government and private entities, including the supply of energy-efficient appliances, LED bulbs, and street lighting.

EESL plays an important role in promoting the use of energy-efficient motors in various sectors, including industry, agriculture, and commercial buildings. Some of the specific roles of EESL in energy-efficient motors include: Creating awareness: EESL conducts awareness campaigns and training programs for various stakeholders to promote the benefits of energy-efficient motors and to encourage their adoption. Standards and labeling: EESL work with regulatory bodies to establish energy efficiency standards and labeling programs for motors. This helps consumers to identify and purchase energy-efficient motors. Procurement: EESL procures energy-efficient motors in bulk and offers them at an affordable price to various consumers, including industries, farmers, and commercial buildings. Financing: EESL provides financing options to consumers for the purchase of energy-efficient motors. This helps to overcome the initial cost barrier and encourages the adoption of energy-efficient technologies.

B. *BEE role in energy-efficient motor*

BEE stands for Bureau of Energy Efficiency, which is a statutory body under the Ministry of Power, Government of India. BEE works towards creating energy efficiency standards and labeling programs for various appliances and equipment, and provides technical assistance and financial support for energy efficiency projects. BEE plays a critical role in India's efforts towards achieving energy security, reducing greenhouse gas emissions, and promoting sustainable development.

The Bureau of Energy Efficiency (BEE) is responsible for promoting energy efficiency and conservation in various sectors of the economy in India. Some of the key functions of BEE are Developing policies and strategies: BEE develops policies and strategies related to energy efficiency and conservation. These policies aim to reduce energy consumption, enhance energy security, and promote sustainable development. Setting standards and labeling programs: BEE sets energy efficiency standards and labeling programs for various appliances and equipment, including refrigerators, air conditioners, and motors. These programs help consumers to identify and purchase energy-efficient products. Some of the specific roles of BEE in energy-efficient motors include: Developing energy efficiency standards and labeling programs: BEE sets energy efficiency standards and labeling programs for motors. This helps consumers to identify and purchase energy-efficient motors. Creating awareness: BEE conducts awareness campaigns and training programs for various stakeholders to promote the benefits of energy-efficient motors and to encourage their adoption. Providing financial incentives: BEE provides financial incentives to consumers for the purchase of energy-efficient motors. This helps to overcome the initial cost barrier and encourages the adoption of energy-efficient technologies. Technical assistance: BEE provides technical assistance to various stakeholders, including manufacturers, suppliers, and end-users, for the adoption of energy-efficient motors.

III. Standards to be Maintained for Energy Efficient Motors

A. International Electrotechnical Commission (IEC) 60034-1:2014 and 60034-30:2008

The International Electrotechnical Commission (IEC) standards 60034-1:2014 and 60034-30:2008 are essential guidelines for induction motors. IEC 60034-1:2014 provides general requirements for rotating electrical machines, including induction motors. It covers aspects such as mechanical and electrical design, performance, and testing methods. This standard ensures that induction motors meet specified criteria for safety, efficiency, and performance. On the other hand, IEC 60034-30:2008 specifically focuses on energy efficiency classifications for induction motors. Based on the motor's design and performance, it establishes efficiency classes, such as IE1, IE2, IE3, and IE4. These standards play a crucial role in promoting standardized and energy-efficient induction motors, facilitating global harmonization, and enabling informed decision-making for motor selection and usage.

B. Department of Industrial Policy and Promotion Geographical indications Registry (DIPP-GOI) IS 12615:2018

The Department of Industrial Policy and Promotion - Geographical Indications Registry (DIPP-GOI) has formulated the Indian Standard IS 12615:2018 to protect and promote geographical indications (GIs) in India. This standard sets guidelines for the registration and protection of GIs, which are unique signs that identify products originating from a specific geographical location. IS 12615:2018 provides a framework for the examination and registration of GIs, ensuring that the registered GIs receive legal protection and are safeguarded against unauthorized use. By implementing this standard, the DIPP-GOI aims to preserve traditional knowledge, promote rural livelihoods, and prevent misrepresentation or misuse of geographical indications, thereby supporting local economies and cultural heritage associated with specific regions in India.

C. Indian Standards(IS) 15999-2-1

IS 15999-2-1 is a standard published by the Bureau of Indian Standards (BIS) with the title "Information technology - Security techniques - Cryptographic techniques based on elliptic curves - Part 2: Digital signatures - Part 1: General". This standard is part of the IS 15999 series, which specifies cryptographic techniques based on elliptic curves for information security. IS 15999-2-1 specifically focuses on digital signatures, and provides general requirements and guidelines for the use of digital signatures based on elliptic curve cryptography. The standard covers topics such as the cryptographic mechanisms used in digital signatures, the key management and certificate management processes, and the security requirements for the implementation of digital signatures based on elliptic curve cryptography. The purpose of this standard is to provide a framework for the implementation of digital signatures based on elliptic curve cryptography in a secure and interoperable manner. Compliance with this standard can help to ensure the authenticity, integrity, and non-repudiation of electronic documents and transactions, and to protect sensitive information from unauthorized access or modification.

D. Indian Standard(IS) 7816

Indian Standard (IS) 7816 is a significant standard established by the Bureau of Indian Standards (BIS) in India. It specifies the requirements for identification cards, particularly those based on integrated circuit cards (IC cards) or commonly known as smart cards. IS 7816 covers various aspects of smart cards, including their physical characteristics, electrical interface, communication protocols, and data transmission formats. The standard ensures interoperability and compatibility between different smart card systems used in various sectors such as banking, telecommunications, transportation, and identification. By adhering to IS 7816, manufacturers, service providers, and users can ensure the reliability, security, and compatibility of smart cards, facilitating their widespread adoption and usage in a diverse range of applications.

IV. Classes of International Efficiency

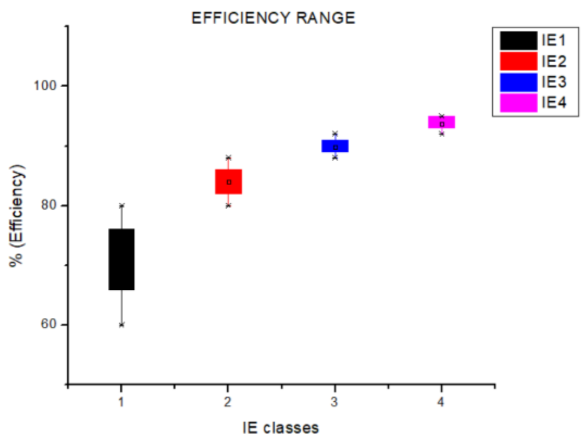

Figure 2. Efficiency range of IE Classes

Figure 2 shows the efficiency range for IE1 motors is typically between 60% and 80%. This means that the motor converts 60% to 80% of the electrical input power into mechanical output power, with the remaining percentage lost as heat. For IE2 motors is generally between 80% and 90%. These motors provide improved efficiency compared to IE1 motors. For IE3 motors is typically between 85% and 95%. For IE4 motors is typically above 95%. These motors represent the highest level of energy efficiency, converting the largest percentage of electrical input power into useful mechanical output power. They provide significant energy savings and are the most environmentally friendly option.

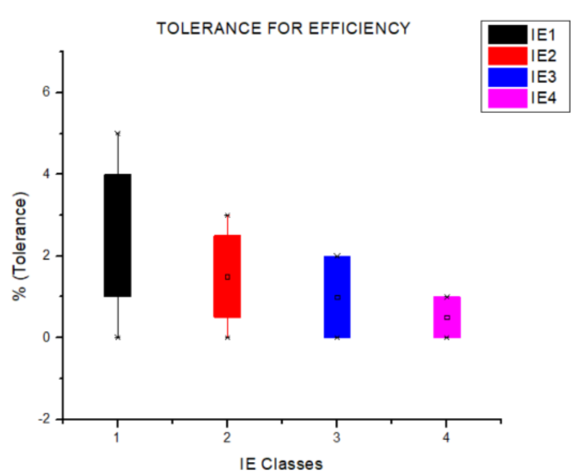

Figure 3. Tolerance for Efficiency of IE Classes

Figure 3 shows the tolerance range for IE1 motors is typically ±5 percentage points from the specified efficiency level. For IE2 motors is typically ±3 percentage points. Motors in this class have a narrower tolerance, allowing for a smaller deviation from the specified efficiency level. For IE3 motors is typically ±2 percentage points. Motors in this class have an even tighter tolerance, resulting in a smaller permissible deviation from the specified efficiency level. For IE4 motors is typically ±1 percentage point. Motors in this class have the narrowest tolerance, allowing for the smallest allowable deviation from the specified efficiency level.

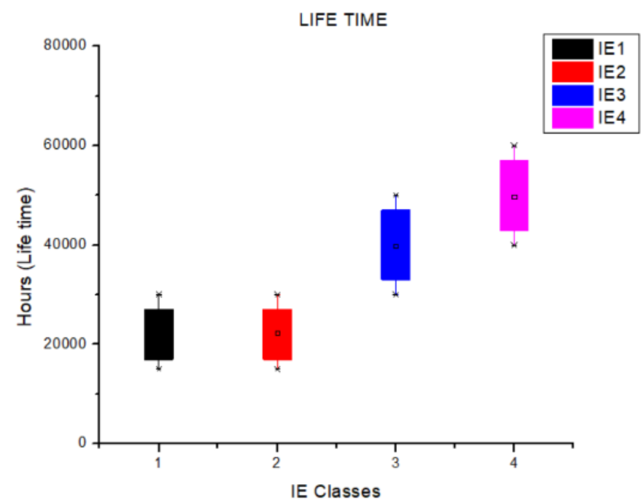

Figure 4. Lifetime of IE Classes

Figure 4 represents the lifetime of IE1 motors typically have a lifetime of around 15,000 to 30,000 hours of operation. The lifetime for IE2 motors has around 15,000 to 30,000 hours of operation. For IE3 motors has around 30,000 to 50,000 hours of operation. For IE4 motors around 40,000 to 60,000 hours of operation or even higher.

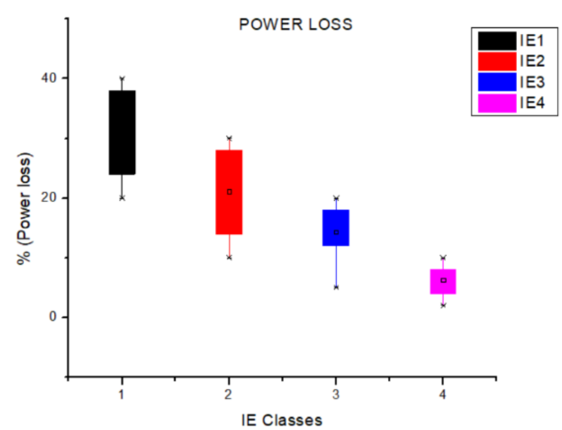

Figure 5. Power loss of IE Classes

Figure 5 represents the power loss of IE1 motors typically have higher power loss compared to higher efficiency classes. The power loss for IE1 motors can range from 20% to 40% of the input power, meaning that 20% to 40% of the energy input is lost as heat. IE2 motors have lower power loss compared to IE1 motors. The power loss for IE2 motors can range from 10% to 20% of the input power. For IE3 motors can range from 5% to 10% of the input power. For IE4 motors is typically below 5% of the input power, resulting in the highest efficiency and minimal energy waste.

V. Conventional Induction Motor Versus Energy-Efficient Induction Motor

Conventional induction motors and energy-efficient induction motors represent two different approaches to motor design and operation. Conventional induction motors have been widely used for decades and are known for their reliability and cost-effectiveness. These motors operate at a fixed speed determined by the power supply frequency and the number of poles. They have a simple and robust design, making them suitable for a wide range of applications. However, conventional induction motors have limitations in terms of energy efficiency. They typically have efficiency levels ranging from 85% to 95%, resulting in energy losses and higher operating costs over time. Additionally, their fixed-speed operation may not be suitable for applications that require variable speed control.

In contrast, energy-efficient induction motors can achieve higher efficiency levels, often reaching up to 97%. This improved efficiency translates into significant energy savings and lower operating costs, making them more environmentally friendly and economically viable in the long run. Energy-efficient induction motors also offer the advantage of variable speed operation, allowing for better control and adaptability in various applications.

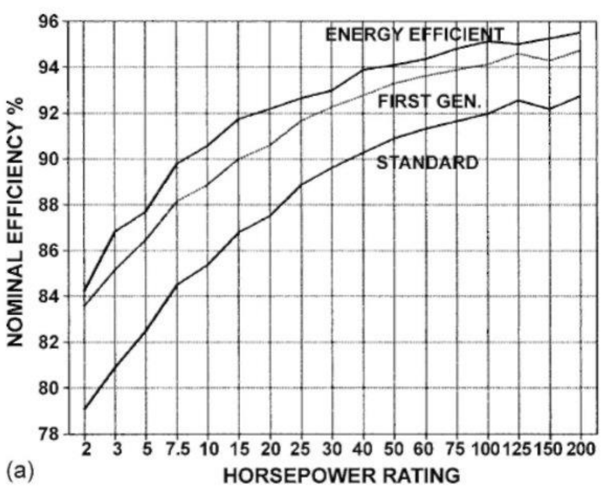

Figure 6. Comparison graph of Conventional induction motor(standard) versus energy efficient induction motor (first gen) concerning efficiency and horsepower rating.

In terms of nominal efficiency, energy-efficient induction motors outperform conventional induction motors by achieving higher efficiency levels. Additionally, both types of motors are available in various horsepower ratings to suit different applications.

However, energy-efficient induction motors may have some drawbacks. They often come with a higher initial cost compared to conventional induction motors, which can be a barrier to adoption for some users. The advanced design features and technologies incorporated in energy-efficient motors can also make them more complex, requiring specialized knowledge for installation and maintenance.

In summary, while conventional induction motors have served as reliable workhorses for many years, energy-efficient induction motors represent a significant advancement in terms of energy savings and improved performance. The decision between the two depends on the specific requirements of the application, considering factors such as the need for variable speed control, energy efficiency targets, and budget constraints. As energy efficiency becomes an increasingly important consideration, the adoption of energy-efficient induction motors is expected to grow, driving sustainability and cost savings in various industries.

VI. Control Technique in Induction Motor

A. Model Predictive Control

Model Predictive Control (MPC) is an advanced control strategy that has gained significant attention in the quest for energy-efficient induction motor operation. MPC considers the motor's dynamic behavior, system constraints, and operating conditions to optimize motor performance and energy efficiency.

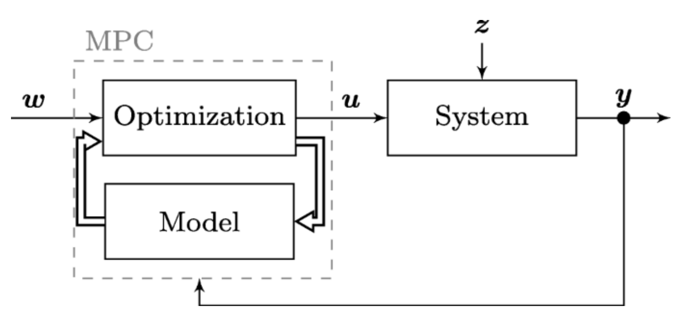

Figure 7. Block diagram of Model Predictive Control.

MPC for energy-efficient induction motors involves a predictive model of the motor system that incorporates the motor's mathematical model, electrical and mechanical dynamics, and motor parameters. This predictive model is used to predict the future behavior of the motor under different control actions and operating conditions.

B. Model Predictive Torque Control

Model Predictive Torque Control (MPTC) is an advanced control technique for induction motors that focuses on precise torque control. It uses a mathematical model of the motor to predict future torque response and optimizes control inputs over a defined time horizon. MPTC minimizes a cost function while satisfying constraints to achieve accurate torque tracking and high dynamic performance.

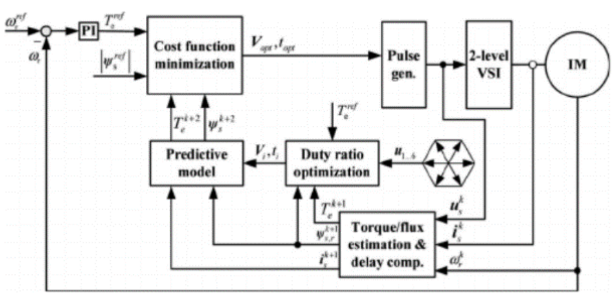

Figure 8. Block diagram of Model Predictive Torque control.

It provides advantages such as precise control, fast transient response, and robustness to disturbances. However, it requires accurate models, computational resources, and a good understanding of motor dynamics for real-time implementation.

C. Model Predictive Flux Control

Model Predictive Flux Control (MPFC) is an advanced control technique for induction motors that focuses on regulating the motor's flux (magnetic field). It utilizes a mathematical model of the motor to predict future flux response and optimizes control inputs over a defined time horizon.

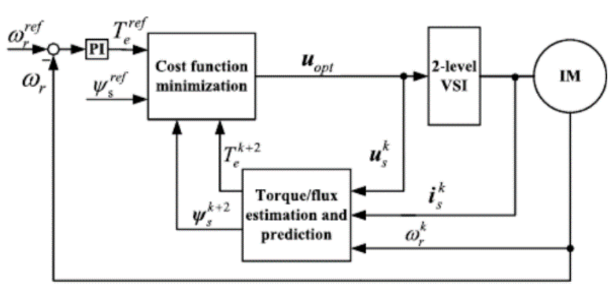

Figure 9. Model Predictive Flux Control

MPFC minimizes a cost function while satisfying constraints to achieve accurate flux control and improved motor efficiency. It provides advantages such as precise control of flux, robustness to disturbances, and improved energy efficiency. However, it requires accurate models, computational resources, and a good understanding of motor dynamics for real-time implementation.

VII. SUMMARY

In conclusion, energy-efficient induction motors are crucial for the success of electric vehicles (EVs). These motors offer improved efficiency, extended driving range, and enhanced performance, making EVs more sustainable and cost-effective.

By reducing energy consumption and minimizing environmental impact, energy-efficient induction motors contribute to the global transition towards clean and green transportation. Their higher torque and power output enable better acceleration and overall performance of EVs, providing a superior driving experience. As the EV industry continues to grow, energy-efficient induction motors will play a pivotal role in driving the adoption of electric vehicles and shaping a more sustainable future of transportation.

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