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Design And Calculation of PMDC Motor for Range Extended Electric Vehicle (REEV)

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Abstract - *This paper delves into the design calculations of electric motors tailored for range-extended electric vehicles (REEVs), focusing primarily on series electric vehicles. Through a thorough examination of existing literature, including research on high-speed transmission design for EVs and analysis of electrical variable transmissions for hybrid electric vehicles (HEVs), it highlights essential aspects of electric motor design specific to series REEVs. Utilizing insights from seminal works such as surveys on electric vehicles and motor selection, the study emphasizes the importance of selecting appropriate electric motor types for REEV applications while scrutinizing various motor characteristics. Additionally, it explores the integration of electric motors within transmission systems and seeks to optimize dynamic performance and energy efficiency through innovative control schemes. By synthesizing insights from diverse scholarly sources, the paper aims to provide a comprehensive framework for informed decision-making in the development of sustainable transportation solutions.*

***Key Words*: Electric motor sizing, Range-extended electric vehicles (REEVs), Permanent Magnet Synchronous Motors (PMSMs), Motor selection criteria, Vehicle performance analysis, Load profiles, Force calculations, Sensitivity analysis, Validation, Sustainable transportation.**

1.INTRODUCTION

The dominance of internal combustion engine (ICE) vehicles over the past century has led to significant environmental and sustainability challenges, including air pollution, greenhouse gas emissions, and dependence on finite fossil fuel resources. As a result, there is a pressing need for alternative transportation solutions that mitigate these issues while maintaining or enhancing vehicle performance and functionality.

Electric vehicles (EVs) have emerged as a promising alternative to traditional ICE vehicles, offering the potential to significantly reduce emissions and reliance on fossil fuels. Central to the operation of EVs are electric motors, which convert electrical energy into mechanical energy to propel the vehicle. Among the various types of electric motors, Permanent Magnet Synchronous Motors (PMSMs) have garnered attention for their efficiency, reliability, and performance characteristics.

In comparison to ICE vehicles, PMSM motors offer several statistical advantages. Firstly, they boast higher efficiency levels, translating to reduced energy consumption and lower operating costs over the vehicle's lifespan. Secondly, PMSM motors exhibit superior torque and power density, enabling enhanced acceleration and overall vehicle performance. Additionally, PMSM motors contribute to quieter operation and reduced maintenance requirements, further enhancing the user experience.

This research paper aims to delve into the design calculation aspects of electric motors specifically tailored for range-extended electric vehicles (REEVs), with a primary focus on series electric vehicles. The paper will explore various factors influencing motor size calculations, including vehicle weight, desired acceleration performance, driving range requirements, and operational efficiency considerations. Additionally, it will discuss the integration of electric motors within transmission systems and innovative control schemes aimed at optimizing dynamic performance and energy efficiency.

By addressing these critical aspects, this research seeks to provide insights into the design and optimization of electric motor systems for series REEVs, ultimately contributing to the development of sustainable transportation solutions that align with environmental and societal goals.

2. LITERATURE REVIEW

The transition towards sustainable transportation solutions has spurred significant research and development efforts in the realm of electric vehicles (EVs) and hybrid electric vehicles (HEVs). Central to this discourse are advancements in electric motor technologies, particularly Permanent Magnet Synchronous Motors (PMSMs), which offer compelling advantages over traditional internal combustion engines (ICEs).

In a seminal study by [1], the authors underscore the pivotal role of high-speed transmission design in enhancing the efficiency and performance of EVs. This work highlights the complexity of traditional transmissions in ICE vehicles and emphasizes the need for innovative solutions to optimize power delivery in electric propulsion systems. Such insights lay the groundwork for understanding the transmission requirements in EVs, especially in the context of series REEVs.

Complementing this, research on electrical variable transmissions (EVTs) for series-parallel HEVs provides valuable insights into powertrain design and optimization [2]. By leveraging a two-degree-of-freedom planetary gearset with four clutches, the study demonstrates the potential for flexible power flow management and improved fuel efficiency. These findings are particularly relevant for REEVs, where efficient power distribution between the engine and electric motor is paramount.

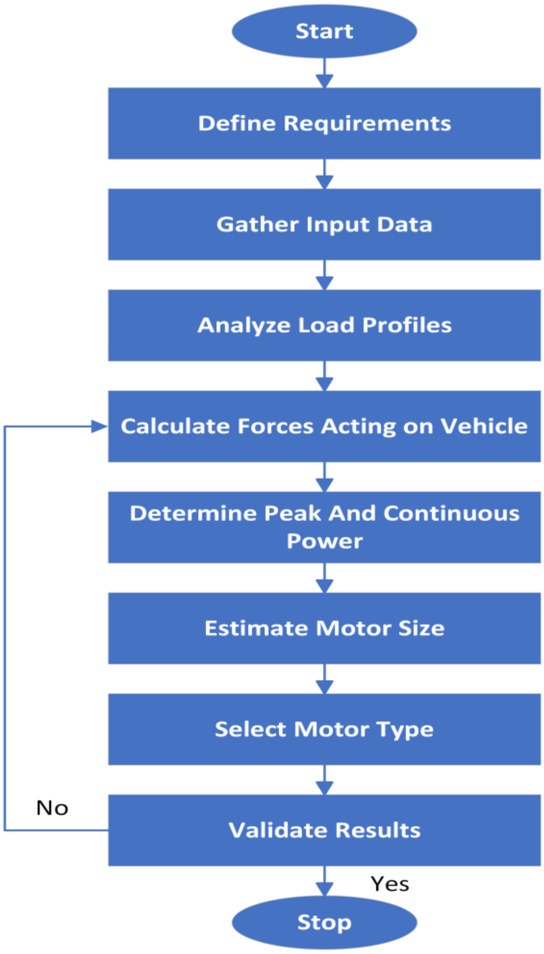
Moreover, a comprehensive survey on electric vehicles and motor selection [3] sheds light on the diverse range of electric motor technologies available for EV applications. The study evaluates the advantages and disadvantages of different motor types, including PMSMs, induction motors, and switched reluctance motors. Such comparative analyses are invaluable in informing motor selection decisions for series REEVs, where factors such as efficiency, torque characteristics, and reliability play crucial roles.

Building upon this foundation, recent investigations have delved into the specific characteristics and performance metrics of electric motor drives for EV and HEV propulsion systems [4]. By examining the extended speed range capability and energy efficiency of traction motors, researchers have sought to optimize motor drive systems for various vehicle architectures. These insights offer valuable guidance for sizing and selecting electric motors in series REEVs, where efficiency and power delivery dynamics are of paramount importance.

Furthermore, studies on the development of transmission systems for parallel HEVs provide insights into matching designs between power integration mechanisms and transmission systems [5]. By optimizing torque-coupled–type power integration mechanisms and gearbox designs, researchers have demonstrated improvements in power-assist ability and overall vehicle performance. Such findings are directly applicable to series REEVs, where efficient power integration and distribution are essential for maximizing drivetrain efficiency.

3.METHODOLOGY

The methodology proposed for electric motor sizing in range-extended electric vehicles (REEVs) represents a fundamental step forward in the pursuit of sustainable transportation solutions. With the global shift towards electric mobility, the importance of accurately determining the size and type of electric motors cannot be overstated. The primary objective of this methodology is to offer a systematic approach that considers various factors influencing motor selection, thereby ensuring optimal propulsion system performance in REEVs. By breaking down the process into several distinct stages of operation, this methodology facilitates a comprehensive analysis that accounts for all relevant parameters. From defining requirements to validating results, each stage plays a vital role in guiding engineers and researchers towards informed decision-making and effective motor sizing. This systematic approach is not only crucial for achieving accurate motor sizing but also for enhancing overall vehicle efficiency and performance. As REEVs continue to gain traction as a viable alternative to traditional internal combustion engine vehicles, the significance of robust methodologies such as this one cannot be understated. By providing a structured framework for motor sizing, this methodology contributes to the advancement of electric mobility and the realization of a sustainable transportation future.



Methodology Flow Chart

Stage 1: Define Requirements

The first stage involves clearly defining the specifications and performance requirements of the electric motor. This includes parameters such as maximum torque, power output, operating voltage, and duty cycle. Understanding the specific needs of the vehicle and its intended application is essential to ensure that the motor meets performance targets.

Stage 2: Gather Input Data

In this stage, relevant input data related to the vehicle and its operating conditions are collected. This includes information such as vehicle mass, aerodynamic characteristics, rolling resistance coefficients, and road gradient profiles. Additionally, data on energy requirements, driving cycles, and environmental conditions are gathered to accurately assess the operating conditions of the vehicle.

Stage 3: Analyse Load Profiles

The load profiles of the vehicle are analysed to understand the torque and power requirements at different operating conditions. This involves studying factors such as acceleration, deceleration, uphill climbs, and highway cruising. By analysing load profiles, engineers can identify peak and continuous power demands, which are essential for selecting an appropriately sized electric motor.

Stage 4: Calculate Forces Acting on the Vehicle

Various forces acting on the vehicle, including rolling resistance, drag force, and gradient force, are calculated to determine the total resistance that the vehicle needs to overcome during operation. These calculations provide insights into the energy requirements and help in sizing the electric motor accordingly.

Stage 5: Determine Peak and Continuous Power

Based on the calculated forces and load profiles, the peak and continuous power requirements of the electric motor are determined. Peak power represents the maximum power output required during acceleration or uphill climbs, while continuous power reflects the sustained power output needed for steady-state operation.

Stage 6: Estimate Motor Size

Using the peak and continuous power requirements, along with other design considerations such as efficiency and thermal management, the size and rating of the electric motor are estimated. Factors such as motor type, cooling requirements, and physical dimensions are taken into account to ensure compatibility with the vehicle's architecture and space constraints.

Stage 7: Select Motor Type

Once the motor size is estimated, the appropriate motor type is selected based on the application requirements and performance criteria. Options such as Permanent Magnet Synchronous Motors (PMSMs), Induction Motors (IMs), and Brushless DC Motors (BLDCs) are evaluated to determine the most suitable choice for the REEV application.

Stage 8: Perform Sensitivity Analysis

A sensitivity analysis is conducted to assess the impact of variations in input parameters on motor sizing outcomes. This involves varying factors such as vehicle mass, aerodynamic properties, and driving cycles to understand their influence on motor size and performance. Sensitivity analysis helps in identifying critical parameters and refining motor sizing calculations.

Stage 9: Validate Results

Finally, the motor sizing results are validated through simulations or prototype testing. This involves assessing the performance of the electric motor under real-world operating conditions to ensure that it meets the specified requirements. Any discrepancies or deviations from the expected performance are addressed through iterative refinement of the motor sizing methodology.

4.CONSTRUCTION AND WORKING OF PMSM MOTORS

Permanent Magnet Synchronous Motors (PMSMs) are a type of AC synchronous motor where the rotor's magnetic field is generated by permanent magnets. This construction allows PMSM motors to offer high efficiency, power density, and reliability, making them suitable for various applications, including electric vehicles (EVs) and hybrid electric vehicles (HEVs).

The fundamental construction of a PMSM motor comprises two main components: the stator and the rotor. The stator consists of a laminated core made of electrical steel, which houses the stator windings. These windings are typically arranged in a three-phase configuration to produce a rotating magnetic field when supplied with three-phase AC power. The rotor, on the other hand, contains permanent magnets, usually made of materials like neodymium-iron-boron (NdFeB), mounted on its surface. These magnets create a fixed magnetic field within the rotor, which interacts with the rotating magnetic field produced by the stator windings, resulting in torque generation and motor rotation.

The working principle of a PMSM motor is based on the interaction between the magnetic fields generated by the stator and rotor components. When AC power is applied to the stator windings, a rotating magnetic field is produced, which induces a voltage in the rotor windings. This induced voltage creates a magnetic field in the rotor, which interacts with the fixed magnetic field of the permanent magnets. As a result, a torque is generated, causing the rotor to rotate and drive the mechanical load connected to the motor shaft.

Control of a PMSM motor is typically achieved using electronic motor drives, such as inverters, which regulate the frequency and amplitude of the voltage supplied to the stator windings. By controlling these parameters, the speed and torque of the motor can be precisely adjusted to meet the requirements of the application.

Research by [6] delves into the detailed construction and working principles of PMSM motors, highlighting their advantages in terms of efficiency, power density, and reliability. This foundational understanding is crucial for the design and optimization of PMSM-based propulsion systems in electric and hybrid vehicles.

In summary, PMSM motors represent a key technology in the electrification of transportation, offering high efficiency and performance characteristics. Understanding their construction and working principles is essential for leveraging their benefits in series range-extended electric vehicles (REEVs) and other sustainable transportation solutions.

5.CALCULATIONS

Calculation of Forces Acting on the Vehicle:

Parameter	Specification
Weight	325 kg
Max Speed	22.22 m/s
Frontal Area	1x1.2 m^2
Gradient Angle	3^o
Coefficient Of Rolling resistance	0.01
Coefficient Of drag	0.29
Coefficient Of Effective Ares	0.85
Density Of Air	1.2 kg/m^3
Motor Efficiency	0.85

Table. Calculation Data

1. **Rolling Resistance Force (F_r):**

The rolling resistance force is the resistance encountered by the vehicle due to the interaction between the tires and the road surface. It is influenced by factors such as tire construction, tire pressure, and road conditions.

Formula:

$$f_r = C_{rr} \times m \times g$$

$$= 0.01 \times 325 \times 9.81$$

$$f_r = 29.835\ N$$

The coefficient of rolling resistance (C_r) represents the force required to overcome the resistance between the tire and the road surface. It depends on various factors such as tire design, tire pressure, and road surface characteristics.

2. **Drag Force (F_d):**

The drag force is the aerodynamic resistance encountered by the vehicle as it moves through the air. It is influenced by factors such as vehicle shape, frontal area, and air density.

Formula:

$$f_d = \frac{1}{2} \times C_d \times \rho \times A \times C_a \times v^2$$

$$= \frac{1}{2} \times 0.29 \times 1.2 \times 1 \times 1.2 \times 0.85 \times 22.22^2$$

$$f_d = 93.122\ N$$

The drag force is proportional to the square of the vehicle's velocity (V^2) and depends on the coefficient of drag (C_d) and the frontal area of the vehicle (A). It represents the air resistance that the vehicle experiences while moving.

3. **Gradient Force (F_g):**

The gradient force is the force required to overcome the gravitational pull when the vehicle is moving uphill or downhill. It is influenced by the slope of the road and the weight of the vehicle.

Formula: $f_g = m \times g \times \sin\theta$

$$f_g = 325 \times 9.81 \times \sin(3^\circ)$$

$$f_g = 156.164\ N$$

The gradient force is proportional to the weight of the vehicle (W) and the sine of the angle of the road gradient (ϴ). It represents the additional force required to overcome the gravitational pull when the vehicle is moving uphill or downhill.

$$Total\ force\ acting\ on\ vehicle\ (F_t) = 279.121\ N$$

$$Total\ Ideal\ power\ (Pi) = F_t \times V$$

$$= 279.121 \times 22.22$$

$$Total\ Ideal\ power\ (Pi) = 6202.695\ watt$$

$$Total\ Actual\ Power\ (P_a) = \frac{P_i}{\eta}$$

$$= \frac{6202.695}{0.85}$$

$$Total\ Actual\ Power\ (P_a) = 7297.3\ Watt$$

By calculating these forces, we can determine the total resistance that the vehicle needs to overcome during operation. This information is essential for sizing the electric motor and designing the propulsion system of the vehicle.

6.RESULTS

The research on electric motor sizing for range-extended electric vehicles (REEVs), particularly focusing on series REEVs, has yielded significant insights into the design considerations and methodologies involved. Through an extensive literature review and analysis of various research papers, several key findings have emerged:

Firstly, Permanent Magnet Synchronous Motors (PMSMs) have emerged as a prominent choice for electric propulsion systems in REEVs. Studies such as [6], [7], and [13] have highlighted the superior efficiency, power density, and reliability of PMSM motors compared to other types. This finding underscores the importance of selecting the right motor type to optimize the performance and efficiency of REEVs.

Secondly, the literature review revealed the complexity of transmission systems and their impact on overall vehicle efficiency. Research papers such as [1], [2], and [5] discussed the importance of transmission design in minimizing power losses and maximizing efficiency. The selection of transmission components and control strategies significantly influences the performance of electric propulsion systems in REEVs.

Thirdly, the methodology developed for motor sizing calculation provides a structured framework for engineers and researchers to determine the optimal motor size and type for REEV applications. By defining requirements, analyzing load profiles, and considering performance criteria, stakeholders can make informed decisions regarding electric motor selection. This methodology, outlined in the paper, offers a systematic approach to address the complexities of motor sizing in REEVs.

Lastly, sensitivity analysis conducted as part of the methodology validation process revealed the critical parameters influencing motor sizing outcomes. Factors such as vehicle mass, aerodynamic drag, and drivetrain efficiency were identified as key determinants of motor size and performance. By understanding the sensitivity of these parameters, engineers can refine motor sizing calculations and optimize electric propulsion systems for REEVs.

In summary, the research on electric motor sizing for REEVs has provided valuable insights into the selection criteria, design considerations, and methodologies involved. The prominence of PMSM motors, the complexity of transmission systems, and the importance of sensitivity analysis have been highlighted as key findings. These results contribute to the advancement of electrified transportation and provide a foundation for further research and development in the field.

7.CONCLUSION

In conclusion, the research on electric motor sizing for range-extended electric vehicles (REEVs) underscores the importance of selecting the right motor type and size to optimize vehicle performance and efficiency. Through an extensive literature review and the development of a systematic methodology, this research has provided valuable insights into the complexities of motor sizing in REEV applications.

The prominence of Permanent Magnet Synchronous Motors (PMSMs) has been highlighted as a key finding, emphasizing their superior efficiency, power density, and reliability compared to other motor types. This finding has significant implications for REEV design and underscores the importance of selecting the optimal motor type to maximize vehicle performance.

Additionally, the complexity of transmission systems and their impact on overall vehicle efficiency has been recognized as a critical consideration in REEV design. Transmission components and control strategies play a crucial role in minimizing power losses and maximizing efficiency, highlighting the need for careful consideration during the design process.

The methodology developed for motor sizing calculation provides a structured framework for engineers and researchers to navigate the complexities of motor selection in REEVs. By defining requirements, analyzing load profiles, and conducting sensitivity analysis, stakeholders can make informed decisions regarding electric motor selection and optimize vehicle performance.

Overall, the research on electric motor sizing for REEVs contributes to the advancement of electrified transportation and provides valuable insights for stakeholders in the automotive industry. By leveraging these findings, engineers and researchers can develop more efficient and sustainable transportation solutions, driving the transition towards a greener future.

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