Abstract

INTRODUCTION

Electric vehicles represent one of the most significant technological innovations of the 21st century, offering a sustainable alternative to conventional internal combustion engine vehicles. The growing global interest in electric technology in transportation is fueled by the numerous economic, environmental and social benefits that these vehicles bring. From reducing greenhouse gas emissions and reducing air pollution, to significant savings in operating and maintenance costs, electric vehicles play a crucial role in the transition to a green and sustainable economy.

Widespread adoption of electric vehicles is essential to achieving the global goals of reducing CO_2 emissions and combating climate change. In contrast to traditional vehicles, electric vehicles do not emit pollutants during operation, thus contributing to improving air quality and protecting people's health. They are also much more energy efficient, converting a greater proportion of the energy stored in batteries into motion compared to the reduced efficiency of internal combustion engines.

The economic benefits of electric vehicles are not negligible. Although the initial costs may be higher, they are compensated over time by the reduced costs of electricity compared to fossil fuels, as well as the need for less maintenance, given the simplicity of the design of electric motors and the lack of mechanical components that commonly wear on traditional vehicles. This economic aspect is particularly attractive to both consumers and industry, thus stimulating innovation and technological development.

In addition to economic and environmental benefits, electric vehicles also bring significant social advantages. They contribute to the reduction of noise pollution in urban areas, thus improving the quality of life. The development of charging infrastructure for electric vehicles generates jobs and boosts the local economy. At the same time, educating the public about the advantages of electric mobility plays an important role in the acceptance and adoption of this technology.

A fascinating aspect of electric vehicle technology is the possibility of revitalizing historic vehicles by converting them into electric cars. This practice, in addition to allowing the preservation and use of vehicles of historical and sentimental value, also brings numerous ecological and economic advantages. Converting a classic vehicle to an electric vehicle involves replacing the internal combustion engine and traditional transmission system with an electric motor and battery pack, while maintaining the original design of the car.

The benefits of this conversion are multiple. First, it avoids pollutant emissions and reduces the carbon footprint associated with the production of new vehicles. Second, converted vehicles can benefit from modern technological advantages such as increased range, improved performance and reduced maintenance costs. This means owners of historic vehicles can continue to enjoy them without compromising performance or contributing to pollution.

A significant benefit of converting classic vehicles to electric vehicles is the applicability of this process in the educational field. Making a teaching stand for the conversion of classic vehicles to electric vehicles gives students a valuable opportunity to learn about emerging technologies by applying theoretical knowledge to practical projects. It promotes STEM (Science, Technology, Engineering and Mathematics) education and prepares future engineers for the challenges of the modern automotive industry.

CHAPTER 1

STATE OF THE ART IN ELECTRIC VEHICLES

Chapter 1 of the PhD thesis analyzes the evolution and impact of electric vehicles (EVs) as sustainable solutions in the field of transport, highlighting the ecological, economic and social transformations they bring. The introduction of electric vehicles is seen as a necessity to achieve the global goals of reducing CO_2 emissions and combating climate change. Because these vehicles do not emit pollutants during operation, they contribute to improving air quality and protecting public health. In addition, they are much more energy efficient, converting a greater proportion of the electricity stored in the batteries into motion.

The chapter also details the economic benefits of EVs, which, while having higher initial costs, deliver significant long-term savings through reduced fuel and maintenance expenses. The mechanical simplification of the electric motor compared to the internal combustion engine reduces the frequency and complexity of service operations. In addition to the economic aspects, electric vehicles contribute to reducing noise pollution in urban areas and stimulate the local economy by developing charging infrastructure, creating new jobs.

In addition, the thesis addresses the challenges and future directions of EV research. Advances in battery technology, energy management systems and the development of charging infrastructure are examined. An analysis of more than 50 scientific articles was carried out to identify existing gaps and provide a clear picture of the current state of research in this field.

In conclusion, Chapter 1 of the thesis establishes a solid foundation for understanding the importance and impact of electric vehicles in today's global context. Highlighting both the benefits and challenges associated with this technology, the thesis encourages the continued development of innovative solutions for a sustainable transition to electric mobility. This provides valuable insight for researchers, engineers and decision-makers, helping to shape future electric transport policy and practice.

CHAPTER 2

MATHEMATICAL MODELING OF A VEHICLE

Chapter 2 of the PhD thesis focuses on the mathematical modeling of the behavior of an electric vehicle, starting with the longitudinal dynamics of the vehicle and ending with the complex forces acting on the chassis. By developing a detailed dynamic model, the chapter provides an in-depth understanding of the interactions between various vehicle subsystems, such as the engine, transmission, and wheels, and how they influence overall vehicle performance.

First, the mathematical model is built to describe the vehicle's response to the accelerator pedal, taking into account aspects such as engine torque and how it is transmitted to the wheels via the gearbox. The model includes equations that describe the relationship between accelerator pedal position and engine torque, as well as the influence of physical factors such as wheel radius and rolling resistance.

Further, the chapter deals with external forces acting on the vehicle, such as propulsive force, aerodynamic drag and gravitational forces generated by slopes. The detailed analysis of these forces enables a better understanding of the vehicle's behavior under varied operating conditions, helping to optimize performance and efficiency.

A key aspect addressed in the chapter is state-space modeling, which allows the simulation and prediction of vehicle behavior under various loading and driving conditions. This model is essential for the design of advanced control systems that can improve the vehicle's response to commands and reduce energy consumption.

Thus, Chapter 2 provides a solid foundation for understanding and improving the dynamics of electric vehicles. By using mathematical modeling, the thesis makes important contributions to the specialized literature and opens new directions for applied research in electric vehicle engineering, emphasizing the role of modeling and simulation in the development of modern vehicle technologies.

CHAPTER 3

BRUSHLESS DC MOTOR (BLCD)

Chapter 3 of the PhD thesis is devoted to the analysis of the brushless direct current (BLDC) motor, with an emphasis on its operation and control principles. The chapter begins with a detailed description of how the BLDC motor works, highlighting the difference from traditional DC motors. Instead of mechanical commutation through carbon brushes, the BLDC motor uses electronic commutation, which improves efficiency and reduces wear.

An important section is devoted to describing the operation of the Hall sensors, which are used to detect the rotor position. This is essential for proper commutation of the stator windings, allowing the motor to run efficiently. The chapter details how the signals generated by these sensors are used to determine the energization sequence of the windings so that the motor maintains optimum torque and speed.

Various BLDC motor control strategies are also discussed, including the use of microcontrollers to process signals from Hall sensors and generate commands for the force circuit. This enables high precision in motor control, essential for applications that demand fast and reliable responses, such as electric vehicles.

The chapter also explores ways to improve BLDC motor performance by optimizing the command sequences and driving algorithm. Technical details are presented on the implementation of variable speed control, using pulse width modulation (PWM) techniques to adjust the power supplied to the windings.

Chapter 3 provides a solid foundation of technical knowledge about BLDC motors, illustrating their complexity and effectiveness in modern applications. The information presented is useful for engineers who design and implement electric propulsion systems, providing them with tools and methods to exploit the full potential of these engines.

CHAPTER 4

EXPERIMENTAL STAND DESIGN

Chapter 4 of the PhD thesis explores the design and realization of an experimental stand for electric vehicles, emphasizing the transition from traditional to electric and hybrid vehicles. A significant part is devoted to the history of electric vehicles, highlighting their evolution since 1828 and the revival of interest in 2008 due to the development of battery technologies. The role of the electric vehicle in reducing emissions and making energy consumption more efficient is highlighted, in the context of increasing ecological awareness and economic pressures.

The discussion progresses to detail hybrid systems, from series to parallel, showing the complexity and efficiency of each configuration. A clear distinction is made between the different types of hybrid vehicles, highlighting the advantages of each in terms of fuel economy and reduced emissions. In addition, the benefits of integrating hybrid systems into vehicles are presented, such as reduced taxes due to lower emissions and improved vehicle performance.

An important section is devoted to the conversion of a traditional ARO model into an electric version, illustrating the technical and engineering steps required for this transformation. The process of removing the traditional engine and integrating an electrical system is described in detail, including the necessary adaptations to the transmission and control system. This concrete example highlights the potential of reusing and adapting existing vehicles for greener transport.

In addition, the chapter discusses the development of the infrastructure needed to support electric vehicles, such as charging stations and battery management systems. This also includes technical details on charging systems, battery performance monitoring and management, essential for the efficient operation of electric vehicles.

Chapter 4 provides a comprehensive view of the transition from traditional to electric and hybrid vehicles, focusing on technological innovations and infrastructure adaptations. It explains in detail the technical aspects of electric and hybrid vehicles and demonstrates the viability and benefits of converting existing vehicles to greener options, representing a significant step in the evolution of motor transport.

CHAPTER 5

SYSTEM INTEGRATION

Chapter 5 of the PhD thesis discusses the integration of a photovoltaic system in an ARO 243 vehicle modified to be electric, with the aim of increasing the autonomy and energy efficiency of the vehicle. The technical details are detailed, starting with the configuration of the charging circuit, the use of gel batteries for energy storage and the implementation of a "Battery Balancer" to optimize charging and extend the life of the batteries.

A major issue addressed is charge imbalance between batteries, which can significantly reduce the life of an expensive battery bank. The chapter explains how using a battery stabilizer can remedy this problem by equalizing the state of charge, detailing the functions and meanings of the stabilizer's LED indicators. This ensures that all batteries reach an even state of charge, preventing problems caused by overcharging or undercharging.

Flexible photovoltaic panels are described as an ideal solution for vehicles, providing technical specifications and explanations of their advantages compared to traditional solar panels. The integration of these panels on the roof of the ARO 243 vehicle allows for the efficient collection of solar energy, which is then converted and stored to power the vehicle.

Next, technologies for charging and monitoring the state of charge of batteries are discussed, introducing devices such as the MPPT solar charger that optimizes the conversion of solar energy into electricity, thereby maximizing the efficiency of energy collection. This also includes aspects related to the monitoring and control of the photovoltaic system, which are essential for the efficient management of the energy produced by the panels.

The chapter concludes with a detailed view of the integration of all system components, clearly and technically describing the necessary connections and implementation steps to ensure optimal and safe operation of the modified electric vehicle. Thus, innovative and sustainable solutions for the improvement of electric vehicles are presented, highlighting the significant contribution of this project to sustainable mobility and electric vehicle technologies.

CONCLUSIONS

This research demonstrated the feasibility and benefits of converting a classic vehicle to an electric vehicle using components specifically designed for electric cars and the Resolve controller. Through detailed analysis and implementation of the required components and their connections, I was able to create a teaching stand that not only educates students about electric vehicle technologies, but also provides a practical platform for innovation and research. The result of the conversion is visible in the image below.

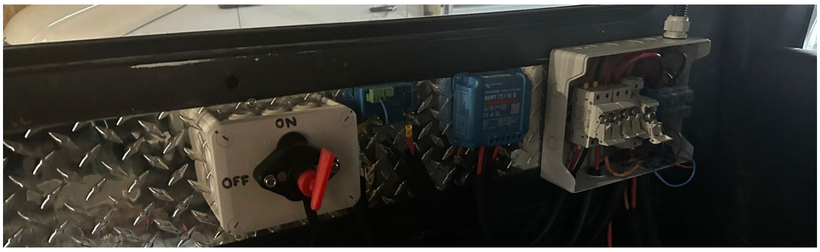
Throughout this thesis, I have emphasized the importance of electric vehicles in the transition to a sustainable and green economy. We highlighted the multiple economic, social and environmental benefits of the widespread adoption of electric vehicles, such as reduced greenhouse gas emissions, improved air quality, reduced maintenance and operating costs, and increased energy efficiency. We have also explored the potential of revitalizing historic vehicles by converting them to electric vehicles, thus preserving automotive heritage while adopting sustainable technologies.

The developed teaching stand provides a valuable platform for student education in the field of electric vehicles. By engaging in practical vehicle conversion and optimization projects, students have the opportunity to apply theoretical knowledge and develop essential skills for a career in automated systems engineering applied to electric vehicles and emerging technologies. This hands-on experience contributes to the formation of a new generation of engineers and researchers.

There are numerous research and development directions that can be explored based on this project. These include: Development of advanced algorithms for more efficient energy management in batteries and optimization of regenerative braking. Exploring new battery technologies with higher energy density and increased durability. Studying how electric vehicles can be integrated into smart energy grids to contribute to grid stability and efficiency. Extending the functionality of assisted driving and exploring the possibilities of automation and autonomous driving.

By completing this thesis I demonstrated that classic vehicles can be transformed into efficient and sustainable electric vehicles, thus contributing to reducing the impact on the environment and promoting sustainable mobility. The integration of modern technologies and the use of the educational platform offered by the educational stand open new opportunities for innovation and research in the field of electric vehicles. These efforts represent an important step towards a greener and more sustainable future in the automotive industry.

Below are some constructive details of the electric car.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CONTRIBUTIONS

Chapter 2:

• Development of a mathematical model for the longitudinal dynamics of the vehicle, which includes the interaction between the engine, transmission and wheels.

• Implementation of a 1st order dynamic model for the engine, which describes the response to accelerator pedal actuation through state variables and specific parameters.

• Adoption of a gearbox model that amplifies engine torque in proportion to the transformation ratio, contributing to the fine details of power transmission to the wheels.

• Modeling the wheels and their relationship with the ground, by assuming the absence of slip, and calculating the force applied to the road.

• Separating and detailing the forces that influence vehicle motion, including propulsive force, rolling resistance, aerodynamic drag, and gravitational forces due to pitch.

• Formulation of the model in the state space, indicating the relevant state variables and the equations describing their evolution over time.

• Inclusion of nonlinearities in the dynamic model, such as trigonometric functions in the equations, which capture the variable behavior under real operating conditions.

• Numerical analysis and simulation using specific data for vehicle parameters to evaluate and optimize the performance of the proposed model.

• Evaluation of the influence of design parameters on system performance, such as vehicle mass, drag coefficient and wheel radius.

• Develop and apply a model for engine torque required under different operating conditions, such as acceleration on a level road.

• The study of the maximum acceleration capacity of the vehicle, determining the physical limits imposed by the design and configuration of the propulsion system.

• Approaching suspension models, introducing a quarter-car model to better understand suspension behavior and vehicle dynamics.

• Detailed analysis of suspensions, focusing on the relationships between components, such as springs and dampers, and their impact on driving comfort and performance.

• Exploring how suspension components influence response to external stresses such as road bumps.

Chapter 3:

• Detailed description of the operating principle of the BLDC motor, highlighting the advantages of electronic switching over mechanical switching through carbon brushes.

• Explain the use of Hall sensors to detect the rotor position, which allows precise control of the energization sequences of the stator windings.

• Details of motor winding configuration and their influence on motor performance.

• Presentation of torque generation methods by varying the current amplitude and the number of active windings.

• Analysis of the influence of permanent magnet design and air gap between rotor and windings on motor performance.

• Introduction of a complex electronic control system for managing power sequences based on Hall sensor signals.

• Details on the implementation of a microcontroller to process signals from Hall sensors and generate commands for the force circuit.

• Description of variable speed BLDC motor driving algorithm using pulse width modulation (PWM) to control electromagnetic field strength.

• Presenting a BLDC motor design method using RMxprt software for detailed simulations and analysis.

• Calculation of machine performance, including estimates of the electrical and mechanical rotations required for a full rotation of the rotor.

• Development of control sequences for the control of the direction of rotation, detailing the relationship between the binary combinations of Hall sensor signals and the motor power phases.

• Detailed analysis of winding configuration and properties, including the effect of different winding connection configurations on motor behavior.

• Use of advanced simulation techniques to validate motor design, including electromagnetic transient analysis and thermal analysis.

• Presentation of an application case study for an electric ATV, highlighting the applicability of BLDC technology in electric vehicles.

• Theoretical and experimental discussions on engine design optimization to improve efficiency and reduce losses.

Chapter 4:

• Develop a historical perspective on the evolution of electric vehicles, highlighting key stages of development and technological changes up to modern vehicles.

• Analysis of hybrid system types, highlighting the differences between series and parallel configurations, and how they influence vehicle efficiency.

• Detailed description of the components of a hybrid vehicle, including the role and function of each component within the hybrid system.

• Implementation of an experimental stand for the conversion of a traditional ARO into an electric vehicle, providing a platform for testing and validating electric technologies.

• Integrating an electric propulsion system into an ARO vehicle, including details on mounting and coupling the electric motor to the existing transmission.

• Use of a battery management system (BMS), explaining its functions in monitoring and protecting the battery, and managing charge and discharge.

• Design and realization of an interface for the BMS, which allows extensive customization and configuration of battery operating parameters.

• Experimenting with various electric motor and controller configurations to identify optimizations needed to improve vehicle performance.

• Demonstration of the regenerative capability of the propulsion system, which allows recapturing energy during braking and improving the vehicle's energy efficiency.

• Development of a model for simulating and evaluating electric vehicle performance, which can be used to test different operating scenarios and road conditions.

• Analysis of the impact of changes on vehicle dynamics, such as weight distribution and dynamic behavior due to the addition of electrical components.

• Study of the integration of charging technologies, including the use of network chargers and their adaptation to existing standards.

• Exploring options for reusing and adapting existing commercial electric vehicle components, such as using the engine and batteries from a Nissan Leaf.

• Evaluation of energy regeneration capacity and its influence on vehicle autonomy, demonstrating the advantages brought by energy recovery.

Chapter 5:

• Integration of a photovoltaic system on an ARO 243 vehicle to increase autonomy, with detailed technical specifications and justifications of technological choices.

• Development of a complete circuit for the charging system of the electric car, using gel batteries to optimize energy storage.

• Use of a "Battery Balancer" device for voltage correction during charging, explaining the impact of charging imbalance on battery life.

• Presentation of battery stabilization solutions in 24 V and 48 V systems, with details on the operation and advantages of battery stabilizers.

• Integration and optimization of a flexible photovoltaic panel system on a vehicle, with technical descriptions and analysis of solar energy conversion efficiency.

• Implementation of an MPPT (Maximum Power Point Tracking) charge controller to maximize solar energy collection efficiency.

• Design and implementation of a monitoring and control system of the entire propulsion and energy system using modern interface and monitoring devices.

• Detailed description of electrical components and how they are integrated into the vehicle design to ensure operational efficiency and safety.

• Use of advanced techniques for managing and monitoring the state of charge of batteries, including cell balancing methods and over-discharge prevention.

• Incorporating safety solutions into electrical circuit design, including the use of DC fuses and surge protectors.

• Efficient integration of a pure sine wave inverter to convert the stored energy into the format required to power the various electrical components of the vehicle.

• Evaluation and optimization of integrated photovoltaic system performance, including the impact of weather conditions on solar panel efficiency.

• Adaptation and compatibility of electrical system components with various Nissan Leaf vehicle models, ensuring the flexibility and extensibility of the proposed solutions.

• Description of the electromagnetic protection measures (EMC) necessary to ensure the correct and safe operation of electronic equipment in the context of the electric vehicle.

• Adaptation and testing of propulsion and charging systems to ensure compatibility with current standards and technical requirements of modern electric vehicles.

FUTURE ENHANCEMENTS

As electric vehicle technology evolves, the integration of advanced computer vision algorithms and assisted driving systems is becoming increasingly relevant to optimize performance and energy efficiency. The didactic stand developed for the conversion of classic vehicles to electric vehicles can significantly benefit from these technologies, giving students the opportunity to explore and implement innovative solutions for energy management and improving the driving experience.

Computer vision, or artificial vision, allows vehicles to "see" and interpret their surroundings using cameras and image processing algorithms. This technology can be used to detect the angle of the road, traffic conditions, traffic signs and obstacles. In the context of the teaching stand, the integration of computer vision algorithms can help collect route data and adjust vehicle behavior in real time to optimize energy consumption.

Advanced Driver Assistance Systems (ADAS) use advanced sensors, cameras and algorithms to assist the driver in various driving scenarios. These systems include automatic braking, lane keeping, pedestrian detection and adaptive cruise control. By integrating these systems into the teaching stand, functionalities that improve the safety and energy efficiency of electric vehicles can be tested and developed.

A concrete example of the use of computer vision and ADAS technologies in the teaching stand is the detection of the road angle and the optimal use of the regenerative brake. Regenerative braking allows the kinetic energy of the vehicle to be recovered during deceleration and converted into electrical energy, which is stored in the battery. By detecting the angle of the road, the vehicle can anticipate descents and adjust the braking mode to maximize energy regeneration.

Implementation scenario:

1. Descent Detection: Cameras mounted on the vehicle detect the angle of the road and identify the start of a descent.

2. Regenerative Brake Activation: As the vehicle begins to descend, the assisted driving system activates the regenerative brake to slow the vehicle and recover kinetic energy.

3. Charge Optimization: The control algorithm adjusts the intensity of regenerative braking according to the road angle and vehicle speed to ensure a constant and efficient charge of the battery throughout the descent.

4. Performance Monitoring: Collected data on regenerative braking efficiency and battery charge is analyzed in real time, enabling further adjustments and continuous optimization of the system.