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Article

Design of Wiring Harness and Performance Analysis of Powertrain Using Matlab and E-Cad for Electric Vehicle

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Abstract: : In this work, we aim to design the electrical harness of an electric vehicle, which serves as the crucial network that connects all components within the vehicle. The primary objective is to ensure that the harness is designed to optimize cost, serviceability, and safety during vehicle operation. To achieve this, we use AutoCAD Electrical software, which allows for precise and systematic layout of the wiring harness. Designing a vehicle involves several complex calculations, including those related to fuel economy, vehicle dynamics, transmission configurations, motor sizing and its control strategies, motor performance mapping, and battery capacity sizing. These calculations are essential for ensuring optimal performance and efficiency. For accurate evaluation, we employ Excel spreadsheets to carry out powertrain sizing calculations. This process helps in identifying the required capacity of both the battery pack and the motor suitable for the vehicle. Additionally, we utilize MATLAB Simulink software to simulate and analyze the electric vehicle's overall performance. By integrating these tools, we can evaluate the system's efficiency and functionality during the design and testing stages. This method allows us to make necessary adjustments and optimize the vehicle's performance before moving to large-scale production, reducing the risks and costs associated with design errors.

Keywords: zero-emission vehicles; automotive electrification; vehicle electrical harnesses; computer-aided design (cad); electromagnetic compatibility; current type and manufacturability; wire harness design

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1. Introduction

Electric vehicles (EVs) represent a transformative leap forward in automotive technology, promising cleaner, more sustainable transportation and a significant shift in the way humanity approaches mobility [9]. In contrast to traditional vehicles powered by internal combustion engines (ICEs) that rely on fossil fuels such as gasoline and diesel, electric vehicles derive their energy from electricity stored in rechargeable battery packs [10]. This fundamental difference in the energy source dramatically reduces greenhouse gas emissions and contributes to cleaner air and a lower carbon footprint [11]. Moreover, the development of EVs aligns with global initiatives aimed at mitigating climate change and reducing the dependency on finite, non-renewable energy sources like crude oil [12]. The momentum behind the EV revolution is fueled by rapid advancements in battery technology, electric drivetrains, and the widespread expansion of charging infrastructure [13]. These technological strides have enabled the mass production of a wide range of electric vehicles, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel cell electric vehicles (FCEVs) [14]. BEVs rely entirely on electric energy stored in batteries, while PHEVs combine a traditional ICE with an electric motor and battery pack, allowing for dual power sources [15]. FCEVs, on the other hand, generate electricity through chemical reactions between hydrogen and oxygen, emitting only water vapor as a byproduct [16].

One of the most compelling reasons for the growing interest in electric vehicles is their environmental benefit. By eliminating tailpipe emissions, EVs drastically reduce the amount of carbon dioxide (CO_2), nitrogen oxides (NO_x), and particulate matter released into the atmosphere [17]. These pollutants are major contributors to urban air pollution, respiratory problems, and climate change [18]. In addition, as power grids increasingly incorporate renewable energy sources such as solar and wind power, the environmental advantages of EVs become even more pronounced [19]. Charging an EV using electricity derived from clean sources further reduces its overall life-cycle emissions compared to ICE vehicles. Beyond the environmental aspect, electric vehicles offer remarkable performance advantages [20]. Electric motors deliver instant torque, which translates into quick acceleration and a highly responsive driving experience [21]. Many drivers report that EVs provide smoother and quieter rides compared to conventional vehicles, owing to the simplicity of their drivetrains and the absence of gear shifts or engine noise [22]. The mechanical simplicity of EVs also means fewer moving parts, which results in lower maintenance requirements and costs [23]. There's no need for oil changes, timing belt replacements, or exhaust system repairs, all of which are common in ICE vehicles [24].

From an economic perspective, the operational costs of EVs are generally lower than those of gasoline-powered vehicles [25]. Electricity is cheaper than gasoline in most regions, and the efficiency of electric motors means that EVs convert more of the energy stored in batteries into forward motion [26]. Furthermore, governments around the world are actively encouraging the adoption of electric vehicles through various incentive programs [27]. These include tax credits, rebates, reduced registration fees, access to carpool lanes, and free or discounted parking [28]. Several countries and states have also set ambitious targets to phase out ICE vehicles entirely over the coming decades, providing regulatory support for a swift transition to electric mobility [29]. The deployment of EV charging infrastructure is a critical enabler of widespread EV adoption. Public and private investments are being funneled into the development of fast-charging stations along highways, in urban areas, and at workplaces and residential complexes [30]. Fast chargers can replenish an EV battery to 80% in 30 minutes or less, alleviating range anxiety and making electric cars more practical for long-distance travel [31]. Home charging options, such as Level 1 and Level 2 chargers, allow owners to recharge their vehicles overnight, providing convenience and eliminating the need for frequent trips to gas stations [32].

Despite the many advantages, electric vehicles do face several challenges that need to be addressed for their mainstream acceptance [33]. One of the most frequently cited concerns is range anxiety—the fear that an EV will run out of charge before reaching a destination or charging station [34]. Although modern EVs offer ranges exceeding 300 miles on a single charge, this concern persists, particularly in regions with limited charging infrastructure [35]. Additionally, the initial purchase price of EVs can be higher than that of comparable ICE vehicles, primarily due to the cost of lithium-ion batteries [36]. However, battery costs have been declining steadily over the past decade, and continued innovation is expected to bring down prices further [37]. Battery performance is another area of focus in EV development [38]. The energy density, charging speed, lifespan, and environmental impact of battery production and disposal are under constant scrutiny [39]. Researchers are exploring alternative battery chemistries, such as solid-state batteries and lithium-sulfur batteries, which promise improved safety, faster charging times, and longer lifespans [40]. Moreover, efforts are being made to establish robust battery recycling systems to recover valuable materials like lithium, cobalt, and nickel, thereby reducing the environmental footprint of EVs and supporting a circular economy [41].

Electric vehicles are not limited to personal transportation. The electrification of commercial fleets, public transit, and heavy-duty vehicles is gaining momentum [42]. Electric buses are being deployed in major cities to reduce urban air pollution and noise [43]. Logistics companies are incorporating electric delivery vans and trucks into their fleets to meet sustainability goals and reduce fuel costs [44]. Additionally, the emergence of electric two-wheelers and three-wheelers is transforming mobility in densely populated and low-income regions, where affordable and sustainable transport solutions are crucial [45]. Autonomous driving technology is also synergistic with electric mobility [46]. Many self-driving vehicle prototypes and test models are built on electric platforms due to their controllability, energy efficiency, and lower environmental impact [47]. The integration of autonomous systems with EVs has the potential to revolutionize transportation by enabling shared, on-demand mobility services that are efficient, safe, and accessible to a broader population [48].

As electric vehicles continue to evolve, consumer perceptions are gradually shifting [49]. The early skepticism regarding EV performance, reliability, and practicality is being replaced with enthusiasm and confidence [50]. Reviews from early adopters and high-profile EV launches have highlighted the benefits and reliability of electric cars [51]. Marketing campaigns and public awareness initiatives further reinforce the advantages of transitioning to electric mobility [52]. Government policies play a pivotal role in the growth of the EV market [53]. In addition to financial incentives, many governments are implementing stricter emissions standards and fuel economy regulations that compel automakers to invest in cleaner technologies [54]. Some jurisdictions are setting deadlines for the cessation of ICE vehicle sales, compelling the auto industry to accelerate EV development [55]. These policy measures, combined with consumer demand and technological innovation, are driving unprecedented investment in EV research and infrastructure [56].

Major automakers are committing to electrification in a big way [57]. Companies like Tesla, Ford, General Motors, Volkswagen, Hyundai, and Toyota are investing billions of dollars in EV research, manufacturing facilities, and product lines [58]. Tesla has been at the forefront of this revolution, pushing the boundaries of EV range, performance, and software integration [59]. Traditional manufacturers are following suit, releasing a variety of EV models that cater to different segments of the market, from compact cars to luxury SUVs and high-performance sports cars [60]. The global electric vehicle market is expected to witness exponential growth in the coming years. According to various market analysts, EV sales could account for more than half of all new vehicle sales by 2040, with some regions reaching this milestone much earlier [61]. This transition will have profound implications for the automotive supply chain, labor market, energy sector, and urban planning [62]. The demand for electricity will increase, necessitating upgrades to the power grid and the integration of renewable energy sources. Urban planners will need to consider EV charging in their infrastructure designs, and new business models will emerge around vehicle charging, battery leasing, and energy management [63].

In electric vehicles represent the future of transportation, offering a cleaner, more efficient, and technologically advanced alternative to traditional internal combustion engine vehicles [64]. The journey towards full-scale electrification is well underway, driven by environmental imperatives, economic considerations, and technological progress [65]. While challenges such as charging infrastructure, battery limitations, and upfront costs remain, the pace of innovation and the collective efforts of governments, industries, and consumers are rapidly overcoming these barriers [66]. As the world strives to combat climate change and build a more sustainable future, electric vehicles stand as a powerful and promising solution at the heart of this transformation.

2. Materials and Methods

An algorithm for designing complex vehicle electrical harnesses has been created to reduce both the design time and overall weight of electrical wiring. This algorithm automates the design process of electrical systems in modern vehicles. Its primary function is to manage the integration of wires into a harness while addressing critical limitations such as electromagnetic compatibility, current type, manufacturability, geometric constraints, and wiring locations [67]. The foundation of the harness design is a circuit diagram that outlines the power supply system and specifies the positions of the electrical components and design constraints. The algorithm utilizes an approximate method that treats the harness design as a multi-step decision-making process. By converting this methodology into software, the design time can be reduced by 5%, and the total weight of wiring decreased by 3%. This innovation leads to increased efficiency and precision in the production of vehicle electrical systems, crucial for modern automotive engineering needs [1].

With the rise of electric, intelligent, and networked vehicles, the complexity and cost of automotive electronics have grown significantly. As a result, the design of high-quality, low-cost wire harnesses has become a rapidly developing field [68]. This paper investigates wire harness design from multiple dimensions: network topology connection, power distribution systems, overlapping contact areas, unit principles, and layout. These integrated design considerations contribute to the development of a comprehensive and efficient harness framework. This new harness framework reduces the number of connectors, loops, and terminals throughout the vehicle. Additionally, it enhances electrical performance and reliability, all while minimizing manufacturing costs and reducing vehicle weight [69]. By applying such holistic design strategies, manufacturers can meet the increasing functional demands of modern vehicles without compromising performance or budget. This structured approach enables the efficient development of electrical harnesses tailored for intelligent electric vehicles and supports the continued evolution of advanced automotive technology [2].

The study titled "Design process improvement for electric car harness" was conducted in an automotive parts design company, where customer satisfaction plays a crucial role in product development. The objective of this research is to refine the design process for electric car harnesses, which directly affects production scheduling. To achieve this, two analytical tools—Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA)—are employed [70]. FTA helps identify the root causes of design flaws, while FMEA ranks them based on a High-Risk Priority Number (RPN), indicating the most critical issues affecting harness design. After applying these methodologies, the company observed a significant reduction in the frequency of design changes, dropping from 0.26% to 0.08% [71]. This improvement not only boosts efficiency but also ensures a higher level of design accuracy, ultimately contributing to better product quality, streamlined production, and increased customer satisfaction in the electric vehicle manufacturing sector [3].

This research focuses on the dynamic crosstalk in electric vehicle wiring harnesses, considering the variable conditions present during actual vehicle operation. Due to the movement of the vehicle and the random placement of harnesses inside undulating tubes, the relative positions of wires fluctuate, resulting in variable crosstalk values. To analyze this, the paper uses a statistical simulation method [72]. Mutual inductance and capacitance values between insulated wires are calculated using the mirror image method. These parameters are then used to simulate and predict the dynamic range of near-end crosstalk. The results indicate that crosstalk fluctuates within a 3 dB range at an 80% confidence level [73]. These findings provide valuable insights into the design of automotive wiring systems, especially regarding electromagnetic compatibility (EMC). By addressing dynamic crosstalk, designers can enhance the reliability of signal transmission and ensure that automotive electronic systems function correctly under varying real-world conditions [4].

At James Madison University, engineering students participate in hands-on extracurricular projects involving electric vehicle systems. One such initiative focuses on building a laboratory powertrain system that replicates the configurations of real electric vehicles [74]. The setup includes a battery pack, battery management system (BMS), electric motor, and controller, all mounted on a cart to allow easy visibility and access. The aim is to help students grasp the subsystem integration within an electric motorcycle. The design process follows a bottom-up approach that begins with assembling the battery pack, incorporating the BMS for regulation, and integrating a controller to manage vehicle functions and power the motor [75]. This project yields valuable documentation such as schematics and performance data from charging and discharging tests. By working with real components, students gain deeper insights into EV architecture, promoting practical knowledge and innovation in the field of electric mobility, while also preparing them for future careers in automotive engineering [5].

This paper investigates the performance of less popular yet affordable electric vehicles (EVs) like the Ford Focus and Nissan Leaf, which are often overlooked due to public skepticism. The study merges both mechanical and electrical models to build a comprehensive analytical model of an EV powertrain, aiming to understand its real-world driving dynamics [76]. The electrical system includes a motor, DC/DC converter, DC/AC inverter, battery pack, Battery Management System (BMS), and a control system, while the mechanical system comprises transmissions, wheels, and an axle shaft. Simulation tests using MATLAB/Simulink and real driving tests evaluate the performance metrics of these vehicles. Key comparisons include the state of charge (SOC), speed, motor torque, and axle torque over time and vehicle range [77]. The analysis helps clarify the performance capabilities of these affordable EVs and contributes to changing the negative perceptions surrounding them by providing quantitative evidence of their operational efficiency and effectiveness [6].

To enhance energy efficiency and performance, a new electric powertrain system has been developed, featuring an integrated motor and two-speed gearbox specifically designed for pure electric vehicles. The system incorporates a high-efficiency double-V hybrid synchronous motor, an 800V inverter, a park and shift system, and a transmission control unit [78]. This configuration achieves a power density of 2.0 kW/kg, a peak efficiency of 93%, and an average efficiency of 89% under the WLTP driving cycle. The two-speed gearbox is particularly significant, as it enables the motor to operate in its most efficient range more often. When tested in a commercial electric SUV on the Chinese market, the system demonstrated over 8% energy savings during a typical driving cycle [79]. These results not only highlight improved energy utilization but also confirm enhanced vehicle dynamics, with better acceleration and performance across various driving speeds. This advancement marks a significant step toward more efficient electric mobility solutions [7].

Modeling and simulation play a pivotal role in the design and optimization of electric vehicle powertrains. This study explores the critical parameters and performance aspects of powertrain components, including electric motors, power electronics, and battery management systems. Using simulation tools, the research models the entire powertrain to analyze energy efficiency, torque generation, and power output under different operational conditions [80]. It also investigates the state of charge, voltage, and current of the battery pack and how these factors influence the motor's performance [81]. By simulating various driving scenarios, the study aims to identify configurations that offer the best balance between performance and efficiency. The insights gained can guide the development of more advanced and efficient EV systems. These findings contribute to extending the range, reducing energy consumption, and enhancing the dynamic behavior of electric vehicles, which are essential goals in the global effort to promote sustainable and high-performance automotive technology [8].

3. Results and Discussion

1. Electric Vehicle

Electric vehicles (EVs) are automobiles that utilize electric motors for propulsion, drawing power from rechargeable batteries or other energy storage devices. Unlike conventional vehicles that rely on internal combustion engines fueled by gasoline or diesel, EVs operate solely on electricity, making them environmentally friendly and energy-efficient alternatives [82].

Electric Motor: The electric motor is the primary source of propulsion in an EV. It converts electrical energy from the battery into mechanical energy to drive the wheels [83]. Electric motors can be AC (alternating current) or DC (direct current) and are typically more efficient than internal combustion engines. Battery Pack: The battery pack stores electrical energy that powers the electric motor [84]. These batteries are usually lithium-ion, although other types, such as nickel-metal hydride, may be used in some vehicles. The battery pack's capacity determines the vehicle's driving range, and advancements in battery technology are continuously improving energy density and reducing costs [85].

Power Electronics: Power electronics manage the flow of electrical energy between the battery, electric motor, and other components of the EV. This includes inverters, converters, and controllers, which regulate voltage, current, and frequency to ensure efficient operation and protect the battery and motor [86]. Charging System: The charging system allows the EV's battery to be recharged from an external power source, such as a wall outlet or a dedicated charging station [87]. It includes onboard chargers, charging ports, and charging cables. Charging systems can vary in speed and compatibility with different charging standards [88]. The wiring harness enables communication and power distribution between different parts of the EV, including the battery, electric motor, charging system, power electronics, sensors, control modules, lights, HVAC system, entertainment system, and other electrical components [89]. The wiring harness is organized into different circuits, each responsible for specific functions within the vehicle. For example, there are circuits for power distribution, lighting, propulsion, safety systems, and communication between onboard computers [90].

Components: The main components of a wiring harness include wires made of copper or aluminum, connectors, terminals, fuses, relays, and protective insulation. Connectors and terminals allow for easy connection and disconnection of components during manufacturing, maintenance, or repairs [91].

Protection: The wiring harness is typically encased in a plastic, rubber, or thermoplastic elastomer protective sheath to shield the wires from moisture, heat, abrasion, and other environmental hazards. This helps ensure the reliability and longevity of the electrical system [92].

Integration with Vehicle Architecture: The wiring harness is designed and integrated into the overall vehicle architecture during the vehicle's development process. It must accommodate the vehicle's specific layout and packaging constraints, ensuring efficient routing and proper clearance from moving parts [93].

1.1 Manufacturing Process

Wiring harnesses are typically manufactured using automated processes, where wires are cut to length, stripped of insulation, crimped with terminals, and assembled into harnesses according to specific wiring diagrams and schematics [94]. Quality control measures are employed to ensure the integrity and functionality of the harness. In the event of a malfunction or damage, troubleshooting and repairing the wiring harness can be challenging due to the electrical system's complexity. Proper diagnosis, testing equipment, and technical expertise are required to identify and resolve issues effectively.

Splices are connections made between two or more wires within the harness [95]. They can be permanent or temporary and are typically made using soldering, crimping, or other methods to ensure a reliable electrical connection (Figure 1).

Figure 1: Splices

Grounding points in an electric vehicle play a vital role by providing connections to the vehicle's chassis or ground [96]. These points are essential for ensuring the safe return of electrical current to the battery, which is critical for the reliable functioning of the electrical system [97]. Proper grounding helps prevent electrical faults and electromagnetic interference that could disrupt or damage sensitive components [98]. Equally important are labels and identification tags that are attached to wires and connectors within the wiring harness [99]. These tags help indicate the function, location, or connection point of each wire, making it easier for technicians and engineers during installation, maintenance, and troubleshooting procedures. These elements together form the wiring harness, creating a structured and dependable electrical network that supports the operation of various systems within the vehicle.

The wiring harness in electric vehicles serves multiple essential functions. One of its primary roles is power distribution, which involves delivering electrical energy from the battery pack to various vehicle components. This includes the electric motor, power electronics, lighting systems, climate control, entertainment units, and other accessories. Signal transmission is another critical function, as the harness carries electrical signals between different parts of the vehicle. These signals enable communication among control modules, sensors, switches, and actuators to manage functions such as propulsion, braking, and steering. The harness also plays an important role in integrating numerous electrical components within the EV, ensuring that systems such as battery management, traction control, regenerative braking, and HVAC work together harmoniously.

Safety and reliability are inherent benefits of a well-designed wiring harness. By providing robust and secure connections, the harness minimizes the risk of short circuits, electrical faults, and other hazards. It incorporates protective devices like fuses, relays, and circuit breakers to guard against electrical overloads and failures. Environmental protection is another vital function of the harness, as it must endure the challenging conditions experienced by vehicles, including exposure to moisture, heat, vibration, and abrasion. Therefore, the harness is typically constructed with high-quality insulation and protective materials to maintain performance and durability. Routing and packaging are also considered during the design phase to ensure the harness fits efficiently within the vehicle's layout, avoids contact with moving parts, and optimizes space utilization.

The wiring harness aids in diagnostics and maintenance by allowing technicians to test and troubleshoot circuits and components efficiently. Proper labeling and systematic organization facilitate quick identification and resolution of issues, enhancing overall serviceability. Designing a wiring harness for electric vehicles involves several critical steps to ensure system integration, optimal performance, and safety. The process begins with requirements analysis, where the electrical needs of components such as the motor, battery, power electronics, and accessories are defined. Regulatory guidelines and vehicle-specific constraints are also considered. From there, the system architecture is developed to determine circuit layout, voltage and current specifications, and necessary redundancies. Wire sizing and material selection follow, with considerations for current-carrying capacity, voltage drop, environmental exposure, and mechanical durability.

Routing and packaging are then planned based on vehicle layout, component positioning, and access needs. This often involves the use of CAD and 3D modeling software to visualize and optimize the harness configuration. Choosing the right connectors and terminals is critical to ensure compatibility, durability, ease of assembly, and environmental resistance. Protective elements such as fuses and relays are integrated into the design to safeguard against faults. Insulation and additional protection are applied to shield the harness from external hazards and to ensure long-term reliability. Testing and validation are conducted rigorously, including continuity checks, insulation tests, voltage drop analysis, and environmental resilience evaluations. Documentation is generated in detail, covering diagrams, schematics, layouts, component specifications, and labeling instructions. This documentation supports both manufacturing and post-production servicing.

Manufacturing and assembly involve automated processes for cutting, stripping, crimping, and arranging wires, all performed under strict quality control to ensure uniformity and reliability. The power harness in an electric vehicle is specifically responsible for distributing electrical power from the battery to all critical systems. This includes connections to the electric motor, control systems, power converters, and additional electric components. It serves as the central electrical distribution system within the EV, designed to handle high voltages and currents safely and efficiently. Its layout, material composition, and assembly process must ensure minimal power losses, robust insulation, and the ability to withstand the thermal and mechanical stresses encountered during vehicle operation. In essence, the power harness forms the backbone of the electric vehicle's electrical infrastructure, enabling seamless energy flow and communication among systems that define the vehicle's performance and safety.

The power harness plays a crucial role in ensuring that electrical power is transmitted efficiently and safely to all the necessary components, allowing the vehicle to operate smoothly. It must be designed to handle high voltages and currents associated with EVs while considering factors like heat dissipation, electromagnetic interference, and mechanical stress. Hence, we have used AutoCAD Electrical Software to design the vehicle wiring harness and added a fuse to increase the safety of the harness (Figure 2).

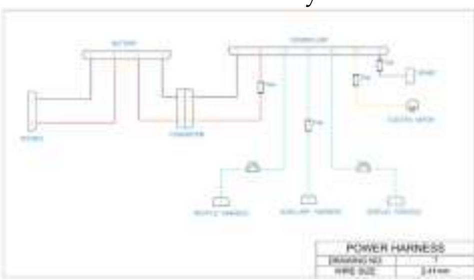

Figure 2: Power Harness

1.2 Auxillary Harness of Electric Vehicle

The auxiliary harness in an electric vehicle (EV) is a subsystem of the overall wiring harness. While the main power harness is responsible for distributing electrical power to the essential components like the battery, motor, and drivetrain, the auxiliary harness is dedicated to powering and connecting secondary or auxiliary components within the vehicle, such as,

- Interior lighting
- Indicator Lighting
- Sensors for various systems (e.g., parking sensors, rain sensors)
- Interior accessories (e.g., USB ports, auxiliary power outlets), etc.

Thus, all the auxiliary systems were connected using AutoCAD Electrical, the vehicle's auxiliary wiring (Figure 3).

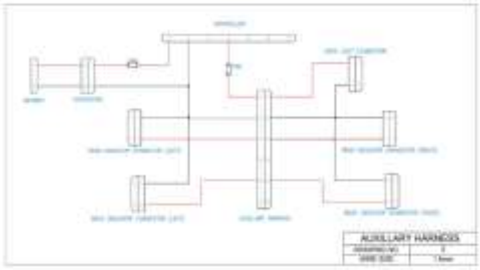

Figure 3: Auxiliary Harness

2. **Powertrain Sizing Calculation**

2.1 Introduction To Powertrain Sizing

Calculating the powertrain of an electric vehicle (EV) involves determining the requirements and specifications for the components responsible for propelling the vehicle, primarily the electric motor, battery pack, and power electronics (Figure 4).

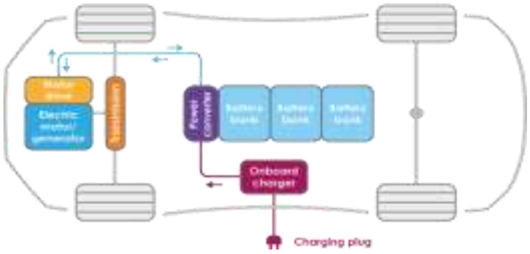

Figure 4: Powertrain in Electric Vehicle

Here’s an overview of the key considerations and calculations involved:

2.1.1 Vehicle Performance Requirements

Determine the performance requirements for the EV, including maximum speed, acceleration, and driving range. These requirements will influence the selection of components and the overall powertrain design.

Vehicle Mass and Aerodynamics: Estimate the vehicle’s total mass, including the chassis, body, occupants, cargo, and other components. Consider the vehicle’s aerodynamic characteristics, such as drag coefficient and frontal area, which affect energy consumption and driving range.

Rolling Resistance: Calculate the vehicle’s rolling resistance, which is influenced by factors such as tire type, tire pressure, road surface, and vehicle weight. Rolling resistance affects energy consumption and powertrain efficiency (Figure 5).

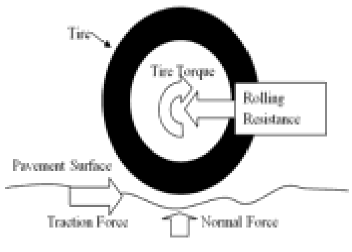

Figure 5: Rolling Resistance

Gradeability: Determine the vehicle’s ability to climb hills or inclines, known as grade ability. Consider the maximum gradient, vehicle weight, and available traction. Gradeability influences the torque and power requirements of the electric motor (Figure 6).

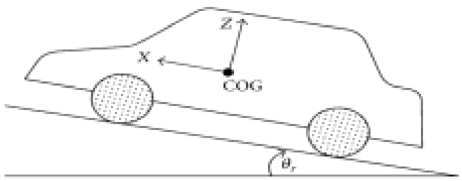

Figure 6: Gradeability of Vehicle

Driving Cycle Analysis: Analyze the expected driving cycle or usage profile of the EV to estimate the average power and energy consumption during typical driving conditions. Consider urban driving, highway driving, stop-and-go traffic, and regenerative braking (Figure 7).

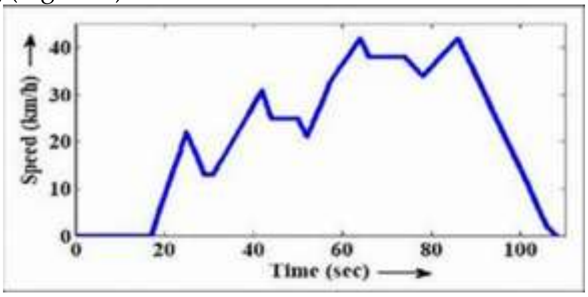

Figure 7: Indian Drive Cycle

Electric motor selection is a crucial step in the design of an electric vehicle, as the motor must fulfill the required torque, power, and efficiency characteristics based on performance targets and vehicle parameters such as mass, rolling resistance, gradeability, and the results of the driving cycle analysis. Choosing the right motor involves evaluating factors like the motor type—whether direct current (DC) or alternating current (AC)—and understanding the torque-speed characteristics, power output, and cooling requirements to ensure sustained performance without overheating. Additionally, the motor's compatibility with the intended powertrain layout and control system should also be considered. Battery pack sizing is another critical element that determines the vehicle's range and energy availability. The battery must store enough energy to meet the driving range requirements derived from driving cycle analyses. Calculating this requires estimating energy consumption per kilometer, taking into account the total vehicle efficiency, terrain, and operating conditions. Key considerations in battery pack design include the choice of battery chemistry (such as lithium-ion), total capacity measured in kilowatt-hours (kWh), voltage, and energy density. These factors not only influence the range but also the weight and packaging of the battery system. Power electronics and control systems serve as the interface between the battery and the electric motor. These systems include inverters, which convert direct current from the battery into alternating current for the motor, and converters, which manage voltage levels for various components. Motor controllers regulate motor operation based on input from the driver and sensors, while regenerative braking systems recover energy during deceleration. The power electronics must be selected and configured to handle the anticipated electrical loads efficiently and reliably.

Thermal management is essential for maintaining the performance and lifespan of key components such as the battery, electric motor, and power electronics. Excessive heat can degrade these systems over time or lead to sudden failures. To counteract this, thermal management strategies such as liquid cooling systems, heat sinks, and thermal insulation are incorporated into the vehicle design. These solutions help dissipate heat effectively, ensuring that all components operate within their optimal temperature ranges even under high-load conditions. Efficiency analysis is conducted to evaluate the performance of the entire powertrain, accounting for energy losses in the electric motor, drivetrain, battery pack, and power electronics. The goal is to minimize these losses to improve vehicle range and reduce energy consumption. Such analysis typically involves the use of simulation tools and performance data to identify areas of inefficiency and propose design optimizations. This may include reselecting components, adjusting gear ratios, or refining control algorithms.

By integrating all these considerations and conducting detailed calculations, engineers can design a powertrain that delivers the desired performance while maintaining energy efficiency and cost-effectiveness. This process requires a collaborative effort among electrical engineers, mechanical engineers, and system integrators to ensure that each subsystem aligns with the overall design goals and vehicle requirements. The calculation of powertrain sizing using Excel sheets is a practical approach to determine the appropriate motor and battery pack specifications for an electric vehicle. This method involves inputting several known parameters and assumptions related to vehicle specifications, operating conditions, and performance requirements. For instance, values such as vehicle mass, frontal area, coefficient of rolling resistance, aerodynamic drag coefficient, gradient percentage, and desired acceleration performance are either measured or assumed based on the design objective. The calculations involve determining the torque needed to overcome various forces acting on the vehicle, such as rolling resistance, aerodynamic drag, gradient resistance, and acceleration force.

The total torque required is derived by summing the torques from each of these individual forces. Once the torque is determined, the rotational speed or revolutions per minute (rpm) needed from the motor to achieve the desired vehicle speed can be calculated. Using the torque and rpm, the power requirement of the motor is then established. Similarly, the energy capacity of the battery pack is estimated by calculating the energy consumption over a given distance, typically expressed in kilowatt-hours per 100 kilometers, and scaling it to match the intended range of the vehicle. These calculations also take into account system inefficiencies and safety margins. The Excel sheet serves as a dynamic tool, allowing designers to adjust input values and instantly see how changes affect the sizing of key components. This iterative process helps in optimizing the configuration of the powertrain for specific use cases, whether the goal is to maximize range, reduce cost, or achieve high performance. Additionally, the structured format of an Excel sheet allows for easy documentation and presentation of results, making it useful for both design verification and stakeholder communication. Ultimately, this approach provides a clear and flexible method for ensuring that the powertrain is properly sized to meet the needs of the electric vehicle.

3. Vehicle Modelling Using Matlab

Vehicle modeling in MATLAB involves simulating the behavior and dynamics of vehicles using mathematical equations and computational techniques. It is a crucial aspect of automotive engineering, allowing engineers to analyze vehicle performance, design control systems, and evaluate various vehicle configurations without the need for physical prototypes. This modeling process serves several essential purposes. First, it supports the design and analysis of multiple vehicle aspects such as dynamics, performance, fuel efficiency, and safety. By simulating different design choices in a virtual environment, engineers can predict how the vehicle will behave in real-world scenarios and make informed design decisions early in the development process (Figure 8).

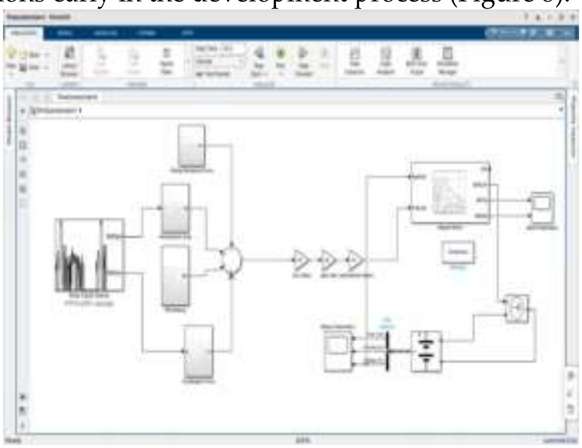

Figure 8: Vehicle Modeling in Matlab Simulink

Another key purpose of MATLAB-based vehicle modeling is control system development. Accurate vehicle models serve as the foundation for creating and testing control algorithms for components such as steering, braking, suspension, and traction control systems. This allows engineers to refine and validate control strategies in a safe and cost-effective manner before implementing them in physical prototypes. Additionally, simulation and validation are essential parts of the process, as they allow the testing of vehicle behavior under various operating conditions, road surfaces, and driver inputs. This reduces the need for extensive physical testing and helps to identify potential performance issues or safety concerns (Figure 9).

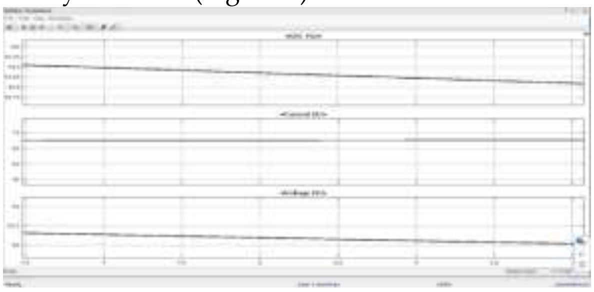

Figure 9: Output Garph (Soc, Current, and Voltage)

Optimization is also a significant benefit of vehicle modeling. Engineers can use vehicle models to conduct optimization studies aimed at improving performance, energy efficiency, and ride comfort. By varying design parameters and configurations within the model, they can identify optimal solutions without the expense of building multiple physical prototypes (Figure 10).

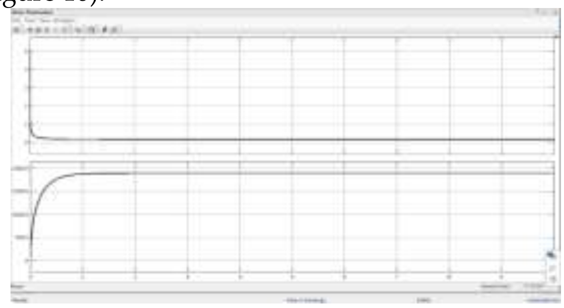

Figure 10: Output Graph (Torque and Rpm of Motor)

In this work, vehicle modeling is performed using MATLAB Simulink, with a focus on a mapped motor. This type of motor is used to visualize the running behavior of different motors graphically. The mapped motor can simulate the behavior of other motors by inputting their parameters, thus making it possible to generate performance outputs in a graphical format. A critical component of the simulation is the drive cycle, which defines how the vehicle is expected to perform over time and includes various forces acting on the vehicle. These forces are integrated into the simulation to determine the motor's performance. A scope is added to the model to monitor and record the behavior of the battery's state of charge (SOC), current, and voltage. The scope also tracks essential motor parameters, such as torque and revolutions per minute (rpm), providing a detailed understanding of the system's performance under different simulated conditions.

4. Conclusion

The paper's objective is to design the style of an electrical vehicle harness that connects all the components of the electric vehicle and optimizes the cost, serviceability, and safety of the vehicle by adding the fuse to the wiring. Thus, safety has been increased, and the wiring harness design has been modelled using AutoCAD Electrical software. The powertrain sizing calculation for the electric vehicle to identify the battery pack power and motor rating was calculated using the Excel sheet. Finally, the electric vehicle modelling using MATLAB has also been completed, and the software output, as mentioned above, has been attached. By completing the paper, we have built an Electric Vehicle in real-time. For future work, the built vehicle can be added with the additional drive cycle and power to increase the range of the vehicle, and it can also be added with solar panels to power the vehicle.

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