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Time-Domain Modeling and Simulation of Performance Electric Vehicle Powertrain with Variable Battery Sizing Configurations

by

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of BACHELOR OF SCIENCE in ELECTRICAL AND ELECTRONIC ENGINEERING

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Declaration of Authorship

We, Md. Mahfuzul Islam (190021113), Shadman Saad Farazi (190021329) and Md. Syeed Hasan (190021205) hereby declare that the thesis entitled "Time-Domain Modeling and Simulation of Performance Electric Vehicle Powertrain with Variable Battery Sizing Configurations" is a result of our own original work conducted under the supervision of Mr. Quazi Nafees-Ul-Islam.

We confirm that –

- This Work has been done for the partial fulfillment of Bachelor of Science in Electrical and Electronic Engineering degree at this University.
- Any Part of this thesis has not been submitted anywhere else for obtaining any degree.

We certify that all sources of information and data have been acknowledged and referenced accordingly. Any assistance and collaboration from other individuals or organizations have been explicitly mentioned in the acknowledgments section of the thesis.

We understand that our thesis may be made available to others in accordance with the regulations of Islamic University of Technology. We are aware that any infringement of the ethical standards in conducting research, including but not limited to plagiarism and fabrication of data, may lead to severe academic consequences.

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List of Acronyms

- **EV**: Electric Vehicle
- **HEV**: Hybrid Electric Vehicle
- **PHEV**: Plug-in Hybrid Electric Vehicle
- **BEV**: Battery Electric Vehicle
- **PID**: Proportional-Integral-Derivative
- **SOC**: State of Charge
- **RUL**: Remaining Useful Life
- **OCV**: Open Circuit Voltage
- **HESS**: Hybrid Energy Storage System
- **NMC**: Nickel Manganese Cobalt Oxide
- **LTO**: Lithium Titanate Oxide
- **NEDC**: New European Driving Cycle
- **WLTP**: Worldwide Harmonized Light Vehicle Test Procedure
- **HIL**: Hardware-in-the-Loop
- **PWM**: Pulse Width Modulation
- **UC**: Ultracapacitor
- **IEA**: International Energy Agency
- **FISITA**: International Federation of Automotive Engineering Societies
- **BMS:** Battery Management System
- **LEV:** Light Electric Vehicle
- **SOC:** State of Charge

Abstract

Electric vehicle (EV) modeling has advanced to previously unheard-of levels of precision and sophistication in 2023 thanks to developments in simulation software, computing capacity, and the growing need for environmentally friendly transportation options. The state-of-the-art methods for EV modeling are examined in this work, with a particular emphasis on battery performance, powertrain efficiency, and dynamic vehicle behavior. This work presents a time-domain modeling and simulation framework for the Tesla Model Y's powertrain, aiming to enhance EV performance through precise simulation models. Key parameters such as mass, drag coefficient, rolling resistance, and wheel radius are integrated into MATLAB/Simulink. Proportional-Integral-Derivative (PID) controllers regulate motor current and vehicle speed, optimizing performance. The study explores variable battery sizing configurations, analyzing their impact on weight, internal resistance, acceleration, and efficiency. Results identify an optimal battery configuration, improving the balance between acceleration and power loss. This research contributes to advancing EV technology and sustainable transportation solutions.

Chapter 1

Introduction

Electric vehicles (EVs) are at the forefront of the transition towards sustainable transportation, offering a promising solution to reduce greenhouse gas emissions and decrease reliance on fossil fuels. However, optimizing the performance of EV powertrains remains a complex challenge due to the intricate interplay between various components and the diverse needs of different driving conditions. The powertrain, comprising the electric motor, battery pack, power electronics, and control systems, plays a pivotal role in determining the overall efficiency, range, and drivability of an electric vehicle.

In this context, the ability to model and simulate the dynamic behavior of an EV powertrain in the time domain becomes invaluable. Time-domain modeling provides a detailed and continuous analysis of system performance over time, capturing transient phenomena that are critical for understanding real-world operations. Furthermore, exploring variable battery sizing configurations adds another layer of complexity and opportunity, as battery size directly impacts key performance metrics such as range, weight, cost, and charging requirements.

This thesis aims to address these challenges by developing comprehensive models and simulations that account for the dynamic interactions within the powertrain. By leveraging advanced simulation tools and methodologies, this research seeks to provide insights into optimizing powertrain performance across different battery configurations, thereby contributing to the advancement of electric vehicle technology and supporting the broader goals of environmental sustainability and energy efficiency.

1.1 Basic Functionalities of the project

The operation’s aim is to integrate accurate simulation models for electric vehicle powertrains that can predict performance over time. Utilizing advanced tools such as MATLAB/Simulink, the research focuses on creating dynamic models that capture the intricate behavior of powertrain components. A key aspect of the work involves ensuring seamless integration of battery dynamics with the overall powertrain system, evaluating the impact of different battery sizing configurations on performance.

By improving key performance indicators such as acceleration, and efficiency, the research explores innovative configurations that balance power output and energy efficiency. The comprehensive analysis addresses the electrical, mechanical, and thermal aspects of the powertrain, tackling engineering challenges related to harmonizing various system components. Through detailed simulations, the thesis tests the impact of different battery configurations and validates models with real-world data to ensure reliability and accuracy.

Additionally, the research investigates the effects of varying the number of parallel battery branches to find the optimal balance between vehicle weight and internal resistance, aiming to maximize performance and efficiency. Looking forward, the thesis proposes advancements in battery modeling, including considerations of temperature and aging, and suggests the development of adaptive control algorithms for real-time powertrain parameter adjustments based on driving conditions. By integrating these elements, the thesis provides a robust framework for enhancing electric vehicle powertrain performance through innovative battery sizing configurations and comprehensive modeling techniques.

1.2 Short Explanation of the overall system designed

The research aims to optimize electric vehicle (EV) performance through advanced modeling and simulation techniques. This project is crucial for enhancing the efficiency, and overall viability of EVs, contributing to sustainable transportation solutions.

1. Electric Motor

The electric motor converts electrical energy from the battery into mechanical energy to propel the vehicle. In our model, we focused on accurately simulating the motor's dynamics, including the torque production and efficiency, using detailed equations and parameters specific to the Tesla Model Y.

2. Battery Pack

The battery pack is the energy source for the EV, providing power to the electric motor. Our study explored various battery configurations, adjusting the number of parallel and series cells to optimize performance. Key factors considered include internal resistance, weight, and energy capacity.

3. Power Electronics

Power electronics manage the flow of electrical energy between the battery and the motor. This includes the inverter, which converts DC from the battery to AC for the motor. Efficient power electronic systems are crucial for minimizing energy losses and enhancing overall vehicle performance.

4. Transmission System

The transmission system transfers the motor's power to the wheels. We modeled the transmission dynamics, including the gear ratios and the effects on vehicle acceleration and speed. The transmission system's efficiency is vital for maximizing the motor's performance and the vehicle's drivability.

5. Control Systems

Control systems, including Proportional-Integral-Derivative (PID) controllers, regulate the motor's speed and torque. These controllers ensure that the vehicle responds accurately to driver inputs and maintains optimal performance under various conditions. We focused on tuning these controllers to balance power output and energy consumption.

6. Vehicle Dynamics

Vehicle dynamics encompass the overall behavior of the EV, including acceleration, braking, and handling. Our model integrated parameters such as mass, drag coefficient, rolling resistance, and frontal area to simulate real-world driving conditions accurately. Understanding vehicle dynamics is essential for optimizing performance and efficiency.

Adjusting battery configurations can significantly improve acceleration and energy efficiency. Increasing parallel battery cells reduces internal resistance, while decreasing parallel cells reduces vehicle weight. We identified a configuration that balances acceleration and power loss, optimizing overall performance and improved battery management extends driving range and reduces charging frequency.

For the purpose of developing, refining, and assessing vehicle performance characteristics such as handling, stability, and safety, MATLAB vehicle dynamics simulation is essential. Before actual prototyping, it enables engineers to create and improve car systems like suspension and control algorithms, saving money and time. Moreover, MATLAB simulations help with regulatory compliance, integrating with other engineering fields, and evaluating environmental effect. They offer a computer-generated proving ground for precisely forecasting real-world behaviors, facilitating well-informed decision-making and improving overall vehicle design and development procedures.

1.3 Background and Motivation

The EV (BEV and PHEV) global sales in 2022 surpassed the 10 million marks, representing a 55% increase from the previous year, 2021, bringing the population to 26 million EVs globally. Of this number, 70% were BEV. The 2022 global sales exceeded the EV population in Europe, which stood at 9.5 million. However, this number was almost half of the total EV population in China. In 2022 alone, the BEV sales in China were 4.4 million, while the PHEV were 1.5 million. This occurrence made China the biggest EV consumer, representing 59% of global sales. In Europe, EV sales stood at 2.7 million in 2022, representing a 15% increase from 2021. Europe was the second biggest EV market, with 30% of the total EV population and sales of 2.5 million in 2022, which was 25% of total global sales. Norway had the highest sales volume in Europe, with 29% owing to its EV-friendly policies, such as tax incentives and road toll exemptions for EVs. The United States EV sales represented 8% of the global EV sales [1].

EV adoption in developing nations remained low. The adoption of 4-wheeler EVs in India remains less than 1%. However, the 2-wheelers and 3-wheelers have been adopted in Asian countries like India, Taiwan and Vietnam [2]. Indonesia projects that by the year 2025, EV sales should be above 20%. They have implemented tax reliefs on EVs and EV components manufacturing, such as batteries. To increase EV uptake in developing countries, charging infrastructure should be developed. Malaysia plans that by 2030, it should have built 125,000 charging stations. Thailand has implemented EV policies to increase EV volumes to 1.2 million and 690 charging stations before 2036 [3].

Powering an EV is around 70% cheaper than fuel-driven cars, with significantly less energy consumption and emissions. The project seeks to leverage these benefits by enhancing the adaptability and cost-efficiency of EVs through variable battery sizing.

EVs generally require less energy compared to traditional fuel-driven vehicles, leading to lower overall energy consumption. Moreover, the shift from fuel-driven to electric vehicles promises a substantial decrease in greenhouse gas emissions, contributing to global efforts against climate change and environmental degradation.

The work focuses on variable battery sizing, tackles the need for batteries that are not only high-performing but also adaptive to changing vehicle requirements. This includes determining how different battery designs affect overall vehicle performance. By creating exact time-domain simulation models, the study hopes to improve important performance metrics such as acceleration and economy, making EVs more competitive with regular vehicles.

By leveraging practical data and models based on popular EV models, such as the Tesla Model Y, the findings are directly applicable to current and future EV designs. Ensuring seamless integration of battery performance with powertrain dynamics is crucial for the practical deployment of EV technologies, which this thesis aims to address using sophisticated simulation tools and control systems.

The insights gained have the potential to influence the design and manufacturing of future electric vehicles, making them more adaptable to a variety of use cases and markets. Supporting the development of sustainable transportation solutions aligns with global goals for reducing carbon footprints and promoting green technologies.

The work advances academic knowledge by introducing novel techniques to EV powertrain modeling and simulation, notably in the temporal domain. The techniques and conclusions can serve as a platform for future study into improving EV performance and battery technology.

1.4 Literature Review

Recent research in the field of electric vehicle (EV) energy storage systems has shifted to hybrid energy storage systems (HESS), which combine high-energy (HE) and high-power (HP) storage technologies to optimize performance, cost, and battery life.[4]

Naseri et al. (2022) explores the optimal sizing of hybrid high-energy/high-power battery energy storage systems to improve battery cycle life and charging power in electric vehicle applications. Their study emphasizes the need for a multi-objective optimization approach to balance various requirements such as driving range, acceleration, fast-charging capability, and battery lifespan. They propose a hybrid battery pack consisting of Nickel Manganese Cobalt Oxide (NMC) cells for high energy and Lithium Titanate Oxide (LTO) cells for high power, utilizing a genetic algorithm to optimize the system based on driving cycles like the New European Driving Cycle (NEDC) and Worldwide Harmonized Light Vehicle Test Procedure (WLTP). Their findings suggest that the hybrid pack significantly extends battery life and improves fast-charging capabilities compared to single-type battery systems, providing a more than 40,000 km increase in driving range under certain conditions and allowing for fast charging up to 70% within 6 minutes.[4]

Shen et al. (2014) offer a comprehensive approach for optimizing the sizing and battery cycle life in HESS for EVs by combining high-energy density batteries and ultracapacitors. The hybrid system takes advantage of the complementary properties of batteries and UCs, with batteries providing high energy density and UCs offering high power density and efficiency. This hybridization not only improves overall performance, but it also dramatically increases battery cycle life by reducing peak power and improving dynamic performance. Shen et al. use a validated battery cycle life estimation model and a multi-objective optimization strategy to balance the trade-offs between system size, weight, cost, efficiency, and driving range. Their findings show that the improved HESS significantly improves battery cycle life by 76% as compared to a battery-only system.[5]

The battery pack is made up of a large number of batteries connected in series and parallel. The performance of these batteries (SOC, RUL, and OCV) varies during use. Inconsistent battery performance is caused by inconsistencies in its parameters. It significantly impacts the battery pack's efficiency and lifetime. Take the cylindrical LiFePO4 battery as an example; a 20% mismatch in parameters affects lifetime by 40% [6]. It has a much shorter service life than a single battery. Consistently improving battery settings improves battery pack performance.[7]

Vidal-Bravo et al. (2020) extensively detailed the use of PSIM for modeling and simulating light electric vehicle (LEV) powertrains, including comprehensive descriptions of electrical and mechanical subsystems and their interactions. This includes detailed descriptions of each subsystem, such as DC-DC power converters and mechanical load models, which are often overlooked in other studies. The inclusion of lead-acid battery models and SOC estimation further enhances the simulation's realism and accuracy.[17]

A motor, a DC/DC converter, a DC/AC inverter, a battery pack, and a Battery Management System (BMS) are all part of the EV powertrain model. An axial shaft, vehicle wheels, and power transmissions are examples of mechanical components [18]. The Simulink model aims to replicate real-world behavior by comparing lithium-ion and lead-acid batteries using State of Charge (SOC), vehicle range, motor torque, axle torque, and speed-battery discharge characteristics as key performance metrics taking Nissan leaf as an example for designing the powertrain and the following equations were developed to meet the design specifications [18].

Voltage Calculation, $V_b=E_b+I_{batt}R_{int}$

Battery Current, $I_{batt}=I_{in}/N_p$

Battery Voltage, $V_{mod}=N_s*V_{cell}$

State of Charge, $SOC= 1-\frac{1}{Cap(batt)}\int I_{batt}dt$

Critical for monitoring the state of charge (SOC), ensuring stable power supply, and quick response to power demands. The SOC indicates the amount of electrical energy stored in the battery, which is essential for efficient vehicle operation [19]

Two battery cells are connected in series and then in parallel with other two cells to forms a battery module. The battery characteristics show that the battery cells are of the laminate type, incorporating a cathode made from a blend of LiMn2O4 and LiNiO2. Each cell boasts a capacity of 32.5 Ah and operates at a nominal voltage of 3.75 V. The exterior dimensions of these cells are 290 mm by 216 mm, making them compact and suitable for integration into the vehicle's battery pack. The energy density of the cells is notably high, at 317 Wh/L in volumetric terms and 157 Wh/kg in gravimetric terms, which ensures that the battery can store a significant amount of energy relative to its size and weight.[19]

The cell voltage is rated at 3.75 V but can reach 4.2 V. The battery pack is arranged into 3 sections. One section contains 24 modules in the center of the pack. Two other sections of 12 modules each are connected in series with the central section on the two sides. The battery pack voltage is rated at 360V and its capacity is 24 kWh.[19]

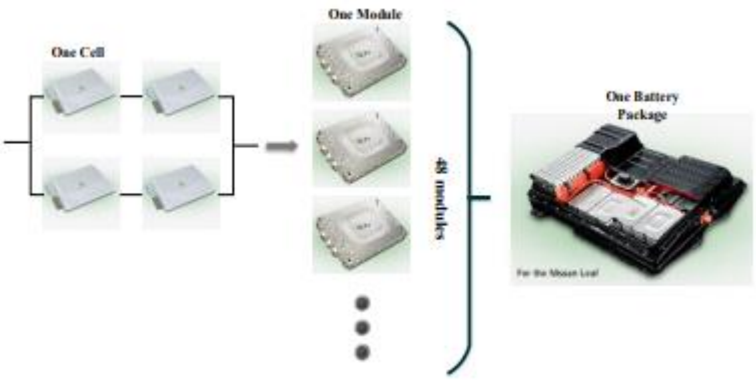

Fig- 1: Structure of an EV battery pack [19]

Chapter 2

Overview of Our Work

In order to enhance the efficiency and performance of electric vehicle (EV) powertrains through precise modeling and simulation, this project focuses on the Tesla Model Y, utilizing MATLAB/Simulink for simulations. The objectives include developing accurate time-domain models, integrating battery performance with powertrain dynamics, improving acceleration and efficiency, and assessing the impact of different battery sizes on performance.

2.1 Introduction

Understanding how the EV operates under various driving and environmental situations is crucial for maximizing vehicle performance, health, and safety. Temperature, road conditions, road grade/elevation, aggressive/conservative driving, and other factors that may affect vehicle performance must be validated in order to estimate vehicle reliability and performance [8]. Central to the performance and efficiency of EVs is the powertrain, a sophisticated system that converts electrical energy from the battery into mechanical energy to propel the vehicle.

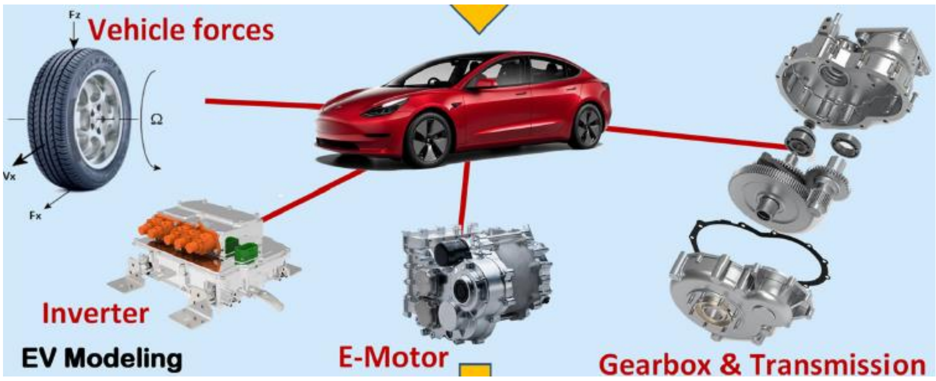

Fig – 2: Power Profiling [4]

2.2 Methodology

Modeling and Solving Differential Equations in Integral Format:

We developed differential equations that represent the various dynamic components of the EV powertrain, such as the electric motor, battery, and vehicle dynamics. Given the non-linear nature of these systems, we converted these differential equations into their integral forms. This approach facilitates the numerical solution of the equations, making it suitable for simulation in the time domain.

Time Domain Simulation:

We accounted for the non-linear behavior of EV powertrain components; time-domain simulation is used. This enables the capture of transitory reactions and dynamic interactions among components. We ensured that the time step size is modest enough to accurately capture the dynamics while avoiding substantial numerical mistakes.

Modeling with MATLAB Simulink:

We implemented the resulting integral equations in MATLAB Simulink, a powerful tool for modeling, simulating, and analyzing dynamic systems. Then we created a block diagram of the EV powertrain, with each block representing a specific component or subsystem (for example, motor, battery, transmission). Finally, we connected these blocks based on the physical relationships and dependencies between components.

Some predefined Simulink blocks (e.g., integrators, gains, sum blocks) to represent mathematical operations were used by us. And we utilized custom blocks or MATLAB functions for more complex or specific behaviors not covered by standard blocks.

Designing PI/PID controllers:

Implementing PI and PID controllers to govern and regulate subsystem outputs, such as motor current and vehicle speed, we then designed the controllers such that they are stable and function optimally. The controller parameters (proportional gain K_p, integral gain K_i, and derivative gain K_d) are tuned based on system dynamics and desired performance.

In practical applications, controller outputs are often saturated to prevent excessive commands that could damage components or cause unsafe behavior. We simulated and observe the behavior of the controllers under various conditions, noting how saturation limits affect system performance and stability. Example: If the motor current exceeds a safe limit, the controller output is clamped to this limit, and the system behavior under this condition is analyzed.

Battery Size and Configuration:

We optimized the performance and efficiency of the EV powertrain, experiment with different battery cell sizes in the simulation and then change the number of parallel and series cell configurations to mimic various battery capacity and internal resistances.
For example, increasing the number of parallel cells reduces internal resistance while increasing capacity, which influences acceleration and energy loss.

This was used to analyze the impact of different battery configurations on key performance indicators such as acceleration, range, and efficiency and identify an optimal battery configuration that balances performance and efficiency, taking into account practical constraints such as weight and cost.

This precise technique allows for systematic and accurate modeling and simulation of the EV powertrain, guaranteeing that the insights acquired are dependable and applicable to real-world settings. This technique not only improves our understanding of EV dynamics, but it also helps to create more efficient and resilient powertrain systems.

2.2.1 Selecting an EV model

When choosing an electric vehicle (EV) model for powertrain simulation in MATLAB, it is vital to evaluate the many types of EV architectures, as shown in the image [9] There are three types of electric vehicles: hybrid (HEV), plug-in hybrid (PHEV), and battery electric (BEV). Each type has unique properties and energy sources that might affect the modeling process and simulation results.

A hybrid electric vehicle (HEV) combines a gasoline engine, an electric motor, and a small battery pack (6-12 kWh). The primary fuel source is gasoline, with the electric motor providing additional power to enhance fuel efficiency and lower pollutants. HEVs do not require external charging because the battery is charged by regenerative braking and an internal combustion engine. HEVs are ideal for modeling studies that focus on fuel economy optimization and the integration of electric assist technologies. However, the dual power sources and complicated control systems may complicate the simulation.[10]

Plug-in Hybrid Electric Vehicle, PHEVs have both a gasoline engine and an electric motor, but with a larger battery pack (6-12 kWh) that can be charged from an external electric grid. This allows PHEVs to operate in pure electric mode for short distances, lowering fuel consumption and pollutants. PHEVs are appropriate for simulations that seek to investigate the advantages of integrating electric and internal combustion power, optimize energy management between the two sources, and assess the influence of grid charging on overall efficiency. The real-world fuel consumption of PHEVs in Europe is on average three to five times higher than WLTP type-approval values.[11] PHEVs are a versatile choice for full powertrain investigations because they have both petrol and electric powertrain components.

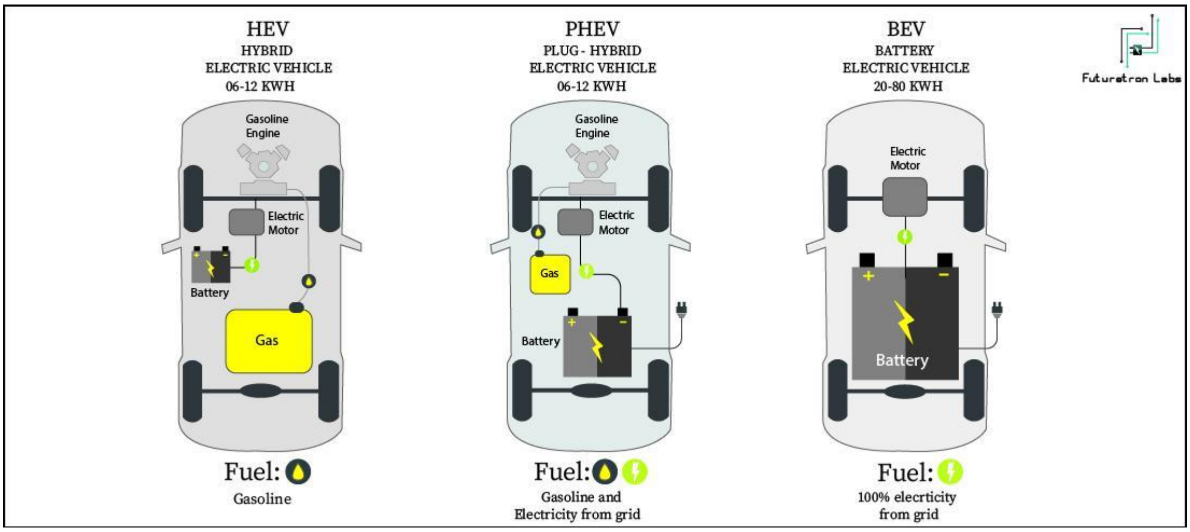

Fig – 3: Model Comparison [12]

Battery Electric Vehicle (BEVs) rely only on an electric motor powered by a huge battery pack (20-80 kWh) and are powered fully by grid electricity. They lack an internal combustion engine, which simplifies powertrain components while increasing battery management and energy efficiency requirements. BEVs are the chosen choice for simulations that focus only on electric powertrains, with the goal of optimizing battery performance, increasing vehicle range, and improving overall energy economy. BEVs' simple electric architecture makes them an ideal model for researching the dynamics and control techniques of electric powertrains.[12]

2.2.1.1 Tesla Model 3/Y

Choosing a BEV like the well-researched and well-documented Tesla Model Y allows for a clear focus on electric powertrain dynamics in a MATLAB powertrain simulation, without the added complication of including internal combustion components. Because of its vast real-world performance data, sophisticated battery technology, and exhaustive technical specifications, the Tesla Model Y is a great option for precise and in-depth simulations. The simulation may dig extensively into optimizing battery usage, controlling electric drive systems, and promoting energy efficiency by concentrating on a BEV. This is in line with the objectives of advancing electric vehicle technology and sustainability.

The key aspects of the Tesla Model Y [13] –

- Affordable Model: Positioned between Model 3 and Model X in pricing and performance.
- Heat Pump Feature: First Tesla to feature a heat pump for interior heat and battery preconditioning.
- Dual Motor AWD: Available in Long Range and Performance versions with 75 kWh battery pack.
- Long Range Version: 326 miles range, 135 mph top speed, 0-60 mph in 4.8 seconds.
- Performance Version: 303 miles range, 155 mph top speed, 0-60 mph in 3.5 seconds.
- Standard Range RWD: 244 miles range, 135 mph top speed, 0-60 mph in 5.3 seconds.
- Vehicle Weight: Weighs 4,416 lbs., heavier than Model 3.
- Unibody Casting: Uses Mega cast for front and rear frame portions.
- Tow Hitch Option: Available add-on, offers 3,500 lbs. towing capacity.
- Seven Seat Option: Only available on Long Range trim, limited headroom and legroom.
- Dimensions Compared to Model 3**:** Longer, wider, taller, more cargo volume.
- Pricing: Long Range from $54,990 to $73,990; Performance from $61,990 to $75,990.
- Charging Times: Level 1: 20-40 hours, Level 2: 8-12 hours, Supercharger: 15-25 minutes.
- Charging Costs: Average $12.35 for full charge at home, $8.68 at Supercharger.
- Efficiency: Long Range: $0.038/mile, Performance: $0.041/mile at home charging.

2.2.1.2 Tesla Model 3/Y parameters

A number of crucial design elements have a big influence on the efficiency and performance of the Tesla Model Y. With an average mass of 2003 kg, the vehicle strikes a compromise between weight efficiency and structural integrity. Its comparatively low drag coefficient of 0.23 contributes to the reduction of aerodynamic drag, increasing the vehicle's efficiency at greater speeds. Tesla has reduced the frictional losses between the tires and the road to improve energy saving, as seen by the rolling resistance coefficient of 0.02.

Air density, which is 1.29 kg/m³, is a critical quantity in aerodynamic calculations. This parameter aids in calculating the vehicle's aerodynamic drag force. Since the frontal area of 2.22 m² represents the surface area facing the airflow of the vehicle, it is important in determining this aerodynamic drag.

The 255/44 tire size's wheel radius of 0.38145 meters has an impact on the vehicle's characteristics, notably on how well it accelerates and brakes. Numerous computations employ the usual acceleration due to gravity, 9.8 m/s^2, to find the forces and torques operating on the vehicle. Last but not least, the performance of the electric motor depends on the back electromotive force (EMF) constant, which is equivalent to the torque constant at 0.245 and affects how well electrical energy is transformed into mechanical energy.[14][15][16]

2.2.2Modelling and Simulation

2.2.2.1 Software Selection

The selection of appropriate software is crucial for the successful completion of any engineering project, especially those involving complex simulations and modeling tasks. In the context of time-domain modeling and simulation of electric vehicle (EV) powertrains with variable battery sizing configurations, the chosen software must offer robust capabilities in system modeling, simulation, data analysis, and visualization. For this project, MATLAB was selected as the primary software tool. This section outlines the rationale behind this choice, highlighting the specific features and advantages that make MATLAB an ideal platform for this project.

- **Rationale for MATLAB Selection**
- **Comprehensive Toolset for Modeling and Simulation**

MATLAB offers a robust suite of tools for modeling and simulating dynamic systems. Its Simulink environment enables detailed modeling of complex systems like EV powertrains, with built-in libraries for electrical components, mechanical systems, and control algorithms.

- **High-Level Programming Environment**

MATLAB's high-level programming language is ideal for numerical computation, visualization, and algorithm development. Its intuitive syntax allows for rapid prototyping and model iteration, enhancing flexibility and scalability in exploring various battery sizing configurations and their impact on powertrain performance.

- **Extensive Support for Time-Domain Analysis**

Time-domain analysis is crucial for understanding the transient behavior of EV powertrains. MATLAB's built-in functions and toolboxes support a wide range of time-domain analyses, including time-series data manipulation, signal processing, and control system design, ensuring accurate modeling of dynamic responses to different conditions.

- **Integration with External Hardware and Software**

MATLAB supports interfacing with external hardware and software, making it suitable for hardware-in-the-loop (HIL) testing and real-time data acquisition. This capability is essential for validating simulation models against experimental data to ensure real-world accuracy.

- **Rich Visualization and Data Analysis Tools**

Effective visualization and data analysis are vital for deriving insights and making informed decisions. MATLAB offers extensive plotting functions and interactive visualization tools for clear presentation and interpretation of simulation results, aiding in the optimization of battery sizing configurations.

- **Strong Community and Support Resources**

MATLAB is widely used in both academia and industry, with a large and active user community. Extensive documentation, technical support from MathWorks, and a wealth of online tutorials and forums provide valuable resources for troubleshooting and learning, ensuring efficient resolution of any project challenges

2.2.2.2 Equation Formation

In the context of modeling an electric vehicle (EV) powertrain, especially with variable battery sizing configurations, several key equations need to be formulated to accurately represent the dynamics and performance of the system. The main components of an EV powertrain include the battery, electric motor, power electronics, and drivetrain.

1. Battery Modeling

The battery model typically includes equations for state of charge (SoC), terminal voltage, and internal resistance.We used default Datasheet Battery (Lithium Ion) Pack from Matlab and updated the parameters of the block as Tesla Model Y’s Battery Pack.

2. Electric Motor Modeling

The electric motor model includes equations for torque, speed, and power.

- **Torque Equation:**

$$T_m = k_t * I_m$$

  where T_m is the motor torque, k_t is the torque constant, and I_m is the motor current.

- **Current Equation :**

From motor equivalent circuit, $V_{in}(t) = L\frac{di(t)}{dt} + \mathrm{Ri(t)} + Eb$

$$\text{So, } \boldsymbol{i(t) = \frac{1}{L}\int (v_{in}(t) - Ri(t) - E_b)\,dt}$$

Where R is the resistance, L is the inductance, and E_b is the back emf.

- **Power Equation:**

$$\mathbf{P_m = T_m * \omega_m}$$

3. Power Electronics Modeling

The power electronics, typically an inverter, converts the DC power from the battery to AC power for the motor.

- **Inverter Efficiency:**

$$\boldsymbol{\eta_{inv} = \frac{Pout}{Pin}}$$

4. Drivetrain Modeling

The drivetrain transmits the motor torque to the wheels, and includes losses due to friction and other factors.

- **Drivetrain Efficiency:**

$$\boldsymbol{\eta_{drivetrain} = \frac{\tau_{\omega}\omega_{\omega}}{\tau_m \omega_m}}$$

5. Vehicle Dynamics

The vehicle dynamics include equations for acceleration,

To form the velocity equation, we consider Newton's second law of motion, which states that the rate of change of momentum of an object is directly proportional to the net force acting on it and inversely proportional to its mass:

$$\mathbf{m\frac{dv}{dt} = Fnet}$$

☐ Then, we define the net force (F_{net}) as the sum of the forces acting on the vehicle:

$$\mathbf{F_{net} = F_{drag} + F_{rr} + F_{grade}}$$

☐ We derive expressions for each force:

- Aerodynamic drag force: $\mathbf{F_{drag} = 0.5\ \rho A C_d\, v^2}$
- Rolling resistance force: $\mathbf{F_{rr} = C_{rr} mg}$
- Gradient force: $\mathbf{F_{grade} = mg\sin(\theta)}$

- Finally, we substitute these expressions into the velocity equation to obtain the complete model.

2.2.2.3 Modelling The Equations

<u>Velocity model</u>

- **Derived equation,** $\boldsymbol{v(t) = \frac{1}{m}\int\left(F - mgsin\theta - mgc_{rr}cos\theta - \frac{1}{2}\rho v^2(t)AC_D\right)dt}$

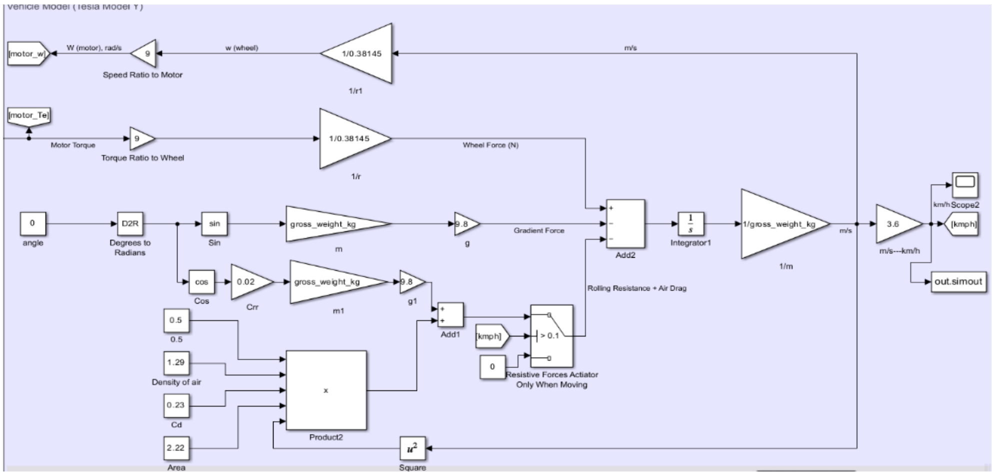

Fig-4: Velocity Model

<u>Motor Model</u>

- Derived equation**,** $\boldsymbol{i(t) = \frac{1}{L}\int(v_{in}(t) - Ri(t) - E_b)\,dt}$
- Back emf, $\boldsymbol{E_b = Back\ emf\ constant\ (Kbemf) * Angular\ velocity\ of\ motor}$
    - **Constant power of Tesla Model Y = 110 kW**
      Now, Current = $\frac{Constant\ Power}{Battery\ Voltage} = \frac{110\ kW}{400\ V}$ = 275 A
      At top speed of 217 km/h,
      $\boldsymbol{\tau = F.r}$ = 1589.204 N * 0.38145 m
      = 606.20034 N-m
      This is the wheel torque.
      Now, Motor Torque = 606.20034/9
      = 67.35 N-m
      We know, Motor Torque**,** $\boldsymbol{\tau_m = k_T * I}$
      $\mathbf{k_T}$ = 676.35/ 275 = 0.245

Interestingly, the torque constant, $\mathbf{k_T}$ and the back EMF constant, $\mathbf{k_b}$ are equal. This can be demonstrated by applying the law of conservation of energy: electrical power in must be equal to mechanical power out plus motor electrical losses.

- **R** is calculated by the back calculation from the top speed of Tesla Model Y = 217 km/h.
    - back calculation of R from top speed
      V = 227 kmh^{-1} **=** 60.2778 m/s
      Total force, F = 1589.204 N
      P = F . v
      = 1589.204 N × 60.2778 kmh^{-1}

= 95.8 kW

Now, loss = 110 kW - 95.8 kW

= 14.2 kW

So, $\mathbf{R} = \mathbf{loss}/\mathbf{I}^2 = \frac{14.2 \times 10^{\wedge}3}{(275)^{\wedge}2}$

R = 0.187 Ω

- **L** is assumed from real life values of DC motor Inductance and a higher value is taken for the ease of simulation.
  - $L = 187 \times 10^{-4}$ F

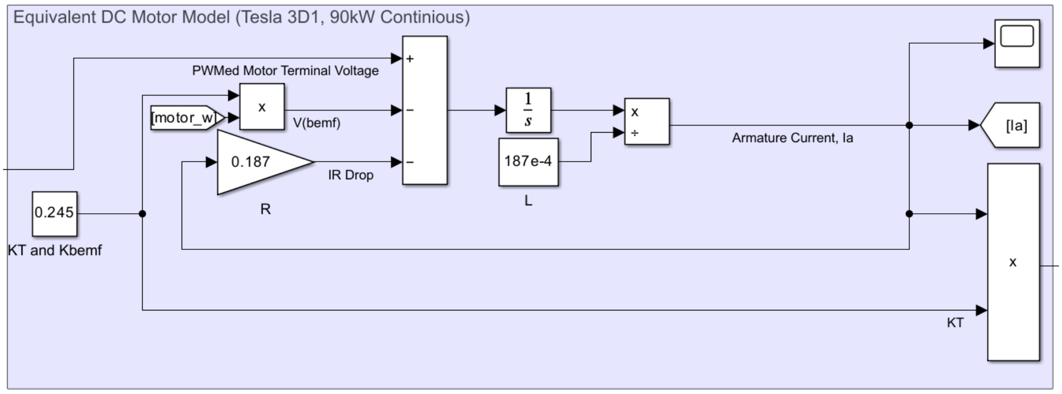

Fig-5: Motor Model

Transmission Model

- There are two transmission process –
  - First one is from motor torque to wheel force,

$$wheel\ force = \frac{Motor\ torque}{gear\ ratio * wheel\ radius}$$

  - Second one is from velocity to angular velocity of motor,

$$Angular\ velocity\ of\ motor = \frac{Velocity}{gear\ ratio * wheel\ radius}$$

  - Where,
    - Gear ratio = 1:9
    - Wheel Radius = 0.38145 m

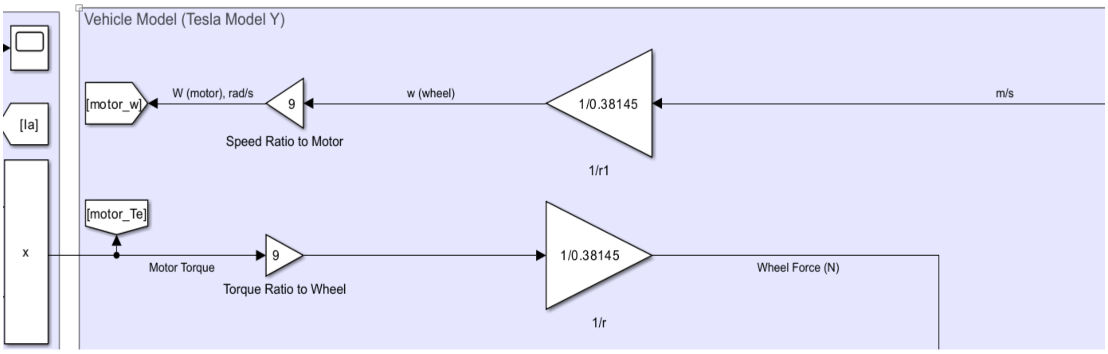

Fig-6: Transmission Model

Battery pack and Motor Current Control

- We used default Datasheet Battery (Lithium Ion) Pack from Matlab and updated the parameters of the block as Tesla Model Y's Battery Pack.
- PWM generator block is used for motor control.
- PI controller is used to control current with feedback.

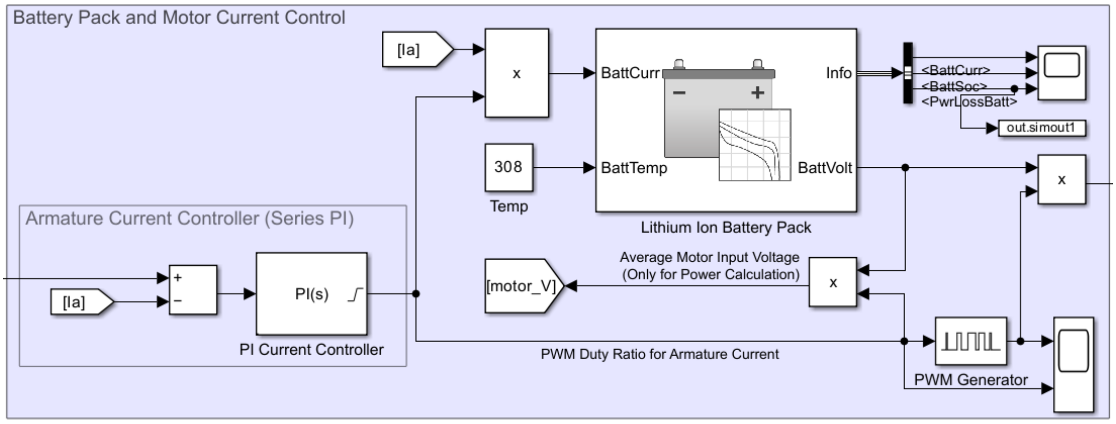

Fig-7: Battery Pack and Motor Current Control

Velocity Controller

- The velocity controller adjusts motor torque based on the difference between desired and actual vehicle velocity. A proportional-integral-derivative (PID) controller is commonly used.
- Upper and lower limits are employed to provide the current controller with a current command.

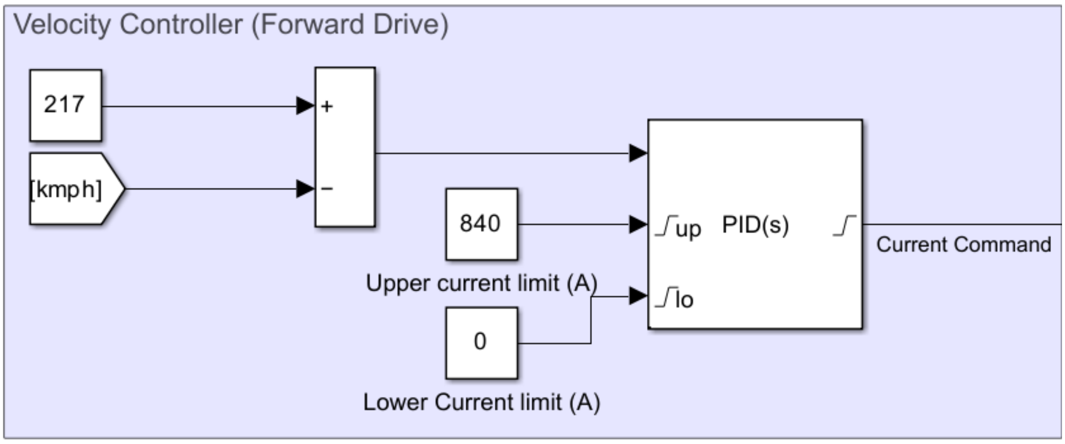

Fig-8: Velocity Controller

Power and Efficiency Calculation

- Power is calculated for both Mechanical power generated and Electrical power given to motor.
- Efficiency of system,

$$Efficiency = \frac{Mechanical\ Power\ generated\ by\ motor(kW)}{Electrical\ Power\ Given\ to\ Motor(kW)} * 100\%$$

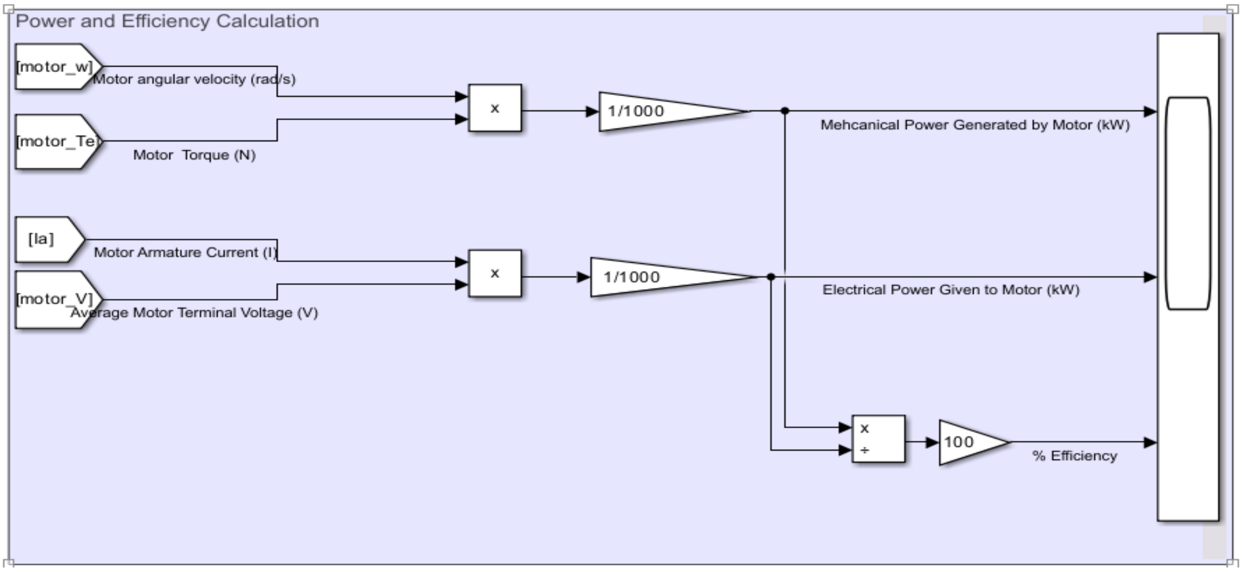

Fig-9: Power and Efficiency Calculation

2.3 Running Simulation

The simulation process involves setting up the model parameters, defining the control strategies, and running the simulation to analyze the performance of the electric vehicle powertrain under various battery sizing configurations. The following sections describe the detailed steps involved in running the simulation.

2.3.1 Setting Up the Simulation Environment

To begin with, the simulation environment is set up using MATLAB/Simulink. The following components are modeled and configured:

1. **Vehicle Dynamics:**
    - The vehicle dynamics are modeled to calculate the velocity and acceleration based on forces acting on the vehicle, including aerodynamic drag, rolling resistance, and traction force from the motor.
2. **Motor Model:**
    - The motor model includes the equations for motor torque and speed, taking into account the electrical and mechanical parameters of the motor.
3. **Transmission Model:**
    - The transmission model is used to calculate the torque and speed delivered to the wheels, considering the gear ratio and transmission efficiency.
4. **Battery Pack and Motor Current Control:**
    - The battery pack model includes the equations for battery voltage, internal resistance, and state of charge (SOC). The motor current control ensures the desired torque output by adjusting the current supplied to the motor.
5. **Velocity Controller:**
    - A PID controller is used to maintain the desired vehicle speed by adjusting the motor torque based on the error between the desired and actual vehicle speeds.
6. **Power and Efficiency Calculation:**
    - The power consumption and efficiency of the powertrain are calculated based on the motor power, battery power, and losses in the system.

System Overview

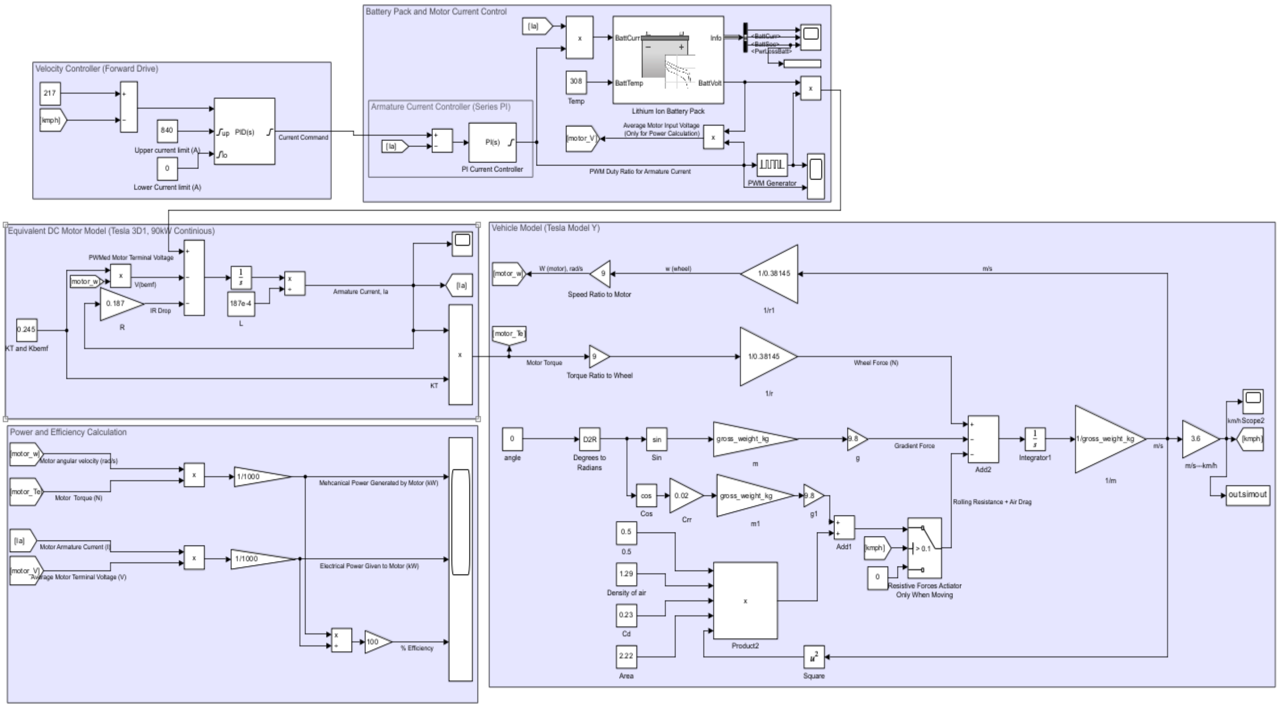

Fig-10: System Overview

Tesla Model Y/3 parameters –

- Mass (avg.) , m = 2003 kg
- Drag Coefficient, C_d = 0.23
- Rolling Resistance Coefficient , C_{rr} = 0.02
- Air Density , $P_{ai\ r}$= 1.29 kgm^{-3}
- Area = $2.22m^2$
- Wheel radius , r = 0.38145(for 255/44 tyre)
- Acc. due to gravity = $9.8ms^{-2}$
- Back emf constant, $K_{bemf} = K_t$ = 0.245
- Battery Voltage = 400V

2.3.2 Running the Simulation

1. **Initialize the Simulation:**
   - Open the Simulink model and ensure all blocks are connected correctly.
   - Set the simulation time to the desired duration (e.g., 100 seconds).
2. **Start the Simulation:**
   - Execute the simulation in Simulink.
   - Monitor the progress of the simulation to ensure it runs smoothly without any errors.
3. **Log Data:**
   - Record the output data, including vehicle speed, motor torque, battery voltage, battery current, and powertrain efficiency.

2.3.3 Obtaining Results

Simulation Graphs

Vehicle Model (Tesla Model 3/Y)

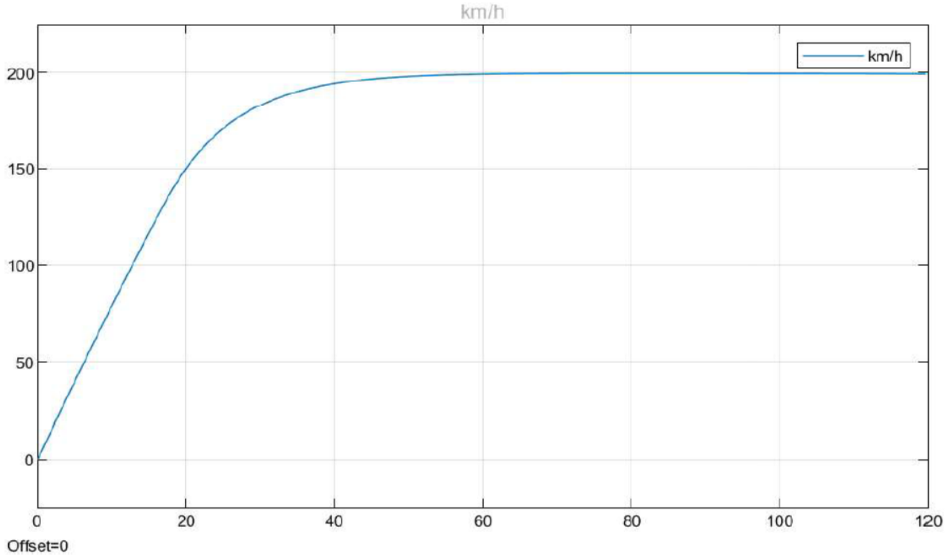

Fig-11: Vehicle Model

- ☐ Equivalent DC Motor Model :

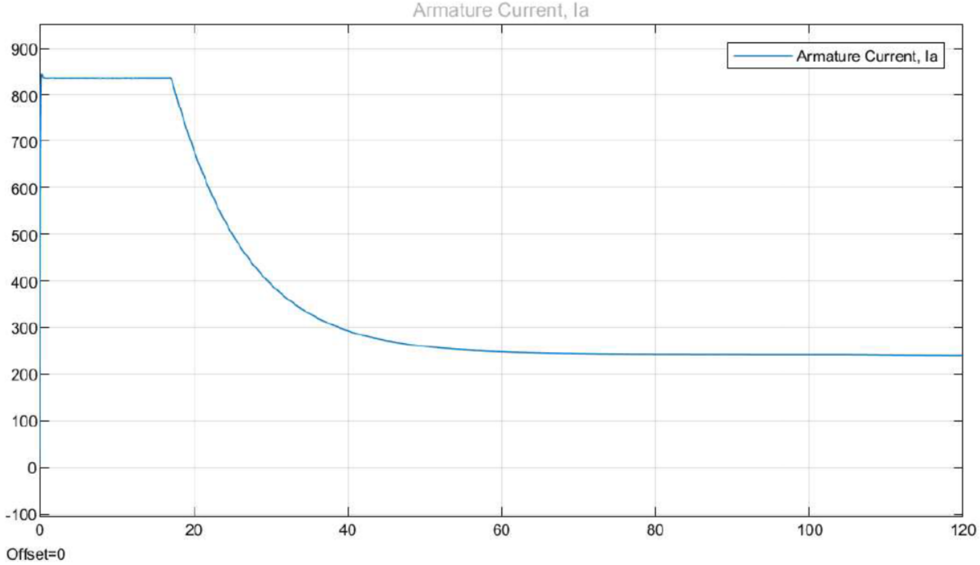

Fig-12: Equivalent DC Motor Model

The graph gradually stabilizes around 200 A by 100 seconds. The current surge indicates high initial torque, then decreases as the Initially, the armature current is near 900 A, drops sharply to 300 A at 20 seconds, and then motor reaches steady-state operation.

❑ Battery Pack Output:

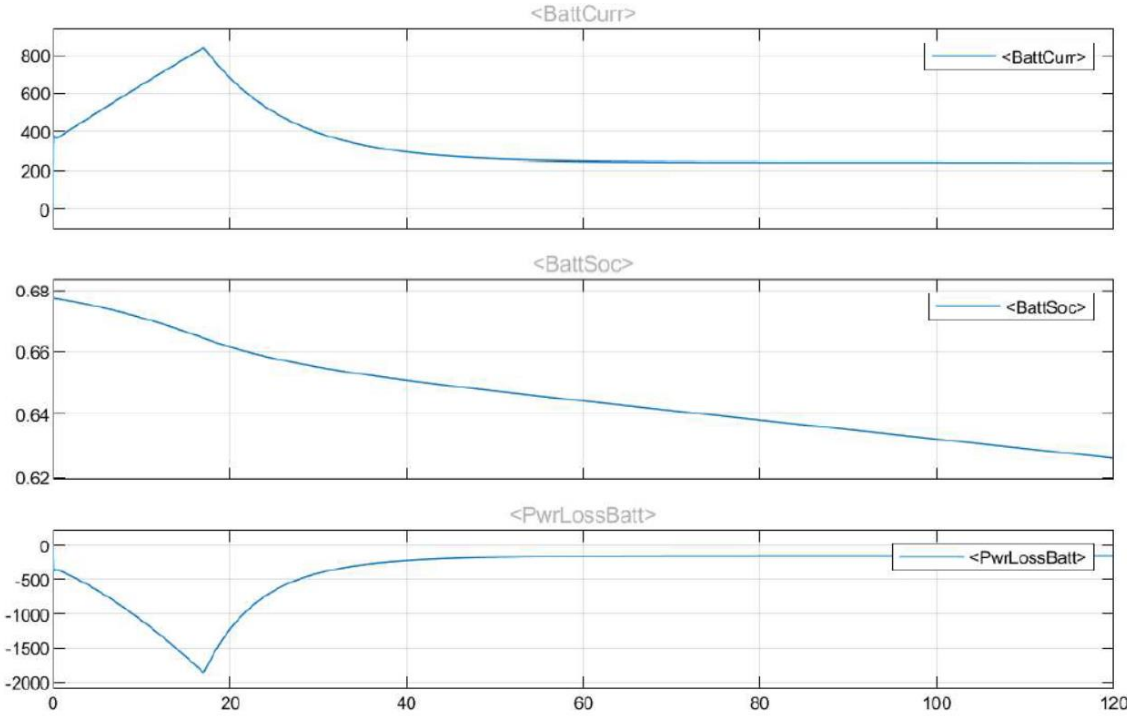

Fig-13: Battery Pack Output

❑ PWM generator output:

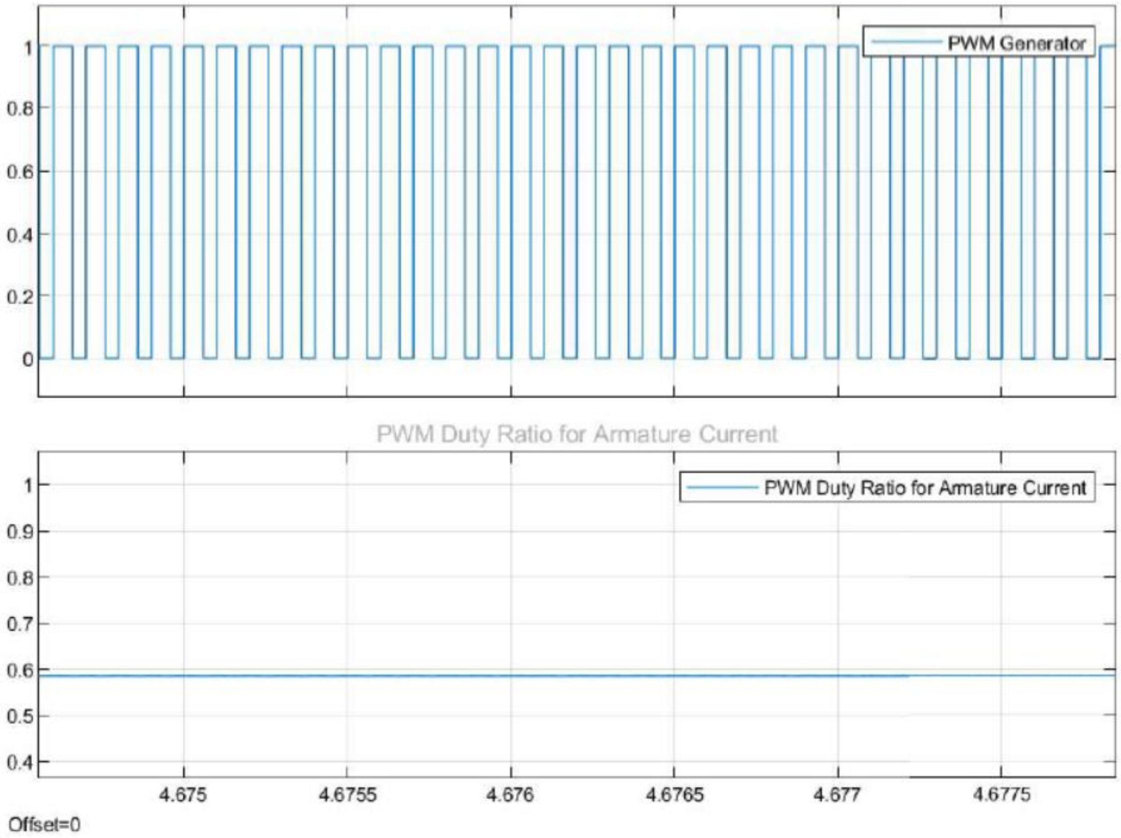

Fig-14: PWM Generator Output

☐ Power and efficiency Calculation:

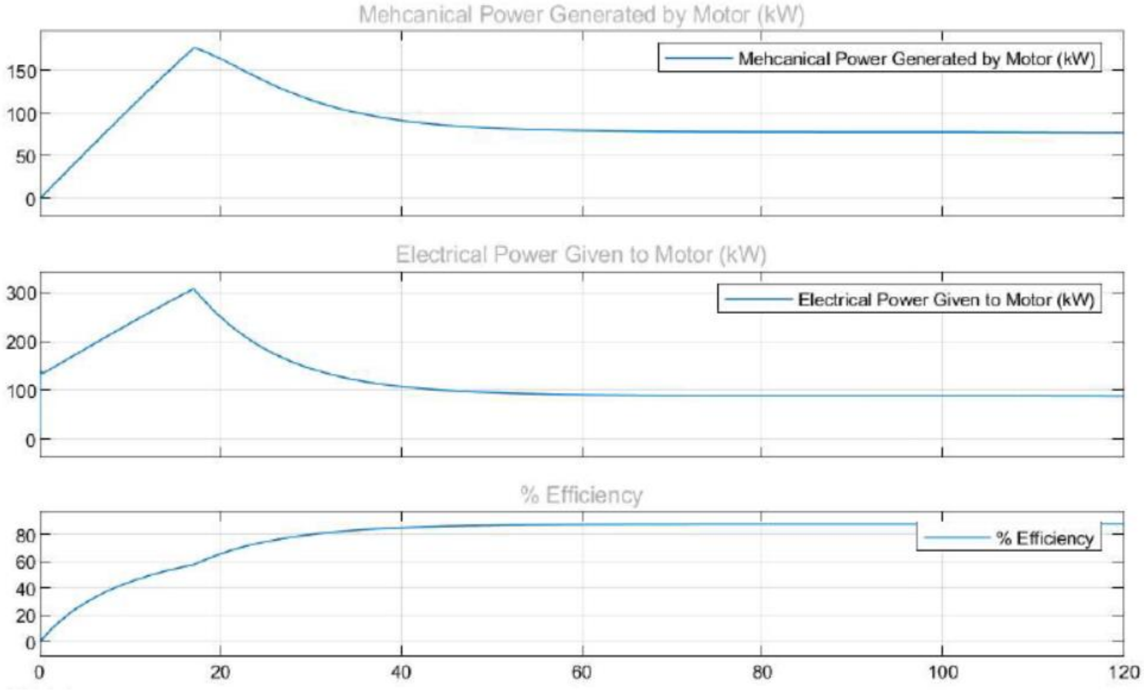

Fig-15: Power And Efficiency Calculation

2.4 Battery sizing of Tesla Model Y/3

- Default Datasheet Battery (Lithium Ion) block from Matlab.
- Parameter tuning of this battery block -
    - Tesla Model Y Battery parameters-
        - Battery Voltage, 400 V
        - Cell capacity, 4.8 Ah
        - Battery type, 2170.
        - Total 4416 battery cells.
        - 96 cells in one series.
        - 46 series cells in parallel.
        - Battery weight, 771 kg.
        - Per series of cells weight = 771/46
          = 16.7609 kg.

What happens if we change the number of parallel branch??

- If we reduce parallel branch:
    - Reduces the weight of vehicle.
    - Increases the Internal resistance of battery.
- If we increase parallel branch
    - Increases the weight of vehicle.
    - Reduces the Internal resistance of battery.

2.4.1 Result analysis

- We used a Matlab code to simulate the performance graph for different parallel branch modes.

Matlab Code:

```
weight_per_series_branch_kg = 16.7609;

no_cells_parallel = 46;
cell_cap_Ah = 4.8;

calculated_bat_weight = weight_per_series_branch_kg * no_cells_parallel;


gross_weight_kg = 1232 + calculated_bat_weight
```

By changing the number of parallel branches simultaneously to 10, 16, 28, 46, 58, and 65. We can see that there are 2 types of effect.

1. **Effect in Performance :**
    - If we reduce parallel branch due to loss of weight, acceleration increases.
    - If we increase parallel branch due to gain in weight, acceleration decreases.

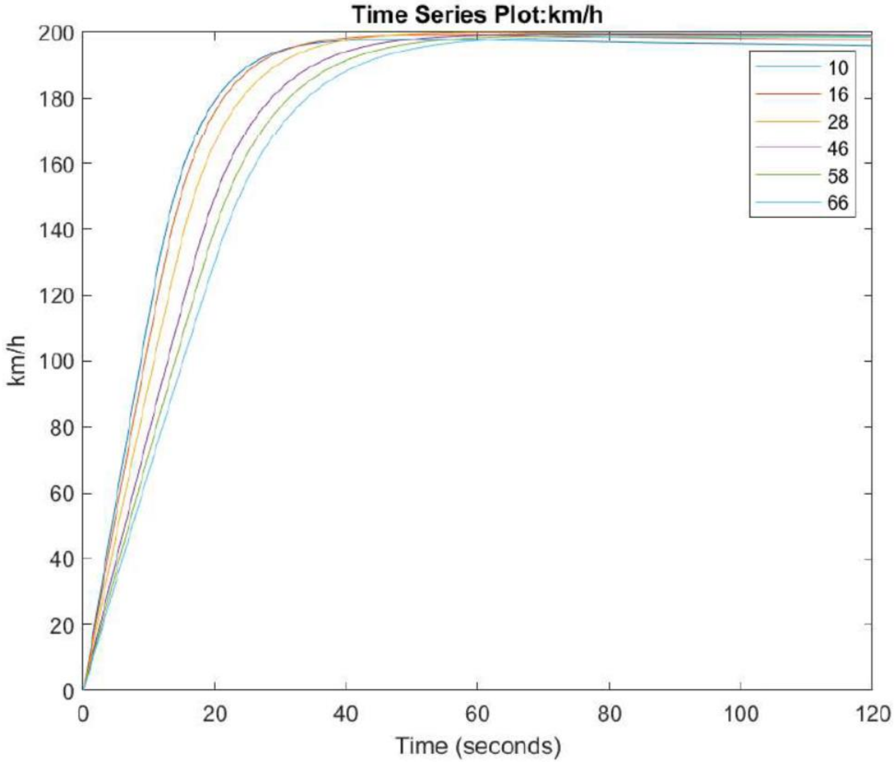

Fig-16: Effect In performance

2. **Effect in Efficiency :**
    - If we reduce parallel branch then due to increase in Internal Resistance power loss inside the battery increases.

- If we increase parallel branch then due to decrease in internal resistances power loss inside the battery is minimum.

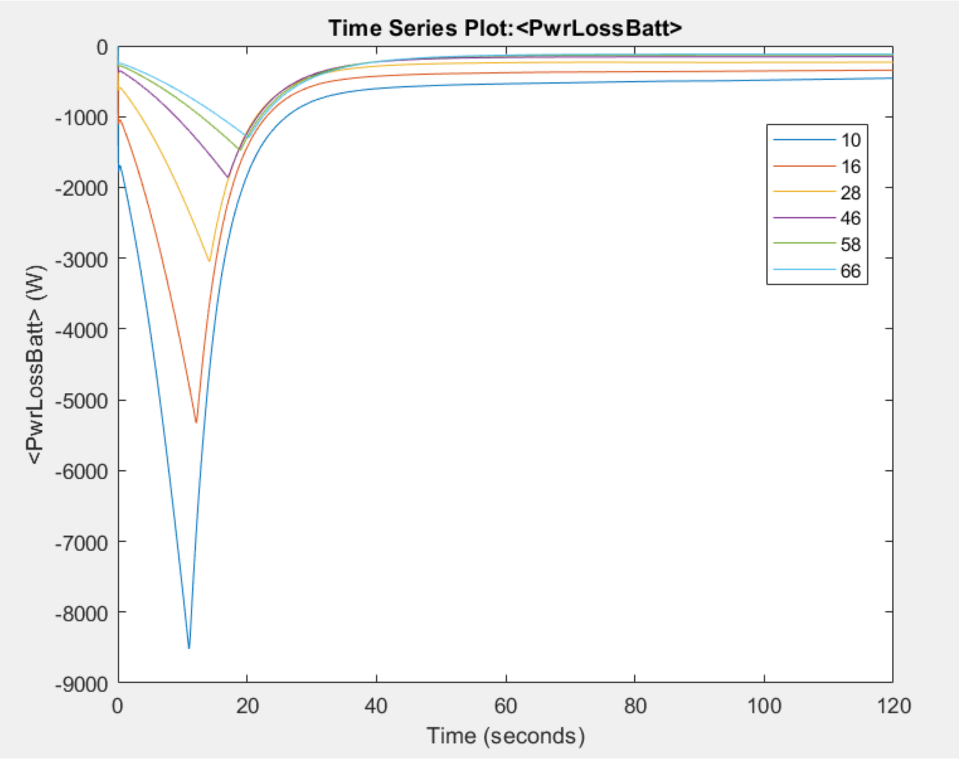

Fig-17: Effect In Efficiency

Conclusion

Our results demonstrate that careful adjustment of battery sizing can substantially enhance EV performance. Increasing the number of parallel battery cells reduces internal resistance and improves acceleration, while decreasing the number of parallel cells reduces vehicle weight, also positively impacting acceleration. Our simulations identified an optimal configuration balancing these factors, achieving the best trade-off between acceleration and power loss. Efficient battery management extends driving range and improves overall efficiency. These findings underscore the importance of advanced battery modeling and simulation, paving the way for more efficient, cost-effective, and high-performing electric vehicles, and supporting the transition to sustainable transportation solutions.

Chapter 3

Demonstration of Outcome Based Education (OBE)

At highlighting the importance of identifying particular learning goals or expertise that students should achieve at the conclusion of their academic journey, Outcome-Based Education (OBE) revolutionizes the landscape of electrical and electronic engineering education. This method makes sure graduates have the fundamental information and abilities needed to succeed in the profession by carefully designing the curriculum to meet industry demands and technological improvements.

3.1 Introduction

The world is moving faster toward more environmentally friendly transportation, and electric vehicles (EVs) are starting to show up as a key component of this shift away from fossil fuels and toward more environmentally friendly transportation. Optimizing battery size, which has a significant impact on performance (speed and acceleration), overall weight, range, battery efficiency and environmental impact, is essential to EV efficacy.

Our goal is to create accurate time-domain simulation models for electric vehicle powertrains, maximizing important performance metrics like efficiency and acceleration, and combining battery performance with powertrain dynamics. This project is a practical application of the information and abilities we have gained, showcasing our capacity to carry out intricate technical assessments, make use of cutting-edge simulation tools, and provide creative solutions.

Our effort demonstrates how well the OBE approach fosters a thorough understanding of engineering principles and their practical applications by tackling real-world EV technology difficulties. Our research's substantial influence on the development of sustainable transportation will be demonstrated, along with our methodology and conclusions, in this presentation.

3.2 Course Outcomes (COs) Addressed

The following table shows the COs addressed in EEE 4700 for Project and Thesis.

COs	**CO Statement**	**POs**	**Put Tick (√)**
			EEE 4700
CO1	Identify a contemporary real-life problem related to electrical and electronic engineering by reviewing and analyzing existing research works.	PO2	√
CO2	Determine functional requirements of the problem considering feasibility and efficiency through analysis and synthesis of information.	PO4	√
CO3	Select a suitable solution and determine its method considering professional ethics, codes and standards.	PO8	√
CO4	Adopt modern engineering resources and tools for the solution of the problem.	PO5	√
CO5	Prepare management plan and budgetary implications for the solution of the problem.	PO11	√
CO6	Analyze the impact of the proposed solution on health, safety, culture and society.	PO6	√
CO7	Analyze the impact of the proposed solution on environment and sustainability.	PO7	√
CO8	Develop a viable solution considering health, safety, cultural, societal and environmental aspects.	PO3	√
CO9	Work effectively as an individual and as a team member for the accomplishment of the solution.	PO9	√
CO10	Prepare various technical reports, design documentation, and deliver effective presentations for demonstration of the solution.	PO10	√
CO11	Recognize the need for continuing education and participation in professional societies and meetings.	PO12	√

3.3 Aspects of Program Outcomes (POs) Addressed

The following table shows the aspects addressed for certain Program Outcomes (POs) addressed in EEE 4700 for Project and Thesis.

	Statement	Different Aspects	Put Tick (√)
PO3	**Design/development of solutions**: Design solutions for complex electrical and electronic engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	Public health	
		Safety	√
		Cultural	
		Societal	√
		Environmental	√
PO4	**Investigation:** Conduct investigations ofcomplex electrical and electronic engineering problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis ofinformation to provide valid conclusions	Design of Experiments	√
		Analysis and interpretation of data	√
		Synthesis of information	√
PO6	**The engineer and society:** Apply reasoning informed by contextual knowledge to assesssocietal, health, safety, legal and cultural issues and the consequent responsibilitiesrelevant to professional engineering practice and solutions to complex electrical and electronic engineering problems.	Societal	√
		Health	
		Safety	√
		Legal	
		Cultural	
PO7	**Environment and sustainability:** Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex electrical and electronic engineering problems in societal and environmental contexts.	Societal	√
		Environmental	√
PO8	**Ethics:** Apply ethical principles embedded with religious values, professional ethics and responsibilities, and norms of electrical and electronic engineering practice.	Religious values	
		Professional ethics and responsibilities	√
		Norms	√
PO9		Individual	√

	Individual work and teamwork: Function effectively as an individual, and as a member or leader in diverse teams and in multi- disciplinary settings.	Teamwork	√
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend andwrite effective reports and design documentation, make effective presentations, and give and receive clear instructions.	Comprehend and write effective reports	√
		Design documentation	√
		Make effective presentations	√
		Give and receive clear instructions	√
PO11	**Project management and finance:** Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	Engineering management principles	√
		Economic decision-making	√
		Manage projects	
		Multidisciplinary environments	
PO12	**Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the context of electrical and electronic engineering related technological change.		√

3.4 Knowledge Profiles (K3 – K8) Addressed

The following table shows the Knowledge Profiles (K3 – K8) addressed in EEE 4700 for Project and Thesis.

K	**Knowledge Profile (Attribute)**	**Put Tick (√)**
K3	A systematic, theory-based formulation of engineering fundamentals required in theengineering discipline.	√
K4	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at theforefront of the discipline.	√

K5	Knowledge that supports engineering design in a practice area.	√
K6	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline.	√
K7	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the engineer's professional responsibility to public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability.	
K8	Engagement with selected knowledge in the research literature of the discipline.	√

3.5 Use of Complex Engineering Problems

The work presented us with some complex engineering challenges which were tackled as such having knowledge in specific branches of engineering disciplines

- The integration of multidisciplinary knowledge, encompassing electrical engineering for developing accurate models of the electric motor, battery, and power electronics; mechanical engineering for understanding vehicle dynamics, including the effects of mass, drag, and rolling resistance; and control systems engineering for designing and tuning PI/PID controllers to optimize performance.

- Handling the non-linear dynamics of powertrain components, which necessitates sophisticated mathematical modeling and simulation techniques. Implementing time-domain simulations allows us to capture the dynamic interactions between the motor, battery, and vehicle systems under various operating conditions. Additionally, our study investigates the impact of variable battery sizing on vehicle performance and efficiency, performing trade-off analysis to balance factors such as battery weight, internal resistance, acceleration, and energy efficiency to determine the optimal battery configuration.

- Enhancing system efficiency and improving performance metrics are also crucial components of our research. We focus on optimizing energy management within the powertrain system and improving key performance indicators such as acceleration, range, and regenerative braking efficiency. To ensure practical relevance and reliability, we validate our simulation results with real-world data, making sure that the developed models and solutions can be effectively applied in real-world scenarios, thereby contributing to the advancement of EV technology.

3.6 Socio-Cultural, Environmental, And Ethical Impact

Socio-Cultural Impact

Electric cars (EVs) are leading the way in a revolutionary change in how society views transportation. Our study advances EV technology by improving its accessibility and efficiency through accurate modelling and simulation. This accessibility encourages broad adoption, which has the potential to significantly alter social attitudes towards environmentally friendly transportation. There is a movement in culture as more individuals choose electric vehicles (EVs) and place a higher value on eco-friendly behavior. Furthermore, by concentrating on improving battery designs, we may lower the cost of EVs, thereby expanding access to cutting-edge transportation technology and promoting inclusivity in sustainable mobility options.

Impact on the Environment

Electric cars have well-established environmental benefits, chiefly related to decreased greenhouse gas emissions and less dependency on fossil fuels. Our research focuses on enhancing EV powertrain performance and efficiency, which directly contributes to increased energy efficiency and a smaller environmental impact. Our work contributes to the development of EVs that use less energy per mile travelled, reducing overall energy consumption and emissions by improving engine dynamics and optimizing battery sizing. In the worldwide endeavor to slow down climate change and lower air pollution, which will eventually result in healthier ecosystems and communities, this contribution is vital.

Ethical Impact

Our thesis incorporates ethical guidelines for responsible engineering and creativity. The drive for more environmentally friendly and energy-efficient EV technologies is consistent with the moral need to provide cutting-edge technology solutions that also benefit society and the environment. In addition, our study advocates for battery topologies that maximize lifespan economy and minimize waste, taking into account the long-term sustainability of electric vehicle components. Additionally, our research promotes social fairness by helping to develop more inexpensive EV solutions, guaranteeing that the advantages of cutting-edge transportation technology are available to a wider population rather than just a privileged few.

3.7 Attributes of Ranges of Complex Engineering Problem Solving (P1 – P7) Addressed

The following table shows the attributes of ranges of Complex Engineering Problem Solving (P1 – P7) addressed in EEE 4700 for Project and Thesis.

P	**Range of Complex Engineering Problem Solving**	**Put Tick (√)**
Attribute	Complex Engineering Problems have characteristic P1 and some orall of P2 to P7:	
Depth of knowledge required	**P1:** Cannot be resolved without in-depth engineering knowledge atthe level of one or more of K3, K4, K5, K6 or K8 which allows a fundamentals-based, first principles analytical approach	√
Range of conflicting requirements	**P2:** Involve wide-ranging or conflicting technical, engineering andother issues	√
Depth of analysis required	**P3:** Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	√
Familiarity of issues	**P4:** Involve infrequently encountered issues	
Extent of applicable codes	**P5:** Are outside problems encompassed by standards and codes ofpractice for professional engineering	
Extent of stakeholder involvement and conflicting requirements	**P6:** Involve diverse groups of stakeholders with widely varyingneeds	√
Interdependence	**P7:** Are high level problems including many component parts orsub-problems	√

3.8 Attributes of Ranges of Complex Engineering Activities (A1 – A5) Addressed

The following table shows the attributes of ranges of Complex Engineering Activities (A1 – A5) addressed in EEE 4700 for Project and Thesis.

A	**Range of Complex Engineering Activities**	**Put Tick (√)**
Attribute	Complex activities mean (engineering) activities or projects that have some or all of the following characteristics:	
Range of resources	**A1:** Involve the use of diverse resources (and for this purpose resources include people, money, equipment, materials, information and technologies)	√
Level of interaction	**A2:** Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues	√
Innovation	**A3:** Involve creative use of engineering principles and research-based knowledge in novel ways	√
Consequences for society and the environment	**A4:** Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation	
Familiarity	**A5:** Can extend beyond previous experiences by applying principles-based approaches	√

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OBE Form

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Demonstration of Outcome Based Education (OBE)

At highlighting the importance of identifying particular learning goals or expertise that students should achieve at the conclusion of their academic journey, Outcome-Based Education (OBE) revolutionizes the landscape of electrical and electronic engineering education. This method makes sure graduates have the fundamental information and abilities needed to succeed in the profession by carefully designing the curriculum to meet industry demands and technological improvements.

3.9 Introduction

The world is moving faster toward more environmentally friendly transportation, and electric vehicles (EVs) are starting to show up as a key component of this shift away from fossil fuels and toward more environmentally friendly transportation. Optimizing battery size, which has a significant impact on performance (speed and acceleration), overall weight, range, battery efficiency and environmental impact, is essential to EV efficacy.

Our goal is to create accurate time-domain simulation models for electric vehicle powertrains, maximizing important performance metrics like efficiency and acceleration, and combining battery performance with powertrain dynamics. This project is a practical application of the information and abilities we have gained, showcasing our capacity to carry out intricate technical assessments, make use of cutting-edge simulation tools, and provide creative solutions.

Our effort demonstrates how well the OBE approach fosters a thorough understanding of engineering principles and their practical applications by tackling real-world EV technology difficulties. Our research's substantial influence on the development of sustainable transportation will be demonstrated, along with our methodology and conclusions, in this presentation.

3.10 Addressing COs and POs

The following table shows the COs for EEE 4700/4800 (Project and Thesis).

COs	CO Statement	POs
CO1	Identify a contemporary real-life problem related to electrical and electronic engineering by reviewing and analyzing existing research works.	PO2
CO2	Determine functional requirements of the problem considering feasibility and efficiency through analysis and synthesis of information.	PO4
CO3	Select a suitable solution and determine its method considering professional ethics, codes and standards.	PO8
CO4	Adopt modern engineering resources and tools for the solution of the problem.	PO5
CO5	Prepare management plan and budgetary implications for the solution of the problem.	PO11
CO6	Analyze the impact of the proposed solution on health, safety, culture and society.	PO6
CO7	Analyze the impact of the proposed solution on environment and sustainability.	PO7
CO8	Develop a viable solution considering health, safety, cultural, societal and environmental aspects.	PO3
CO9	Work effectively as an individual and as a team member for the accomplishment of the solution.	PO9
CO10	Prepare various technical reports, design documentation, and deliver effective presentations for demonstration of the solution.	PO10
CO11	Recognize the need for continuing education and participation in professional societies and meetings.	PO12

Table 1

The following table shows the aspects addressed for certain Program Outcomes (POs) addressed in EEE 4700/4800 for Project and Thesis.

	Statement	**Different Aspects**	**Put Tick (√)**
PO3	**Design/development of solutions**: Design solutions for complex electrical and electronic engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	Public health	
		Safety	√
		Cultural	
		Societal	√
		Environmental	√

PO4	**Investigation:** Conduct investigations of complex electrical and electronic engineering problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	Design of experiments	√
		Analysis and interpretation of data	√
		Synthesis of information	√
PO6	**The engineer and society:** Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex electrical and electronic engineering problems.	Societal	√
		Health	
		Safety	√
		Legal	
		Cultural	
PO7	**Environment and sustainability:** Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex electrical and electronic engineering problems in societal and environmental contexts.	Societal	√
		Environmental	√
PO8	**Ethics:** Apply ethical principles embedded with religious values, professional ethics and responsibilities, and norms of electrical and electronic engineering practice.	Religious values	
		Professional ethics and responsibilities	√
		Norms	√
PO9	**Individual work and teamwork:** Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.	Individual	√
		Teamwork	√
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	Comprehend and write effective reports	√
		Design documentation	√
		Make effective presentations	√
		Give and receive clear instructions	√
PO11	**Project management and finance:** Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	Engineering management principles	√
		Economic decision-making	√
		Manage projects	
		Multidisciplinary environments	
PO12	**Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the context of electrical and electronic engineering related technological change.		√

Table 2

The following table explains or justifies how the COs and corresponding POs have been addressed in EEE 4700/4800 (Project and Thesis).

COs	POs	Explanation/Justification
CO1	PO2	• Analyzing existing research works, we can identify can identify gaps and limitations issues related to energy density, power density, cycle life, or thermal management. • By examining the latest advancements in materials science, battery chemistry, and design methodologies, we can identify pressing real-life problems that require further investigation to unlock new solutions and breakthroughs.
CO2	PO4	• Developing innovative structural designs for battery packs to reduce weight while maintaining structural integrity and safety. • Implementing effective thermal management systems to maintain optimal battery temperature, maximizing energy storage capacity to increase range
CO3	PO8	• Identifying and assess cutting-edge battery chemistries and materials that have the potential to increase cycle life, power density, and energy density while lowering weight and environmental effect through thorough study. • Verifying the viability and efficacy of the improved battery solutions by thorough performance testing, which should include evaluations of safety, dependability, and environmental impact.
CO4	PO5	• MATLAB/Simulink provides a versatile platform for designing and optimizing battery management systems (BMS) and power electronics for EV applications.
CO5	PO11	• Determining and allotting resources to assist software-based EV battery optimization initiatives, such as funds, staff, software licenses, and computer infrastructure. • Spending in cloud computing services and data analysis applications to process, visualize, and comprehend the massive datasets created during software development and testing.
CO6	PO6	• EVs produce zero tailpipe emissions, reducing air pollution in urban areas and improving public health by lowering exposure to harmful pollutants such as particulate matter, nitrogen oxides, and volatile organic compounds. • Optimization efforts focus on enhancing the safety features of EV batteries, including thermal management systems, cell monitoring, and emergency response protocols, to minimize the risk of thermal runaway events and battery-related accidents. • EV battery optimization aligns with cultural values emphasizing sustainability and environmental stewardship.

CO7	PO7	• Enhanced battery performance means fewer batteries are needed over the lifetime of an EV, reducing the overall demand for raw materials and minimizing environmental impact • The widespread adoption of EVs with optimized batteries plays a crucial role in mitigating climate change by reducing the transportation sector's reliance on fossil fuels
CO8	PO3	• Implement smart charging strategies that prioritize charging during periods of high renewable energy generation and grid stability, reducing reliance on fossil fuels and lowering carbon emissions. • Decreasing the danger of overcharging, overheating, and battery deterioration by implementing algorithms that dynamically regulate charging and discharging rates based on battery status and operating conditions.
CO9	PO9	• Utilizing your analytical and problem-solving skills to assess challenges, propose viable solutions, and overcome obstacles encountered during the optimization process. • Clarifying roles and responsibilities within the team, ensuring that each member understands their contribution towards achieving project objectives.
CO10	PO10	• Providing an overview of the project objectives, scope, and methodology used for EV battery sizing optimization as reports. • Documenting the overall architecture in the software system used for EV and EV battery sizing, including data flow diagrams, component interactions, and system interfaces. • Anticipating potential questions from the audience and preparing thoughtful responses to address inquiries about the optimization methodology, results, and implications.
CO11	PO12	• Participation in meetings and conferences allowing us to showcase our work, gain recognition for our contributions, and establish ourselves as thought leaders in the field. • By sharing insights, best practices, and research findings, its in our hands to influence decision-making processes and shape the future direction of the field.

Table 3

3.11 Addressing Knowledge Profiles (K3 – K8)

The following table shows the Knowledge Profiles (K3 – K8) addressed in EEE 4700/4800 (Project and Thesis).

K	Knowledge Profile (Attribute)	Put Tick (√)
K3	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline	√
K4	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline	√
K5	Knowledge that supports engineering design in a practice area	√
K6	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	√
K7	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the engineer's professional responsibility to public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability	
K8	Engagement with selected knowledge in the research literature of the discipline	√

Table 4

The following table explains or justifies how the Knowledge Profiles (K3 – K8) have been addressed in EEE 4700/4800 (Project and Thesis).

K	Explanation/Justification
K3	• EV and its battery often computational modeling and simulation techniques to analyze complex interactions between battery components, operatingconditions, and optimization objectives. • The research involves the application of fundamental engineering principles to model and simulate electric vehicle (EV) powertrains. This includes understanding and applying theories of electrical circuits, energy storage systems, power electronics, and vehicle dynamics to create accurate time-domain models.
K4	• Control systems engineer helps to develop algorithms and software for managing and optimizing the operation of EV components, such as traction control, regenerative braking, and energy management. They integrate sensors, actuators, and feedback loops to maintain stability, efficiency, and safety. • The research employs advanced EV powertrain and battery technologies, driving innovative solutions and cutting-edge development.

K5	- Proficiency in using simulation software and modeling tools, such as MATLAB/Simulink is important for building and simulating comprehensive models of EVs and EV components. - Practical skills in data analysis, statistical methods, and model validation techniquesare essential for comparing simulation results with experimental data, identifying discrepancies, and refining models to improve accuracy and reliability.
K6	- The research applies practical knowledge of EV powertrain technologies, including battery management, electric motors, and power electronics, for realistic, implementable simulations.
K7	- This is not addressed
K8	- This likely includes reviewing previous studies, theories, models, and methodologies relevant to time-domain modeling, electric vehicle performance, powertrain dynamics, and battery technologies.

Table 5

3.12 Addressing Attributes of Ranges of Complex Engineering Problem Solving (P1 – P7)

The following table shows the attributes of ranges of Complex Engineering Problem Solving (P1 – P7) addressed in EEE 4700/4800 (Project and Thesis).

P	**Range of Complex Engineering Problem Solving**	**Put Tick (√)**
Attribute	Complex Engineering Problems have characteristic P1 and some or all of P2 to P7:	
Depth of knowledge required	**P1:** Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8 which allows a fundamentals-based, first principles analytical approach	√
Range of conflicting requirements	**P2:** Involve wide-ranging or conflicting technical, engineering and other issues	√
Depth of analysis required	**P3:** Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	√
Familiarity of issues	**P4:** Involve infrequently encountered issues	
Extent of applicable codes	**P5:** Are outside problems encompassed by standards and codes of practice for professional engineering	
Extent of stakeholder involvement and conflicting requirements	**P6:** Involve diverse groups of stakeholders with widely varying needs	√
Interdependence	**P7:** Are high level problems including many component parts or sub-problems	√

Table 6

The following table explains or justifies how the attributes of ranges of Complex Engineering Problem Solving (P1 – P7) have been addressed in EEE 4700/4800 (Project and Thesis).

P	**Explanation/Justification**
P1	The problems cannot be resolved without in depth knowledge on Electrical Circuits and Systems, Battery Technology, Mechanical Design and Dynamics, Control Systems and Algorithms and some other branches of engineering proficiency.
P2	The research on time-domain modeling and simulation of electric vehicle powertrains with variable battery sizing configurations likely encounters a range of technical and engineering challenges. These could include optimizing performance metrics like range, acceleration, and efficiency while considering factors like battery weight, cost, and charging infrastructure compatibility.
P3	Modeling EV powertrains with variable battery sizes requires abstract thinking and originality to capture dynamic system behavior accurately under diverse conditions.
P4	This Issue is not addressed.
P5	This Issue is not addressed.
P6	Electric vehicles and their powertrains involve a diverse range of stakeholders, including manufacturers, policymakers, environmentalists, consumers, and more. Each stakeholder group may have different priorities, such as performance, affordability, sustainability, and regulatory compliance, which must be considered when developing and optimizing electric vehicle powertrain models.
P7	This research involves high-level problems with multiple sub-problems: modeling the electric motor, battery pack, power electronics, and control systems, all interacting complexly, necessitating a comprehensive modeling and simulation approach.

Table 7

3.13 Addressing Attributes of Ranges of Complex Engineering Activities (A1 – A5)

The following table shows the attributes of ranges of Complex Engineering Activities (A1 – A5) addressed in EEE 4700/4800 (Project and Thesis).

A	**Range of Complex Engineering Activities**	**Put Tick (√)**
Attribute	Complex activities mean (engineering) activities or projects that have some or all of the following characteristics:	
Range of resources	**A1:** Involve the use of diverse resources (and for this purpose resources include people, money, equipment, materials, information and technologies)	√
Level of interaction	**A2:** Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues	√

Innovation	**A3:** Involve creative use of engineering principles and research-based knowledge in novel ways	√
Consequences for society and the environment	**A4:** Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation	
Familiarity	**A5:** Can extend beyond previous experiences by applying principles-based approaches	√

Table 8

The following table explains or justifies how the attributes of ranges of Complex Engineering Activities (A1 – A5) have been addressed in EEE 4700/4800 (Project and Thesis).

A	Explanation/Justification
A1	• Workstations equipped with software development tools, simulation software, and data analysis platforms are essential for algorithm design, coding, testing, and validation • Access to real-world battery data, including voltage, current, temperature, and state of charge (SoC) measurements, enables algorithm development, calibration, and validation. • Software tools for data analysis (e.g., MATLAB, Python), algorithm development (e.g., Simulink, TensorFlow), and simulation (e.g., ANSYS, COMSOL) are indispensable for designing, implementing, and testing optimization algorithms.
A2	• Increasing energy density may result in reduced power density and vice versa, impacting factors such as acceleration, range, and charging speed. • Increasing battery capacity to extend vehicle range typically adds weight to the vehicle, reducing overall efficiency and handling.
A3	• Implementing a metaheuristic in MATLAB to optimize the EV and EV battery design
A4	• This issue is not addressed
A5	• By considering the interactions and interdependencies between different components, subsystems, and performance metrics, leading to more balanced and optimized EV and battery architectures.

Table 9