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Examining the Range Estimates of Electric Vehicle Designs That Can Be Achieved on a Single Charge, Depending on the Battery Charge Rate (SoC)

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Abstract— *This study presents a comprehensive analysis of electric vehicle (EV) battery technologies, and energy management strategies within the framework of sustainable transportation development. In the practical scope of the study, an electric vehicle model was developed in the MATLAB/Simulink environment, and simulations were conducted to estimate the driving range of the vehicle under a single charge based on the state of charge (SoC) of the battery. Furthermore, the charging process from 1% to 100% SoC was modeled, and the effects of charging duration on overall performance were analyzed under different charging conditions, supported by numerical data.The findings indicate that driving range estimations and charging times are of critical importance for battery technology, energy management strategies, and vehicle design. In this context, the study contributes to the literature and industry by providing both an evaluation of current technologies and insights into potential future developments from a scientific perspective.*

Keywords—Electric vehicles, Battery technologies, Lithium-ion batteries.

1. INTRODUCTION

The transportation sector is currently at a critical stage of transformation, and electric vehicles (EVs) have become a fundamental element of sustainable transportation. Data for 2025 show that the EV market has gained significant momentum: In March, the global EV market grew by 29% compared to March of the previous year (Benchmark Mineral, 2025). Similarly, global sales in February 2025 reached 1.2 million units, an increase of approximately 50% compared to February 2024 (Electric Cars, 2025). In line with this expanding trend, international organizations predict that EV sales will exceed 20 million units globally in 2025, representing a 25% increase compared to 2024 (BloombergNef, 2025; International Energy, 2025; World Economic Forum, 2025). This growth reflects not only technological advancements but also increased public and government awareness of climate and environmental policies. The importance of electric vehicles is not limited to sales volumes; they promise radical changes in energy consumption habits, natural resource management, and environmental sustainability. EV technologies have the potential to reduce greenhouse gas emissions, reduce fossil fuel use and local air pollution, and redefine the interaction between transportation and energy systems. According to the EPA, electric vehicles eliminate tailpipe emissions, producing lower greenhouse gas emissions throughout their lifecycle compared to comparable internal combustion engine vehicles (US EPA, 2025). Furthermore, EVs are noted to make significant contributions to reducing harmful exhaust gases (e.g., particulate matter, VOCs, carbon monoxide, NO_x) in cities (Wikipedia, 2025a). According to an IEA report, the electrification of the transportation sector will enable approximately 2 Gt CO_2 equivalents less emissions by 2035 (International Energy, 2024).

From a technological perspective, rapid advances in areas such as battery technology, power electronics, motor systems, and energy management are significantly improving EV performance; They extend ranges, increase efficiency, and shorten charging times. These advancements strengthen user confidence and enhance environmental benefits. Modern electric vehicles have evolved into advanced electromechanical systems that integrate electrical, mechanical, chemical, materials, and software engineering.

Battery systems play a critical role in the development of electric vehicle (EV) technology. Lithium-ion batteries dominate the electric vehicle market due to their high energy density, long lifespan, and decreasing costs. As of 2023, approximately 85% of batteries produced for electric vehicles worldwide will utilize lithium-ion technology. The energy density of these batteries varies depending on the chemical composition used. For example, lithium iron phosphate (LFP) batteries are lower in cost and offer longer lifespans (Wikipedia, 2025b).

Each battery chemistry type offers unique advantages and limitations. Lithium-ion batteries are distinguished by their high energy density and long lifespan, while lithium iron phosphate (LFP) batteries offer lower costs and longer lifespans. However, the energy density of LFP batteries is lower than that of nickel cobalt manganese (NCM) batteries. Therefore, battery selection should be made carefully based on application requirements and cost objectives (McKinsey and Company, 2024; Wikipedia, 2025b).

Lithium Nickel Manganese Cobalt Oxide (NMC) batteries have become the preferred choice for many electric vehicle manufacturers thanks to their balanced performance. The NMC811 form, in particular, stands out with its energy density ranging from 244–300 Wh/kg. However, with a decrease in cobalt content, thermal stability decreases, and cycle life is limited to 800–1,500 cycles (Hasselwander et al., 2023).

Lithium Iron Phosphate (LFP) batteries stand out for their safety and durability. The energy density of these batteries generally ranges from 90–160 Wh/kg. Their cycle life is between 2,000 and 4,000 cycles, and because they do not contain cobalt or nickel, they offer advantages in terms of cost and environmental sustainability (PowerTech, 2023).

Lithium Nickel Cobalt Aluminum Oxide (NCA) batteries are particularly preferred by manufacturers such as Tesla, and their energy density ranges from 200 to 260 Wh/kg. However, due to their high nickel content, they face challenges with thermal stability (Evercars, 2024).

Solid-state batteries are considered a revolutionary development in electric vehicles. These batteries stand out with their energy density reaching up to 400–500 Wh/kg. Their cycle life can maintain 80% capacity after 5,000 cycles.

In this study, the range the vehicle can travel on a single charge is estimated based on the battery charge level (SoC) using an electric vehicle model created in the MATLAB/Simulink environment. Furthermore, the battery's charge level can range from 1% to 100%.

2. System Design

2.1. An Example Electric Vehicle Design

In this study, a sample electric vehicle model was simulated in the MATLAB Simulink environment. MATLAB R2021a and the Simscape Electrical and Powertrain libraries were used for simulation. The model was designed to evaluate vehicle performance using realistic basic parameters accepted in the literature.

Vehicle performance was examined by comparing the actual speed with the driver-specified input speed, while energy consumption was analyzed based on the initial and final battery charge levels. Furthermore, the effects of various parameters on performance and energy consumption were evaluated in detail. The simulation provided the opportunity to observe the battery's operating behavior, energy recovery during braking, and charging processes.

In the model, the electric vehicle's motor power was 200 kW, its no-load speed was 14,000 rpm, and its rated speed was 12,000 rpm. The DC supply voltage was 400 V, and the armature inductance was 12×10^{-6} H. The vehicle's mass is 1,700 kg, the aerodynamic drag coefficient is 0.23, and the center of gravity is 0.5 m above the ground. The horizontal distance to the front axle is 1.4 m, the horizontal distance to the rear axle is 1.6 m, and the front façade area is 2.22 m^2. Air density is assumed to be 1.18 kg/m^3 in the simulation.

2.2. Simulink Model

Electric vehicles contain numerous components and a comprehensive network of cables connecting them. The internal combustion engine found in traditional vehicles has been replaced by an electric motor in electric vehicles, and the battery pack serves as the primary energy source powering the motor. The primary components of electric vehicles are the motor, vehicle body, control unit, and battery pack. In this study, a direct current (DC) motor is used in the model, and motor control is provided via an H-bridge and PWM voltage control.

The simulation system is divided into four main subsystems: the vehicle body, motor and control circuit, driver input system, and battery pack. The tires, differential, transmission, and body blocks in the vehicle body subsystem were imported from the Simscape library, and their parameters can be adjusted according to design requirements. The motor and control circuit subsystem enables the motor to convert the energy from the battery into mechanical torque and transmit this torque to the wheels through the transmission and differential. The motor control manages acceleration, deceleration, and braking according to driver commands. Figure 1 shows a block diagram of this system.

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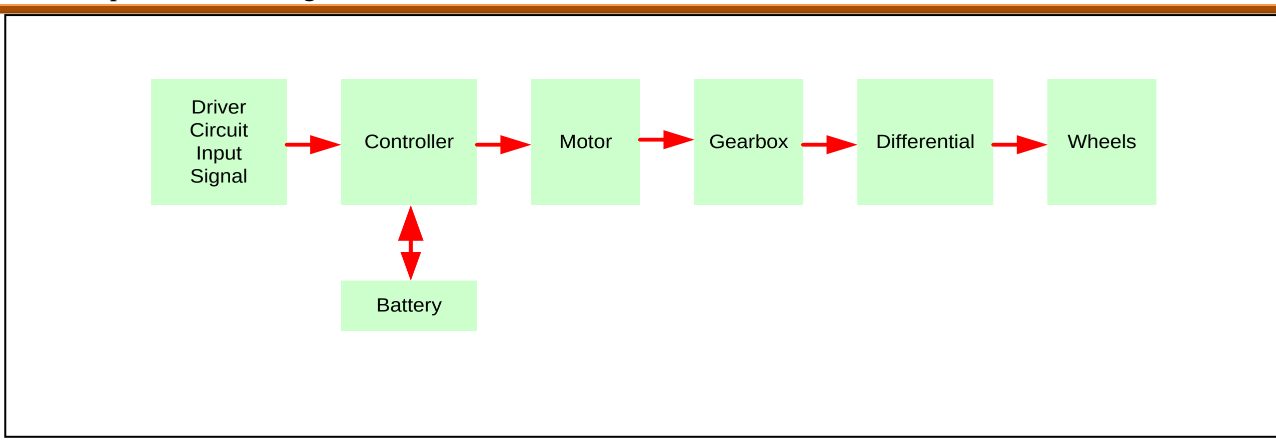

Fig. 1. *Basic Components of the Electric Vehicle System*

The driver input subsystem generates an error signal by calculating the difference between the reference speed and actual speed. This error signal allows adjustment of the engine torque, bringing the vehicle speed closer to the target value. A lithium-ion battery is used in the battery pack subsystem, and its State of Charge (SoC) is continuously monitored, allowing for both charging and discharging processes to be observed. Regenerative braking allows the battery to be recharged as the vehicle decelerates.

The general simulation model (Figure 2) is supported by the Powergui and Scope blocks, and the system's feedback loop performance is evaluated. As the engine uses energy, the battery discharges, and the difference between the reference speed and actual speed is continuously minimized by the control mechanism. Thanks to this closed-loop control, the vehicle achieves balanced acceleration, stable cruising at a constant speed, and effective braking, while battery consumption and energy efficiency can be simultaneously monitored.

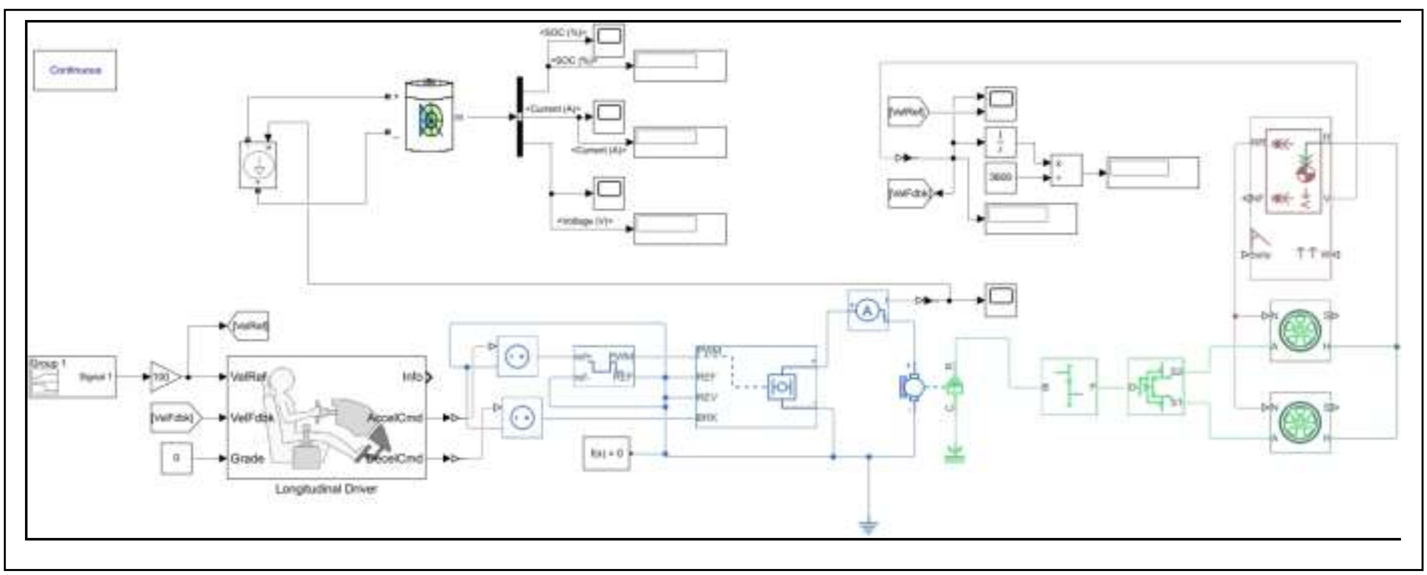

Fig. 2. *Simulation Model of a Sample Electric Vehicle*

2.3. Battery Charging Time

In this study, a MATLAB/Simulink model was developed to determine the total time required to fully charge a lithium-ion battery pack used in electric vehicles from 1% initial charge (SoC) to 100% charge. The primary objective of the study was to estimate battery charging time under realistic charging conditions, considering constant current (CC) and constant voltage (CV) charging stages.

2.4. Simulink Model

The simulation model consists of four main subsystems to reflect real-life battery behavior: the battery pack, constant current (CC) mode, constant voltage (CV) mode, and stateflow-based control logic. A lithium-ion battery pack with a nominal voltage of 400 V and a capacity of 154 Ah was modeled by continuously monitoring the SoC parameter in the simulation. The SoC value determined the transitions between charging stages, ensuring the realistic nature of the simulation.

In CC mode, a controlled current source was used to provide a 1C (154 A) charging current appropriate to the battery capacity. This mode activated the SoC between 1% and 80%, allowing the battery to be charged quickly with a high initial current. In CV mode, the charge voltage was held constant at 485 V and activated when the SoC exceeded 80%. This phase ensured that the battery safely reached maximum voltage and prevented overcharging.

The transition between CC and CV modes was managed by a Stateflow-based control block. This block determined the active charging mode by comparing the SoC value with predefined thresholds and automatically terminated the simulation when the SoC reached 100%.

The Powergui, Scope, and indicator blocks were added to the general model to examine the system's operating principles and outputs. This allowed the battery charging time and SoC variation to be analyzed, and the performance of the constant current-constant voltage charging logic was verified.

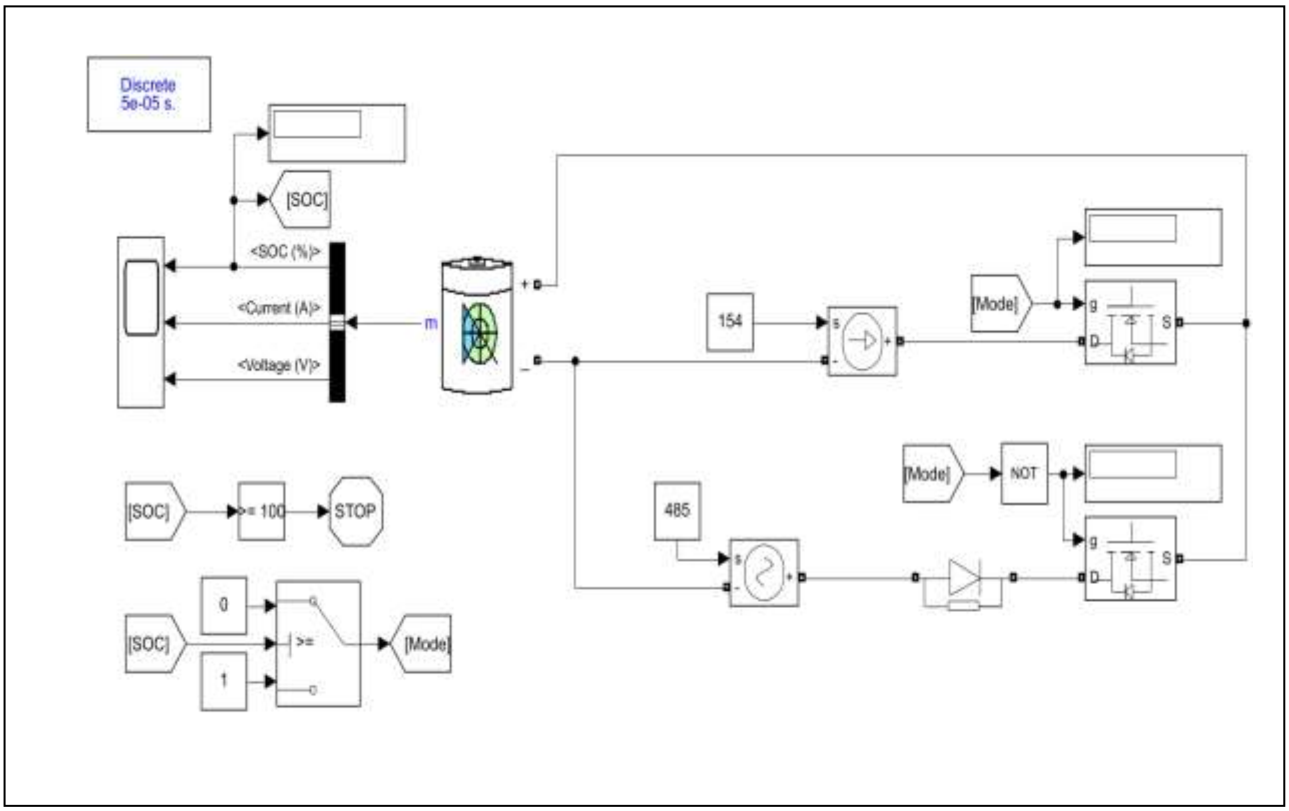

Fig. 3. *Battery Charging Time Simulation Model*

3. Findings and Discussion

In the first simulation run, a reference speed profile was generated using a signal generator block at a maximum speed of 100 km/h, and the model was run for 600 seconds. It was observed that the vehicle speed gradually increased to 100 km/h in the first 240 seconds of the simulation, remained constant for the next 180 seconds, and then decreased to 40 km/h in the final 180 seconds (Figure 4).

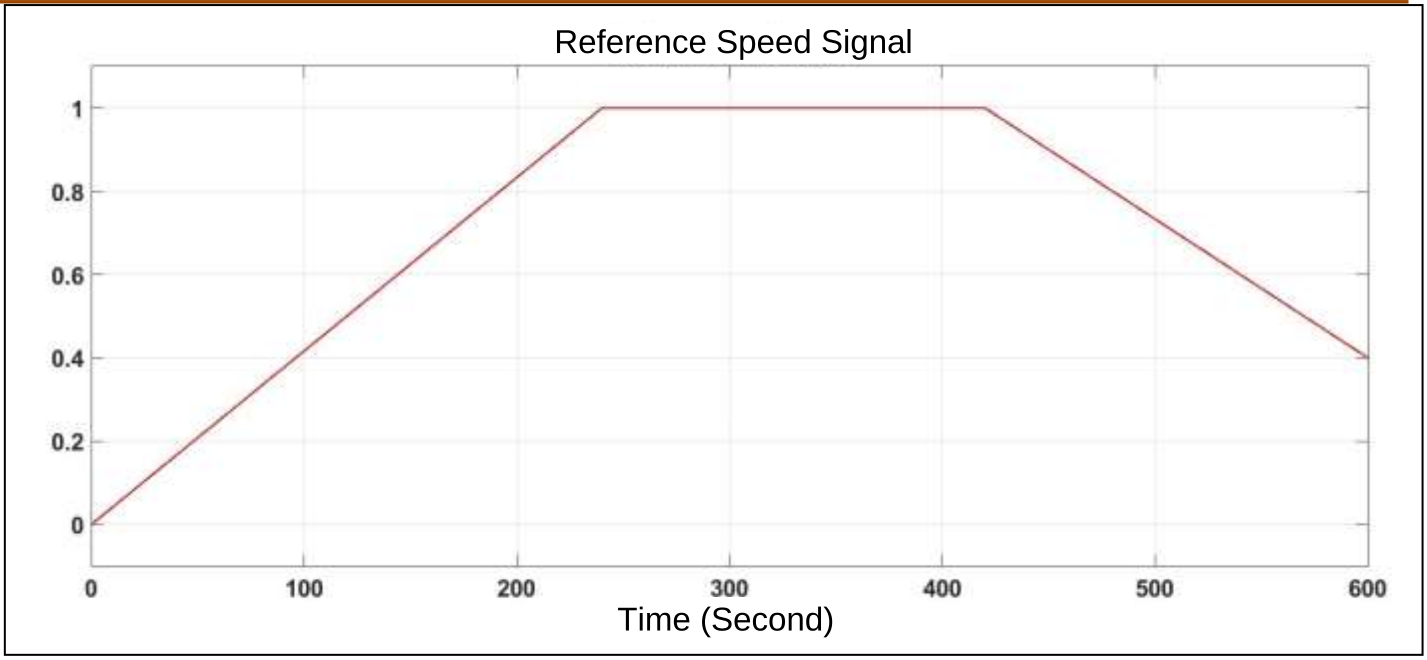

Fig. 4. *Reference Speed Signal*

The actual speed data shows a tracking behavior consistent with the reference speed (Figure 5), demonstrating the effectiveness of the feedback mechanism. Battery State of Charge (SoC) analyses show an irregular discharge process in the first 240 seconds, followed by a regular discharge in the following 180 seconds. In the final phase, the battery both consumes energy and can be charged through regenerative braking (Figure 6). The speed and SoC graphs clearly show that the battery consumes energy when accelerating and recovers and recharges when decelerating.

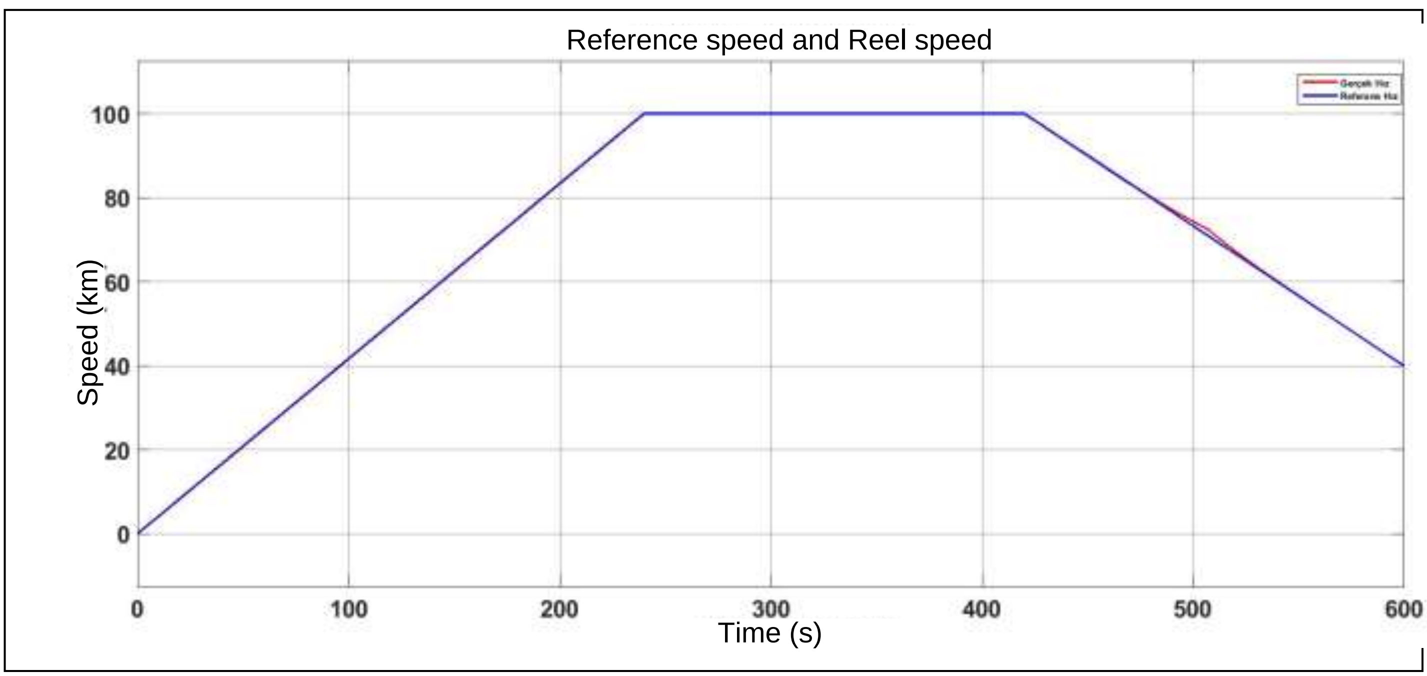

Fig. 5. *Reference and Actual Speed*

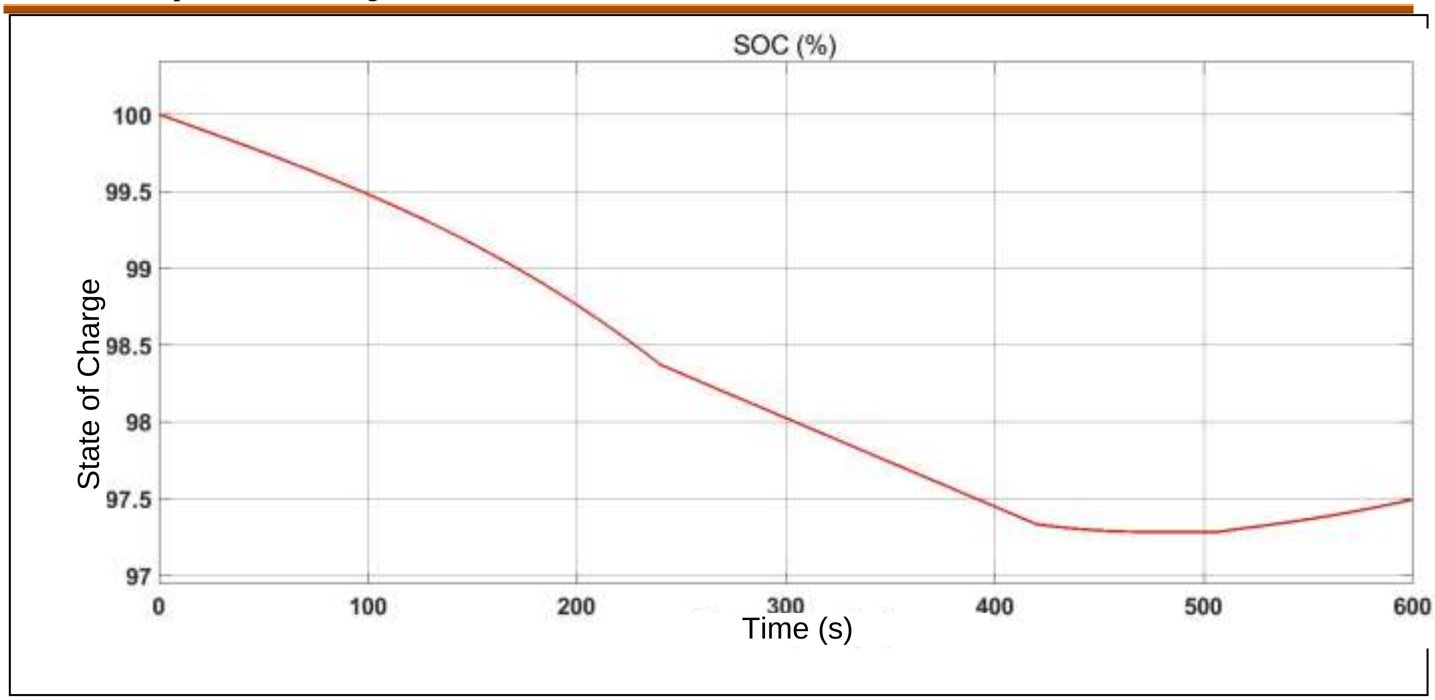

Fig. 6. *Battery State of Charge (SoC) analysis*

During the simulation period, the vehicle traveled approximately 11.83 km. Average speed calculations indicate that the vehicle was traveling at 70.98 km/h, which is largely consistent with the average speed shown in the graph. Based on the obtained SoC data and performance values, the electric vehicle in the model is projected to have a range of approximately 472 km on a single charge.

These results demonstrate that the Simulink model can effectively simulate the speed and energy management of electric vehicles and reliably predict battery performance.

In the second simulation run, the battery State of Charge (SoC) graph showed two distinct charging stages. The SoC showed a linear increase from 1% to 80%, representing the constant current (CC) stage. As the SoC exceeded 80%, the rate of increase decreased significantly, reflecting the transition to the constant voltage (CV) stage (Figure 7).

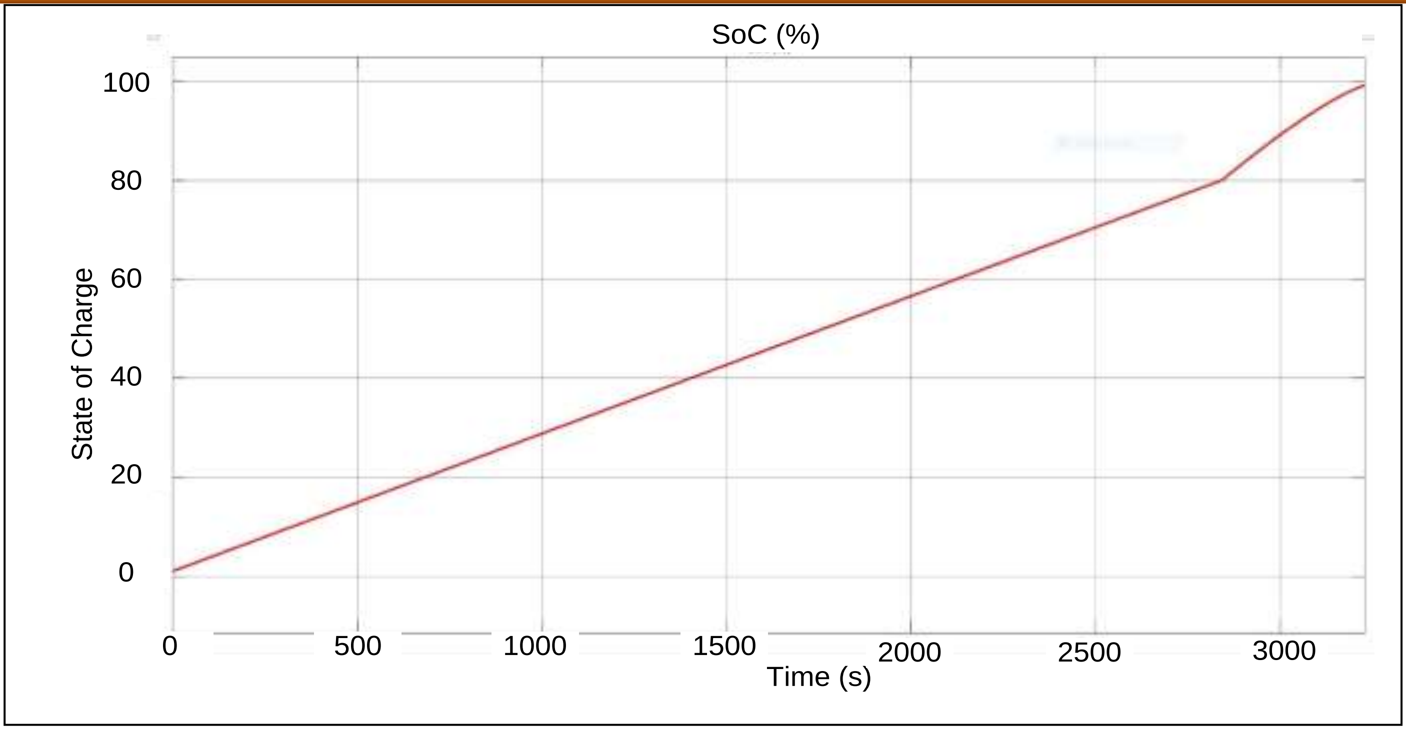

Fig. 7. *SoC (Battery Charging Time)*

Simulation results showed that a total of 3,228.2 seconds (~54 minutes) was required to charge the battery from an initial 1% charge to full capacity (100% SoC). This time is in line with the realistic values expected for electric vehicles in high-power DC fast charging scenarios and those reported in the literature.

4. Conclusions and Recommendations

This study presented a comprehensive analysis of the design and battery systems of electric vehicles (EVs). Simulation results indicated that the first model electric vehicle traveled approximately 11.83 km over a 600-second period, with an average speed of 70.98 km/h. Battery charge factor (SoC) analysis indicated that the vehicle could cover approximately 472 km on a single charge. The speed and SoC graphs clearly demonstrate that the battery consumes energy when accelerating, and recovers and recharges through regenerative braking when decelerating. These results confirm that the model can realistically simulate the speed and energy management of an electric vehicle.

The second simulation study examined the time required to charge a lithium-ion battery from 1% SoC to full capacity (100% SoC). The simulation, considering both constant current (CC) and constant voltage (CV) phases, yielded a total charging time of 3,228.2 seconds (~54 minutes). In the CC phase, a linear increase in SoC charge was observed from 1% to 80%, while in the CV phase, the rate of increase slowed as the SoC reached 80%. These findings provide realistic and reliable charging time estimates for high-power DC fast charging scenarios.

Both simulations allow for the evaluation of key electric vehicle performance parameters such as battery management, motor control, and energy consumption. The obtained data demonstrate that EV technology has evolved from simple past experiments to today's high-performance integrated systems, offering advantages over ICE systems in many areas thanks to improvements in battery, motor, and control algorithms.

Furthermore, the simulation results provide important insights into understanding the impact of system integration, battery management, and control strategies on performance and range. These findings provide guidance for advanced applications in electric vehicle design and battery optimization.

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