

UNIVERSITY OF WALES TRINITY SAINT DAVID
WALES INSTITUTE OF SCIENCE AND ART



DRIVE CYCLE REQUIREMENT SPECIFICATION
AHYBRID POWER TRAIN AND CONTROL (ACEA7007)

Mr Vishnuvardhan Reddy Kesavarapu

2215387

Automotive Engineering

University of Wales Trinity Saint David, Swansea, SA1 8PH

Abstract

Alternative powertrains for automotive applications aim at improving emissions and fuel economy. Lack of experience with these relatively new technologies makes them ideal applications for computer-based modelling and simulation studies. There is a variety of configurations, control strategies, and design variable choices that can be made. If mathematical models exist, rigorous optimization techniques can be used to explore the design space. The major goal of this research is to attempt to obtain a similar WLTP range by replacement of 50% of the battery with a fuel cell and testing drive cycle calculations against the WLTP range and comparing those graphs which are extracted with 50% fuel cell with the graphs which are exported from the 100% battery.

Table of Contents

1. Introduction.....	5
1.1 Overview and background	5
2. Methodology	7
2.1 Assessment of the technology options	7
2.2 Power Storage systems	8
2.3 Methods.....	11
2.4 Capacitor Energy Storage	12
2.5 Energy Store level.....	12
3. Proposed solution	13
4. Results	13
4.1 Types of fuel cells	Error! Bookmark not defined.
4.2 Decision matrices	14
4.3 Velocity vs Time after replacing 50% battery with fuel cell	15
4.4 Velocity vs Time with 100% battery	16
4.5 Traction energy vs Regenerative energy.....	17
4.6 Motor Selection	17
4.7 Energy Requirements.....	19
5. Conclusion	21
6. References	22

Figures and Tables

Figure 1.1.1 Market Growth of battery Electric Vehicles across the world.....	5
Figure 1.1.2: Market share of different vehicle manufacturers.....	6
Figure 2.1.1: Battery system Capacity of Tesla Model 3.....	8
Figure 2.1.2: Energy consumption of Tesla Model 3.....	9
Figure 2.1.3: Charging capacity of Tesla Model 3.....	9

Table 2.1.4: Advantages and Disadvantages of battery-electric powertrain system.....	11
Figure 4.2 : Decision matrices of fuel cells.....	14
Figure.4.3 : Velocity vs Time graph after replacing 50% of the battery with fuel cell.....	15
Figure 4.4 : Velocity vs. time graph with 100% battery.....	16
Figure 4.5 : Traction energy vs Regenerative energy graph.....	17
Figure 4.6 : Simulation results.....	18
Figure 4.7.1: Change in rpm with change in time.....	19
Figure 4.7.2: Change in the torque of the wheels.....	20
Figure 4.7.3: Simulink model.....	20

1. Introduction

1.1 Overview and background

The emerging urgency and socioeconomic pressure of reducing carbon, and GHG emissions have increased the market demand for “Hybrid Electric Vehicle (HEV)” and “Battery Electric Vehicles (BEV)” across the world. In fact, all the traditional ICE vehicle manufacturers are integrating the manufacturing of Hybrid Electric vehicles.

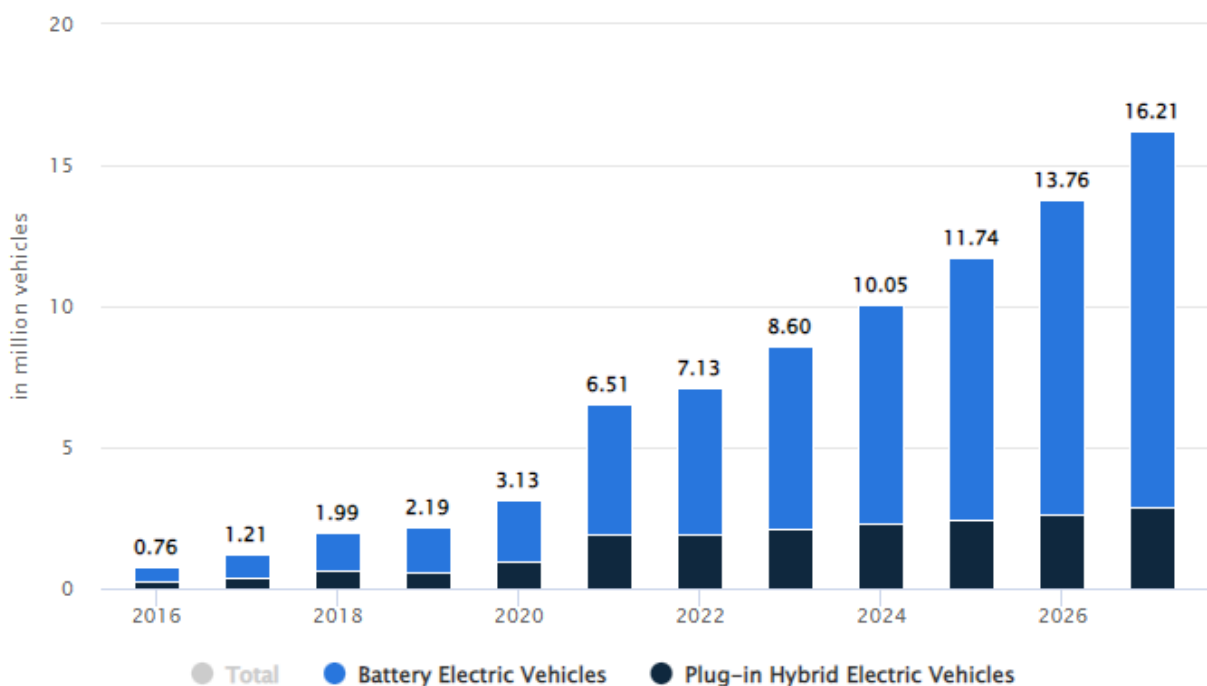


Figure 1.1.1: Market Growth of battery Electric Vehicles across the world

(Source: Statista, 2022)

The growth of the EVs (electric vehicles) market has been significant over the past few years despite the supply chain bottlenecks occurring due to the occurrence of Covid-19 pandemic and global Chip shortage. The global chip shortages and increasing prices of batteries and other raw materials have resulted in the increasing price of EVs. Over the past few years, the sales growth of Hybrid Electric Vehicles has surpassed the conventional vehicles with ICE (Internal Combustion Engines). The sales of Hybrid electric vehicles motor have increased by almost 51.8% (Statista, 2022). In the year 2022, the number of electric vehicles sold has

reached 7.13 million. In fact, it is expected to reach 13.76 million by the end of 2026 (Statista, 2022). The revenue of Hybrid electric vehicles is expected to reach US\$457.60 billion by the end of 2023 (Statista, 2022). On top of that, the annual growth rate of HEV and Plug-in Hybrid Electric vehicles is expected to reach 17.02% (CAGR 2023-2027).

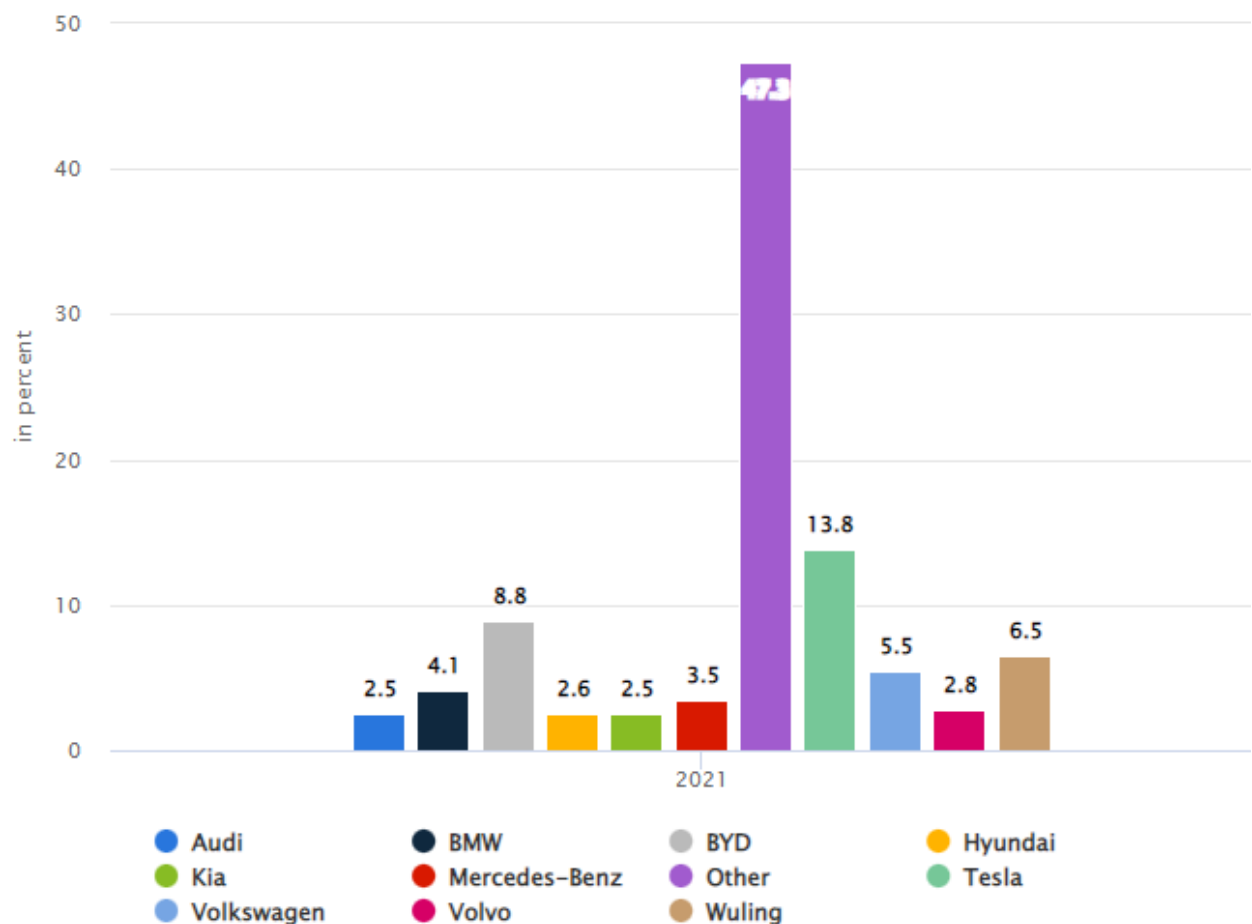


Figure 1.1.2: Market share of different vehicle manufacturers

(Source: Statista, 2022)

Tesla has maintained a market share of 13.8% in the global EV marketplace. On the other hand, almost 47.3% of the EV market has been captured by specialized electric vehicle manufacturers. The battery capacity of the Tesla Model 3 is set at 91.8% and the battery capacity is degraded by 8.2% (Kane, 2022). The battery degradation in the Tesla Model 3 depends on multiple factors such as the age of the battery, temperatures, and many more. Based on the results of the “Long-range battery degradation test” it has been found that the

battery usable battery capacity is 67 KWh and the battery capacity degradation rate is almost 8.2% (Kane, 2022).

The main disadvantages that have been found in the battery cell powertrain in Tesla Model 3 are a lower driving range, range anxiety, and longer charging time. In fact, the over-dependency on hydrogen fuel cells can be a challenge in the battery-electric power train. Therefore, converting the Tesla Model 3 from a “battery-electric powertrain” to a “fuel cell-electric powertrain”, it becomes possible to enhance the driving range, and “faster refueling times”.

2. Methodology

2.1 Assessment of the technology options

The advanced technologies within the “battery-electric powertrain” in Tesla Model 3 are stated below.

- ***Lithium-ion Battery***

Tesla Model 3 uses the “high-capacity” lithium-ion battery pack in the powertrain. The integration of the in-house battery technology has helped in achieving high-energy density. On the other hand, the disadvantage of the powertrain system of the Tesla Model 3 is a lower driving range.

- ***Electric Motor***

The Front Motor used in Tesla Model 3 uses an AC induction Motor with a liquid-cooled facility and variable frequency drive. On the other hand, the rear motor that is used in Tesla Model 3 is AC Permanent Magnet Synchronous Motor with a variable frequency drive and liquid-cooled facility (Tesla, 2022).

- ***Use of Regenerative Braking***

The “battery-electric powertrain” system includes a regenerative braking system that is capable of capturing energy. The efficiency of the regenerative braking system in the “fuel cell” powertrain is higher compared to the “battery-electric” powertrain system. Henceforth, through the conversion of the powertrain system from a “battery-electric powertrain” to a “fuel-cell powertrain”, it will become possible to reduce the braking loss, enhance the driving range, and increase the overall efficiency of the vehicles.

- **Power Electronics system and thermal management system**

The power electronic system includes a high-performance inverter that is used to convert the DC power from the battery to the AC power of the main and rear motor.

2.2 Power Storage systems

A hydrogen Fuel cell is used in order to convert the battery-electric powertrain to a fuel powertrain. As per the view of Cunanan *et al.* (2021), the working principle of the fuel cell is based on the conversion of hydrogen fuel and oxygen from the air to electricity, where water vapor is formulated as the byproduct. According to Aguilar and Groß (2022), within the “fuel cell-electric powertrain”, the fuel cell has been used as the range extender, which helps in providing “electricity to power” the electric motor. This has helped in propelling the vehicles (Tesla Model 3). Within the “fuel cell-electric powertrain” the hydrogen fuel gets stored within the high-pressure tanks and gets fed into the fuel cell. Inside the fuel cell tank, the hydrocarbons react with oxygen in order to generate electricity. The electricity produced has been used to power the “electric motor” that is responsible for driving the vehicle wheels. The fundamental advantages that can be achieved through the integration of the “fuel cell-electric powertrain” is rapid refuel capacity and longer traveling distance.

Battery

Nominal Capacity *	60.0 kWh	Useable Capacity*	57.5 kWh
Battery Type	Lithium-ion	Cathode Material	LFP
Number of Cells	106	Pack Configuration	106s1p
Architecture	400 V	Nominal Voltage	340 V

Figure 2.1.1: Battery system Capacity of Tesla Model 3

(Source: Ev-database.org, 2022)

The nominal battery capacity within the battery-electric powertrain system in Tesla Model 3 is 60 kWh, where the usable capacity is 57.5 kWh (Ev-database.org, 2022). The type of battery that is used within the powertrain system is a Lithium-ion battery. The nominal voltage that can be extracted from this powertrain system is 340V (Ev-database.org, 2022).

Energy Consumption

EVDB Real Range

Range *	380 km	CO2 Emissions	0 g/km
Vehicle Consumption *	151 Wh/km	Vehicle Fuel Equivalent *	1.7 l/100km

WLTP Ratings (TEL)

Range	495 km	CO2 Emissions	0 g/km
Rated Consumption	144 Wh/km	Rated Fuel Equivalent	1.6 l/100km
Vehicle Consumption	116 Wh/km	Vehicle Fuel Equivalent	1.3 l/100km

WLTP Ratings (TEH)

Range	491 km	CO2 Emissions	0 g/km
Rated Consumption	No Data	Rated Fuel Equivalent	No Data
Vehicle Consumption	117 Wh/km	Vehicle Fuel Equivalent	1.3 l/100km

Figure 2.1.2: Energy consumption of Tesla Model 3

(Source: Ev-database.org, 2022)

The above figure has demonstrated the energy consumption profile of the Tesla Model 3. From the WLTP ratings (TEL) of the Tesla Model 3 vehicle, it can be observed that the range, rated consumption, and vehicle consumption are respectively 495 km, 144 Wh/km, and 116 Wh/km (Ev-database.org, 2022).

Charging

Home / Destination

Charge Port	Type 2
Port Location	Left Side - Rear
Charge Power	11 kW AC
Charge Time (0->380 km)	6h15m
Charge Speed	62 km/h

[Click here for all charging information](#)

Fast Charging

Fastcharge Port	CCS
FC Port Location	Left Side - Rear
Fastcharge Power (max) *	170 kW DC
Fastcharge Time (38->304 km)	25 min
*	
Fastcharge Speed *	630 km/h

Figure 2.1.3: Charging capacity of Tesla Model 3

(Source: Ev-database.org, 2022)

The above figure has demonstrated the position along with the charging capacity of the Tesla Model 3.

Battery-Electric Powertrain system in Tesla Model 3	
Advantages	• As per the view of Guo <i>et al.</i> (2022), the Lithium-ion batteries are used in Tesla Model 3, which has high energy storage capability in the case of a lower weight vehicle profile. • In order to enhance the voltage capacity based on situational demand, the batteries within the electric powertrain system, battery modules can be arranged in series combination or in parallel combination. • It has the capability to withstand high discharge rate, which can be helpful for fulfilling the high power demand. • Lower cost of operation as compared to the conventional “fuel cell-electric” powertrain system (Guo <i>et al.</i> 2022; Kane, 2022).
Disadvantages	• It has not the capability to fulfill the high power demand. • The fundamental disadvantages of the battery-electric powertrain system is the lower energy density. • As per the view of Wassiliadis <i>et al.</i> (2021), within the battery-electric powertrain system, the minimum depth of discharge is high. As a result, the within a powertrain system the remaining useable battery life can diminish the number of cycles. • As per the view of Tran <i>et al.</i> (2021), the existence of rapid charging and discharging is can be treated as a disadvantages of the battery-electric powertrain system, as the occurrence of the rapid charging and discharging can cause damage to the battery cell and

	makes the battery cell poorly suited for recovering the regenerative braking energy via “KERS”.
--	---

Table 2.1.4: Advantages and Disadvantages of battery-electric powertrain system

(Source: Developed by the learner)

2.3 Methods

The first step involves the conversion of the battery-electric powertrain to a “fuel cell-electric powertrain” to develop the code in MATLAB for the “Tesla Model 3 drive cycle”. After successfully running the MATLAB code, the WLTP velocity versus Time charts has been extracted from MATLAB to excel sheets. Based on the physical model and parameter specification of Tesla Model 3, the aerodynamic velocity, “Tractive Forces”, Spewed, and “Regenerative Forces” are calculated. As per the view of Gupta (2020), the functionality of the regenerative braking system is to restore energy in the case when the tractive force exerts in a negative area. The force is necessary for moving the vehicle equivalent to the tractive effort.

Within the process, it has been found that the tractive force is lesser with a “battery-electric powertrain” system. The fundamental reason behind the lesser value of the Tractive Force in a battery-electric powertrain system is the reduction in weight. The lesser weight of the powertrain system is equivalent to the lesser negative force applied in the electric vehicle. As a result, the amount of energy captured during the process of regenerative braking gets decreased.

As per the view of Gupta (2020), the regenerative braking system can be treated as an efficient method of reusing the “kinetic energy” of the deaccelerating e-vehicle system through restoring electrical energy to the battery system. The recovered energy is used in order to supply the power to the grid system inside the powertrain system. As per the view of Gupta (2020), the use of electric motors in Hybrid Electric vehicles depends on torque-speed characteristics. It has been observed that the more the value of the torque-speed characteristics of the motor in the case of a hybrid electric vehicle, efficient the motor will be higher. Due to this reason, BLDC and PMSM motor are used for the development of the Tesla Model 3. It has been found that, the regenerative braking power in the “fuel cell-electric powertrain” system is less than the battery-electric powertrain system. Henceforth, the travelling distance with same energy profile is higher in Fuel cell-electric vehicle.

2.4 Capacitor Energy Storage

As per the view of Verma *et al.* (2021), the rapid inclination within the emission of traditional vehicles makes a contribution towards the enhancement of environmental issues. According to the research of Verma *et al.* (2021), HEV (Hybrid Electric Vehicle) can have an efficient level of fuel economy which has the capability to reduce the overall operating and running costs. The main constraint in the Tesla Model 3 is the “energy storage capability”. The capacitor storage system of the battery-electric powertrain requires a value of “specific weight (w/kg)” and a high value of “specific energy (W.h/kg)” in order to increase the traveling distance. In fact, the existence of high “specific weight (w/kg)” and high value of “specific energy (W.h/kg)” helps in reducing the time consumes in charging. The main topologies of the “battery-electric powertrain” system is based on the combination of fuel cells, flywheels, “super-capacitor”, “regenerative braking systems”, and many more.

As per the view of Hasan *et al.* (2021), the prime purpose of using the capacitor-based energy storage system is to maintain rapid regenerative braking and rapid acceleration. In Tesla Model 3’s battery-electric powertrain system, the “capacitor-based energy storage system” gets located near electric motor, which helps in managing the high power demand. It has been observed that a high amount of power is required during the regenerative braking and rapid acceleration process. Henceforth, the “capacitor-based energy storage system” is capable of discharging the stored energy, which provides a rapid power boost to the electric motor.

2.5 Energy Store level

As per the view of Kucevic *et al.* (2021), the energy stored in the battery-electric powertrain included multiple Lithium-ion batteries. Electricity exerted from the system due to discharging of the battery cells. The size and capacity of the battery packs influences the amount of energy generation in the powertrain system. On the other hand, through the converting the battery-electric powertrain system to fuel cell-electric powertrain system, it has become possible to enhance the energy generation and energy storing capacity. Within a “fuel cell-electric powertrain” system hydrogen has been used as the fuel in order to generate electricity through the process of chemical reactions. In the “fuel cell-electric powertrain system”, the size along with the capacity of the “hydrogen storage tanks” greatly influenced the energy generation capacity. It has been found that the energy density in the “fuel cell-electric powertrain” system the energy storing capacity higher.

3.PROPOSED SOLUTION

Calculations to find the mass of a vehicle after replacing 50% of the battery

Mass of hydrogen = 1.58kg

Mass of hydrogen tank = 31.6kg

Mass of battery after replacing 50% with fuel cell = 239kg

The total mass of the car = 1980kg

The total mass of the car after removing 50% battery = 1741kg

Fuel stack size = 2kg

The total mass of the car after taking consideration of all components = 1776kg

WLTP range of vehicle with battery = 425.6927km

WLTP range after replacing 50% battery with fuel cell = 442.6866km

4. Results

4.1Types of fuel cells

Fuel cells are electrochemical devices that convert the energy of a fuel directly into electricity, without combustion. There are several types of fuel cells, each with its own unique advantages and disadvantages. Here are some of the most common types: Proton exchange membrane fuel cells (PEMFCs):

1. PEMFCs are the most widely used type of fuel cell and are commonly used in vehicles and stationary power systems. They operate at relatively low temperatures (between 60-100°C) and use a polymer electrolyte membrane to conduct protons from the anode to the cathode. PEMFCs are known for their high-power density and fast start-up times, making them well-suited for applications that require rapid response times.

2. Solid oxide fuel cells (SOFCs): SOFCs operate at high temperatures (between 800-1000°C) and use a solid oxide electrolyte to conduct oxygen ions from the cathode to the anode. They are known for their high efficiency and ability to use a wide range of fuels, including hydrogen, natural gas, and biogas. SOFCs are commonly used in large-scale power generation and combined heat and power systems.

3. Molten carbonate fuel cells (MCFCs): MCFCs operate at high temperatures (between 600-700°C) and use a molten carbonate electrolyte to conduct carbonate ions from the cathode to the anode. They are highly efficient and can use a variety of fuels, including natural gas, biogas, and even coal gas. MCFCs are typically used in large-scale power generation applications.

4. Alkaline fuel cells (AFCs): AFCs use an alkaline electrolyte (usually potassium hydroxide) to conduct hydroxide ions from the cathode to the anode. They operate at relatively low temperatures (around 70°C) and can use a variety of fuels, including hydrogen and methanol. AFCs were used extensively in the Apollo spacecraft program and are still used in some specialized applications.

5. Phosphoric acid fuel cells (PAFCs): PAFCs use a phosphoric acid electrolyte to conduct hydrogen ions from the anode to the cathode. They operate at moderate temperatures (between 150-200°C) and are highly efficient. PAFCs are commonly used in stationary power generation applications, such as hospitals and data centers.

4.2 Decision matrices:

	Operating Temp °C	Efficiency	Low operation cost	Size	Start up	Typical stack size	Power density	Total
Proton ex membrane	5	4	4	4	5	4	5	31
alkaline	4	5	4	4	4	3	5	29
Phosphoric acid	4	3	3	4	3	2	4	23
Molten carbonate	2	3	3	2	2	2	3	17
Solid oxide	2	4	3	2	2	2	2	17

Figure 4.2 : Decision matrices of fuel cells

There are various types of fuel cells that can be used, with 50% of fuel cells set to replace batteries. Based on research, various fuel cell types were examined, and ranked from worst to best (1–5) in terms of their effectiveness, operating temperature, low operating cost, startup, fuel cell size, power density, and stack size. After researching various fuel cell types, it was decided to use a proton exchange membrane fuel cell to replace 50% of the battery in order to achieve a similar WLTP range to the Tesla model with a 100% battery. Due to their low weight, low operating temperature, exceptional dynamics, and great power density, PEM fuel cells are preferred by the majority of businesses. It has been demonstrated that PEM fuel cells can provide high energy densities of up to 39.7 kW/kg, as opposed to solid oxide fuel cells'

2.5 kW/kg. Due to this high-power density, a lot of research is being done on potential uses in wearable technology and transportation.

4.3 Velocity vs Time after replacing 50% of the battery with fuel cell



Figure.4.3 : Velocity vs Time graph after replacing 50% of the battery with fuel cell

The velocity vs time profile of an electric car after replacing 50% of its battery with a fuel cell would depend on various factors such as the capacity of the fuel cell, the efficiency of the fuel cell, the power rating of the electric motor, and the driving conditions. Assuming that the fuel cell has a comparable power output to the battery that was removed, the electric car should be able to maintain its velocity for a similar amount of time as before. However, the total range of the car would likely be increased due to the additional energy provided by the fuel cell.

4.4 velocity vs. time graph with a full battery is displayed in the graph above

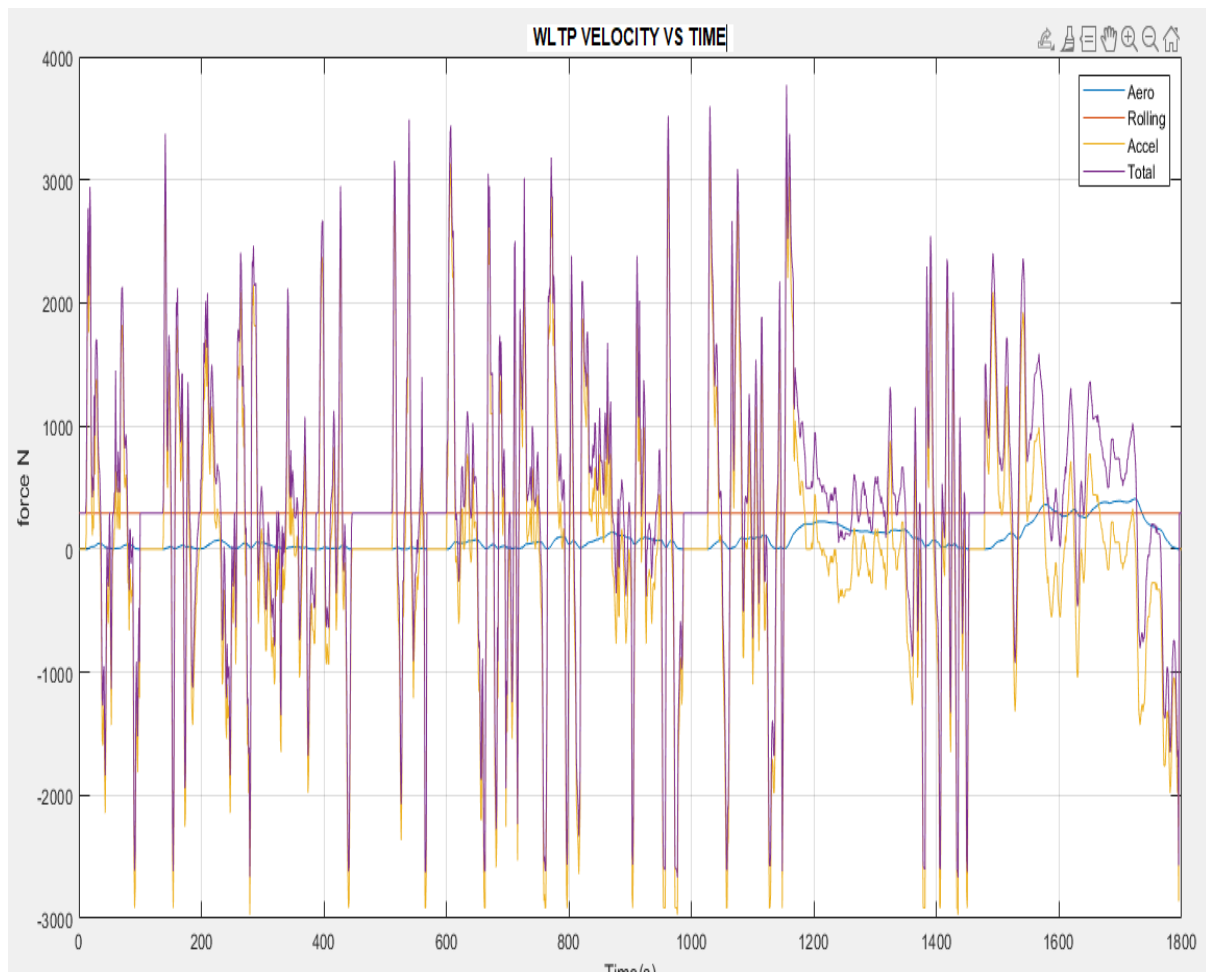


Figure 4.4 : Velocity vs. time graph with 100% battery

It is possible to plot all of the energy level graphs by computing the total energy flows through the systems in a MATLAB or Excel sheet. The findings show that the fuel cell, which replaces the battery by 50%, is more effective as a vehicle than the battery. In contrast to batteries, fuel cells include the same components. when both the fuel cell and the battery have efficiencies of 60%. The weight of the driver, an adult who weighs 70 kg on average, varies as well.

Tesla Model 3's battery-powered range is 425.6927 kilometers. Tesla Model 3's fuel cell-powered range is 442.6866 kilometers. The vehicle is lighter in mass than the fuel cell with battery, which accounts for the longer range. The graphs higher up show a comparison between the system's level of charge at 100% battery and 50% battery with a fuel cell. The graphs up above also display the Tesla's various energies during the course of its successful run.

4.5 Traction energy vs Regenerative energy graph

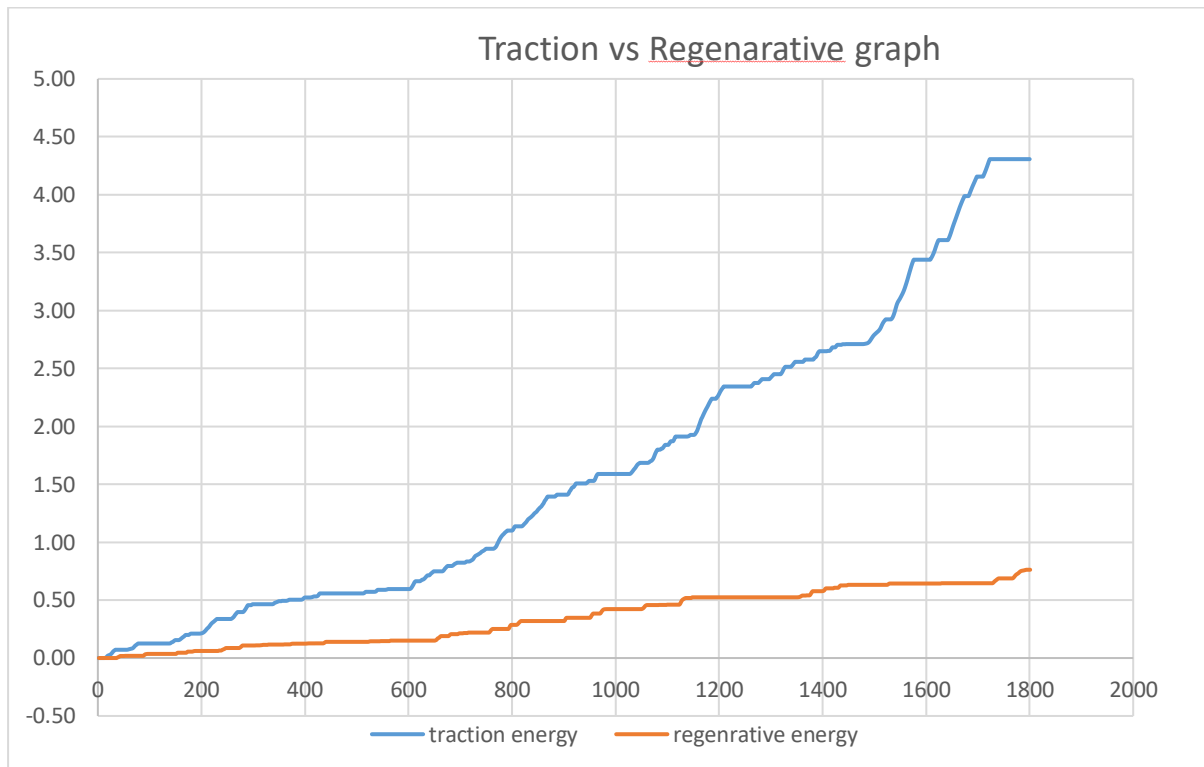


Figure 4.5 : Traction energy vs Regenerative energy graph

The above graph shows the Plots between Traction energy and the Regenerative energy.

The traction energy is the which energy used from the when the car is in acceleration.

The regenerative energy is the which energy restored by the battery. The regenerative braking system restores energy when the tractive is in the negative area, which signals that the car is braking. The force necessary to move the vehicle is equal to the tractive effort while it is in the positive region. The tractive effort is less than with a battery system because of the weight decrease. Less weight equals less negative force applied on the vehicle, which reduces the amount of energy captured during regenerative braking.

4.6 Motor Selection

The motor is one of the most important and required parts of the EV that has been looked after in this case. It can be seen that the motor has been selected as per the requirements so that maximum efficiency can be achieved. *“AC electric motor”* has been used to match the requirements of the tasks. It has been seen that two types of AC motors can be applied. One

of them is the induction motor or asynchronous motor. The other type of motor is the synchronized motor. It can be seen that a synchronous motor has been used for the task so that a rotating magnetic field can be created with the help of a stator.

“Tesla” has been taken into account for all the required calculations and as the *“Electric Vehicle”* in this case. It can be seen that a synchronous and magnet motor has been used for the task and a permanent magnet has been implemented into the motor. Alternative current is required to be used for the task.

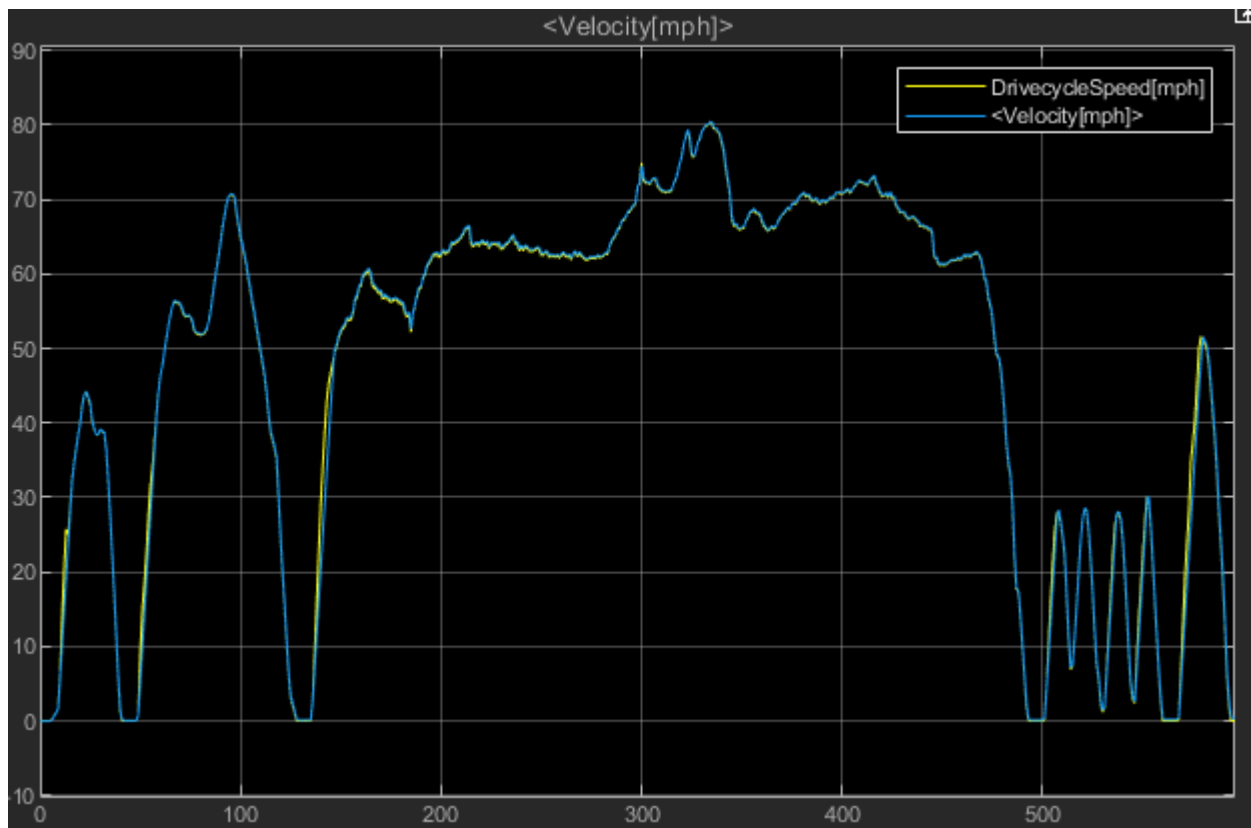


Figure 4.6 : Simulation results

(Source: Self-created using Matlab)

The result of the simulation has been presented in the image above and it can be seen that the result has been shown with the help of a graphical representation. The speed of the drive cycle has been presented along with the velocity of the model and the same has been shown in the image above. A spike in the middle of the simulation has been identified with the help of the image. It can be seen that the velocity, as well as the speed of the vehicle, are almost identical.

4.7 Energy Requirements

The energy requirements for the EV has been addressed and all the necessary calculation has been shown in this particular section. It can be seen that the same has been done using “*Matlab*” software and a “*Simulink model*” has been presented to identify the required energies. A low energy loss can be seen in this case. It has been seen that the vehicle that has been selected in this case can cover up to 100 kilometers with the help of 15 kWh. The result of the simulation shows that the EV is not that energy intensive (Sarathkumar *et al.* 2020). It can also be seen that 90% of the energy can be converted into a driving force in the case of an electric vehicle.

The requirement of energy can be defined with the help of the battery as well as the motor. A brief description of the motor has been provided in the previous section and based on the “Synchronous motor”, all the calculator has been provided. It has been identified that the mass of the car and the battery capacity are closely related to each other.

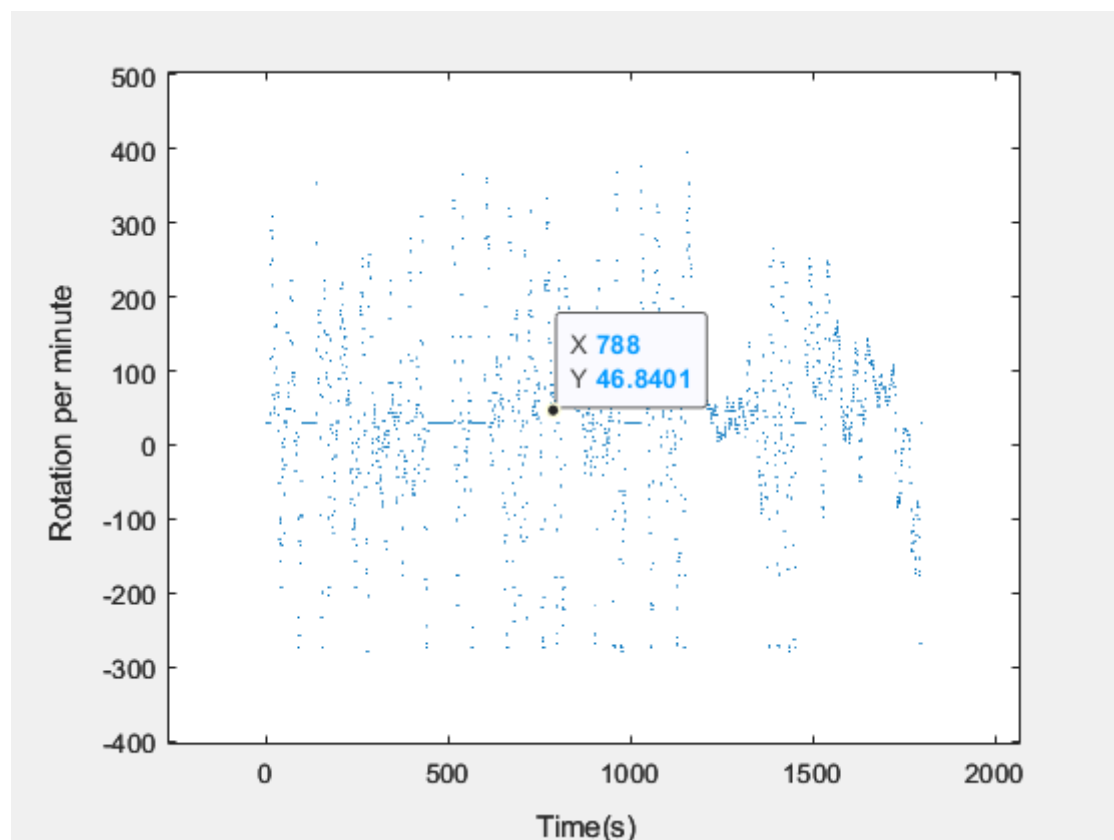


Figure 4.7.1: Change in rpm with change in time

(Source: Self-created using Matlab)

The change of the rpm of the wheels of the car has been displayed with the help of the image above. It can be seen that the change has been calculated with the change in time. The change of time has been taken in the x-axis. On the other hand, the vertical axis denotes the change in

the total per minute. The coordinate of the graphical representation can be seen in the image as well.

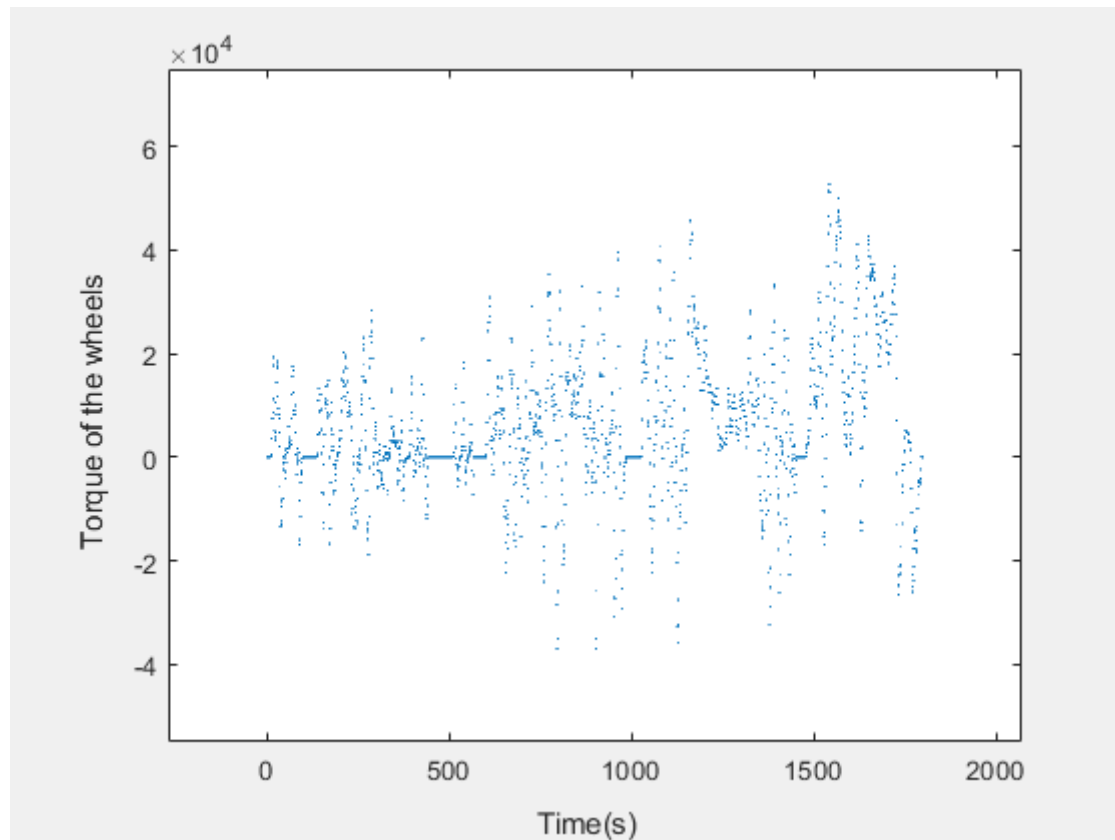


Figure 4.7.1: Change in the torque of the wheels

(Source: Self-created using Matlab)

The change in the Torque of the wheels has been identified in this case and the same has been displayed in the image above. A discontinuity in the plot can be seen in the image as well (Sayed *et al.* 2020)

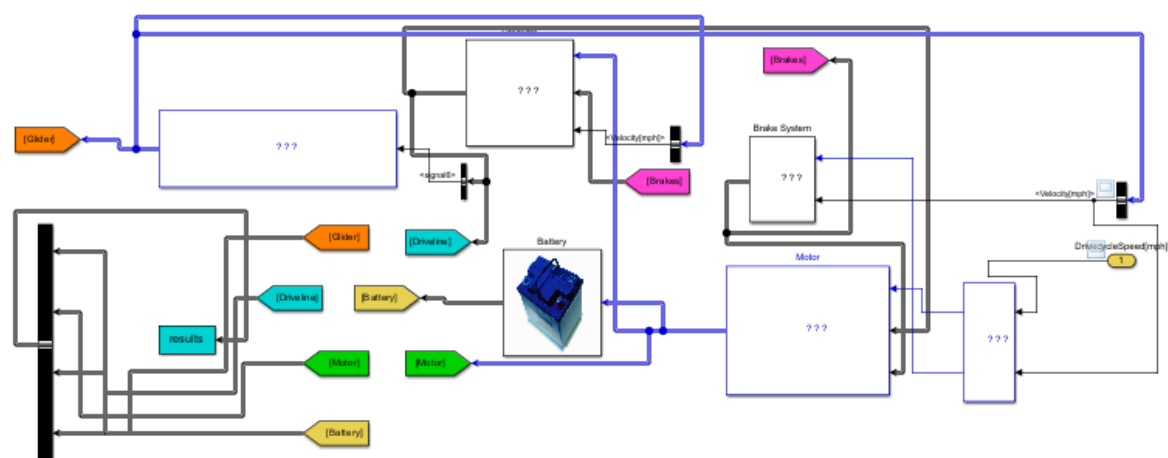


Figure 4.7.2: Simulink model

(Source: Self-created using Matlab)

The Simulink model that has been created for the drive cycle can be seen in the image. All the components that have been used for the manufacturing of the model can be seen in the image as well (Szántó *et al.* 2022). A details connection among the components of the Simulink model has been shown in the image as well. The location, as well as the battery, can be seen in the image as well.

5. Conclusion

The point of discussion in this report is based on the conversion of the minimum of 50% energy storage to Fuel Cell for “Tesla Model 3”. The main requirement for the conversion is the maintenance of similar WLTP range for optimal value of WLTP Wh/km in case the replacement of minimum of 50% of the energy storage to the fuel cell-electric powertrain. Within the first step, the drive cycle of Tesla Model 3 has been performed to estimate the energy required for the fulfillment of the energy demand of the vehicle. Henceforth, this step has played a crucial role in the determination of the power output required for fuel cell. After the development of the electric design of the system has been performed. Within this stage, the designing and selection of the appropriate fuel cell stack, electric motor along with hydrogen storage tanks has been performed. It has been found the Fuel cell stack is the main components within the “fuel cell-electric powertrain system” which plays the role of converting the hydrogen and oxygen into electricity. In fact, in order to fulfill the energy demand, the selection of size and power output is important. Based on the discussion it can be stated that the conversion of the fuel cell electric powertrain helps in increasing the travelling distance.

6.References

- Aguilar, P. and Groß, B., 2022. Battery electric vehicles and fuel cell electric vehicles, an analysis of alternative powertrains as a mean to decarbonise the transport sector. *Sustainable Energy Technologies and Assessments*, 53, p.102624.
- Cunanan, C., Tran, M.K., Lee, Y., Kwok, S., Leung, V. and Fowler, M., 2021. A review of heavy-duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles. *Clean Technologies*, 3(2), pp.474-489.
- Ev-database.org, 2022. *Tesla Model 3*. Available at: <https://ev-database.org/car/1555/Tesla-Model-3> [Accessed on: 12-03-2023]
- Guo, Y., Li, F., Xu, X., Zhou, Y., Ma, R. and Chen, B., 2022, November. A survey on co-optimization of sizing and energy management for fuel cell electric vehicles. In *2022 10th International Conference on Systems and Control (ICSC)* (pp. 564-569). IEEE.
- Gupta, M., 2020, June. Evaluation of regenerative braking and its functionality in electric vehicles. In *2020 International conference for emerging technology (INCET)* (pp. 1-6). IEEE.
- Hasan, M.K., Mahmud, M., Habib, A.A., Motakabber, S.M.A. and Islam, S., 2021. Review of electric vehicle energy storage and management system: Standards, issues, and challenges. *Journal of Energy Storage*, 41, p.102940.
- Kane, M., 2022. *Tesla Model 3 Battery Degradation Test: 8% Down In 3-Years/102k Miles*. Available at: <https://insideevs.com/news/593068/tesla-model3-battery-degradation-3years-102k-miles/> [Accessed on: 12-03-2023]
- Kucevic, D., Englberger, S., Sharma, A., Trivedi, A., Tepe, B., Schachler, B., Hesse, H., Srinivasan, D. and Jossen, A., 2021. Reducing grid peak load through the coordinated control of battery energy storage systems located at electric vehicle charging parks. *Applied energy*, 295, p.116936.
- Sarathkumar, T.V., Poornanand, M. and Goswami, A.K., 2020, July. Modelling and Simulation of Electric Vehicle Drive Through SAEJ227 & EUDC Cycles. In *2020 IEEE Students Conference on Engineering & Systems (SCES)* (pp. 1-5). IEEE.

Sayed, K., Kassem, A., Saleeb, H., Alghamdi, A.S. and Abo-Khalil, A.G., 2020. Energy-saving of battery electric vehicle powertrain and efficiency improvement during different standard driving cycles. *Sustainability*, 12(24), p.10466.

Statista, 2022. *Electric Vehicles - Worldwide*. Available at: <https://www.statista.com/outlook/mmo/electric-vehicles/worldwide> [Accessed on: 12-03-2023]

Szántó, A., Hajdu, S. and Deák, K., 2022. Longitudinal Dynamic Modeling and Driving Cycle Tracking Control of an Electric-Driven Vehicle by Means of MATLAB/Simulink/Simscape. *Periodica Polytechnica Transportation Engineering*, 50(2), pp.146-152.

Tesla, 2023. *Subsystems*. Available at: [https://www.tesla.com/ownersmanual/model3/en_cn/GUID-E414862C-CFA1-4A0B-9548-BE21C32CAA58.html#:~:text=Motor%20Type\(s\),cooled%2C%20with%20variable%20frequency%20drive](https://www.tesla.com/ownersmanual/model3/en_cn/GUID-E414862C-CFA1-4A0B-9548-BE21C32CAA58.html#:~:text=Motor%20Type(s),cooled%2C%20with%20variable%20frequency%20drive). [Accessed on: 12-03-2023]

Tran, M.K., Bhatti, A., Vrolyk, R., Wong, D., Panchal, S., Fowler, M. and Fraser, R., 2021. A review of range extenders in battery electric vehicles: Current progress and future perspectives. *World Electric Vehicle Journal*, 12(2), p.54.

Verma, S., Mishra, S., Gaur, A., Chowdhury, S., Mohapatra, S., Dwivedi, G. and Verma, P., 2021. A comprehensive review on energy storage in hybrid electric vehicle. *Journal of Traffic and Transportation Engineering (English Edition)*, 8(5), pp.621-637.

Wassiliadis, N., Schneider, J., Frank, A., Wildfeuer, L., Lin, X., Jossen, A. and Lienkamp, M., 2021. Review of fast charging strategies for lithium-ion battery systems and their applicability for battery electric vehicles. *Journal of Energy Storage*, 44, p.103306.