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**DYNAMIC MODELLING AND PERFORMANCE ANALYSIS OF A CONVERTED
ELECTRIC VEHICLE DRIVEN BY INDUCTION MOTOR**

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A PROJECT REPORT

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled " DYNAMIC MODELLING AND PERFORMANCE ANALYSIS OF A CONVERTED ELECTRIC VEHICLE DRIVEN BY INDUCTION MOTOR" submitted by Aarogya Shrestha, Anam Maharjan, Subin Manandhar in partial fulfillment of the requirements for the Degree of Bachelor in Mechanical Engineering.



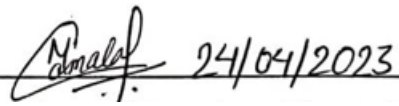
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ABSTRACT

This comprehensive study details the modeling and performance analysis of the drive train of a converted electric vehicle to determine the appropriate gear ratio and battery pack for the vehicle conversion project. The resistive force model and drive cycle simulations are used for determining the power and torque requirements of the motor in order to select the appropriate gear. The effect of vehicle mass, rolling resistance, and torque requirements significantly affect the vehicle's performance and driving range. The drivetrain modeled in MATLAB/Simulink provides a comprehensive view of the system's behavior, including the battery state of charge, battery current, and motor power considering the battery's internal resistance and power losses in the motor. Overall, the analysis described suggests that the chosen LiFePO₄ battery cells, coupled with an appropriate gear ratio, should be able to provide sufficient power and driving range for the vehicle in the selected drive cycles. The vehicle coupled in the 2nd gear provided the mileage of 0.173 kWhr/km for HWFET drive cycle. In the developed drive cycle, the vehicle has a mileage of 0.231 kWhr/km. However, it is essential to test the system thoroughly in real-world conditions to validate the simulation results and optimize the system's performance.

Keywords: Drive train Modelling, Drive Cycle, Regenerative Braking, Tractive Power

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AC	Alternating Current
ADVISOR	Advanced Vehicle Simulator
AEV	All Electric Vehicle
APP	Accelerator Pedal Position
BEV	Battery Electric Vehicle
BLDC	Brushless DC Motor
CES	Centre for Energy Studies
DC	Direct Current
DCGT	Drive Cycle Generation Tool
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVB	Electric Vehicle Battery
FCEV	Fuel Cell Electric Vehicle
FTP	Federal Test Procedure
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GTR	Global Technical Regulation
HEV	Hybrid Electric Vehicle
HP-VEHSAP	High Performance Vehicle Simulation and Analysis Package
HWFET	Highway Fuel Economy Test
IC	Internal Combustion
ICE	Internal Combustion Engines
IM	Induction Motor
INR	International Normalized Ratio
MiEV	Mitsubishi in-wheel hub motor Electric Vehicle
MPG	Mileage Per Gallon

NEDC	New European Driving Cycle
NEEP	Nepal Energy Efficiency Project
PHEV	Plug-in Hybrid Electric Vehicle
PID	Proportional-Integral-Derivative
PKE	Positive Kinetic Energy
PMSM	Permanent Magnet Synchronous Motor
PSAT	Preliminary Scholastic Aptitude Test
REEEP	Renewable Energy and Energy Efficiency Programme
RPM	Revolutions Per Minute
SAFD	Statistical Analysis of Fatigue Data
SoC	State of Charge
SUV	Sports Utility Vehicle
UPS	Uninterruptible Power Supply
VDMS	Virtual Desktop Managed Service
VSP	Vehicle Specific Power
WLTP	Worldwide harmonized Light vehicle Test Procedure

LIST OF SYMBOLS

a	Acceleration
g	Acceleration due to gravity
P_{actual}	Actual Battery Power
F_a	Aerodynamic Resistance Force
A	ampere
Ah	Ampere hour
ω	Angular Velocity of Motor
I	Battery Current
R_{int}	Battery Internal Resistance
F_B	Braking Force
C_d	Coefficient of Drag
K_R	Coefficient of Rolling friction
C	Constant Losses in Motor
K_c	Copper loss constant
ρ	Density of Air
K_d	Derivative Gain
$e(t)$	Error signal
A_f	Frontal Area
G	Gear Ratio
θ	Grade angle
F_g	Grade Force
gm	gram
hp	Horsepower
P_{ideal}	Ideal battery Power
P_{ideal}	Ideal power
m_i	Inertial mass
F_i	Inertial Resistance Force
K_i	Integral Gain
dE_{int}	internal Energy drop in battery
K_i	Iron loss constant

km	kilometer
kg	kilogram
km/hr	kilometer per hour
kW	kilowatt
kWh	kilowatt hour
m	Mass of Vehicle
θ_{\max}	Maximum Grade Angle
V_{\max}	Maximum Velocity
m	meter
mA	milli Ampere
mAh	milli Ampere hour
mm	millimeter
P_{in}	Motor Power Input
P_{loss}	Motor Power Loss
P_{mot}	Motor Power Output
N	Motor Speed
T_{mot}	Motor Torque Output
Nm	Newton meter
V_{OC}	Open Circuit Voltage
K_p	Proportional Gain
r_w	Radius of Wheel
P_{\max}	Rated motor power
F_{RR}	Rolling Resistance Force
t	Time of Acceleration
T	Torque
T_{loss}	Torque loss
E	Total Energy Capacity of Battery
F_{tr}	Traction Force
v	Velocity
V	Volts
Wh/km	Watt hour per kilometer
W	Watts

K_w	Winding Loss Constant
δ	Mass Correction Factor
$m\Omega$	milli Ohm

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

Air pollution in the urban areas is climbing to its peak day by day among which the automobile emissions are the second highest contributor to global warming with approximately 24% of greenhouse gases emissions (Tran et al., 2020). In the same manner, the depletion of fossil fuels and their increasing prices has contributed hugely in the popularity and development of Electric Vehicles. EV offers a comprehensive, secure and balanced energy option that is efficient and environment friendly. Additionally, EV technology is developing and getting smarter, which enhances road usage and traffic safety.

The instant shift from ICs engine vehicle to Electric vehicle might be a long leap. The appeal to increase in usage of EVs can be through replacement of existing ICE vehicles with new EVs or modification of existing ICE vehicles into EVs. Theoretically, any ICE automobile might be converted to run on electricity with older vehicles being less complicated than more recent models, and the modifications necessary to install an electric powertrain are typically easier to complete. With the lift in restriction in modification of engines and chassis by Nepal Government on March 2022, the opportunity of research and implementation of vehicle conversion seems promising.

The electric vehicle conversion project aims to convert conventional fuel-powered vehicles into battery-powered electric vehicles. The basics of converting ICE car into an EV involves replacing the engine, exhaust system, radiator and drivetrain with an electric motor and battery pack. With specific motors catered for specific vehicular configuration and geographic conditions, intensive research needs to be conducted to compare and assess its performance and output on a different vehicle, with challenging topography of Nepal adding to its complexity. The expected vs. actual performance/output of motor also contributes directly to the size of the battery pack required. Therefore, by assessing the performance of the motor on a standard drive cycle, the required configuration of the battery pack can be determined.

1.1.ABOUT THE PROJECT

The EV conversion project is being carried out by **Centre for Energy Studies (CES), Institute of Engineering, Tribhuvan University** along with the support from

Deutsche Gesellschaft für Internationale Zusammenarbeit(GIZ), Nepal. On July 22, 2022, a combustion engine vehicle and an e-engine conversion were handed to the Center of Energy Studies, Institute of Engineering, Tribhuvan University with the goal of providing a platform for conducting practical research on the conversion of combustion engine vehicles to electric vehicles. GIZ, part of the German Development Cooperation, provided the vehicle and conversion kit to the university as part of the Renewable Energy and Energy Efficiency Programme (REEEP) and the Nepal Energy Efficiency Project (NEEP).

1.1.1. Experimental Vehicle

The vehicle selected for conversion is 2000 Nissan Frontier XE Regular Cab. The vehicle is a pickup truck with manual rear wheel drive transmission. Its I-4 2.4-liter engine produces 143 hp (106 kW) power. The vehicle features characteristics which make it suitable for such conversion processes. The hood is spacious, useful for installing electrical subsystems in it. The IC engine has to be disassembled from its transmission box and replaced with electric motor.



Figure 1: Nissan Frontier XE Regular Cab (2000 Model)

Table 1: Nissan Frontier XE Regular Cab Specification

Items	Value/Range
Engine Type	Diesel 4 cylinder 2.4ltr
Max. Torque	209 Nm (@4000RPM)
Max. Power	106 kW(@5200RPM)
Transmission	RWD 5-speed manual transmission with overdrive
Curb Weight	1360 kg
Gross Combined Weight Rating	2127 kg
Overall Height (H)	62.8 inch (1.595 m)
Overall Width (B)	66.5 inch (1.689 m)
Overall Length (L)	184.3 inch (4.681 m)

1.1.2. Components Provided for The Electric Vehicle

The necessary components for the conversion that has already been provided by GIZ are listed below with their respective weights.

Table 2: List of parts provided by GIZ

No.	Product	Qty.	Total weight(kg)
1	Asynchronmotor (85015290/DE) and Curtis Controller 1238(90328900/USA), including Accessories and software	1	(75 +29) kg
2	Adapter parts(76169990/DE)	1	20kg
3	Cable orange unshielded, including cable shoes(85444995/IL)	14	10kg
4	DCDC converter	1	1kg
5	3 KW Charger(85044055/IT)	1	
6	2KW heater PTC with contractor and switch(85168080/DE)	1	0.8kg

7	Break pump Hella including Accessories (84141089/DE)	1	1kg
8	Servopump new including delaymodul(84133080/FR)	1	5kg
9	Klimakompressor electric complete 96V (84152000/CN)	1	6kg
10	Programing software with hardware for controller(85447000/USA)	1	0.3kg
11	Hydraulic tongs (82032000/CN)	1	5kg
12	Batter disconnecting fuse 630A (85365080/CN)	1	0.8kg
13	BMS complete for app control with Bluetooth (90308930/DE)	1	1kg
Total			155 kg

1.2.ELECTRIC VEHICLE

An Electric Vehicle (EV) is a vehicle that uses electric motor to propel the vehicle. The energy for propulsion is obtained either from a battery or fuel cells. EVs don't produce exhaust emissions and are less noisy than automobiles with internal combustion engines (ICEs). An electric motor powers an EV as opposed to an internal combustion engine, which produces power by burning a mixture of fuel and gases. Therefore, in order to solve issues like as increased pollution, global warming, the depletion of natural resources, etc., such a vehicle is considered as a potential substitute for current generation automobiles. The concept of electric vehicles has been around for a while, but in the last ten years it has gained a lot of attention as a result of the increasing carbon footprint and other environmental impacts of fuel-powered vehicles.

1.3. BATTERY ELECTRIC VEHICLES

Battery Electric Cars, often known as BEVs or more commonly referred to as EVs, are entirely electric vehicles without a gasoline engine. The battery pack, which is recharged from the grid, provides all of the energy needed to power the vehicle. BEVs are considered "zero emissions" cars since they don't produce any of the air pollution dangers or toxic exhaust emissions that are produced by conventional gasoline-powered vehicles. BEVs are often known as all-electric vehicles (AEV). Electric cars based on BEVs utilize electric drivetrains that are solely powered by batteries. It is possible to

charge the massive battery pack that contains the electricity required to operate the automobile by plugging it to the power grid. The completely charged battery pack then powers one or more electric motors, which in turn power the electric vehicle. In an electric car, a DC-to-DC converter is used to replenish the auxiliary battery. This electrical device provides power to the 12-volt auxiliary battery from the high-voltage battery pack used to power the vehicle. The auxiliary battery powers the systems such as Air Conditioning, Wipers, Radio/Stereo, and Lights etc. The configuration of BEV is shown in figure:

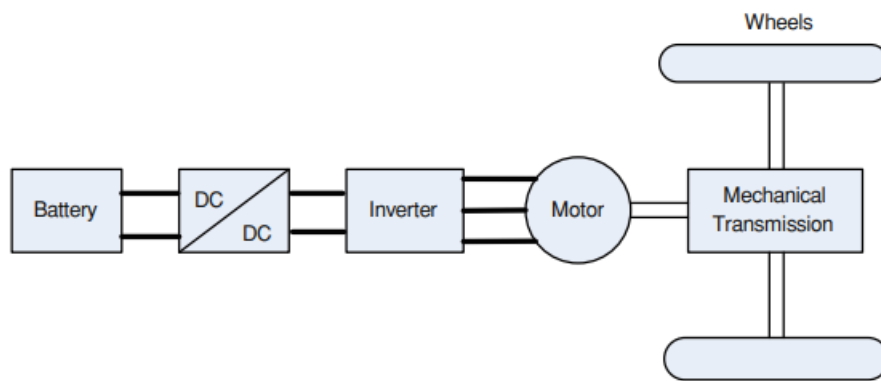


Figure 2: Configuration of a Battery-powered EV

BEV is comprised of a battery for energy storage, an electric motor, and an inverter. The battery is rechargeable and can be charged through a charger carried onboard or at a charging station. The inverter is in charge of controlling the quantity and direction of current flowing to and from the electric motor so that the speed and direction of the motion may be changed. The battery is also charged by regenerative energy during the braking process. The battery pack voltage and the DC bus voltage of the inverter are matched using the DC-DC converter. Mechanical transmission refers to gears and speed reduction in general. Unlike traditional automobiles, advanced vehicles such as EVs do not require manual transmissions as they do in conventional vehicles.

Electric vehicle traction motors are often categorized as DC motors, induction motors, or permanent magnet motors. Due to the drawbacks of DC motors, EV researchers are now focusing on AC motors. Many EV developers have been drawn to induction motors because of their low cost and lack of maintenance. The problem with size and weight for high-speed operation still exists in the meantime. Despite their expensive price, permanent magnet motors have a significant advantage over other propulsion

technologies in the form of high-power density.

1.3.1. Components Of Electric Vehicle

1.3.1.1. Electric Motor

The major part of an electric vehicle is the traction motor. Electrical energy is transformed into kinetic energy by the motor. The wheels are turned by this energy. The electric motor is the major element that sets an electric vehicle apart from conventional vehicles. The regenerative braking system of an electric motor is a crucial component. By transforming the vehicle's kinetic energy into another form and storing it for later use, this system slows down the moving object. Electric vehicle traction motors are often categorized as DC motors, induction motors, or permanent magnet motors. Due to the drawbacks of DC motors, EV researchers are now focusing on AC motors. Many EV developers have been drawn to induction motors because of their low cost and lack of maintenance. The problem with size and weight for high-speed operation still exists in the meantime. Despite their expensive price, permanent magnet motors have a significant advantage over other propulsion technologies in the form of hi-power density.

1.3.1.2. Controller

An electric car's operation is governed by a power electronics controller. It manages the electrical energy flow from the batteries to the electric motors. Both the vehicle's speed and the frequency of voltage variations sent to the motor are controlled by the pedal that the driver sets. Additionally, it manages the generated torque.

1.3.1.3. Traction Battery Pack

The electric motor of an EV is powered by the traction battery pack also known as Electric Vehicle Battery (EVB). The energy in the battery is stored in the form of DC current. The driving range of the vehicle is directly related to the capacity of the battery. Most BEVs use lithium-ion battery because of their comparative weight advantage over other secondary batteries.

1.3.1.4. DC To DC Converter

The battery pack delivers a constant voltage. The DC-DC converter is an electrical device that converts the power output of a battery to a required level according to the

requirements of different components of an EV. The battery pack voltage and the DC bus voltage of the inverter are matched using the DC-DC converter.

1.3.1.5. Power Inverter

The inverter changes the DC power to AC power for operating the electric motor. It also governs the speed at which the motor rotates by changing the frequency of the alternating current. It also operates in the reverse direction by converting AC generated during regenerative braking into DC which further charges the battery.

1.3.1.6. Onboard Charger

The onboard charger is used to convert the AC supplied through a charger into DC which is supplied to the battery. It keeps track of several battery characteristics and regulates the amount of current that flows into the battery pack.

1.3.1.7. Charger Port

The electric car is connected to an external source through the charging port. The battery pack is charged through the port. The vehicle's front or back may occasionally house the charging port.

1.3.1.8. Thermal Cooling System

The thermal management system monitors the operating temperature of various components of the vehicle such as motor, battery, controller etc. It functions during charging as well to protect the battery from heating. It makes use of forced air cooling, liquid cooling, and thermoelectric cooling.

1.3.1.9. Transmission

The transmission comprises of a gearbox and differential connected by propeller shaft which transfers the mechanical power from the electric motor to the wheels.

1.4. RATIONALE OF PROJECT

The instant shift from ICs engine vehicle to electric vehicle might be a long leap. The appeal to increase in usage of EVs can be through replacement of existing ICE vehicles with new EVs or modification of existing ICE vehicles into EVs. Theoretically, any ICE automobile might be converted to run on electricity with older vehicles being less complicated than more recent models, and the modifications necessary to install an electric powertrain are typically easier to complete. With the lift in restriction in

modification of engines and chassis by Nepal Government on March 2022, the opportunity of research and implementation of vehicle conversion seems promising.

The basics of converting ICE car into an EV involves replacing the engine, exhaust system, radiator and drivetrain with an electric motor and battery pack. With specific motors catered for specific vehicular configuration and geographic conditions, intensive research needs to be conducted to compare and assess its performance and output on a different vehicle, with challenging topography of Nepal adding to its complexity. The expected vs. actual performance/output of motor also contributes directly to the size of the battery pack required. Therefore, by assessing the performance of the motor on a standard drive cycle, the required configuration of the battery pack can be determined.

1.5. OBJECTIVES

1.5.1. Main Objective

- To model the drivetrain of a battery-operated electric vehicle and analyze the performance of the traction motor.

1.5.2. Specific Objective

- To choose a fixed gear ratio for coupling the motor with the transmission.
- To determine the capacity and configuration of the battery pack according to the performance output of the motor in standard drive cycle.
- To visualize the effect of change in power requirement and mileage of the electric vehicle with vehicle parameters.
- To analyze the State of Charge (SoC) and energy consumption of the battery with and without regenerative braking.
- To develop a time dependent drive cycle for an EV representing the traffic condition of a specific route of Kathmandu Valley.
- To analyze the torque produced by the motor and the battery power during the drive cycle.

CHAPTER 2: LITERATURE REVIEW

For this project, various research papers and books related to modelling of electric vehicle and its performance analysis were studied. The procedure for conversion of internal combustion engine vehicle to electric vehicle was also consulted. In addition to that, different methods were reviewed to develop a new drive cycle and analyze the performance of EV on that particular drive cycle to some extent. However, this project will be mainly focused on modelling of drive train of electric vehicle and development of Driving Cycle.

2.1. VEHICLE MODELLING

- BEVs can achieve zero emission unlike hybrid electric vehicles (HEVs). BEVs also have the advantage of relatively low cost and reliable technology compared to fuel cell electric vehicle (FCEVs) (Shi et al., 2017).
- The vehicle modelled and designed consumed 148.3Wh/km of energy in which a large amount of energy loss was caused due to the auxiliary loads including the battery, comfort, sound and lighting systems (Schaltz, 2011).
- When calculating the acceleration resistance force, it is best to include the equivalent vehicle weight which includes the effective weight of the powertrain rotating components. When the vehicle is accelerating, the rotational components of the powertrain undergoing angular acceleration are also directly related to the linear acceleration of the vehicle (Sun & Zhu, 2017).
- A comprehensive vehicle simulation software package, known as HP-VEHSAP, has been developed. It is a complete simulation tool that can be used to study all aspects of race car performance like predict lap times, perform transient simulations and calculate steady state vehicle characteristics. The software is based upon a complete system model of a race car which solves the nonlinear physical equations governing the dynamics of the individual components and subsystems that make up the vehicle. A key element of HP-VEHSAP is the Vehicle Component Model Library that allows the user to simulate virtually any type of race car and to match the vehicle model level of detail with analysis requirements (Jennings, 1996).

- A simple and low run-time electric vehicle was modelled using sim scape components in MATLAB / Simulink. The dynamic model was used with the drive cycle source, battery, driver controller, power converter, motor, and vehicle subsystem and the power converter were designed using H-bridge with regenerative braking. Performance parameters, such as vehicle speed, current, State of Charge (SoC), motor RPM and distance, were verified with various drive cycles whereas the distance travelled, speed and torque by the electric vehicle were obtained using the simulation model (Sharmila et al., 2021).
- The city driving conditions requires an average electrical consumption of 84 Wh/km for the low power 4-wheeler, and 123 Wh/km for the high power 4-wheeler.(Saxena et al., 2014)

2.2. DRIVING CYCLE

A driving cycle is a plot of standardized speed-time profile driving under a specified condition to evaluate the vehicle performance in various ways, as for instance fuel consumption, electric vehicle autonomy and polluting emissions. The drive-cycle is the representation of the driving condition of the road. They are basically used to reduce the expense and time spent on road test. The whole idea is to bring the road to the test lab (a chassis dynamometer) or to the computer simulation.

There are two kinds of drive cycle that are widely used. One is distance dependent (speed versus distance versus altitude) and the other one is time dependent (speed vs time vs gear shift). The distance dependent is the actual replica of the test road whereas time dependent is the compressed version of the actual time taken to conduct the test on road. Examples of time dependent drive cycles are European NEDC cycle, FTP-75. Time dependent drive cycles are used specifically for chassis dynamometer testing because in a short time the results can be availed and repeated tests can be done easily.

Experiences in applied research show that customized cycles are used as input for virtual and tested testing procedures during product development. A large number of parameters influence vehicle energy consumption and the related emissions, including driver capabilities, driving context, traffic conditions, ambient temperature, etc.: such a variability causes the need for extensive testing on the road of any kind of vehicle during its final development phase. EV design parameters that are optimized for just one average-assumed drive cycle are not necessarily optimal for other cycles or for the

entire driving profile, which is the collectivity of all drive cycle in the lifetime of a vehicle. Thus, single cycle optimization might lead to cycle beating. Cycle beating refers to performing well while fulfilling the specifications of the cycle.

- According to previous research, "modal" cycles may not accurately represent real driving behavior because they statistically smooth out the impact of the vehicle's modal activities. Therefore, research in the past decades has been focusing on developing transient driving cycles.(Tong & Hung, 2010)
- The achievable improvement in fuel efficiency strongly depends on the particular EV system and on driving conditions. Control and design parameters that perform well under certain conditions may lead to poor behavior under different conditions. Hence, they suggested adopting meaningful objective functions (Guzzella & Sciarretta, 2007).
- By choosing micro-trips from speed groups to create candidate cycles, the Pune cycle was created. Unlike earlier Asian studies, the US researchers' Markov process methodology was used to generate the Manila driving cycle (Terras et al., 2010).
- Five major highways in Pune, India, with a combined length of 55 km and higher Average Annual Daily Traffic (AADT), were chosen as sample routes to gather information for the development of a driving cycle. The greatest overall AADT in the Pune driving cycle was paired with a pre-defined set of origin/destination pairs, and this was used as a benchmark when calculating the traffic density. Then, the most commonly used routes were chosen. In addition, routes were selected based on time of the day which will represent the majority of vehicles according to AADT (Galgamuwa et al., 2015).
- The drive cycle generation tool (DCGT) distinguishes itself from the given methods by operating entirely non-deterministically in terms of data. It does not use a database of recorded data that are combined to form a cycle. Instead, all key parameters of a drive cycle are stochastically described. The drive cycle is created in a modular fashion by assigning probabilistic values to each key parameter. The modules are then assembled to form a drive cycle according to predetermined rules (Schwarzer & Ghorbani, 2013).

- An application case study has been proposed through monitoring of a small fleet of EVs Driving data within the city of Florence which took place for nine months. The usable acquired data was taken for 2500 km. The speed of the vehicles, together with other powertrain information was obtained from on-board diagnostics; GPS data which was used for geo-referencing and identification of driving context when manually examining the data in post processing (Berzi et al., 2016).
- A new approach on the modelling of each component and latter designing a conceptual model in Simulink which takes up the data of speed of vehicles in SI unit which is m/s and draws out distance travelled and acceleration of the vehicle together with driving cycle of the route for given timestamp was developed. This relation was verified with existing Kuala Terengganu BaskITe driving cycle, highway fuel economy test (HWFET), new European driving cycle (NEDC) and worldwide harmonized light vehicle test procedure (WLTP) driving cycles for the use of future projects and improvements of technology in studies and analysis of powertrain and electric vehicle performances (Arun et al., 2017).

2.3. BATTERY PACK

A lithium-ion battery is a type of rechargeable battery that stores energy by reversibly reducing lithium ions. Li-ion batteries have high energy densities, little self-discharge, and no memory effect as compared to other rechargeable battery technologies. Because cells contain volatile electrolytes and can explode or catch fire if broken or inappropriately charged, lithium-ion batteries can prove to be dangerous if not properly developed and manufactured. The open-circuit voltage is larger in comparison to aqueous batteries (such as lead–acid, nickel–metal hydride and nickel-cadmium). Internal resistance of Li-ion battery rises as a result of both cycling and aging.

- Nowadays in automobile sector, the electric vehicles which are battery-powered are beginning to play an important role. The electric motors of battery electric cars and hybrid electric vehicles are powered by electric batteries. Alkaline Battery, Molten Salt, Lithium Ion, Nickel-Metal Hydride, Mercury Battery, Lithium Sulphur, etc. are some of the types of electric batteries utilized today. It is also challenging to choose the right battery because there are so many variables to consider while determining if the battery selected is the best. A comparison study was done with Lithium Ion, Nickel Metal Hydride, Molten Salt and Lithium Sulphur batteries by

keeping the energy storage capacity constant for all of them and through the study and experiments it was found that Lithium Ion (Li-Ion) batteries as the most suitable one because they have a low price, are light in weight, have a high energy and power density and 14.7kWh/100km energy consumption rate which is average (Iclodean et al., 2017).

- Min Ye and his team examined the performance of two connection styles of battery packs based on shifting the positions of inconsistent cells. The first is that cells are joined in parallel and then the parallel modules are assembled in series while in the second configuration the cells are directly connected in series and then in parallel. The first pack's initial capacities were more distributed than those of the second pack by comparing the initial capacities of the packs when cells are arranged in all possible configurations. The capacity of the first pack is always greater than the capacity of the second pack when the cells in the two packs are in the identical places.(Ye et al., 2019)
- Although constant effort has been made in improving the attributes of Li-ion cell, there are very few researches on integration issues of batteries into battery packs. Cells packaged into different shapes provide a wide variety of choices for energy storage system design in EVs (Fagas et al., 2014). For example, Tesla Roadster used more than 7000 pieces of 18650 cells (3.1 Ah) for the Tesla Model S while Mitsubishi used 88 pieces of large prismatic cells (50 Ah) for their Mitsubishi i-MiEV.
- Li-ion batteries have gained popularity for applications in the energy storage system of EVs because of high energy density, low maintenance, cost, no memory effect, no need for periodic deliberate full discharge, capability of accepting high charging and discharging rate, high depth of discharge and low self-discharge. Cells are connected in series to produce the necessary voltage and in parallel to enhance the battery pack's capacity. Having additional cells linked in parallel improves battery pack dependability and reduces the impact of low-quality cells.(Saw et al., 2016)
- After a certain period of time, a large prismatic cell battery pack with fewer parallel cells will lose approximately 50% of its capacity, whereas an 18650 cells battery pack will lose only 20% of its capacity, resulting in significant degradation in EV performance when compared to users of the 18650 cells battery pack (Andrea, 2008).

- Lithium iron phosphate batteries have good voltage discharges, at greater temperatures. The discharge rate doesn't significantly degrade the lithium iron phosphate battery as the capacity is reduced. It is well suited to high discharge rate requirements such as military, electrical car, power tool, mobile necessities, UPS (Interrupt / Backup), and solar energy systems (Brasil & Melo, 2017).

2.4. ELECTRIC MOTOR

Electric motor is an electric device that converts electrical energy into mechanical energy. The electric motor operates through the interaction between the magnetic field of motor and electric current in a wire winding to generate force in form of torque which causes shaft of motor to spin and perform useful work. The electric motor can be classified into various types according to the arrangement of conductor and the field and also the control that can be exercised over mechanical output (torque, speed, position).

In electric motors, the magnetic fields are formed in both stator and rotor which gives rise to a force, and thus a torque on motor shaft. The change in these fields causes the rotation of rotor, which is done by either switching the poles on and off at right time or by varying the strength of pole.

The main types of electric motor are DC motors and AC motors. Some of the electric motors used in electric vehicles are:

1. Brushless DC Motor

A BLDC motor is a self-rotating machine with a permanent magnet rotor, electrical commutation through an inverter circuit, and a rotor-position sensor device. When compared to other motors, BLDC motors generate more torque at peak current and voltage values, are more efficient, and require less maintenance. (Ravindra & Thosar, 2017) These motors are used in compressors, pumps, and ventilation systems due to their superior working qualities at greater speeds.

2. Permanent Magnet Synchronous Motor

Permanent Magnet Synchronous Motors (PMSMs) are brushless and provide extremely high reliability and efficiency. Due to their permanent magnet rotor, they have higher torque with smaller frame size and no rotor current. The permanent magnets also provide field excitation. The PMSM can create torque at zero speed due to the

permanent magnets. The permanent magnet synchronous electric motors in comparison with other electric motors have the best performance: power/volume, torque/inertia, etc.

3. Three Phase AC Induction Motor

An induction motor is powered by alternating current (AC). A three-phase alternating current source is linked to the stator winding, creating a spinning magnetic field. This spinning magnetic field interacts with stationary rotor conductors, causing induced current to flow through them. The induced current creates its own magnetic field. The interaction of the rotating magnetic field and the field owing to induced currents produces unidirectional torque.

4. Switched Reluctance Motor

Switched reluctance motor produce the torque by using the variable reluctance approach. Variable reluctance is created in the air gap between the stator and the rotor when the stator coils are energized. The rotor tends to rotate to the point with the least reluctance, resulting in torque. Switched Reluctance motors provide strong starting torque, a broad speed range, and good inherent fault-tolerance capabilities, making them suitable for electric vehicle applications with lower motor and controller costs and high efficiency at peak and 10% load (Ravindra & Thosar, 2017).

Some relevant studies related to motor used in BEV.

- The performance study of Induction Motor (IM) used as main drive for the electrical vehicle with different number of passengers and speeds of MITSUBISHI I-MIEV model city car was modelled and simulated using MATLAB/Simulink. The simulation results concluded that IM drives the EV with high stability in all conditions including cruising, accelerating, deceleration and reverse motion mode (Hadboul & Ali, 2021).
- At peak load and at 10% load, a three-phase induction motor has an efficiency of greater than 90%. Three phase induction motors are extensively used in electric vehicles due to its high efficiency, precise speed control, and lack of commutators (Ravindra & Thosar, 2017).
- An electric vehicle modelled with two motors: a permanent magnet synchronous motor and asynchronous motor had high efficiency both at high and low speed (Baser, 2016).

2.5. REGENERATIVE BRAKING SYSTEM

Regenerative braking is a technique wherein a short-term storage device temporarily stores some of the kinetic energy of the vehicle. A power transfer system directs energy that would often be lost in the brakes to the energy reserve during deceleration. That energy is stored until required again by the vehicle, whereby it is converted back into kinetic energy and used to accelerate the vehicle. The total amount of energy depends on how often, how hard and for how long the brakes are applied.

- The first car to employ regenerative braking to store energy and recharge the battery on deceleration was an electric concept car which was named Amirton. It was discovered by American Motors in 1967. Gradually, the number of cars using regenerative braking has increased. Cars such as the Audi e-Tron, Ford Fusion Hybrid, Hyundai Kona Electric, Nissan Leaf, Tesla Model 3, and Toyota Prius have regenerative braking systems in them (Lamichhane et al., 2020).
- Different researches and studies have been performed to enhance the regenerative braking system. The regenerative braking can save about 5% to 8 % of waste energy. They also reported that power electronics components like DC-DC converters, flywheels, and ultra-capacitors can upgrade the regenerative braking systems as ultra-capacitor provides smoother charging characteristics of the battery as well as a transient state of the car during startup and overall performance of the vehicle are improved, DC-DC converters are used to maintain power management in regenerative braking systems and power recovery process through wheels are improved by the help of flywheel. They concluded regenerative braking techniques can be developed more in the future by using the fuzzy controller or PID controller methods (Sheladia et al., 2019).
- A regenerative braking system was designed and developed at real axle where external generator was used as a new methodology. And the feasibility was tested using MATLAB Simulink simulation. Through their experiment, it was found that by using regenerative braking system, the amount of battery energy that could be recuperated is around 11% which then increases the Electric vehicle mileage by 10 to 12% (Warake et al., 2018).
- A powertrain model of a PHEV was constructed to analyze available energy from regenerative braking for different driving cycles and showed that braking energy

can represent up to 70% of useful motor energy for some urban driving conditions, 40% for sub-urban and 18% for motorway conditions (Martins et al., 2009).

- A mathematical model was developed to evaluate potential regenerative braking energy. In Sweden, real-world driving tests were conducted, and data were recorded in a data logger at a rate of 2.5 measures per second. A battery electric vehicle (BEV) could typically save 15% energy while light hybrid vehicle saved around 10% energy (Björnsson & Karlsson, 2016).

CHAPTER 3: METHODOLOGY

The following approach is used to fulfill our primary and specific objectives. Firstly, a review of the relevant literature is conducted to gain a general understanding of Electric Vehicle modelling.

The vehicle input parameters such as frontal area, coefficient of drag, curb weight, and so on are taken from the experimental vehicle Nissan Pickup 2000 XE Regular Cab, whereas different standard drive cycles such as HWFET, WLTC-2, BEV FLEET, and so on are used as parameter, and the complete model of an electric vehicle's drive train was developed using the basic principle of the components of the vehicle.

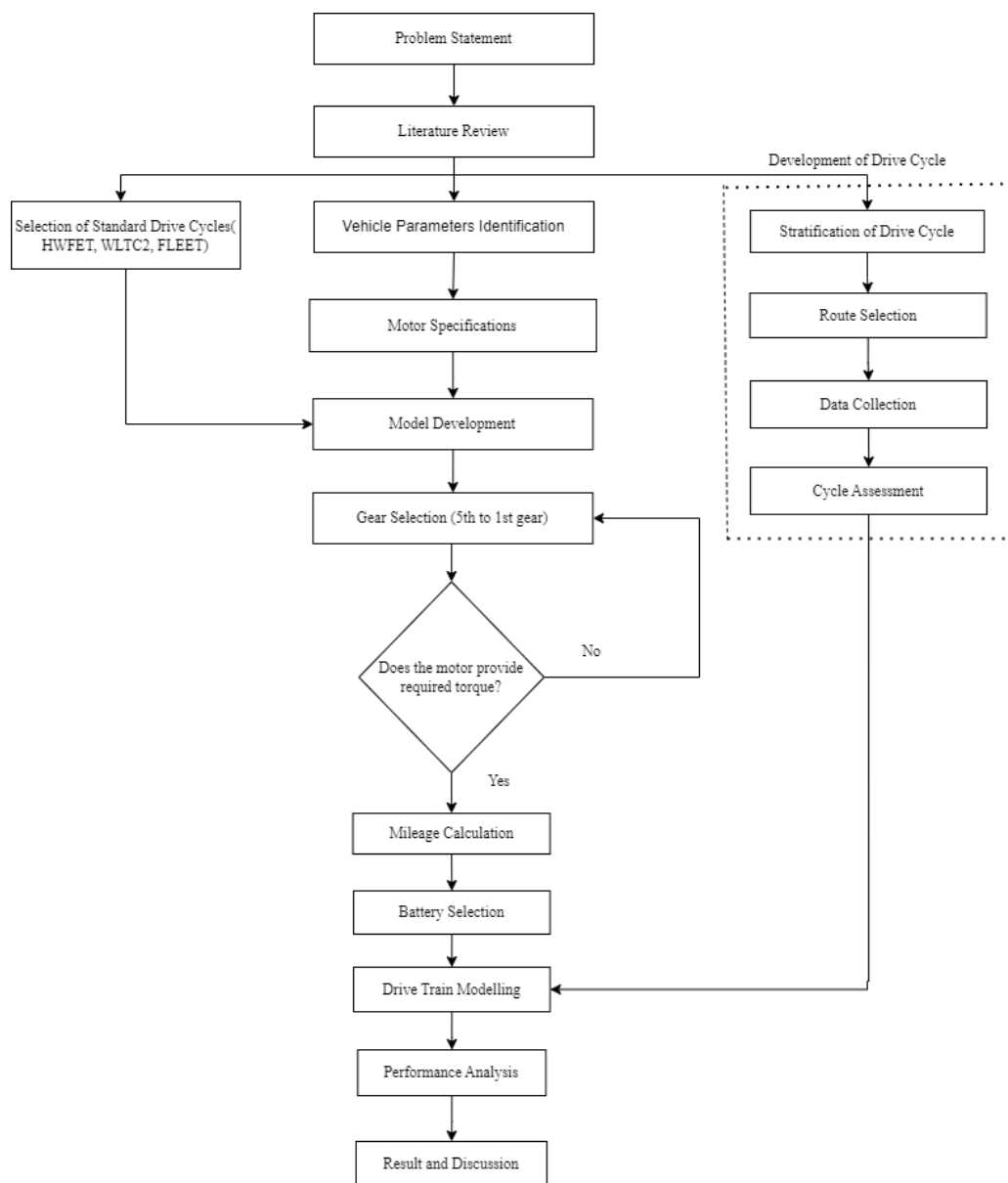


Figure 3: Flowchart of the Project

3.1. PROBLEM STATEMENT

The EV conversion project requires an electric motor to replace the diesel engine of the vehicle and a battery to power that motor. The electric motor needs to provide the same performance as that of the engine in various driving conditions. It is an absolute necessity to find out that the motor will provide the required power whenever necessary. The battery also should be able to provide the required current to meet the power demand of the motor.

3.2. SPECIFICATION OF THE MOTOR

The traction motor which is going to be used to power the vehicle is an asynchronous motor. The motor has a maximum power output of 40 KW and a maximum torque output of 200 Nm. The motor has a length of 470 mm and a width of 318mm. The motor is an air-cooled type, and the fan is operated at the end of motor by the rotor shaft itself. Adapter plates have been provided along with the motor that can be used during coupling with the gearbox.



Figure 4: Asynchronous Motor

Table 3: Motor Specifications

Item	Parameters
Type	3-Phase Induction Motor
Max. RPM	6000
Running RPM	3235 rpm
Max. Power Output	40 kW
Max. Torque	200 Nm
Voltage	61-96 V
Motor Weight	75 kg
Current	429 A

The torque-speed characteristics curve of a similar motor shows that the motor gives the maximum torque of 200 Nm up to the speed of 2500 rpm and as the speed increases above 2500 rpm, the torque decreases. The power also increases gradually up to 2500 rpm. The current and voltage curve shows the current and voltage drawn by motor at different speed.

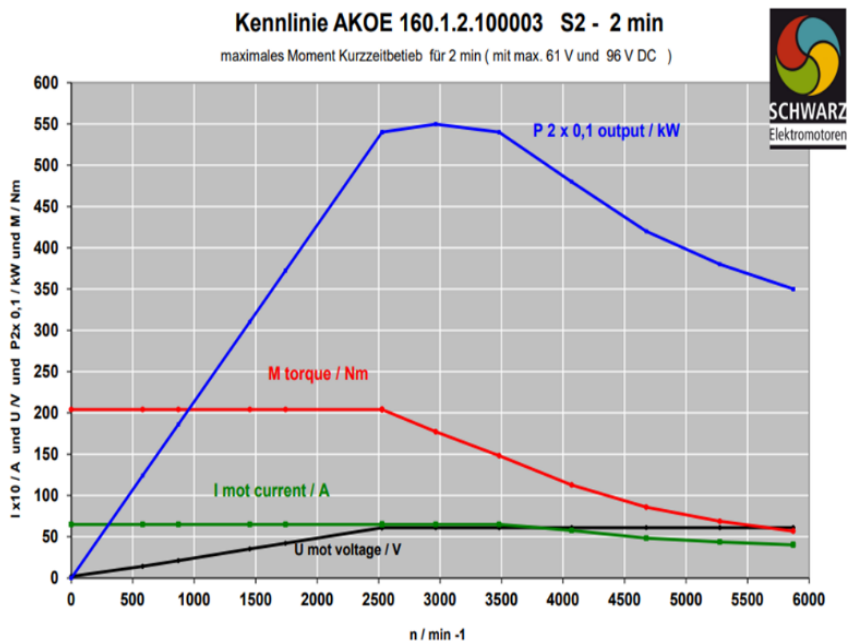


Figure 5: Torque Speed Characteristics Curve

3.3. MODELLING OF VEHICLE RESISTANCE FORCE

It is necessary to know if the motor that is going to replace the IC engine can provide similar performance in different running conditions. The modelling of the vehicle provides the basis for carrying out the test. The vehicle model consists of mechanical and mathematical principles that define how an operating vehicle behaves. Considering a one-dimensional vehicle fundamental motion, the power requirement of the vehicle in each second in a specific drive-cycle depends upon the basic vehicle loads forces, such as aerodynamic drag, rolling resistance and acceleration force.

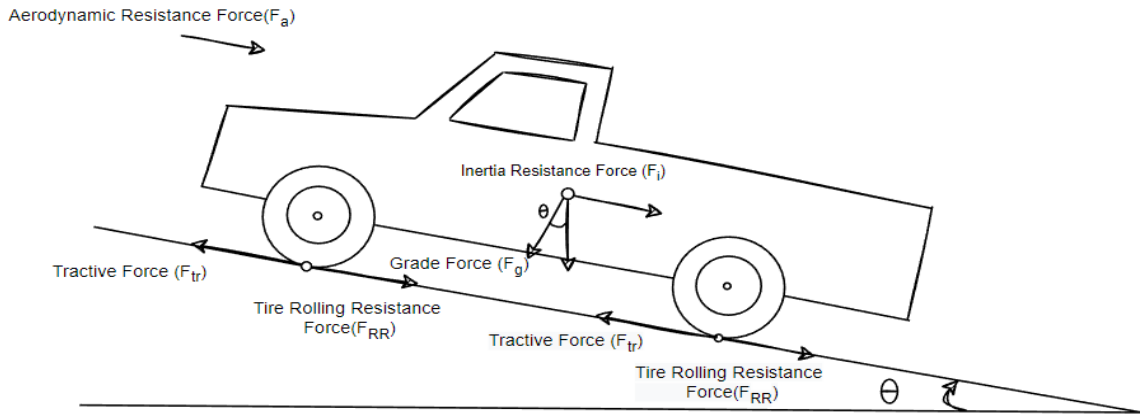


Figure 6: Vehicle Resistance Forces

- **Aerodynamic Force**

Aerodynamic force is the force exerted on the vehicle due to the drag produced by the air when the vehicle is moving which is calculated as:

$$\text{Aerodynamic Force } (F_a) = \frac{1}{2} \rho C_d A_f v^2$$

Coefficient of Drag (C_d) is around 0.25-0.45 for a vehicle (Zhang & Mi, 2011).

- **Rolling Resistance Force**

Rolling resistance force is the force between the road and the tires which is calculated as:

$$\text{Rolling Resistance } (F_{RR}) = K_R m g \cos \theta$$

Where, K_R is taken as 0.015 for average paved roads.

- **Acceleration Resistance Force (Inertial Resistance force)**

Linear acceleration resistance force is the force required to move a mass with certain acceleration which is given by:

$$\text{Acceleration Resistance Force } (F_i) = m_i a$$

Where $m_i = \delta * m$

δ is the mass correction factor to compensate for the increase in the mass of the vehicle due to the rotational components of the powertrain system (Shi et al., 2017).

- **Grade Force**

Grade force acting on a vehicle depends upon the slope of the road and is given by:

$$F_g = mg \sin \theta$$

Taking into account all these forces, the traction force (F_{tr}) required to move the vehicle is given by;

$$F_{tr} = F_a + F_{RR} + F_i + F_g \quad (3.1)$$

The power required to propel the vehicle is given by:

$$P = F_{tr} \times v = \left(\delta m \frac{dv}{dt} + \frac{1}{2} \rho C_d A_f v^2 + K_R mg \cos \theta + mg \sin \theta \right) \times v \quad (3.2)$$

The torque that needs to be provided by the motor is given by:

$$T_{\text{motor}} = \frac{P \times R_w}{G} \quad (3.3)$$

Where,

R_w = Wheel Radius

G = Final Gear Ratio (Includes both transmission and differential gear ratio)

3.4. INPUT PARAMETERS IDENTIFICATION

Various parameters have to be considered to get the required output of the motor. The input parameters needed for the model are:

3.4.1. Vehicle Parameters

The various parameters such as the weight of the vehicle, rolling resistance, wheel radius, coefficient of aerodynamic drag have to be known before the velocity profile of the vehicle is obtained from the drive cycle. Most of the vehicle parameters of experimental vehicle are taken from the vehicle manual while others are obtained from various references and literatures.

3.4.1.1. Curb Weight of the Vehicle

During the conversion, the engine is replaced by a motor and a battery. Also, various parts of the ICE which is unwanted needs to be removed. The weight of the accessories that are to be equipped with the motor and the battery also needs to be added. This altogether might alter the curb weight of the vehicle.

Table 4: New Calculated Curb Weight

Removed Weight

Part	Weight(kg)
Engine	220
Exhaust	35
Fuel Tank	10
Inlet Pipe + Fuel Filter	10
12V Battery	20
A/C pump	5
Alternator	7
Total Weight	307

Added Weight

Components	Weight(kg)
Asynchronous Motor	75
Controller	6
Battery Charger	6
Other Components and accessories	65
Battery Pack	150 (Estimated for 60 LiFePO4 Cell)
Total Weight	302

The curb weight of the vehicle is 1360 kg according to the vehicle specifications and after the conversion the new curb weight is assumed to be 1355 kg considering the weight of the battery pack would be around 150 kg. After the conversion, there seems to be only a slight change in the curb weight of the vehicle. Thus, even if the actual curb

weight of the vehicle is taken for various calculations, there won't be any significant change in the results obtained.

3.4.1.2. Frontal Area

The frontal area of experimental vehicle Nissan Pickup 2000 is calculated by using overall width and height of the vehicle. The frontal area A_f is calculated by multiplying the width and height of a rectangle that encircles the front of an automobile by 0.85 to get a reasonable estimate of the frontal projection of the area of the car. While looking at the automobile from a direction normal to the front grills, this region will be noticed. The 0.85 factor is used to adjust for rounded corners, open space below the bumper, and so on (Moaveni, 2010).

Overall Width (B) = 1.689 m

Overall Height (H) = 1.595 m

The frontal area of the vehicle is given by:

$$\begin{aligned} A_f &= 0.85 * B * H \\ &= 0.85 * 1.689 * 1.595 \\ &= 2.290 \cong 2.3 \text{ m}^2 \end{aligned}$$

3.4.1.3. Vehicle Mass

The vehicle effective mass is taken as the curb weight plus the weight of the driver which is taken as 65 kg and a payload of 30 kg.

$$\text{Vehicle mass} = 1355 + 65 + 30 = 1450 \text{ kg}$$

Table 5: Vehicle Input Parameters

Input Parameters	Values
Aerodynamic Drag Coefficient, C_d	0.4313
Air Density, ρ	1.206 kg/m ³
Frontal Area, A_f	2.3 m ²
Inclination Angle, Θ	0°
Curb Weight	1355 kg
Vehicle Mass	1450 kg
Rolling Resistance Coefficient, k_R	0.015

3.4.2. Drive Cycle Speed

A drive cycle is a type of standardized test used to assess a vehicle's performance, particularly in terms of emissions and fuel economy. To assess a vehicle's performance in actual driving circumstances, a particular set of driving conditions, such as accelerations, speeds, and idle times, must be simulated. Drive cycles are used by vehicle manufacturers, regulatory bodies, and researchers to assess and compare the performance of various vehicles. Drive cycles are created to replicate common driving patterns, such as city or highway driving. Drive cycle test results are used to assess engine, gearbox, and electrified powertrain efficiency as well as whether or not a vehicle complies with emissions regulations. In our case, the input speed at different driving conditions helps to assess the performance of the traction motor and whether the motor can provide the required torque to propel the vehicle.

While testing the modelled vehicle, there is a significant chance that it will only be optimized for one driving cycle and performs poorly under different driving cycles (Schwarzer & Ghorbani, 2013). The driving conditions such as the maximum speed, average speed, distance covered, acceleration time, idling time etc. varies according to the drive cycle. Thus, testing the motor under a single drive cycle will not provide the true results if the motor can provide the required torque in different driving conditions. Thus, it is necessary to test the model in different drive cycles and assess the performance of the motor. For our purpose, three driving cycles have been used to test the model:

1. Highway Fuel Economy Test (HWFET)

HWFET stands for the Highway Fuel Economy Test. The Environmental Protection Agency (EPA) of the United States uses it as a standardized driving cycle to assess the fuel economy of light-duty vehicles, such as automobiles, SUVs, and pickup trucks. The HWFET drive cycle is used to calculate the vehicle's miles per gallon (MPG) rating, which is a gauge of its fuel efficiency. It is intended to imitate highway driving conditions. The HWFET drive cycle consists of a series of accelerations, decelerations, and steady-state speeds that are intended to mimic real-world driving situations. The cycle involves idling, quick acceleration, and both high-speed and low-speed driving.

- Duration: 765 seconds
- Total distance: 16.45 km (10.26 miles)

- Average Speed: 77.7 km/h (48.3 mph)

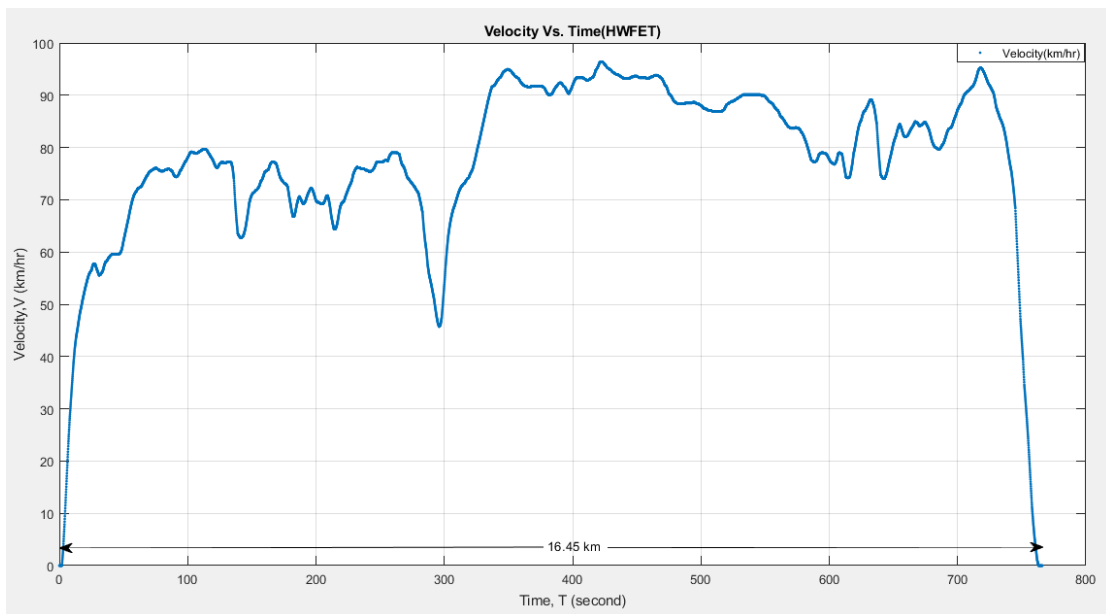


Figure 7: HWFET Driving Cycle

2. World-wide harmonized Light-duty Test Cycle (WLTC)

The Worldwide Harmonized Light Vehicle Test Cycles (WLTC) is introduced by UNESE on Global Technical Regulation (GTR15) to ensure global compliance especially on fuel consumption and emissions performance for light-duty vehicles. The new harmonized driving cycle is to seek a better real-world behavior to be representative enough for global typical driving characteristics, and also improving the test procedures. Thus, various driving data from five different regions has been accounted to assist the development, which includes European Union with Switzerland, United States, India, Korea and Japan. The final driving cycle scheme separates vehicles into three different vehicle classes based on vehicle's power-to-mass ratio and its maximum speed. The vehicle's power to mass ratio is defined as ratio of rated power (W) / curb mass (kg), and its maximum speed (v_{max}) are the speed declared by manufacturer for the vehicle, without use restriction or safety-based limitation.

- Class 1 – low power vehicles with $PWr \leq 22$;
- Class 2 – vehicles with $22 < PWr \leq 34$;
- Class 3 – high-power vehicles with $PWr > 34$

The rated power of the motor is 40 kW and the curb weight of our vehicle is 1355 kg. Thus, the vehicle's power to mass ratio is 29.52. So, the vehicle falls under the class 2 category of the WLTC cycle.

The WLTC-Class 2 is broken down in three phases: low speed (589 seconds and 3.132 km), medium speed (433 seconds and 4.712 km) and high speed (455 seconds and 6.82 km). These phases are designed to represent urban traffic, mixed conditions and highway conditions respectively.

- Duration: 1477 seconds
- Total distance: 14.664 km (9.11 miles)
- Average Speed: 37.433 km/h (23.26 mph)

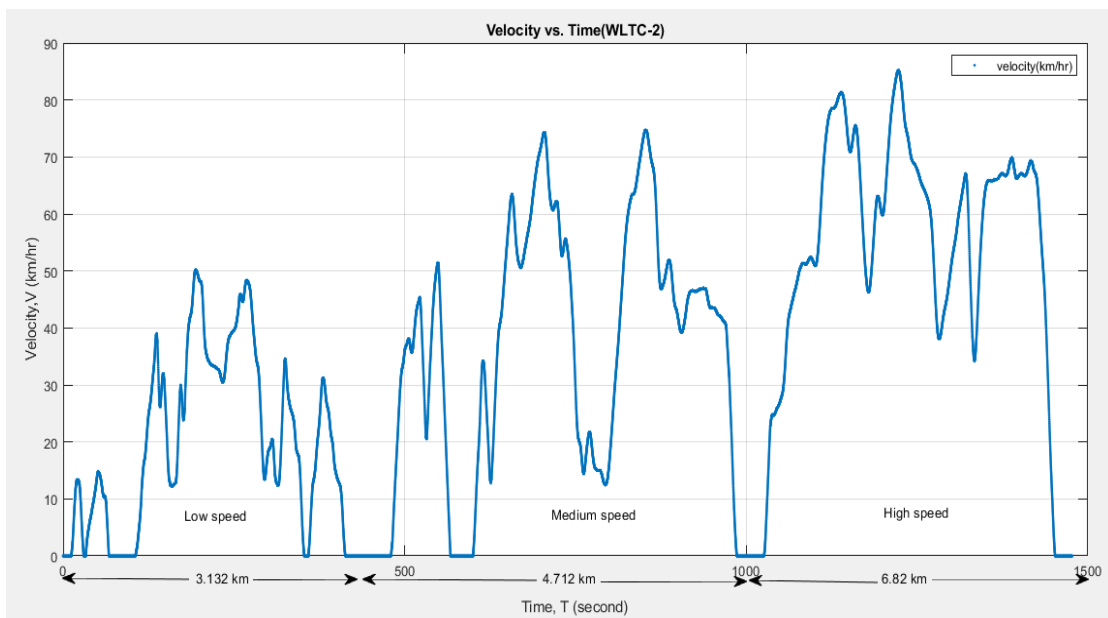


Figure 8: WLTC-Class 2 Drive Cycle

3. Fleet-BEV Cycle

Fleet-BEV Cycle is intended to represent the overall usage of the BEV and therefore consists of four of urban as well as one rural micro-trip, so the driving cycle reflects predominant urban operation. In sum 13.7% of the actual driving time without idle phases shows a speed of 60 km/h or more. The Fleet-BEV Cycle includes phases with speed limits of 50 and 30 km/h as well as an initial 27-second sequence with a peak speed of 21 km/h that takes place when a large parking lot needs to be exited (Pfriem & Gauterin, 2016). Also, a sizeable portion of the class drives between 70

and 80 km/h as a result of the rural driving pattern. The speed of acceleration and deceleration is approximately +/- 2.2 m/s².

- Duration: 783 seconds
- Total distance: 5.828 km (3.62miles)
- Average Speed: 26.79 km/h (16.646 mph)

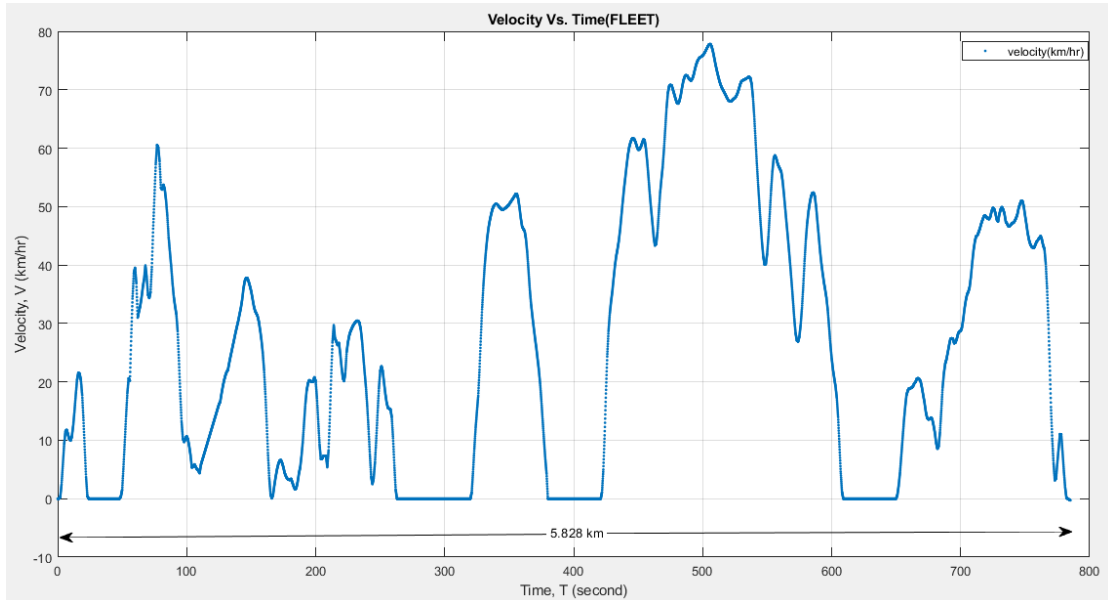


Figure 9: Fleet BEV Cycle

3.5. CALCULATION OF SPEED AT DIFFERENT GEARS

The speed of vehicle according to the gear ratio and the speed of motor is calculated as:

$$v = \frac{2\pi N}{60} \times \frac{r}{G}$$

Where, v is the velocity of the vehicle

r is the radius of wheel (For the given vehicle, r=0.34m)

G is the final gear ratio

N is the rotational speed of the motor

Axle Gear Ratio = 3.55

3.6. MODEL DEVELOPMENT

Using the equations for the vehicle resistance forces, the model is built as shown below:

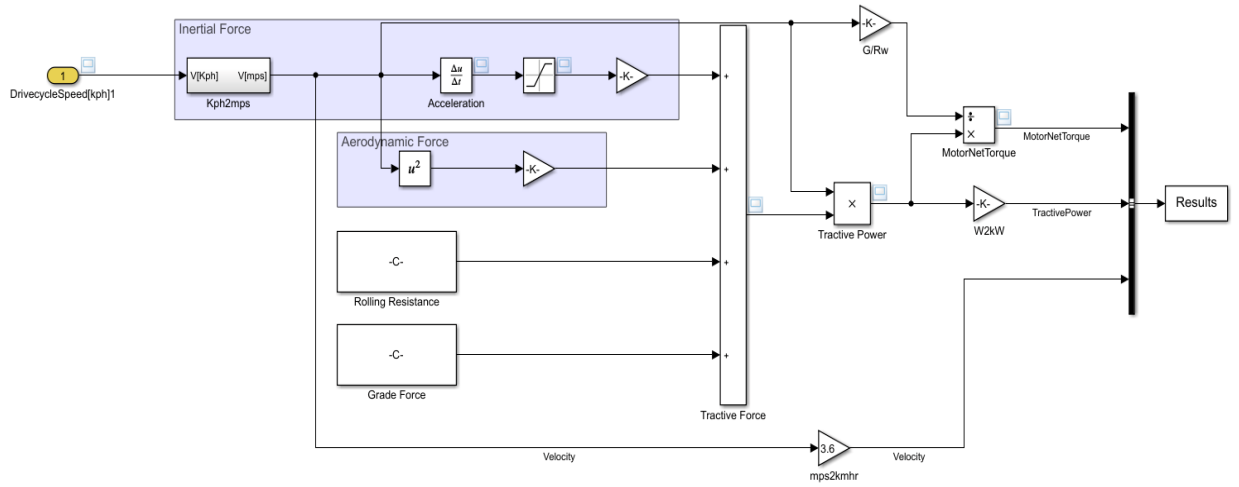


Figure 10: Vehicle Resistance Forces Modelling

The torque requirement of the motor and the power consumption profile in a selected drive cycle is calculated using the model. The velocity profile obtained from the drive cycle along with the vehicle parameters are used as an input parameter to calculate the traction force that the motor needs to provide. The traction power calculation is based on the assumption that the motor doesn't provide torque during retardation. Instead, the calculation is based only on the portion of drive cycle where the vehicle is accelerating. During deceleration the inertial resistance that needs to be overcome is considered zero. However, the power required to overcome the other resistance force is being provided by the motor. The regeneration which is possible during deceleration and braking is not being considered.

3.7. CALCULATION OF MAXIMUM TORQUE AT DIFFERENT GEARS

The torque required to move the vehicle is given by the equation:

$$T_{\text{motor}} = \frac{P \times R_w}{G}$$

Using the model shown in figure 2.2, the torque that needs to be produced by the motor is determined for different drive cycles. The torque required for different gear ratio of the transmission is also determined. Based on the maximum torque and peak power

obtained from the three test cycle a suitable gear will be selected for coupling the motor with the transmission system.

3.8. BATTERY SELECTION

The battery needs to power a motor of 40kW and the accessories load of 600W. The accessories load includes the power to run the power steering pump, brake vacuum pump and other auxiliary units. The range and power requirement determine the capacity of the battery required. The total power consumed while operating the vehicle in different drive cycle is calculated by using the model shown in figure 2.2 and hence the mileage. By considering a suitable driving range, the battery capacity is determined.

The battery cost reaches approximately 20-50% of EV conversion cost (Kaleg et al., 2015). The battery pack is composed of individual battery cells whose arrangement in series and parallel gives the required voltage and capacity.

Considering the battery cells available in the market, Li-ion polymer and LiFePO₄ cell are two prominent cells for the battery pack. These batteries have high charge density, low self-discharge and high operating temperature range (Megahed & Ebner, 1995). Prismatic cells have been preferred in applications with moderate current density requirements in which prismatic form factor will result in 15-30% capacity advantage over the cylindrical form factor.

3.9. DRIVETRAIN MODELLING

The method used to model the drivetrain of the vehicle is the Forward approach, also known as the engine-to-wheel or back-to-front method. It employs a driver model that attempts to adhere to the intended speed profile. Forward-thinking models include a driver model, which provides information into the electric car's driveability (Atamnia et al., 2021). The forward-looking model improves comprehension of the power train's dynamics and physical restrictions.

The performance of the drivetrain of EV in different operating condition was assessed by developing a model using the MATLAB/Simulink toolbox in MATLAB R2020a. In this project, the drive train has been modelled using the mathematical equations. The basic structure of the developed model is as shown in figure below:

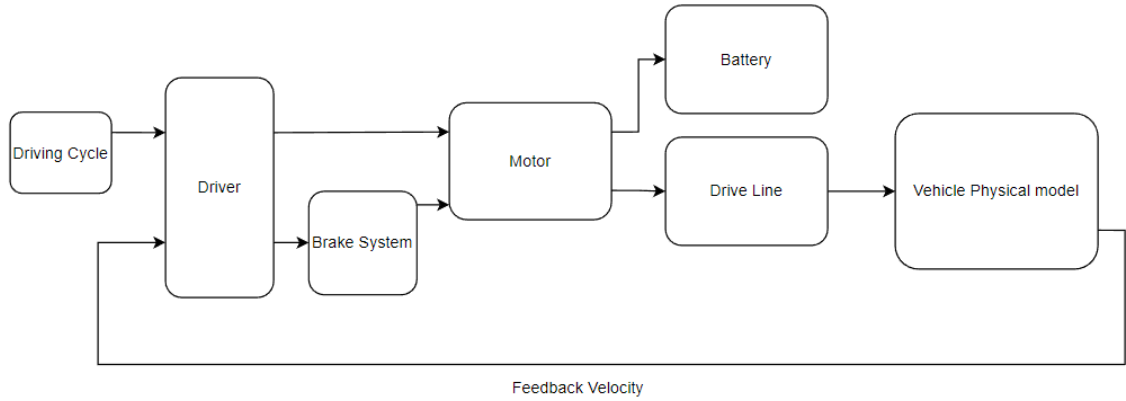


Figure 11: Basic Structure of Drivetrain Model

A physical model is used to represent the vehicle body. The difference in velocity of the vehicle and that of the drive cycle is used as a basis for power input to the motor through the driver which acts as a controller. The information from the motor is then used to determine the power that will be transmitted to the wheels through the driveline. The whole process is repeated through the velocity feedback loop. During the whole process, the energy and state of charge (SoC) of the battery is also constantly monitored. This information is then transmitted to the motor, which uses the required energy for acceleration by drawing it from the battery. During the regenerative process, the motor behaves as a generator which produces the energy during deceleration and is stored in the battery.

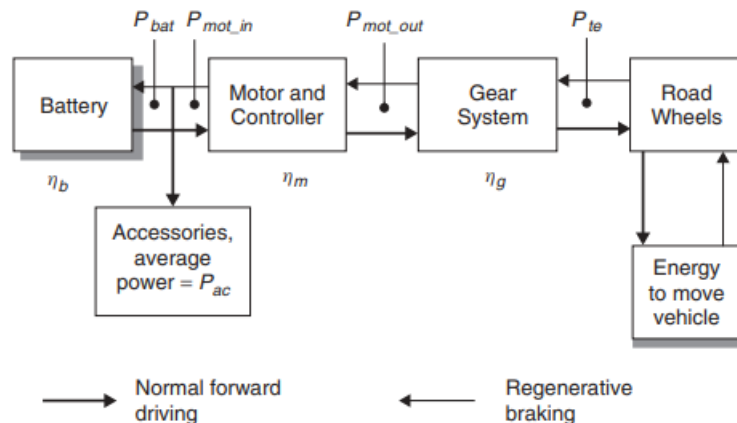


Figure 12: Energy Flow in a Typical Battery-Powered Electric Vehicle with Regenerative Braking

The model consists of seven subsystems: drive cycle, driver, vehicle physical model, driveline, motor, battery and brake system.

3.9.1. Driver

This subsystem controls the motion of the vehicle depending upon the difference in speed between the time-based drive cycle speed and the actual speed of the vehicle. The difference is monitored through a PID controller and the input to the throttle is given accordingly. If the vehicle speed exceeds the drive cycle speed the brake pedal will be actuated. If the vehicle speed is below the drive cycle speed the acceleration throttle will be actuated.

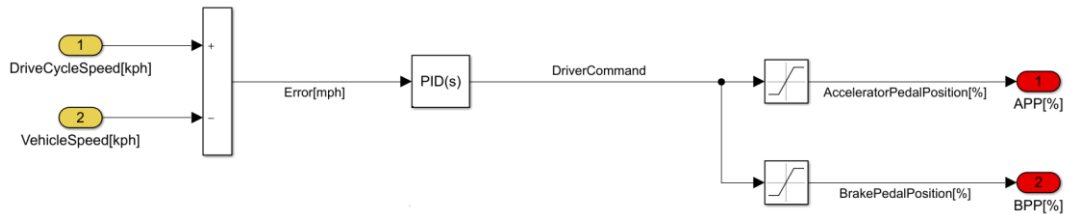


Figure 13: Driver Model

The model acts as a controller that controls the acceleration and braking of the vehicle. The PID controller is used to minimize the steady state error between the drive cycle speed and the vehicle speed obtained from the vehicle resistance force model.

3.9.1.1. PID Controller

The proportional-integral-derivative controller (PID controller) is a control loop mechanism with feedback used for continuously modulated control. The PID controller is used to calculate an error value ($e(t)$) as the difference between the drive cycle speed and the actual speed and apply a correction based on proportional, integral and derivative terms. The output of the PID controller is calculated in the time domain from the feedback error as:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de}{dt}$$

As the focus is to reduce the steady state error, the proportional gain (K_p) is used only for this controller. Even though the derivative term (K_d) helps to anticipate the error, has no effect on the steady-state error. Due to the sign change in the error signal, the

integral term can make the system more sluggish even though it helps to reduce the steady-state error.

3.9.2. Motor Modelling

The traction motor selected for the modelling is an induction motor. The motor performs dual functions: converts the electrical power from the battery into mechanical power at the wheels and converts the mechanical power into electrical energy during the regenerative braking process to charge the battery. The power of the motor in real time is given by:

$$P_{mot} = T_{mot} \times \omega$$

This equation represents the true torque that is used to power the wheel excluding all the losses in the motor. The amount of torque produced by the motor is expressed as a function of the input throttle or Accelerator Pedal Position (APP). A torque limiter subsystem is used which ensures that the maximum torque during forward movement and regenerative process is not exceeded.

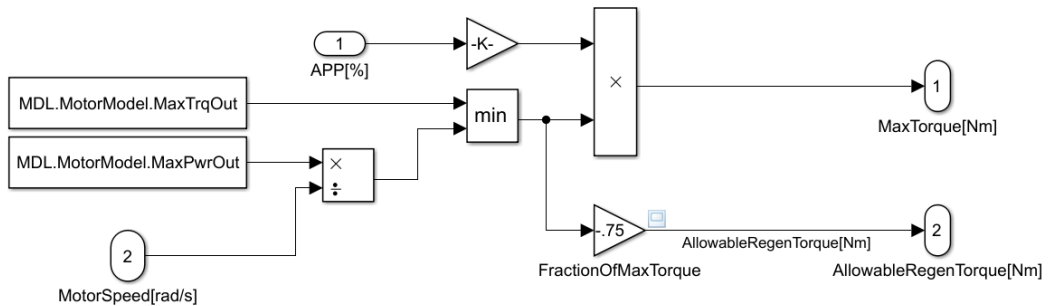


Figure 14: Motor Torque Limiter

The torque limiter subsystem ensures that the maximum torque during forward movement and regenerative process is not exceeded. The maximum torque and power output of the motor is set to a predefined value through the specification of the motor. A minmax block is used to ensure that the torque produced is always below the maximum torque output of the motor

The maximum allowable torque for regeneration is assumed to be 75% of the maximum input torque to the motor to protect both the motor and the battery from the power surge.

$$Regenerative Torque_{allow} = 0.75 \times Maximum Torque_{allow}$$

The regenerative torque limiter subsystem is used to limit the regenerative brake input within the value of allowable regenerative torque.

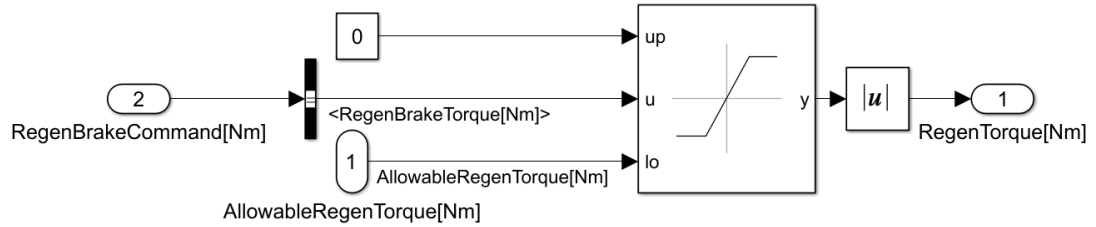


Figure 15: Regeneration Torque Limiter

During the operation, there will always be some losses present in the motor. Thus, the total power input to the motor is given by:

$$P_{in} = T_{mot} \times \omega + P_{loss}$$

The major sources of losses are same for all types of electric motor and can be divided into four main types:

The copper losses are caused due to the electrical resistance of the wires of the motor, which causes heating. The copper losses are given by

$$Copper\ Loss = k_c \times T^2$$

Where, k_c is constant depending upon resistance of coil and magnetic flux (ϕ)

The iron losses are caused due to the continuous magnetizing and demagnetizing of the iron and aligning and realigning of magnetic dipoles (hysteresis loss) and the electromagnetic induction which generates current (eddy current) in iron and causes its heating (Larminie & Lowry, 2012). The iron losses are proportional to frequency with which the magnetic field changes and is given by

$$Iron\ Loss = k_i \times \omega$$

Where, k_i is iron loss constant.

The losses due to friction in the bearing is negligible. The winding loss is due to the wind resistance of the rotor. The wind resistance force will increase with the square of speed and is given by

$$Windage\ Loss = k_\omega \times \omega^3$$

There are also the losses which occurs even when motor is stationary and that vary neither with speed nor torque which is denoted by C .

$$Total\ Losses = k_c \times T^2 + k_i \times \omega + k_\omega \times \omega^3 + C$$

3.9.3. Battery Modelling

The battery here is simply represented as a voltage source with an internal resistance. The model accounts for internal power loss in the resistance of the battery in the form of heat. The battery is assumed to have constant internal voltage, and the terminal voltage equals the difference between internal voltage and internal resistance voltage drop.

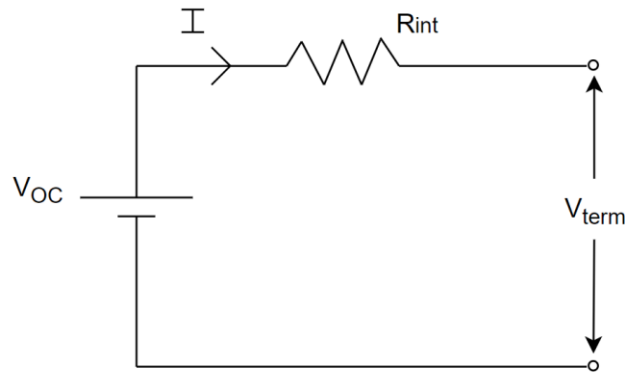


Figure 16: Battery Circuit

The battery powers the traction motor as well as other accessories of the vehicle. So, the power that the accessories draw from the battery will also have to be considered. The total power drawn from the battery will be the sum of the accessory load and the input power of the motor.

The ideal power output of the battery is given by:

$$P_{ideal} = I \times V_{OC}$$

Some power is lost as heat due to the internal resistance of the battery which is given by:

$$P_{loss} = I^2 \times R_{int}$$

Therefore, actual power output of the battery is given by:

$$P_{actual} = P_{ideal} - P_{loss}$$

$$P_{actual} = I \times V_{OC} - I^2 \times R_{int}$$

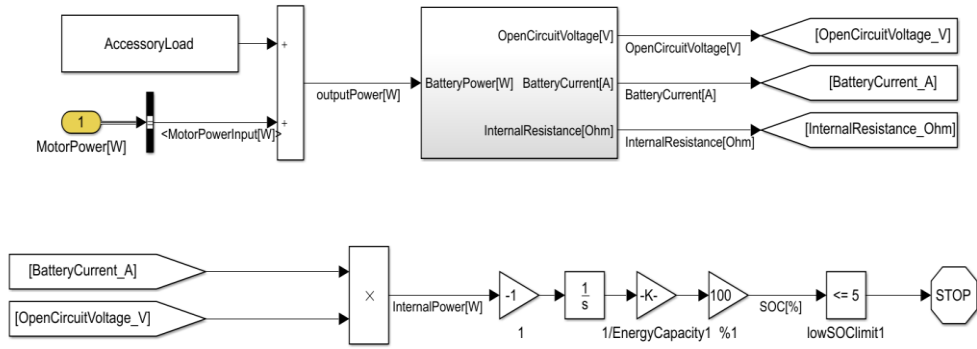


Figure 17: Battery Model

The current that can be drawn from the battery is obtained by solving above equation as:

$$I = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4R_{int}P_{actual}}}{2R_{int}}$$

State of charge (SoC) is defined as the ratio of the remaining charge in the battery, divided by the maximum charge that can be delivered by the battery. It is associated with the quantity of electric power still available in the battery. For the safety of the battery cell, the SoC is not allowed to fall below 5%.

$$SoC = SoC_{old} + 100 \frac{dE_{int}}{E}$$

3.9.4. Driveline

The driveline transfers the traction force from the motor to the wheel through a single reduction gear is assumed. The loss in driveline associated with churning (drag and pocketing) of oil surrounding the gears and bearing are also taken in account.

The traction force of motor transmitted by the driveline can be described as:

$$F_{tr} = (T_{motor} - T_{loss}) \frac{G}{r_w} - F_B$$

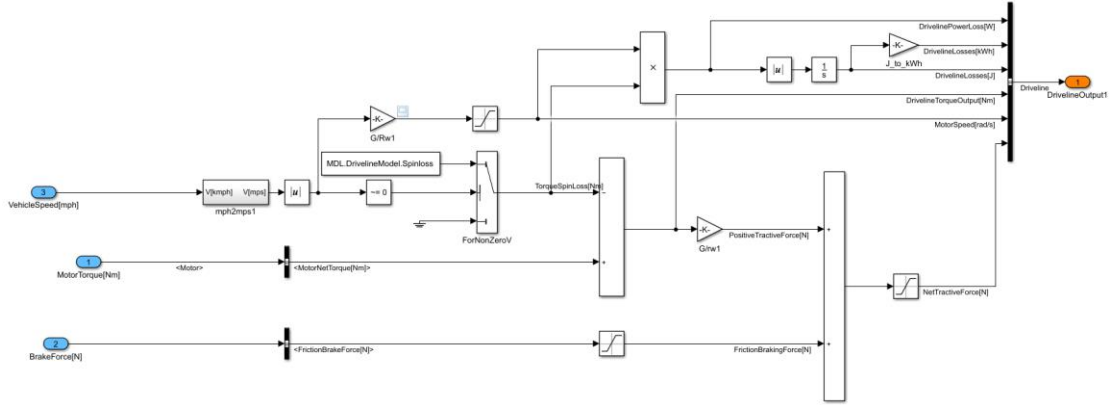


Figure 18: Driveline Model

3.9.5. Braking System

The braking strategy has strong effect on both the battery energy and performance of the converted vehicle. The model uses a parallel braking system at rear axle i.e. the maximum available braking force ($B_{F_{max}}$) is distributed between friction braking ($B_{friction}$) and regenerative braking (B_{regen}).

$$B_{F_{max}} = \varphi * m * g$$

$$B_{regen} = BP \times B_{F_{max}}$$

$$B_{friction} = (1-BP) \times B_{F_{max}}$$

Where, φ is the Coefficient of Adhesion

BP is the fraction of friction braking in total brake force.

The desired braking force depends on the pedal position and the maximum braking force which are predefined.

$$B_{desired} = BPP\% \times \frac{B_{max}}{100}$$

$$B_{desired} = B_{friction} + B_{regen}$$

$$B_{desired} = BP \times B_{regen} + (1-BP) \times B_{friction}$$

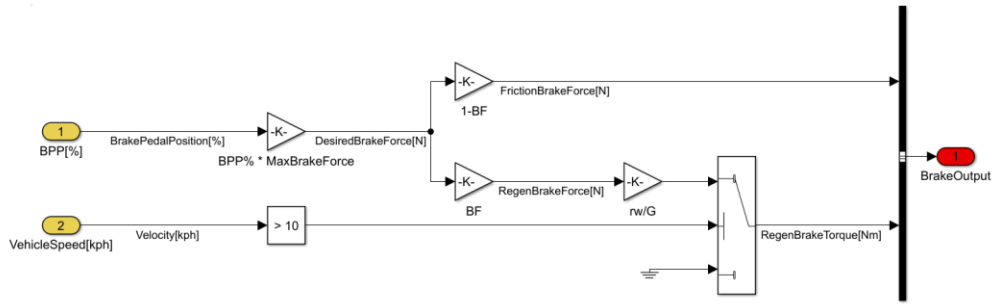


Figure 19: Brake Model

The desired braking force depends on the pedal position and the maximum braking force is predefined. A percentage of the required braking effect is used for regenerative depending on the type of motor and controller. At low speed, the vehicle has less kinetic energy and needs less braking effort. As a result, regenerative braking system is fed with less energy and battery pack will receives less charge. So, the regeneration is neglected at the vehicle speed below 10m/s.

3.10. VEHICLE RANGE CALCULATION

The vehicle range is calculated by considering total battery capacity available, battery capacity used in one cycle and total distance covered during that drive profile. The SoC_{max_rated} and SoC_{min_rated} represents the allowable battery limit. Battery power cannot be used until it is completely drained. There will always a minimal energy stored in the battery, however the energy cannot drive the car. The minimal energy is the energy equal to the vehicle's tractive resistance (Kaleg et al., 2015).

The SoC_{start} and SoC_{end} is the battery capacity at the beginning and end of drive cycle profile.

$$Vehicle\ range = \frac{SoC_{max_rated} - SoC_{min_rated}}{SoC_{start} - SoC_{end}} \times drive\ cycle_{distance}$$

The maximum rated SoC and minimum rated SoC is considered to be 100% and 5% respectively.

3.11. DEVELOPMENT OF DRIVE CYCLE

A driving cycle is a speed-time profile for a vehicle operating under specific conditions, typically chosen to simulate real-world conditions, predict fuel consumption and exhaust emission in a specific location. The average speed of urban driving cycles is often lower, but the PKE and acceleration rates are bigger. This depicts the congested driving behavior that are typical in urban locations with large traffic flows and numerous crossroads, such as frequent stop-and-go driving. The smooth highway driving features with few stops and traffic interruptions are reflected in the highway driving cycles, which show a clear tendency toward a greater average speed but smaller PKE values and acceleration rates (Tong & Hung, 2010).

3.11.1. Stratification of Driving Cycle

The initial stratification of the drive cycle should reflect the purposes of developing drive cycle and subsequently relate to the selection of test route. It is based on local traffic characteristics.

The stratification of driving cycle is qualitative and suitable for developing pre-defined region-wide or facility-based cycle. The major stratification factor includes road type, vehicle type, time period, speed level, vehicle operating modes and traffic management schemes.

The purpose of development of this drive cycle is to represent the traffic condition of selected route at that particular time and analyze the performance of the vehicle in that specific route. The drive cycle is only used for the testing of vehicle performance in that particular driving condition. The vehicle selected for collection of data is an ICE vehicle TATA Indica Vista.

3.11.2. Selection of Route

The selection of route is based on the stratification of driving cycle and it should represent most typical driving patterns in the area of interest. It is simply based on commuter home to work trips, population density and road classifications.

The route from Tinkune to Radhe-Radhe was selected as a test route and the test was implemented around half past six in the evening.

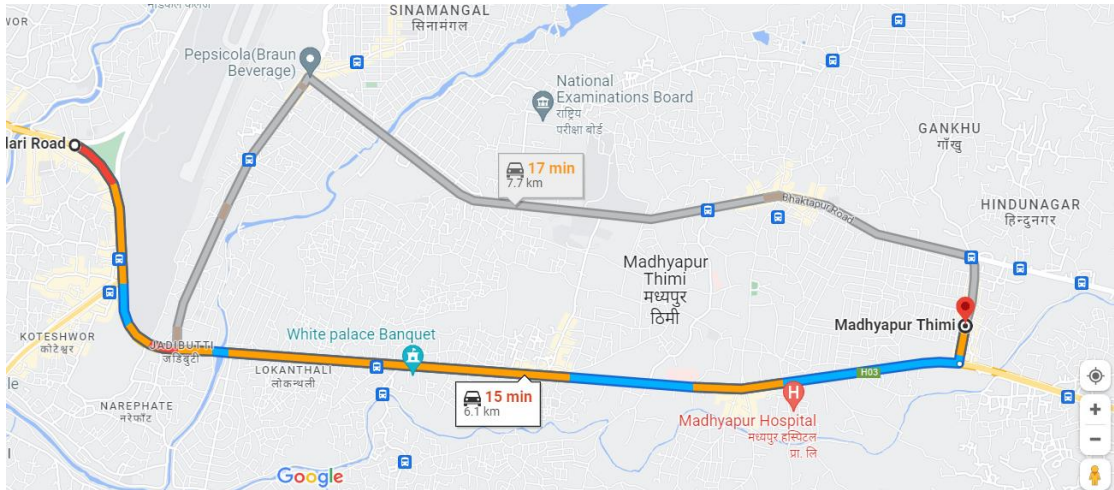


Figure 20: Route Selection for Drive Cycle

3.11.3. Speed Time Data Collection

The Data collection of Speed Vs Time can be obtained either by on-board measurement approach or by vehicle chase approach. In our study, we have employed on-board measurement approach (data collection from GPS) as it ensures collection of accurate driving data overcoming the delay caused by the driver response time and over estimation of hard acceleration and decelerations. A GPS was used to obtain the coordinate in that particular route along with a Pixhawk for logging the data while driving in that route. The device recorded the data at every second and stored it in the memory.

3.11.4. Refinement of Speed Data

The data received from GPS includes all the information since the GPS is on and represents data while the vehicle is in idle state as well. The micro trips are constructed between two adjacent stops including leading idle period. The micro trips are partitioned into different group according to average speed.

3.11.5. Cycle Assessment

The assessment criteria assure that the developed cycle truly represents the actual driving pattern on road in that particular area. The target parameter for population and candidate driving cycle is calculated and its percentage deviation is taken after multiplying each absolute deviation by weightage. The target parameter includes average speed, average running speed, average acceleration and average deceleration.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. MOTOR PERFORMANCE ANALYSIS

4.1.1. Calculation of Speed at Different Gears

The theoretical speed of the vehicle speed at different gears when coupled with the motor are given below:

Table 6: Speed of the Vehicle at Different Gears

Gears	Gear Ratio (G)	Peak Speed at 6000rpm (km/hr.)	Speed at Max Torque (2500 rpm) (km/hr.)
1 st	11.786	65.25	27.18
2 nd	6.745	114.01	47.5
3 rd	4.6505	165.37	68.90
4 th	3.55	216.63	90.26
5 th	2.982	257.90	107.45

4.1.2. Calculation of Maximum Torque at Different Gears

The torque that needs to be produced by the motor is determined for different drive cycles. The torque required for different gear ratio of the transmission is also determined which are given below:

1. HWFET Driving Cycle

Table 7: Maximum Torque in HWFET Cycle

Gear	Maximum Torque (Nm)
1	67
2	117
3	169
4	222
5	264

The torque that needs to be produced by the motor to propel the vehicle in the given drive cycle is calculated for a given period of time. The maximum torque required to drive vehicle in 1st gear is 67 Nm and that in 2nd and 3rd gear is 117 Nm and 169 Nm respectively. While operating the vehicle in 4th gear, the maximum torque required is 222 Nm which exceeds the maximum torque that the motor can produce.

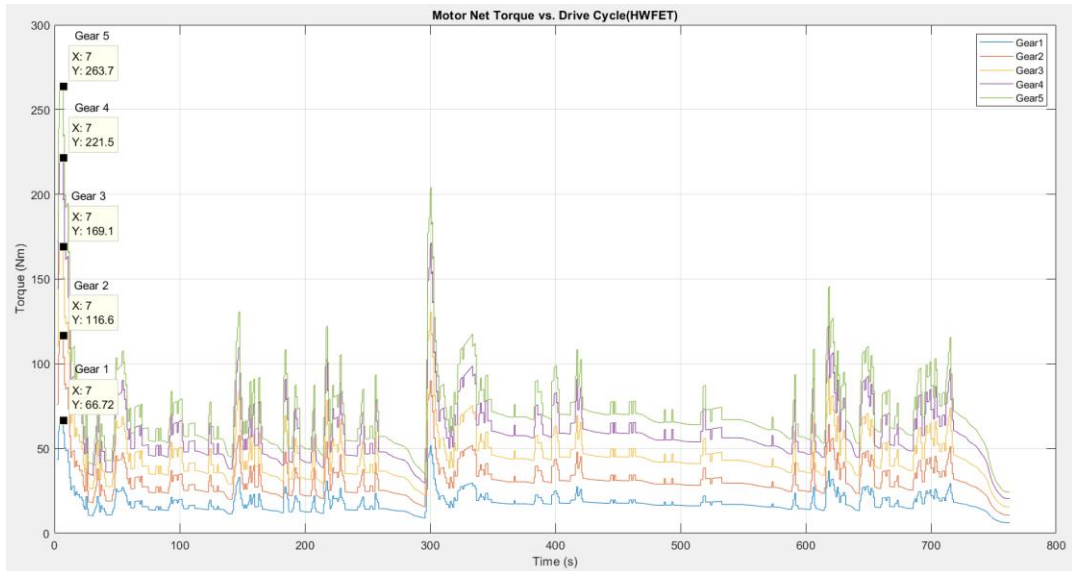


Figure 21: Torque vs. Drive Cycle for HWFET Driving Cycle

2. WLTP-Class 2 Driving Cycle

Table 8: Maximum Torque in WLTC-2 Cycle

Gear	Maximum Torque (Nm)
1	49
2	86
3	125
4	163
5	194

The required torque for the motor to produce during this drive cycle falls within its operating range. When driving in first gear, the vehicle needs a maximum torque of 49 Nm. The vehicle can be operated with a maximum torque of 194 Nm while in fifth gear.

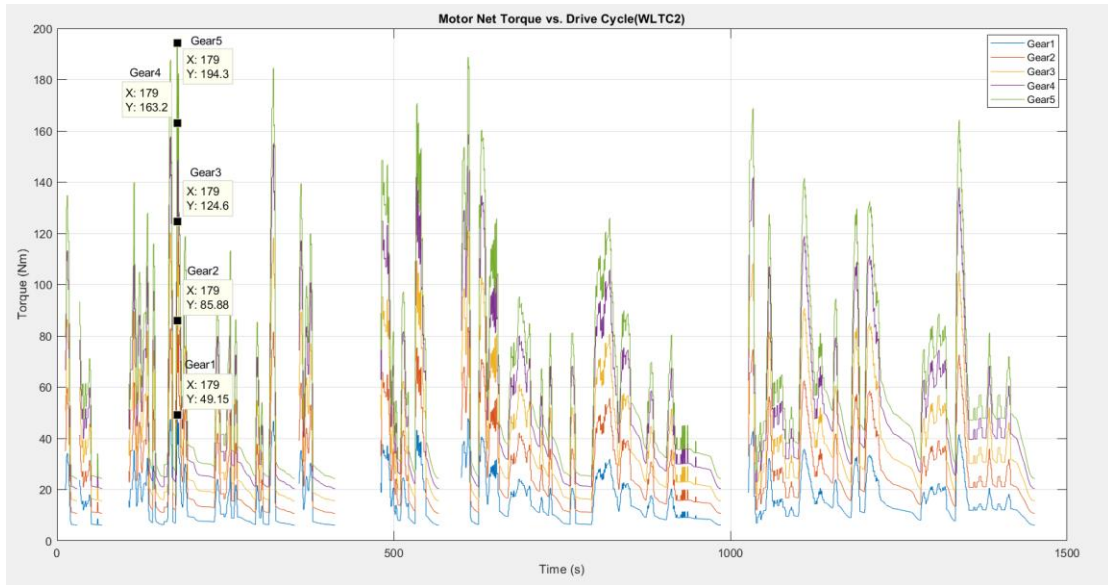


Figure 22: Torque vs. Drive Cycle for WLTC-2 Driving Cycle

3. BEV FLEET CYCLE

Table 9: Maximum Torque in Fleet-BEV Cycle

Gear	Maximum Torque (Nm)
1	95
2	165
3	240
4	314
5	374

Compared to other driving cycles, this driving cycle calls for much higher torque. First and second gears each require a maximum torque of 95 Nm and 165 Nm, respectively. Nevertheless, the motor's required maximum torque in third gear is 240 Nm, exceeding the maximum torque that our motor is capable of producing.

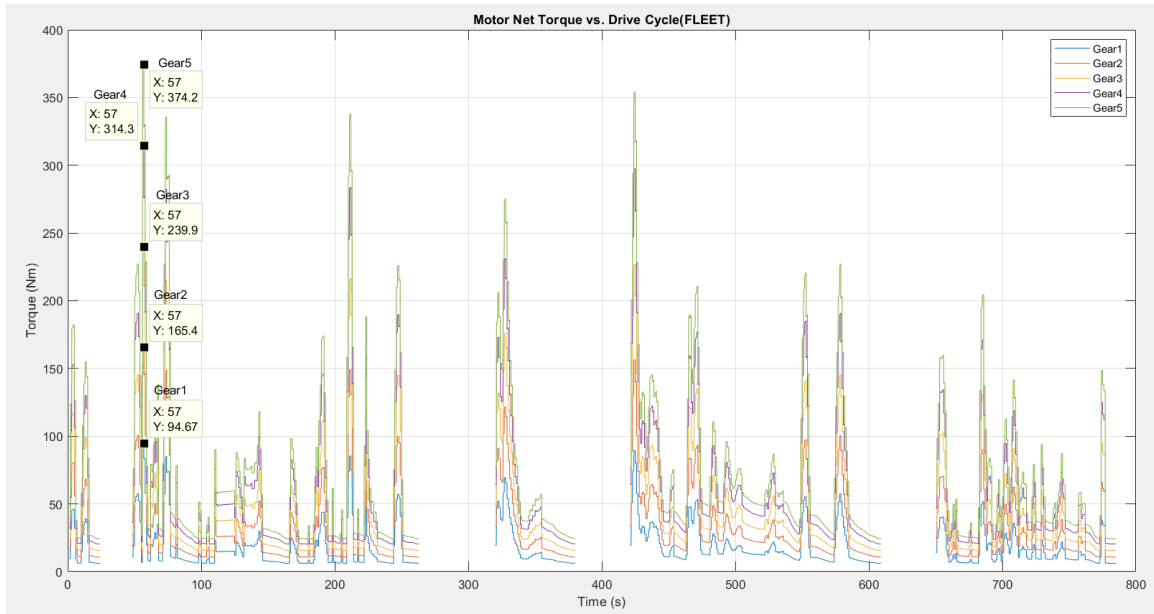


Figure 23: Torque vs. Drive Cycle for FLEET Driving Cycle

The figures above shows that the torque vs drive cycle graph is similar for each gear ratio. The torque only varies in terms of magnitude for each gear ratio. The torque requirement from the motor increases with decreasing gear ratio.

4.1.3. Selection of Appropriate Gear

From the torque Speed characteristics curve provided by the supplier, we can see that the maximum torque that the motor can provide is around 200 Nm at a maximum speed of 2500 rpm. The results from testing the vehicle model varied greatly in the three different driving cycle. In the WLTC-Class 2 model, the motor could provide enough torque to propel the vehicle even when coupled in fifth gear. The vehicle can achieve higher speed as well as the required torque easily in the drive cycle. However, in the HWFET model, it can be seen that if the vehicle is to be operated in this drive cycle, the maximum gear that can be selected is the third gear. The BEV Fleet Cycle is a high-performance cycle and the torque requirement in this cycle is higher as compared to these other two cycle. In this model, the motor can provide the required torque only up to the second gear.

The results obtained from these different drive cycle gives an insight that the suitable gear for coupling is the second gear. The maximum theoretical speed that the vehicle can achieve in second gear is around 114 km/h at 6000 rpm. Also, when the motor is operating at maximum torque at the speed of 2500 rpm, the vehicle can achieve a speed

of 47 km/h. Even though the actual speed achievable by the vehicle will be below the theoretical speed, it will still be satisfactory enough for almost all driving conditions. In order to ensure that the motor will provide the required power and torque at different running conditions, it will be better to couple the motor with the gearbox while keeping the gears fixed in second gear.

4.2. BATTERY PARAMETERIZATION

4.2.1. Mileage Calculation

The total power required for vehicle to operate in each drive cycle is calculated by calculating the area of the power vs. time graph. The total power is obtained by integrating the area under the curve.

1. HWFET Driving Cycle

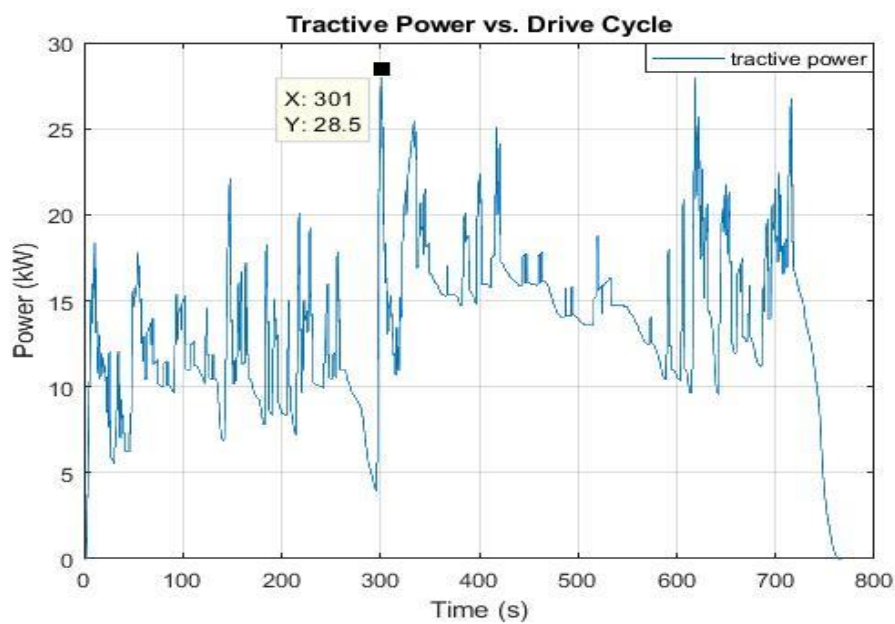


Figure 24: Power vs. HWFET Drive Cycle for Second Gear

The figure above indicates that the peak power consumption during the cycle is 28.5 kW which falls within the range of the motor. From the curve, the total power required to propel the vehicle in given drive cycle is 2867 Whr.

Total power = 2867 Whr

Distance Covered= 16.45 Km

$$\text{Mileage} = \frac{\text{Total Energy}}{\text{Distance Covered}}$$

$$= \frac{2867}{16.45}$$

$$= 174.3 \text{ Whr/km} = \mathbf{0.1743 \text{ kWhr/ km}}$$

2. WLTC-Class 2 Driving Cycle

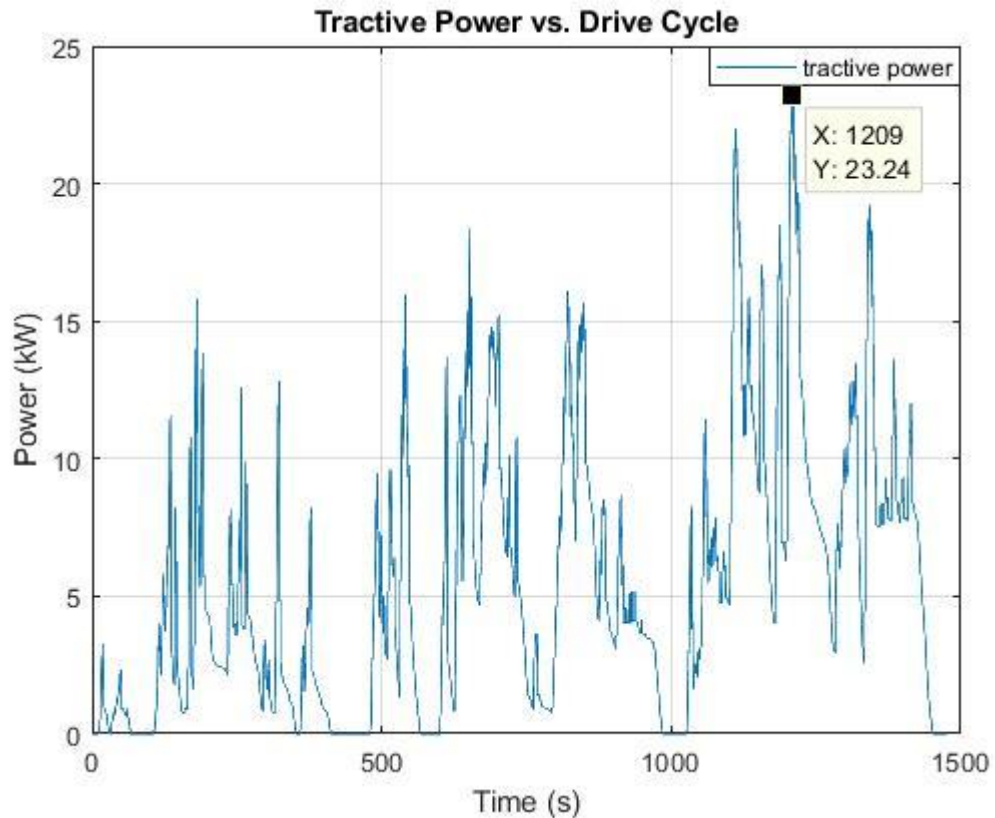


Figure 25: Power vs. WLTC-2 Drive Cycle for Second Gear

The aforementioned graph shows that the cycle's peak power consumption is 23.24 kW, which is within the motor's operating range. According to the curve, a vehicle needs 2214 Whr of total power to move throughout the particular drive cycle.

Total power = 2214 Whr

Distance Covered= 14.664 Km

$$\text{Mileage} = \frac{\text{Total Energy}}{\text{Distance Covered}}$$

$$= \frac{2214}{14.664}$$

$$= 151.0 \text{ Whr/km} = 0.151 \text{ kWhr/ km}$$

3. BEV FLEET Driving Cycle

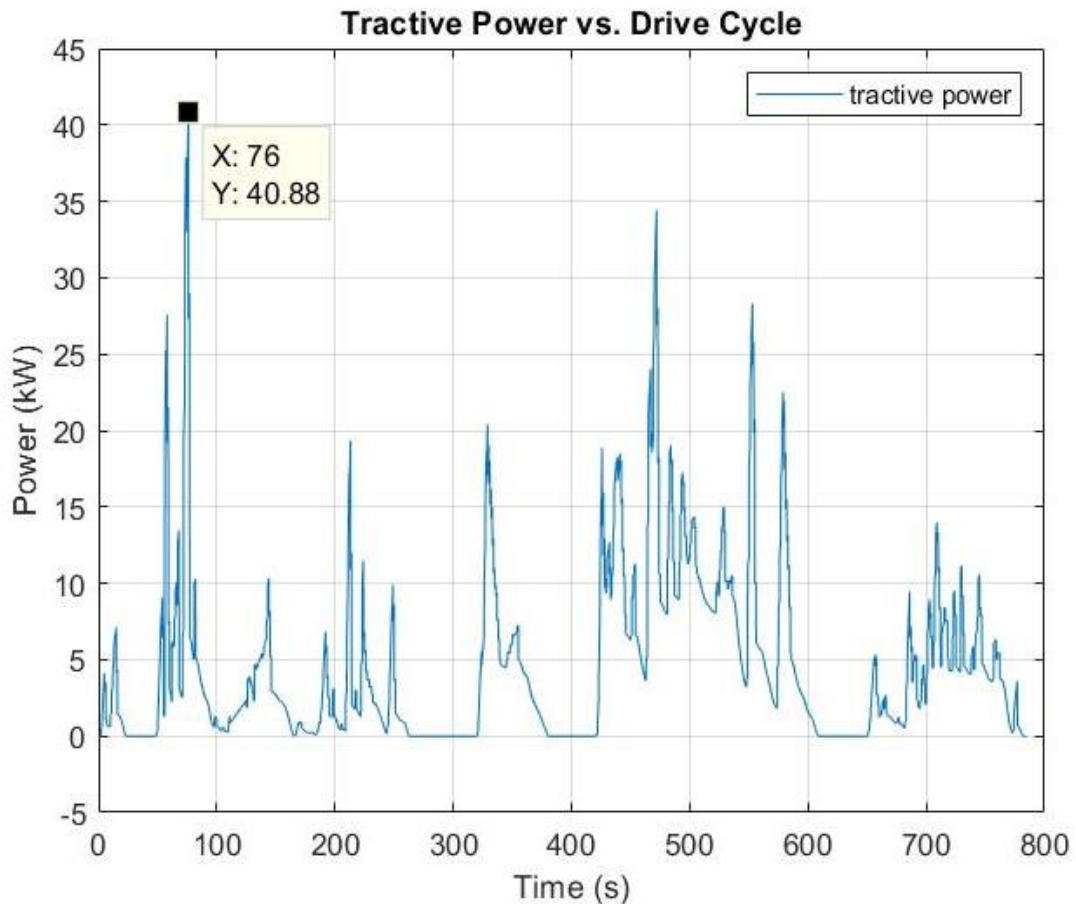


Figure 26: Power vs. FLEET Drive Cycle for Second Gear

Compared to other cycles, this cycle has a high-power requirement. The maximum power output spikes up to 40.88 kW. The maximum power required in this cycle is slightly above the power rating of the motor. The mileage is reduced because of the high-power requirement of the motor even if the total energy consumption is 991.6 Whr, which is lower than other cycles.

Total power = 991.6 Whr

Distance Covered= 5.828 Km

$$\text{Mileage} = \frac{\text{Total Energy}}{\text{Distance Covered}}$$

$$= \frac{991.6}{5.828}$$

$$= 170.1 \text{ Whr/km} = \mathbf{0.170 \text{ kWhr/ km}}$$

Table 10: Energy Consumption in Three Drive Cycles

Drive Cycle	Total Energy Consumption (Whr)	Distance Covered (km)	Mileage (kWhr/km)
HWFET	2867	16.45	0.1743
WLTC-Class 2	2214	14.664	0.151
BEV FLEET	991.6	5.828	0.170

The result shows that the mileage seems to be the lowest in the HWFET and BEV FLEET drive cycle. The vehicle has better mileage in the WLTC-Class 2 cycle. The WLTC cycle is a low-speed cycle which represent sub-urban, urban and main road conditions. The HWFET cycle is a high-speed cycle which is used to determine the vehicle performance on a highway. The BEV FLEET is a drive cycle developed for EVs. The power requirement in this drive cycle is significantly high which has resulted in the low mileage in the cycle.

The mileage plays an important role in the sizing of the battery. A vehicle with good mileage can be powered by a battery of low capacity while meeting the required driving range. It is necessary to take into account the vehicle's intended use and the mileage it will be driven. That's why it will be better to choose the lowest mileage possible so that the selected battery can provide the required driving range. The mileage of **0.1743 kWhr/km** is a better estimate to be taken to select a battery size for the selected driving range.

4.2.2. Battery Capacity Calculation

For **120 Km** range, the required battery Capacity is given by:

$$= 120 \times 0.1743$$

$$= \mathbf{20.916 \text{ KWhr.}}$$

The controller requires a voltage of 96 V which needs to be supplied by the battery.

During the rated power operation of the motor i.e. 40 kW, the peak current requirement is given by:

$$\text{Peak Current} = \frac{\text{Peak Power}}{\text{Required Voltage}} = \frac{40000}{96} = \mathbf{417\text{ A}}$$

For the driving range of 120km, the battery capacity required is 20.916 kWhr. It is to be noted that the calculation of the battery capacity is based on the energy required for driving the vehicle in the given drive cycle. The energy required for operating different accessories load, energy loss due to battery's internal resistances and the losses in motor and driveline has not been taken into account. Thus, the acquirable driving range could be less than the one taken with the selected battery size. The voltage required for the controller is 96 V which has to be supplied by battery pack. So, the battery pack also needs to have output voltage of 96 V. The motor has rated power rating of 40 kW and hence the peak current required is 417 A.

Table 11: Li-ion Battery Specifications

Specifications

Item	LiFePO4 cell	Li-Polymer Cell
Maximum charging voltage	3.65V	3.65V
Nominal voltage	3.2V	3.25V
Rated capacity	100Ah	100Ah
Standard Charging Current	0.5C	0.5C
Max. Continuous Charging Current	1C	
Max. Continuous Discharging Current	3C (30S, 100%SOC 25°C±2°C)	300A (short pulse)
Discharging Cut-off Voltage	2.5V	2.5 V
Operating Temperature Range	Charging:0~45°C, Discharging: -20~60°C	Charging:0~55°C, Discharging: -20~55°C
Relative Humidity	60±20%RH	

Recommended Storage Temperature	15~35°C	
Cell Weight	2.3kg	1.7kg
Impedance	≤0.6mΩ	≤0.35mΩ
Cell dimension (inclusive wrap foil)	40.2(T)*130.2(W)*220(L)mm	52(T)*95(W)*148(L)mm
Cycle life	3500 cycles @80%DOD	≥1000 cycles @80%DOD

a. LiFePO₄ prismatic battery cell (3.2V 100Ah)

Each cell has a nominal voltage of 3.2 V and a rated capacity of 100 Ahr with a maximum continuous discharging current of 3C. The battery pack needs to supply a voltage of 96V to the motor controller and variable current to meet the power demand with a peak reaching around 417 A.

The arrangement of 30 prismatic LiFePO₄ in series yields 30*3.2=96V with the maximum discharge current being 300A. Two such arrangements in parallel give 600A of peak current.

Peak Current: 300A

30Series → 96 V

2Parallel → 600 A (peak)

Hence, a total of 60 cells are required

Weight of each prismatic LiFePO₄ = 2.3 kg.

Therefore, the battery pack's total weight, including the casing and the connecting plates, is assumed to be around 150kg.

b. Li-ion polymer prismatic battery cell (3.25V,100Ahr)

Each Li- ion polymer prismatic cell has nominal voltage of 3.25V and the capacity of 100Ah with the short pulse maximum discharging current of 300A.

The arrangement of 30 Li- ion polymer cells yield $30 * 3.25 = 97.5V$ with maximum discharge current of 300A. Two such arrangement in parallel gives 600A of peak current.

Peak Current: 300A

30Series \longrightarrow 97.5 V

2Parallel \longrightarrow 600 A (peak)

Hence, a total of 60 cells are required

The weight of each Li- ion polymer cells = 1.7kg

Therefore, the total weight of battery pack considering the connecting plates and casing is around 120kg.

c. Battery Pack

Specification

Rated Capacity: 150 Ahr (3.2V 50 Ahr 3C cell 3P)

Rated Voltage: 96 V

Energy: 14.4 KWhr

Dimension (L * W * H): 1030 * 640 * 130 mm

Weight: 140 Kg

Maximum Continuous Discharging Current: 200 A

Peak Discharging Current: 300A for 30sec



Figure 27: CTS96C150Ah Battery Pack

Table 12: Battery Pack Specification

MODEL	CTS96120
ELECTRICAL SPECIFICATIONS	
Cell Type - Chemistry	Prismatic- LiFePO4
Rated Capacity	150Ah (3.2V 50Ah 3C cells 3P)
Rated Voltage	96V
Energy	14.4kWh
Resistance	30m Ω
Self Discharge	<2% per month
PDU	BMS, 200A relays, fuses, COM socket
MECHANICAL SPECIFICATIONS	
Dimensions (L x W x H)	L1030*W640*H130mm
DISCHARGE/CHARGE SPECIFICATIONS	
Discharge Cut-off Voltage	84V
Max Continuous Discharging Current	200A
Peak Discharge Current	300A for 30 seconds
Recommended Discharge Current	150A
CHARGE SPECIFICATIONS	
Charging Limited Voltage	109.5V
Max Charging Current	150A
	50A
TEMPERATURE SPECIFICATIONS	
Charge Temperature Range	0~50°C
Discharge Temperature Range	-20~60°C
Recommended Operating Temperature	15~35°C
Storage Temperature & Humidity Range	-10~35°C, 45~75%RH
(Less than 3 months)	
Recommended Storage Temperature & Humidity Range	15~35°C, 45~75%RH

The battery pack can also be a good option but its capacity is only 14.4 kWh. So, the range it can provide will not meet our criteria for 120 km.

The lithium iron phosphate (LiFePO₄) cells are safer because of their superior thermal and chemical stability. These cells are also tolerant to extremes of temperature and their performance doesn't drop at both high and low ends of their temperature range.

4.3. VARIATION OF PERFORMANCE WITH VEHICLE PARAMETERS

4.3.1. Variation of Maximum Torque with Vehicle Mass and Rolling Resistance

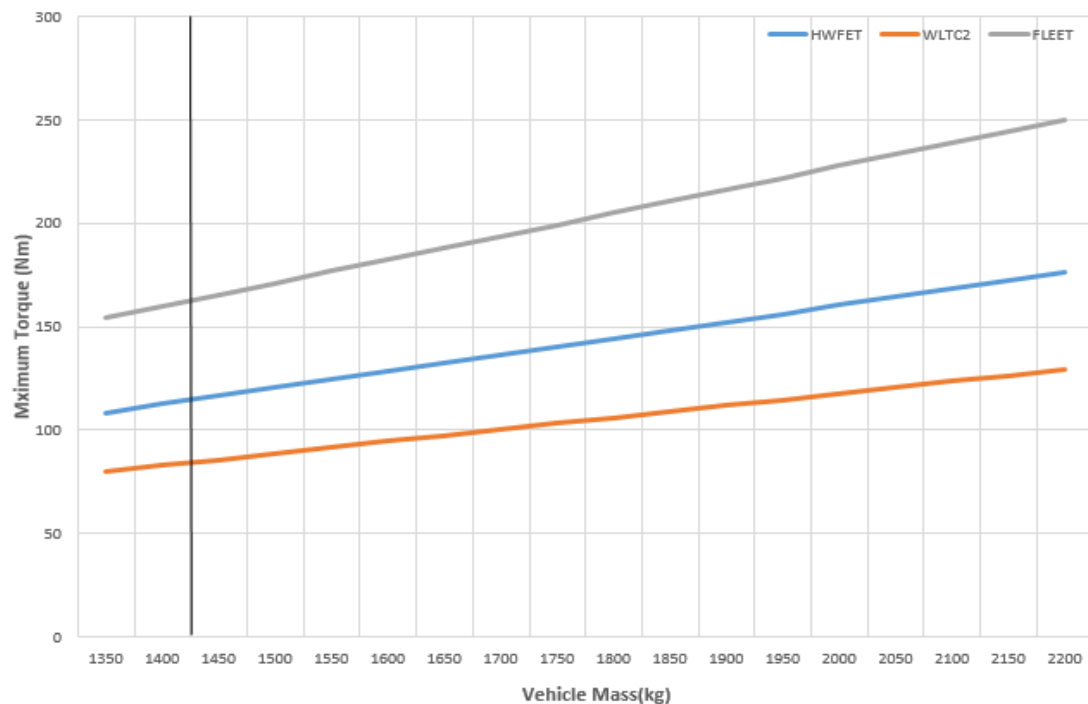


Figure 28: Variation of Maximum Torque with Vehicle Mass

In determining the variation of maximum torque coupled with 2nd gear of the Gear Box, we have obtained the values of maximum torque for the mass ranging from Vehicle's Curb Weight (1360 kg) to Vehicle's Gross weight (2127 kg) in three different drive cycles. From the graph below, we can visualize that the maximum torque in all three drive cycles varies linearly with vehicle mass. The maximum torque of 165.4 Nm is obtained in FLEET cycle which is the maximum among the three drive cycles at vehicle mass of 1450kg. The torque requirement in the two drive cycles doesn't exceed the maximum torque that the motor can produce even the vehicle is loaded to its maximum

capacity. However, in the FLEET cycle the torque limit exceeds when the vehicle mass increases above 1750 kg.

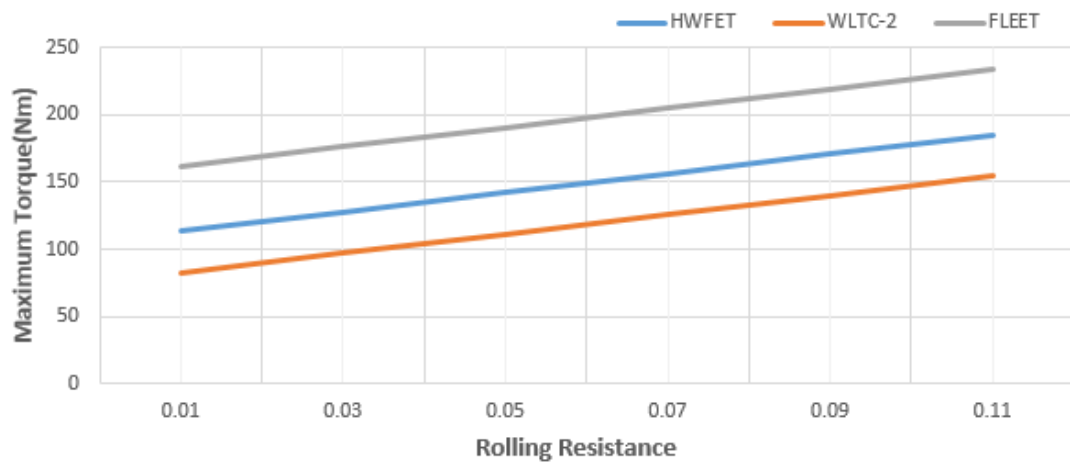


Figure 29: Variation of Maximum Torque with Rolling Resistance

Similarly, the variation of maximum torque with rolling resistance is also observed from 0.01 to 0.11 rolling coefficient. The graph signifies linear dependency of maximum torque with rolling resistance in all three drive cycles and maximum torque is again obtained in FLEET cycle with the value of 165.4 Nm at 0.015 rolling coefficient.

4.3.2. Variation of Mileage with Vehicle Mass and Rolling Resistance

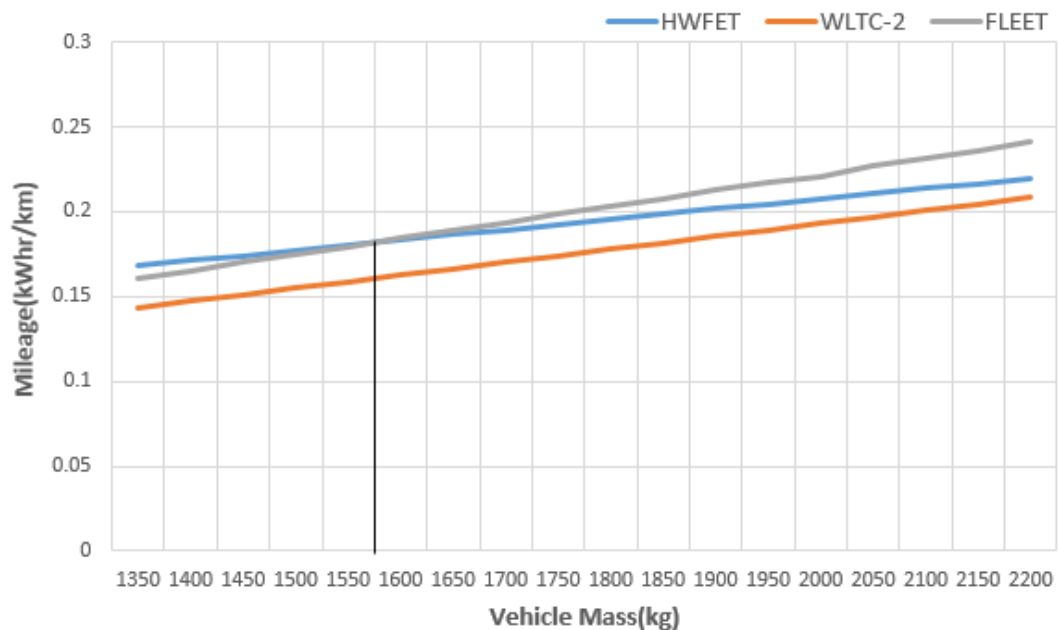


Figure 30: Variation of Mileage with Vehicle Mass

Mileage is an important factor to consider when evaluating the performance of an electric vehicle (EV). It indicates the practicality and usefulness of the vehicle. While varying the vehicle mass from curb weight to gross weight, the mileage increases linearly in all the three drive cycle. The graph below shows that mileage line of HWFET and FLEET Cycle intersects at 0.1843 kWhr/km when the vehicle mass is around 1600 kg.

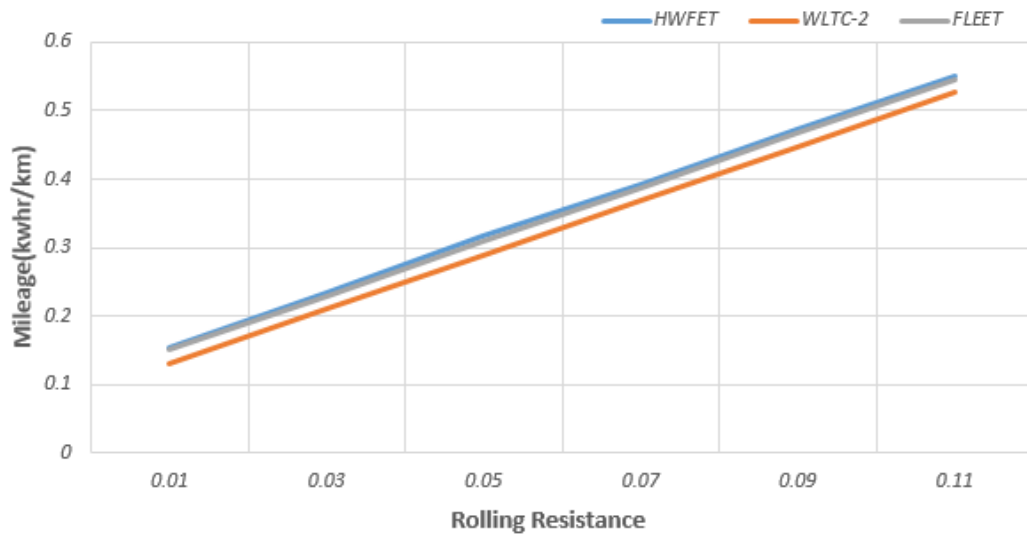


Figure 31: Variation of Mileage with Rolling Resistance

The coefficient of rolling resistance represents the amount of force needed to move the axle of a wheel laterally in the direction of motion. This force rises with the increase in coefficient of rolling resistance. The mileage of a vehicle increases as the coefficient of rolling resistance increases because more energy is needed to move the wheel. The mileage is proportional to the rolling resistance. The results indicate that the mileage value is nearly identical for drive cycles HWFET and FLEET at all rolling resistance coefficient values. The WLTC-2 drive cycle results in slightly increased mileage. Irrespective of the drive cycles used, the variation of the mileage with the rolling resistance coefficient is same.

4.3.3. Variation of Maximum Power with Vehicle Mass and Rolling Resistance

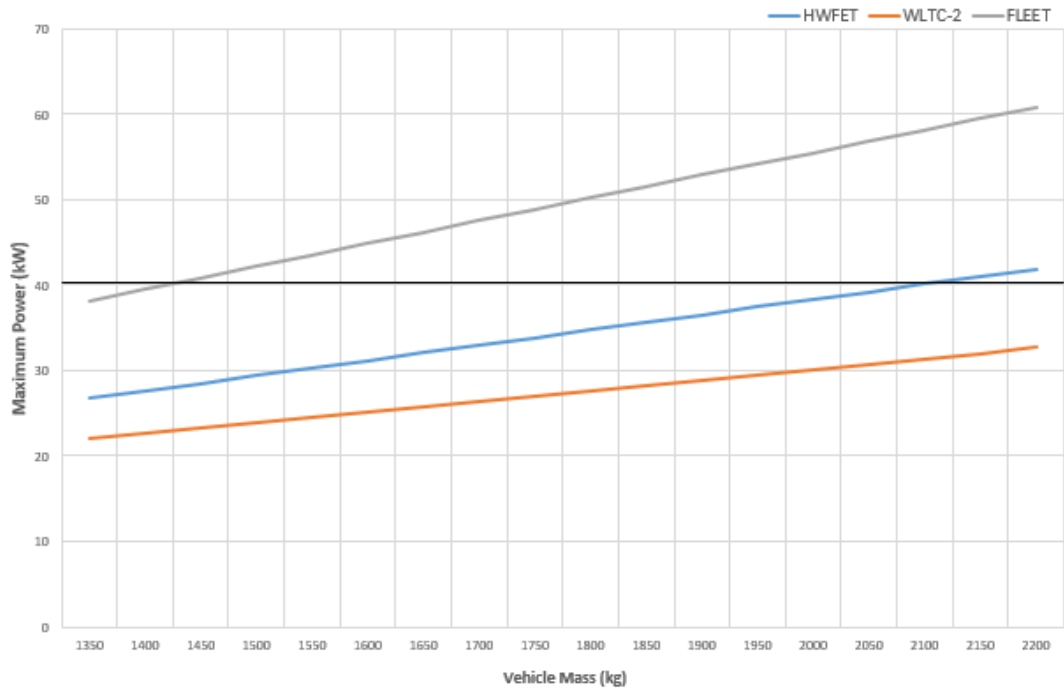


Figure 32: Variation of Maximum Power with Vehicle Mass

The maximum power of the motor can vary widely depending on the vehicle mass, rolling resistance, etc. Electric motors can produce much more power than internal combustion engines of comparable size. From the graph obtained, we can observe that maximum power exceeds the rated power of provided motor (40 kW) only in FLEET drive cycle for the vehicle mass above 1600 kg and whereas the maximum power exceeds the rated power of the motor when the weight of the vehicle is above 2150 kg. The power requirement doesn't exceed in the WLTC-2 cycle when varying the weight from curb weight to the gross weight of the vehicle.

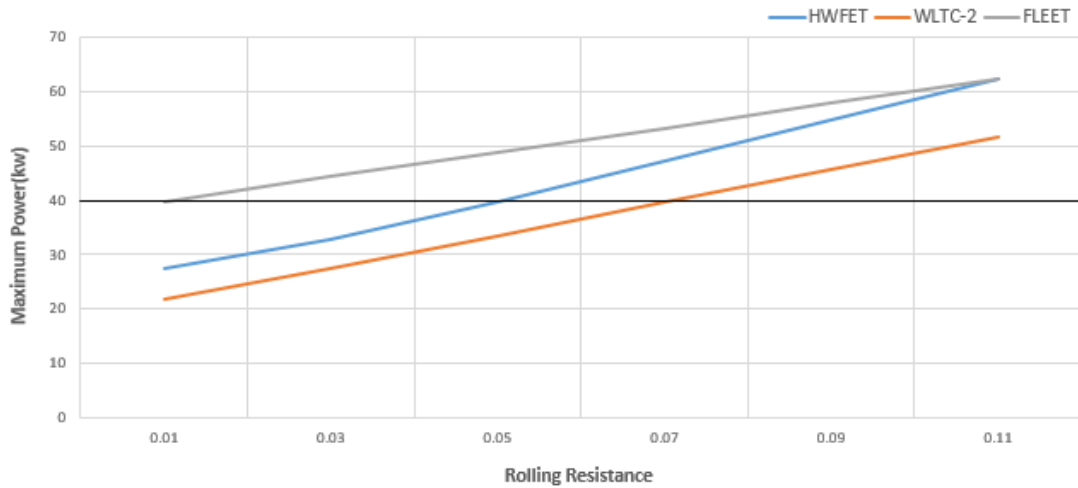


Figure 33: Variation of Maximum Power with Rolling Resistance

In case of varying rolling resistance from 0.01 (Identical to Good paved roads) to 0.11 (Identical to sand), the maximum power exceeds the rated power of motor in all three drive cycles.

4.3.4. Variation of Motor Performance with Velocity of Vehicle

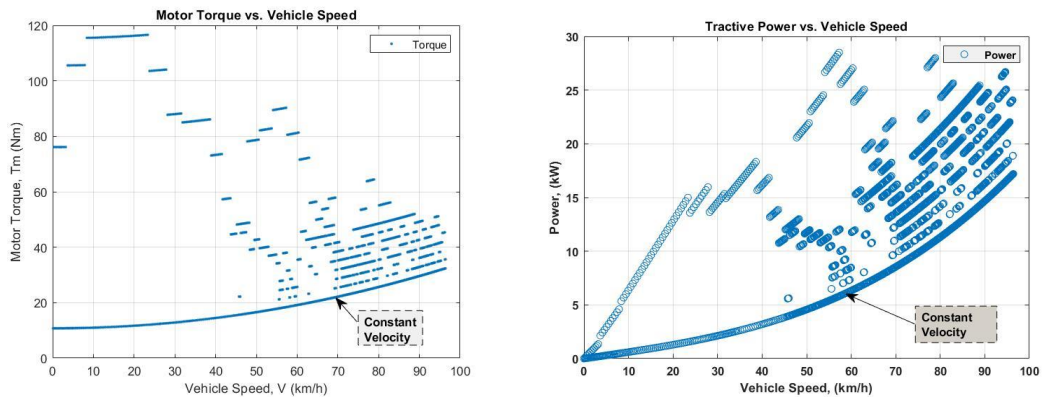


Figure 34: Variation of Torque and Power with Vehicle Speed

The power vs velocity graph shows that there is multiple value of power for a particular value of velocity too. This is possible because at that particular velocity, the vehicle could be accelerating or retarding as per the drive cycle and hence has multiple value of torque too. The plot of power vs velocity considering constant velocity shows the variation to be cubic. Similarly, the torque vs velocity considering constant velocity shows quadratic variation.

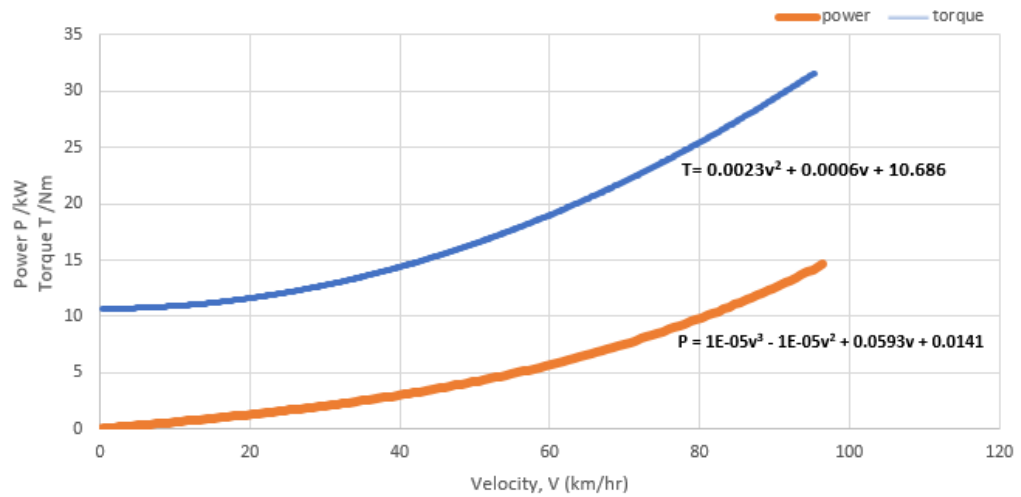


Figure 35: Constant Velocity Curve for Motor Torque and Power

The figures above depict the variation of torque and power while the velocity in the cycle is constant. The given equation provides the best fit to the curve for constant velocity in the HWFET cycle.

4.4. DISCHARGE OF BATTERY AT DIFFERENT REGENERATION RATE

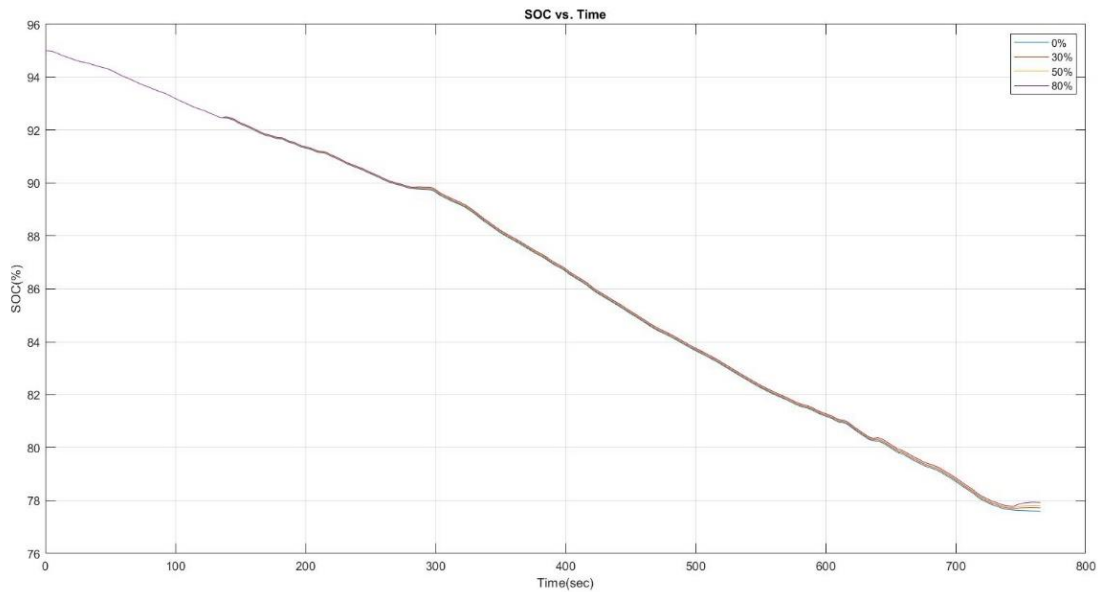


Figure 36: SoC Variation with Regeneration Level for HWFET Cycle

The state of charge is a percentage indication of the quantity of battery energy available at any one time. As indicated in the figure above, the SoC in a HWFET drive cycle with 80% regeneration is 77.93%, but without regeneration, the SoC drops to 77.6% at the conclusion of the cycle. Because the HWFET driving cycle does not contain many braking and decelerations, there is no substantial regeneration. Similarly, the SoC of the battery is 77.7% and 77.8% at 30% and 50% regeneration, respectively. There is the visible regeneration only at the last phase when vehicle is decelerating to zero velocity for HWFET drive cycle.

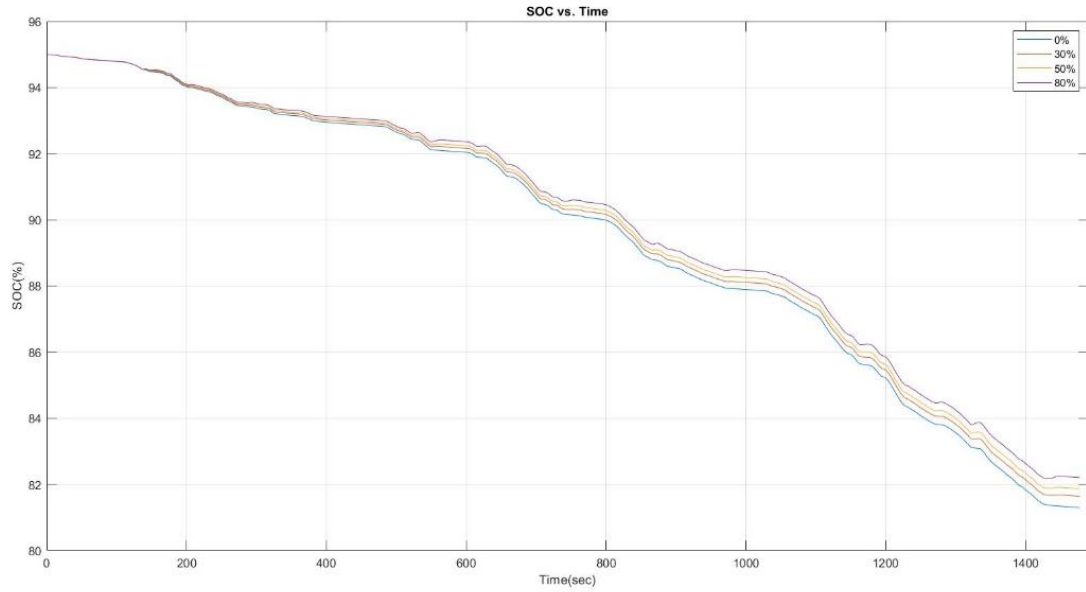


Figure 37: SoC Variation with Regeneration Level for WLTC-2 Cycle

During the cycle, the SoC drops from 95% to 82.2% at 80% regeneration. Without considering regeneration, the SoC at the end of the cycle is seen 81.2%. This indicates that the regenerative braking system is able to recover some of the energy that would otherwise be lost during braking thus reducing the rate of discharge of the battery pack and hence the drop in the SoC. The 80% regeneration can save 1% of battery in 14.664 km. The SoC with 30% and 50% regeneration is 81.6% and 81.8% respectively. This indicates that the regenerative braking system is less effective at lower regeneration level.

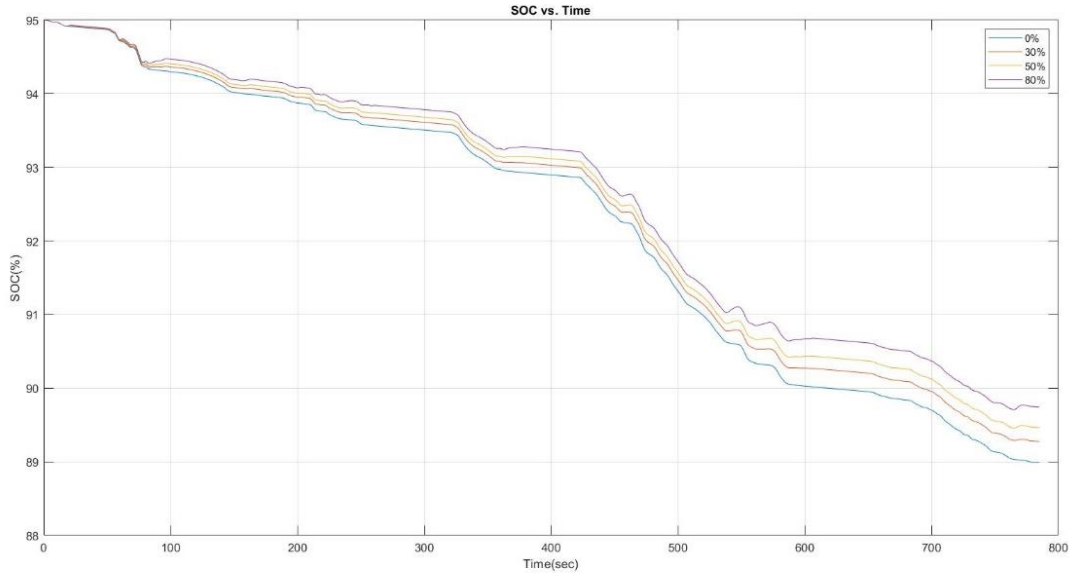


Figure 38: SoC Variation with Regeneration Level for Fleet-BEV Cycle

The results show that the use of regenerative braking can significantly increase the SoC of the battery pack. At 80% regeneration, the SoC increases to 89.45%, compared to 88.98% without regeneration. Despite the short route of the drive cycle (5.858 km), the SoC drops significantly from 95%. This is because the drive cycle is designed to be a high-power demanding cycle, which places a significant load on the battery pack but also provides opportunities for regenerative braking, i.e., the recovery of energy that would otherwise be lost during braking. This highlights the importance of testing electric vehicles under realistic conditions, as it allows manufacturers to identify and address any potential issues with battery performance and range.

4.5. VEHICLE RANGE CALCULATION

For the HWFET drive cycle, the SoC depletes from 95% to 77.8% over the distance of 16.45km.

$$\text{So, vehicle range} = \frac{100-5}{95-77.8} \times 16.45$$

$$=95.6\text{km}$$

For the WLTC-2 drive cycle, the SoC depletes from 95% to 81.86% over distance of 14.664km.

$$\text{So, vehicle range} = \frac{100-5}{95-81.86} \times 14.664$$

$$=106.02\text{km}$$

For the BEV-FLEET drive cycle, the SoC depletes from 95% to 89.46% over the distance of 5.828km.

$$\text{So, } \textit{vehicle range} = \frac{100-5}{95-89.46} \times 5.828$$

$$=99.9\text{km}$$

But the theoretical range of vehicle was considered to be 120km. The decrease in the vehicle range is due to the losses in the motor and the driveline. Also, the total battery capacity is not used as the complete drainage may shorten battery life and decrease its overall capacity.

4.6. MAXIMUM CURRENT VARIATION

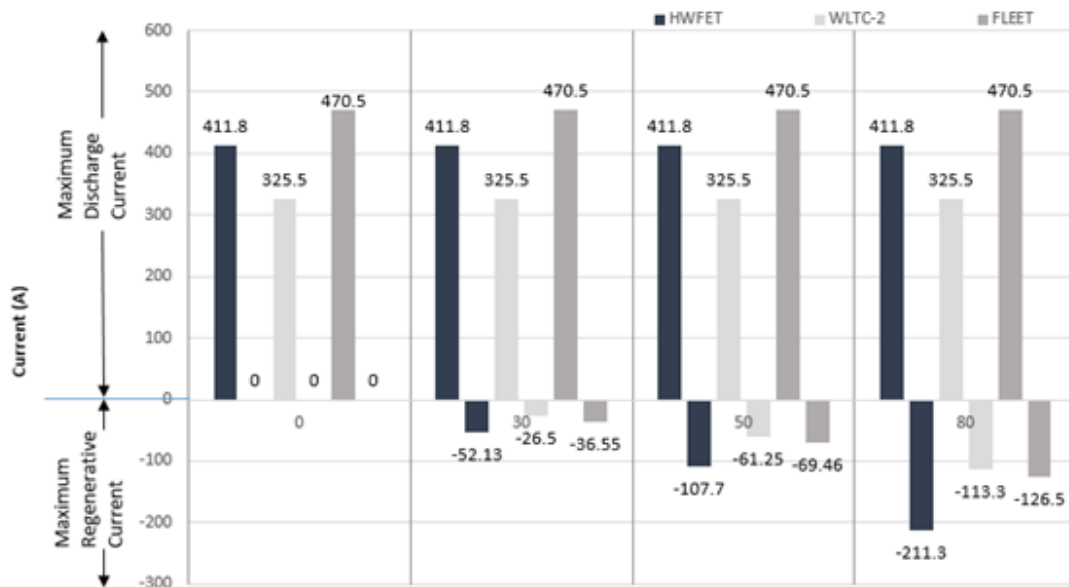


Figure 39: Maximum Current Variation with Regeneration Level

The maximum current demands for the BEV-FLEET, HWFET, and WLTC-2 drive cycles indicate the peak power requirements of the electric vehicle during those cycles. The maximum current demand during the BEV-FLEET drive cycle was the highest at 470.5 A, which exceeds the theoretical maximum current limit of the battery pack. This is because the battery pack experiences voltage drop due to internal resistance and the motor losses that require additional power from the battery. The maximum regenerative current during the HWFET driving cycle was 211.3A at 80% regeneration, which indicates the potential for significant energy recovery during braking. At lower

regeneration levels such as 30% regeneration, the maximum regenerative current was only 26.5A, which shows that the energy recovery is lower at lower regeneration levels. At 50% regeneration, the maximum regenerative current is nearly double that at 30% regeneration, indicating that increasing the regeneration level can significantly improve energy recovery during braking.

4.7. MOTOR LOSSES

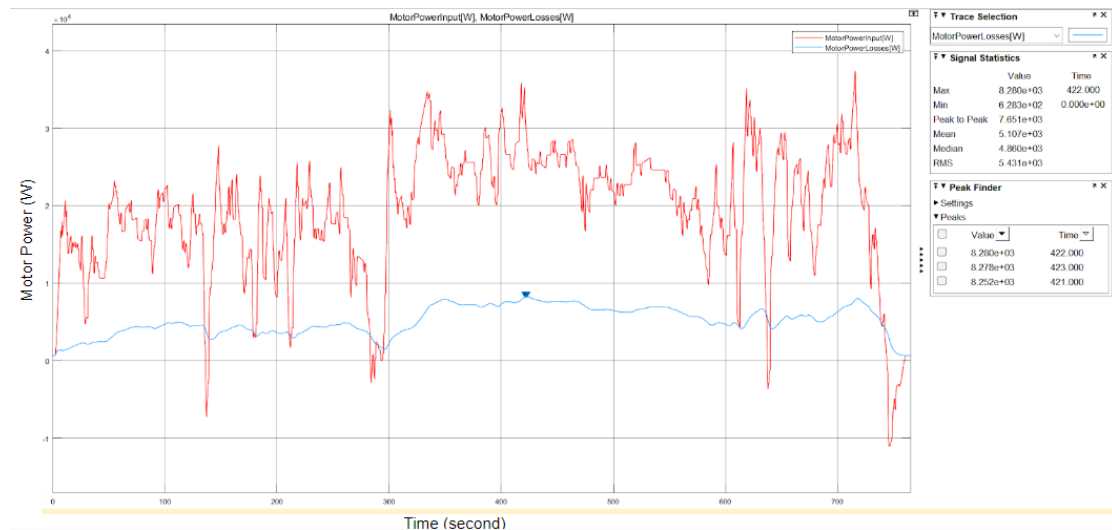


Figure 40: Motor Power Loss in HWFET Cycle

The figure above represents the motor power and motor power loss during the HWFET (Highway Fuel Economy Test) driving cycle. The motor power can reach a maximum of 37kW. In the HWFET driving cycle, the highest regenerative power that the motor can output is 11kW. This value indicates the maximum energy that the motor can regenerate during the deceleration.

The motor's losses rise as the speed of the motor increases. This trend is expected, as the electric motor has to overcome more windage, friction, and core losses as the speed increases. The motor loss can reach a maximum of 8.2kW and a minimum of 0.62kW. This means that the electric motor can lose up to 8.2 kilowatts of power due to the inefficiencies in the motor, and this loss is the highest when the motor is operating at its maximum speed. Conversely, when the motor is operating at its lowest speed, the losses are minimal, and the motor only loses 0.62 kilowatts of power.

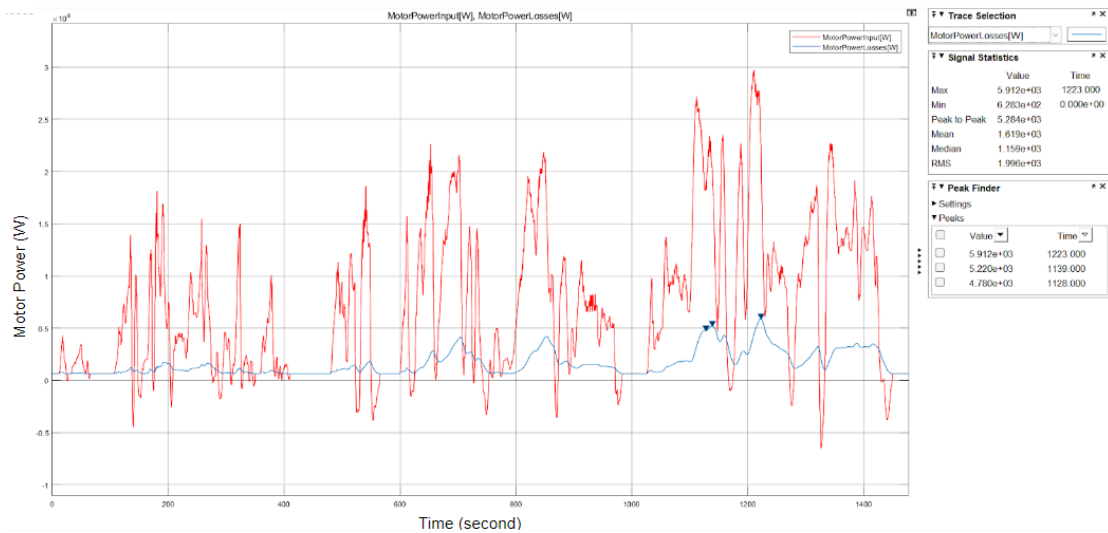


Figure 41: Motor Power Loss in WLTC-2 Cycle

The picture depicts the plot for motor power and motor power loss. While running in the WLTC-2 driving cycle, the motor must generate a maximum power of 29.5kW. Similarly, the highest regeneration power available is 6.5kW. The maximum loss of the motor is 5.9 kW. The motor is constantly affected by the minimum losses of 0.62kW.

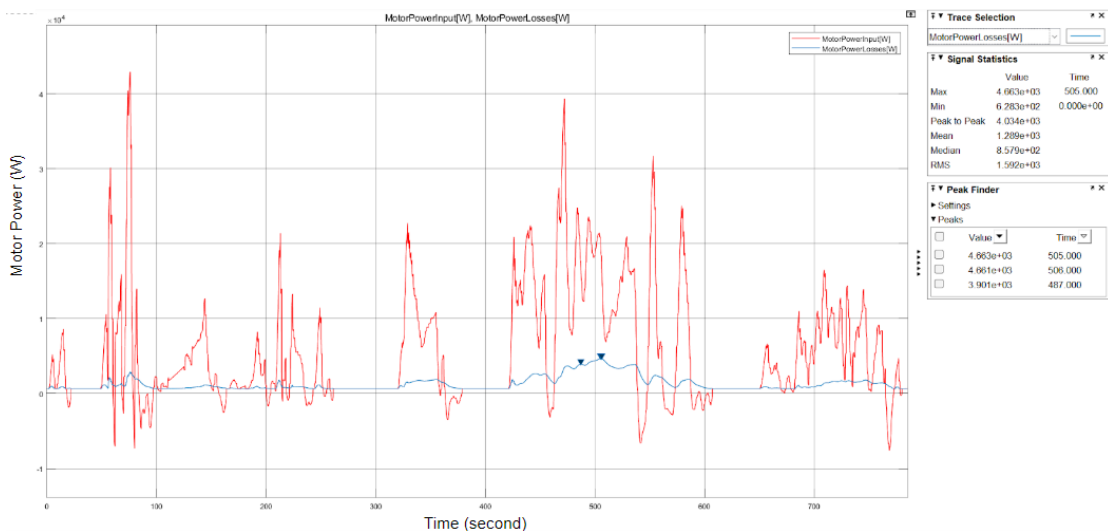


Figure 42: Motor Power Loss in Fleet-BEV Cycle

As illustrated in the figure, the motor must provide a maximum power of 43kW while running in the BEV-FLEET driving cycle. The highest regeneration power available is 8kW. Motor losses are greatest when the motor speed and torque requirements are high. The largest motor power loss is 4.06kW, while the lowest is 0.62kW.

4.8.ENERGY SAVED DUE TO REGENERATION

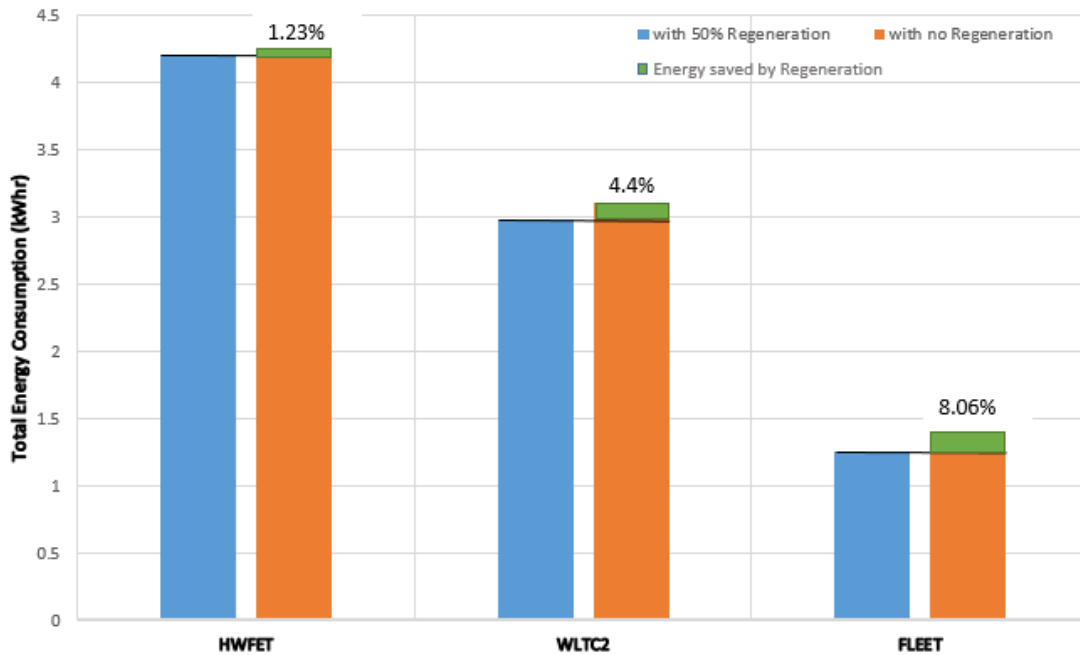


Figure 43: Energy Consumption in a Cycle

For the HWFET drive cycle, the total energy consumption with 50% regeneration is 4.205 kWhr, and without regeneration, it would have been 4.257 kWhr. The total regenerated energy is 0.052 kWhr, which is only 1.23% of total energy consumption.

For the WLTC-2 drive cycle, the total energy consumption at 50% regeneration is 2.981 kWhr, and without regeneration, it would have been 3.112 kWhr. The regenerative braking saves a total of 0.131 kWhr energy, which is 4.4% of total energy consumption in that cycle.

For the BEV-FLEET drive cycle, the total energy consumption with 50% regenerative braking is 1.254 kWhr, and without regeneration, it would have been 1.364 kWhr. The total energy saved by regenerative braking is 0.11 kWhr, which is 8.06% of total energy consumption in that cycle. The energy regenerated by regenerative braking in the BEV-FLEET drive cycle is higher compared to other two drive cycles because of frequent deceleration of vehicles at the end of each micro-trip.

Overall, regenerative braking can significantly reduce the energy consumption in electric vehicles, and the amount of regenerated energy depends on the drive cycle's

characteristics. By increasing the regenerative braking percentage, the total regenerated energy can be further increased.

4.9. DRIVE CYCLE DEVELOPMENT AND PERFORMANCE ANALYSIS

4.9.1. Developed Drive Cycle

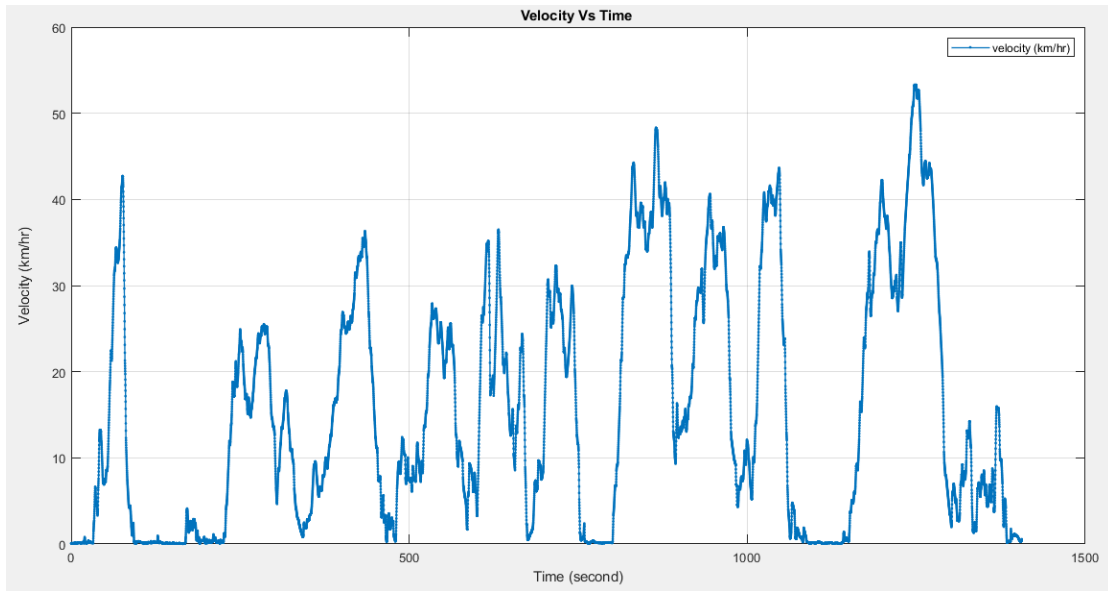


Figure 44: Velocity Profile in the Developed Drive Cycle

The graphic above depicts the velocity profile when the vehicle was driven at the time the data was logged. Because the data was collected at a period of high traffic, there is a sudden drop and rise in velocity for such a small distance.

Table 13: Drive Cycle Data

Parameters	Value
Vehicle Run Time	23 minutes 26 seconds
Distance Covered	6.09 km
Average Speed	15.5 km/hr
Maximum Speed	53.6 km/hr
Maximum Acceleration	1.766 m/s ²

4.9.2. Motor Performance

The motor performance includes the torque that the motor needs to supply while operating in the drive cycle and the power drawn to supply that torque. The power is supplied by the battery pack by means of current variation to meet the power demand.

The variation of torque and motor power in the developed drive cycle is as shown in the figure below.

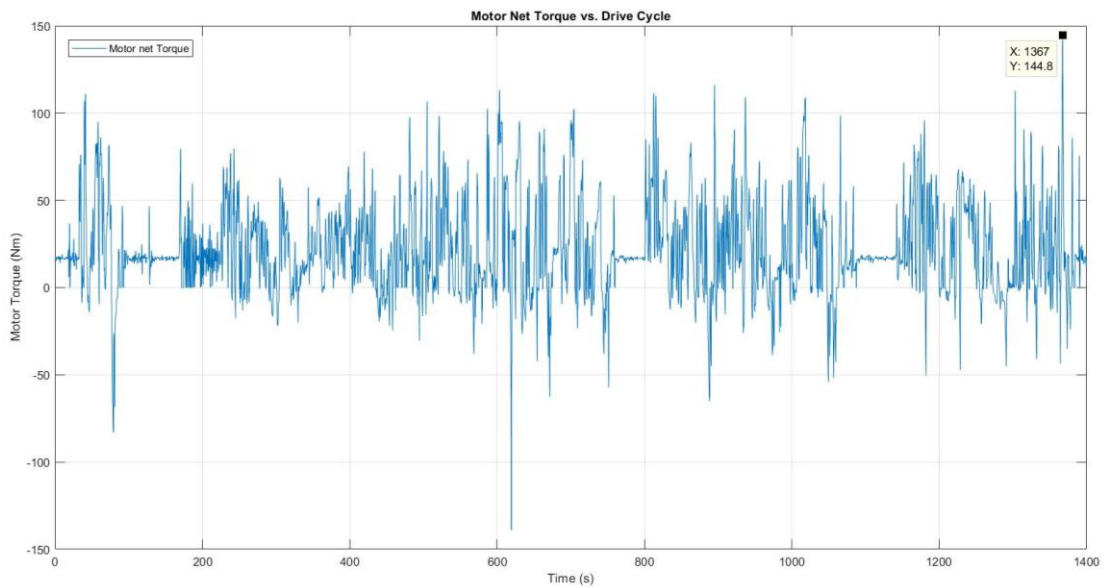


Figure 45: Torque Variation in Developed Drive Cycle

The motor needed to supply the maximum torque of 144.8 Nm during the vehicle operation in the drive cycle. The negative torque signifies that the motor is not producing any torque at that instant, rather it is converting the kinetic energy produced during braking into useful energy to charge the battery.

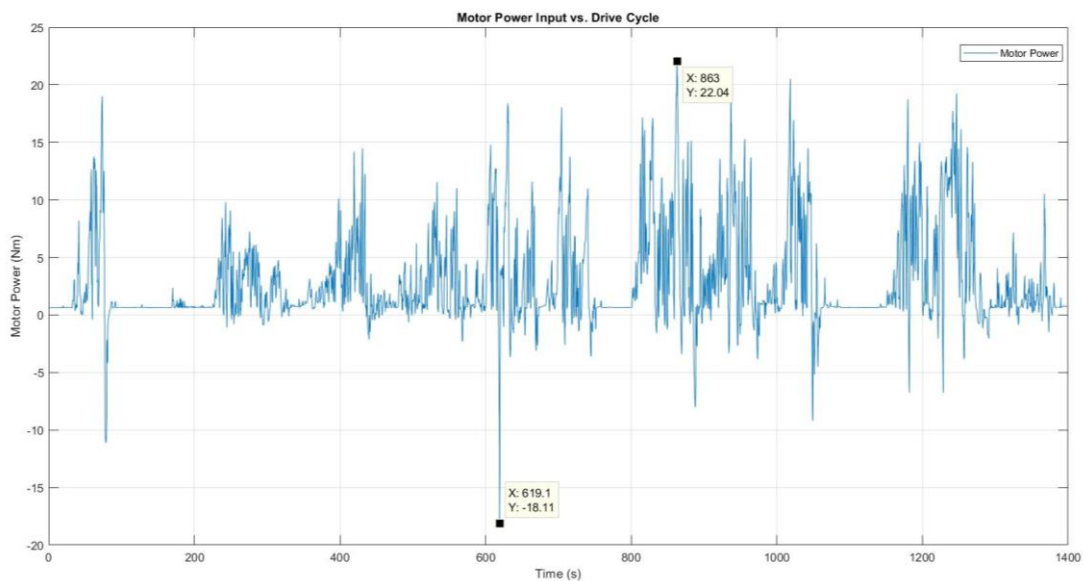


Figure 46: Motor Power Requirement in the Drive Cycle

In order to supply the torque required by motor, the battery needs to provide power to the motor. The battery supplies maximum power of 22.04 Kw to the motor for its operation. The maximum regenerative power is 18.11 Kw.

4.9.3. Current Variation

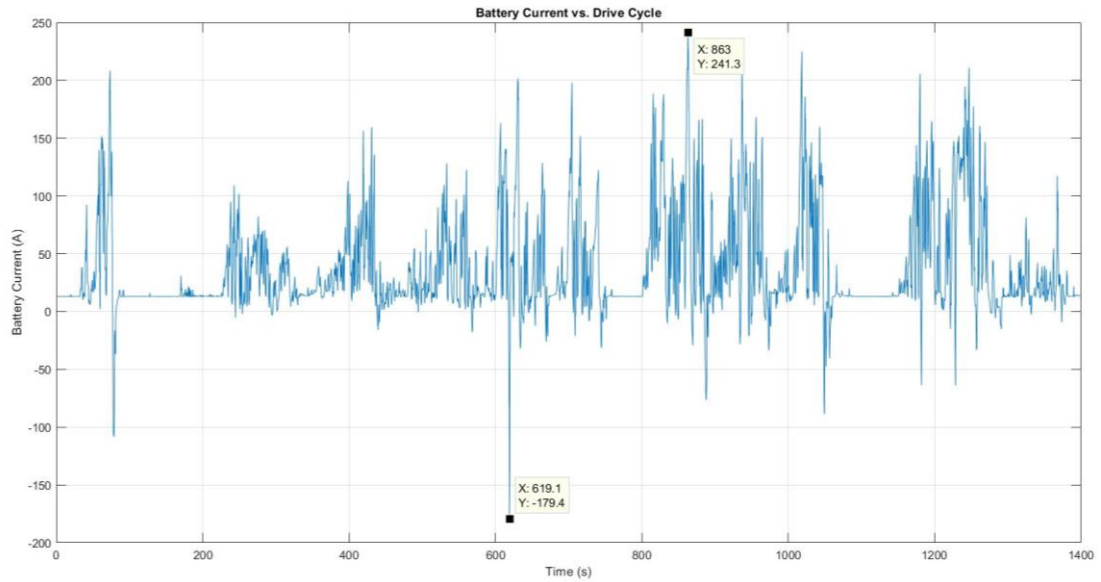


Figure 47: Variation of Battery Current

The current demanded by the motor at various time during its operation in the developed drive cycle is shown in the figure. The motor requires the maximum current of 241.3 A to deliver the peak power demanded. The maximum regenerative current is 179.4A. the current demanded by the motor is within the range of the battery.

4.9.4. Energy Consumption in The Developed Drive Cycle

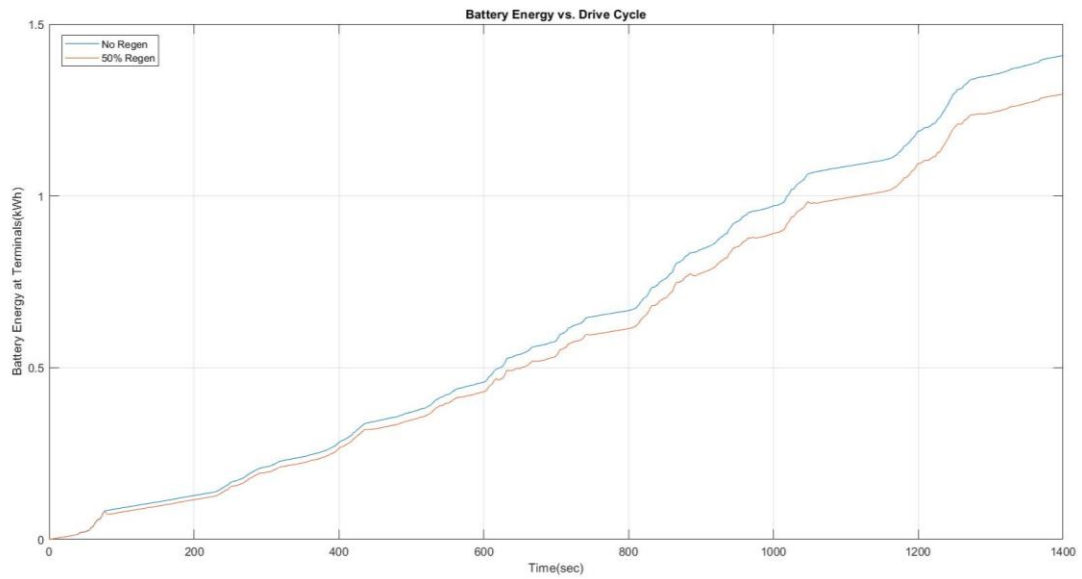


Figure 48: Energy Consumption in a Cycle

The total energy consumption by the vehicle at the end of driving cycle at 50% regeneration is 1.296kWhr. Without considering the regeneration, the vehicle consumes 1.408kWhr of battery energy. The total energy shaved by the regeneration is 0.112kWhr which is 7.9% of total energy consumption.

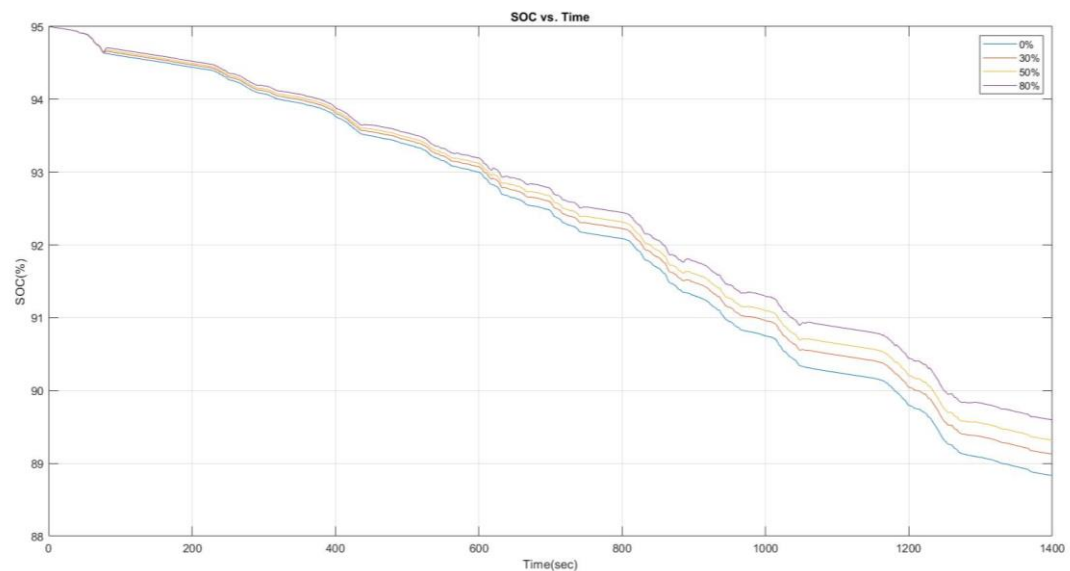


Figure 49: SoC with Different Regeneration Level

The effect of regeneration the state of charge of battery at the end of driving cycle is shown in the figure above. The state of charge drops from 95% to 88.83% at 0% without regeneration. The SoC drops to 89.59% and 89.12% at the end of driving cycle considering 80% and 30% regeneration.

At the 50% regeneration, the SoC is 89.31%. The total driving range considering 50% regeneration is given by

$$\begin{aligned} \text{vehicle range} &= \frac{100 - 5}{95 - 89.31} \times 6.09 \\ &= 101.67 \text{ km.} \end{aligned}$$

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The vehicle resistive force model was developed in MATLAB/Simulink considering various resistive force acting on the vehicle. Different drive cycles, namely HWFET, WLTC-2 and BEV-FLEET are used to calculate the maximum torque that the motor needs to produce for running vehicle in these drive cycle. The maximum required torque doesn't exceed the maximum torque of motor until the coupling is done in 2nd gear. Also, the maximum speed attainable in 2nd gear is 114km/hr. So, the motor was coupled with the gear box in 2nd gear.

The total power required to drive the vehicle in different drive cycles were calculated by integrating the power vs time graph and considering the total distance of drive cycle, the theoretical mileage of the vehicle was calculated. The mileage for HWFET drive cycle was maximum among three drive cycles (0.173kWhr/km). Considering appropriate driving range (120km), the battery capacity was calculated. The lithium iron phosphate (LiFePO₄) battery cells of 3.2V,100Ah are used for the battery pack which are arranged in 30S2P configuration to obtain required voltage and capacity of 96V and 20kWhr.

The increase in vehicle mass and the rolling resistance also increases the mileage of the vehicle. the variation is linear as expected. The vehicle mass and rolling resistance coefficient along with the grade angle are major parameter that determines the maximum torque and power requirement. The maximum power and the maximum torque also vary linearly with the vehicle mass and the rolling resistance coefficient.

The vehicle drivetrain was modeled in the MATLAB/Simulink which consisted of seven subsystems: driver, vehicle physical model, driveline, motor, battery and brake system. Using this model, the state of charge of battery at the end of each drive cycle considering 0%, 30% ,50% and 80% regeneration is calculated. the driving range at 50% regeneration is calculated for each drive cycle which is lower than actual considered value. This is because there is significant power loss in the motor and the battery internal resistance. Also, the minimum SoC of 5% is set to lower limit. The auxiliary load of 600W also consumed significant battery energy during whole cycle.

The battery current reached the peak value of 370A for BEV-FLEET drive cycle. The motor power also reached the peak value of 43kW for the same drive cycle. At high power requirement, the current requirement is also high. But there is a voltage drop in the internal resistance of battery, which decreases the terminal voltage. Thus, the battery current required is further increased.

For the development of drive cycle, the speed- time data was collected through the GPS device and the performance of motor and the energy consumption throughout drive cycle was analyzed. The performance was quite satisfactory as the torque and power did not exceed the rated value.

5.2. RECOMMENDATIONS

After completion of this project, the following recommendations can be made for better modelling of electric vehicle:

- The PID controller can be tuned finely to minimize the error signal and accurately trace the drive cycle speed.
- A more optimum controller like a fuzzy controller can be used to improve the results of energy regeneration.
- The advanced and more accurate battery model like generic model could have been used to accurately represent the battery behaviour.
- The losses in the inverter can be considered to increase the accuracy of the model.
- The use of EV for the drive cycle development could have represented the performance in better way.
- The data for drive cycle could have been taken at different time to represent the driving condition of the route more accurately.

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**APPENDIX A: VALUES OF DIFFERENT VEHICLE
PARAMETERS**

1. Typical Values for the Rolling Resistance Coefficient

K_R	Road Condition
0.01	Good paved roads
0.015	Average paved roads
0.02~0.025	Good gravel or soil
0.1~0.15	Sand

2. Typical values for the loss constant of the induction motor

Parameter	'Lynch'-type PM motor with brushes	High-speed Induction Motor
K_c	1.5	0.3
K_i	0.1	0.01
K_w	10^{-5}	$5 * 10^{-6}$
C	20	600

3. Typical values for Wind Resistance Coefficient

K_w	Vehicle Type
0.2995	Passenger Cars
0.4313	Small Trucks
0.599	Large Trucks

APPENDIX B: DEVELOPED DRIVE CYCLE DATA

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
0	0.079	22.5	0.107	45	11.417
0.5	0.065	23	0.091	45.5	10.345
1	0.092	23.5	0.103	46	9.284
1.5	0.1	24	0.184	46.5	8.133
2	0.065	24.5	0.188	47	7.249
2.5	0.056	25	0.132	47.5	7.017
3	0.071	25.5	0.41	48	7.038
3.5	0.087	26	0.303	48.5	6.899
4	0.101	26.5	0.193	49	7.128
4.5	0.089	27	0.172	49.5	7.507
5	0.122	27.5	0.158	50	7.493
5.5	0.107	28	0.235	50.5	7.299
6	0.126	28.5	0.284	51	7.191
6.5	0.147	29	0.127	51.5	7.907
7	0.083	29.5	0.164	52	8.563
7.5	0.089	30	0.136	52.5	8.547
8	0.078	30.5	0.131	53	8.449
8.5	0.091	31	0.131	53.5	8.664
9	0.079	31.5	0.14	54	9.068
9.5	0.102	32	0.12	54.5	10.173
10	0.156	32.5	0.11	55	11.608
10.5	0.152	33	1.448	55.5	13.211
11	0.146	33.5	2.239	56	14.672
11.5	0.145	34	2.749	56.5	16.261
12	0.143	34.5	4.019	57	17.871
12.5	0.129	35	5.48	57.5	18.984
13	0.136	35.5	6.649	58	20.501
13.5	0.118	36	6.367	58.5	22.405
14	0.101	36.5	5.347	59	22.436
14.5	0.094	37	4.717	59.5	22.363
15	0.108	37.5	4.621	60	21.275
15.5	0.111	38	4.348	60.5	22.633
16	0.117	38.5	3.993	61	23.9
16.5	0.141	39	3.31	61.5	25.366
17	0.145	39.5	4.043	62	27.032
17.5	0.128	40	6.27	62.5	28.442
18	0.208	40.5	7.578	63	29.868
18.5	0.33	41	9.638	63.5	31.153
19	0.062	41.5	11.952	64	31.747
19.5	0.315	42	12.725	64.5	31.733
20	0.808	42.5	13.249	65	32.201
20.5	0.23	43	13.231	65.5	33.281
21	0.113	43.5	13.141	66	34.136
21.5	0.148	44	13.025	66.5	34.434
22	0.142	44.5	12.021	67	34.189

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
67.5	33.984	90	1.145	112.5	0.071
68	33.462	90.5	0.98	113	0.099
68.5	32.912	91	1.158	113.5	0.145
69	32.625	91.5	1.9	114	0.227
69.5	32.882	92	2.441	114.5	0.168
70	33.17	92.5	1.368	115	0.158
70.5	33.576	93	0.321	115.5	0.163
71	34.162	93.5	0.221	116	0.178
71.5	34.695	94	0.077	116.5	0.117
72	35.415	94.5	0.197	117	0.148
72.5	36.586	95	0.242	117.5	0.135
73	38.123	95.5	0.093	118	0.333
73.5	39.638	96	0.07	118.5	0.102
74	40.636	96.5	0.186	119	0.134
74.5	41.283	97	0.256	119.5	0.139
75	41.584	97.5	0.295	120	0.148
75.5	42.062	98	0.318	120.5	0.2
76	42.722	98.5	0.229	121	0.198
76.5	42.619	99	0.269	121.5	0.222
77	41.484	99.5	0.304	122	0.22
77.5	38.593	100	0.31	122.5	0.289
78	34.679	100.5	0.303	123	0.315
78.5	30.605	101	0.281	123.5	0.249
79	25.846	101.5	0.251	124	0.179
79.5	21.295	102	0.255	124.5	0.196
80	19.73	102.5	0.245	125	0.203
80.5	16.529	103	0.21	125.5	0.209
81	12.308	103.5	0.199	126	0.211
81.5	10.904	104	0.181	126.5	0.211
82	9.74	104.5	0.13	127	0.208
82.5	8.531	105	0.135	127.5	0.219
83	7.492	105.5	0.155	128	0.958
83.5	6.763	106	0.128	128.5	0.579
84	6.047	106.5	0.159	129	0.353
84.5	5.308	107	0.094	129.5	0.258
85	4.688	107.5	0.023	130	0.228
85.5	4.247	108	0.068	130.5	0.106
86	4.217	108.5	0.113	131	0.219
86.5	4.351	109	0.068	131.5	0.262
87	4.443	109.5	0.173	132	0.188
87.5	4.293	110	0.164	132.5	0.219
88	3.66	110.5	0.147	133	0.181
88.5	2.921	111	0.131	133.5	0.147
89	2.133	111.5	0.139	134	0.145
89.5	1.485	112	0.06	134.5	0.126

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
135	0.078	157	0.062	179	1.748
135.5	0.077	157.5	0.049	179.5	1.602
136	0.102	158	0.046	180	2.08
136.5	0.086	158.5	0.074	180.5	2.896
137	0.089	159	0.089	181	2.22
137.5	0.069	159.5	0.091	181.5	1.908
138	0.065	160	0.111	182	2.633
138.5	0.074	160.5	0.069	182.5	2.883
139	0.092	161	0.092	183	2.292
139.5	0.115	161.5	0.061	183.5	1.891
140	0.119	162	0.072	184	2.441
140.5	0.117	162.5	0.04	184.5	1.756
141	0.129	163	0.034	185	0.885
141.5	0.135	163.5	0.034	185.5	0.485
142	0.105	164	0.041	186	0.418
142.5	0.091	164.5	0.026	186.5	1.483
143	0.083	165	0.024	187	1.534
143.5	0.08	165.5	0.053	187.5	0.611
144	0.084	166	0.063	188	0.297
144.5	0.104	166.5	0.083	188.5	0.434
145	0.074	167	0.071	189	0.793
145.5	0.119	167.5	0.061	189.5	0.33
146	0.105	168	0.058	190	0.079
146.5	0.084	168.5	0.103	190.5	0.064
147	0.079	169	0.221	191	0.407
147.5	0.066	169.5	0.87	191.5	0.183
148	0.079	170	2.077	192	0.451
148.5	0.079	170.5	3.624	192.5	0.425
149	0.088	171	3.82	193	0.394
149.5	0.097	171.5	4.118	193.5	0.431
150	0.11	172	3.695	194	0.397
150.5	0.13	172.5	3.039	194.5	0.417
151	0.093	173	2.427	195	0.463
151.5	0.112	173.5	1.76	195.5	0.383
152	0.129	174	1.325	196	0.454
152.5	0.099	174.5	1.564	196.5	0.798
153	0.082	175	1.682	197	0.771
153.5	0.061	175.5	1.548	197.5	0.148
154	0.067	176	2.073	198	0.154
154.5	0.05	176.5	2.665	198.5	0.448
155	0.074	177	2.552	199	0.048
155.5	0.104	177.5	1.997	199.5	0.345
156	0.083	178	2.048	200	0.073
156.5	0.079	178.5	2.335	200.5	0.572

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
201	0.197	223	0.321	245	18.391
201.5	0.366	223.5	0.361	245.5	18.243
202	0.129	224	0.268	246	18.901
202.5	0.135	224.5	0.182	246.5	19.215
203	0.26	225	0.162	247	19.947
203.5	0.327	225.5	0.351	247.5	21.011
204	0.333	226	1.135	248	21.927
204.5	0.467	226.5	1.253	248.5	22.396
205	0.208	227	0.93	249	23.184
205.5	0.205	227.5	0.841	249.5	24.259
206	0.355	228	1.406	250	24.92
206.5	0.276	228.5	2.702	250.5	24.377
207	0.333	229	3.946	251	23.342
207.5	0.137	229.5	4.379	251.5	23.566
208	0.415	230	4.679	252	23.497
208.5	0.24	230.5	5.174	252.5	22.641
209	0.376	231	5.9	253	22.344
209.5	0.254	231.5	6.96	253.5	22.837
210	0.732	232	7.964	254	22.244
210.5	1.124	232.5	8.788	254.5	20.935
211	0.508	233	9.779	255	20.185
211.5	0.507	233.5	11.059	255.5	19.403
212	0.368	234	11.941	256	18.749
212.5	0.63	234.5	11.922	256.5	18.396
213	0.771	235	11.468	257	17.699
213.5	0.374	235.5	11.954	257.5	16.85
214	0.519	236	12.905	258	16.83
214.5	0.305	236.5	13.72	258.5	17.242
215	0.183	237	14.071	259	17.391
215.5	0.18	237.5	15.112	259.5	17.387
216	0.319	238	16.51	260	16.801
216.5	0.135	238.5	17.973	260.5	15.751
217	0.281	239	18.818	261	15.083
217.5	0.264	239.5	18.746	261.5	15.511
218	0.221	240	17.935	262	16.385
218.5	0.336	240.5	17.113	262.5	17.006
219	0.422	241	17.131	263	16.516
219.5	0.091	241.5	17.261	263.5	15.522
220	0.051	242	18.225	264	14.976
220.5	0.423	242.5	18.812	264.5	15.043
221	0.464	243	20.344	265	14.967
221.5	0.27	243.5	21.209	265.5	14.675
222	0.139	244	20.569	266	15.051
222.5	0.211	244.5	19.986	266.5	15.567

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
267	15.804	289	25.208	311	13.307
267.5	16.173	289.5	25.24	311.5	13.586
268	16.48	290	24.886	312	13.431
268.5	16.761	290.5	24.228	312.5	13.383
269	17.408	291	23.285	313	13.818
269.5	17.775	291.5	23.077	313.5	14.283
270	18.375	292	22.987	314	14.66
270.5	19.117	292.5	22.686	314.5	15.223
271	19.687	293	21.763	315	15.876
271.5	20.064	293.5	21.004	315.5	16.535
272	20.405	294	20.002	316	16.962
272.5	20.887	294.5	18.686	316.5	16.954
273	21.424	295	17.55	317	17.226
273.5	21.635	295.5	16.25	317.5	17.579
274	21.549	296	15.306	318	17.793
274.5	21.823	296.5	14.762	318.5	17.7
275	22.387	297	14.587	319	17.438
275.5	22.863	297.5	14.52	319.5	16.936
276	23.635	298	14.04	320	16.434
276.5	24.208	298.5	13.65	320.5	15.323
277	24.442	299	13.666	321	14.745
277.5	24.074	299.5	13.666	321.5	14.079
278	23.575	300	13.432	322	13.451
278.5	23.398	300.5	13.167	322.5	13.067
279	23.308	301	12.626	323	12.796
279.5	23.808	301.5	10.834	323.5	11.895
280	24.274	302	9.333	324	11.227
280.5	24.144	302.5	7.842	324.5	10.854
281	24.182	303	6.582	325	10.808
281.5	24.69	303.5	5.806	325.5	10.808
282	25.165	304	5.007	326	11.035
282.5	25.254	304.5	4.649	326.5	10.956
283	25.045	305	5.798	327	10.425
283.5	24.75	305.5	6.893	327.5	9.855
284	24.821	306	7.982	328	9.692
284.5	25.038	306.5	8.806	328.5	9.599
285	25.517	307	8.666	329	9.198
285.5	25.351	307.5	8.472	329.5	8.14
286	24.901	308	9.037	330	6.492
286.5	24.399	308.5	9.919	330.5	5.821
287	24.416	309	10.913	331	5.424
287.5	24.81	309.5	11.475	331.5	4.854
288	24.989	310	11.782	332	4.373
288.5	24.985	310.5	12.522	332.5	4.108

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
333	4.01	355	3.598	377	9.943
333.5	3.623	355.5	3.948	377.5	9.67
334	3.333	356	4.5	378	9.229
334.5	3.128	356.5	5.309	378.5	9.04
335	2.966	357	6.14	379	8.745
335.5	2.875	357.5	6.874	379.5	9.087
336	2.859	358	7.727	380	9.704
336.5	2.635	358.5	8.582	380.5	10.234
337	2.419	359	9.101	381	10.549
337.5	2.208	359.5	9.198	381.5	11.222
338	2.159	360	9.188	382	11.424
338.5	1.915	360.5	9.257	382.5	11.48
339	1.708	361	9.593	383	11.985
339.5	1.575	361.5	9.494	383.5	12.385
340	1.434	362	9.134	384	12.74
340.5	1.339	362.5	8.665	384.5	12.48
341	1.15	363	8.053	385	12.846
341.5	1.071	363.5	7.544	385.5	13.359
342	0.934	364	7.105	386	14.138
342.5	0.849	364.5	6.716	386.5	14.559
343	0.819	365	6.255	387	15.002
343.5	1.126	365.5	5.787	387.5	15.607
344	2.137	366	5.537	388	16.135
344.5	2.491	366.5	5.511	388.5	16.032
345	2.116	367	5.857	389	16.318
345.5	1.949	367.5	6.416	389.5	16.472
346	1.812	368	6.643	390	16.465
346.5	1.886	368.5	6.547	390.5	16.875
347	1.862	369	6.449	391	16.723
347.5	1.829	369.5	6.304	391.5	16.423
348	1.922	370	6.265	392	16.471
348.5	2.378	370.5	6.189	392.5	16.911
349	2.831	371	6.415	393	17.06
349.5	2.858	371.5	7.042	393.5	16.737
350	2.737	372	7.686	394	17.245
350.5	2.672	372.5	7.999	394.5	18.038
351	2.691	373	7.822	395	18.925
351.5	2.747	373.5	7.806	395.5	19.524
352	2.794	374	7.848	396	19.908
352.5	3.177	374.5	8.134	396.5	20.213
353	3.32	375	8.706	397	20.695
353.5	3.393	375.5	9.364	397.5	21.791
354	3.469	376	9.729	398	22.983
354.5	3.515	376.5	10.037	398.5	24.246

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
399	24.568	421	31.06	443	22.706
399.5	24.811	421.5	30.902	443.5	22.233
400	24.94	422	30.954	444	21.839
400.5	25.525	422.5	31.261	444.5	20.712
401	26.465	423	31.836	445	20.085
401.5	26.92	423.5	32.159	445.5	19.401
402	26.798	424	32.296	446	18.888
402.5	26.601	424.5	32.858	446.5	18.719
403	26.463	425	33.163	447	17.889
403.5	25.899	425.5	33.419	447.5	16.78
404	25.239	426	33.309	448	15.686
404.5	25.101	426.5	33.221	448.5	14.946
405	25.175	427	32.865	449	14.258
405.5	25.22	427.5	32.986	449.5	13.434
406	24.838	428	33.675	450	12.495
406.5	24.421	428.5	33.915	450.5	12.193
407	24.729	429	33.716	451	11.465
407.5	24.887	429.5	33.324	451.5	11.175
408	24.57	430	33.348	452	11.112
408.5	24.938	430.5	34.299	452.5	11.178
409	25.479	431	35.498	453	10.52
409.5	25.76	431.5	35.423	453.5	9.041
410	25.783	432	34.937	454	7.413
410.5	25.563	432.5	34.552	454.5	7.4
411	25.169	433	34.504	455	7.289
411.5	24.895	433.5	34.891	455.5	7.35
412	25.408	434	35.445	456	7.582
412.5	25.42	434.5	36.33	456.5	7.783
413	26.101	435	36.006	457	7.85
413.5	26.479	435.5	35.377	457.5	7.443
414	26.227	436	34.864	458	5.616
414.5	25.841	436.5	33.983	458.5	3.683
415	25.719	437	33.404	459	3.117
415.5	25.88	437.5	33.182	459.5	3.116
416	26.417	438	32.233	460	3.479
416.5	27.104	438.5	31.076	460.5	4.243
417	27.287	439	29.76	461	5.133
417.5	27.627	439.5	28.496	461.5	5.623
418	27.957	440	27	462	5.588
418.5	28.478	440.5	26.303	462.5	2.886
419	29.145	441	25.052	463	2.472
419.5	30.608	441.5	23.663	463.5	2.737
420	31.51	442	22.702	464	3.004
420.5	31.187	442.5	22.817	464.5	3.355

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
465	2.525	487	8.148	509	7.345
465.5	0.967	487.5	8.454	509.5	7.231
466	0.603	488	9.45	510	8.09
466.5	0.307	488.5	10.337	510.5	9.219
467	0.299	489	11.419	511	10.272
467.5	0.934	489.5	12.403	511.5	11.305
468	2.118	490	11.974	512	11.769
468.5	3.271	490.5	12.106	512.5	11.405
469	3.225	491	12.108	513	10.353
469.5	3.425	491.5	12.002	513.5	9.907
470	3.543	492	10.898	514	9.601
470.5	3.028	492.5	10.429	514.5	9.355
471	2.107	493	10.481	515	8.776
471.5	1.711	493.5	10.386	515.5	8.434
472	1.718	494	10.212	516	8.166
472.5	1.904	494.5	7.702	516.5	7.738
473	2.331	495	7.09	517	7.22
473.5	2.819	495.5	6.984	517.5	8.09
474	3.012	496	7.379	518	8.968
474.5	3.037	496.5	7.836	518.5	9.638
475	2.279	497	8.549	519	9.317
475.5	2.139	497.5	9.788	519.5	8.927
476	2.236	498	10.041	520	8.235
476.5	2.664	498.5	8.923	520.5	9.257
477	1.211	499	7.561	521	11.132
477.5	0.904	499.5	7.441	521.5	13.13
478	0.729	500	7.42	522	13.746
478.5	0.645	500.5	7.327	522.5	13.631
479	0.462	501	7.245	523	13.559
479.5	0.29	501.5	7.226	523.5	13.625
480	0.537	502	7.309	524	14.33
480.5	1.153	502.5	7.613	524.5	15.026
481	2.961	503	7.674	525	15.392
481.5	4.952	503.5	6.199	525.5	15.263
482	6.401	504	6.098	526	15.608
482.5	7.193	504.5	6.822	526.5	16.417
483	8.093	505	9.045	527	17.757
483.5	8.772	505.5	8.912	527.5	19.248
484	9.425	506	8.495	528	19.665
484.5	9.464	506.5	7.875	528.5	19.606
485	9.58	507	7.647	529	20.162
485.5	8.941	507.5	7.358	529.5	21.505
486	8.232	508	7.609	530	22.814
486.5	8.272	508.5	7.532	530.5	23.49

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
531	24.307	553	20.961	575	11.368
531.5	24.983	553.5	21.292	575.5	11.294
532	25.384	554	21.15	576	11.07
532.5	25.683	554.5	21.063	576.5	10.967
533	26.596	555	21.519	577	10.769
533.5	27.846	555.5	22.453	577.5	10.508
534	27.903	556	22.936	578	10.216
534.5	27.308	556.5	23.587	578.5	9.928
535	26.632	557	24.624	579	9.59
535.5	26.13	557.5	25.127	579.5	7.745
536	26.161	558	24.348	580	6.796
536.5	26.36	558.5	23.618	580.5	6.524
537	26.843	559	22.641	581	6.21
537.5	27.02	559.5	22.647	581.5	5.89
538	26.966	560	23.759	582	5.594
538.5	26.96	560.5	25.115	582.5	5.437
539	27.239	561	25.588	583	5.215
539.5	27.33	561.5	25.565	583.5	5.037
540	27.043	562	24.846	584	4.551
540.5	26.513	562.5	23.936	584.5	3.582
541	25.955	563	23.176	585	2.517
541.5	25.249	563.5	22.936	585.5	1.781
542	24.524	564	22.948	586	1.686
542.5	23.856	564.5	23.112	586.5	3.379
543	23.329	565	22.531	587	5.494
543.5	23.313	565.5	22.079	587.5	5.732
544	23.639	566	21.492	588	6.098
544.5	23.987	566.5	20.877	588.5	7.854
545	24.015	567	20.14	589	9.356
545.5	24.191	567.5	18.738	589.5	9.278
546	24.808	568	16.447	590	9.176
546.5	25.718	568.5	13.999	590.5	8.976
547	25.704	569	12.766	591	8.92
547.5	25.092	569.5	12.687	591.5	8.705
548	24.463	570	12.313	592	8.477
548.5	23.802	570.5	10.707	592.5	8.244
549	23.271	571	10.064	593	7.829
549.5	22.647	571.5	9.716	593.5	7.598
550	21.932	572	9.038	594	7.304
550.5	21.007	572.5	9.019	594.5	6.056
551	20.11	573	10.229	595	6.112
551.5	19.306	573.5	11.268	595.5	6.198
552	19.293	574	11.963	596	7.127
552.5	19.971	574.5	11.813	596.5	8.267

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
597	8.069	619	26.896	641	20.456
597.5	7.392	619.5	19.563	641.5	21.438
598	6.517	620	17.274	642	21.332
598.5	6.227	620.5	17.657	642.5	20.894
599	5.875	621	17.922	643	21.102
599.5	4.525	621.5	18.172	643.5	22.197
600	3.33	622	18.416	644	21.939
600.5	3.267	622.5	18.79	644.5	20.9
601	4.156	623	19.027	645	19.878
601.5	6.205	623.5	19.16	645.5	18.717
602	7.924	624	19.552	646	17.712
602.5	9.513	624.5	18.824	646.5	17.15
603	11.618	625	17.206	647	16.471
603.5	13.985	625.5	18.445	647.5	15.256
604	15.593	626	19.496	648	14.837
604.5	17.351	626.5	20.689	648.5	13.961
605	18.956	627	22.061	649	13.369
605.5	20.873	627.5	23.287	649.5	12.918
606	22.763	628	24.625	650	12.59
606.5	24.632	628.5	26.002	650.5	12.694
607	26.511	629	27.469	651	12.842
607.5	26.433	629.5	29.144	651.5	13.249
608	26.324	630	30.972	652	13.913
608.5	25.7	630.5	32.845	652.5	14.757
609	26.372	631	34.565	653	15.652
609.5	27.497	631.5	36.02	653.5	15.413
610	27.091	632	36.494	654	13.411
610.5	26.602	632.5	36.117	654.5	10.496
611	27.651	633	34.824	655	10.069
611.5	28.617	633.5	33.088	655.5	9.575
612	29.535	634	31.196	656	9.097
612.5	30.596	634.5	29.696	656.5	8.564
613	31.682	635	28.68	657	10.238
613.5	32.799	635.5	28.591	657.5	12.018
614	33.827	636	27.791	658	13.73
614.5	34.841	636.5	26.644	658.5	13.416
615	34.7	637	25.587	659	13.123
615.5	33.973	637.5	24.468	659.5	12.887
616	34.588	638	23.18	660	13.939
616.5	35.017	638.5	21.727	660.5	14.99
617	35.195	639	20.786	661	15.99
617.5	34.705	639.5	21.221	661.5	16.16
618	33.37	640	20.783	662	15.641
618.5	31.084	640.5	19.845	662.5	16.406

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
663	18.006	685	5.633	707	28.698
663.5	19.486	685.5	6.807	707.5	29.163
664	21.294	686	7.162	708	29.361
664.5	22.777	686.5	7.292	708.5	28.109
665	22.473	687	7.376	709	26.249
665.5	22.394	687.5	7.176	709.5	25.31
666	22.321	688	6.111	710	25.135
666.5	23.26	688.5	6.159	710.5	25.989
667	24.395	689	6.303	711	26.841
667.5	24.095	689.5	6.436	711.5	26.8
668	23.566	690	6.804	712	26.216
668.5	22.061	690.5	8.274	712.5	25.755
669	19.937	691	9.687	713	25.607
669.5	17.3	691.5	9.673	713.5	26.084
670	17.082	692	9.639	714	27.095
670.5	15.979	692.5	9.343	714.5	28.158
671	12.855	693	9.022	715	29.058
671.5	8.919	693.5	9.228	715.5	30.197
672	7.786	694	8.969	716	31.534
672.5	6.533	694.5	8.511	716.5	32.226
673	4.43	695	7.855	717	32.287
673.5	2.36	695.5	7.48	717.5	32.246
674	2.178	696	7.57	718	31.578
674.5	1.079	696.5	7.72	718.5	30.443
675	0.525	697	7.993	719	29.528
675.5	0.499	697.5	8.177	719.5	29.203
676	0.474	698	8.447	720	29.409
676.5	0.595	698.5	9.094	720.5	29.645
677	0.75	699	10.414	721	29.022
677.5	0.815	699.5	12.224	721.5	28.12
678	0.858	700	14.101	722	28.185
678.5	0.999	700.5	16.032	722.5	28.668
679	1.131	701	17.681	723	29.111
679.5	1.222	701.5	19.506	723.5	28.913
680	1.275	702	21.387	724	28.078
680.5	1.321	702.5	22.98	724.5	27.277
681	1.409	703	24.37	725	27.042
681.5	1.553	703.5	25.918	725.5	27.181
682	1.693	704	27.967	726	26.663
682.5	1.763	704.5	30.025	726.5	26.281
683	2	705	30.483	727	26.098
683.5	2.553	705.5	30.701	727.5	25.014
684	3.474	706	30.007	728	23.599
684.5	4.566	706.5	28.938	728.5	22.384

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
729	22.246	751	8.924	773	0.32
729.5	22.458	751.5	5.177	773.5	0.332
730	22.761	752	3.483	774	0.299
730.5	21.874	752.5	1.373	774.5	0.25
731	20.846	753	1.163	775	0.181
731.5	20.12	753.5	0.699	775.5	0.177
732	19.643	754	0.481	776	0.156
732.5	19.415	754.5	0.42	776.5	0.168
733	19.421	755	0.484	777	0.166
733.5	19.914	755.5	0.539	777.5	0.167
734	20.299	756	0.59	778	0.181
734.5	20.709	756.5	0.705	778.5	0.18
735	21.175	757	0.809	779	0.166
735.5	21.647	757.5	0.833	779.5	0.132
736	22.18	758	0.916	780	0.125
736.5	22.824	758.5	1.811	780.5	0.144
737	23.45	759	2.384	781	0.135
737.5	24.089	759.5	0.619	781.5	0.114
738	24.946	760	0.259	782	0.13
738.5	25.884	760.5	0.262	782.5	0.155
739	26.868	761	0.271	783	0.132
739.5	27.891	761.5	0.259	783.5	0.113
740	28.882	762	0.241	784	0.122
740.5	29.919	762.5	0.235	784.5	0.12
741	29.916	763	0.228	785	0.085
741.5	29.65	763.5	0.212	785.5	0.089
742	29.045	764	0.16	786	0.101
742.5	28.506	764.5	0.101	786.5	0.119
743	27.735	765	0.083	787	0.129
743.5	26.784	765.5	0.071	787.5	0.134
744	25.102	766	0.074	788	0.115
744.5	22.699	766.5	0.096	788.5	0.108
745	20.289	767	0.1	789	0.128
745.5	19.347	767.5	0.14	789.5	0.146
746	18.097	768	0.185	790	0.177
746.5	16.386	768.5	0.225	790.5	0.154
747	14.591	769	0.232	791	0.163
747.5	14.017	769.5	0.257	791.5	0.171
748	12.719	770	0.255	792	0.174
748.5	12.375	770.5	0.287	792.5	0.177
749	11.783	771	0.323	793	0.184
749.5	11.62	771.5	0.365	793.5	0.188
750	11.531	772	0.371	794	0.194
750.5	10.829	772.5	0.33	794.5	0.191

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
795	0.185	817	28.677	839	37.324
795.5	0.177	817.5	28.658	839.5	36.952
796	0.17	818	29.975	840	36.719
796.5	0.153	818.5	31.626	840.5	37.094
797	0.167	819	32.42	841	37.647
797.5	0.179	819.5	32.455	841.5	38.287
798	0.199	820	32.617	842	39.028
798.5	0.178	820.5	33.089	842.5	39.6
799	0.157	821	33.483	843	39.521
799.5	0.126	821.5	33.436	843.5	38.909
800	0.149	822	33.302	844	38.508
800.5	0.125	822.5	33.236	844.5	38.78
801	0.325	823	33.313	845	39.252
801.5	1.612	823.5	33.485	845.5	38.996
802	3.296	824	33.72	846	37.854
802.5	3.821	824.5	33.799	846.5	37.026
803	4.42	825	33.998	847	36.739
803.5	5.23	825.5	34.675	847.5	37.043
804	6.093	826	35.726	848	37.446
804.5	6.722	826.5	36.738	848.5	37.317
805	6.752	827	37.515	849	36.251
805.5	6.708	827.5	38.281	849.5	35.125
806	6.874	828	38.996	850	34.206
806.5	8.493	828.5	40.074	850.5	34.243
807	9.025	829	41.228	851	34.594
807.5	9.196	829.5	42.384	851.5	34.322
808	9.126	830	43.413	852	33.946
808.5	9.531	830.5	43.74	852.5	34.162
809	10.657	831	43.879	853	34.709
809.5	11.731	831.5	44.02	853.5	35.365
810	12.865	832	44.264	854	35.97
810.5	13.965	832.5	43.902	854.5	36.045
811	14.954	833	43.185	855	36.068
811.5	15.95	833.5	42.547	855.5	36.639
812	17.502	834	41.492	856	37.293
812.5	19.817	834.5	40.399	856.5	37.842
813	21.335	835	39.244	857	38
813.5	21.3	835.5	38.42	857.5	38.52
814	21.275	836	38.081	858	38.538
814.5	22.236	836.5	38.267	858.5	38.035
815	24.338	837	38.5	859	37.059
815.5	26.594	837.5	37.605	859.5	36.729
816	28.417	838	36.79	860	37.37
816.5	28.583	838.5	36.888	860.5	38.196

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
861	39.213	883	39.511	905	13.816
861.5	40.589	883.5	38.735	905.5	13.523
862	41.993	884	39.411	906	13.893
862.5	43.335	884.5	39.55	906.5	14.49
863	44.873	885	38.934	907	14.763
863.5	46.205	885.5	38.042	907.5	14.188
864	47.229	886	36.243	908	15.082
864.5	47.991	886.5	34.032	908.5	15.696
865	48.31	887	31.598	909	14.998
865.5	48.257	887.5	28.043	909.5	13.579
866	48.176	888	24.169	910	13.044
866.5	47.994	888.5	20.755	910.5	13.431
867	47.554	889	20.294	911	14.185
867.5	46.927	889.5	18.628	911.5	14.435
868	46.074	890	15.857	912	14.495
868.5	44.694	890.5	13.08	912.5	15.025
869	43.242	891	12.748	913	15.898
869.5	41.662	891.5	12.344	913.5	16.157
870	40.804	892	11.939	914	16.04
870.5	40.215	892.5	10.822	914.5	16.383
871	40.731	893	10.106	915	17.039
871.5	41.547	893.5	9.739	915.5	17.092
872	40.95	894	9.318	916	16.909
872.5	40.154	894.5	10.449	916.5	16.996
873	39.343	895	12.9	917	17.224
873.5	38.555	895.5	14.652	917.5	17.715
874	38.072	896	16.335	918	18.345
874.5	38.389	896.5	15.972	918.5	19.31
875	39.031	897	14.393	919	20.616
875.5	39.726	897.5	12.958	919.5	20.901
876	40.173	898	12.395	920	20.394
876.5	39.999	898.5	12.345	920.5	20.599
877	39.981	899	13.062	921	21.842
877.5	40.741	899.5	13.269	921.5	23.462
878	41.711	900	12.782	922	25.245
878.5	41.968	900.5	12.732	922.5	26.193
879	41.472	901	13.241	923	26.27
879.5	41.093	901.5	13.631	923.5	26.022
880	40.314	902	13.264	924	26.519
880.5	39.493	902.5	13.03	924.5	27.612
881	38.486	903	13.192	925	28.171
881.5	38.299	903.5	13.416	925.5	28.085
882	38.99	904	13.823	926	28.298
882.5	40.048	904.5	14.311	926.5	28.788

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
927	29.372	949	36.32	971	28.706
927.5	29.747	949.5	35.02	971.5	28.075
928	29.643	950	34.13	972	27.113
928.5	29.443	950.5	33.129	972.5	26.292
929	29.278	951	32.293	973	23.956
929.5	29.441	951.5	31.926	973.5	21.399
930	29.315	952	32.445	974	19.322
930.5	29.265	952.5	33.388	974.5	18.995
931	29.167	953	33.332	975	17.335
931.5	29.875	953.5	32.9	975.5	15.222
932	30.984	954	32.324	976	13.04
932.5	31.876	954.5	32.304	976.5	12.231
933	31.948	955	32.886	977	11.966
933.5	31.205	955.5	34.108	977.5	11.65
934	29.01	956	35.411	978	11.335
934.5	27.513	956.5	35.73	978.5	11.027
935	26.063	957	35.621	979	10.746
935.5	25.654	957.5	35.549	979.5	10.46
936	26.11	958	35.351	980	10.187
936.5	27.959	958.5	35.15	980.5	9.871
937	30.188	959	35.397	981	9.739
937.5	31.887	959.5	36.052	981.5	9.565
938	33.058	960	36.039	982	9.431
938.5	34.075	960.5	35.488	982.5	9.307
939	34.793	961	35.044	983	9.111
939.5	35.292	961.5	34.662	983.5	6.943
940	35.768	962	34.622	984	6.855
940.5	36.123	962.5	34.437	984.5	6.69
941	36.44	963	34.114	985	4.558
941.5	37.07	963.5	34.663	985.5	4.493
942	37.989	964	35.643	986	4.309
942.5	38.799	964.5	36.687	986.5	4.421
943	39.267	965	36.772	987	5.142
943.5	39.837	965.5	36.378	987.5	6.185
944	40.234	966	35.93	988	6.68
944.5	40.51	966.5	35.306	988.5	6.593
945	40.628	967	34.477	989	6.422
945.5	40.148	967.5	33.438	989.5	6.333
946	38.438	968	32.416	990	6.777
946.5	37.076	968.5	31.366	990.5	7.261
947	36.6	969	30.211	991	7.723
947.5	36.79	969.5	29.571	991.5	7.83
948	37.56	970	29.242	992	7.756
948.5	37.342	970.5	29.249	992.5	7.53

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
993	7.3	1015	18.1	1037	40.102
993.5	7.414	1015.5	19.936	1037.5	40.46
994	7.612	1016	21.924	1038	39.894
994.5	8.164	1016.5	23.835	1038.5	39.337
995	8.9	1017	25.734	1039	39.308
995.5	9.737	1017.5	27.814	1039.5	39.624
996	10.839	1018	30.021	1040	39.96
996.5	10.538	1018.5	32.231	1040.5	39.38
997	10.436	1019	32.121	1041	38.72
997.5	10.257	1019.5	32.189	1041.5	38.125
998	9.188	1020	31.971	1042	38.361
998.5	10.199	1020.5	33.004	1042.5	39.064
999	11.295	1021	33.799	1043	40.048
999.5	12.11	1021.5	34.196	1043.5	40.486
1000	11.821	1022	35.075	1044	40.997
1000.5	11.743	1022.5	36.214	1044.5	41.411
1001	11.444	1023	37.607	1045	42
1001.5	10.885	1023.5	38.728	1045.5	42.456
1002	9.99	1024	39.411	1046	42.9
1002.5	9.644	1024.5	40.189	1046.5	43.234
1003	9.192	1025	40.812	1047	43.656
1003.5	8.446	1025.5	40.184	1047.5	43.489
1004	7.586	1026	39.468	1048	42.746
1004.5	7.097	1026.5	38.989	1048.5	40.673
1005	6.626	1027	38.47	1049	37.508
1005.5	6.121	1027.5	37.785	1049.5	34.166
1006	5.518	1028	37.451	1050	33.289
1006.5	5.22	1028.5	37.751	1050.5	32.434
1007	5.211	1029	38.535	1051	30.58
1007.5	6.151	1029.5	39.157	1051.5	27.808
1008	7.722	1030	39.373	1052	26.092
1008.5	9.271	1030.5	39.459	1052.5	25.478
1009	10.084	1031	40.098	1053	24.74
1009.5	9.767	1031.5	40.907	1053.5	24.032
1010	9.483	1032	40.935	1054	23.103
1010.5	9.699	1032.5	40.993	1054.5	23.69
1011	10.791	1033	41.139	1055	23.823
1011.5	12.224	1033.5	41.6	1055.5	23.813
1012	13.641	1034	41.017	1056	21.815
1012.5	14.015	1034.5	41.29	1056.5	18.311
1013	14.069	1035	41.191	1057	16.372
1013.5	14.358	1035.5	40.273	1057.5	14.689
1014	15.092	1036	39.656	1058	12.961
1014.5	16.305	1036.5	39.544	1058.5	12.053

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
1059	9.472	1081	0.755	1103	0.18
1059.5	6.76	1081.5	0.475	1103.5	0.147
1060	5.523	1082	0.297	1104	0.157
1060.5	4.069	1082.5	0.211	1104.5	0.212
1061	3.591	1083	0.871	1105	0.241
1061.5	3.149	1083.5	1.893	1105.5	0.278
1062	2.616	1084	1.706	1106	0.278
1062.5	1.892	1084.5	1.524	1106.5	0.218
1063	0.953	1085	1.37	1107	0.19
1063.5	0.623	1085.5	1.197	1107.5	0.217
1064	0.731	1086	1.018	1108	0.202
1064.5	0.961	1086.5	0.91	1108.5	0.184
1065	1.45	1087	0.847	1109	0.173
1065.5	2.39	1087.5	0.384	1109.5	0.169
1066	4.412	1088	0.285	1110	0.1
1066.5	4.787	1088.5	0.274	1110.5	0.074
1067	4.666	1089	0.252	1111	0.053
1067.5	4.528	1089.5	0.22	1111.5	0.044
1068	4.352	1090	0.199	1112	0.041
1068.5	4.124	1090.5	0.191	1112.5	0.042
1069	3.976	1091	0.192	1113	0.047
1069.5	3.885	1091.5	0.122	1113.5	0.069
1070	3.414	1092	0.092	1114	0.075
1070.5	2.295	1092.5	0.074	1114.5	0.109
1071	0.864	1093	0.06	1115	0.108
1071.5	0.688	1093.5	0.067	1115.5	0.12
1072	0.596	1094	0.091	1116	0.118
1072.5	0.587	1094.5	0.134	1116.5	0.104
1073	0.876	1095	0.122	1117	0.103
1073.5	1.688	1095.5	0.165	1117.5	0.078
1074	1.883	1096	0.16	1118	0.099
1074.5	1.79	1096.5	0.141	1118.5	0.117
1075	1.631	1097	0.14	1119	0.125
1075.5	1.487	1097.5	0.143	1119.5	0.117
1076	1.367	1098	0.131	1120	0.126
1076.5	1.196	1098.5	0.131	1120.5	0.12
1077	1.034	1099	0.135	1121	0.143
1077.5	0.896	1099.5	0.107	1121.5	0.123
1078	0.831	1100	0.094	1122	0.122
1078.5	0.802	1100.5	0.077	1122.5	0.127
1079	0.705	1101	0.082	1123	0.145
1079.5	0.66	1101.5	0.113	1123.5	0.169
1080	0.688	1102	0.151	1124	0.153
1080.5	0.817	1102.5	0.167	1124.5	0.136

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
1125	0.126	1147	0.654	1169	15.326
1125.5	0.114	1147.5	0.567	1169.5	16.137
1126	0.109	1148	0.481	1170	17.106
1126.5	0.069	1148.5	0.464	1170.5	18.497
1127	0.07	1149	0.427	1171	19.843
1127.5	0.052	1149.5	0.361	1171.5	21.23
1128	0.038	1150	0.285	1172	22.714
1128.5	0.069	1150.5	0.542	1172.5	23.9
1129	0.076	1151	1.256	1173	23.968
1129.5	0.102	1151.5	2.169	1173.5	23.263
1130	0.104	1152	3.526	1174	22.715
1130.5	0.116	1152.5	3.799	1174.5	23.113
1131	0.115	1153	3.634	1175	24.849
1131.5	0.113	1153.5	3.883	1175.5	26.229
1132	0.109	1154	4.481	1176	27.142
1132.5	0.118	1154.5	5.095	1176.5	27.579
1133	0.12	1155	4.967	1177	28.146
1133.5	0.109	1155.5	4.878	1177.5	29.147
1134	0.096	1156	4.821	1178	28.49
1134.5	0.087	1156.5	4.707	1178.5	28.691
1135	0.078	1157	4.905	1179	29.78
1135.5	0.09	1157.5	5.321	1179.5	31.449
1136	0.065	1158	5.894	1180	33.336
1136.5	0.058	1158.5	6.106	1180.5	33.942
1137	0.072	1159	5.854	1181	33.214
1137.5	0.045	1159.5	5.943	1181.5	30.716
1138	0.075	1160	6.725	1182	27.327
1138.5	0.088	1160.5	7.805	1182.5	26.531
1139	0.11	1161	8.979	1183	26.505
1139.5	0.116	1161.5	9.161	1183.5	27.483
1140	0.101	1162	9.133	1184	28.508
1140.5	0.151	1162.5	9.364	1184.5	28.999
1141	0.186	1163	8.997	1185	29.061
1141.5	0.216	1163.5	8.554	1185.5	29.172
1142	0.371	1164	9.411	1186	29.373
1142.5	1.142	1164.5	10.154	1186.5	30.398
1143	1.42	1165	11.091	1187	31.399
1143.5	1.125	1165.5	12.154	1187.5	31.213
1144	0.815	1166	13.756	1188	31.252
1144.5	0.583	1166.5	15.247	1188.5	32.117
1145	0.386	1167	16.52	1189	33.173
1145.5	0.372	1167.5	16.268	1189.5	34.299
1146	0.67	1168	16.077	1190	35.08
1146.5	0.739	1168.5	15.907	1190.5	34.943

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
1191	34.954	1213	30.112	1235	39.1
1191.5	35.642	1213.5	29.538	1235.5	39.779
1192	36.089	1214	28.884	1236	40.47
1192.5	36.387	1214.5	28.549	1236.5	41.003
1193	36.497	1215	28.647	1237	41.634
1193.5	36.397	1215.5	28.85	1237.5	42.181
1194	36.148	1216	29.396	1238	42.777
1194.5	35.99	1216.5	29.852	1238.5	43.355
1195	36.503	1217	29.673	1239	43.904
1195.5	37.554	1217.5	29.324	1239.5	44.688
1196	38.657	1218	29.735	1240	45.109
1196.5	39.535	1218.5	30.418	1240.5	45.266
1197	39.844	1219	30.554	1241	45.972
1197.5	40.634	1219.5	30.505	1241.5	46.986
1198	41.429	1220	30.709	1242	47.799
1198.5	41.851	1220.5	31.228	1242.5	48.642
1199	42.198	1221	30.327	1243	49.254
1199.5	42.24	1221.5	28.7	1243.5	49.649
1200	41.743	1222	28.032	1244	50.026
1200.5	40.942	1222.5	27.282	1244.5	50.65
1201	40.132	1223	27.023	1245	50.873
1201.5	39.537	1223.5	27.612	1245.5	50.923
1202	39.03	1224	28.534	1246	51.413
1202.5	38.43	1224.5	29.459	1246.5	52.215
1203	38.059	1225	30.595	1247	53.11
1203.5	37.972	1225.5	31.747	1247.5	53.31
1204	37.918	1226	32.942	1248	52.968
1204.5	37.635	1226.5	34.021	1248.5	52.722
1205	37.12	1227	34.972	1249	52.825
1205.5	36.593	1227.5	34.957	1249.5	53.315
1206	36.929	1228	32.536	1250	53.206
1206.5	37.635	1228.5	29.331	1250.5	52.714
1207	38.097	1229	28.589	1251	52.064
1207.5	37.865	1229.5	29.012	1251.5	51.762
1208	37.326	1230	30.004	1252	51.724
1208.5	36.831	1230.5	31.01	1252.5	51.985
1209	36.242	1231	32.117	1253	52.641
1209.5	35.417	1231.5	33.284	1253.5	52.685
1210	34.548	1232	34.287	1254	52.177
1210.5	33.98	1232.5	35.373	1254.5	51.72
1211	33.392	1233	36.435	1255	50.789
1211.5	32.439	1233.5	37.26	1255.5	49.886
1212	31.567	1234	37.877	1256	49.049
1212.5	30.796	1234.5	38.44	1256.5	47.966

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
1257	46.154	1279	33.131	1301	2.787
1257.5	44.636	1279.5	33.025	1301.5	2.334
1258	43.762	1280	32.898	1302	1.969
1258.5	43.215	1280.5	32.631	1302.5	2.697
1259	42.733	1281	32.295	1303	5.071
1259.5	42.661	1281.5	31.845	1303.5	6.085
1260	42.037	1282	30.96	1304	5.66
1260.5	41.642	1282.5	29.933	1304.5	5.94
1261	42.2	1283	28.793	1305	6.887
1261.5	43.065	1283.5	27.956	1305.5	6.987
1262	43.827	1284	27.147	1306	6.612
1262.5	44.059	1284.5	26.602	1306.5	6.247
1263	44.245	1285	26.062	1307	5.88
1263.5	44.473	1285.5	25.361	1307.5	5.401
1264	44.228	1286	24.48	1308	4.879
1264.5	43.649	1286.5	23.634	1308.5	4.736
1265	43.223	1287	22.855	1309	5.252
1265.5	42.827	1287.5	22.06	1309.5	4.539
1266	42.449	1288	21.225	1310	3.851
1266.5	42.475	1288.5	20.345	1310.5	3.229
1267	42.736	1289	19.373	1311	2.706
1267.5	42.741	1289.5	17.593	1311.5	2.712
1268	42.898	1290	15.7	1312	3.048
1268.5	43.431	1290.5	13.599	1312.5	2.94
1269	44.118	1291	10.673	1313	2.608
1269.5	44.214	1291.5	9.514	1313.5	3.162
1270	43.724	1292	8.961	1314	2.78
1270.5	43.453	1292.5	8.53	1314.5	3.599
1271	43.261	1293	7.958	1315	5.426
1271.5	43.608	1293.5	7.959	1315.5	6.784
1272	43.324	1294	7.923	1316	7.174
1272.5	42.939	1294.5	7.487	1316.5	7.161
1273	42.416	1295	7.172	1317	8.035
1273.5	41.718	1295.5	6.73	1317.5	8.157
1274	41.061	1296	6.302	1318	9.192
1274.5	40.362	1296.5	5.959	1318.5	9.2
1275	39.659	1297	5.552	1319	7.434
1275.5	38.91	1297.5	5.111	1319.5	6.72
1276	37.994	1298	4.68	1320	7.197
1276.5	37.06	1298.5	4.32	1320.5	7.729
1277	36.134	1299	3.908	1321	8.248
1277.5	35.192	1299.5	3.471	1321.5	8.448
1278	34.268	1300	3.386	1322	7.951
1278.5	33.445	1300.5	3.274	1322.5	7.496

Time (s)	Speed(km/h)	Time (s)	Speed(km/h)	Time (s)	Speed(km/h)
1323	8.078	1345	5.523	1367	8.534
1323.5	8.595	1345.5	6.262	1367.5	11.713
1324	9.652	1346	6.66	1368	13.956
1324.5	11.438	1346.5	7.65	1368.5	15.559
1325	13.165	1347	8.052	1369	15.967
1325.5	13.035	1347.5	7.734	1369.5	15.768
1326	12.813	1348	7.541	1370	15.86
1326.5	12.577	1348.5	7.143	1370.5	15.716
1327	12.262	1349	6.893	1371	15.786
1327.5	12.386	1349.5	7.668	1371.5	15.77
1328	13.124	1350	8.544	1372	15.475
1328.5	14.162	1350.5	8.064	1372.5	14.902
1329	14.245	1351	6.921	1373	13.627
1329.5	13.157	1351.5	5.81	1373.5	10.976
1330	12.332	1352	5.668	1374	9.751
1330.5	11.534	1352.5	6.703	1374.5	9.816
1331	11.158	1353	6.912	1375	9.81
1331.5	9.067	1353.5	5.987	1375.5	9.839
1332	6.27	1354	4.864	1376	9.529
1332.5	4.355	1354.5	4.383	1376.5	8.897
1333	3.101	1355	4.558	1377	7.958
1333.5	1.758	1355.5	4.323	1377.5	7.008
1334	1.48	1356	4.484	1378	5.097
1334.5	1.371	1356.5	4.649	1378.5	3.91
1335	1.314	1357	5.231	1379	2.319
1335.5	1.42	1357.5	5.594	1379.5	2.002
1336	1.722	1358	6.555	1380	2.516
1336.5	2.539	1358.5	6.891	1380.5	4.225
1337	2.311	1359	6.859	1381	5.267
1337.5	1.996	1359.5	6.559	1381.5	5.011
1338	1.581	1360	5.157	1382	4.845
1338.5	1.477	1360.5	4.867	1382.5	4.178
1339	2.054	1361	4.997	1383	2.308
1339.5	3.372	1361.5	5.651	1383.5	1.081
1340	4.959	1362	7.243	1384	0.263
1340.5	6.391	1362.5	8.769	1384.5	0.155
1341	6.485	1363	8.406	1385	0.217
1341.5	6.507	1363.5	8.096	1385.5	0.277
1342	6.87	1364	7.549	1386	0.312
1342.5	7.146	1364.5	4.173	1386.5	0.339
1343	6.967	1365	3.725	1387	0.317
1343.5	6.718	1365.5	3.833	1387.5	0.336
1344	6.029	1366	4.453	1388	0.344
1344.5	5.496	1366.5	5.954	1388.5	0.321

Time (s)	Speed(km/h)
1389	0.274
1389.5	0.298
1390	1.755
1390.5	0.784
1391	0.539
1391.5	0.703
1392	0.806
1392.5	0.92
1393	0.898
1393.5	1.086
1394	1.093
1394.5	1.053
1395	1.171
1395.5	1.153
1396	1.076
1396.5	1.009
1397	0.95
1397.5	0.977
1398	1.002
1398.5	1.014
1399	0.951
1399.5	0.839
1400	0.83
1400.5	0.752
1401	0.712
1401.5	0.589
1402	0.515
1402.5	0.421
1403	0.402
1403.5	0.369
1404	0.293
1404.5	0.271
1405	0.277
1405.5	0.389
1406	0.562

APPENDIX C: MODELS IN SIMULINK

APPENDIX D: MATLAB/PYTHON CODES

1. Python Code to Convert ULOG File into CSV File

usage: ulog2csv [-h] [-m MESSAGES] [-d DELIMITER] [-o DIR] file.ulg

Convert ULog to CSV

positional arguments:

file.ulg ULog input file

optional arguments:

-h, --help show this help message and exit

-m MESSAGES, --messages MESSAGES

 Only consider given messages. Must be a comma-separated list of names, like

 'sensor_combined,vehicle_gps_position'

-d DELIMITER, --delimiter DELIMITER

 Use delimiter in CSV (default is ',')

-o DIR, --output DIR Output directory (default is same as input file)

2. Plot Codes

```
clc
```

```
clear all
```

```
Time=xlsread('Final Model.xlsx','HWFET','A5:A7655');
```

```
B1=xlsread('Final Model','HWFET','B5:B7655');
```

```
B2=xlsread('Final Model','HWFET','C5:C7655');
```

```
Time1=xlsread('Final  
Model.xlsx','WLTC2','A5:A14775');
```

```
B3=xlsread('Final Model.xlsx','WLTC2','B5:B14775');
```

```
B4=xlsread('Final Model.xlsx','WLTC2','C5:C14775');
```

```
Time2=xlsread('Final Model.xlsx','FLEET','A5:A7855');
```

```
B5=xlsread('Final Model.xlsx','FLEET','B5:B7855');
```

```

B6=xlsread('Final Model.xlsx','FLEET','C5:C7855');

Time3=xlsread('Final Model.xlsx','EXP','A5:A14005');
B7=xlsread('Final Model.xlsx','EXP','B5:B14005');
B8=xlsread('Final Model.xlsx','EXP','C5:C14005');

figure
plot(Time,B1,Time,B2);
box on
grid on
legend('No Regen','50% Regen');
xlabel('Time(sec)');
ylabel('Battery Energy at Terminals(kWh)');
title('Battery Energy vs. HWFET Cycle');

figure
plot(Time1,B3,Time1,B4);
box on
grid on
legend('No Regen','50% Regen');
xlabel('Time(sec)');
ylabel('Battery Energy at Terminals(kWh)');
title('Battery Energy vs. WLTC-Class 2 Cycle');

figure
plot(Time2,B5,Time2,B6);
box on
grid on
legend('No Regen','50% Regen');
xlabel('Time(sec)');
ylabel('Battery Energy at Terminals(kWh)');
title('Battery Energy vs. FLEET Cycle');

figure
plot(Time3,B7,Time3,B8);
box on
grid on
legend('No Regen','50% Regen');
xlabel('Time(sec)');
ylabel('Battery Energy at Terminals(kWh)');
title('Battery Energy vs. Drive Cycle');

```

```

clc
clear all

Time=xlsread('SOC.xlsx','HWFET','A5:A7655');
SOC1=xlsread('SOC.xlsx','HWFET','B5:B7655');
SOC2=xlsread('SOC.xlsx','HWFET','C5:C7655');
SOC3=xlsread('SOC.xlsx','HWFET','D5:D7655');
SOC4=xlsread('SOC.xlsx','HWFET','E5:E7655');

Time1=xlsread('SOC.xlsx','WLTC2','A5:A14775');
SOC5=xlsread('SOC.xlsx','WLTC2','B5:B14775');
SOC6=xlsread('SOC.xlsx','WLTC2','C5:C14775');
SOC7=xlsread('SOC.xlsx','WLTC2','D5:D14775');
SOC8=xlsread('SOC.xlsx','WLTC2','E5:E14775');

Time2=xlsread('SOC.xlsx','FLEET','A5:A7855');
SOC9=xlsread('SOC.xlsx','FLEET','B5:B7855');
SOC10=xlsread('SOC.xlsx','FLEET','C5:C7855');
SOC11=xlsread('SOC.xlsx','FLEET','D5:D7855');
SOC12=xlsread('SOC.xlsx','FLEET','E5:E7855');

Time3=xlsread('SOC.xlsx','EXP','A5:A14005');
SOC13=xlsread('SOC.xlsx','EXP','B5:B14005');
SOC14=xlsread('SOC.xlsx','EXP','C5:C14005');
SOC15=xlsread('SOC.xlsx','EXP','D5:D14005');
SOC16=xlsread('SOC.xlsx','EXP','E5:E14005');

figure
plot(Time,SOC1,Time,SOC2,Time,SOC3,Time,SOC4);
box on
grid on
legend('0%','30%','50%','80%');
xlabel('Time(sec)');
ylabel('SOC(%)');
title('SOC vs. Time')

figure
plot(Time1,SOC5,Time1,SOC6,Time1,SOC7,Time1,SOC8);
axis([0 1490 80 96])
box on
grid on
legend('0%','30%','50%','80%');
xlabel('Time(sec)');
ylabel('SOC(%)');
title('SOC vs. Time');

```

```

figure
plot (Time2, SOC9, Time2, SOC10, Time2, SOC11, Time2, SOC12);
box on
grid on
legend('0%', '30%', '50%', '80%');
xlabel('Time(sec)');
ylabel('SOC(%)');
title('SOC vs. Time');

```

```

figure
plot (Time, SOC3, Time1, SOC7, Time2, SOC11);
box on
grid on
legend('HWFET', 'WLTC2', 'FLEET');
xlabel('Time(sec)');
ylabel('SOC(%)');
title('SOC vs. Time')

```

```

figure
plot (Time3, SOC13, Time3, SOC14, Time3, SOC15, Time3, SOC16)
;
box on
grid on
legend('0%', '30%', '50%', '80%');
xlabel('Time(sec)');
ylabel('SOC(%)');
title('SOC vs. Time')

```

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