

A REPORT
ON
SMALL COMMERCIAL VEHICLE: POWERTRAIN OPTIMISATION

BY

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ID. No.(s)

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2019A4PS0368P
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AT

SIRIUS MOTORSPORTS, CHENNAI

A Practice School-I Station of



BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI
(July 2021)

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**BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE PILANI
(RAJASTHAN)
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Title of the Project: Small Commercial Vehicle: Powertrain Optimisation

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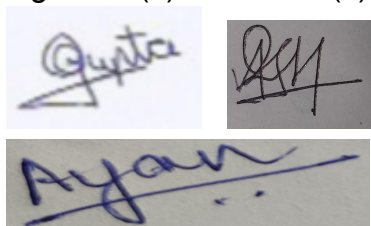
Key Words: Powertrains, hybrid vehicle, Simulink, Power Management Strategies, Simulations, Control Strategies, etc.

Project Areas: Electric vehicle, simulation and modelling, developing control strategies.

Abstract: The project for our group at PS-I station, Sirius Motorsports is “Small Commercial Vehicle Powertrain Optimisation” This report describes all that we have learnt and worked on in the full duration of 7 weeks of PS-I. We first learned the fundamentals of IC engines via video modules, books and online lectures by PS faculty (primarily on ReynLab). These lectures were in parallel with lectures by industry mentor on more practical aspects of our projects. We also learnt the basics of using MATLAB and Simulink for calculations and some basic modelling techniques. Besides, we also tried our hands on Ricardo Wave and Ricardo Ignite tutorials of which were provided by the Practice School Faculty and even a webinar was held to get us on the platform.

Signature(s) of Student(s):

Signature of PS Faculty:



Date: 16th July, 2021

Date:

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1. Introduction

Sirius Motorsports started off as an engine calibration firm catering to race cars in 2010. Today, along with ECU and engine tuning services, they also provide training services in the field of automobiles through tie-ups with ReynLab, started by Mr Sajeeth Kumar who is also the founder of Sirius Motorsports.

The project we are currently working on is how an electric motor could be introduced into the powertrain. In an effort to arrive at a control strategy that enables the same, we have been taught various concepts and have been introduced to different software applications that will play a vital role in our project. As of this point in time, we have learned about the fundamentals of IC Engines, the various systems involved in an IC engine and how each system contributes to its performance. We have also been introduced to basic control strategies and engine calibration. This has been useful in understanding how we are to go about our project and understanding what is required of us as a group. The main objective of the project will be to model a Simulink (or Ricardo Ignite) model of the powertrain and optimize it to fulfil the requirements of an SCV.

The software that we are currently learning includes MATLAB, Simulink, Ricardo Wave as well as Virtual Dyno. We have learned about how MATLAB can be used for various data analysis as well as the use of Simulink in devising basic control strategies. A brief introduction to engine calibration was facilitated by ReynICE, a software developed by ReynLab that provides a virtual dynamometer as well as an ECU to make tuning more convenient for students.

Our project involves running motor simulations to obtain the necessary data with respect to powertrains to understand how it behaves and changing the different parameters of powertrains to improve the performance of the vehicles. Hence, the majority of the project will be work that involves the use of Simulink.

The significance and role of each software as well as our learning experience will be expanded upon further in the report.

1.1 Powertrain

A powertrain is an assembly of every component that pushes your vehicle forward. Your car's powertrain creates power from the engine (or motor) and delivers it to the wheels on the ground. If any of these components become neglected or experience malfunctions then it can affect the performance of other car parts in succession.



Fig 1.1: ICE Powertrain

1.2 Components Of Powertrain

Main Components of a 'Internal Combustion Engine' Powertrain

Engine: As the heart of your vehicle, an engine generates power to drive the car. An engine consists of pistons that move up and down inside cylinders and a crankshaft that translates the reciprocating motion into a rotating motion.

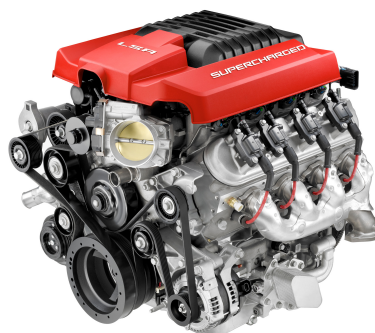


Fig 1.2: Engine

Transmission: A transmission is a basic component in your car that makes sure the proper amount of power is transmitted to the wheels. Like a car's gearbox, the transmission takes the power from the engine and adjusts it according to driving conditions, ultimately transferring it to the wheels.

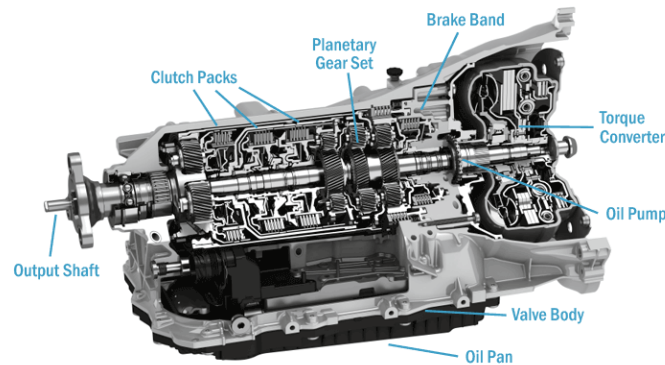


Fig 1.3: Transmission

Driveshaft: A driveshaft is a component that transfers the torque from the transmission to the wheels. To perform this task, it has to work through various angles and change its length to adjust to movement in the suspension.



Fig 1.4: Driveshaft

Axles: Axles are an important member of a powertrain. It lies between the wheels and mainly performs two functions: first, it puts up with the weight of the vehicle and it also rotates and transmits the power of the engine to the wheels.



Fig 1.5: Axle

Differential: A differential is a part of the rear axle. It allows each rear wheel to turn at a different speed. For instance, the differential is essential when turning a corner, as the outside wheel needs to rotate faster than the inside wheel.

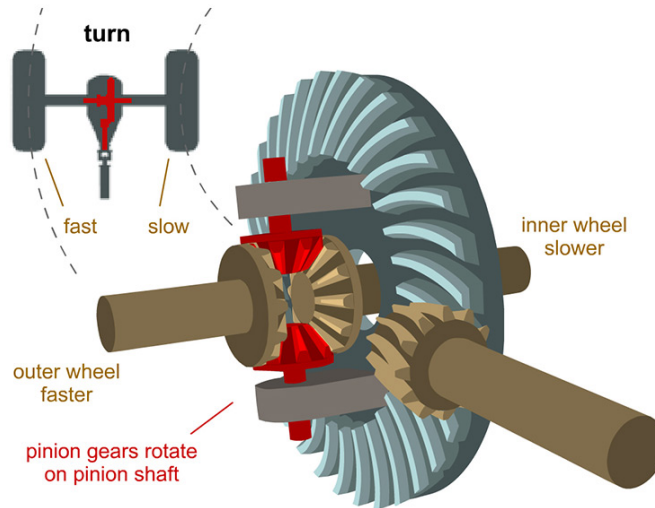


Fig 1.6: Differential

Main Components of an 'Electric Vehicle' Powertrain

Electric Motor: Converts electrical energy to mechanical energy that is delivered to the wheels via single ratio transmission. Many Evs use motor generators that can perform regeneration as well.

Battery Pack: The battery pack comprises of multiple lithium-ion cells and stores the energy needed to run the vehicle. Battery packs provide direct current (DC) Output.

DC-AC Converter: The DC supplied by the battery pack is converted to AC and provided to the electric motor. This conversion is managed by a motor control mechanism that controls the frequency and magnitude of the voltage supplied to the electric motor to drive the speed and acceleration as per the driver's inputs.

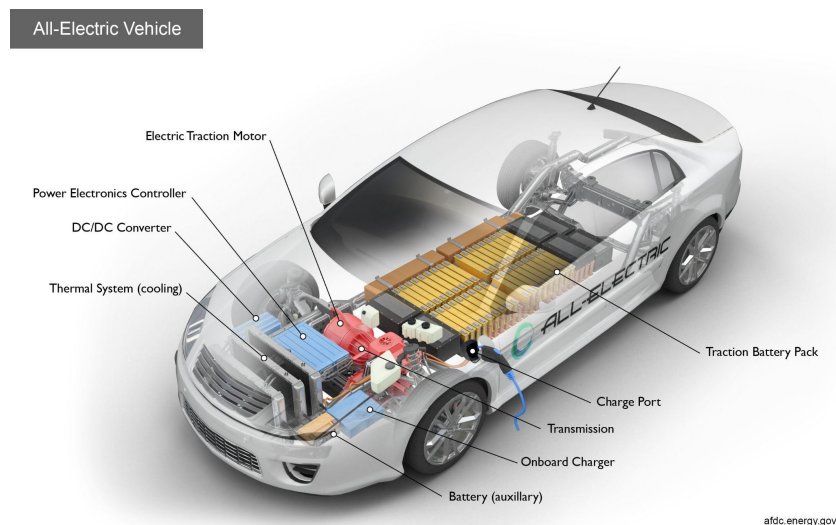


Fig 1.7 Electric Vehicle Powertrain and its components

On-board charger: Converts AC received through the charge port to DC and controls the amount of current flowing into the battery pack.

There are Multiple Electronic Control Units (ECUs) in the EV powertrain:-

Battery management system (BMS): A BMS continuously monitors the state of the battery and is responsible for taking necessary measures in case of a malfunction. It is also responsible for communicating with other ECUs and sensors.

DC-DC converter: A battery pack delivers a fixed voltage, but the requirement of different accessories in the EV would vary. The DC-DC converter helps distribute power to different systems by converting the output power from the battery pack to the expected level.

Thermal Management system: Responsible for maintaining optimum operating temperature range for powertrain components.

1.3 Different Types of Powertrain and it's Technologies

Different types of 'Internal Combustion Engine' Vehicle Powertrain Technologies

In ICE vehicles the main power source is the Engine of the car. To define different types of Powertrain for an ICE vehicle, we can include the use of different types of Engines, Transmissions, and differentials.

ICE Engines: Mainly two types of engines are used in the cars, i.e, spark ignition Engine and Combustion ignition engine and use petrol and diesel as fuel respectively.

Transmission: Transmission is the main component to moderate the power and torque coming from the engine. There are different types of transmissions in cars nowadays.

Manual transmission: It is a multi speed transmission and requires the manual input from the driver via a gear stick and clutch to shift gears and moderate the output to the wheels. Constant mesh gear box is the most commonly used technology in Manual transmission. Clutch is used to separate power from the engine to the transmission gearbox for smooth shifting of gears.

Automatic Transmission: The gears in automatic transmission are controlled by a computer unit and changes automatically to the required gear ratio according to the speed and acceleration of the car. Torque converters are used in automatic transmission in place of the clutch to increase the torque to the wheels and it also works as the clutch to disengage power from the engine to the transmission gearbox. Automatic manual transmission (AMT), Continuous variable transmission (CVT),

Dual-clutch Transmission (DCT) are some of the examples of fully automatic and semi-automatic Transmission systems in modern cars.

Different types of Electric Vehicle Powertrain Technologies

There are three main types of electric vehicles (EVs). BEVs, or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs, or hybrid electric vehicles.

BEV: Battery electric vehicles (BEVs) are powered solely by batteries. They use an electric motor to turn the wheels and produce zero emissions.

PHEV: Plug-in hybrids are capable of zero-emission driving, typically between 20-30 miles, and can run on petrol or diesel for longer trips. As the name suggests, they need to be plugged into an electricity supply in order to maximise their zero-emission capability.

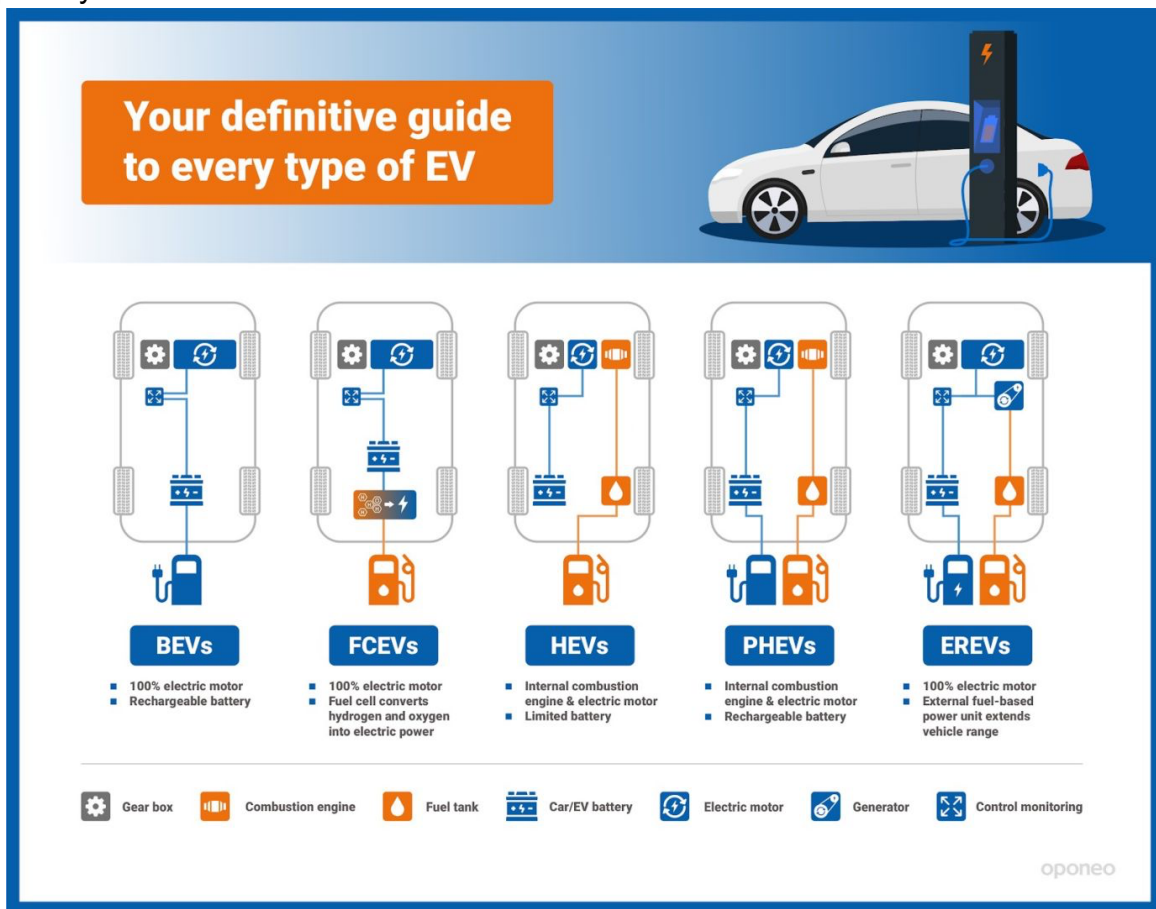


Fig 1.7: Different types of electric vehicles.

HEV: Hybrid Electric Vehicles (HEVs) are capable of zero-emission driving but typically over less range than a PHEV. They use electric power generated during braking to improve fuel economy and run on petrol or diesel for longer trips.

MHEV: Mild Hybrid Electric Vehicles (MHEVs), sometimes known as hybrid assist vehicles, have a petrol or diesel internal combustion engine equipped with an electric motor that can allow the engine to be turned off as the car is coasting or braking. The motor can also be used to provide assistance to the engine, reducing fuel consumption and CO2 emissions. MHEVs cannot be driven on electricity alone.

FCEV: Fuel Cell Electric Vehicles (FCEV) are zero-emission electric vehicles, which use hydrogen fuel cells to generate power. Hydrogen stored in an onboard fuel tank is combined with oxygen in the fuel cell, and the only outputs are electricity, heat and water.

1.4 Objectives of Project

Our project is related to small commercial vehicles, for which electrification seems difficult due to its small size and specifications as compared to the existing EVs in India. The key lies in optimizing the powertrain and several other components so that most of the vehicles can have an option to switch to battery electric vehicles or plug-in hybrid electric vehicles. The Indian start-up scenario is looking at electric mobility as the next big evolution. Delhi-based Euler Motors, an automotive technology start-up focussed on EVs, has announced its plan to launch an electric three-wheeler in the small commercial vehicle category in the first half of 2020. The company claims that around 100 prototype EVs are already running on the Delhi-NCR roads used by companies like BigBasket, EcomExpress, BlueDart and Udaan among others for their last-mile delivery. Saurav Kumar, founder and CEO, Euler Motors said, “Euler Motors is working towards providing sustainable last-mile transportation by accelerating the adoption of EVs. We understand the challenges of the sector, but we believe that our indigenously created battery pack and upcoming innovation in light commercial vehicles will set industry standard and thereby help the ecommerce companies, logistics providers and independent fleet owners”. The company claims that at present the range of the electric small commercial vehicles, which has a payload capacity of 500kg, is 80-100km. The objective of our project is to quantify the requirements, speculate, identify components, model and simulate the powertrain for real world conditions. Project outcomes will give us mathematical models to represent behavior and performance of the small commercial vehicles.

2. Literature and Market Survey

2.1 Literature Survey

As the global population continues to grow, the need for increased logistics, infrastructure and agricultural production do also. As a result, improving commercial diesel powertrain efficiency as well as electrifying them, and reducing its climate and emissions footprint has become a major topic of focus. Using typical commercial applications from the market, we will discuss the measures to optimise different parameters to efficiency enhancing and promising technologies.

Due to the sheer number of units, on-road applications contribute significantly more energy consumption, as well as pollutant emissions, compared to mobile machinery. Until 2040, commercial on-road vehicles are forecasted to increase energy consumption by 1.4 percent year-over-year. During this time, a majority of the transportation will be sourced by liquid fuels.

While starting our research on electric LCVs, we came across many startups and companies. Tata has been actively working on this and we found the innovation challenge they are holding in Europe where they had explained the difficulties faced and what all they expect as the final outcome of the project. Even Ashok Leyland has been planning to launch an electric LCV by next year. However, they haven't launched the specifications due to market competition. Amidst all these, I came across this startup called Etrio.

Etrio, A Pune based startup retrofitted a Tata ace with a 20kWh battery on a 96V system to shell a range of 120 km. It is equipped with a 15kW power motor providing a torque of 120 Nm and can handle gradients of 7 degrees. However it has a cost of 7.75 lacs which might not be very attractive.

We also came across the government rule that all commercial vehicles can only have a maximum speed of 60 km/hr on city roads^[1]. This is important because we can give up a bit on maximum speed if that increases the range or the peak torque while tuning the parameters of the powertrain. We plan to have a performance somewhere close to this.

During this period, we came across a few papers which helped us get an idea about the research and development in this field. We read this paper^[2] which looked quite helpful. It explained the single objective optimization and multi objective optimization, how many companies go on with optimizing just one parameter or many at a time. They explained how changing one parameter has an opportunity cost on other parameters. Hence it made much sense to go with Multi Objective Optimization.

But here's the catch, with altering so many parameters at the same time, computation cost increases. In order to tackle this, they had proposed an idea of a two stage optimization, where the first model was for the motor which inputs the max current and voltage and outputs the torque curves for the motor. The other model was for vehicle dynamics. So the two models worked in parallel and reduced simulation time. The vehicle model requirements were: motor power, acceleration time, and energy consumption, and the design parameters are presented as the voltage and current of the motor and the gear ratio of the transmission.

Hence we finally had the max current, voltage and the gear ratio to optimize. Even this was difficult to individually test all combinations, so they had implemented an Artificial Neural Network (ANN) which computed the cost (difference in performance between current and surrogate model) and tried to converge it.

This approach seemed interesting and useful because if it's implemented once, we just need to change the parameters of the motor and the vehicle according to our needs and the algorithm will take care of the rest to output the best performance.

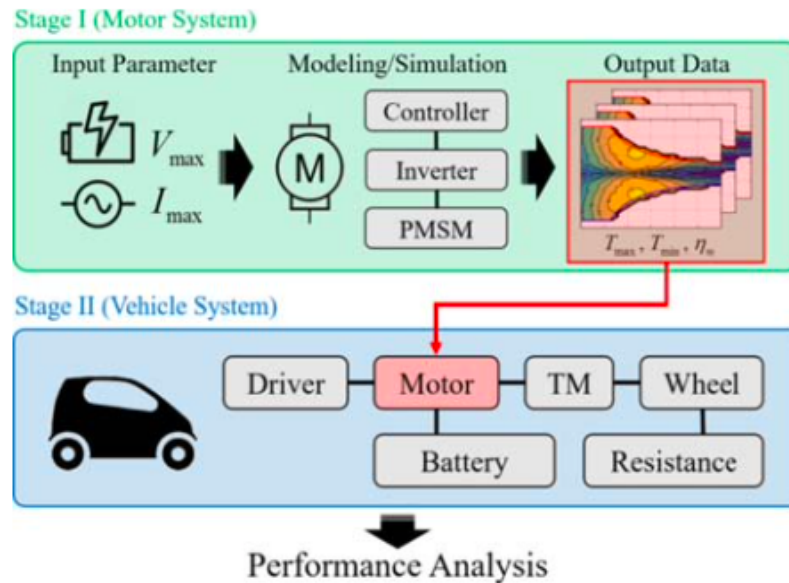


Fig 2.1 Configuration of two-stage analysis model

However, we were facing problems in computing this in simulink and this would output any decimal value so we would have to deal with the manufacturing processes for the gears. Therefore, our mentors suggested that we go with the standard gear ratios. On looking a bit for them, we found another interesting paper^[3], which had implemented the gear ratios of 1:6, 1:8 and 1:10 only as they were easily available and then had drawn inferences on how they affect the different parameters of automobile performance which we decided to try too. And finally, we read a research paper^[4] which got us acquainted with electric vehicle architecture. It had all the necessary equations that would have been useful to us in implementing the gradient descent algorithm for powertrain optimisation.

We also came across a product called a Powertrain Blockset that seemed to be helpful in designing and optimizing the powertrain in Simulink.^[5] Apart from this, Mathworks Racing Lounge had another vehicle modelling package which had EV as an option^[6]. Here are some Small Commercial Vehicles which we have studied and tried to convert them to a Simulink Model.

2.2 Market Survey

Tata Ace Electric: Tata Ace Is a commercial electrical vehicle van / van with a capacity of load of more than 750 kg. One of the big aims that has posed the company in the last years is the one to put at the front in what sustainable transport represents. A good sample of this is this Tata Ace, a small vehicle of ideal light load for any type of business. It is perfect so much for its use in cities as for rural areas. Its versatility for different uses and the low operative costs that it offers make it a profitable option for the transport of commodities. The Tata Ace has an electrical propellant of 5.2 kWh, with which reaches the 40 km/h, and has an autonomy of some 50 km, that recharges connecting it to a normal network. The technology is based on sour lead (Gel), with a capacity of 85 Ah, and a time of recharge to 100% of 7 hours. The dimensions of the vehicle are perfect for the load (Long x High x Wide): 3.788 x 1.828/1.585 x 1.500 and the dimensions of the box (Long x High x Wide): 2.200 x 1.470 x 300.



Fig 2.2 Tata Ace Electric

Mahindra Bolero Maxi Truck: The Mahindra Bolero Maxitruck Plus has Diesel Engine on offer. The Diesel engine is 2523 cc. It is available with the Manual transmission. Depending upon the number of tyres and body type the loading capacity of Bolero Maxitruck Plus is 1200 Kg. The Mahindra Bolero Maxitruck Plus is a Pickup and has a length of 4925 mm, width of 1700 mm and a wheelbase of 3150mm. It has a fuel tank of 45 Litres capacity and gross vehicle weight of 2700 Kg.



Fig 2.3 Mahindra Bolero Maxi Truck

Ashok Leyland Dost: The Ashok Leyland Dost Strong is one of the topmost mini-truck models manufactured by the company under the Dost lineup. The vehicle is specially designed to offer superior performance with the help of its extended payload and uncompromising operating provisions. It comes with an exceptionally spacious and comfortable cabin which enables the driver to drive for longer hours. The vehicle comes in three variants namely, Ashok Leyland DOST STRONG LE, Ashok Leyland DOST STRONG LS, and Ashok Leyland DOST STRONG LX. While the basic features are the same for all the variants, they are available in two colours, White and Irish-Cream. Furthermore, the vehicle is equipped with a robust engine that can move the vehicle effortlessly at its fully loaded condition. Along with this, the enhanced fuel efficiency helps to minimize fuel consumption and offers higher mileage. However, some additional features are available to improve safety and comfort. The gross vehicle weight of Ashok Leyland Dost Strong is measured at 2,545 kg. In the case of payload, it is rated at 1,250 kg. The dimension of the load body is specified as 2500 mm x 1620 mm x 380 mm. The extended load body enables the vehicle to transport more goods and commodities easily. Besides this, a ground clearance of 177 mm is there. With the help of a 2350 mm wheelbase, the vehicle offers a minimum turning radius of 5.85 m. It helps the driver to have better control and stability while navigating through a small city lane. A fuel tank of 40-litre capacity is available with the vehicle.



Fig 2.4 Ashok Leyland Dost

3. Methodology

3.1 Software Applications

The software we have been introduced to include - MATLAB, Simulink

1. MATLAB

MATLAB is a numerical computing software and programming language. MATLAB allows its user to carry out mathematical and trigonometric operations and plot graphs. It also allows matrix manipulations, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.

- It has built-in graphics for the visualisation of data and tools for the creation of custom plots.
- It provides an interactive environment for iterative exploration, design and problem-solving.
- It helps in solving linear algebra, integration and differential equations.
- It also has development tools for improving code equality and maintainability.
- It also has tools for maximising performance.

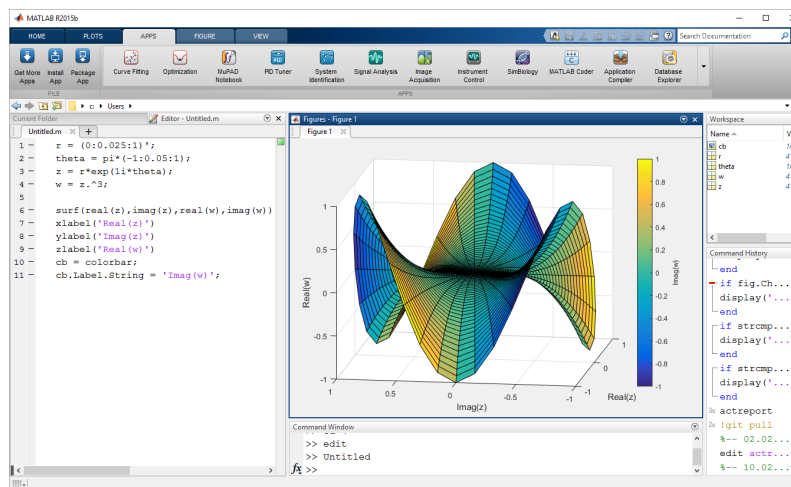


Fig 3.1: MATLAB interface

2. Simulink

Simulink is an additional package in MATLAB which provides an environment for multi-domain modelling and simulation software. It provides a wireless environment for design control. Using this, one can design and simulate systems before moving to hardware without having to write C, C++, or Hardware descriptive language code.

It allows a model-based design that supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. It has a graphical editor for modelling components of a system and has a library of pre-programmed algorithms for modelling and physical conditions. It can also be used for comparing different situations and results from other simulations, hence providing a more comprehensive environment for testing.

3.2 Driving cycle

The Drive cycle is one of the techniques used by a vehicle's PCM (Powertrain Control Module) to ensure that an emission system test is performed successfully. It is a series of data points representing the vehicle's speed on the vertical axis and time on the horizontal axis. Different drive cycles are set by different countries and authorities to determine the vehicle's performance in various ways, for example, polluting emissions and fuel consumption.

There are two kinds of driving cycles:

1. The modal cycle is the European standard NEDC, Japanese 10-15 MODE.
2. The transient cycles are the FTP-75, IDC, or Artemis cycle.

A Modal cycle is a Velocity v/s Time plot having regions of both linear acceleration and uniform velocity. They involve protracted periods at constant speeds and are representative of actual driver behaviour. The transient cycles involve speed variations, representing the continuous speed changes typical of on-road driving.

In India, the ARAI (Automotive Research Association of India) provides technical expertise in testing and certification, homologation, and framing of vehicle regulations. The IDC (Indian Driving Cycle) was first developed by ARAI in 1985 under the Central Motor Vehicles Rules of India. The cycle was based on actual on-road measurements and is still followed to test emissions for two/ three-wheelers. IDC (for 1981, 92 & 98 norms for 4W) was a concise cycle (although comprising six driving cycle modes) of just 108 seconds and did not cover all the different driving conditions observed on the road. The average speed of IDC is 21.9 km/h, covering 3.94km, which also seems to be high in view of rising congestion in Indian cities. Moreover, all two-and-three wheeler vehicles except diesel vehicles are run with 40 seconds idling as preconditioning before sampling on a chassis dynamometer. The modified IDC introduced a few years ago is 1180 sec long and covers a total distance of about 10.647 km. The organisation carefully worked on the driving cycle and took urban streets, rural roads and highways or motorways running conditions and predicted how the vehicle would behave in these scenarios.

Next up, we had to get the motor data. Our mentor suggested that we should go with this company <https://emf-i.com/> and we chose the 3kW, 4kW, 5kW and 6kW ones. The rest had lesser capacity, and we faced troubles with getting them to push the required payload. Seeing the Etiro's motor capacity of 15kW, we knew we wouldn't be able to achieve that much efficiency. Still, we can try improving the torque that it provides by testing various gear ratios.

Initially, we had planned to go with the gradient descent algorithm, which computes the gradient of a cost function which was a parameter that we wanted to optimise for example range or the payload that we wanted to lift. It would be dependent on the gear ratio and we can differentiate the cost function with respect to the gear ratio. Then finally update the gear ratio according to equation 3.1:

$$i = i - \gamma \cdot \frac{\partial \phi}{\partial i} \quad \text{-- (3.1)}$$

Where i : gear ratio ,
 ϕ : cost function and
 γ : learning parameter

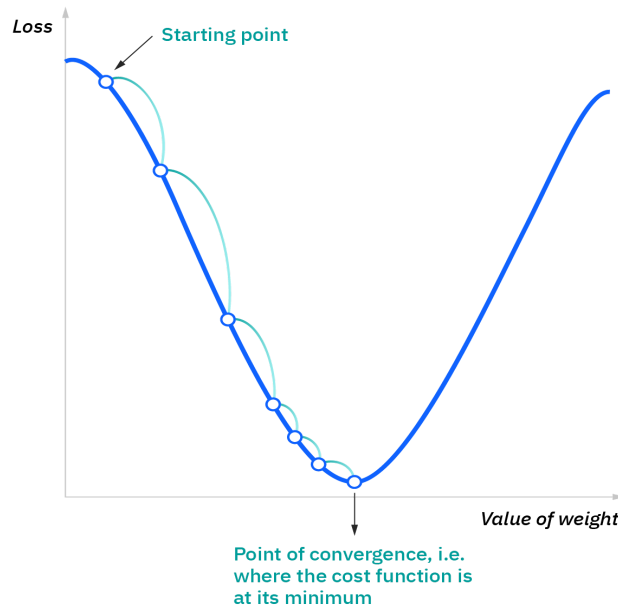


Fig 3.3: Illustration of the basic functioning of gradient descent

However, our mentor advised that although this was a valid option to adopt, this will have certain limitations as very likely, we'll obtain a gear ratio that won't be available easily. Moreover, we'll have to look into the manufacturing process of them as well. Besides, we need to iteratively update the gear ratio, which doesn't happen on Simulink. So they suggested using the standard gear ratios, which were readily available and in a few papers, we found this approach too, which made us test the model with the standard ratios of 1:6, 1:8 and 1:10.

We needed to test the model on a particular Drive cycle which we chose as the UDDS. This was closest to the Indian road condition from the available options in the model.

So we started with a 6kW motor and tested the motor torque, range, traction force at wheels and velocity response to the driver commands on a UDDS drive cycle. Earlier models didn't work well, and we had to change the parameters like weight and payload along with battery capacity. We decided on a battery capacity of 12.3 kWh since anything greater will increase the weight and cost of the battery pack, which is made of lithium-ion cells. On testing all the three gear ratios, the results of maximum current and motor torque were quite similar(although the 1:6 gear ratio uses slightly less current hence having a few more kilometres in the range), but the traction force had lots of variation. The 1:10 gear provided a maximum force of 2188 Nm at the wheels, which meant more payload could be carried by the vehicle as compared to 1:6 (997 Nm) and 1:8 (1312 Nm) ones. Hence giving up a bit on range made sense since they all provided a working range well above 80 km, our initial target.

Moreover, we had set the payload to 700 kg for all our simulations and a kerb weight of 850 kg. We even accounted for the accessory power devices like the sensors, headlights, etc., in our model to get a realistic idea of the range. As shown in the graphs below, the 1:6 gear wasn't able to provide enough torque to push the vehicle beyond 50 mph(80 kmph) and was even slow in delivering the acceleration since the traction force was less than the 1:10 gear ratio.

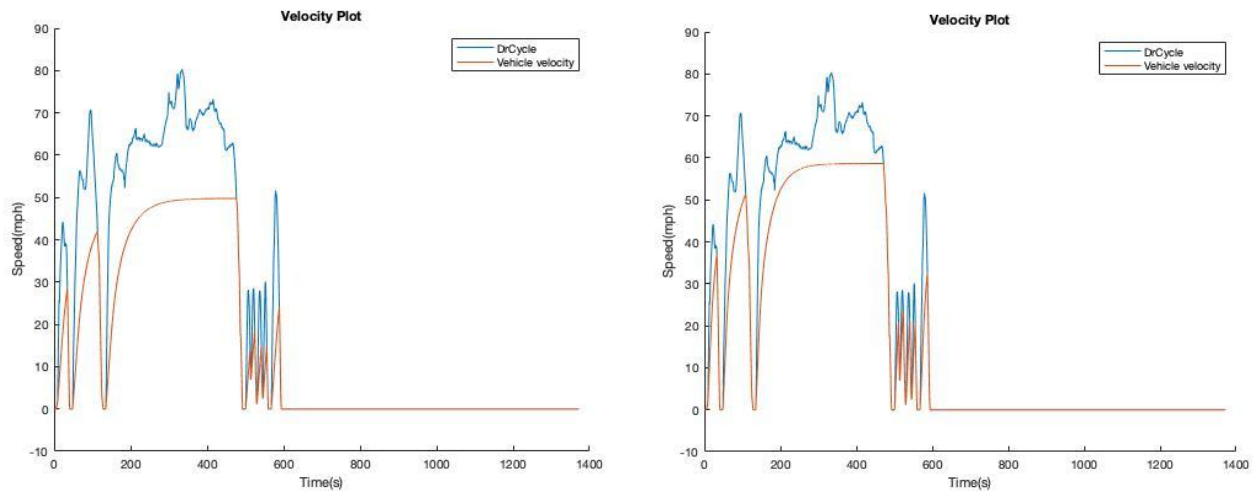


Fig 3.4: Velocity response for 6kW motor for a) 1:6 gear ratio and b) 1:10 gear ratio.

Hence it was more alluring to go with a 1:10 transmission due to more payload and quicker response (acceleration), and we carried out the results for other motors at 1:10 gear ratio only. The predicted range from the SOC drop levels for this model came to be **88 km**.

4. Results and Discussion

In order to ‘electrify’ an SCV, it is important that we observe that the preliminary step of downsizing the engine should also be thought of, for the analysis of weight reduction. This will result in partially increased performance. However, the transmission gear ratios and the shifting strategy (for automatic transmission vehicles) were optimized in order to get the maximum possible benefits, equalizing the performance of all vehicles within the segment as much as possible. The impacts of weight and load reduction on system size and cost should be assessed. Improvements in battery power density should be considered and current ICE specifications were used for cost assessments.

4.1 Result

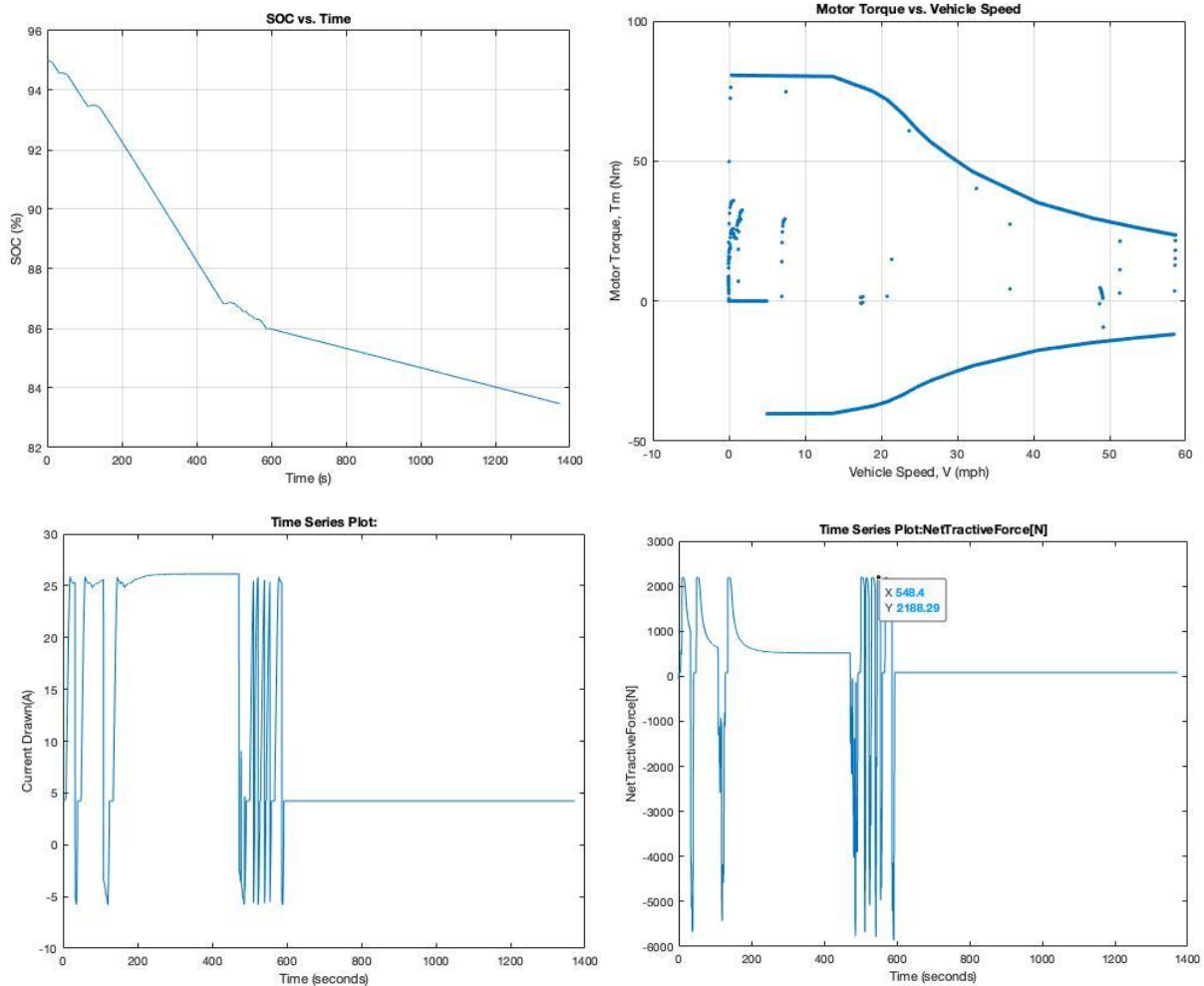


Fig 4.1: Observed parameters for the 6kW motor: a) SOC level, b) Motor torque v/s speed c) Current draw variations d) Variation of Traction force at wheels.

As can be seen from the first plot, the more power exerted by the motor, the more is the SOC drop, and in between, it gets charged too, which happens due to the regenerative braking system. The second plot helps understand the torque output by motors with speed variation. So for our case, we need maximum torque even at higher speeds, so for instance, this model provided 43 Nm at 40 mph (64 kmph). The other motors could not provide this much and hence limited themselves to lower speeds as motor torque decreases with the motor speed. The third plot shows the maximum current required will be 25 A, so we needed heavier wires to withstand the load, increasing the kerb weight and reducing the range. The final plot was helpful in analysing the traction force values at the wheels and thus give an idea of the motors' acceleration.

These were the results obtained for the 5kW motor and 1:10 transmission ratio:

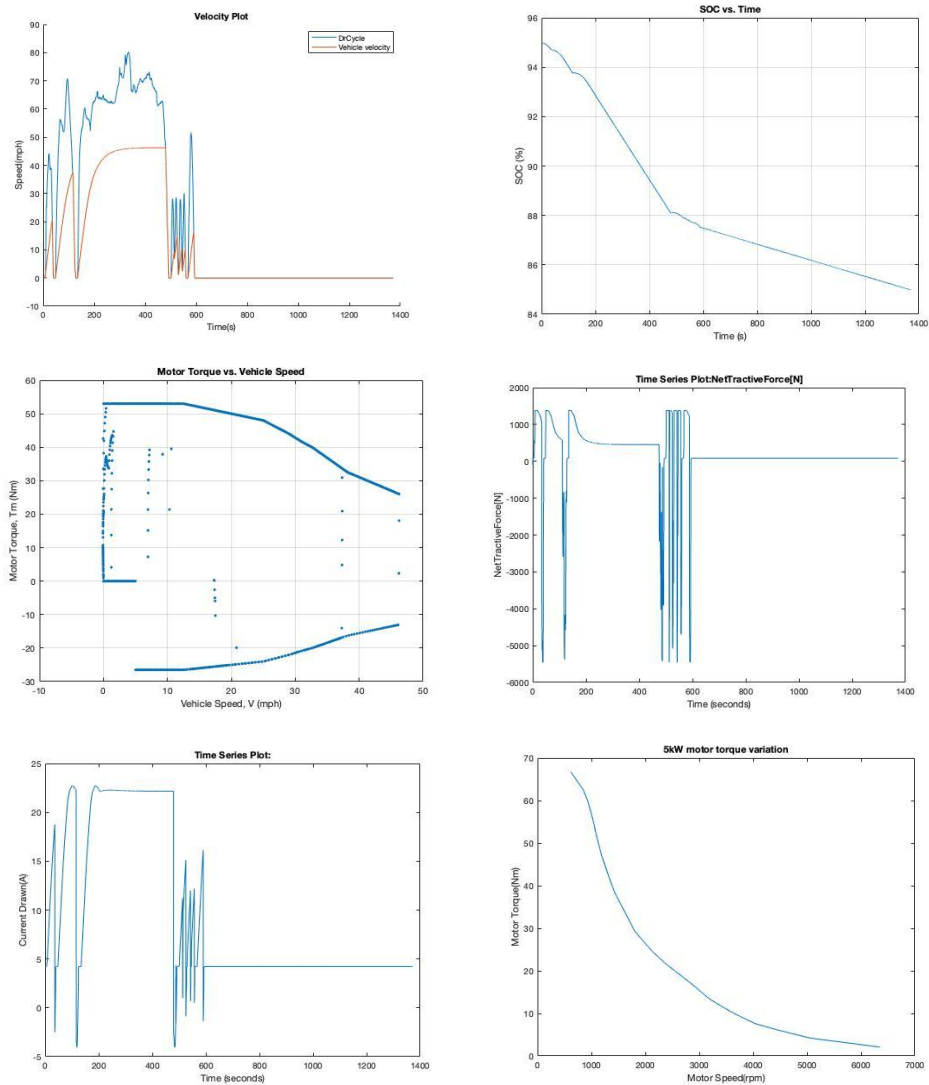


Fig 4.2: Observed parameters for the 5kW motor: a) velocity response b) SOC level, c) Motor torque v/s speed d) Variation of Traction force at wheels e) Current draw variations f) motor torque v/s speed.

This motor model predicted a range of **97 km**. The maximum current drawn was 23 A, so the wires were the same, but the motor was low powered and drew less energy from the battery pack. Also, another critical aspect to notice here was the torque it can lift. At 40 mph(64 kmph), it provided a torque of just 31 Nm and hence to carry a payload of 700 kg, it cannot push the vehicle beyond 46 mph and had slower acceleration than the previous motor.

Similarly, we performed tests on the 4 and 3 kW motors, which predicted a range of **99 km** and **115 km**, respectively. The plots have been presented on the following page.

For the 4 kW motor,

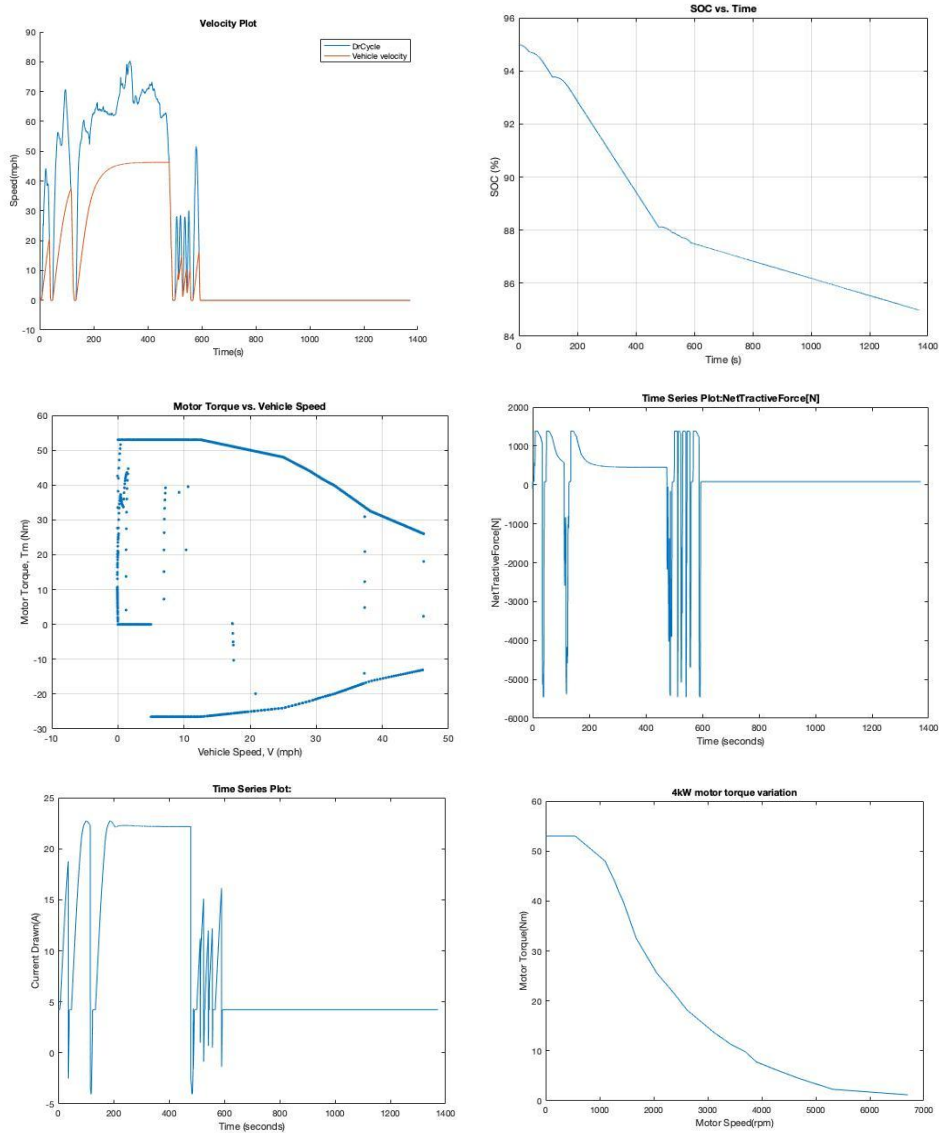


Fig 4.3: Observed parameters for the 4kW motor: a) velocity response b) SOC level, c) Motor torque v/s speed d) Variation of Traction force at wheels e) Current draw variations f) motor torque v/s speed.

Similarly, for the 3kW motor with gear ratio 1:10:-

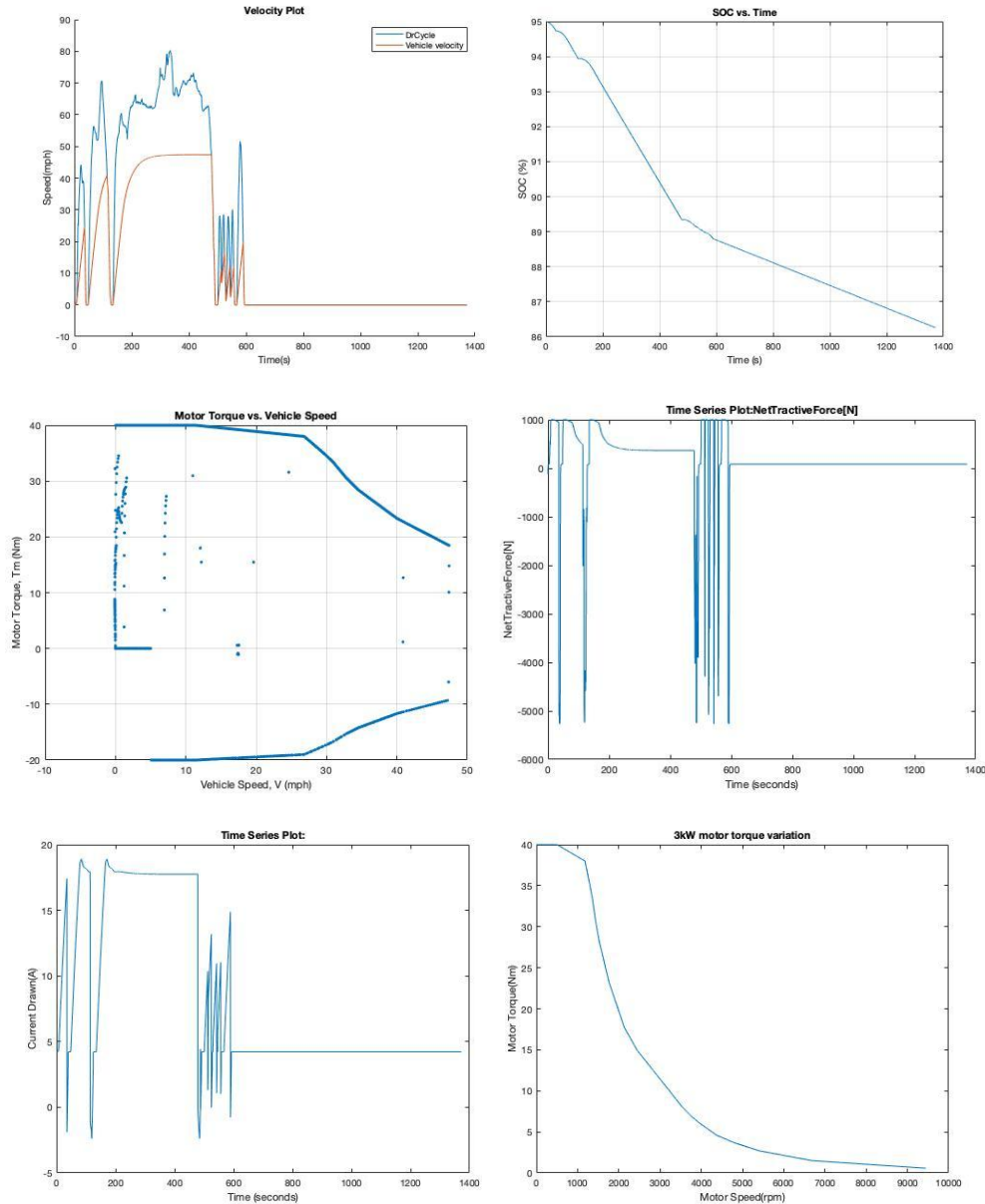


Fig 4.4: Observed parameters for the 3kW motor: a) velocity response b) SOC level, c) Motor torque v/s speed d) Variation of Traction force at wheels e) Current drawn variations f) motor torque v/s speed.

As observed from the graphs, although the higher rating motors provide greater torque and traction force along with quicker acceleration, they have a slight disadvantage of the range, which requires more battery capacity, but that would also mean less payload since the kerb weight increases.

The lower rating motors have better range but can't push enough to lift the required load, which leads them to run at lower speeds to generate the necessary traction force. This can be used as a significant cost-cutting criterion but creates a destructive impact on the customers. So it's better to go with higher rating motors provided we can get sufficient torque to pull the necessary payload and have an acceptable range of operation. The 6kW one predicted a range of 88 km. Comparing this with the competitors like Etrio, they have used a 15 kW motor for the Ace along with a 20 kWh battery to provide a range of 100 km. But they had quicker response times, so our model isn't much far from them.

5. Conclusion

After doing all the simulations, we found that the 6 kW motor would be better than the other motors available though we should use a motor that could provide slightly more torque to the wheels. Then we analysed the different transmission ratios and concluded that the 1:10 provided much more traction force and hence acceleration. This was therefore better to pull a larger payload. The only drawback that happened was that both the motor and transmission ratio reduced the efficiency and hence the range of the vehicle had to compromise. However, since we had given more preference to the torque provided by motors to fulfil the requirements of an SCV, a minor range loss was acceptable.

In order to get better accelerations, we tried giving even higher gear ratios but the range decreased even more as now for the same rotation for the wheels, the motor had to complete more number of turns, and lesser torques were observed at 40 mph (33 Nm) for a 6 kW motor with a 1:18 gear ratio.

As seen from the results, the main problem with our model was that the motor wasn't very powerful. That could have increased the performance, but with that range would have decreased so that higher battery capacity will be needed, and hence the payload may or may not improve. However, we can indeed say that the acceleration would have been quicker, and it might have achieved higher speeds.

Also, since the batteries^[1] contribute a lot towards the kerb weight, Tesla has brought up newer technology that uses fewer cells, and hence kerb weight will decrease drastically. Although it's currently not public, similar research can be done, and if successful, more EV SCVs will be encouraged in the future.

We can, however, use the lower motor ratings currently as well, provided the payload isn't much. If we decrease the kerb weight and maximum allowed load, an affordable SCV can be manufactured for a small range of tasks.

Glossary

ECU: An engine control unit (ECU), also commonly called an engine control module (ECM), controls a series of actuators on an internal combustion engine to ensure optimal engine performance by reading values from the sensors within the engine bay, interpreting the data using lookup tables, and adjusting the engine actuators.

I.C. engine: An internal combustion engine is a heat engine. The combustion of a fuel occurs with an oxidiser (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit that converts the energy present in fuels to mechanical energy.

S.I. engine: A spark-ignition engine is an IC engine, generally a petrol engine, where a spark from a spark plug ignites the combustion process of the air-fuel mixture.ignition

Hybrid Engine: A hybrid engine is an engine where there is more than one source of power. More specifically, a combustion engine (SI or CI) is paired with an electric motor.

Combustion: Combustion, also known as burning, is the primary chemical process of releasing energy from a fuel and air mixture.

AFR: Air–fuel ratio (AFR) is the mass ratio of air to a solid, liquid, or gaseous fuel present in a combustion process.

Ignition Timing: Ignition timing refers to the timing, relative to the current piston position and crankshaft angle, of releasing a spark in the combustion chamber near the end of the compression stroke.

CI engine: A CI engine is an engine in which the fuel charge is ignited by the heat of compression. The process of combustion in the CI engine is fundamentally different from that in a spark-ignition engine.

Valve Overlap: Valve Overlap is the time during which both the inlet and exhaust valves remain open at the same time.

Scavenging Effect: Scavenging is the process of replacing the exhaust gas in a cylinder with the fresh air/fuel mixture (or fresh air, in the case of direct-injection engines) for the next cycle.

State Of charge(SOC): is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points (0% = empty; 100% = full).

UDDS: The EPA Urban Dynamometer Driving Schedule (UDDS) is commonly called the "LA4" or "the city test" and represents city driving conditions. It is used for light duty vehicle testing.

ANN: An artificial neural network (ANN) is the piece of a computing system designed to simulate the way the human brain analyzes and processes information.

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