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Report on

'DESIGN AND DEVELOPMENT OF POWERTRAIN IN A FRONT WHEEL DRIVE ELECTRIC TADPOLE TYPE VEHICLE'

Submitted by

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DEPARTMENT OF MECHANICAL ENGINEERING
PROGRAM: B. TECH – MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Report entitled

'DESIGN AND DEVELOPMENT OF POWERTRAIN IN AFRONT WHEEL DRIVE ELECTRIC TADPOLE TYPE VEHICLE'

is a Bonafide work carried out by

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In partial fulfillment for the completion of 7^{th} semester course work in the Program of Study **B.Tech in Mechanical Engineering** under rules and regulations of PES University, Bengaluru, during the period **Aug-Dec 2022.** It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report. The Report has been approved as it satisfies the 7^{th} semester academic requirements in respect of project work.

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Signature of Examiners during Viva – Voce (End Semester Assessment)			
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1.			
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3.			

DECLARATION

We, **Samartha S, Sameer Joshi, Uday Kumar M S, and Sai Sampath Goutham Jangala,** hereby declare that the Report entitled, '**DESIGN AND DEVELOPMENT OF POWERTRAIN IN A FRONT WHEEL DRIVE ELECTRIC TADPOLE TYPE VEHICLE**' is an original work by us under the guidance of **Prof. Sharanbassappa S Patil**, Professor and Lead, Automobile Engineering Department, and is being submitted in partial fulfillment of the requirements for completion of the 7th Semester course work in the Program of Study **B. Tech in Mechanical Engineering**.

Place: Bengaluru

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ABSTRACT

With the need for a compact transportation system, three-wheelers have evolved over the years, and in the future, we can see these tadpoles in commercial aspects. These are electrified as IC engine-based three-wheelers have been contributing excessively towards air pollution and the efficiency of the electric vehicle is more. It also requires less energy than the IC engine-based vehicles.

The primary aim of this project is to develop a powertrain for a “Front wheel-drive electric tadpole-type vehicle”. Compared to Tadpole configuration, delta configuration provides poor confidence while driving at high speed and corner maneuvering. As there are two wheels at the front , there is better braking performance and shorter stopping distance compared to delta configuration and also tadpole provides good high speed aerodynamic performance because of teardrop shape in contrast to delta type.

As there are many advantages of front wheel drive over rear wheel driven tadpole which will discussed subsequently in this paragraph such as better natural cooling that’s air cooling for the components like motor, gearbox, controller, and wiring harness. Another major reason would be lifting of wheels while cornering at high speed and over steering characteristics for rear wheel driven tadpole which needs to be overcome with the help of using front wheel driven tadpole which provides high stability at cornering and understeering characteristics which is preferred by drivers.

Here, we have set few performance parameters and calculated the torque and power required from MATLAB and Simulink and found the different types of resistive forces that tadpole needs to overcome in order to move. Based on which we have selected the motor specifications and the battery capacity and also using these parameters.

We have procured various powertrain components like motor, battery pack, controller, gearbox, drive shaft, throttle pedal, power cable, phase cables and wiring harness to fabricate the EV powertrain assembly and build a tadpole. After procuring the components of the powertrain, we have to fabricate and integrate the components with the tadpole vehicle.

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NOMENCLATURE

m - Mass of the vehicle

a - Acceleration of the vehicle

μ - Rolling resistance coefficient

Cd - Aerodynamic drag coefficient

ρ - Air density

A_f - Frontal area of the vehicle

D_W - Wheel diameter

v_{kmph} - Vehicle velocity in km/h

F_{Trac} - Force developed at the wheels

F_{roll} - Rolling resistance force

F_{aero} - Aerodynamic resistance force

θ - Gradient angle in degrees

F_{trac} - Tractive effort force

F_{grad} - Force developed at wheels for climbing a grade

F_{ac} - Force developed at wheels for acceleration

T_{W-Peak} - Peak torque at the wheel

T_{M-Peak} - Peak torque at the motor shaft

N_{M-Peak} - Peak RPM at the motor shaft

SOC – State of charge

CHAPTER 1: INTRODUCTION

1.1 Introduction to tadpole vehicles

In the current day and age, traveling from one place to another is very much needed. Since the tadpole is a compact vehicle, it takes less time to commute than the Four-wheeled vehicles. This three-wheeler has been integral part of the public transport in most of countries like India, China and many other developing countries and also three wheelers cost less and easy to maintain compared to the four-wheeler.

There is an increase in environmental pollution as well, which is caused by IC engine-based vehicles. Also, the cost per kilometer is extremely high for an IC engine-based vehicle. An electric tadpole is an optimal solution for these problems.

In this project, we have attempted to develop a Front wheel drive electric tadpole, a three-wheeled vehicle which has two wheels at the front and one wheel at the rear.

Fig 1.01: Tadpole vehicle [14]

1.2 History of three wheelers

First three wheeled vehicle was developed by Karl Benz in the year 1885 named it as Benz patent Motorwagen and it had been power with less than 1bhp. Then in 1897, Edward Butler developed three-wheeler IC engine car. Velorex was an automotive company from Solnice, they developed a tadpole type vehicle in the year 1950.

In 1973, Reliant manufactured three wheeled car named Reliant Robin in England. It has three variants. It comes with 750cc engine and then due to demand they started to manufactured 850 cc engine. In 2015, Pembleton started manufacturing three-wheeler vehicles with a tadpole type configuration.

Fig 1.02: Benz Patent Motorwagen (1885) [15]

Fig 1.03: Velorex Car (1950) [16]

Fig 1.04: Reliant Robin (1973) [17]

1.3 Comparison between tadpole and delta configuration

Tadpole configuration has two wheels in the front and one wheel in the rear, having two wheels in front makes cornering better compared to delta configuration. However, this increases the turning radius of the tadpole. Centre of gravity of the tadpole tends to be on the front. Braking performance is better compared to delta configuration. Tadpole has better aerodynamic shape compared to delta configuration.

Delta configuration has two wheels in the rear and one wheel in the front. Cornering is difficult compared to tadpole configuration but the advantage here is that the turning radius is less compared to tadpole. Centre of gravity of the tadpole tends to be on the rear. Vehicle control is difficult in high speeds in case of delta configuration. Braking performance is poor when compared to tadpole configuration. Delta tends to roll more than the tadpole type vehicles

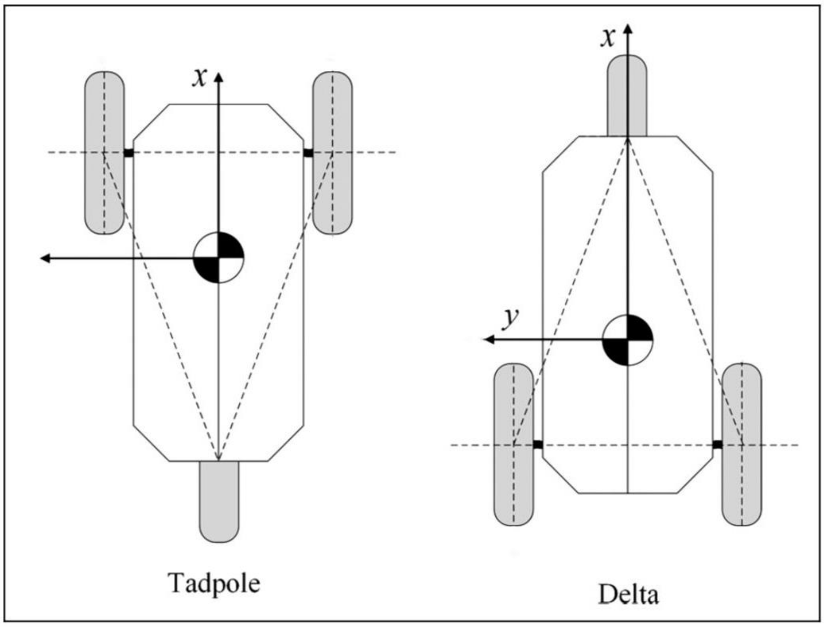


Fig 1.05: Two types of configurations for three wheelers [6]

1.4 Comparison of Rear wheel drive and forward wheel drive tadpole

Rear wheel drive:

In rear-wheel-drive layout, there are two types of configurations: Front engine with rear wheel drive and rear engine with rear wheel drive. In this layout there are components such as motor, clutch, gear box and propeller shaft with universal joints. The balanced weight distribution between the front and the rear wheel contributes towards better handling system and better road adhesion preferably on steep hills and while accelerating with increased weight on the driving wheel.

Front wheel drive:

In this layout all components such as motor, clutch, gear box and shaft are mounted on front end of vehicle. This drive indeed provides the vehicle with good road holding while cornering due to its major weight on front side of the vehicle. The chance of skidding on slippery road are reduced. Good road adhesion is provided by the large proportion of the vehicles weight acting on the drive wheels. When the vehicles are to be steered into the curve it provides understeer characteristics always preferred by the driver. Since the components are mounted at the front of the vehicle the natural air cooling is better than components at the rear end of vehicle.

1.5 Introduction to powertrain

Powertrain refers to a system of components in a vehicle that generates power and delivers it to the wheels in an automobile. It has many components, such as the energy source, torque converter, transmission system, and final drive. The powertrain is classified mainly into three categories which are internal combustion (IC), hybrid electric and electric.

The main components of an Electric powertrain are:

- Traction battery pack
- Electric motor
- Controller
- Transmission system
- Drive shafts

Although IC vehicles are popular and used in high numbers, Electric Vehicles (EVs) are becoming more popular due to the following reasons:

They have higher efficiency than internal combustion vehicles (IC).Some of the bulky components, such as engines, clutch and multiple gear system are eliminated. High starting torque is available. Gears can be eliminated since torque and speed can be varied by using the motor & controller. Less rotating elements, therefore less rotating inertia than the internal combustion vehicles.

CHAPTER 2: LITERATURE SURVEY

In this paper [1], authors have tested performance of powertrain system. Theoretical and experimental test are carried out to prove the applicability of electric vehicle under different road circumstances. 12kW PMSM Motors are used for powertrain of electric vehicle.$LiFePO_4$ Battery to provide energy to the motor is used which includes a battery management system. The traction force required and the driving torque required are calculated theoretically by using real data. It is found that maximum power required by motor is found to be 11kW which is within the range of the rated power of the motor. To check the maximum acceleration of the vehicle, the vehicle is lifted and tested for no load condition, the acceleration was found to be $1.386\ m/s^2$.The performance of battery at various discharge rates is found in the laboratory maintaining 100vdc voltage. Finally, the complete vehicle has been tested on a dynamometer system. Using different driving cycles, the speed, force, and distance are checked. The battery has been fully charged during testing and when the speed reaching 70 km/hr high fluctuations in current (ripple effect) is observed. To conclude, the powertrain's performance was tested in lab conditions and on the road and then comparison of both was performed.

In this paper [2], different motors with different control strategies are compared. The advantages and disadvantages are also discussed in the paper. Direct current motor known as DCM is studied, it has simple control technique but due to its low efficiency and heavy weight it is not considerable to be used in electric vehicles. Switch Reluctance Motor is also studied, it has high operational efficiency and direct control strategy are the advantages but due to high torque fluctuation, high noise, and vibration it cannot be used in electric vehicles. Next the Induction motor is studied it has similar advantages as SRM motors due to its low power density it is not suitable to use these motors in electric vehicles. Finally, PMSM Motor is studied. It has high efficiency, high power density, low heat, low noise simple structure makes this motor suitable for the use in electric vehicles.

This paper [3], focuses on the study to find the effects of vehicle dynamic parameters and its powertrain based on simulation and model of an electric vehicle's dynamics when integrated with an electric motor. Analysis of Field Oriented Control (FOC) for better efficiency and energy savings in motors is also performed. The latest powertrain technology was implemented to achieve the parameters of the drive system. They also have discussed all the powertrain key components and compared electric vehicle powertrain parameters using MATLAB simulation, which helps in the development of a prototype or vehicle model.

In this paper [4], The Vehicle simulation model was developed using MATLAB/Simulink, including the powertrain system and the longitudinal vehicle dynamics. The resistive forces which opposed the vehicle motion were modelled in the longitudinal vehicle dynamics section. The power required is calculated, which depends on gradient resistance, rolling resistance, aerodynamic drag, transmission losses. Then, it was compared with the vehicle's actual performance using the car BMW i3. The difference between the simulation results and the test data of the car was about 6% .

In this paper [5], different kinds of batteries and their parameters are compared like maximum charge, mass, cost, operating temperature range, and nominal voltage. Four different batteries are used for comparison they are Li-Ion, Na-NiCl2, Ni-MH, Li-S batteries. Then each of the battery is tested on same track of length 12.6 km by for knowing behavior of batteries under same operating conditions. It has been found that Na-NiCl2 had lowest energy consumption but due to it higher operating temperature this battery is not feasible to be used in electric vehicles. Secondly, Li-S had highest energy consumption and even produce less power compared to all other battery. Ni-MH and Li-ion are found to consume comparable amount of energy. But Ni-MH is not feasible due to heating issues, chances of exploding if it’s not properly charged or discharged. Li-ion and $LiFePO_4$ is found be optimal battery for electric vehicle due to average energy consumption, operating temperature, optimal power.

In this paper [6], authors explain the advantages of the BLDC motor over brushed DC motors, like maintenance, high density, and lower moment of inertia. Authors have classified different types of permanent magnet BLDC motors based on different types of the wave form. Mathematical model of the BLDC motor was also developed, and it was used to examine the controllers' performance. PID controller was used as a speed controller. When a PI controller was used in the outer speed loop, it reaches steady state time quickly. When the PID controller was used, it reduces overshoot and also the settling time. When a fuzzy logic controller has been used, the overshoot and settling time was reduced more quickly. Later the results were compared with a fuzzy logic controller, also it was used as a speed controller

In this paper [7], the authors explain the components of EV vehicle and how is it different from IC engine. They also classify different types of self-commuted motor like mechanical commutator, electronic commutator, torque requirement, motor and gearbox selection. The authors briefly introduce the powertrain system for electric vehicles, use of gearbox for electrical powertrain systems, and its advantages. The torque is dependent on current and electric car's speed is dependent on the voltage. The authors also select a motor for Bajaj RE compact vehicle. The motor which was chosen as the golden motor of 5kW. The types of motors have been discussed.

In this paper [8], the authors speak about how three-wheelers are important in metropolitan cities. They also use the parameters to find the power and torque required for the motor. The authors compare lead-acid and lithium-ion batteries, issues with electric vehicles, and how to overcome them and about different Indian drive cycles used to modelling for 3-wheeler. The advantages of lithium-ion batteries over lead-acid batteries, and battery sizing factors. The load modelling for auto rickshaw motor and battery specification selection was also made based on Indian drive cycle requirements.

In this paper [9], they have explained the different types of transmissions which can be used in an EV, such as single-speed gearbox and multi-speed gearboxes (MT, DCT, CVT, IVT). The advantages of multispeed gear boxes over single-speed gear boxes were described. The multispeed gearbox has several benefits. It enables vehicle traction, helps in the efficient working of the inverter, increases acceleration gradeability, top speed and overall mass and volume. It also improves the performance of light-weight vehicles compared to heavy-duty vehicles. They have reviewed different types of gear boxes with their costs and their characteristics. But on the other hand, by adding more gears, we must use associated clutches and synchronizers which increase gearbox loss and also increases the mass as well, so we have to consider all these and then select suitable transmission.

In this paper [10], the authors have discussed about the development of battery electric vehicles that are efficient, economically and environmentally competitive with internal combustion engines in this paper, with battery technology playing a critical role in this process. They have chosen five battery technologies and compared them with their performance and cost over the medium and long term. The battery characteristics for different environments and economic characteristics for electric vehicles were analyzed using different drive cycles. They have performed all five tests on specific energy, specific power, efficiency, cycle life, operating temperature safety, and cost for the medium and long term. They have also made a comparison of battery cost and battery weight with the range. They concluded that lithium-ion batteries are the ones that can meet all of the requirements for electric vehicles in the medium term.

In this paper [11], authors have discussed the different configurations of a 3-wheeler. They compare the delta configuration and tadpole configuration and their advantages over each other. The analysis of the center of gravity, acceleration, and braking of 3-wheeler in a straight line,understeer and oversteer characteristics also discusses about rollover stability

2.1 Summary of literature review

- The authors have made comparison between tadpole and delta configuration, and they have also discussed about their advantages and disadvantages.
- The researchers have conducted study on different types of motors with respect to electric vehicles and they concluded that the BLDC and PMSM are best suitable for EV application.
- They have explained the different types of transmissions which can be used in an EV. The multispeed gearbox has several benefits. But adding more gears and adds the associated clutches and synchronizers which increase gearbox loss, complexity and increases the mass. Since motor has a wide range of speed and torque, we can use single speed gear for an electric vehicle.
- The researchers have carried out study on different types of batteries and their characteristics and they have arrived at a conclusion that Li-ion and Lithium ferro phosphate ($LiFePO_4$) is better suited for EV application.

2.2 Literature gap

Majority of studies concentrated on the powertrain system, we can compare both rear wheel drive and front wheel drive tadpole systems, Development of the powertrain for the FWD tadpole system and analysis can be done with respect to stability, acceleration, braking, and other aspects. There is significantly fewer data collected about real-life drive cycles in India for three -wheeler and also about front wheel drive electric tadpole. we can learn in-depth about optimizing powertrain parameters like optimum motor operating range.

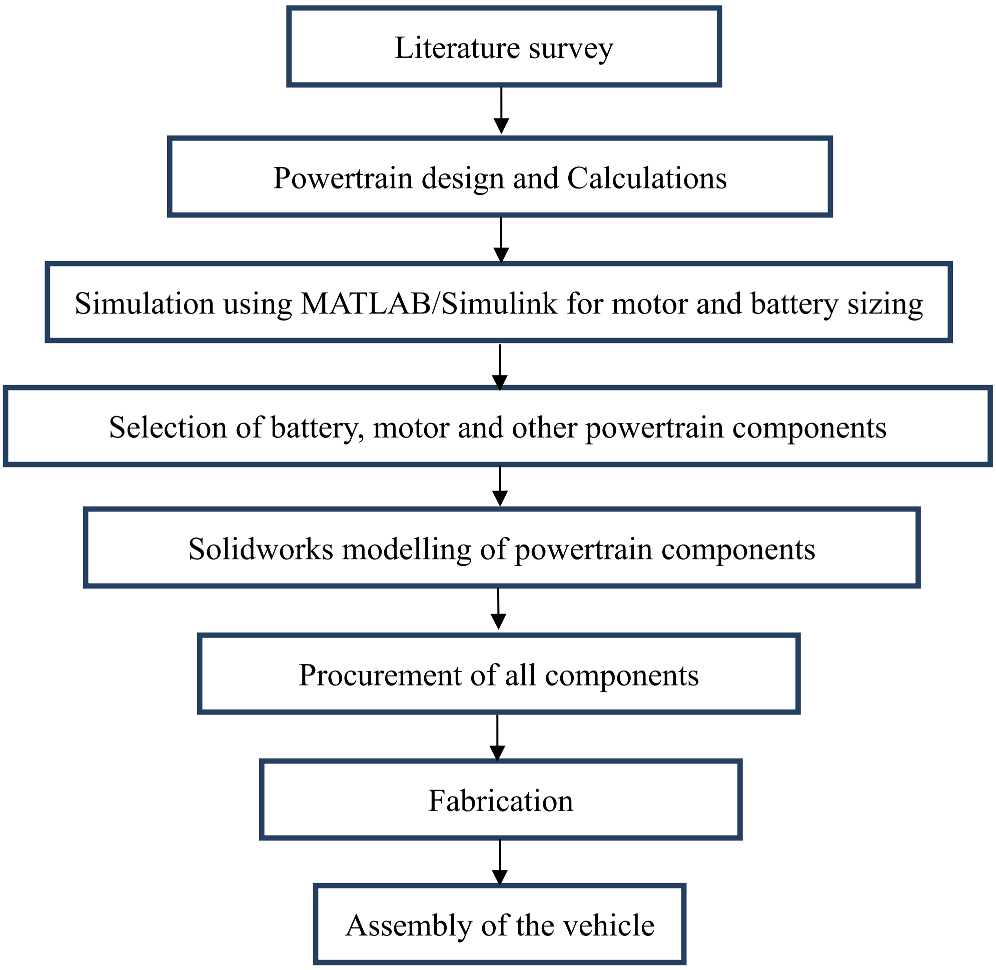
CHAPTER 3: PROBLEM STATEMENT:

The idea is to design and develop a front-wheel-driven electric tadpole vehicle. Although the three-wheelers are compact vehicles and are unstable vehicles in sharp maneuvers to resolve this issue, the placement of the powertrain placement plays a significant role and the position of the center of gravity of the vehicle. Among the three-wheeler, the tadpole is stable compared to the delta. Most personal mobility vehicles (PMV) have front wheel is driven, which tends to understeer compared to the oversteer characteristics of a rear wheel driven. The added traction is due to the two front wheels. The acceleration of the tadpole is stable and compared to pitching or dipping of the delta configuration

3.1 Objective

The first objective is to determine the characteristics of the motor and then select the motor and battery accordingly. The second objective is to procure and assemble the powertrain. The third objective is to build the electric tadpole.

3.2 Methodology



CHAPTER 4: POWERTRAIN CALCULATIONS AND SIMULATIONS USING MATLAB AND SIMULINK

4.1 Powertrain parameters

Now that we know the tadpole's purpose, we need to set certain performance parameters for the powertrain system to comply with the problem statement.

The parameters taken are as follows:

- Top speed of 47 kmph (12.96 m/s) on a flat road (i.e., 0% gradient)
- Acceleration of 0-30 kmph(0-8.33m/s) in 6 seconds on a flat road (i.e., 0% gradient)
- Gradeability of 20% at 20 kmph (5.556m/s with 11.3 degrees)

Parameter	Value
Mass of the vehicle (m)	**450 Kg**
Wheel diameter (D_w)	**0.537 m**
Frontal area (A_f)	**1.8 m^2**
Air density (ρ)	**1.178 Kg/m^3**
Aerodynamic drag coefficient (C_d)	**0.25**
Coefficient of rolling resistance (μ)	**0.015**

Table 4.01: Vehicle parameters taken for motor sizing

4.2 Determination of peak power

The power required for each of these scenarios was calculated to determine maximum power demanded by the vehicle

Where F_{net} is the algebraic sum of all forces on the vehicle; F_{trac} is the tractive force of the vehicle and F_r is the sum of all resistances acting on the vehicle, i.e., F_{roll} (rolling resistance), F_{aero} (aerodynamic resistance), F_{grad} (gradient resistance).

$$F_r = F_{roll} + F_{aero} + F_{grad} \tag{4.1}$$

$$F_{roll} = \mu \times m \times g \times \cos(\Theta) \tag{4.2}$$

$$F_{aero} = ½ \times (\rho \times C_d \times A_f \times v^2) \tag{4.3}$$

$$F_{grad} = m \times g \times sin(\theta) \tag{4.4}$$

Where,

θ is the gradient the vehicle is climbing

g is the acceleration due to gravity

v is the speed of the vehicle

$$F_{net} = F_{trac} - F_r \tag{4.5}$$

Case (i): To determine the power required for a top speed of 47 km/h (12.96 m/s) on a flat road (gradient 0)

In this scenario,

$\theta = 0$ degrees

$v_1 = 12.96\text{m/s}$

At this condition, the vehicle was at its top speed, and there was a netforce on it as it moved with constant velocity (zero acceleration). This means the term F_{Net} was 0. So, the equation becomes

$$F_{trac1} = F_{r1} \tag{4.6}$$

Therefore, the tractive effort required to make the vehicle move at the required speed was equal to the sum of resistance forces on the vehicle

This gives us the following:

$$F_{roll} = \mu \times m \times g \times cos(\Theta) \tag{4.7}$$

$$F_{roll} = 66.22\text{N} \tag{4.8}$$

$$F_{aero} = ½ (\rho \times C_d \times A_f \times \vartheta^2) \tag{4.9}$$

$$F_{aero} = 44.85\ N \tag{4.10}$$

$$F_{r1} = F_{roll} + F_{aero} = 111.07\,N \tag{4.11}$$

Therefore, a net tractive force of 111.07 N is required at the wheels to run the vehicle at 47 km/h. To calculate power at this instant

$$P_1 = F_{tract1} \times v_1 = 1.439\ \text{kW} \tag{4.12}$$

Case(ii): To determine the power demand for gradeability of 20% at 20km/h (5.66m/s) (no acceleration)

In this scenario,

θ_2=11.3 degrees

$v_2 = 5.66\text{m/s}$

The vehicle speed is constant. Hence $F_{trac2} = F_{r2}$

The resistance force arises due to the combined effect of a gradient, aerodynamic, and rolling resistance forces.

So,

$$F_{roll} = \mu \times m \times g \times cos(\Theta)$$

$$F_{roll} = 64.93N$$

$$F_{aero} = ½(\rho \times C_d \times A_f \times v^2)$$

$$F_{aero} = 8.18\,N \tag{4.13}$$

$$F_{grad} = m \times g \times sin(\theta)$$

$$F_{grad} = 865.75\,N \tag{4.14}$$

$$F_{r2} = F_{roll} + F_{aero} + F_{grad} = 938.86N \tag{4.15}$$

Therefore, a net tractive force of 938.86 N was required at the wheels to run the vehicle at 20km/h on a 20% gradient.

To calculate power at this instant

$P_2 = F_{trac2} \times v_2$ (4.16)

$P_2 = 5.21$ kW (4.17)

Case(iii): To determine the power demand for the acceleration of 0-30km/hr in 6 seconds on a flat road

In this scenario,

$\theta_3 = 0^o$

v_3 =8.33m/s

a_3 =1.3m/s^2

The resistance force arises due to the combined effect of a gradient, aerodynamic, and rolling resistance forces. These values were calculated to be

Since the gradient is 0, the F_{grad} is zero.

$F_{roll} = \mu \times m \times g \times cos(\Theta)$ (4.18)

$F_{roll} = 16.2\ N$ (4.19)

$F_{aero} = ½ \times (\rho \times C_d \times A_f \times v^2)$ (4.20)

$F_{aero} = 18.4\ N$ (4.21)

$F_{ac} = m \times a$ (4.22)

$F_{ac} = 671\ N$ (4.23)

$F_{r3} = F_{roll} + F_{aero} + F_{ac} = 705{\cdot}6\ N$ (4.24)

A force of 705.6 N is required to accelerate for the vehicle to have an acceleration of 1.3m/s^2 at 30km/h to calculate power for this instant

$P_3 = F_{trac3} \times v_3$ (4.25)

$P_3 = 5.879\ kW$

After comparing the power required in the three different scenarios, the peak power needed was found to be while accelerating from 0-30km/hr in 6 seconds on a flat road which is 5.879 kW

4.3 Determination of the force on the wheels

It was also necessary to understand the variation of the force at the wheels with changes in the vehicle's speed. First, the tractive effort of the vehicle on the flat road was calculated as a function of vehicle speed. Tractive effort is the force required at the wheels to make the vehicle overcome all the resistance forces and commence moving with a constant velocity. Therefore, the tractive effort is governed by an equation.

Since the vehicle's top speed is 47 km/h, we limit our observation only to 47 km/h (12.96m/s). This graph (Fig 4.01) shows a Tractive force v/s speed plot.

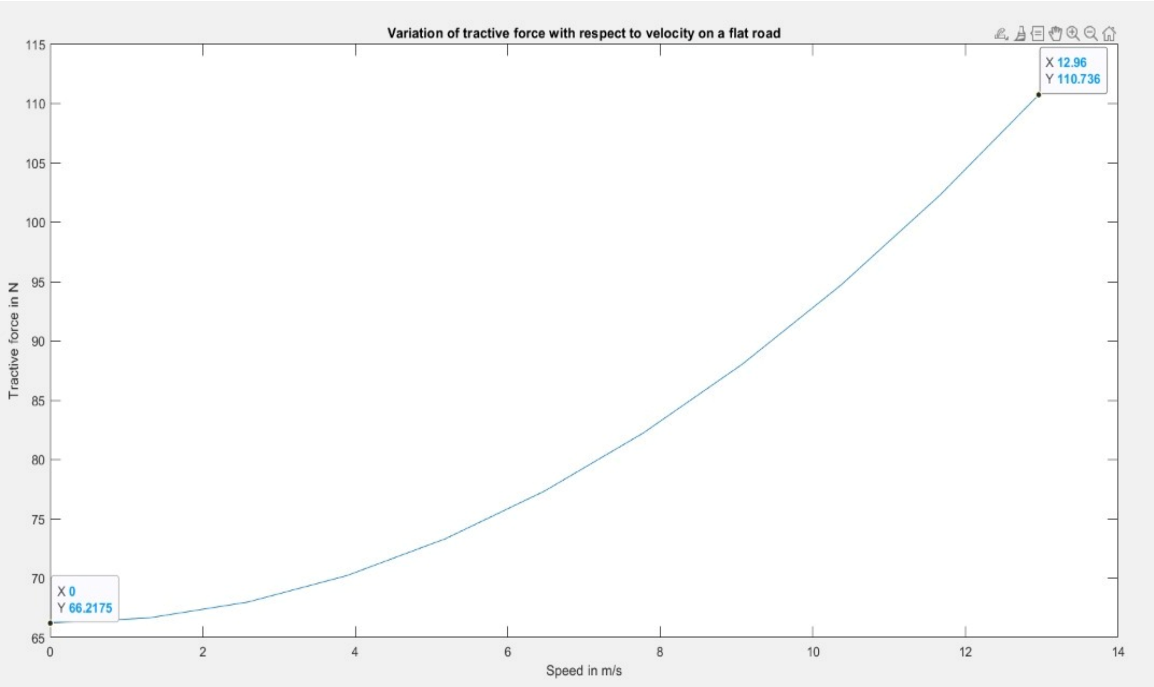


Fig 4.01: Tractive force v/s Speed in case 1

This curve from the graph (Fig 4.01) shows the force required to make the vehicle barely start moving. There is an additional force needed to make a vehicle accelerate. Similarly, an additional force is required to make the vehicle climb a 20% grade. These two forces are also plotted and compared in the following graph.

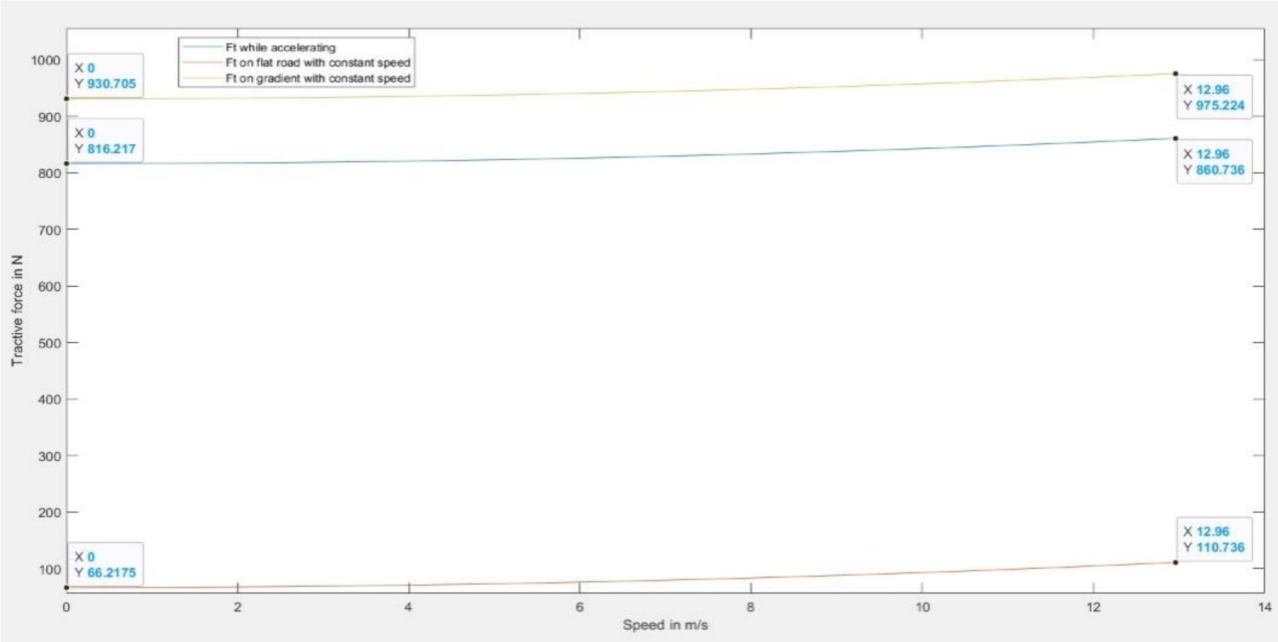


Fig 4.02: Tractive force v/s speed in case 2

It can be inferred from the graph (Fig 4.02) that the maximum force on wheels arises when the vehicle climbs a 20% gradient. Since the vehicle is required to move in this gradient only with a speed of 20 km/h and needs to have this amount of acceleration for only from 0 to 30km/h.

So, we cut down the driving forces beyond these speeds to conserve energy.

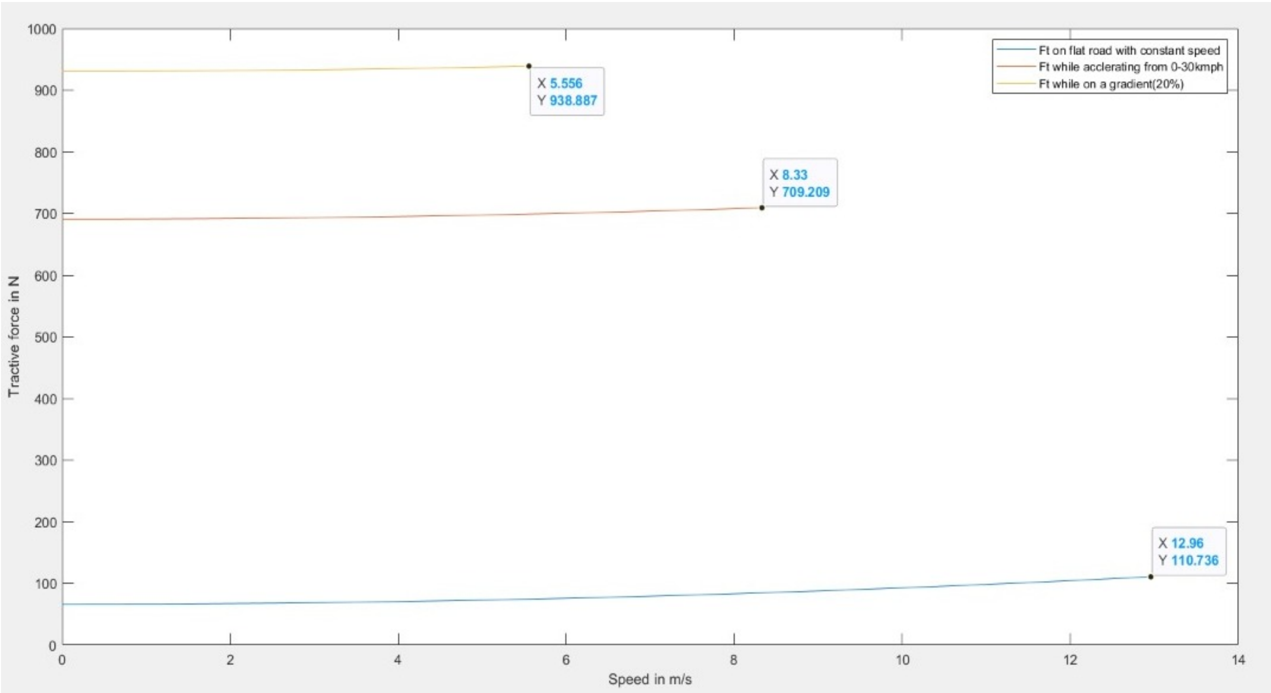


Fig 4.03: Tractive force v/s speed in case 3

This cut of additional force at the wheels to save energy is done by limiting the maximum power at the wheels. As calculated earlier peak power demanded by the vehicle is found to be 5.879 KW.

4.4 Torque requirements

After comprehending the force requirements at the wheels, the peak torque required at the wheels is to be calculated. Studying the force v/s speed diagram, it can be observed that the maximum force needed for the wheels is while climbing 20% grade at 20 km/h.

The peak torque arises when the vehicle climbs 20% at 20 km/h.

$$\tau_{W-peak} = F_{trac2} \times \left(\frac{D_w}{2}\right) \tag{4.26}$$

$$\tau_{W-peak} = 252.08\ Nm \tag{4.27}$$

Since we know the values of the peak power and peak torque at the wheels, we can determine the peak torque and RPM required at the motor shaft. The suitable gear ratio for our requirement was found to be 8.

$$\tau_{m-peak} = \frac{\tau_{w-peak}}{i} \tag{4.28}$$

$$\tau_{W-peak} = 31.51\ Nm \tag{4.29}$$

So, the maximum toque required at the motor was found to be 31.51 Nm .

4.5 QSS toolbox

The QSS toolbox [12] makes it possible for powertrain systems to be designed quickly and in a flexible manner and to calculate the various parameters involved during the design phase.

Components of the QSS toolbox:

- Vehicle block
- Simple wheel block
- Simple transmission block
- Electric motor block
- Battery block
- Drive-cycle block

The amalgamation of these blocks gives rise to the QSS model used to analyze the vehicle's performance.

Each block has specific parameters that the user must enter.

Each program within the QSS toolbox consists of a .mdl file (Simulink) where the system model is described (which contains the description of the drive assembly) .

4.5.1 Drive-Cycle block

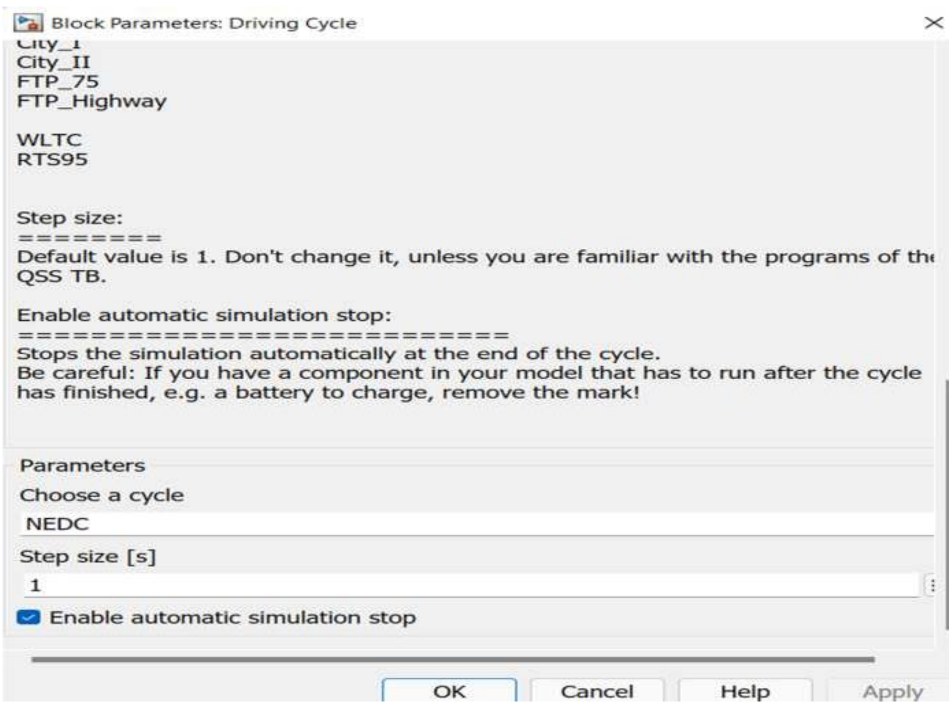


Fig 4.04: Drive cycle block

- This block loads the cycle data, such as time, speed, acceleration and gear number, from the specified data file and makes it available on the output of the cycle block.

The output given by this block is as follows:

- Speed in m/s
- Acceleration in m/s^2
- Road inclination in degrees
- Total distance in m
- The gear ratio

Several drive cycles can be imported from the library, and the simulation stop feature is enabled, which stops the simulation as the drive-cycle ends.

The drive cycle used here is NEDC.

4.5.2 Vehicle block

This block computes the various force experienced by the vehicle based on the inputs from the drive cycle

The input parameters to this block are given from the driving cycle block which are

- The total mass of the vehicle is 450 Kg
- Vehicle cross-section is 1.8 m^2
- Drag coefficient 0.25
- Rolling resistance coefficient 0.015
- Mass increase due to rotating inertia is 10 %

The outputs obtained are

- The vehicle speed in m/s
- The vehicle acceleration in m/s^2
- The traction force in N

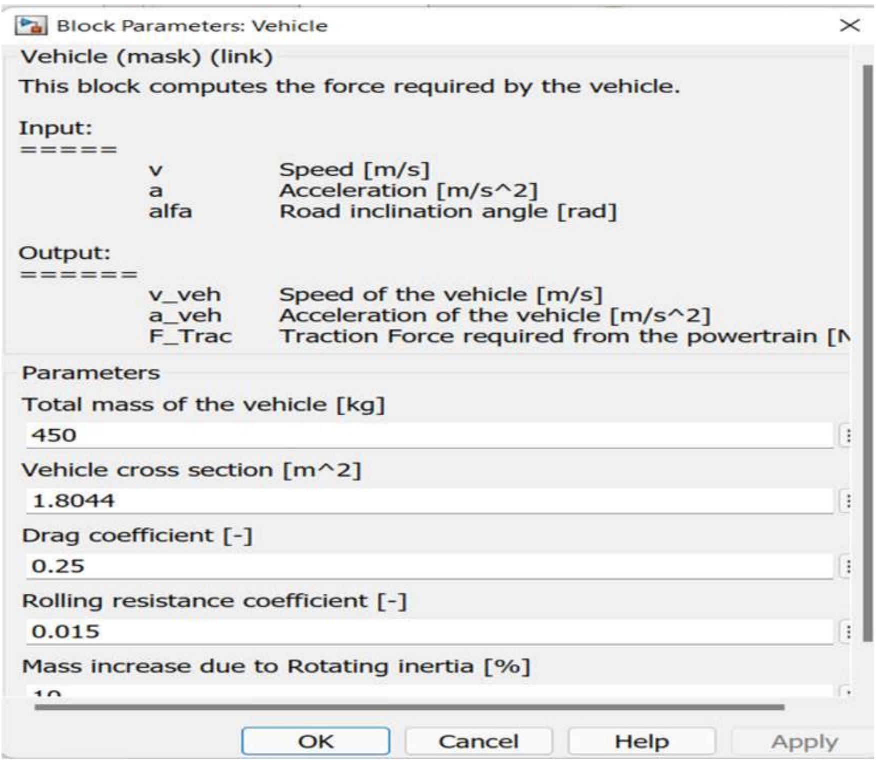


Fig 4.05: Vehicle block

4.5.3 Simple wheel block

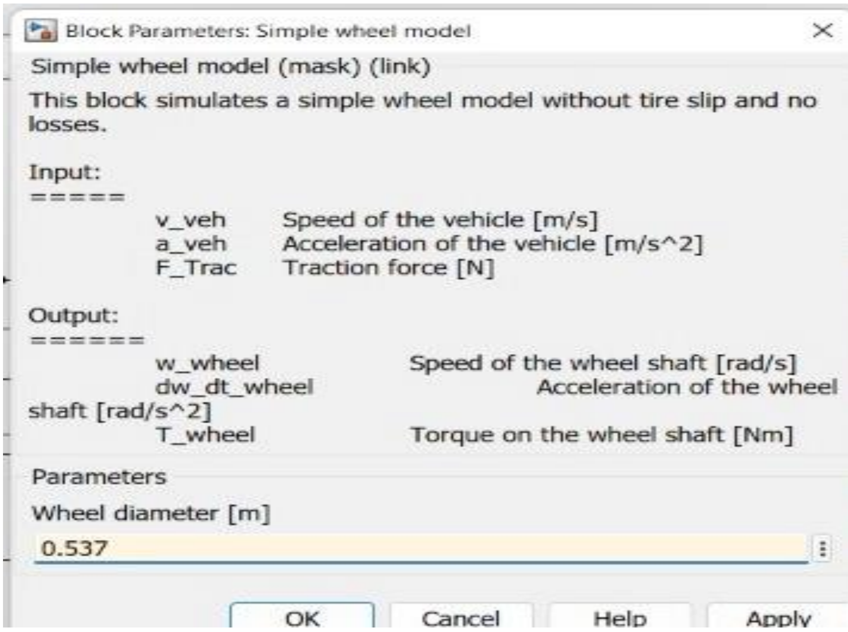


Fig 4.06: Simple wheel block

This block simulates a hypothetical wheel, i.e., it does not have losses and does not slip.

The outputs given by the block are:

- Speed of the wheel shaft in rad/s
- Acceleration of wheel shaft in rad/s^2
- Torque at the wheel shaft in Nm

The parameter given as input is the tire diameter, which is 0.537m.

4.5.4 Simple Transmission Block

This block simulates a simple transmission with a fixed gear ratio. The gear ratio selected was 8. This was done to cover the RPM range of themotor. The QSS toolbox has two types of simple transmission blocks which are Simple Transmission and Simple Transmission 2. The difference between the two is that Simple Transmission 2 does not consider the losses and assumes 100% efficiency.

For our work, the simple transmission model is used.The idling losses are taken as 50W.

The parameters given as input to the block are:

- Gear ratio:8.06 & Efficiency 0.98
- Idling losses (friction) 50W
- Min. wheel speed beyond which losses are generated rad/s: 1

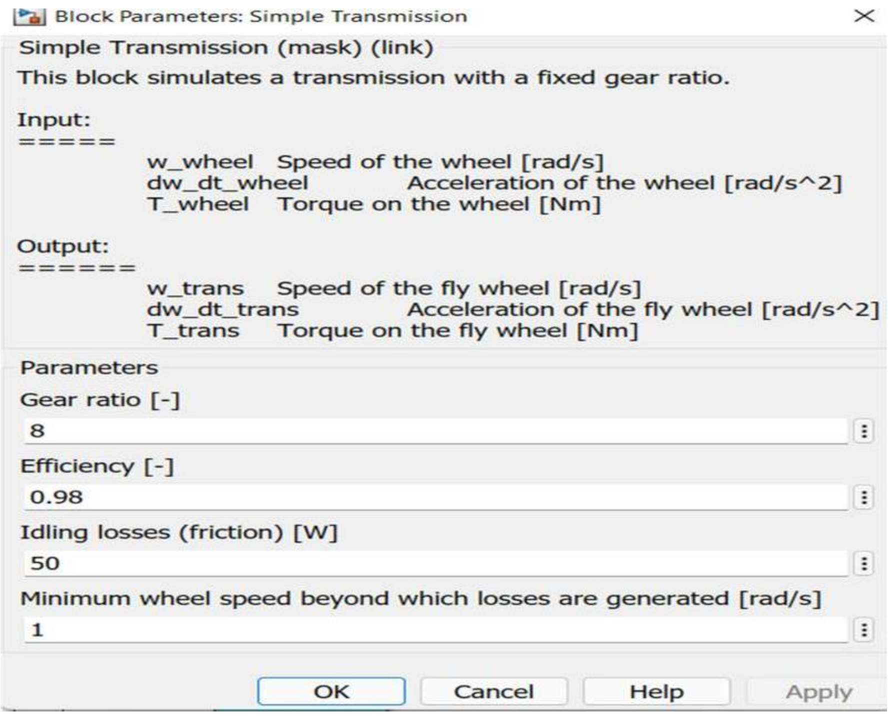


Fig 4.07: Simple transmission

4.5.5 Electric motor

This block simulates a motor based on the efficiency map.

Based on the motor used, a motor map for it was made and entered into the block.

The auxiliary power is taken as 100W.

The parameters given are:

- The motor scaling factor is 1
- Motor inertia in kg.m^2 is 0.1 kg.m^2
- Auxiliary power in W is 100W

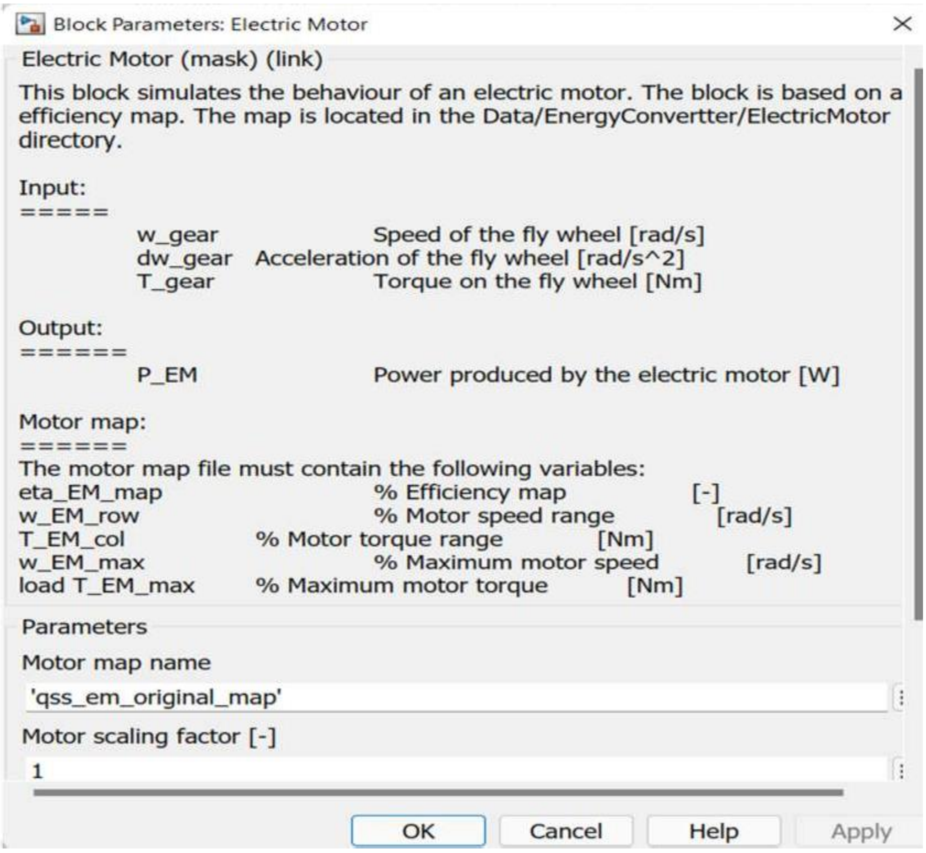


Fig 4.08: Electric motor

4.5.6 Battery block

This block uses the power of the motor and the total distance from the drive cycle as its inputs and gives out the following parameters:

- The state of charge
- Voltage in V
- The energy consumption in kWh/100km

The following parameters were entered into the user interface

- Initial SOC in 90 %.
- The number of cells in the series are 13.
- The number of cells in parallel are 3.

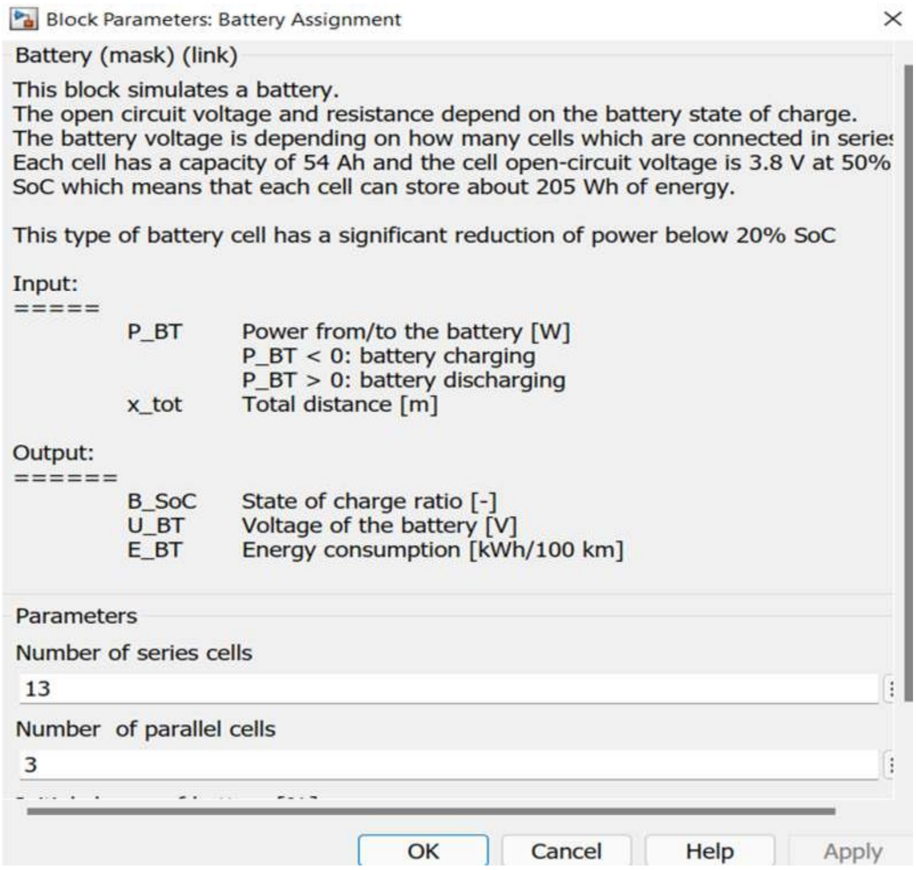


Fig 4.09: Battery block

4.5.7 Complete QSS model

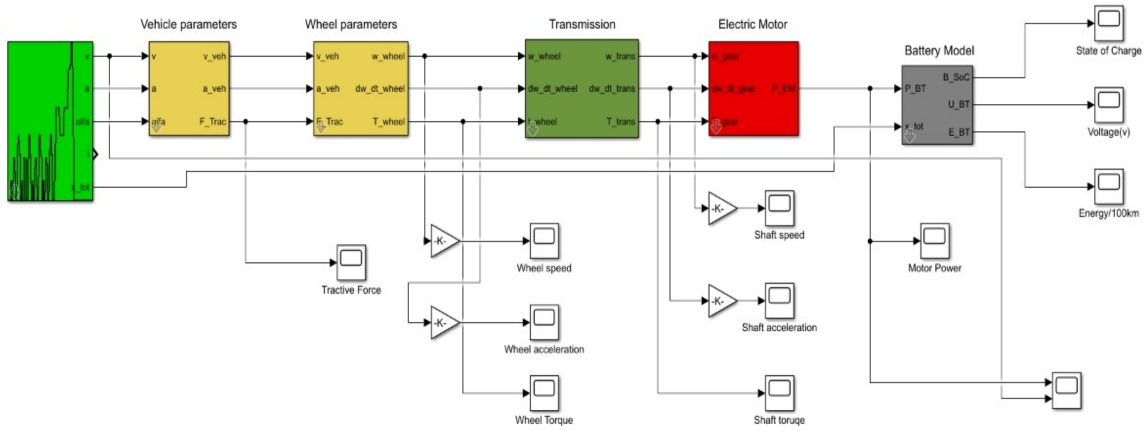


Fig 4.10: QSS model

4.5.8 Power v/s Time

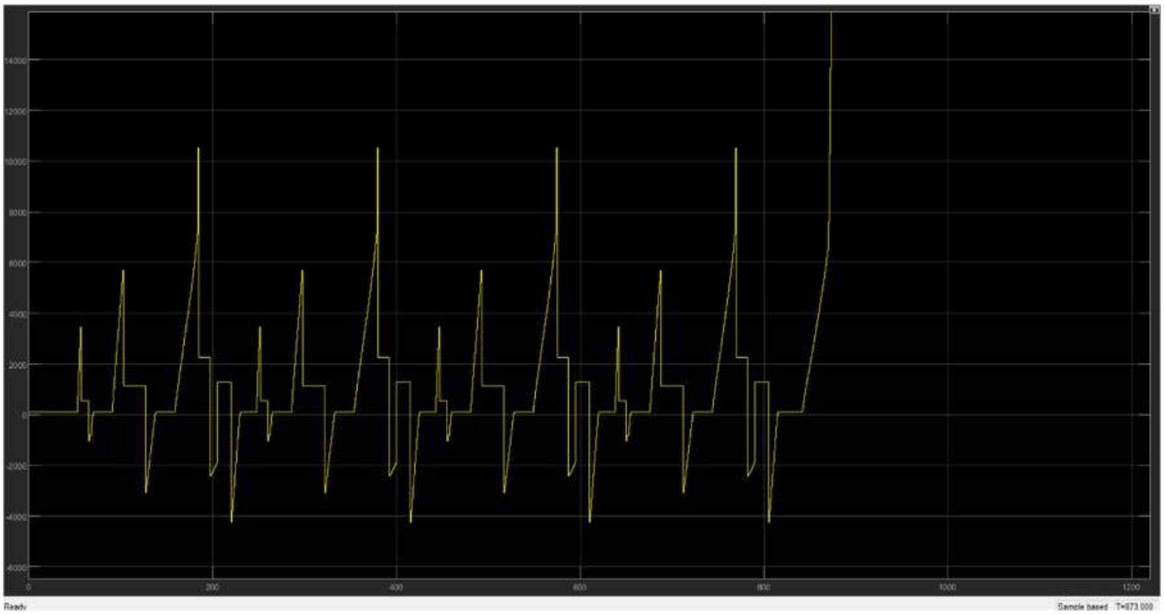


Fig 4.11: Power v/s Time

In (Fig 4.11), The curve is plotted against Power v/s Time. Sometimes it's negative due to the regenerative braking.

4.5.9 Torque requirements for different cycle

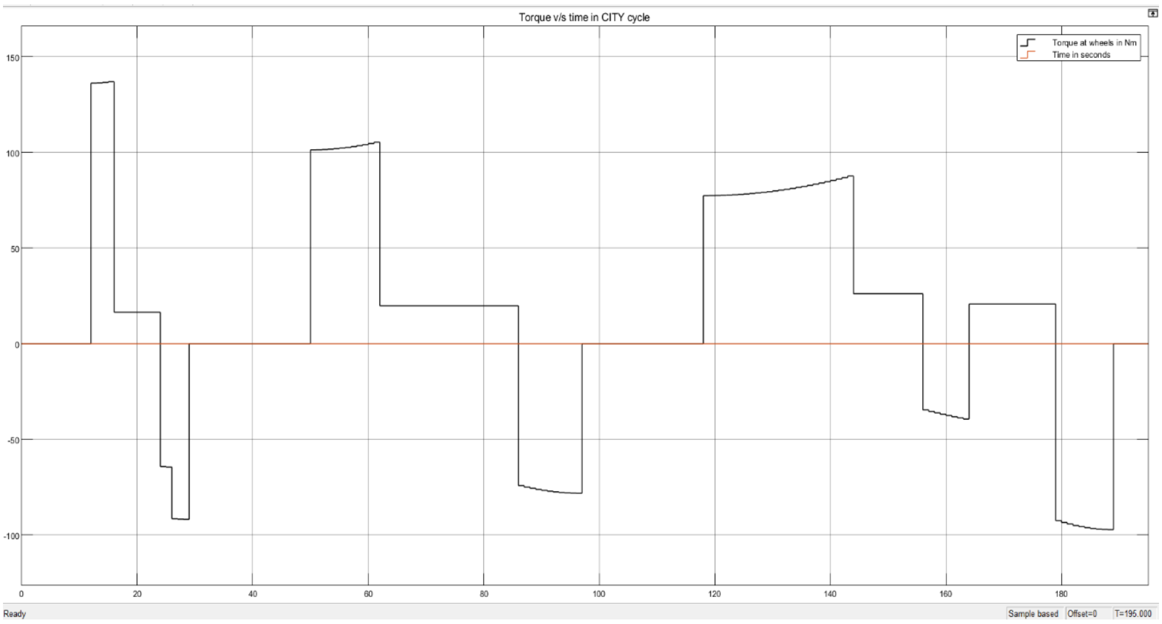


Fig 4.12: Torque requirement for city cycle

Maximum torque required for city drive cycle is 140 Nm which is plotted using QSS toolbox in Simulink

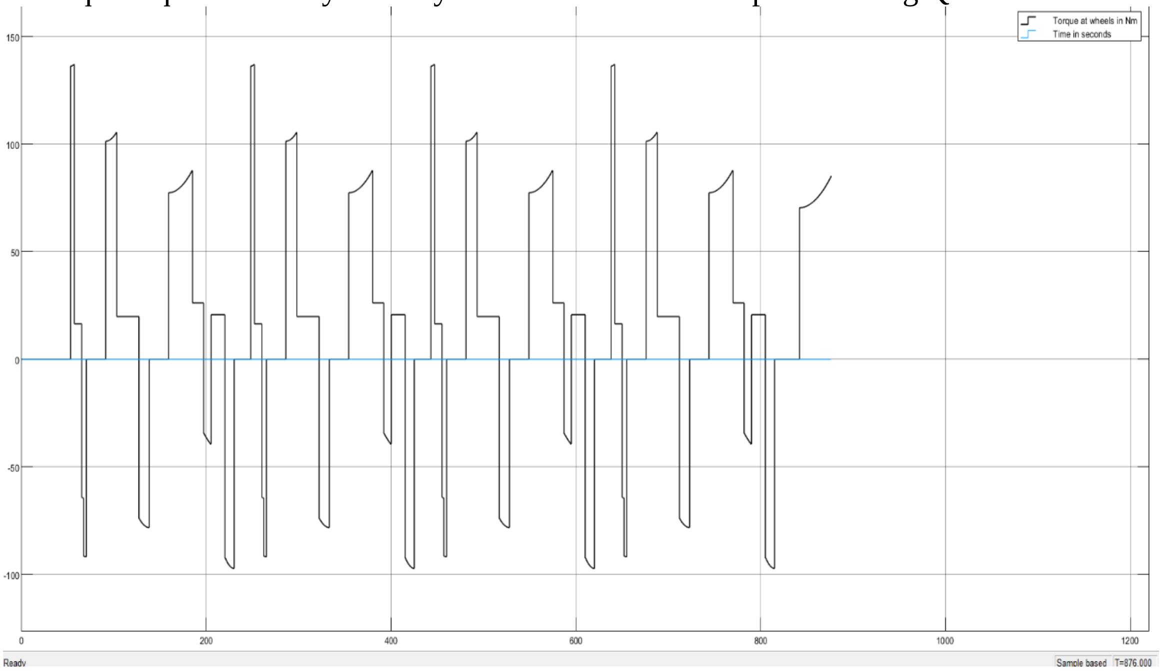


Fig 4.13: Torque requirement for NEDC cycle

Maximum torque requirement for NEDC cycle is 146 Nm which is plotted using QSS toolbox in Simulink

4.6 Electric tadpole vehicle modelling using Simulink

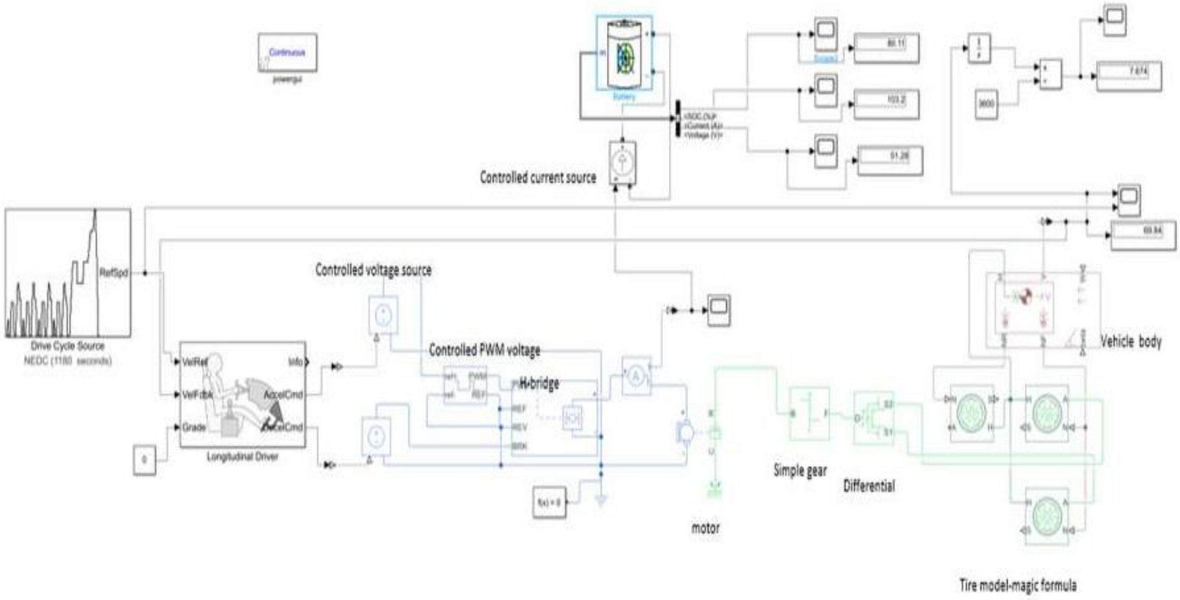


Fig 4.14: Vehicle modelling using Simulink

The input of this model is the NEDC drive cycle of 1180 seconds which is given as V_{ref} for the longitudinal driver model.

This model consists of the drive cycle, longitudinal driver, controlled voltage source, controlled PWM voltage source, H-bridge, PMDC motor, simple gear, differential, vehicle body, wheel body, battery model, and constant current source. The drive cycle gives inputs to the longitudinal driver. The longitudinal driver command's output is either acceleration or braking, which is a physical signal. This physical signal is converted to electric pulses using a controlled voltage source with the help of pulse width modulation (PWM) controlled voltage. This PWM signal is fed to the H-bridge circuit, which helps control the motor's speed, otherwise the motor will only run at the rated speed, H-bridge will allow the vehicle to accelerate or decelerate by controlling the direction and magnitude of the voltage. Then power is transmitted to the wheel with the help of the one speed gearbox and differential to the wheels. The battery here is taken of 3.44kWh.

4.6.1 Battery block

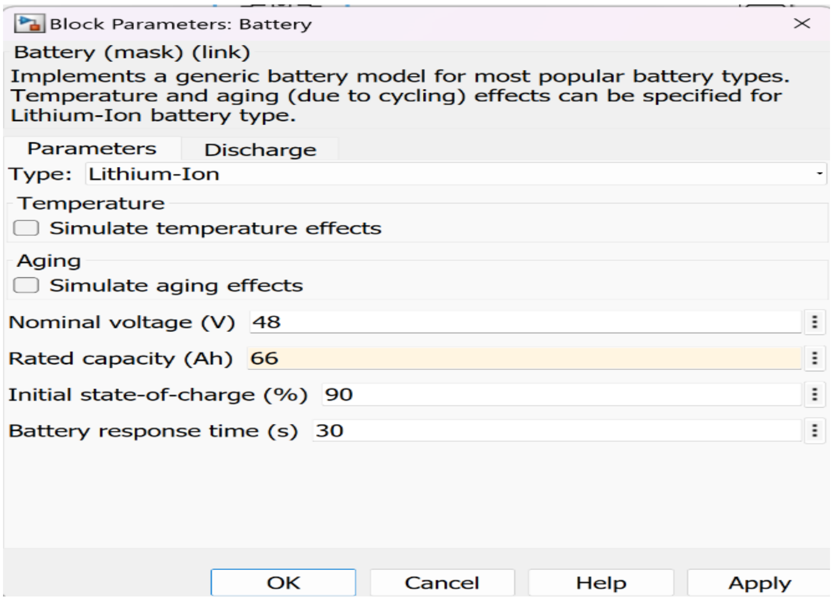


Fig 4.15: Battery block

Battery capacity taken is 3.44kWh. This model helps find the SOC, voltage, current variation with respect to time, which is obtained from the drive cycle.

4.6.2 Vehicle Body Block

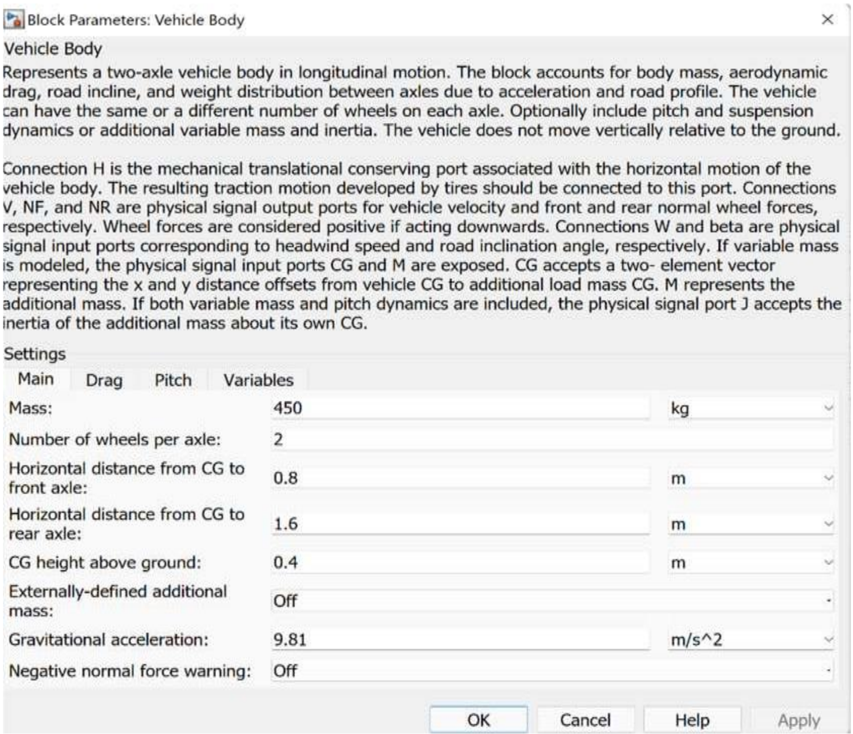


Fig 4.16: Vehicle body block

Parameter	Value
Mass of the vehicle (Gross weight)	**450 Kg**
Wheel diameter	**0.537 m**
Frontal area	**1.8 m^2**
Air density	**1.178 Kg/m^3**
Aerodynamic drag coefficient	**0.25**
Coefficient of rolling resistance	**0.015**
Gravitational acceleration	**9.81 m/s^2**

Table 4.02: Vehicle parameters considered while a simulation

4.6.3 Longitudinal driver Block

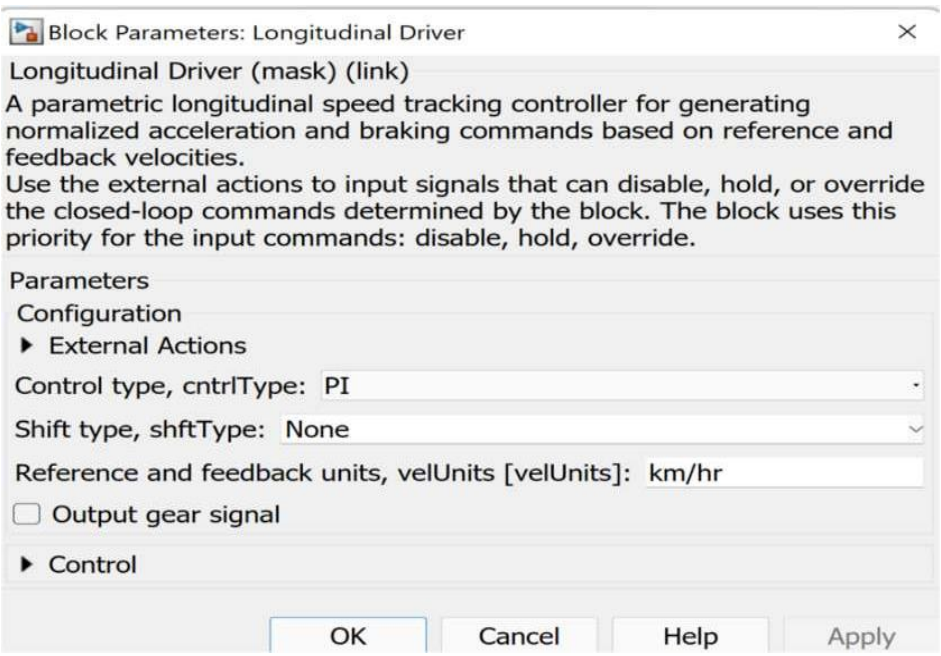


Fig 4.17: Longitudinal driver

In this longitudinal driver block (Fig 4.14), The input from the driving cycle is given to PWM voltage controller, followed by H Bridge.

This block uses a PI controller, and the unit is km/h.

4.6.4 SOC v/s Time

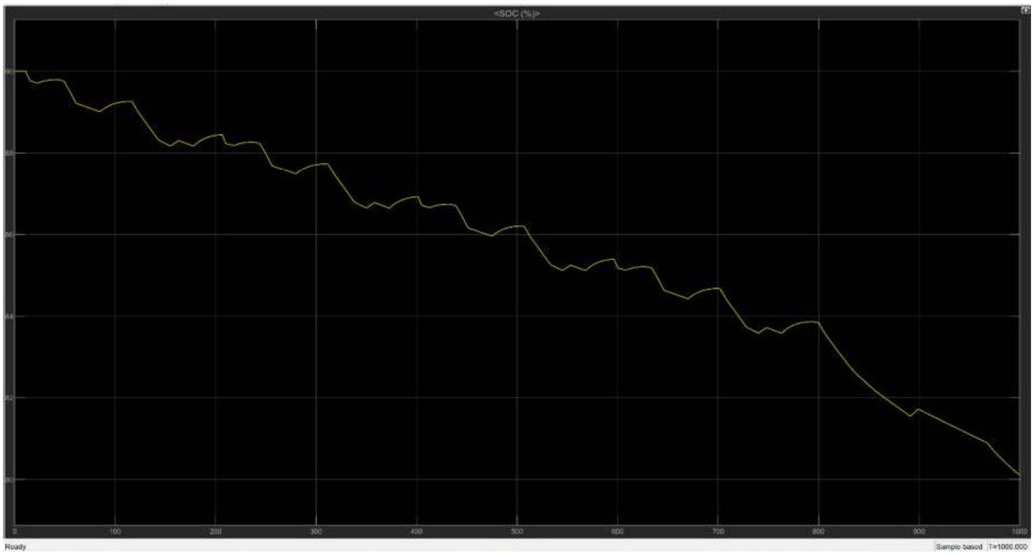


Fig 4.18: SOC v/s Time

SOC % is taken over a span of 1000 seconds

- SOC is a state of charge defined as the ratio of the available capacity q(t) and the maximum possible charge that can be stored in the battery.
- Here the graph is plotted with SOC against time. From these (Fig4.16), it is observed that SOC decreases from 90% to 80.11% over a span of 1000 seconds.
- There is an increase in SOC at some points due to regenerative braking from this state of charge.

4.6.5 Distance traveled in 1000 seconds

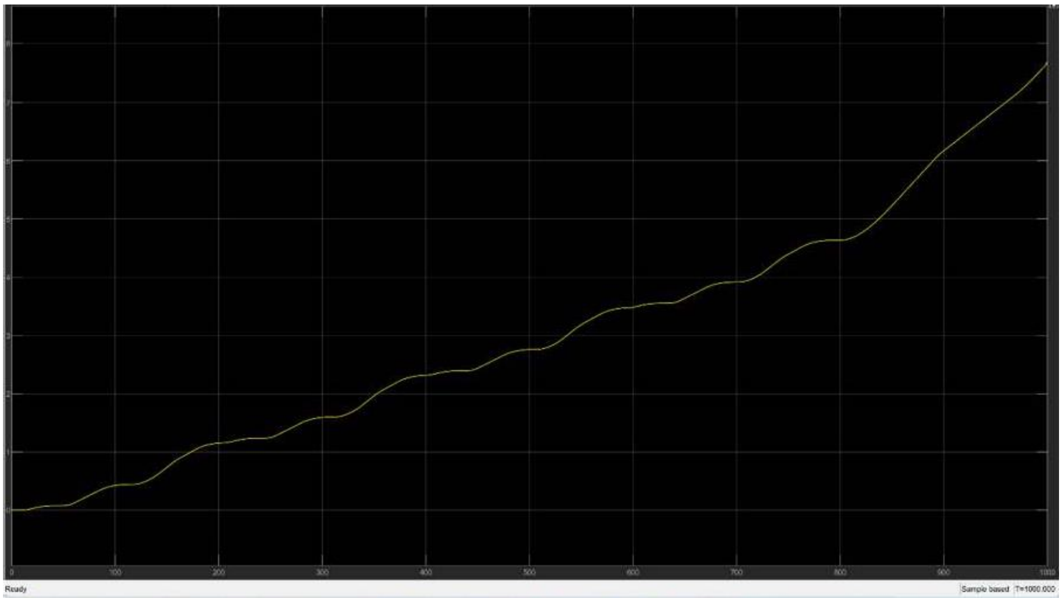


Fig 4.19: Distance travelled in 1000 seconds

- Here the graph plotted the distance traveled by vehicle against 1000 seconds.
- This graph shows the average speed travelled by vehicle for the given period and

the drive cycle.

- The distance traveled is 7.6km in 1000 seconds

v_{avg}= (7.6/0.27) =28.14 km/h

4.6.6 Variation of V_{ref}v/s $V_{feedback}$ from motor

- Here the yellow curve is the drive cycle of NEDC, and the blue curve is the motor variation.

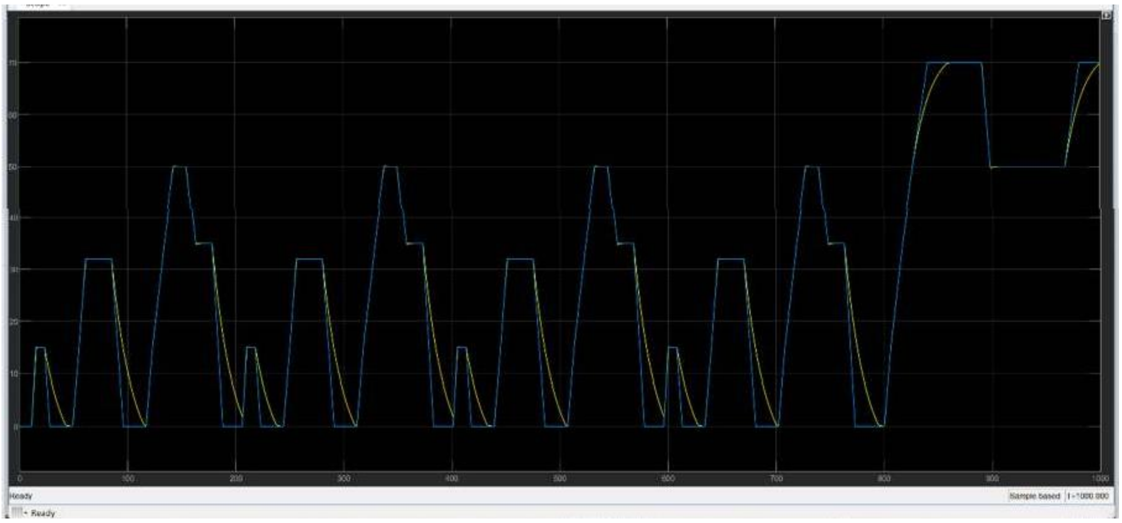


Fig 4.20: Speed v/s Time

- Here the motor tries to vary according to the V_{ref} which is input more the difference between the rated motor rpm and max rpm will be the difference between the velocity reference and velocity feedback.
- Max speed reached is 70 kmph using the NEDC cycle.

4.6.7 Voltage vs Time

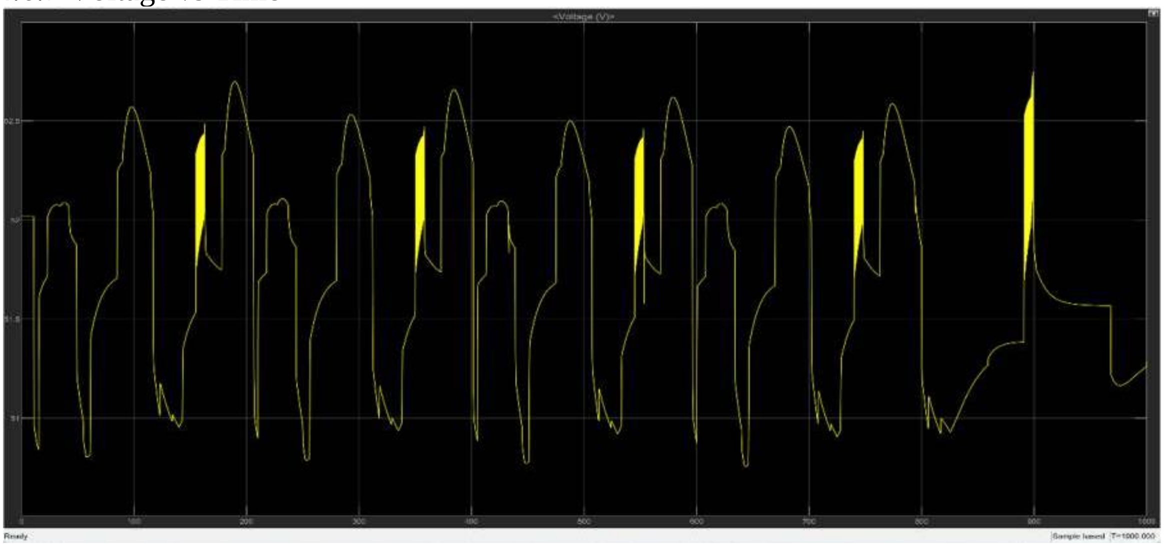


Fig 4.21: Voltage v/s Time

- Here (Fig 4.18), the graph is plotted for voltage against time over 1000 seconds.
- We can compare this voltage v/s time graph and speed v/s time graph from the diagram.
- It's similar because the voltage will control the speed of the motor.

4.6.8 Current vs Time

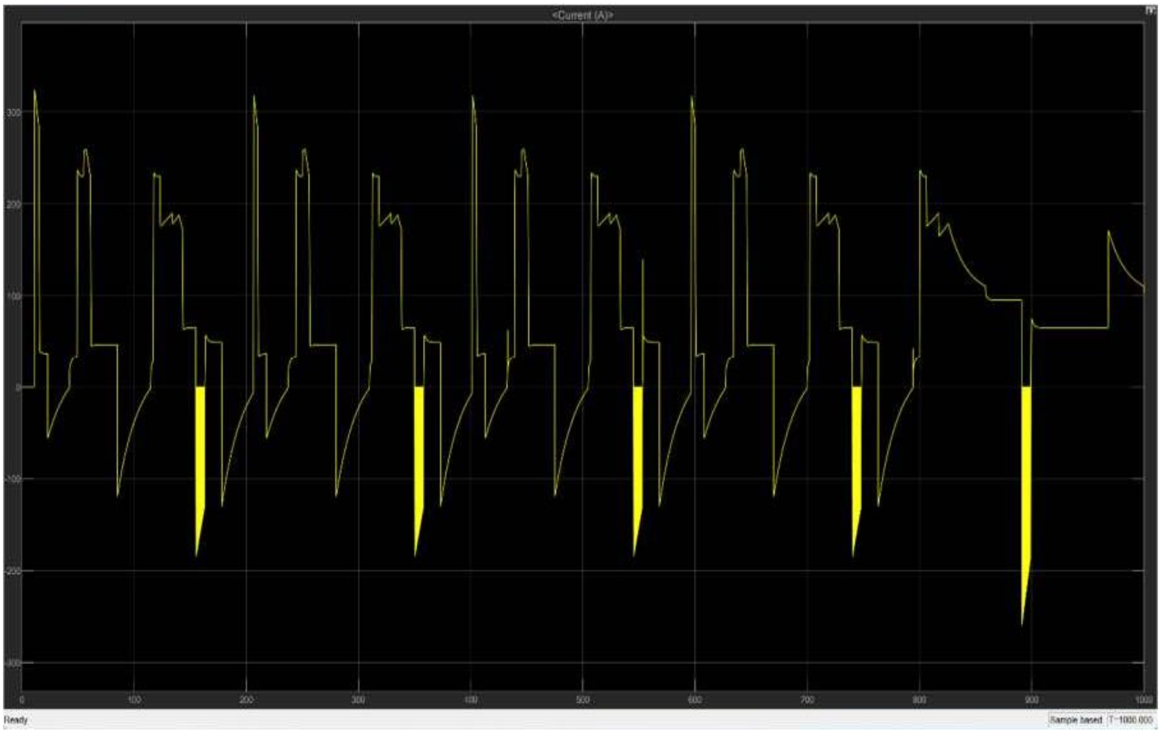


Fig 4.22: Current vs Time

- The graph is plotted current against time.
- Sometimes the current reaches around 300A as the drive cycle requires a boost in current for only a few seconds.

4.6.9 Battery selection

The average distance travelled by a person in Indian cities is around 35 km a day [13].

The cells of the battery pack were of the following specification:

- Each cell has a capacity of 6Ah
- The open circuit voltage is 3.2V at 96% SOC
- Now we need to design a battery pack, so the number of cells in series and parallel were found out.

To design the battery pack, the number of cells in series and parallel were found.To find a number of cells in series:

The maximum voltage of the motor and the peak voltage of each cell was considered and then divided to obtain the number of cells in series

- The maximum voltage of the motor is: 48 V
- The maximum peak voltage of the cell is: 3.2V
- So, it gives us 15 cells in series.

To find a number of cells in parallel:

The motor's maximum current and the max current of each cell were considered and upon dividing, gave us the number of cells in parallel.

- The capacity of each cell is: 6Ah
- So, it gives us 11 cells in parallel

CHAPTER 5: PARTS PROCUREMENT

5.1 Survey of motor

We have carried out a motor survey of different manufacturers and dealers in India; suiting this power requirements.

These are the specifications of motor from different motor manufactures and sellers

Motor kit: A company in Pune which sells motors and controllers.

Parameters	Value
Motor no	PMSM5.0006008CN
Rated power	5kW
Max power	8kW
Voltage	60VDC
Torque @ Rated power	9.6 Nm
Torque @ Max power	23.7 Nm
Speed @ Rated power	5000 RPM
Speed @ Max power	4000 RPM
Rated Current	110 Amps DC
IP Rating	IP55
Efficiency	>80%

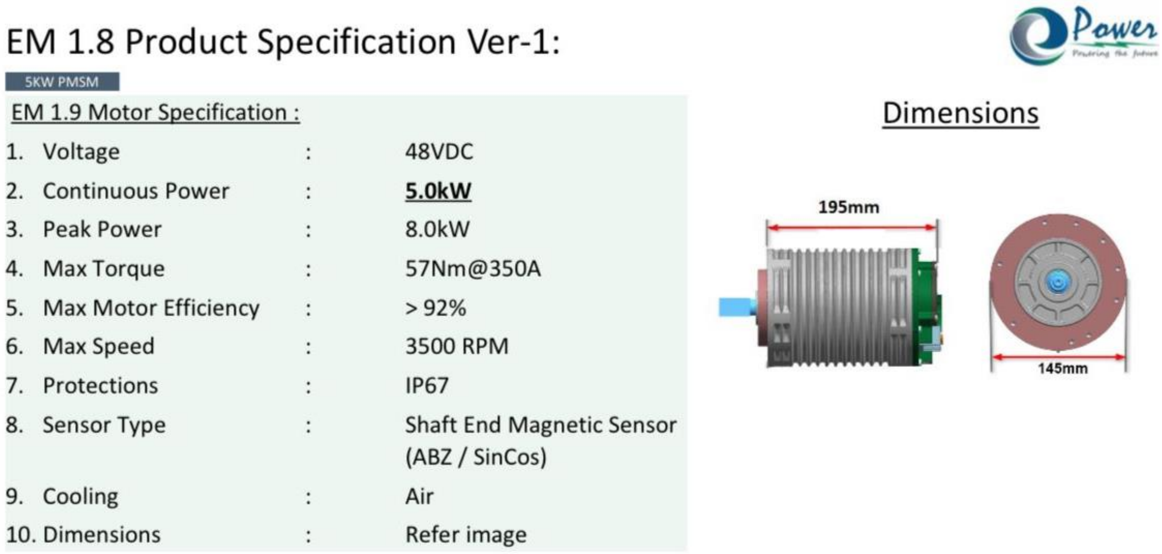
Table 5.01: Specification of motor

Mechatronics trading: A company from Pune which sells motors and controllers

Motor Type	PMSM
Rated power	4kW
Max. Power	6.7kW
Voltage	60
Torque @ Rated Power	18.9Nm
Torque@ Max Power	56Nm
Speed @Rated Power	3100RPM
Speed @MaxPower	4000RPM
Rated current	80Amps DC
Efficiency	>88%

Table 5.02: Specification of motor

SEG Automotive: This is a Bengaluru - based company that manufactures motors, gearboxes, and controllers for three-wheeler and two-wheeler vehicle manufacturers.



EM 1.8 Product Specification Ver-1:

5KW PMSM

EM 1.9 Motor Specification :

1.	Voltage	:	48VDC
2.	Continuous Power	:	5.0kW
3.	Peak Power	:	8.0kW
4.	Max Torque	:	57Nm@350A
5.	Max Motor Efficiency	:	> 92%
6.	Max Speed	:	3500 RPM
7.	Protections	:	IP67
8.	Sensor Type	:	Shaft End Magnetic Sensor (ABZ / SinCos)
9.	Cooling	:	Air
10.	Dimensions	:	Refer image

Fig 5.01: Motor specification [19]

5.1.1 Motor procurement

- We had an opportunity to present our project to them, and they were ready to sponsor us with a motor, gearbox, and controller for our project
- They had motors with different specification like motor operating range , IP rating.
- The EM-1.8 performance and characteristics suited our requirement .

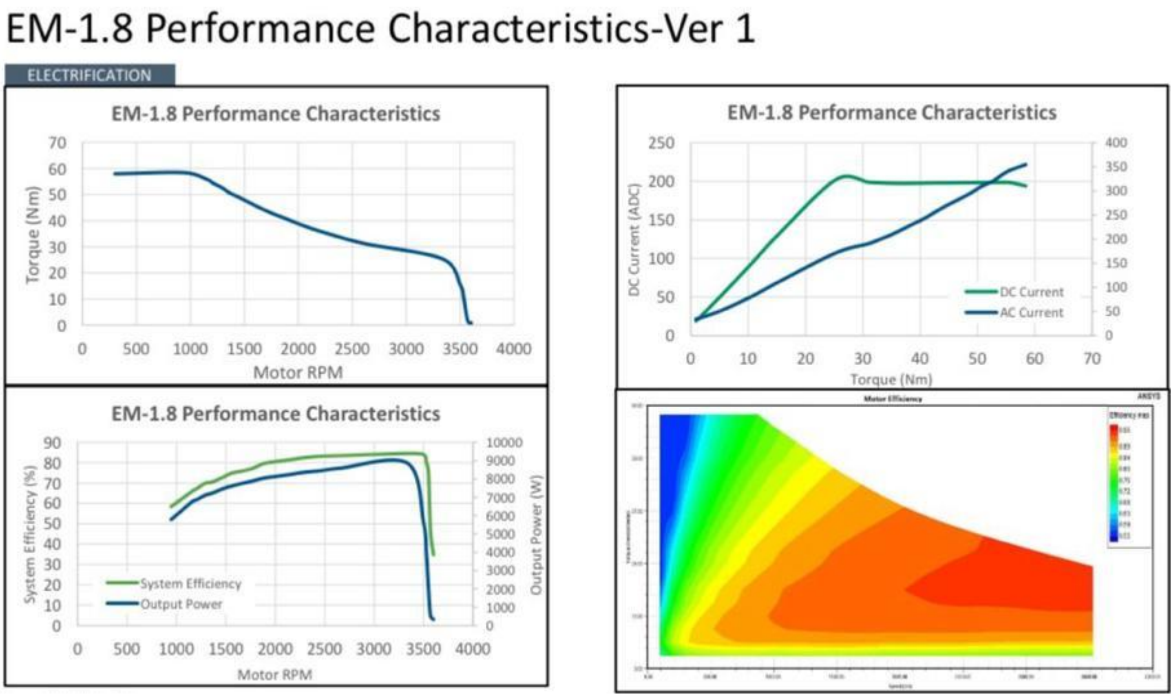


Fig 5.02: Performance and Efficiency mapping of SEG motor [19]

5.1.2 Advantage of SEG Automotive

- Better IP rating
- Better torque output
- Compatible with their gearbox
- Better efficiency
- Gearbox acts as a differential

5.2. Battery requirements

- According to motor requirements, we need 350Amps of current to get 57 Nm of torque. So, for our condition, 31.5 Nm torque is sufficient, which draws around 180Amps.
- So, according to our battery calculation, we need a 48V and 60Ah, which gives 2.8kWh
- The nominal current required is 104A which is continuous power by the motor, i.e., is 5kW by the voltage needed to run the 48V motor
- We need to select a battery that gives a 3C times of discharge for 1/3 hour(60×3=180Amps)
- This 180A is enough for our maximum torque requirements

5.2.1 Battery Survey

JB battery

Specifications

- Type: LiFePO4
- Voltage: 48V
- Nominal capacity: 100Ah
- Peak discharge current :2C

Fig 5.03: JB battery [20]

Micronix Battery

Specifications

- Capacity: 51.2V,66Ah
- Continuous current: 104 A
- Peak current: 210 A
- BMS is included along with the battery
- Warranty of 2 years

Fig 5.04: Micronix battery

5.2.2 Battery procurement

- The battery procured is from Micronix.
- It is a $LiFePO_4$ Cell.
- Each cell has 3.2V and 6Ah capacity.
- We need 15 cells in series and 11 cells in parallel according to our requirements.
- So, this sums up to 165 cells which produce a power of 3.16kWh.
- Its peak discharge is 3C which is sufficient for torque requirements.
- Dimensions of the battery pack 470 mm×290mm×180mm
- The battery comes with passive battery management system of 150A.
- A charger of 10A is used, with a max output current of 10A and output voltage of 54V from Axiom charger.

5.3 Controller

5.3.1 Controller procurement

- An electronics package that operates between the batteries and the motor to control the vehicle's speed and acceleration
- It regulates the torque and power generated by the motor of the electric vehicle.
- We are using a controller from sterling G take e- mobility.

5.3.2 Features of sterling controller

- Applicable for PMSM motors
- The power supply of the control signal can be provided by 12VDC or a power battery
- It is naturally cooled, covering the overall power range.
- It can be flashed and altered to meet different requirements of customers like changing the operating range of motor , regenerative operations , peak current and peak voltage control by the controller to the motor supply.

5.3.3 Pin configuration

Fig 5.05: Pin diagram [19]

PIN	Signal Name	Definition	Remark
1	TEMP+	Motor temperature	Motor temperature sensor +
2	GND	Motor Temperature -	Motor Temperature -
3	5V_EN	5V Encoder	Encoder supply
4	P	Park	12V effective, push once to enable system control
5	5V	Throttle control power	
6	KSI	12V battery + switch	
7	CANL	CANL	Low end of CAN
8	CANH	CANH	High end of CAN
9	PWM	PWM Signal	
10	Reserved pin	No connection	
11	Reserved pin	No connection	
12	ISD	Throttle control signal	0-5V
13	BC	Side bracket signal	When 12V side bracket signal is enabled, the system control is invalid
14	LOW	Low speed gear	12V effective
15	Reserved pin	No connection	
16	Z+(Z)	Encoder Z+(Z)	See connection diagram below
17	A+(A)	Encoder A+(A)	See connection diagram below
18	B+(B)	EncoderB+(B)	See connection diagram below

Table 5.03: Pin configuration [19]

19	GND	Encoder Ground	Ground
20	HIGH	High speed gear	12V effective
21	Reverse	Reverse	12V effective
22	Brake	Brake	12V effective
23	GND	Isolated 12V-	

Table 5.04: Pin configuration [19]

5.3.4 Connection diagram

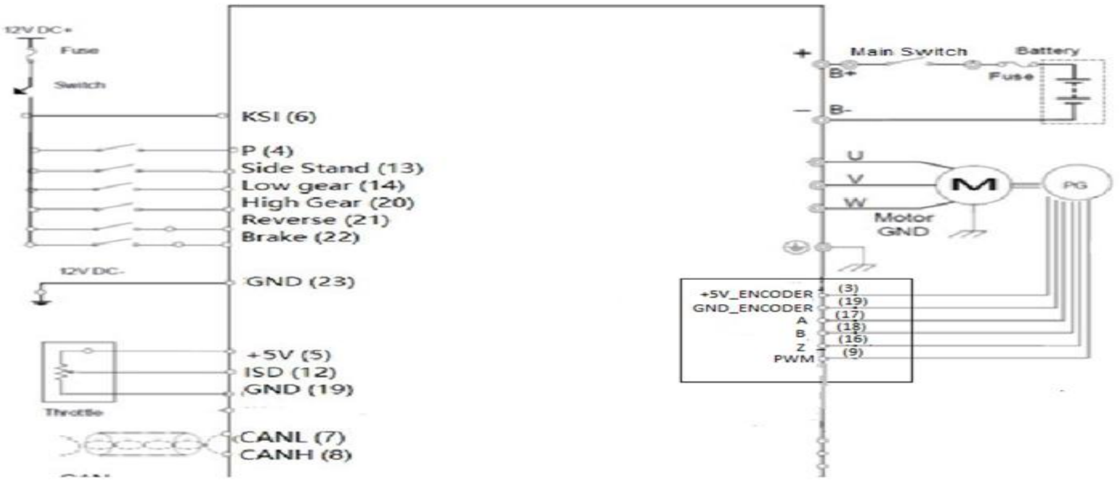


Fig 5.06: Connection diagram [19]

Fig 5.07: Controller image

5.4 Gearbox

5.4.1 Gearbox procurement

- SEG Automotive has sponsored this gearbox
- This gearbox has a maximum input speed of 4500 rpm, which produces maximum torque of 60 nm.
- SAE80W90 oil is used to lubricate the gearbox.
- This gearbox has two gear ratios of 14.96 and 8.06, out of which we are fixing the gear ratio to 8.06.
- This gearbox comes with an integrated differential which indeed reduces the weight of gearbox and increases the compactness of the powertrain system.
- This gearbox can be mounted inclined on the chassis with the help of angle plate .
- This gearbox suitable for broad range of motor RPM
- This gearbox uses Helix gears for high torque and power efficiency .

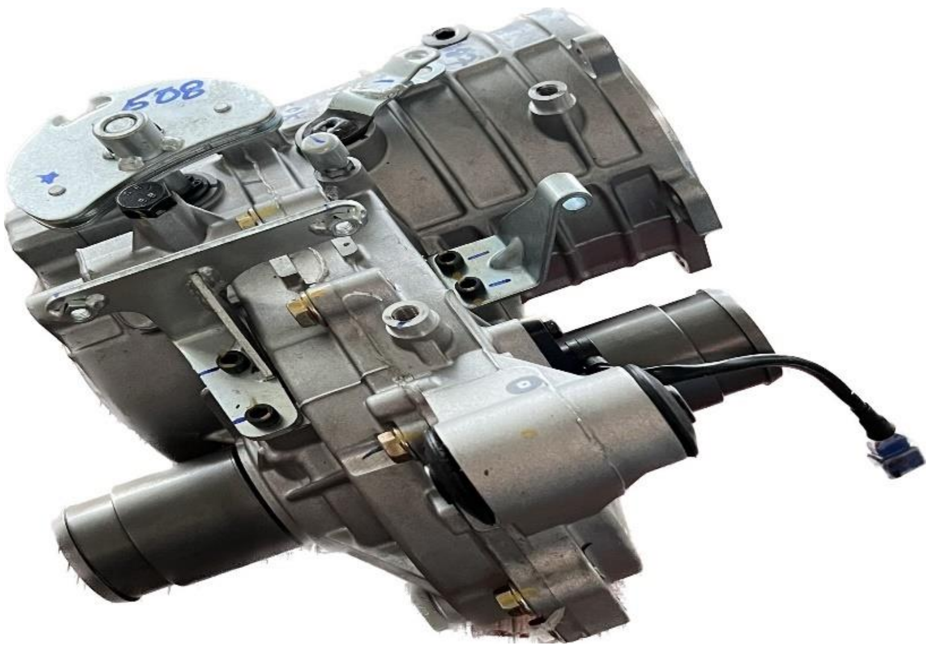


Fig 5.08: Gearbox image

5.5 Drive shaft

5.5.1 Shaft modification

- The gearbox we are using does not accommodate the shaft used in the car instead, it has a cup arrangement used in autorickshaw.
- Since we are doing a front wheel drive vehicle, we need our shaft to turn while we steer the vehicle. This facility is not provided in the autorickshaw shaft since it's a rear-wheel-drive shaft.
- So, we need to alter the drive shaft. We are using the auto shaft at one end (inner joint) and the drive shaft of a front-wheel drive car at the other end (outer joint), which can provide the ability to steer.
- So, we need to cut and weld these two shafts accordingly.
- While welding, we must make sure that male and female parts mate. Giving a chamfer angle of 45°.
- Weld it around the chamfer for better strength.
- The final mounting of the shaft with the chassis is done based on the relative position of the gearbox, a-arms, and knuckle.

Fig 5.09: Drive shaft

5.6 Wiring harness and power cable

- A wiring harness is an organized set of wires, terminals, and connectors that run throughout the entire vehicle and transmit information and electric power, thereby playing a critical role in connecting various components.
- It conducts electricity for all electrical loads on a vehicle.
- The controller needs to take many inputs from various components in the powertrain and needs to act based on the input received.
- We are using four input wires: ignition switch input wire, accelerator pedal, input wire, auxiliary power supply wire, and forward/reverse switch input wire.
- A power cable is a high-power transmitting cable that is connected between battery and controller. The length of the power cables we are using is 3m.
- Phase cable is a high-power transmitting cable that is connected between controller and motor. The length of the phase cables we are using is 1m.

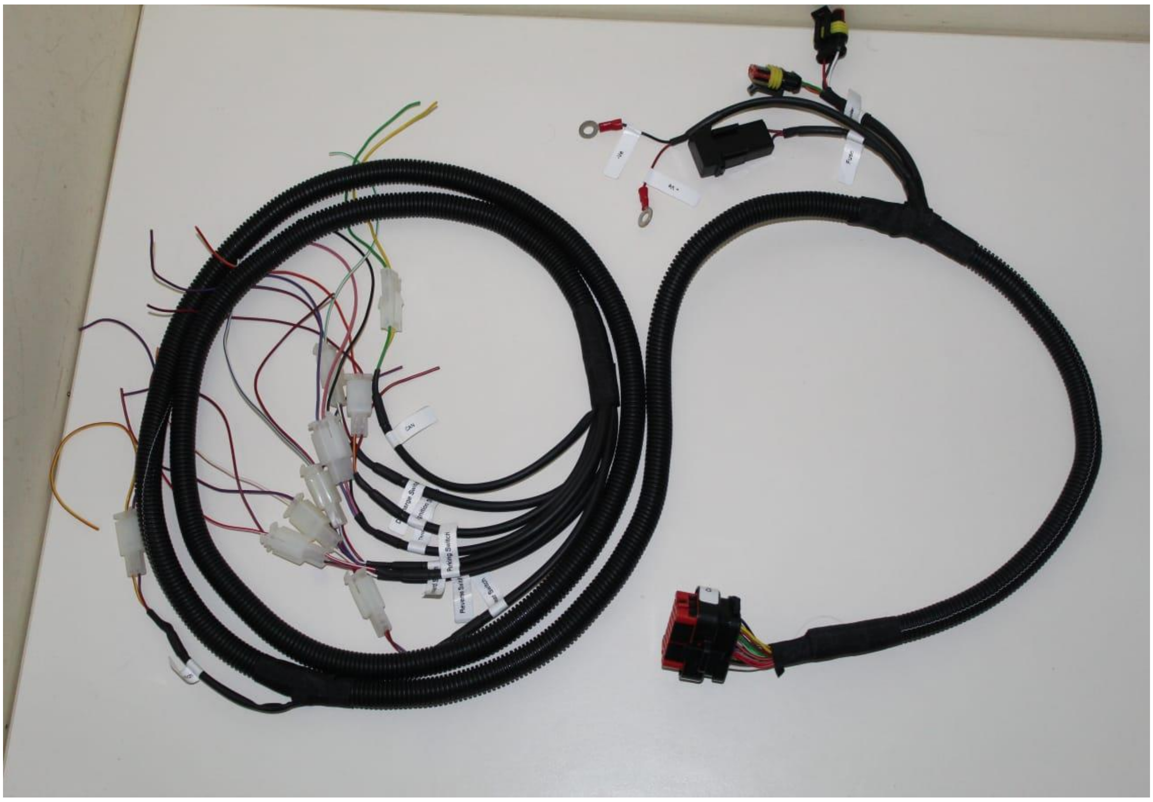


Fig 5.10: Wire harness

Fig 5.11: Power cable (Controller to Motor)

Fig 5.12: Power cable (Battery to Controller)

5.7 Power supply to the controller

- The controller needs the power to regulate the power supply from the battery of 12V. So, we cannot use direct supply from the battery (48V) to the controller, we can use a DC-DC converter.
- Since DC-DC converter was costly and due to its unavailability, we are using a 12V and 7Ah auxiliary battery of lead acid to provide power supply to the controller.

Fig 5.13: Auxiliary battery

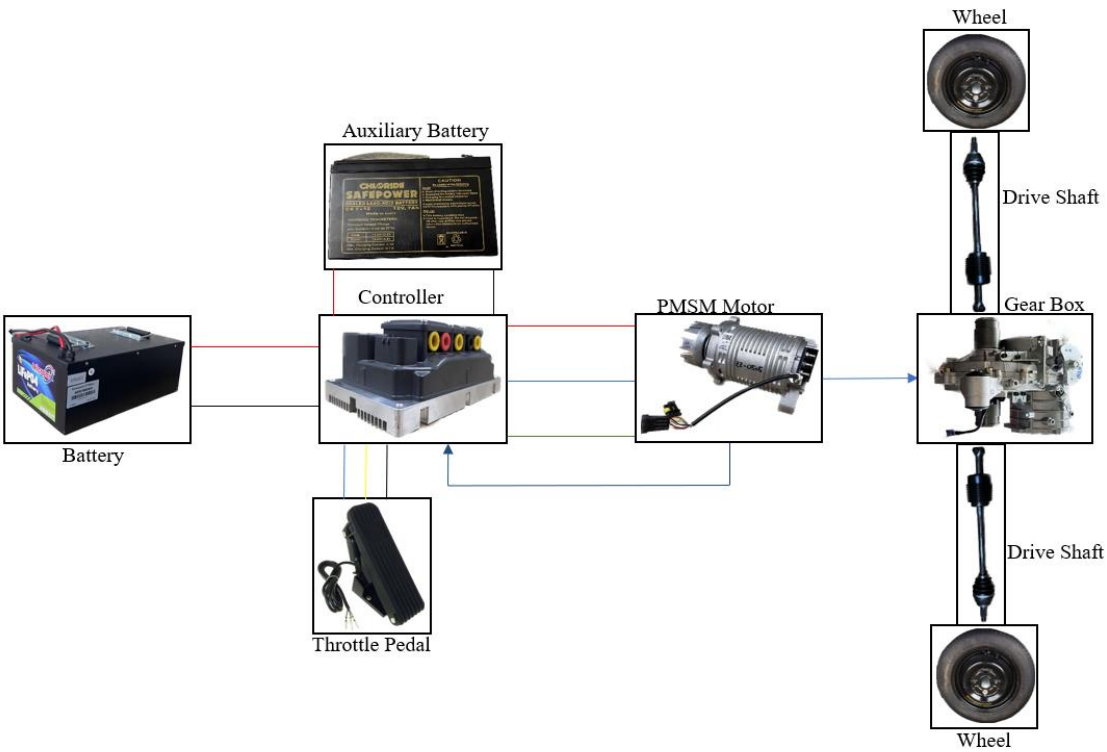


Fig 5.14 Connection of all powertrain components

CHAPTER 6: DESIGN AND ASSEMBLY OF POWERTRAIN USING SOLID WORKS

6.1 Introduction to design and assembly

As we procured the parts for electric tadpole, we went one step ahead in designing different components based on their dimensions and assembling them in SolidWorks

6.2 Modelling of motor

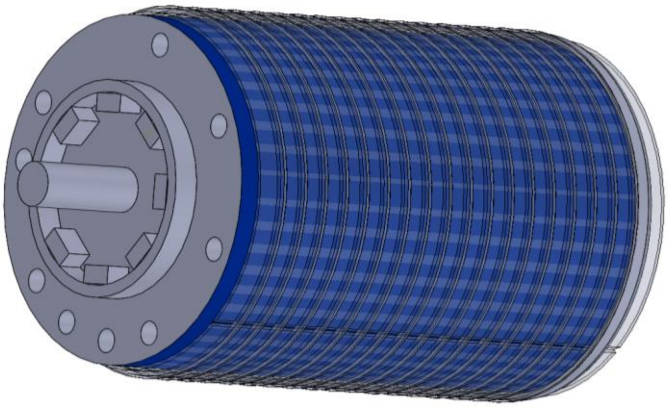


Fig 6.01: Motor model

6.3 Modelling of controller

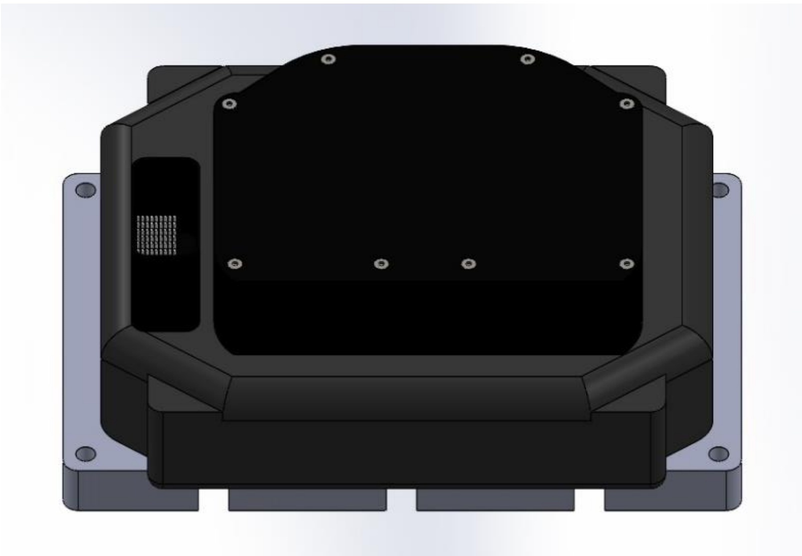


Fig 6.02: Controller model

6.4 Modelling of gearbox

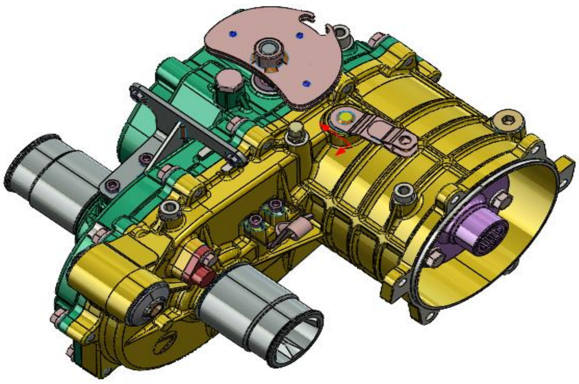


Fig 6.03: Gearbox model [19]

6.5 Modelling of battery

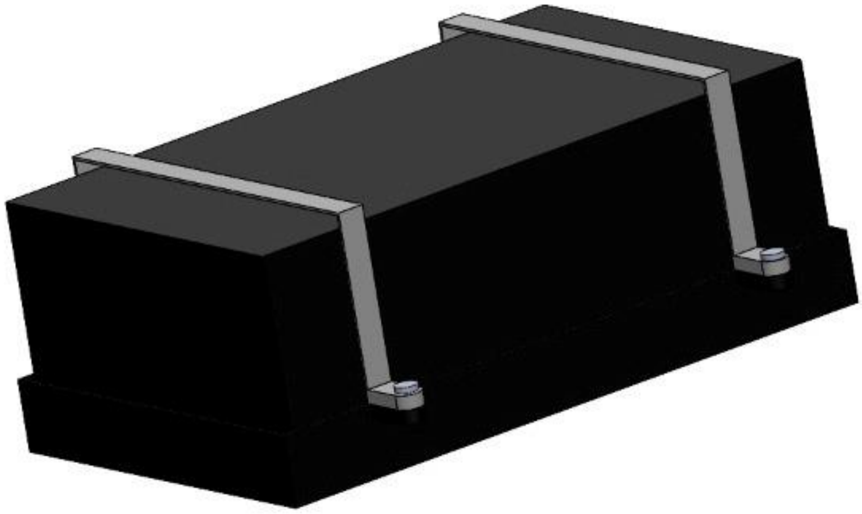


Fig 6.04: Battery model with clamps

6.6 Complete assembly of powertrain

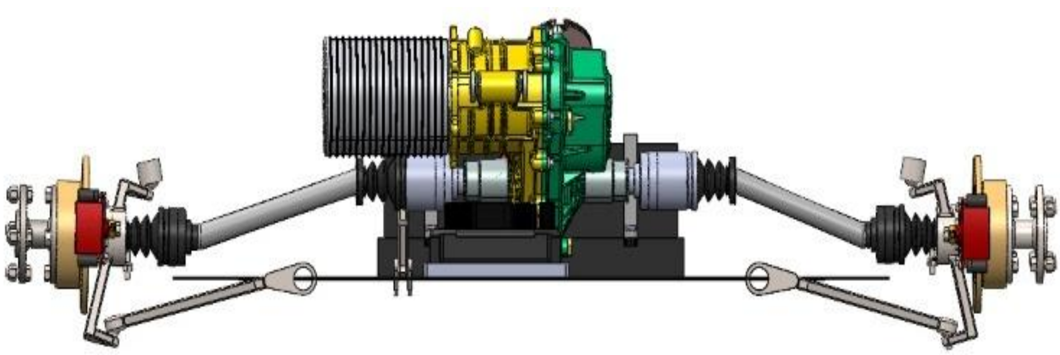


Fig 6.05: Assembly of the powertrain in solid works

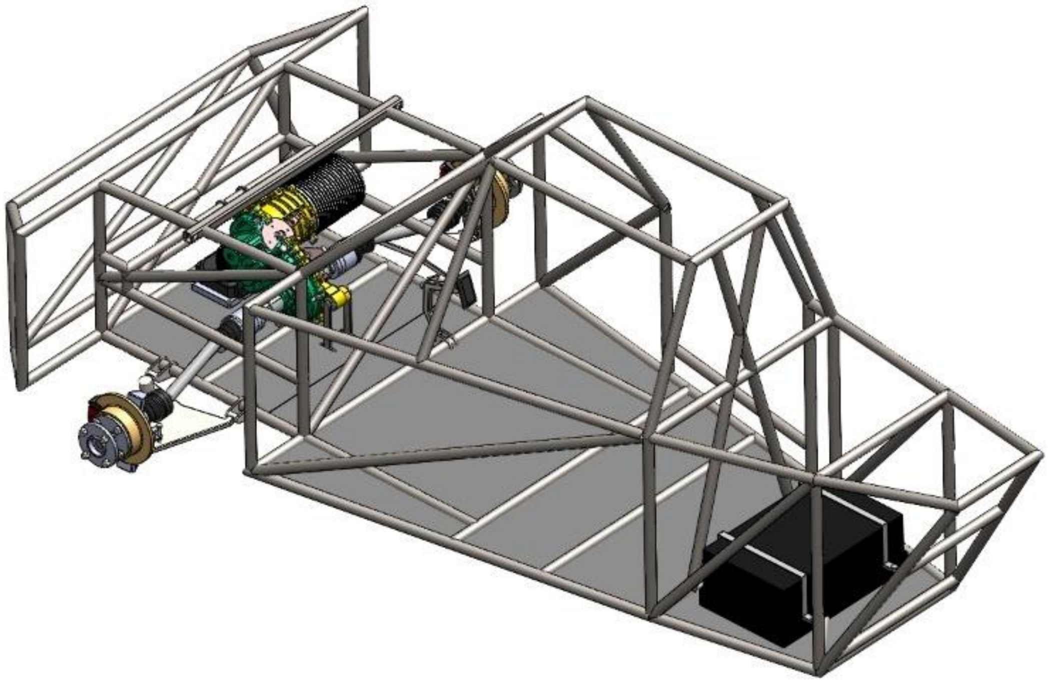


Fig 6.06: Assembly of the powertrain in Solidworks

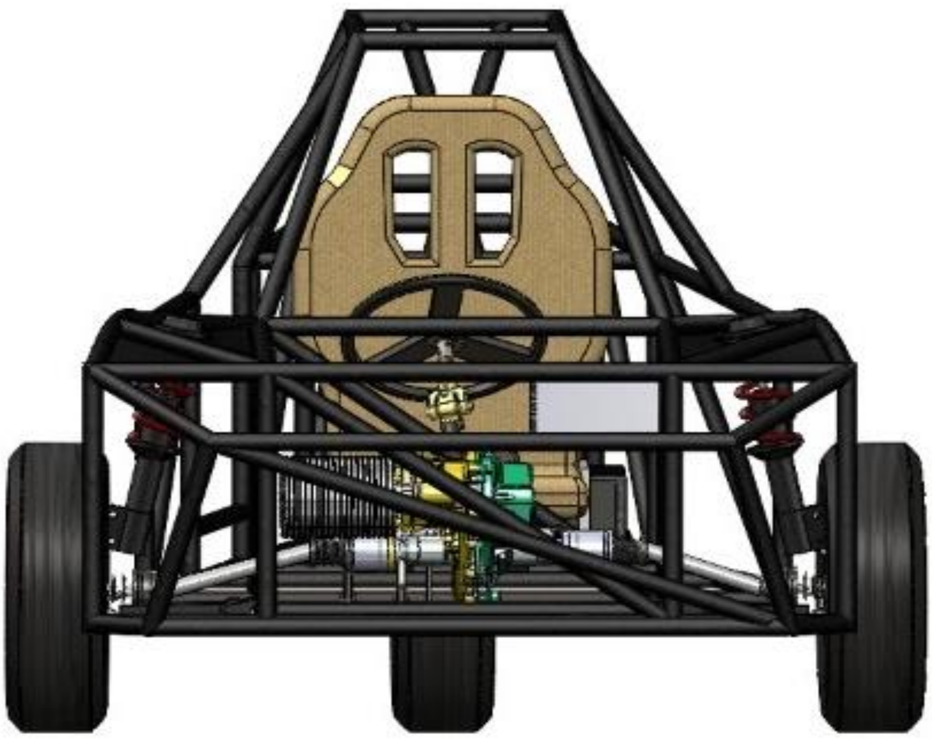


Fig 6.07: Assembly of complete tadpole in Solidworks

CHAPTER 7: FABRICATION

7.1 Mounting of powertrain assembly

We have made the mounting points on the chassis to mount the gearbox, motor, battery, controller, accelerator pedal, ignition key. We used MIG welding for the chassis and arc welding for mounting of gearbox and motor. The motor, gearbox and controller were mounted at the front since it provides better natural cooling and also better performance. The battery was mounted at the back of the tadpole provide better weight balancing on the vehicle. The battery height was made as minimum as possible in order to lower the Centre of gravity of the vehicle which improves the stability of the tadpole.

7.2 Modification of shaft

We used an auto rickshaw shaft and a car shaft as per the requirement as we didn't find any suitable shaft for our requirement which has an input of auto because we are using auto gearbox and output of car. So, we need to cut and weld these two shafts, after cutting them we provided chamfer of 45 degrees for both the ends and then drilled hole in one shaft and were kept on the lathe chuck to obtain exact 180 degrees and welding was done around the chamfer.

7.3 Electrification of powertrain components

Battery: - From the battery there are two output ports. Red and Black wires coupled to Anderson male coupler which is connected to controller via two power cables having female Anderson coupler. It is used to supply 48V power to the electric motor. This battery is mainly used to supply power to the motor which runs the tadpole.

Controller: - In controller there are 5 ports which includes B positive, B negative and R, G, B are used for three phase power supply. The controller also has a 21-pin connecter where signals from different components of the vehicle are supplied to the controller and back.

Auxiliary battery: - It has two ports which is connected via two wires to wiring harness of the controller. It is used to supply power supply of 12V for the controller.

Throttle pedal: - Throttle pedal has 3 pins positive (Blue), negative (Yellow) and control wire (Black) which is connected to the controller via wiring harness for providing throttle commands to the motor from controller which is given by the driver.

Motor: - There are a total of 5 ports in the motor, out of which three ports are used to connect three phase cables which comes from the controller and there are two ports which provides position feedback to controller.

Gearbox: - Motor is connected to the gearbox using 6 bolts of size (M8) Standards and an O-ring which is used in between to increase the water resistance and provides smooth contact between motor and gearbox. The gearbox we are using has two outputs for accommodating the driveshafts.

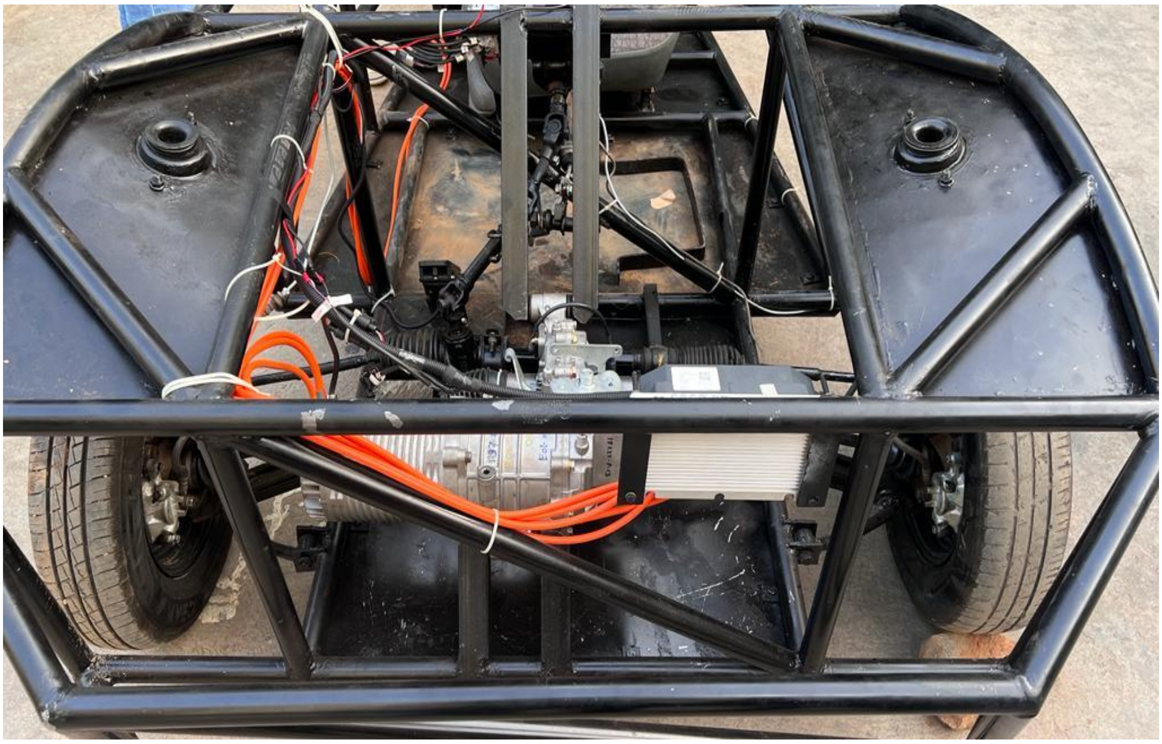


Fig 7.01: Isometric top view

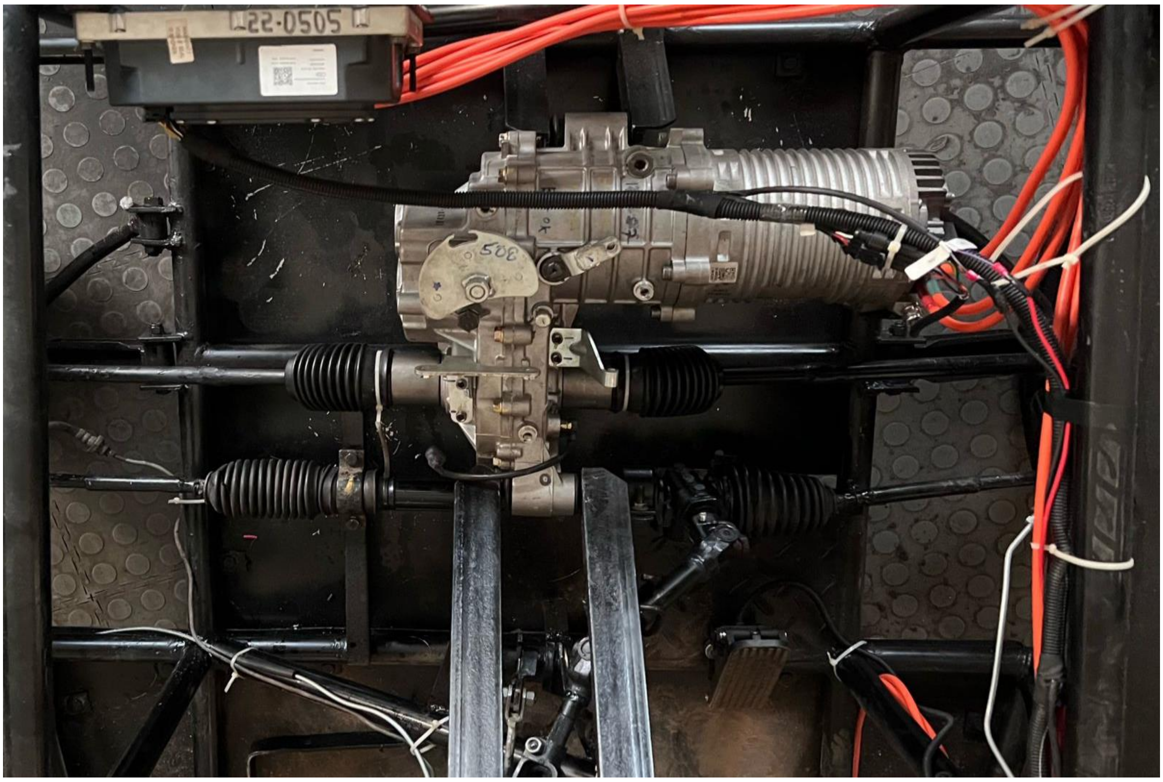


Fig 7.02: Top view of the powertrain

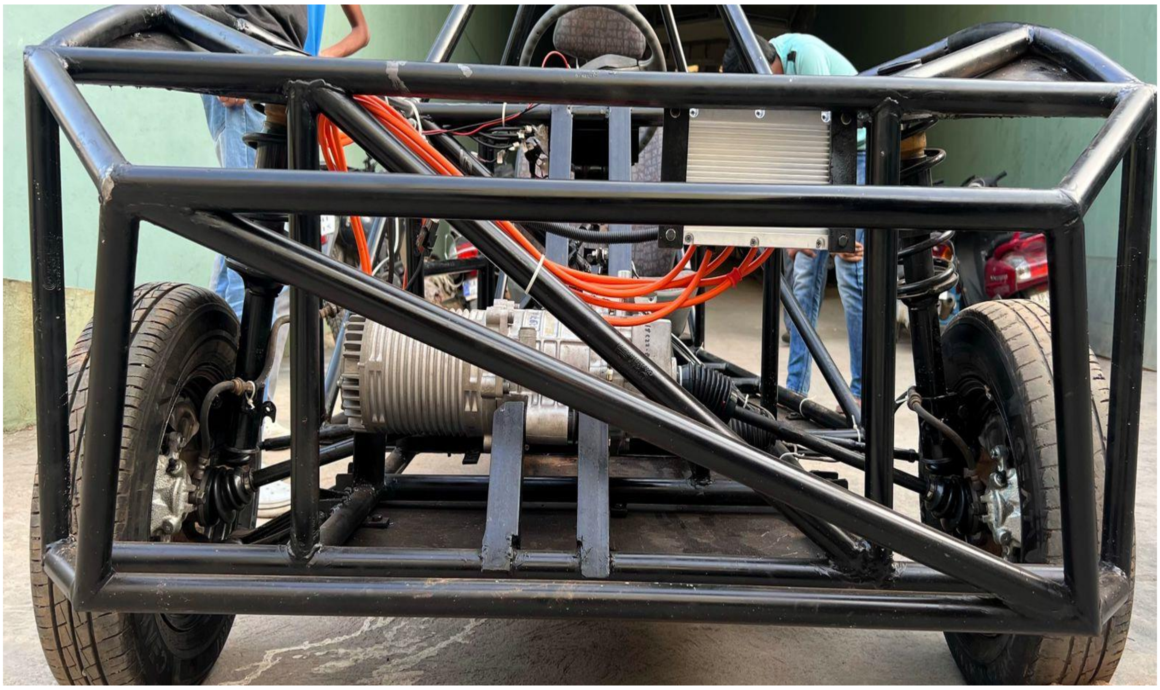


Fig 7.03: Front view of the powertrain

CHAPTER 8: RESULTS AND CONCLUSIONS

QSS model was used for the initial calculations to calculate the required power and torque from the motor. The motor selection was made on the basis of the highest requirement of power for the vehicle from different parameters, which was found to be 5.879 kW, and another vital factor for the SEG motor was the RPM of the motor, which was 3500 RPM which was nearing the ideal requirement of our top speed that's 48 km/hr as per requirement and the gearbox which was used had a gear ratio of 8.06 which helped in developing a top speed of 47km/hr.

This motor and gearbox were selected due to the compactness of the system as the gearbox had an integrated differential which helped in reducing excessive mass at the front of the vehicle and also eased the cooling of the motor due to its placement and air-cooled technology and another critical reason for the selection of this motor was , we are developing this vehicle mainly for city purpose due to very inclined city road vehicle needs to be torquey .Therefore to satisfy this condition, we needed a motor which has to have high torque which was another reason why we selected SEG motor which produced a massive torque of 57 Nm which was sufficient for our requirement . Battery was selected based on maximum torque required for our vehicle which was 252 Nm at the wheels. We selected the Micronix battery that has 48 V and 66Ah, producing energy of 3.16kWh.

This motor and battery, which was selected, were supported gtake e-mobility controller for the PMSM motor, and 12V is required for the controller's operations. The advantages of this controller are that it can be flashed and reprogrammed according to motor requirements using motor mapping technology. The only drawback of that gearbox was that it was three-wheeler delta configuration gearbox box that is used autorickshaw shafts fixed at the rear wheels to convert into a steerable shaft. It was modified with a Maruti alto shaft for our requirements considering all the constraints.

After all the parts were procured, the fabrication was started by mounting the entire powertrain system with the help of clamps and MIG welding, and fabrication was completed. After the completion of fabrication. The vehicle was tested on flat roads and also inclined roads, which had a grade of 20% or more than that. Tadpole vehicle satisfied all three constraints that were top speed of 47 km/hr on a flat road, climbing the road of 20 % grade and accelerating at 0-30 km in sec. The range of the vehicle is calculated to be approximately 30km.

Max power required	5.8 kW
Peak torque required	252. Nm
Max speed of motor	3500 RPM
Drive ratio	8.06
Motor peak power	8 kW
Motor max torque	57 Nm at 350 A
Motor type	PMSM

Table 8.01: Powertrain specifications

Battery voltage	48V
Battery capacity	66Ah
Single cell voltage and capacity	3.2V & 6Ah
No of cells in series	15
No of cells in parallel	11
Energy	3.16 kWh
BMS	Passive type of 150 A

Table 8.02: Battery specifications

Fig 8.01: Tadpole vehicle

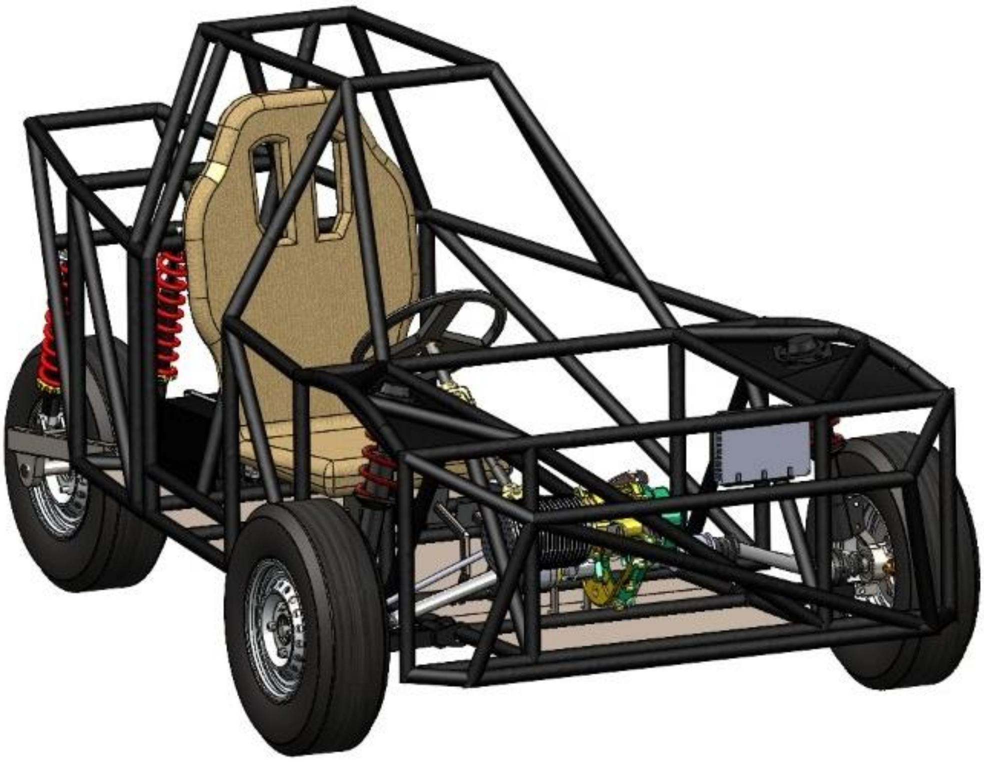


Fig 8.02: Assembly of Tadpole vehicle using Solidworks

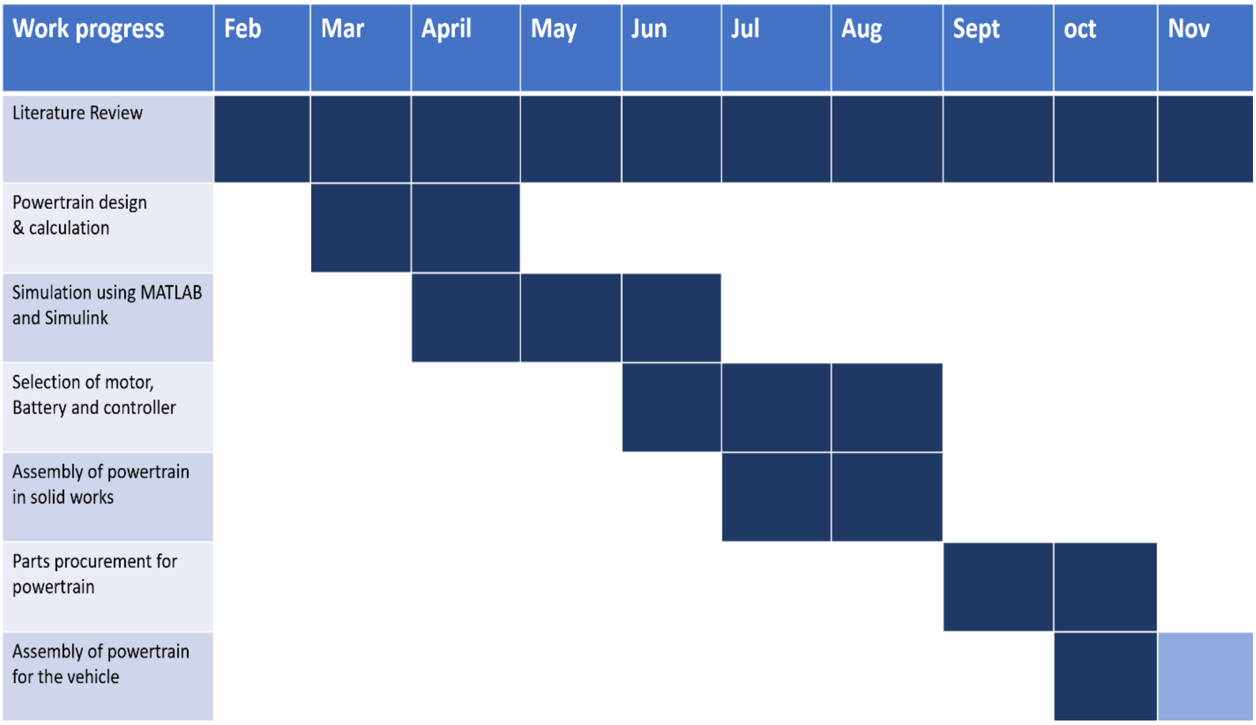
CHAPTER 9: FUTURE SCOPE OF WORK

Optimization of the electric powertrain system can be done by using dual speed gearbox with the help of a clutch which can increase the amount of torque and reduce maximum current requirement therefore, we can use lower C rating cells.

There is scope for converting this tadpole to an autonomous vehicle that can be used as e-commercial delivery vehicle. Regenerative braking system can be added, which converts the kinetic energy to electric energy with the help of regen motors which in fact can increase the range of vehicle. The further creation of a test rig for mounting of powertrain system on it can help find how this system responds to each drive cycle and the efficiency of it in each driving cycle.

There is significantly fewer data collected about real-life drive cycles in India for 3-wheeler. We can use a VBOX to take large samples of each ride and make them into one drive cycle specifically for a 3-wheeler. We can learn in-depth about optimizing powertrain parameters like optimum motor operating range. optimization of gearbox using different composite material for better power and torque transmission. We can develop an oil cooled or water-cooled radiator system for cooling of the powertrain system which indeed increases the efficiency of the powertrain.

TIMELINE


Work progress
Feb
Mar
April
May
Jun
Jul
Aug
Sept
oct
Nov
Literature Review
Powertrain design & calculation
Simulation using MATLAB and Simulink
Selection of motor, Battery and controller
Assembly of powertrain in solid works
Parts procurement for powertrain
Assembly of powertrain for the vehicle

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CHAPTER 10: APPENDIX

MATLAB code

Code to calculate power and torque requirement:

```
clear;
clc;
prompt = "Enter the mass in Kg?";
m = input(prompt);
prompt = "Enter the value of frontal area in m²?";
Af = input (prompt);
prompt = "Enter the co-efficient of rolling resistance";
mu = input (prompt);
prompt = "Enter the co-efficient of Aerodynamic Drag co-efficient";
cd = input (prompt);
prompt = "enter the value of air density in kg/m³";
rho = input (prompt);
prompt = "enter the value of velocity in m/s";
v = input (prompt);
prompt = "enter the gradient in radians";
theta = input (prompt);
prompt = "enter the acceleration in m·s−2";
ac = input (prompt);
prompt = "enter the radius of wheel in m";
r = input (prompt);
g = 9.81;
Fa = 1/2 * (rho* cd *Af * v.^2); % Aerodynamic resistance
Fr = mu*m*g*cos(theta);  % Rolling resistance
Fg = m*g*sin(theta); % Gradient resistance
Facc = m*ac; % Acceleration resistance
Ft = Fa + Fr + Fg + Facc;  % Tractive force
P = (Ft*v)/1000; % Power
T=Ft*r;%torquess
fprintf ('Value of Aerodynamic drag resistance, Fa is %f N \n', Fa )
fprintf ('Value of Rolling resistance, Fr is %f N \n', Fr )
fprintf ('Value of Grading resistance, Fg is %f  N \n', Fg )
fprintf ('Value of Tractive force,Ft is %f  N \n', Ft )
```

```
fprintf ('Value of Acceleration resistance, Ft is %f  N \n', facc )
fprintf ('Value of Power,P is %f  Kw\n', P )
fprintf ('Value of Torque,T is %f  Nm', T)
```

Code to plot Tractive force v/s speed on a flat road

```
clear;
clc;
rho=1.178;
cd=0.25;
m=450;
g=9.81;
mu=0.015;
theta=0;
Af=1.8;
ac=(6/3.6);
x=0:1.296:13.889;
y2= (0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(theta))+m*g*sin(theta)+(m*ac);
plot(x,y2)
hold on
y1= (0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(theta));
plot(x,y1)
hold on
y3=(0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(0.1974))+m*g*sin(0.1974);
plot(x,y3)
hold off
```

Code to plot tractive force v/s speed for all cases before cutoff

```
clear;
clc;
rho=1.178;
cd=0.25;
m=450;
g=9.81;
mu=0.015;
```

```
theta=0;
Af=1.8;
ac=(6/3.6);
x=0:1.296:13.889;
y2= (0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(theta))+m*g*sin(theta)+(m*ac);
plot(x,y2)
hold on
y1= (0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(theta));
plot(x,y1)
hold on
y3=(0.5*(rho* cd *Af * (x.^2)))+(mu*m*g*cos(0.1974))+m*g*sin(0.1974);
plot(x,y3)
hold off
```

Code to plot tractive force v/s speed for all cases after cutoff

```
clear;
clc;
rho=1.178;
cd=0.25;
m=450;
g=9.81;
mu=0.015;
theta=0;
Af=1.8;
Acc=0.833;
x1=0:1.296:13.889;
y1= (0.5*(rho* cd *Af * (x1.^2)))+(mu*m*g*cos(theta))+m*g*sin(theta);
plot(x1,y1)
hold on
x2=0:.833:8.33;
y2= (0.5*(rho* cd *Af * (x2.^2)))+(mu*m*g*cos(theta))+(m*Acc);
plot(x2,y2)
hold on
x3=0:0.5556:5.556;
y3=(0.5*(rho* cd *Af * (x3.^2)))+(mu*m*g*cos(0.1974))+m*g*sin(0.1974);
```

```
plot(x3,y3)
hold off
```

DESIGN AND DEVELOPMENT OF POWERTRAIN IN A FRONT WHEEL DRIVE ELECTRIC TADPOLE TYPE VEHICLE

ORIGINALITY REPORT

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DESIGN AND DEVELOPMENT OF POWERTRAIN FOR FRONT WHEEL DRIVE ELECTRIC TADPOLE

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With the need for a compact system of transportation the three wheelers have evolved over the years and in future we can see these tadpoles in commercial aspects. These are electrified as IC Engine based three wheelers have been contributing excessively towards air pollution and the efficiency of the electric tadpole is more. The primary aim is to develop a powertrain for a front wheel drive electric tadpole type vehicle. The tadpole configuration has many advantages over the delta types as tadpole provides more stability while cornering and braking. Here, we have set few performance parameters and calculated the torque and power required from MATLAB and Simulink and found the different types of resistive forces that tadpole needs to overcome in order to move. Based on which we have selected the motor specifications, the battery capacity and also using these parameters, we have procured various powertrain components like motor, battery pack, controller, gearbox, drive shaft, throttle pedal, power cable, phase cables and wiring harness. After procuring the components of the powertrain, we have fabricated and integrated the components with the tadpole vehicle.

Keywords: Tractive Effort, Motor Sizing, Battery Sizing, Energy Consumption, Electric Vehicle Range, Torque, Drive Cycle, Tadpole Vehicle, Motor Selection, Electric Powertrain Development.

INTRODUCTION

We all use different set of vehicles for our daily commute. They are generally cars, bikes, auto public transport, going on bike may be tedious and car is costly to maintain. There is no vehicle which is economical, easy to maintain and makes us feel comfortable during ride. Compared to Tadpole configuration, delta configuration provides poor confidence while driving at high speed and corner manoeuvring. As there are two wheels at the front there is better braking performance and shorter stopping distance compared to delta configuration and also tadpole provides good high speed aerodynamic stability because of teardrop shape in contrast to delta type. As there are many advantages of front wheel drive over rear wheel driven tadpole which will discussed subsequently in this paragraph such as better natural cooling that's air cooling for the components like motor, gearbox, controller, and wiring harness. Another major reason would be lifting of wheels while cornering at high speed and over steering characteristics for rear wheel driven tadpole which needs to be overcome with the help of using front wheel driven tadpole which provides high stability at cornering and understeering characteristics which is preferred by drivers. The primary aim of this project is to develop a powertrain for a "Front wheel-drive electric tadpole-type vehicle".

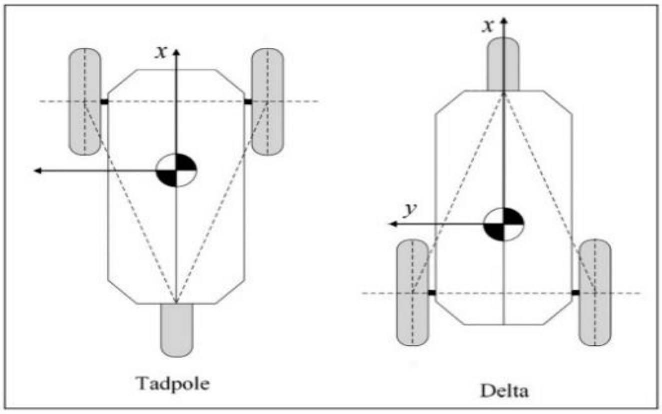
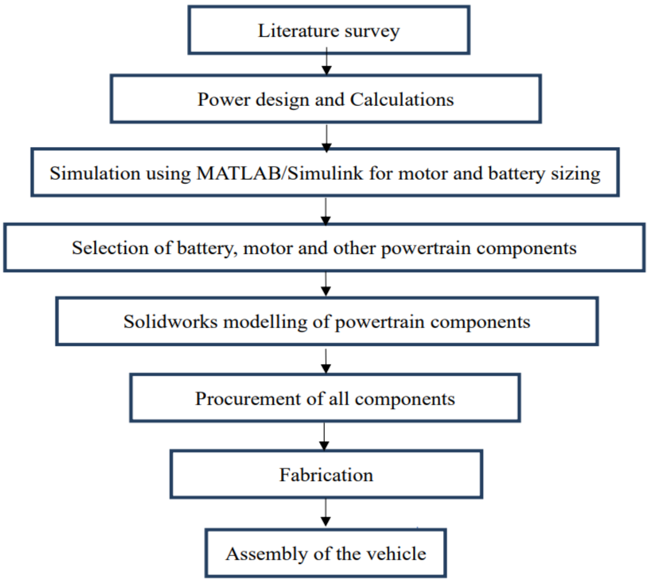


Fig 1: Two types of configurations for three wheelers

So, we have decided to build a front wheel drive electric tadpole meeting all the requirements. We are focussing on development of powertrain for electric tadpole. We had done calculations for torque and power required for our tadpole using QSS toolbox and MATLAB. Then based on our torque and power requirements, we had to research for different components of powertrain which includes motor, controller, battery, shafts, gearbox, power cable, phase cables, auxiliary battery, and wiring harness. After research we had decided to use motor, gearbox and controller from Seg automotive, and battery has been selected by the max current required by the motor. Battery we are using is from Micronix.

Powertrain refers to a system of components in a vehicle that generates power and delivers it to the wheels in an automobile. It has many components, such as the energy source, torque converter, transmission system, and final drive. The main components of an electric powertrain are battery pack, electric motor, controller, transmission system and drive shafts. The electric powertrain has higher efficiency than internal combustion vehicles (IC). Some of the bulky components, such as engines, clutch and multiple gear system are eliminated. High starting torque is available. Gears can be eliminated since torque and speed can be varied by using the motor & controller. Less rotating elements, therefore less rotating inertia than the internal combustion vehicles.

METHODOLOGY



Having identified the purpose of the vehicle, we need to set a few performance parameters with the problem statement. The parameters taken are as follows:

- Top speed of 47 Kmph (12.96 m/s) on a flat road (i.e., 0% gradient)
- Acceleration of 0-30 kmph (0-8.33m/s) in 6 seconds on a flat road (i.e., 0% gradient)
- Gradeability of 20% at 20 Kmph (5.556m/s with 11.3 degrees inclination)

To carry out the calculations, few values were to defined; of that some were assumed and some were determined.

Parameter	Value
Mass of the vehicle (m)	450 Kg
Wheel diameter (D_w)	0.537 m
Frontal area (Af)	1.8 m^2
Air density (ρ)	1.178 Kg/m^3
Aerodynamic drag coefficient (C_d)	0.25
Coefficient of rolling resistance (μ)	0.015

Table 1: Vehicle parameters

Determination of forces on wheels

Tractive effort required to move on a flat road, acceleration requirement on a flat road and a gradient was plotted against the velocity using MATLAB.

$$F_r = F_{roll} + F_{aero} + F_{grad} + F_{ac} \quad (1)$$

$$F_{roll} = \mu \times m \times g \times cos(\Theta) \quad (2)$$

$$F_{aero} = ½ \times (\rho \times C_d \times A_f \times v^2) \quad (3)$$

$$F_{grad} = m \times g \times sin(\theta) \quad (4)$$

$$F_{ac} = m \times a \quad (5)$$

$$F_{r1} = F_{roll} + F_{aero} \quad (6)$$

$$F_{r2} = F_{roll} + F_{aero} + F_{grad} \quad (7)$$

$$F_{r3} = F_{roll} + F_{aero} + F_{ac} \quad (8)$$

The highest resistive force encountered was 938.86 N when it was required to run the vehicle at 20 km/h on a 20% gradient.

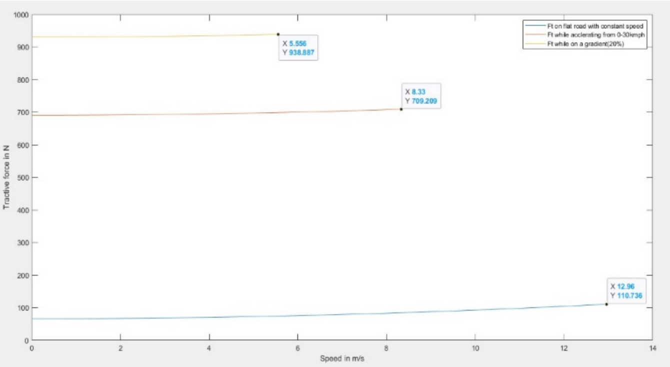


Fig 2: Tractive force v/s speed

Determination of peak power

The power demanded by all the three parameters was determined. The highest among the three is determined as the peak power.

$$F_{net} = F_{trac} - F_r \qquad (9)$$

The power demanded was determined using the formula $P = F_{trac} \times v$ (10)

After comparing the power demanded among the three parameters, the peak power required was found to be 5.879 kW while accelerating from 0-30 kmph (0-8.33m/s) in 6 seconds on a flat road.

Determination of peak torque

The torque required at the wheels is determined by using the formula

$$\tau_W = F_{trac} \times (\frac{D_W}{2}) \qquad (11)$$

After comparing the torque demanded among the three parameters, the peak torque required was found to be 252.08 Nm while climbing a gradient of 20% at 20 kmph.

After determining the peak torque and the peak power required by the vehicle at the wheels, we can determine the torque required by the shaft after selecting the gear ratio i= 8.

The torque required at the shaft is determined by using the formula

$$\tau_{m-peak} = \frac{\tau_{w-peak}}{i} \qquad (12)$$

The torque required at the shaft is found to

be 31.51Nm.

QSS Model

We have used the QSS model under Simulink to help us in determining, torque at the shaft, motor power, energy consumption. Vehicle parameters were given in each block such as mass, vehicle cross section, gear ratio, battery parameters, drag coefficient, rolling resistance coefficient, wheel diameter etc.

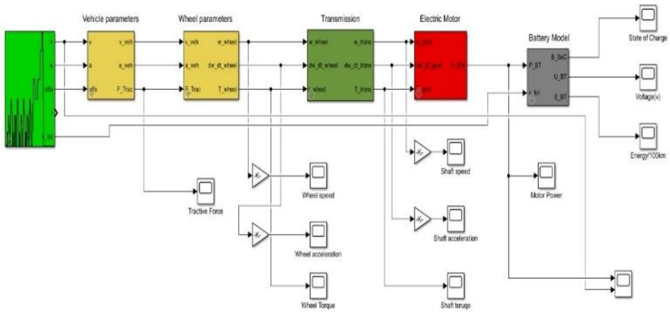


Fig 3: QSS Toolbox

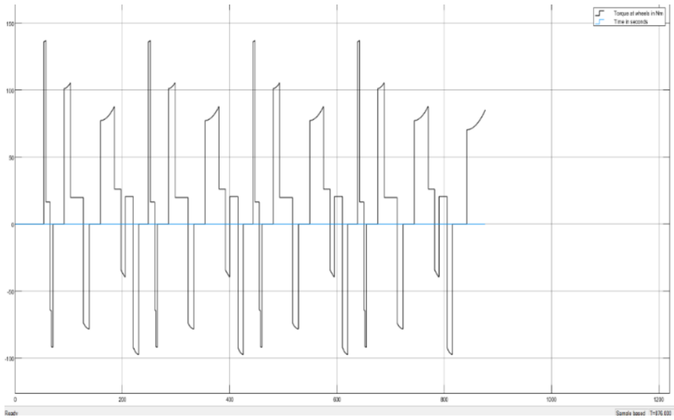


Fig 4: Torque requirement for NEDC cycle

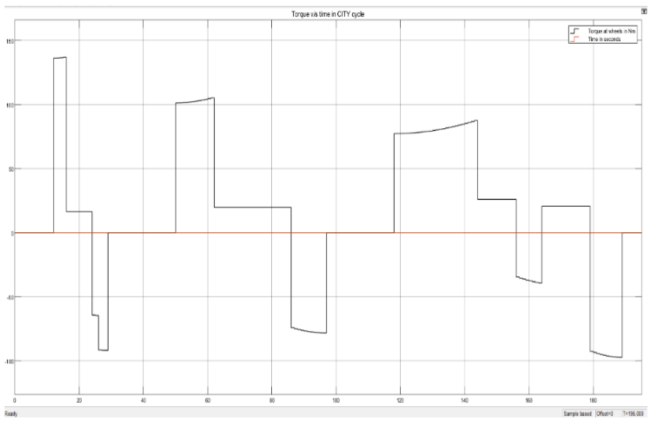


Fig 5: Torque requirement for city cycle

The torque demanded by the NEDC cycle was 140Nm and the torque demanded by the city cycle was 146Nm.

Selection of motor

Considering the peak torque and the peak power we can select the motor which satisfies these requirements.

The motor we have selected is from SEG-Automotive which operates at a 48V and draws a maximum current of 350A which delivers 57Nm and maximum power produced is 8kW.

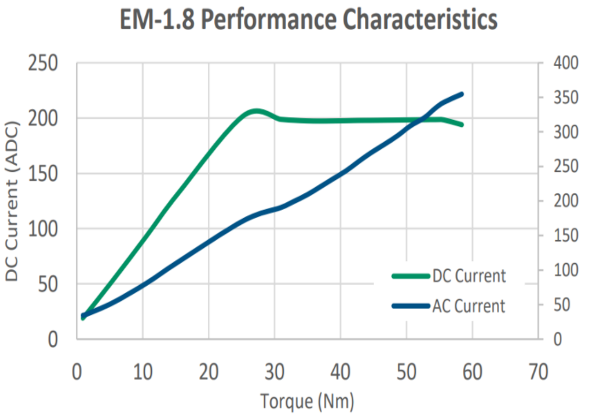


Fig 6: Torque v/s current

5KW PMSM

EM 1.9 Motor Specification :

1.	Voltage	:	48VDC
2.	Continuous Power	:	5.0kW
3.	Peak Power	:	8.0kW
4.	Max Torque	:	57Nm@350A
5.	Max Motor Efficiency	:	> 92%
6.	Max Speed	:	3500 RPM
7.	Protections	:	IP67
8.	Sensor Type	:	Shaft End Magnetic Sensor (ABZ / SinCos)
9.	Cooling	:	Air
10.	Dimensions	:	Refer image

Fig 7: Motor specifications

Battery Sizing

The battery was selected considering the results which were obtained from the calculations, QSS model and the characteristics of the motor.

The peak torque required from the motor is found to be 31.51 Nm for which we need to provide a current of 190A. Considering these conditions, we have selected a $LiFePO_4$ battery of 48V and 66Ah.

This battery can deliver a maximum current of 210A. The capacity of this battery is 3.16 kWh. To design the battery, pack the number of cells to be arranged in parallel and series were to be found. Each cell has 3.2V and 6Ah at 96% SoC. The number of cells in series are calculated to be 15 which gives us and the number of cells in parallel are calculated to be 11.

Design of powertrain components

The Computer Aided Design (CAD) of all components of powertrain were modelled using the software Solidworks and the assembly of the whole powertrain was done to visualize and aid us in procurement of the parts and to fabricate the tadpole vehicle. The total weight of the vehicle was also calculated.

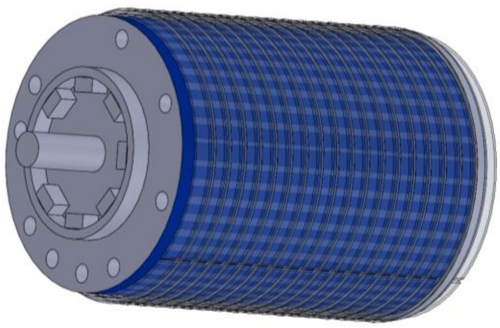


Fig 8: Motor model

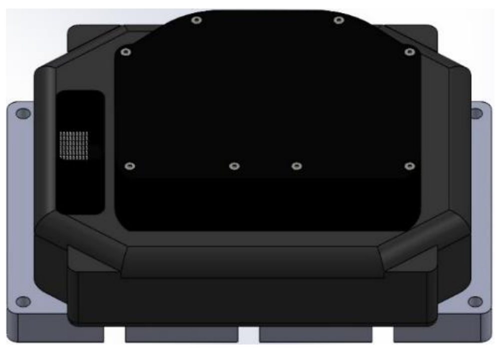


Fig 9: Controller model

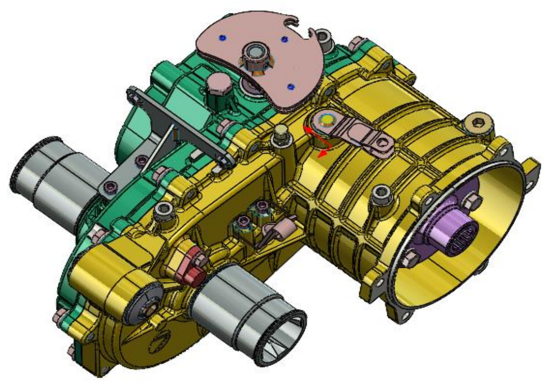


Fig 10: Gearbox model

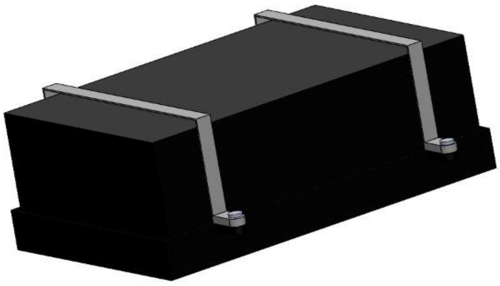


Fig11: Battery model with clamps

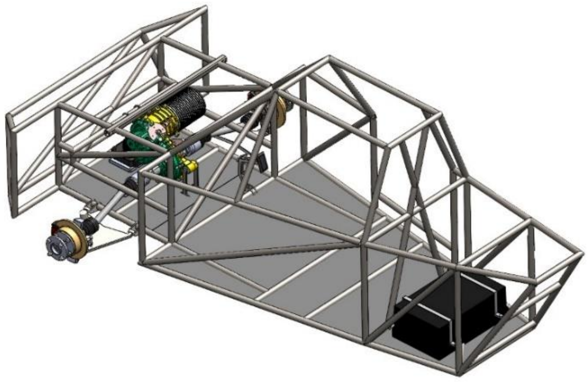


Fig 12: Assembly of the powertrain in Solidworks

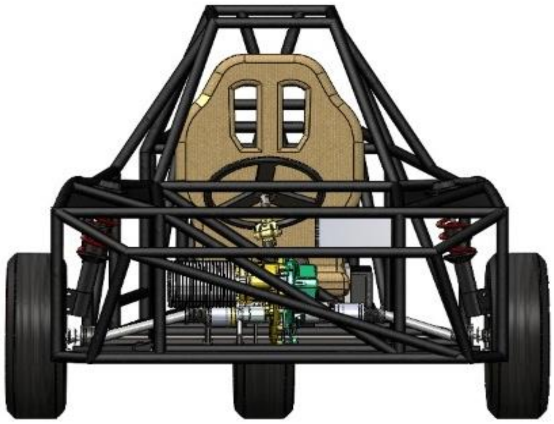


Fig 13: Assembly of complete tadpole in Solidworks

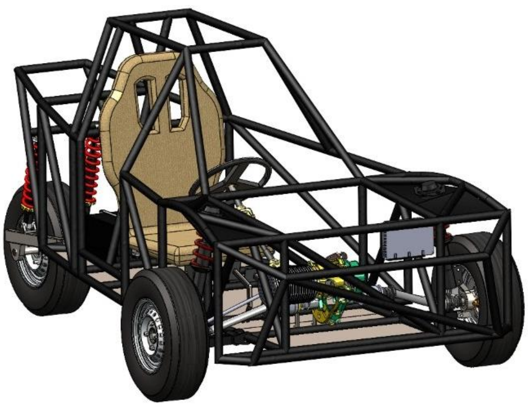


Fig 14: Assembly of Tadpole vehicle in Solidworks

Connection of powertrain components:

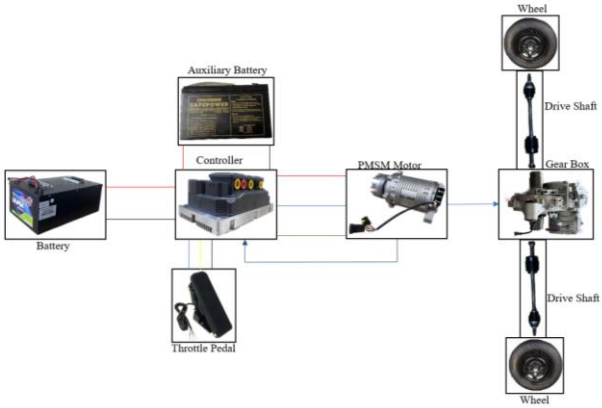


Fig 15: Connection of all powertrain components

Battery: - From the battery there are two output ports. Red and Black wires coupled to Anderson male coupler which is connected to controller via two power cables having female Anderson coupler. It is used to supply 48V power to the electric motor. This battery is mainly used to supply power to the motor which runs the tadpole.

Controller: - In controller there are 5 ports which includes B positive, B negative and R, G, B are used for three phase power supply. The controller also has a 21-pin connecter where signals from different components of the vehicle are supplied to the controller and back.

Auxiliary battery: - It has two ports which is connected via two wires to wiring harness of the controller. It is used to supply power supply of 12V for the controller.

Throttle pedal: - Throttle pedal has 3 pins positive (Blue), negative (Yellow) and control wire (Black) which is connected to the controller via wiring harness for providing throttle commands to the motor from controller which is given by the driver.

Motor: - There are a total of 5 ports in the motor, out of which three ports are used to connect three phase cables which comes from the controller and there are two ports which provides position feedback to controller.

Gearbox: - Motor is connected to the gearbox using 6 bolts of size (M8) Standards and an O-ring which is used in between to increase the water resistance and provides smooth contact between motor and gearbox. The gearbox we are using has two outputs for accommodating the driveshafts.

RESULTS AND CONCLUSION

From the 3D CAD model, we found out the, length of the drive shafts, distance between controller and motor which helps us to decide the length of the phase cables, distance between controller and battery which helps us to decide the length of the power cables and length of the wiring harness.

All the components were procured. After which the fabrication of the whole vehicle including the powertrain was completed. The vehicle was lifted and made to free run for preliminary test. After which the vehicle was tested on flat roads and also inclined roads, which had a grade of 20% or more than that. Tadpole vehicle satisfied all three constraints that were top speed of 47 km/hr on a flat road, climbing the road of 20 % grade and accelerating at 0-30 km in 6 sec.

Motor Peak Power	8 kW
Motor Max Torque	57 Nm at 350 A
Max Speed of Motor	3500 RPM
Battery Voltage	48V
Battery Capacity	66Ah
Drive Ratio	8.06
BMS	Passive (150 A)
Single cell voltage and capacity	3.2V & 6Ah

Table 2: Powertrain specification

Fig 15: Tadpole vehicle

FUTURE WORK:

Optimization of the electric powertrain system can be done by using dual speed gearbox with the help of a clutch which can increase the amount of torque and reduce maximum current requirement therefore, we can use lower C rating cells. There is scope for converting this tadpole to an autonomous vehicle that can be used as e-commercial delivery vehicle. Regenerative braking system can be added, which converts the kinetic energy to electric energy with the help of regen motors which in fact can increase the range of vehicle.

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Nomenclature

m - Mass of the vehicle
a - Acceleration of the vehicle
F_{trac} - Tractive effort force
F_{gr} - Force developed at wheels for climbing a grade
F_{ac} - Force developed at wheels for acceleration
T_{W-Peak} - Peak torque at the wheel
T_{M-Peak} - Peak torque at the motor shaft
D_W - Wheel diameter
ρ - Air density
A_f - Frontal area of the vehicle
SoC - State of charge

PES UNIVERSITY
DEPARTMENT OF MECHANICAL ENGNEERING
Bengaluru, India

DESIGN AND DEVELOPMENT OF POWERTRAIN IN A FRONT WHEEL DRIVE ELECTRIC TADPOLE TYPE VEHICLE –A2

Samartha S(PES1UG19ME158), Sameer Joshi (PES1UG19ME160), Uday Kumar M S(PES1UG19ME212),Sai Sampath Goutham Jangala (PES1UG19ME157)
Under the guidance of Prof. Sharanbassappa S Patil

Introduction: We use different vehicles for our daily commute cars, bikes, public transport, there is no such a vehicle which is economical as a bike and comfortable as a car. So, we decided to build a front wheel drive tadpole suiting these requirements and since India is progressing towards green energy, we have decided to make an electric tadpole. We are focussing on design and development of powertrain for electric tadpole. We have done calculations for torque and power using QSS toolbox and MATLAB. We have set few performance parameters and calculated the Torque and Power required, based on which we have selected the specifications of the motor and the Battery capacity and other powertrain components.

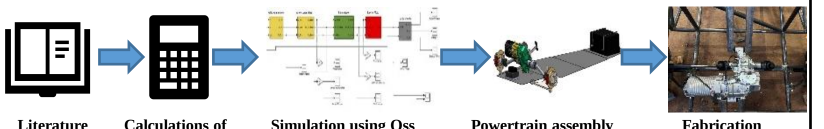
Literature Survey:

[1] An Electric Vehicle Powertrain Design by Ryuji, G. N., Avinashi, K., Kranti Kumar Reddy, P., & Santhosh Rani, M.
[2] Review and Development of Electric Motor Systems and Electric Powertrains for New Energy Vehicle - Cai, W., Wu, X., Zhou, M., Liang, Y., & Wang, Y.
[3] Modeling and Simulation of Powertrain System for Electric Cars. Fadel, S. M. E., Aris, I. B., Misron, N., Halin, I. A., & Iqbal, A. K. M.

Objectives:

- To calculate the power and torque requirement of powertrain, calculation for battery.
- To procure the parts of powertrain .
- Assembly of powertrain and integrating powertrain system for the tadpole.

Methodology :



Literature Survey → Calculations of Torque and power → Simulation using Qss Toolbox → Powertrain assembly in solidworks → Fabrication

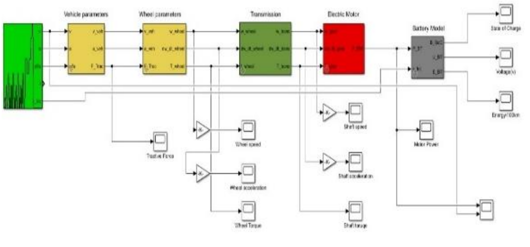


Fig 1. Modelling QSS toolbox

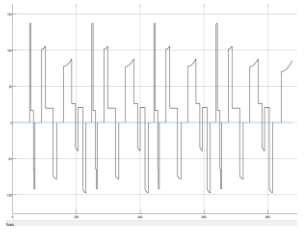


Fig 2. Torque v/s Time

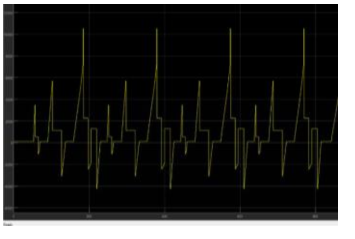


Fig 3. Power v/s Time

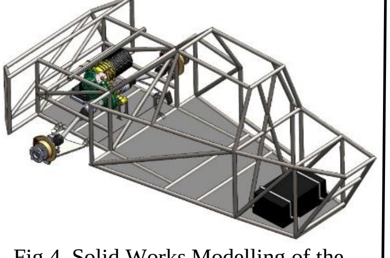


Fig 4. Solid Works Modelling of the powertrain assembled with the chassis

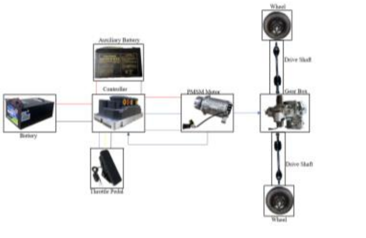


Fig 5. Connection of all powertrain components

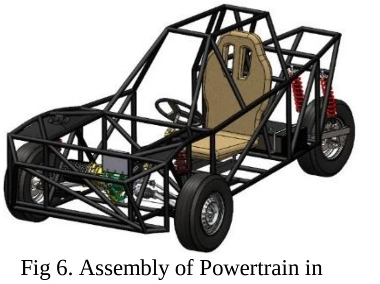


Fig 6. Assembly of Powertrain in Solidworks

Results and Conclusions:

3D model and the assembly of the components was developed using solidworks and procurement of the same components was carried .The fabrication of parts was done and then assembly of the vehicle was carried out.

The vehicle was able to achieve the performance parameters which were taken. The Range of the tadpole vehicle is calculated to be approximately 30Km and Top speed was 48 kmph.

Motor Peak Power	8 kW
Motor Max Torque	57 Nm at 350 A
Max Speed of Motor	3500 RPM
Battery Voltage	48V
Battery Capacity	66Ah
Drive Ratio	8.06
BMS	Passive (150 A)
Single cell voltage and capacity	3.2V & 6Ah

Powertrain specifications

Fig 7. Tadpole vehicle

Acknowledgement: We would like to thank our guide Professor S.S.Patil and PES University for helping us throughout our project. We are grateful to SEG Automotive for sponsoring components for our project.