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Design and Development of Powertrain for Front Wheel Drive Electric Tadpole

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Abstract— ***With the need for a compact transportation system, 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 the tadpole provides more stability during cornering and braking. Tadpole provides us similar esteem of driving a car and also the compactness of a three-wheeler. Tadpole provides us similar esteem of driving a car and also the compactness of a three wheeler[11]. Here, we have set a few performance parameters, calculated the torque and power required from MATLAB and Simulink, and found the different types of resistive forces that a tadpole needs to overcome to move. Based on this, we have selected the motor specifications and the battery capacity[12]. Using these parameters, we have procured various powertrain components like a motor, battery pack, controller, gearbox, drive shaft, throttle pedal, power cable, phase cables and wiring harness. After procuring the powertrain components, we have fabricated and integrated the components with the tadpole vehicle.***

Index Terms- Battery Sizing, Drive Cycle, Energy Consumption, Electric Powertrain Development, Electric Vehicle Range, Tractive Effort, Motor Selection, Motor Sizing, Torque, Tadpole Vehicle.

I. INTRODUCTION

We all use a different type of vehicles for our daily commute. They are generally cars, bikes, and auto public transport; going on the bike may be tedious, and the car is costly to maintain. There is no vehicle which is economical, easy to maintain and makes us feel comfortable during the ride. Compared to the Tadpole configuration, the delta configuration provides poor confidence while driving at high speed and corner maneuvering. There are two wheels at the front, so there is better braking performance and a shorter stopping distance than the delta configuration. Also, tadpole provides good high-speed aerodynamic stability because of its teardrop shape in contrast to the delta type. There are many advantages of front-wheel drive over rear-wheel driven tadpole, which will be discussed in this paragraph, such as better natural cooling, that's, air cooling for the components like motor, gearbox, controller, and wiring harness. Another primary reason would be the 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 is to develop a powertrain for a "Front-wheel-drive electric tadpole-type vehicle".

Powertrain refers to a system of components in a vehicle that generates power and delivers it to the wheels of an automobile. It has many components, such as the energy source, torque converter, transmission system, and final drive.

So, we have decided to build a front-wheel-drive electric tadpole meeting all the requirements. We are focusing on the development of a powertrain for an electric tadpole. We have calculated the torque and power required for our tadpole using the QSS toolbox and MATLAB. Then, based on our torque and power requirements, we had to search different powertrain components, including the motor, controller, battery, shafts, gearbox, power cable, phase cables, auxiliary battery, and wiring harness. Then accordingly motor, gearbox, battery and controller was selected.

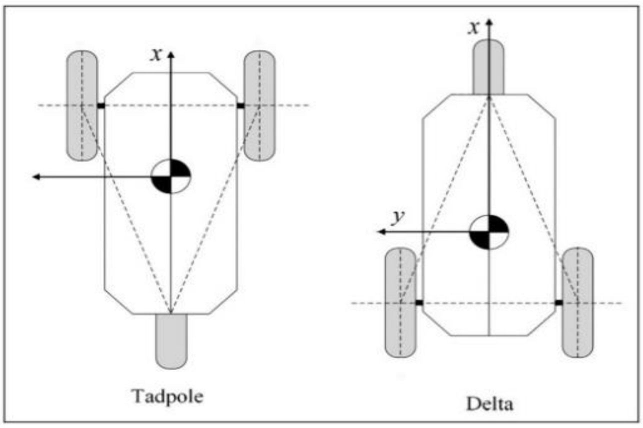

Fig 1: Two types of configurations for three-wheelers[18]

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The main components of an electric powertrain are a battery pack, electric motor, controller, transmission system and drive shafts. The electric powertrain has higher efficiency than internal combustion vehicles (IC). Some bulky components, such as engines, clutch and multiple gear systems, are eliminated. High starting torque is available. Multiple Gears can be eliminated since torque and speed can be varied by using the motor & controller—fewer rotating elements, therefore less rotating inertia than the internal combustion vehicles[9].

II. METHODOLOGY

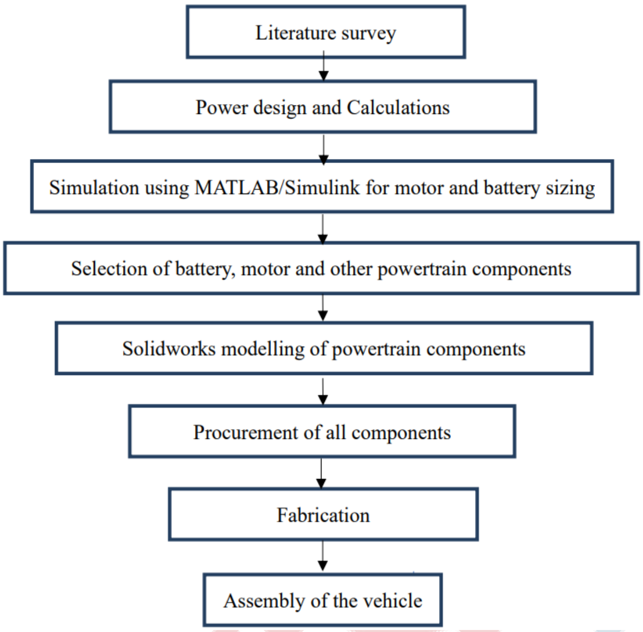

Fig 2: Methodology

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:

A. Top speed of 47 kph (12.96 m/s) on a flat road (i.e., 0% gradient)
B. Acceleration of 0-30 kph (0-8.33m/s) in 6 seconds on a flat road (i.e., 0% gradient)
C. Gradeability of 20% at 20 kph (5.55m/s with 11.3 degrees inclination)

Table I: Vehicle parameters

Parameter	Value
Mass of the vehicle	450Kg
Wheel diameter	0.537m
Frontal area	$1.8m^2$
Air density	$1.17Kg/m^3$
Aerodynamic drag coefficient	0.25
Coefficient of rolling resistance	0.015

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

A. Determination of forces on wheels

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

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

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

$F_{aero} = ½ \times (\rho \times Cd \times .Af. \times v^2)$ (3)

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

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

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

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

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

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

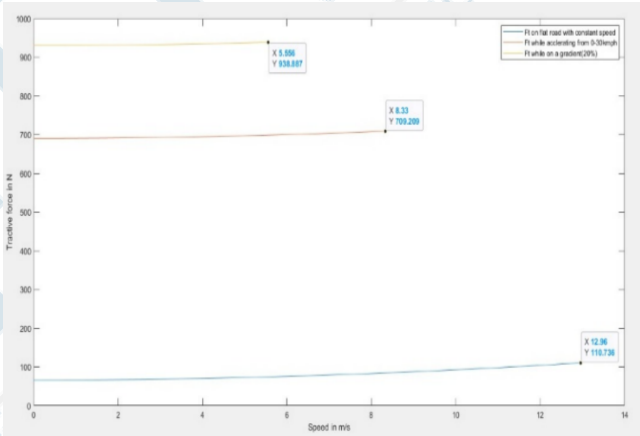

Fig 3: Tractive force v/s speed[17]

B. Determination of peak power

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

$F_{net} = F_{tractive} - F_r$ (9)

The power demanded was determined using the formula

$P = F_{tractive} \times v$ (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 kph (0-8.33m/s) in 6 seconds on a flat road.

C. Determination of peak torque

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

$\tau_W = F_{tractive} \times (\frac{D_w}{2})$ (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 kph.

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.

III. QSS MODEL

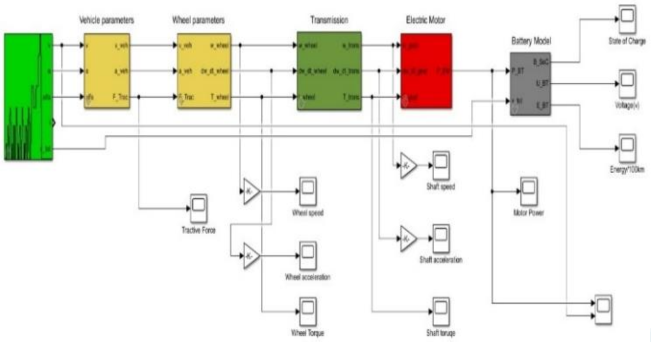

Fig 4: QSS Toolbox [17]

We have used the QSS model under Simulink to help us determine torque at the shaft, motor power, and 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 [3].

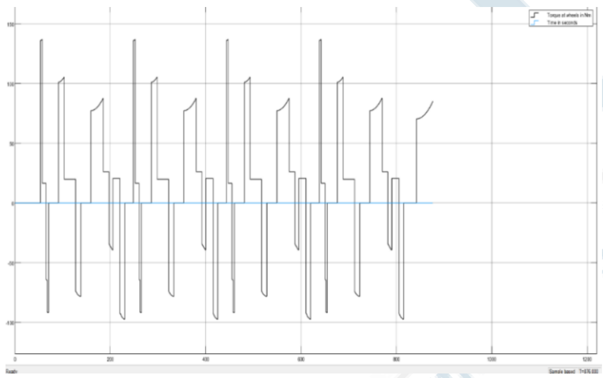

Fig 5: Torque requirement for NEDC cycle [17]

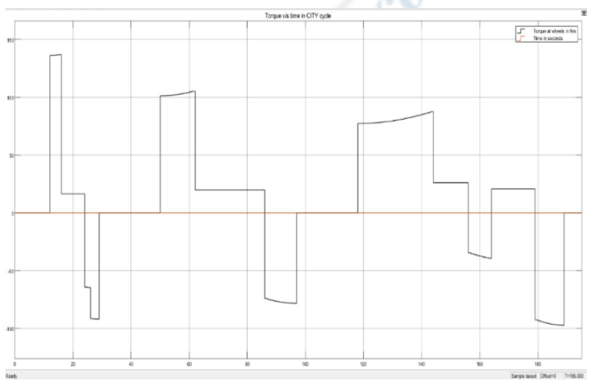

Fig 6: Torque requirement for city cycle [17]

The torque demanded by the NEDC cycle was 140Nm, and the torque demanded by the city cycle was 146Nm [7].

A. Selection of motor

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

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

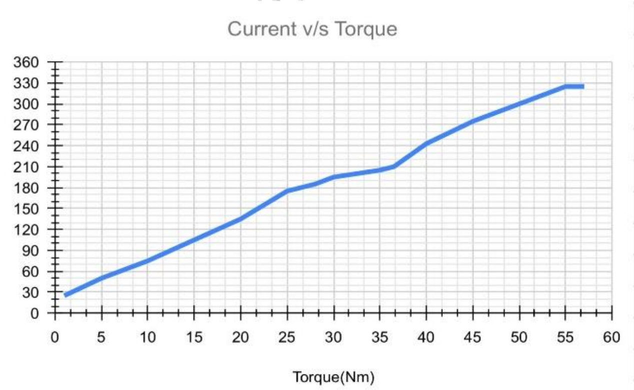

Fig 7 : Current vs Torque

Table 2: Motor specifications [16]

Motor Specification	
Voltage	48VDC
Continuous Power	5.0kW
Peak Power	8.0kW
Max Torque	57Nm@350A
Max Motor Efficiency	>92%
Max Speed	3500RPM
Protections	IP67
Sensor Type	Shaft End Magnet Sensor (ABZ/ SinCos)
Cooling	Air

B. Battery Sizing

The battery was selected considering the results which were obtained from the calculations, the QSS model and the characteristics of the motor [8].

The peak torque required from the motor is 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 [5].

This Micronix battery was selected, which 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[10]. The number of cells in series is calculated to be 15, which gives us the number of cells in parallel calculated to be 11 [4].

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C. Design of powertrain components

The computer-Aided Design (CAD) of all components of the powertrain was modelled using the software Solidworks[19], and the assembly of the whole powertrain was done to visualize and aid us in procuring the parts and fabricating the tadpole vehicle. The total weight of the vehicle was also calculated.

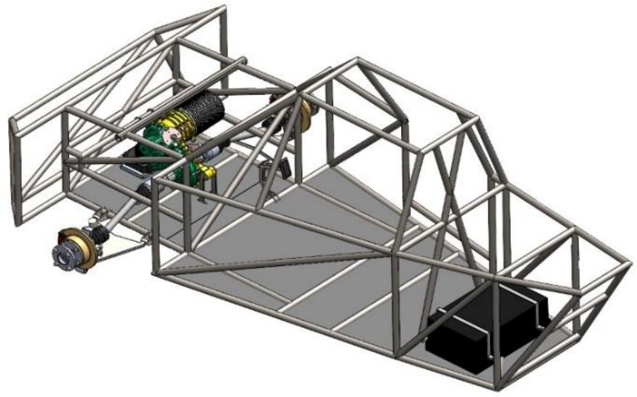

Fig 8: Assembly of the powertrain in solid works [19]

D. Connection of powertrain components:

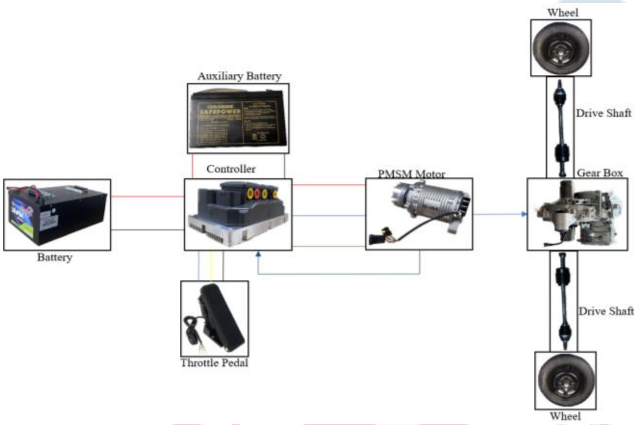

Fig 9: Connection of all powertrain components

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

Controller: - In the controller, there are 5 ports which include B positive, B negative and R, G, and B for a three-phase power supply. The controller also has a 21-pin connecter where signals from different vehicle components are supplied to the controller and back[6].

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

Throttle pedal: - Throttle pedal has 3 pins, positive , negative and a control wire which is connected to the controller via a wiring harness for providing throttle commands to the motor from the controller, which the driver gives and also motor temperature is also given from the port .

Motor: - There are 5 ports in the motor, of which three ports are used to connect three-phase cables which come from the controller and two ports which provide position feedback to the controller.

Gearbox: - Motor is connected to the gearbox using 6 bolts of size (M8) Standards, and an O-ring is used in between to increase the water resistance and provides smooth contact between the motor and the gearbox. The gearbox we are using has two outputs for accommodating the driveshafts[9].

IV. RESULTS AND CONCLUSION

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 5.8 kW.

Once the motor was selected, we had an idea of our current requirement, based on which we found out our battery specifications.

From the 3D CAD model, we found out the length required for the drive shafts, the distance between controller and motor, which helps us to decide the length of the phase cables, the 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, and the fabrication of the whole vehicle, including the powertrain system, was completed. The vehicle was lifted above ground height and made to free run for a 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. The vehicle was able to attain a top speed of 46kph on a flat road. This was tested using GPS based speedometer[14]. We carried out a range test on the outskirts of Bengaluru on empty roads; the true Range of the vehicle was found to be 36.17 km[1].

Fig 10: Tadpole Vehicle

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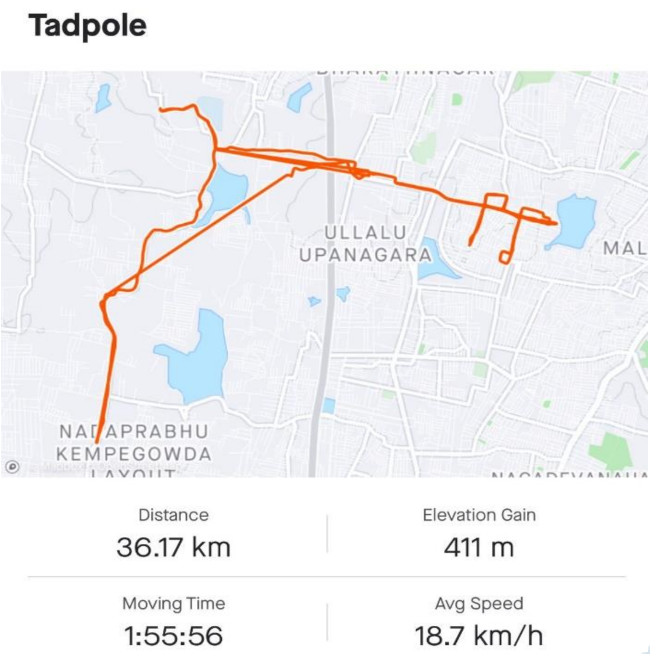

Fig 11: Physical Tested Data collection using Strava[13].

The average acceleration for 5 different trials for 0-30 kph is 5.09m/s^2 .Each trial value is listed below.

Table 3: Acceleration Table

Speed	0-30 kph
TRIAL 1	4.98 (s)
TRAIL 2	5.37(s)
TRAIL 3	5.03(s)
TRAIL 4	5.18(s)
TRAIL 5	4.89(s)

Cost Analysis of EV against CNC Powered 3-wheeler.

A.EV Powered vehicle

The vehicle is powered by a 3.16kwh battery which provides a range of 36.17 km from 100 % SoC to 0% SoC. So we know 1 unit of electricity is 1000 Wh, then 3.16 kWh is 3.16 units. So according to current electricity bill standards, 1 unit costs 4.22 Rupees, then 3.16 unit cost around 13.3 Rupees. As per calculations, the cost per km is 0.36 Rupees.

B.CNC Powered vehicle.

CNC powered 3-Wheeler vehicle has a mileage of 30 Km per litre of CNC, which costs around 85 Rupees compared to our vehicle, which has a range of 36.17 km then, we need around 1.2 litres of CNC, which costs approximately 102 Rupees. The cost per km is around 3.4 Rupees.

So, comparing both, we can see that 3-wheeler powered EVs have better economics than CNC/fossil-fueled powered Vehicles. Hence it can be a viable option in commercial and personal mobility Markets.

REFERENCES

[1] Park, S. H., Lee, J., Lee, Y. I., & A.Ahmed. (2016, December). Development of electric vehicle powertrain: Experimental implementation and performance assessment. In *2016 Eighteenth International Middle East Power Systems Conference (MEPCON)* (pp. 932-937). IEEE.

[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. (2021). Review and development of electric motor systems and electric powertrains for new energy vehicles. *Automotive Innovation*, *4*(1), 3-22.

[3] Modelling and Simulation of Powertrain System for Electric Cars. Fadel, S. M. E., Aris, I. B., Misron, N., Halin, I. A., & Iqbal, A. K. M. (2018). Modelling and simulation of powertrain system for an electric car. *Journal of the Society of Automotive Engineers Malaysia*

[4] Electric vehicle energy consumption modelling and estimation—Miri, I., Fotouhi, A., & Ewin, N. (2021). Electric vehicle energy consumption modelling and estimation—A case study. *International Journal of Energy Research*, *45*(1), 501-520

[5] Comparison of Different Battery Types for Electric Vehicles -Iclodean, C., Varga, B., Burnete, N., Cimerdean, D., & Jurchiș, B. (2017, October). Comparison of different battery types for electric vehicles. In *IOP conference series: materials science and engineering* (Vol. 252, No. 1, p. 012058).

[6] Speed control of Brushless DC Motor: A comparative study- Neethu, U., & Jisha, V.R. (2012, December). Speed control of Brushless DC Motor: A comparative study. In *2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)* (pp. 1-5). IEEE.

[7] An Electric Vehicle Powertrain Design - Ripujit, G. N., Avinash, K., Kranthi Kumar Reddy, P., & Santhosh Rani, M. (2017). An Electric Vehicle Powertrain Design. In *Proceedings of 2nd International Conference on Intelligent Computing and Applications* (pp. 437-450). Springer, Singapore

[8] An insight into motor and battery selections for three-wheeler electric vehicle- Sreejith, R., & Rajagopal, K. R. (2016, July). An insight into motor and battery selections for three-wheeler electric vehicles. In *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)* (pp. 1-6). IEEE.

[9] Multi-speed Gearboxes for Battery Electric Vehicles: Current Status and Future Machado, F. A., Kollmeyer, P. J., Barroso, D. G., & Emadi, A. (2021). Multi-Speed Gearboxes for Battery Electric Vehicles: Current Status and Future Trends. *IEEE Open Journal of Vehicular Technology*, *2*, 419-435.

[10] Performance of batteries for electric vehicles in the short and longer term. -Gerssen- Gondelach, S. J., & Faaij, A. P. (2012). Performance of batteries for electric vehicles in the short and longer term. *Journal of power sources*, *212*, 111-129.

[11] Review on tadpole design – issues & challenges Review on tadpole design – issues & challenges Palash Patodi, Vinay Saxena. IJRAME, 5 June 2014,

[12] Edx MOOC Open Course: Conventional Electric and Hybrid Vehicles, Chalmers University

[13] https://www.strava.com/

[14] https://play.google.com/store/apps/details?id=gps.speedometer.digihud.odometer&hl=en_IN&gl=US&pli=1
[15] http://www.micronixgroup.com/
[16] https://www.seg-automotive.com/
[17] https://in.mathworks.com/matlabcentral/fileexchange/73483-qss-toolbox
[18] https://www.wikiwand.com/en/Three-wheeler
[19] https://www.solidworks.com/

NOMENCLATURE

m - Mass of the vehicle
a - Acceleration of the vehicle
$F_{tractive}$ - Tractive effort force
F_{grad} - Force developed at wheels for climbing a grade
F_{ac} - Force developed at wheels for acceleration
F_r - Resistive force
F_{roll} - Rolling force
T_{W-Peak} - Peak torque at the wheel
T_{M-Peak} - Peak torque at the motor shaft
D_w - Wheel diameter
ρ - Air density
i – Gear ratio
A_f - Frontal area of the vehicle
SoC - State of charge