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Simulation of Electric Vehicle using Scilab for Formula Student Application

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Simulation of Electric Vehicle using Scilab for Formula Student Application

Manu Dubey[1*], Saksham Bhardwaj[1], R. Harish[1] and M.B Shyam Kumar[1]

[1]School of Mechanical Engineering, Vellore Institute of Technology, Chennai Tamil Nadu 600127, India

E-mail: manu.dubey2017@vitstudent.ac.in

Abstract. The principal objective of this research is development of a formula student electric vehicle and its performance analysis using model based simulation using Scilab. This project focuses on determining the technical parameters needed for electric vehicle designing using simulation tools currently available in market. Simulations are carried out using Optimum Lap and Scilab. Dynamic simulations of electric vehicles are conducted using this software for comparative study of different components which can affect the performance of the vehicle. Initially, lap simulation of vehicle is conducted based on various motors available in market using Optimum Lap to record speed, lap time, torque and energy consumption, this data is very crucial while selection of motor for the vehicle. Motors available in the market will be simulated and compared based on their energy consumption and voltage required. After selection of motor different battery cells will be compared based on their technical specifications to design a battery pack. Motor and battery will then be analysed using electric vehicle model created in Scilab to record the performance of the formula student electric vehicle. This project will guide students for selection of motor and battery for their car based on simulated data rather than actually buying and testing these components to save time and money.

1. Introduction

The goal of this paper is to select components of electric vehicle and simulate them using Scilab. EVs are helping to reduce harmful air pollution from exhaust emissions as they have zero exhaust emissions. Electric vehicles are powered by electric motors with an efficiency of up to 95%, this means compared to combustion engine, less energy is required to generate the same amount of power in wheels [1, 2]. Also, multiple gear box is not required in electric vehicles as motor itself can provide high variation in speed and torque [3]. These are some of the reason which makes electric vehicle as obvious future in mobility. In current times, a trend is going on in which organizations are encouraging formula student combustion teams to switch to formula student electric vehicles. This research will help these teams to get started with formula student electric vehicle designing.

First goal of the paper is selection of motor of the vehicle [4]. Various motor available in the market are considered for comparison. The research is carried out using data provided by Shaurya Racing, a formula student team based on VIT Chennai. Lap Simulation of different motors are done using

Scilab. Results like speed, torque and energy consumed are used to shortlist motors available in the market. For selection of battery, cells parameters such as structure, voltage, weight and capacity are considered and a battery pack is designed based on data record during motor simulation [5, 6]. At last, an electric vehicle model is created in Scilab for dynamic simulation based on selected motor and battery. Different drive cycles are considered to evaluate the performance of the electric vehicle [7].

2. Selection of Motor

To initiate the process of designing an electric vehicle, the students must know what is the least performance they can expect from the vehicle. Based on this knowledge, decision regarding the selection of components can be made. To setup the benchmarks for the electric vehicle design, we considered the performance of last combustion vehicle SR 6.0 provided by Shaurya Racing as given in table 1.

Table 1. Results of lap simulation of combustion vehicle (SR 6.0).

Parameters	**Combustion Vehicle Results**
Max Speed of vehicle	125 kmph
Max Input Torque	31.4 Nm at 8600rpm
Lap Time	624.27 seconds
Engine Weight	40kg
Engine Efficiency	35%-40%

While searching for motor we came across different kind of motors used in EVs like IM, PMSM, SRM, series DC and brushless DC motor. For formula student application, a motor with high power to weight ratio and high torque is desirable. We considered parameters like power density, efficiency, reliability, controllability, heat generation and construction for comparison and concluded that PMSM motors best suite our application as given in table 2. Among all the PMSM motors available in the market majority of motors are radial flux motors and very few companies produce axial flux motors. Axial flux motors are more relevant to formula student cars because of its less weight, compact size, high efficiency and better cooling capability as windings are directly in contact with exterior casing [8]. We considered brands like Magnax, AVID Technology, YASA and Emrax which provide axial flux motors. Among these brands we considered Emrax motors for simulation as it produce motor with wide variety of specifications and provide easy mounting. Also all Emrax motors are capable of stacking which will double the torque and power output, this customization can better help students to design their drive train.

Table 2. Comparison of different types of motor available in market.

Motors	Power Density	Efficiency	Controllability	Reliability	Cost	Points
IM	★★★	★★★	★★★★★	★★★★★	★★	18
PMSM	★★★★★	★★★★★	★★★★	★★★★	★★★★	22
SRM	★★★	★★★	★★★	★★★★★	★★★	17
DC	★★	★★	★★★★★	★★★	★★★	15

To evaluate the performance of motor, lap simulation is done using OptimumLap software. OptimumLap has its own track database from which user can select any track he desires. We decided to conduct simulation on Nordschleife circuit of 22.9 km situated in Nürburg, Germany as the distance of the track is close to the total distance covered in endurance event which is 22 km. Lap simulation give results like drive cycle, torque on wheels, speed and lap time as shown in table 4, which are useful for comparing the performance of the electric vehicle. OptimumLap receive data like vehicle mass, aerodynamic coefficients, powertrain data and transmission data from the user. To carry on the simulation we need to find drive ratio associated with each motor to provide maximum power output. For drive ratio calculation we first need to find the (Tw) maximum torque that can be utilized by wheel without slipping using equation (2), where F is normal force exerted by the vehicle, Rw is radius of wheel and magnitude of 1.3 is considered to overcome various losses in transmission. Normal force exerted by vehicle can be calculated using equation (1), where μ is coefficient of friction, m is mass of the car and g is acceleration due to gravity, magnitude of 0.6 is multiplied as mass distribution of considered vehicle has 60% weight distribution on rear wheels. For this research we calculated F as 2.295 kN and Tw as 682 N-m. Drive ratio for the motor can now be calculated using equation (3), where Tm is the peak torque provided by the motor. Drive ratio respect to every motor is shown in table 3.

$$F=0.6\cdot\mu\cdot m\cdot g \tag{1}$$

$$Tw = 1.3\cdot F\cdot Rw \tag{2}$$

$$\text{Drive Ratio} = Tw/Tm \tag{3}$$

Table 3. Drive Ratios respect to every motor.

Motors	Drive Ratio
Emrax 188	7.57
Emrax 208	4.87
Emrax 228	2.96
Emrax 268	1.36

Table 4. Results of lap simulation of different motors.

Parameters	**Emrax 188**	**Emrax 208**	**Emrax 228**	**Emrax 268**
Max speed of vehicle	198.7 kmph	206.3 kmph	236.4 kmph	257.9 kmph
Max speed of motor	5778 rpm	6000 rpm	5500 rpm	4500 rpm
Max Continuous Torque on motor	53 Nm at 2996 rpm	80 Nm at 3000 rpm	127 Nm at 3000 rpm	245 Nm at 2996 rpm
Peak Torque	88 Nm	140 Nm	230 Nm	500 Nm
Max Continuous Power on motor	37.6 hp at 5778 rpm	54.8 hp at 5000 rpm	86.5 hp at 5500 rpm	145 hp at 4500 rpm
Peak Power	52 kW	68 kW	109 kW	200 kW
Lap Time	653.8 seconds	599.2 seconds	559.8 seconds	531.1 seconds
Energy Consumption	11634.2 kJ	15892.7 kJ	20098.5 kJ	27176.5 kJ
Maximum Battery Voltage	300 Vdc	350 Vdc	500 Vdc	650 Vdc
Weight	7 kg	9.1 kg	12 kg	20 kg
Motor Efficiency	95%	95%	95%	95%

Based on results of lap time simulation in table 4, it was concluded that Emrax 228 and Emrax 268 have less lap time and more torque [9-12]. However compared to Emrax228, Emrax 268 has almost 40 % increase in weight and 26 % increase in energy consumption which will increase the size and weight of battery pack. Also, according to design guide lines of the formula student competition, the maximum voltage across any two connection should not be greater than 600 Vdc. Because of these reasons we opted to go with Emrax 228 axial flux motor for dynamic simulation of formula student electric vehicle in Scilab.

3. Selection of Battery

During battery selection process we first researched about the structure of battery cells available in market like button cell, cylindrical cell, prismatic cell and pouch cell [13]. We considered various criteria for selection of cell based on its structure like shape, safety measure, outer casing, mechanical stability, weight, cost, energy capacity and nominal voltage as given in table 5. We preferred prismatic cell and cylindrical cell over button cell and pouch cell due to their good mechanical stability and safety measures provided. Prismatic cell have large capacity and better space utilization than cylindrical cell. However, prismatic cells are costly and have many positive and negative electrodes sandwiched together which are more prone to short circuit and inconsistency. On other hand, cylindrical cells provide good stability and have many safety measures like positive thermal coefficient (PTC) and pressure relief mechanism. The only drawback about cylindrical cell is their more space utilization which is not much of an issue considering air cooled battery packs which requires more space. Also, cylindrical cells are most widely used cell in industry, so students can easily find cell holders to assemble their battery packs.

Table 5. Comparison of different types of cells.

Type	Nominal Voltage	Cell Capacity	Mass	Space Acquired	Safety	Price	Points
Cylindrical Cell	★★★★	★★★★	★★★★	★★★	★★★★★	★★★	23
Prismatic Cell	★★★★★	★★★★	★★	★★★	★★★	★★	21
Pouch Cell	★★★	★★★	★★★	★★★★★	★★	★★★★★	21
Button Cell	★★	★★	★★★★★	★★★★	★★★★	★★★	19

According to table 5 we selected cylindrical cells for battery pack design. We compared different cylindrical cells available in the market based on their chemical composition, nominal voltage, weight, specific energy and life cycle as given in the table 6. Considering these results we concluded to go with LG 18650 HG battery cell as it has a good nominal voltage, better capacity and least weight among other batteries.

Table 6. Comparison of different cylindrical cells available in market.

Manufacturer	Name	Nominal Voltage (V)	Capacity (Ah)	Weight (gms)	Specific Energy (Wh/kg)	Life Cycle
LG	18650 HG	3.6	3	35	223	300-500
LG	INR20650HG6	3.6	3	58	186	>300
Samsung	INR21700-30T	3.6	3	69	156	>300
Samsung	Lithium 18650	3.6	1.5	45	120	300-500
Panasonic	NCR20700B	3.6	4.2	63	242	>300
Panasonic	NCR18650PF	3.6	2.8	46.5	220	>300
Panasonic	NCA103450	3.6	2.2	38.3	200-260	>500
Molicel	INR21700P42A	3.6	4.2	68	150-200	>300
SIRIE	32650(LFP)	3.3	6	140	90-120	>2000
SS	(ER14250)LMO	3.6	1.5	55	150-220	1000-2000
Naccon	NCA103450	3.6	2.6	48.2	100-150	300-700
Naccon	6060100(LCO)	3.6	2.6	48.2	150-200	500-1000
Melasta	LP9759156(LiPo)	3.7	2.5	201	150-260	>100

After selection of cell, we must find the arrangement of cells in battery pack. These calculation will need total energy required and voltage required which can be find out using lap time simulation with motor as given in table 4. We considered total energy consumption as 20% more and battery voltage as 10% more of required voltage, as there will be some unidentified losses in real time scenario and because other electrical devices will also draw energy from battery itself. The calculation for arrangement of battery pack is done based on the fact that total number of cells present in the pack must have combined capacity equal to total energy consumed by the vehicle (4) and the voltage required by motor must be equal to sum of nominal voltage of the cells connected in series (5). Total number of cells can be arranged in series and parallel to get the desired nominal voltage required by the motor. Thus arrangement of cells in battery can be calculated as given below.

$$\text{Battery Capacity (Energy Required)} = 5583\text{Whr} + 20\% = 6700\text{ Whr}$$
$$\text{Battery voltage} = 500+10\% = 550\text{ V}$$
$$\text{Energy Capacity of cell} = 3.6 \times 3\text{Wh} = 10.8\text{Wh}$$
$$\begin{aligned}\text{No. of cells required} &= \text{energy consumed/cell energy} \\ &= 6700/10.8 = 621 \text{ cells (approx)}\end{aligned} \tag{4}$$
$$\begin{aligned}\text{No. of cells in Series connections} &= \text{Battery Voltage / maximum cell voltage} \\ &= 550/3.6 = 152 \text{ cells (approx)}\end{aligned} \tag{5}$$
$$\begin{aligned}\text{No. of cells in parallel connections} &= \text{Battery Capacity/ (cell capacity x cells in Series)} \\ &= 6700/\,(10.8 \times 152) = 4 \text{ cells (approx)}\end{aligned}$$

Following above calculation nominal voltage of the battery pack will be 547.2 V and battery capacity will be 6566.4 Whr. In actual scenario, single battery pack will not contain 152 cells in series rather it will be divided into many battery accumulators. These accumulators will then be connected into series to provide the necessary nominal voltage. Systems like regenerative braking can further decrease the number of cells required as vehicle will be able to produce its own energy while deceleration. This can help in reducing total energy capacity of battery pack further reducing number of cells in battery pack. Battery Management System (BMS) and Battery Thermal management System (BTMS) plays an important role in electric vehicle's performance. They are important for both safety and efficiency as increase in temperature can have serious effects on these factors. In this paper, we have modelled a basic battery pack with motor controller to analyze the performance of the vehicle.

4. Scilab Simulation of Electric Vehicle

After selection of motor and battery, an electric vehicle model is built in Scilab on the basis of mathematical formulas. Four separate sub-models were built including chassis, transmission, motor and battery as given in figure 1, and connected together to give results corresponding to vehicle performance. User is required to input data related to these sub-models, then drive cycle is imported from the workspace to successfully run the model. Model simulates the vehicle based on the given drive cycle and give results about performance of the vehicle like forces on chassis, motor torque, battery C-rate and battery SOC as given in table 7.

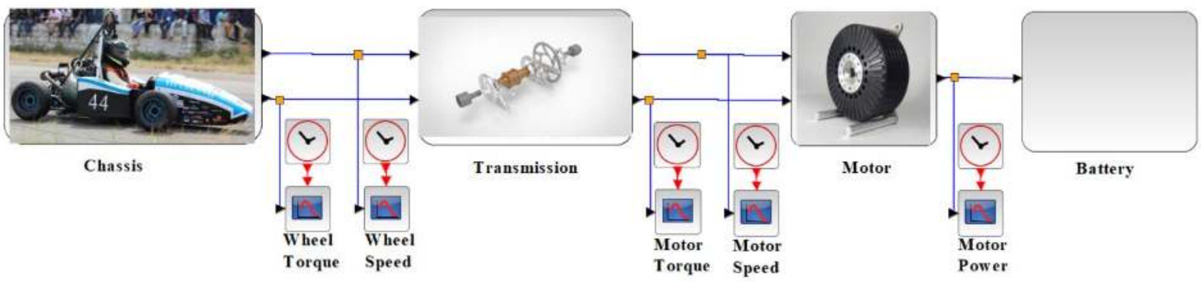


Figure 1. Scilab Model of formula student electric vehicle.

4.1. Chassis

A chassis subsystem contains all the calculations related to vehicle dynamics. User provides drive cycle to the subsystem where drive cycle is a series of data points representing the speed of vehicle versus time. Driving cycles are produced by different countries and organisations to assess the performance of vehicles. Chassis subsystem act as a vehicle body and is subjected to many resistive forces throughout the run. These resistive forces are rolling resistance, grade resistance, aerodynamic resistance and acceleration force. Rolling resistance or rolling friction is basically the force which resists the rolling motion of the wheel. Rolling resistance is equal to product of gross vehicle weight and coefficient of rolling resistance where different road surfaces have different rolling resistance. Grade resistance is the force acting on the vehicle when the vehicle is climbing an inclined surface. It is product of gross vehicle weight and sine of inclination angle, as the angle increase s will the resistance force. Aerodynamic force is the resistance provided by the air during motion. Aerodynamic resistance depends on air density, frontal area, shape and vehicle velocity. Acceleration force is the force that helps the vehicle to reach a predefined speed from rest in a specified period of time. These force constitutes the total tractive effort on vehicle [14]. Chassis subsystem will take drive cycle as vehicle's final velocity from workspace and calculate wheel speed and wheel torque as shown in figure 2, after considering all resistive forces.

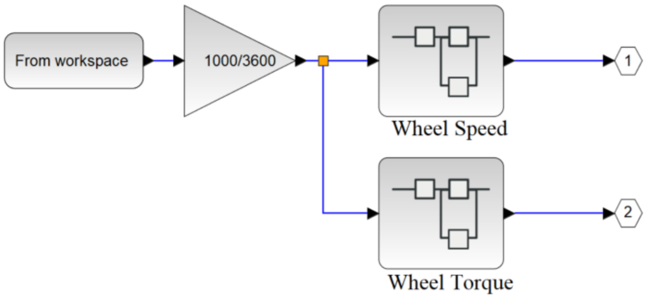


Figure 2: Chassis Subsystem.

4.2 Transmission

Transmission is a system which transfer power from motor to wheel. An electric vehicle gearbox does not have a multi gear system as in internal combustion vehicle. Almost all electric vehicle has a single speed transmission which is big advantage considering the weight and efficiency loss. This difference of transmission between electric vehicle and combustion vehicle is majorly because of two reasons. First, an electric motor can deliver its maximum torque at zero RPM, so it does not need to change gear ratios to get the required torque. Also, electric motors have a larger speed range compared to typical internal engine. This means an electric vehicle can work on a single gear ratio throughout the run.

In formula student electric vehicles, three types of drive train exist: single rear motor, dual rear motor and four in-hub motors. In single rear motor drive train, one motor is connected to a single ratio gear box to provide power to rear wheels. In dual rear motor drive train, two motors are stacked together and connected to a single ratio gear box to transmit power. In both single motor and dual motor drive train, students can use differential to vary the torque in both powered wheels. The most famous drive train system in formula student electric vehicles is the four in-hub motor system. In this system, all the four wheels are connected to separate motors which are assembled in upright. In a more advanced system, all the four wheels can enjoy different torque output controlling the load transfer of vehicle. This way, vehicle can give its optimal performance in every scenario, this technology is called torque vectoring. In this paper, we are modelling a single motor rear drive train with single ratio gear box. Transmission subsystem take wheel speed and wheel torque as input from chassis subsystem and calculate motor speed and motor torque as given in figure 3.

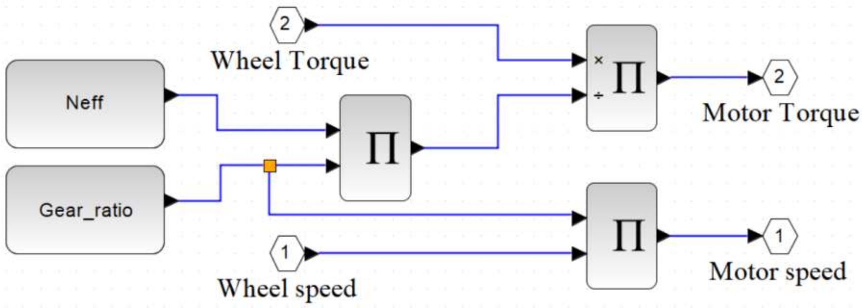


Figure 3. Transmission Subsystem.

4.3. Motor

All input power given to motor is not converted to mechanical power because of all the losses which occur inside the motor. Motor power loss occurs due to factors like friction, stray and windage losses. Also each type of motor is has its own specific losses. All the losses are accounted by using the efficiency map of an electric motor. Figure 4, is the efficiency plot of Emrax 228 motor based on motor speed and torque. Motor power constitutes both motor power loss and motor useful power. Motor subsystem take motor speed and motor torque as input and calculate motor power after considering motor efficiency as shown in figure 5.

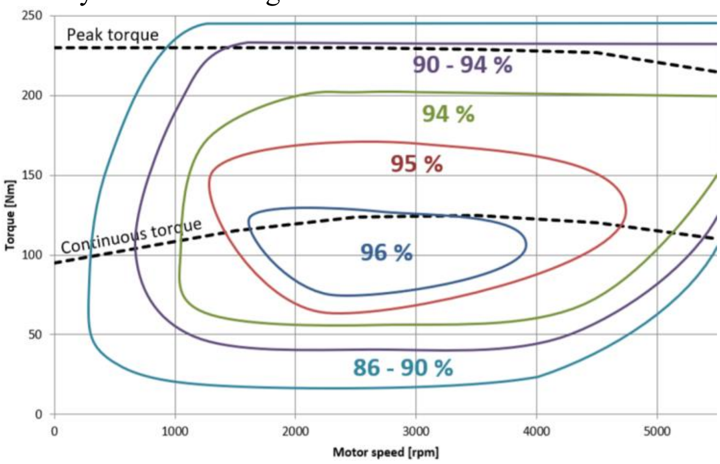


Figure 4. Efficiency map of Emrax 228 motor.

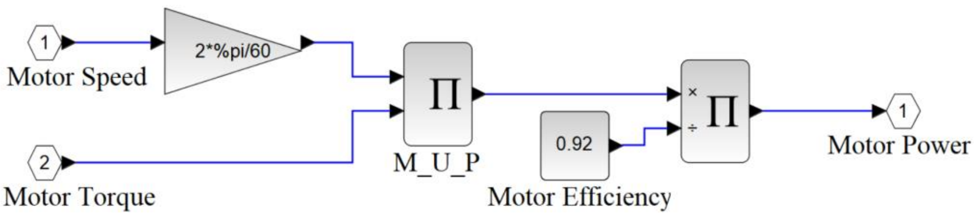


Figure 5. Motor Subsystem.

4.4. Battery

The battery subsystem as shown in figure 6, contains all the calculations related to the battery. Parameters such as battery power, battery voltage, battery current, battery c-rate and state of charge are calculated in the battery subsystem. During the run motor only consumes energy while acceleration. To apply this phenomenon in model, a motor controller is modelled. Motor Controller is the electronics package that operates between the batteries and the motor to control the electric vehicle's speed and acceleration. The controller transforms the battery's direct current into alternative current and regulates the energy flow from the battery. For modelling point of view we took motor controller efficiency as 85%. Battery power is the DC power given out by the battery and is calculated based on motor power. For further modelling data is referred from cell arrangement calculation of battery pack. Nominal voltage of battery pack and battery capacity is taken into account to find battery current, battery C-rate and state of charge of battery. Battery C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. State of charge or SOC of battery denotes the capacity that is currently available as a function of rated capacity. The unit of SOC is percentage, its value varies between 0% and 100%. If the SOC is 100%, then the cell is said to be fully charged, whereas a SOC of 0% indicates the cell is completely discharged. The state of charge of a battery can be estimated by taking into account the amount of electrical current which is going in and going out of the battery [15].

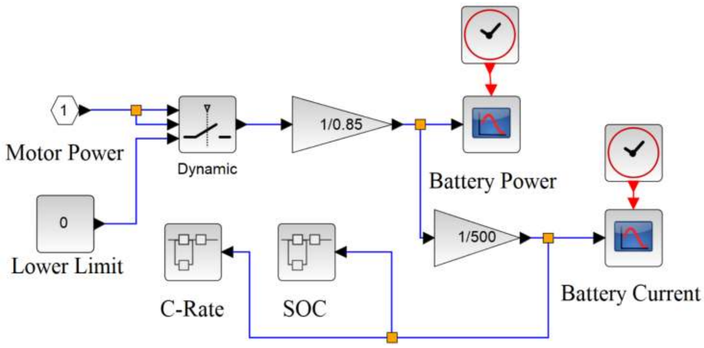
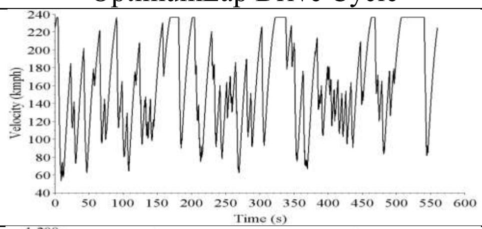
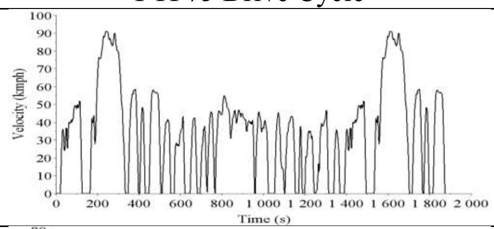
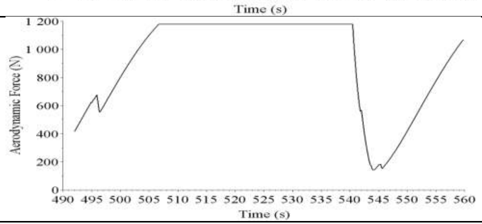
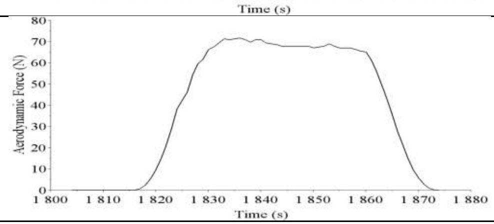


Figure 6. Battery Subsystem.

5. Results of Simulation

Scilab model in Figure 1 was simulated based on two drive cycles, Emrax 228 drive cycle on Nordschleife circuit from OptimumLap and FTP75 drive cycle as shown in table 7. OptimumLap's drive cycle is used because it is close representation of endurance event on which the vehicle is ultimately required to perform and FTP75 drive cycle is a standard drive cycle which can be used to compare the performance of vehicle for future developments. Model is enough flexible to optimize the results by changing the efficiencies and other required parameters. Model performs a time based simulation in which user have to input the total simulation time till which model is required to run. User can visualize the results using graphs and can also import the results to workspace for other calculations.

Table 7(a). Results of simulation.

Parameters	OptimumLap Drive Cycle	FTP75 Drive Cycle
Drive Cycle		
Aerodynamic Force		

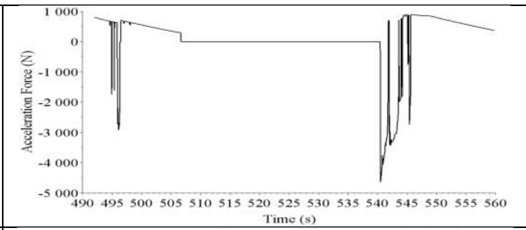
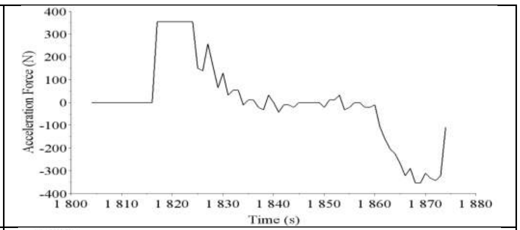
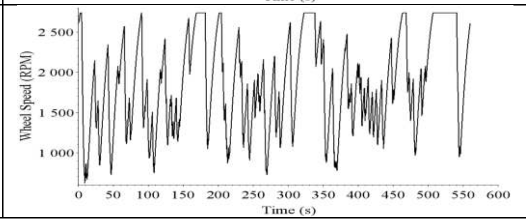
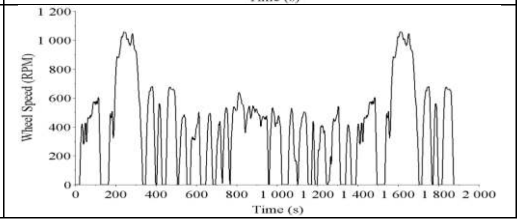
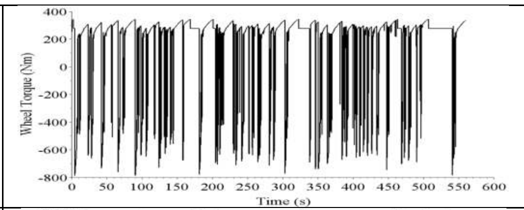
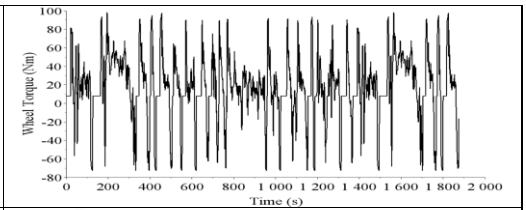
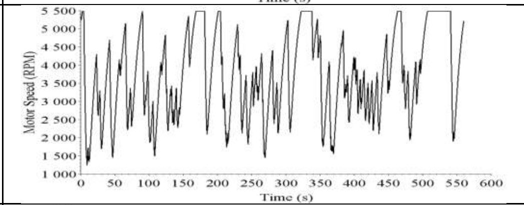
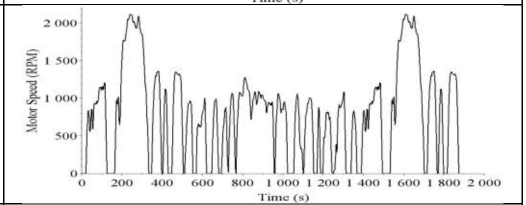
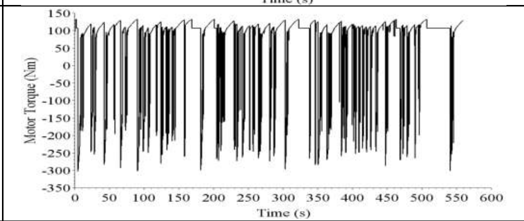
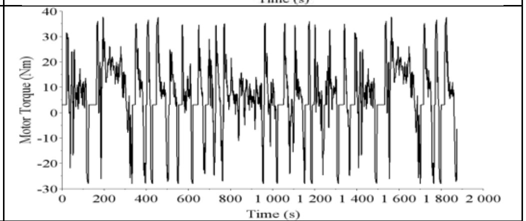
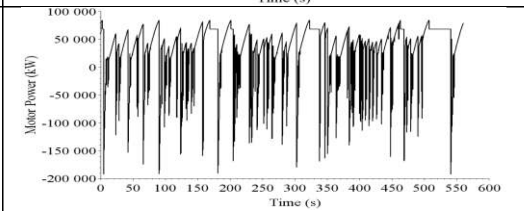
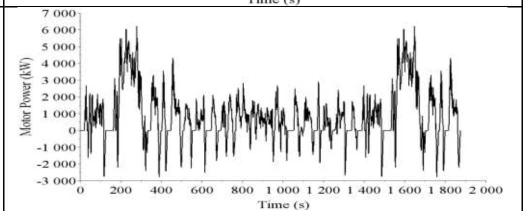
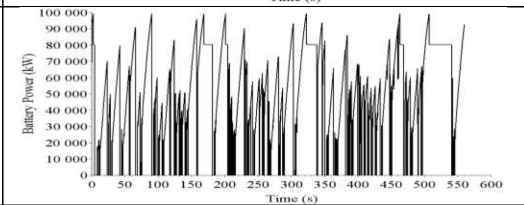
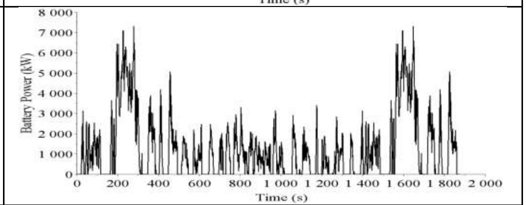
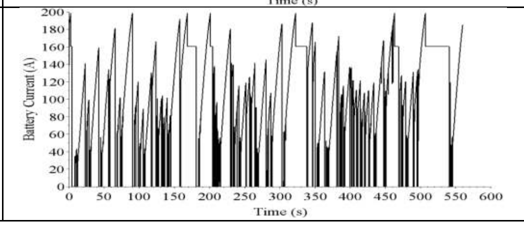
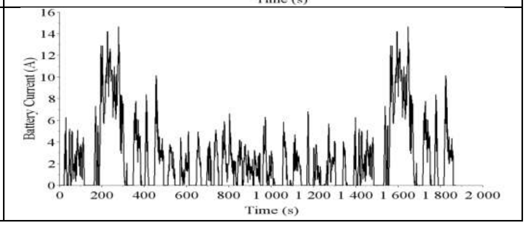
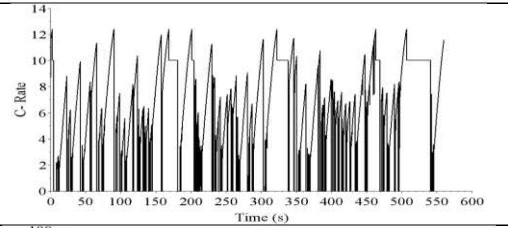
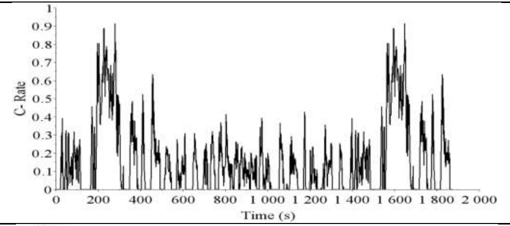
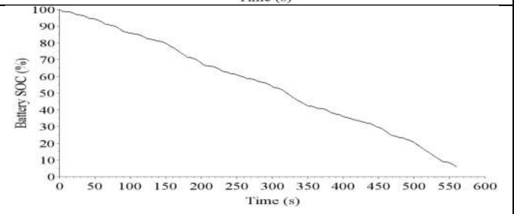
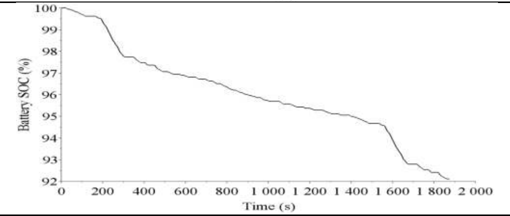
Acceleration Force		
Wheel Speed		

Table 7(b). Results of simulation.

Wheel Torque		
Motor Speed		
Motor Torque		
Motor Power		
Battery Power		
Battery Current		

C- Rate		
Battery SOC		

6. Conclusion

In this paper, we successfully did the simulation of formula student electric vehicle using Scilab. We selected a suitable motor and designed a relevant battery pack using data collected from OptimumLap simulation which is validated using Scilab model. Scilab simulation results corresponding to Motor Speed, Motor Torque and Motor Power in table 7 are similar to OptimumLap's results as given in table 4. The Battery pack design is also appropriate as SOC is decreasing to around 10% on completion of simulation as given in table 7. Also, simulation is done using FTP 75 drive cycles to standardize the performance of the vehicle which can help in future modification of the model. Every simulation has some limitation which can cause inaccuracy compared to real time results obtained from vehicle. However, these simulations are beneficial for selection of components using comparative study based on performance of vehicle as done in this paper.

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