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Mathematical modeling of the electric scooter battery pack using SCILAB

Hrushikesh Anil Chari
charihrushi08@gmail.com
Sinhgad College of Engineering, Pune, Maharashtra

Dr. Rajendra Katikar
rskatikar.scoe@sinhgad.edu
Sinhgad College of Engineering, Pune, Maharashtra

ABSTRACT

Electric vehicles have been a sustainable and environment-friendly mode of transport have gained immense importance since the beginning of the 21st century. Mathematical modelling has been a boon for the design procedure, which helps us understand the real-time output of our design without practical implementation. The research paper, will be discussing mathematical modelling for an electric scooter battery pack. It will be done by calculating the energy consumption for the desired output by an EV and then later comparing the different cells by considering various battery parameters. The modelled scooter would be capable of replicating the output similar to a current CV. SCILAB will be used as the simulation software. For calculating the real-time energy consumption, WLTP cycle data will be used. The data for the WLTP drive cycle is based on the real-time driving scenario. It would help us to estimatethe energy consumption that can be close to the practical value. For accurate results, it is necessary to test the designed model on a dynamometer for better optimization.

Keywords: *Electric Vehicle, Battery Pack, WLTP, and SciLAB*

1. INTRODUCTION

Automobiles have become an integral part oftransportation in today's world. According to EIA, in 2020 world consumed around 92 million barrels of petroleum per day. In the past two decades, awareness of the campaign for safeguarding the environment has increased. It has made us realize the urge to find an efficient and environment-friendly mode of transport. Electricity has been an environmentally friendly alternative in the recent past. The ability to generate electricity through renewable resources has made boosted its popularity. It has proved itself a promising and dependable alternative for CV. With the increase in

the development of electric vehicles, governments have also been promoting them. Electric-powered vehicles have many benefits over Combustion vehicles.

Electric Vehicles are categorized into four types: -

- i **Battery Electric Vehicles or BEVs:** Battery electric vehicles store electricityonboard with high-capacity battery packs.
- ii **Plug-in Hybrid Electric Vehicles or PHEVs:** Plug-in Hybrid Electric Vehicles or PHEVscan recharge through both regenerative brakings and by "plugging in" to an externalsource of electrical power
- iii **Hybrid Electric Vehicles or HEVs:** HEVs are powered by both gasoline andelectricity.
- iv **Hydrogen Fuel Cell Electric Vehicles orFCEV:** Like BEVs, fuel cell electric vehicles (FCEVs)use electricity to power an electric motor.

Battery cells being the prime component of Electric Vehicles have seen tremendous development. Most specifications of an EV depend on the output of the battery pack. It has resulted in an emphasis on the design of a battery pack. Simulation and calculationhave helped to design an optimized battery pack. The majority of parameters that are been scrutinized while selecting a battery are cell capacity, voltages, Gravimetric Density, Volumetric Density, continuouscurrent, peak current, etc.

2. LITERATURE REVIEW

A report titled "HIGH-PERFORMANCE ELECTRIC VEHICLE POWERTRAIN MODELING, SIMULATION AND VALIDATION" by Feyijimi Adegbohun. The authors describe the modeling and simulation steps for high-performance EVs by defining key vehicle specifications and then developing an equation-based model of a battery EV in MATLAB/Simulink software. For this, they have used various models such as the Gliders model, driver model, battery model. In another report titled "MATHEMATICAL MODELLING AND SIMULATION OF ELECTRIC VEHICLE USING MATLAB-SIMULINK" by TA. T. Mohd, M. K.

Hassan and WMK. A. Aziz. The paper presents a simulation model of Full Electric Vehicle in Matlab- Simulink platform to examine power flow during motoring and regeneration. Yet, there were a few limitations as it didn't highlight the use of real-time data and the methods for comparing battery cells.

3. PROPOSED WORK

In this research paper, the modeled electric scooter can replicate the same output as **YAMAHA FASCINO 125cc**. For the modeling purpose, Scilab-6.1.0 will be used for the simulation. The simulation would help usin calculating the total energy consumption for the given WLTP drive cycle. The Worldwide Harmonized Light Vehicles Test Procedure (WLTP) is a chassis dynamometer test cycle for determining emissions and fuel consumption from light-duty vehicles.

3.1. Consideration and Calculation

The preliminary process of any design procedure is of setting goals. To design a Battery Pack, fixing few goals and making required and appropriate consideration is necessary. In an optimized design, iteration plays a critical role. So, redefining our goals and assumptions are necessary for the best possible output.

A. Considerations

After considering the specification of the host vehicle, basic criteria shall be set by considering the constraints and complexities. It will help us to replicate the same performance as the host vehicle. Below mentioned are the consideration based on thisthe battery pack for the electric scooter will be modelled.:-

a. Battery

- Nominal Voltage [V]: - 60
- Chemistry: - Lithium-ion

b. Powertrain

- Electric Motor Type: - BLDC Motor
- Vehicle Range [km]: - 120
- Top Speed [kph]: - 85
- Time 0-85 [s]: - 16
- Kerb weight [kg]: - 99

B. Traction Force Calculations

To understand the total battery consumption, the overall traction force requirement shall be calculated. For this, the kerb weight, final velocity, duration for the acceleration, Tire friction coefficient, radius of the wheel, etc will beconsidered. It will also help us in the selection process of the motor and the gear ratio for the drivetrain.

Table-1: Input Data for Traction Force Calculation

Parameters	Value
Vehicle Total Weight (vehicle kerb weight x mass factor + driver weight)	185.93 kg
Vehicle initial speed	0 kph
Vehicle final speed	85 kph
Vehicle initial time	0 s
Vehicle final time	16 s
Tire radius	0.226 m
Tire friction coefficient	0.9
Gravitational acceleration	9.81 m/s^2

a. Calculation For Traction Force Equation:

Total traction force **(F*t*)** required to achieve 0-85 kph in 16 s:

$$Ft = mv \times \left(\frac{vf - vi}{tf - ti}\right)$$

$$= 185.93 \times \frac{23.61 - (}{16 - 0}$$

$$= 274.36$$

- Total Traction Force is ***274.36 N***

b. Calculation For Frictional Force Equation:

Available friction force **(F*f*)**:

$$Ff = mv \times g \times \mu f$$

$$= 185.93 \times 9.81 \times 0.9$$

$$= 1641.58$$

Total Frictional Force is

1641.58 N

c. Calculation For Finalized Torque Required:

$$Tt = Ft \times rw$$

$$= 274.36 \times 0.226$$

$$= 62.01$$

- Total Torque Required is ***62.01Nm***

3.2. Simulation using Scilab

In this paper, the simulation will be done in 2 stages. In the 1st stage, the simulation for the energy consumption using the WLTP data and Xcos Block diagram. In the 2nd stage, the simulation for comparing the differentbattery cells.

Stage 1: Simulation for Energy Consumption

The primary step for the simulation is to download the WLPT Data from google. Then by calculating the power/weight ratio and selecting the suitable Class. Thenext step is to upload the Scilab for further simulation. By executing the following code, the uploading of the WLPT data will be completed. It will as well generate the plot for the selected Class.

```
clear()
clc()
//Decode xls file, extract and open Excel stream
[fd,SST,Sheetnames,Sheetpos] = xls_open('WLTP-DHC-12-07e.xls');

//Read second data sheet
[Value,TextInd] = xls_read(fd,Sheetpos(2));

//Close the spreadsheet stream
mclose(fd);

//Load WLTP time and speed values in structure
WLTC.time = Value(4:1806,3);
WLTC.values = Value(4:1806,5);

//plot WLTP speed profile
plot(WLTC.time,WLTC.values)
xgrid()
xlabel("Time [s]")
ylabel("Vehicle speed [kph]")
```

Chart -1: Code for Uploading WLTP data

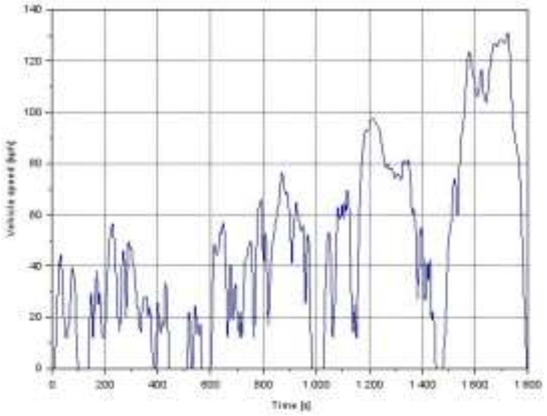

Chart -2: WLTC Data Plot

The next step is to upload the vehicle parameters and build the Xcos block diagram according to the mathematical equations.

Chart -3: Simulation Parameters

Xcos provides a modular approach for complex system modelling, using a block diagram editor. Xcos models are compiled and simulated in a single run

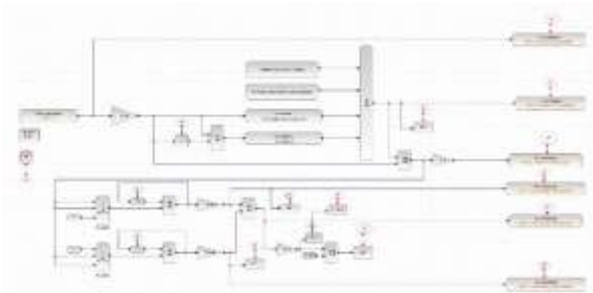

Chart -4: Xcos Block Diagram

Based on the simulation parameters, the uploaded WLTP drive cycle, and the Xcos Block diagram, the plot for the energy consumption during acceleration braking and total consumption for the selected WLTP drive cycle will be generated.

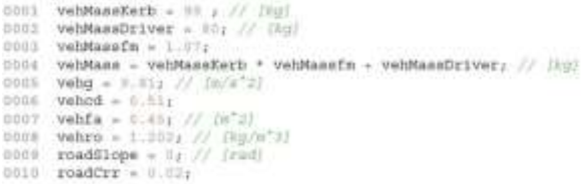

Chart -5: Code for Plotting Energy Consumption

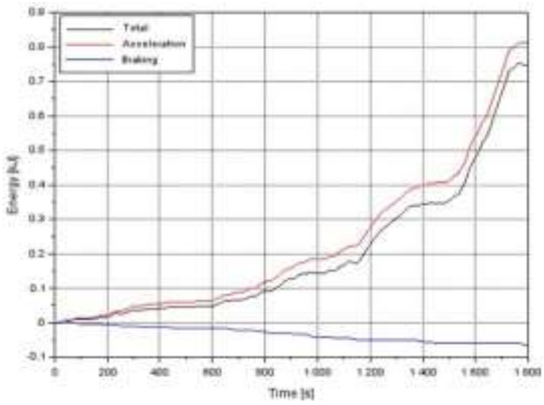

Chart -6: Energy Consumption Plot

From the Xcos Block diagram, the average energy estimated for propulsion over the WLTC drive cycleis ***30.3Wh/k.***

Further adding the energy required for the auxiliarysystem, the total energy consumption for the desired parameters can be calculate.

- **Total energy consumption by the vehicle during the WLTP cycle**

Eavg = (Ep + Eaux) x (2-ήp)

= (30.3+ 0.9) x (2-.87)

= 35.256

Thus, the battery pack will be designed for average energy consumption of ***35.256 Wh/km***

Stage 2: Simulation for Battery Cell Comparison

There are various Battery cells available in the market with trade-offs in their cell chemistry, size, shape, and battery parameters. It is essential to have a thorough market survey before selecting the battery cells. Below listed are a few battery cells that shall be compared for selecting the cell for the battery pack.

Table-2: Battery Cell Data

Manufacture	Orange	Sony	Panasonic	Samsung	Sanyo
Type	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical
Model	ISR18650-5C	US18650 VTC6	NCR18650B	INR18650-25R	NCR18650BL
Length [m]	0.065	0.065	0.065	0.065	0.065
Diameter [m]	0.0182	0.0183	0.0182	0.0183	0.0181
Mass [kg]	0.045	0.046	0.0475	0.0438	0.0466
Capacity [Ah]	2.2	3.12	3.25	2.5	3.35
Voltage [V]	3.7	3.6	3.6	3.64	3.6
C-rate (cont.)	2	6.67	1	8	2.09
C-rate (peak)	5	11.67	1	14	3.65

Table-3: Battery Cell Data

Manufacture	Panasonic	LG	A&S Power	VPH
Type	Cylindrical	Cylindrical	Pouch	Pouch
Model	NCR18650E	INR18650HE4	AS1365132	VPH-C-PLYQPOQ54
Length[m]	0.065	0.065	0	0
Diameter [m]	0.0185	0.0185	0	0
Height [m]	0	0	0.132	0.0965
Width [m]	0	0	0.065	0.34
Thickness [m]	0	0	0.013	0.007
Mass [kg]	0.045	0.047	0.25	0.054
Capacity [Ah]	2.25	2.5	10	2.2

Voltage[V]	3.6	3.6	3.65	3.7
C-rate (cont.)	6.67	8	5	25
C-rate (peak)	11.67	14	10	25

To compare the battery cells, first an excel spreadsheet shall be created and later upload the data on the Scilab console. Further, by executing the code for comparing the cell, the plots for comparing the batteries across various parameters shall be generated.

The essential parameters that shall be considered while selecting a battery cell for a battery pack are listedbelow: -

i. Battery Cell Capacity

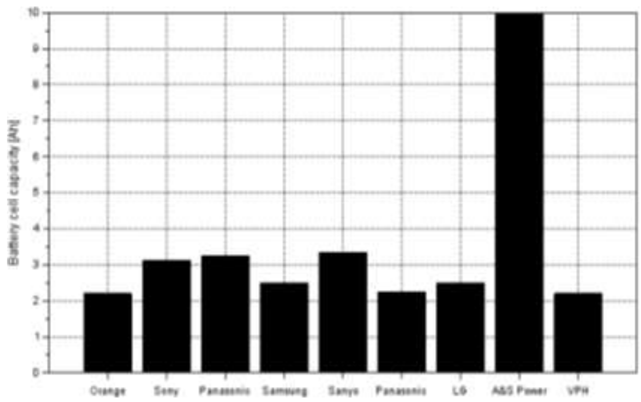

Chart -7: Plot for Battery Cell Capacity Comparison

ii. Battery Cell Voltages

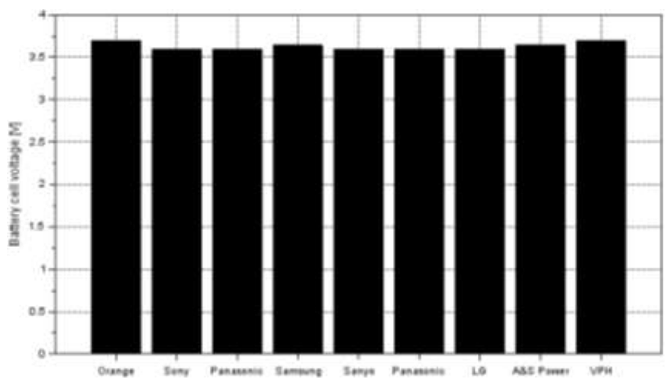

Chart -8: Plot for Battery Cell Voltages Comparison

iii. Energy Density – Gravimetric

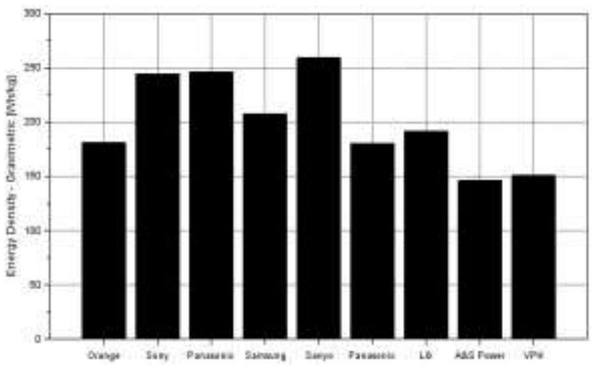

Chart -9: Plot for Energy Density – Gravimetric Comparison

iv. Energy Density – Volumetric

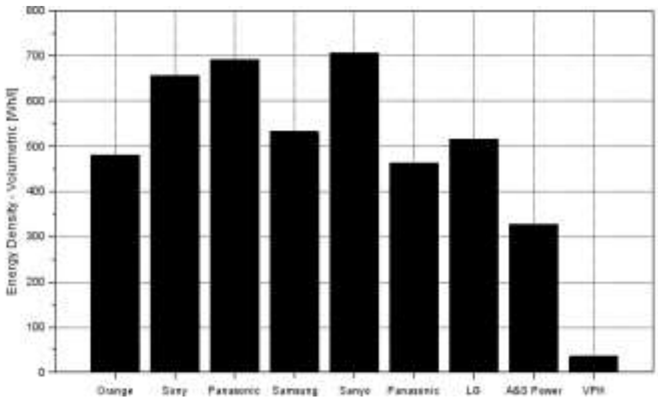

Chart -10: Plot for Energy Density – Volumetric Comparison

v. Battery Pack Capacity

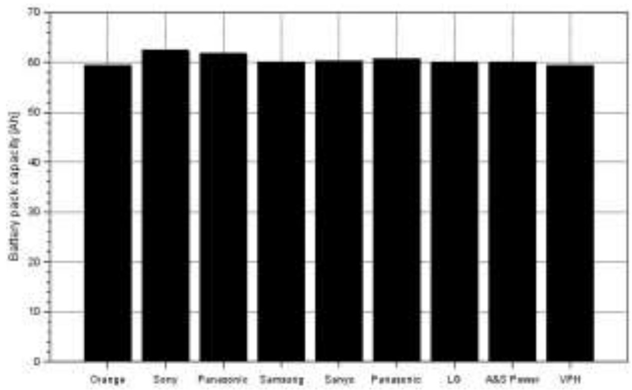

Chart -11: Plot for Battery Pack Capacity Comparison

vi. Battery Pack Continuous Current

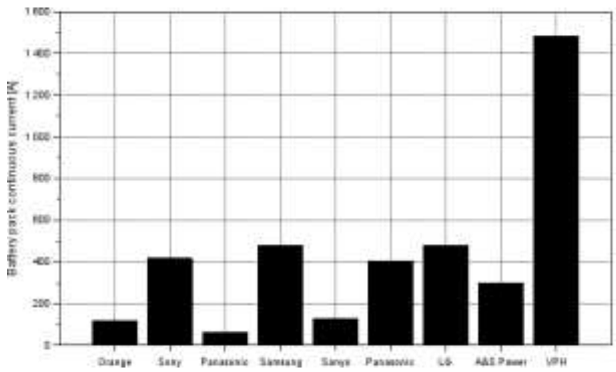

Chart -12: Plot for Battery Pack Continuous Current Comparison

vii. Battery Pack Continuous Power

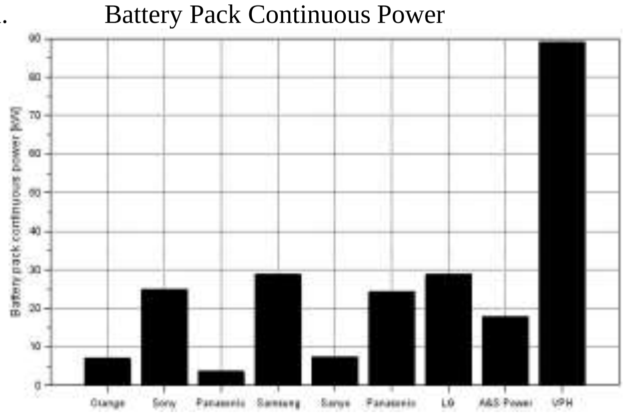

Chart -13: Plot for Battery Pack Continuous Power Comparison

viii. Battery Pack Energy

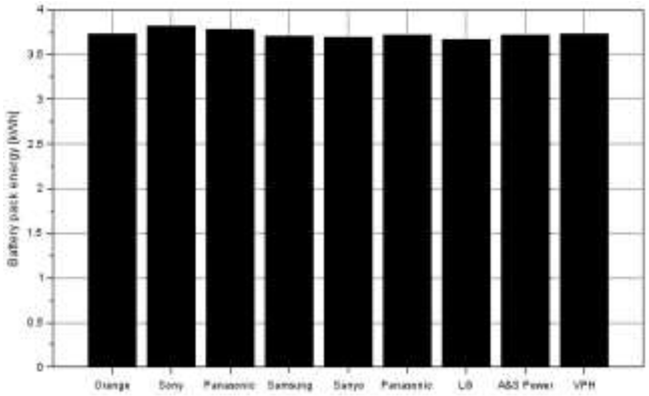

Chart -14: Plot for Battery Pack Energy Comparison

ix. Battery Pack Peak Current

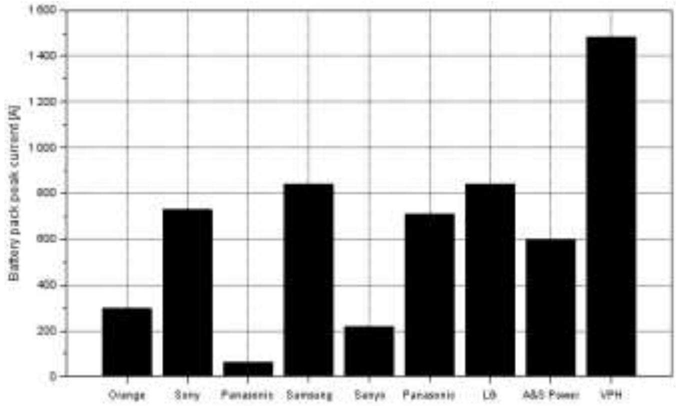

Chart-15: Plot for Battery Pack Peak CurrentComparison

x. Battery Pack Peak Power

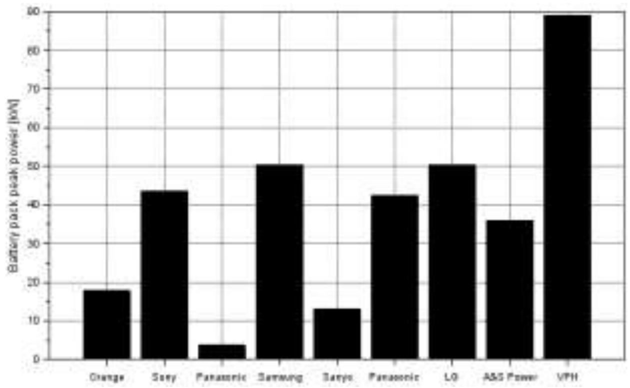

Chart -16:Plot for Battery Pack Peak PowerComparison

xi. Battery Pack Volume

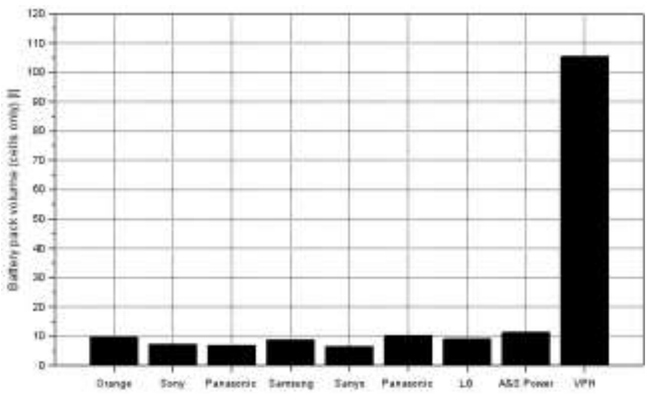

Chart -17: Plot for Battery Pack Volume Comparison

xii. Battery Pack Mass

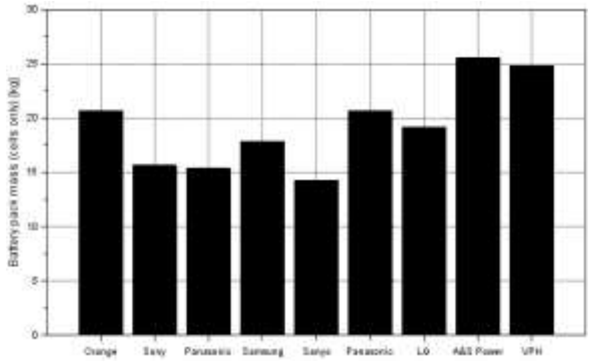

Chart -18: Plot for Battery Pack Mass Comparison

xiii. Total Number of Cells

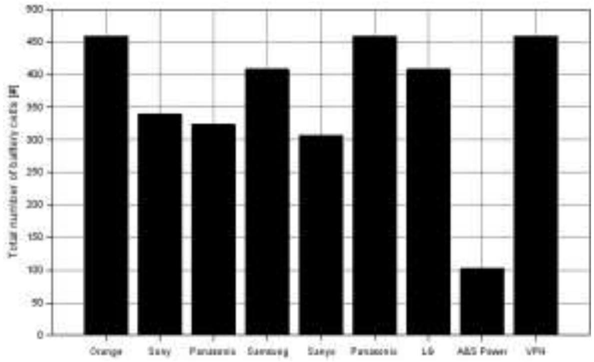

Chart -19: Plot for Total Number of Cells Comparison

3.3. Interpretation of Simulation Output

Considering all the graphs and general requirements, few cell are shortlisted. The battery pack will be designed for a range of **120 km** with a nominal voltage of **60V** with a total energy requirement of **30.3 Wh/Km** for propulsion. The majorly concerned parameters will be Continuous Current, Energy density, Number of cells, and cost.

The below table shows a comparison of the 5 Battery cells considering the output of the graphs: -

Table-4: Battery Cell Comparison

Manufacturer	Cont. current [A]	Mass[kg]	Volume [l]	Pack Density [kg/m^3]	Tot. cell req.	Cell price	Packprice
L.G	480	19.17	9.08	2111.23	408	438	1,78,704
Samsung	480	17.87	8.88	2012.38	408	619	2,52,552
Sony	416	15.64	7.4	2113.51	340	799	2,71,660
Panasonic	405	20.65	10.2	2024.50	459	625	2,86,875
A&S Power	**300**	**25.5**	**11.38**	**2240.77**	**102**	**450**	**45,900**

'A&S Power Pouch cell' has good pack density, and it is very economical than other alternatives. Due to the lesser number of cells required overall dimension of the battery pack will also be compact. It will be selected forthe battery pack.

Now, as the cell is finalized, the nominal voltage, and the size of the battery pack, the best-suited combination
achieving the required voltage and current to meet the desired energy requirement shall be fixed.

Table-5: Permutation for Battery Pack

Combination	No. of cells in series	No. of cells in parallel	Total no. of cells
16s 6p	16	6	96
16s 7p	16	7	112
17s 6p	***17***	***6***	***102***
17s 7p	17	7	119

The Battery Pack will have a combination of ***17s 6p*** for an operation voltage of **60V** and energy density **of 30.3 Wh/Km**.

Hence with the help of the calculations and the simulations, it can infer that an electric scooter battery pack that can replicate the performance similar to the YAMAHA FASCINO 125cc will require the following specification: -

Table-5: Battery Pack Specification

Energy consumption from propulsion	30.3 Wh/km
Energy consumption by secondary components	0.9 Wh/km
Total energy consumption	35.256 Wh/km
Range Selected	120 km
Voltage Selected	60 V
Selected battery cell (product name)	A & S Power (AS1365132)
Number of cells needed	102
Type of battery cell	Pouch
Number of cells in series	17
Number of cells in parallel	6

4. CONCULSION

The prime focus of the paper was on modeling an electric scooter battery pack and using simulation software. With the help of Scilab, the simulations were carried out by writing and executing the required programs for determining the energy consumption. Xcos bock diagram helped calculate the total energy consumption and energy generation through regenerative braking for the WLTC. The execution of the code for comparing the various battery parameters eased the process for battery cell selection.
for connecting the cells in series and parallel for
The major takeaway from the seminar was theimplementation of WLTP data in designing a vehicle. It

enhanced the real-time simulation using SCILAB for the desired vehicle parameters. Such simulations help us optimize our design before practical implementation.There are still a lot of approaches in calculations and simulations that need that can be studied in the future.

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Hrushikesh Anil Chari
Sinhgad College of Engineering, Pune, Maharashtra, India

Dr. Rajendra Katikar
Sinhgad College of Engineering, Pune, Maharashtra, India

