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Battery Cell Comparison for Electric Vehicles Using SCILAB

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Abstract

The Battery Pack is an integral part of an electric vehicle. All the performance parameters of an electric vehicle largely depend on the specification of the battery pack. In recent years, there has been a tremendous advancement in battery cell technology, which has resulted in the betterment of the specification of battery cells. Due to these developments, we can foresee electric vehicles as a sustainable and environment-friendly mode of transport. This paper will describe the critical consideration parameters for the battery cell selection process. The research paper will also explain the comparison of battery cells with the help of Scilab programming for getting accurate results.

Keywords: Scilab, Energy Consumption, Cell Data, Parameter Calculation, Scinotes;

1. Introduction

Electric vehicles have established themselves as an appropriate alternative for conventional gasoline-powered engines due to their environment-friendly and sustainable mode of transport. It has resulted in tremendous research and development of various systems in electric vehicles. The traction Battery Pack is an integral part of the electric vehicle powertrain. The performance of an electric vehicle extensively depends upon the battery pack parameters. With the new inventions of battery chemistries, we can witness a wide range of parameters of battery cells. Thus, the selection process of battery cells becomes a bit difficult in choosing the correct trade-off between the parameters.

There are numerous methods and models for the selection process across various parameters. For an optimal design, it is necessary to have the best trade-off amongst the parameters. Mathematical modeling is one such tool that can help carry out such different and complex tasks with ease.

Today electric vehicles have many drawbacks associated with the battery pack as the range, charging duration, compactness. Such drawbacks can be solved by using an effective and efficient method for selecting the best-suited battery cell of the desired operation. The paper will be discussing one such method that can be effective and convenient for comparing various battery parameters for the desired application.

2. Literature Review

A report by Fengqi Chang has explained the influence of the number of parallel cells in a battery pack is evaluated in Monte-Carlo experiments.[1]

Dr. K.V. Vidyanandan in his report has provided an overview of Li-ion batteries, their limitations, safety concerns, and the emerging battery technologies to meet future requirements. [2]

The report by S. Tamilselvi describes a study of various battery models such as electrochemical models, mathematical models, circuit-oriented models, and combined models for different types of batteries. It also explains the advantages and drawbacks of these types of modeling. [3]

In his report by Hrushikesh Chari has proposed a mathematical method for calculating the total energy consumption for electric scooters and the battery cell selection process using the features of SCILAB. [4]

It can be inferred from the literature reviewed that method used are lengthy and quite complicated and does not elaborate on the battery cell comparison methods.

This paper will explain the application of Scilab programming for the comparison of battery cells conveniently and effectively. For the comparison of the battery cells, some data will be used as a reference from the report by Hrushikesh Chari.

3. Overview of Battery Cell

A. Battery Chemistries

There are various battery chemistries are used in electric vehicles, but all of them have distinct parameters. Below listed are a few common types of battery chemistries: -

- **Lithium-Ion Batteries:** The prominent type of battery used in electric cars is the lithium-ion battery. These batteries cells are used in most portable electronics, like mobile phones and computers. Lithium-ion batteries have a high power-to-weight ratio, high energy efficiency, and good high-temperature performance.

- **Nickel-Metal Hydride Batteries:** Nickel-metal hydride batteries are widely used in hybrid-electric vehicles but are also used successfully application in some all-electric vehicles. These batteries have a longer life cycle than lithium-ion or lead-acid batteries. The biggest issues with these batteries is their high cost, high self-discharge rate, and significant heat generation at high temperatures.

- **Lead-Acid Batteries:** Lead-acid batteries are only currently being used in electric vehicles to supplement auxiliary systems. These batteries are high-powered, economical, safe, and reliable, but they have short lifecycle and poor cold-temperature performance, it make them difficult to use in electric vehicles.

- **Ultracapacitors:** Ultracapacitors are not batteries, instead they store polarized liquid between an electrode and an electrolyte. As the liquid's surface area increases, the capacity for energy storage also increases.[6]

B. *Battery Parameters*

The desired characteristics of a battery from electric vehicles are: for longer drive distances high specific energy, for good acceleration high specific power, high safety features, wide operating temperature range, for fast charging low internal resistance, for high instantaneous torque high peak current long life, and affordable price.[2]

Below listed are a few common battery parameters that must be considered while selecting the battery cells: -

- **Battery cell capacity:** The battery capacity represents the maximum amount of energy that can be extracted from the battery under certain specified conditions. It is expressed in 'Amp-hr'

- **Battery cell nominal voltages:** The voltage of a battery is a basic characteristic of a battery, which is determined by the chemical reactions in the battery, the concentrations of the battery components, and the polarization of the battery. It is expressed in 'Volts'

- **Energy Density – Gravimetric:** The gravimetric energy density *also called as* the specific energy of a battery is a measure of how much energy a battery contains in comparison to its weight, and is typically expressed in Watt-hours/kilogram (W-hr/kg).

- **Energy Density – Volumetric:** The volumetric energy density *also called as* the energy density of a battery is a measure of how much energy a battery contains in comparison to its volume and is expressed in Watt-hours/liter (W-hr/l)

- **Battery cell continuous current:** The maximum current at which the battery can be discharged continuously. It is expressed in 'Amp'.

- **Battery cell peak current:** The peak current is the maximum amount of current that output is capable of sourcing for brief periods. It is expressed in 'Amp'.[5]

- **C-rating:** The battery C rating is the measurement of the current at which a battery is charged and discharged.

EV batteries are *deep cycle* (DC) batteries. DC batteries have thicker positive electrode plates but have relatively less surface area available to take part in electrochemical reactions. They can be discharged down to 30-20% of SOC (state of charge) for over a thousand cycles.[2]

4. Methodology

As mentioned above to compare battery cells the data will be taken from "Mathematical modeling of the electric scooter battery pack using SCILAB" as the reference values for calculation. For the comparison of the battery cell, the predefined values are range=120km, voltage=60V, and energy consumption=30.3Wh/km. [4] The comparison of the cells will be carried out by analyzing the

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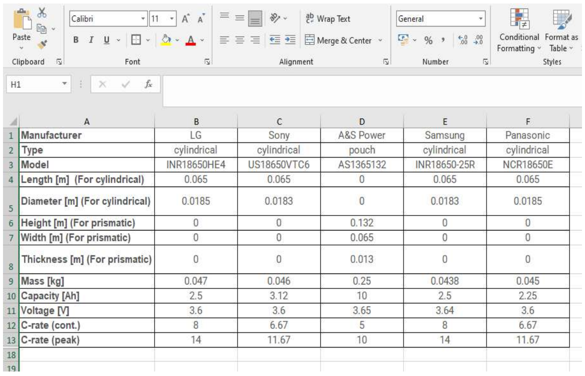
graphs generated by executing the code in SCInotes. The program can be segmented into three sections uploading cell data, calculating parameters, and plotting the graph.

Firstly, the shortlisted cell specification is to be filled in an excel file and saved in a folder. Figure 1 is the screenshot of the selected cells.

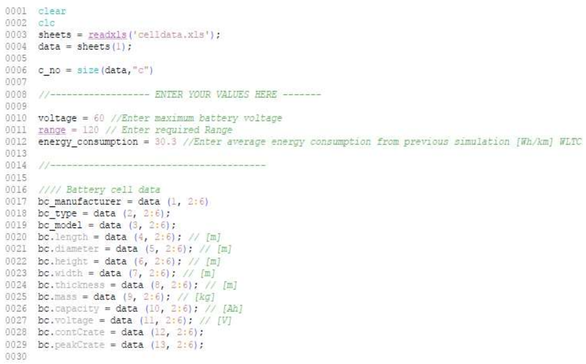
A. *Uploading Cell Data*

After filling the battery cell specification in the excel file, it is saved in the required folder. Later by launching Scilab and opening SCInotes for writing the program. Firstly, the cell data is imported and it is been uploaded to the workspace for further calculation. Then, the values of the predefined values of range, voltage, and energy consumption are entered and the value for each variable is called as shown in figure 2.



	A	B	C	D	E	F
1	Manufacturer	LG	Sony	A&S Power	Samsung	Panasonic
2	Type	cylindrical	cylindrical	pouch	cylindrical	cylindrical
3	Model	INR18650HE4	US18650VTC6	AS1365132	INR18650-25R	NCR18650E
4	Length [m] (For cylindrical)	0.065	0.065	0	0.065	0.065
5	Diameter [m] (For cylindrical)	0.0185	0.0183	0	0.0183	0.0185
6	Height [m] (For prismatic)	0	0	0.132	0	0
7	Width [m] (For prismatic)	0	0	0.065	0	0
8	Thickness [m] (For prismatic)	0	0	0.013	0	0
9	Mass [kg]	0.047	0.046	0.25	0.0438	0.045
10	Capacity [Ah]	2.5	3.12	10	2.5	2.25
11	Voltage [V]	3.6	3.6	3.65	3.64	3.6
12	C-rate (cont.)	8	6.67	5	8	6.67
13	C-rate (peak)	14	11.67	10	14	11.67

Figure 1. Battery cell specification data import



```
clear
clc
sheets = readxls('celldata.xls');
data = sheets(1);

c_no = size(data,"c")

//------------------ ENTER YOUR VALUES HERE -------

voltage = 60 //Enter maximum battery voltage
range = 120 // Enter required Range
energy_consumption = 30.3 //Enter average energy consumption from previous simulation [Wh/km] WLTC

//----------------------------------------

//// Battery cell data
bc_manufacturer = data (1, 2:6)
bc_type = data (2, 2:6);
bc_model = data (3, 2:6);
bc.length = data (4, 2:6); // [m]
bc.diameter = data (5, 2:6); // [m]
bc.height = data (6, 2:6); // [m]
bc.width = data (7, 2:6); // [m]
bc.thickness = data (8, 2:6); // [m]
bc.mass = data (9, 2:6); // [kg]
bc.capacity = data (10, 2:6); // [Ah]
bc.voltage = data (11, 2:6); // [V]
bc.contCrate = data (12, 2:6);
bc.peakCrate = data (13, 2:6);
```

Figure 2. Program for Uploading Cell Data

B. *Calculation*

To generate the graphs for comparison, the calculation of the parameters is essential. The required formulas are written in the program with the necessary conditions. The table below shows the formulas used for the calculation.

TABLE I. Formulas for Parameter Calculation

Sr. No.	**Parameter**	**Formula**
1	Energy Density – Gravimetric [Wh/kg]	$\frac{Battery\ cell\ energy\ [Wh]}{Battery\ cell\ mass\ [kg]}$
2	Energy Density – Volumetric [Wh/ m^3]	$\frac{Battery\ cell\ energy\ [Wh]}{Battery\ cell\ volume\ [m^3]}$
3	Battery Pack Capacity [Ah]	$No.of\ string \times Battery\ cell\ capacity[Ah]$
4	Battery Pack Continuous Current [A]	$Sting\ continous\ current[A] \times No.of\ strings\ in\ pack$
5	Battery Pack Continuous Power [W]	$Battery\ pack\ continous\ current[A] \times Battery\ pack\ voltage[V]$
6	Battery Pack Energy [Wh]	$No.of\ string \times Battery\ cell\ energy\ content[Wh]$
7	Battery Pack Peak Current [A]	$Sting\ peak\ current[A] \times No.of\ strings\ in\ pack$
8	Battery Pack Peak Power [W]	$Battery\ pack\ peak\ current[A] \times Battery\ pack\ voltage[V]$
9	Battery Pack Volume (only cells) [m^3]	$Total\ no.of\ cells \times Volume\ of\ each\ battey\ cell[kg]$
10	Battery Pack Mass (only cells) [Kg]	$Total\ no.of\ cells \times Mass\ of\ each\ battey\ cell[kg]$
11	Total Number of Cells	$No.of\ cells\ in\ string \times No.of\ strings$

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The figure 3 is the screenshot of the Scilab program, it is the further continuation of the previous section.

```
//// Battery parameter calculations
bp.VDC = voltage; // [V]
veh.range = range; // [km]
veh.energyAvg = energy_consumption; // [Wh/km] WLTC

//--------------------------------------------------------------------

veh.totalEnergyRange = veh.range * veh.energyAvg; // [Wh]

//// Energy density calculations
for i=1:max(size(bc_manufacturer))
    bc.energy(i) = bc.capacity(i) * bc.voltage(i); // [Wh]
    if (bc_type(i)=='cylindrical')
        bc.volume(i) = 1000 * bc.length(i) * (%pi*bc.diameter(i)^2/4); //
    else
        bc.volume(i) = 1000 * bc.height(i) * bc.width(i) * bc.thickness(i)
    end
    bc.energyDensityMass(i) = bc.energy(i) / bc.mass(i); // [Wh/kg]
    bc.energyDensityVolume(i) = bc.energy(i) / bc.volume(i); // [Wh/l]
end
clear i

for i=1:max(size(bc_manufacturer))
    bp.noCellsSeries(i) = ceil(bp.VDC / bc.voltage(i)); // [-]
    bp.energyString(i) = bp.noCellsSeries(i) * bc.energy(i); // [Wh]
    bp.noStrings(i) = ceil(veh.totalEnergyRange / bp.energyString(i)); //
    bp.packEnergy(i) = (bp.energyString(i) * bp.noStrings(i))/1000; // [kW
    bp.packCapacity(i) = bp.noStrings(i) * bc.capacity(i); // [Ah]
    bp.totalCells(i) = bp.noCellsSeries(i) * bp.noStrings(i); // [-]
    bp.mass(i) = bc.mass(i) * bp.totalCells(i); // [kg]
    if (bc_type(i)=='cylindrical')
        bp.stringLength(i) = bp.noCellsSeries(i) * bc.diameter(i); // [m]
        bp.stringWidth(i) = bc.diameter(i); // [m]
        bp.stringArea(i) = bp.stringLength(i) * bp.stringWidth(i); // [m2]
        bp.stringVolume(i) = bp.stringArea(i) * bc.length(i) * 1000; // [l
        bp.packVolume(i) = bp.stringVolume(i) * bp.noStrings(i); // [l]
    else
        bp.stringLength(i) = bp.noCellsSeries(i) * bc.thickness(i); // [m]
        bp.stringWidth(i) = bc.width(i); // [m]
        bp.stringArea(i) = bp.stringLength(i) * bp.stringWidth(i); // [m2]
        bp.stringVolume(i) = bp.stringArea(i) * bc.height(i) * 1000; // [l
        bp.packVolume(i) = bp.stringVolume(i) * bp.noStrings(i); // [l]
    end
```

Figure 1.Program for Parameter Calculation

```
//// Plot batt parameters
figure(1)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bc.capacity,'black');
ylabel('Battery cell capacity [Ah]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_cell_capacity.png')

figure(2)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bc.voltage,'black');
ylabel('Battery cell voltage [V]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_cell_voltage.png')

figure(3)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bc.energyDensityMass,'black');
ylabel('Energy Density - Gravimetric [Wh/kg]', 'FontSize',
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_cell_energy_density_gravimetric.png')

figure(4)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bc.energyDensityVolume,'black');
ylabel('Energy Density - Volumetric [Wh/l]', 'FontSize',
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_cell_energy_density_volumetric.png')
```

Figure 2. Program for Plotting Battery Parameters

C. Graph Plotting

Once the program for calculation gets completed the next and final step is of writing the program for generating the graphs. It is processed in two stages: -

i. For Battery parameters

   This will aid to compare all the individual cell parameters such as Voltage, Capacity, Volumetric and Gravimetric energy density. Figure 4 is the screenshot of the Program for Plotting Battery Parameters

ii. For Pack parameter

   This will aid to compare the pack parameters such as no.of cells, Peak current, Peck power, etc. Figure 5 and 6 is the screenshot of the Program for Plotting Pack Parameters

After completing the entire program save the with. sce extension in the same folder where the cell data excel sheet is saved. Later execute the program. Once the program is executed the graphs for the parameters open and the same are saved in the folder as .png files

```
//// Plot pack parameters

figure(5)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.totalCells,'black');
ylabel('Total number of battery cells [#]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Total_number_cells.png')

figure(6)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.mass,'black');
ylabel('Battery pack mass (cells only) [kg]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_mass.png')

figure(7)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packVolume,'black');
ylabel('Battery pack volume (cells only) [l]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_volume.png')

figure(8)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packEnergy,'black');
ylabel('Battery pack energy [kWh]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_energy.png')
```

Figure 5. Program for Plotting Pack Parameters

```
figure(9)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packCapacity,'black');
ylabel('Battery pack capacity [Ah]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_capacity.png')

figure(10)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packPeakCurrent,'black');
ylabel('Battery pack peak current [A]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_peak_current.png')
figure(11)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packPeakPower,'black');
ylabel('Battery pack peak power [kW]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_peak_power.png')

figure(12)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packContCurrent,'black');
ylabel('Battery pack continuous current [A]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_cont_current.png')

figure(13)
hf = gcf();
ha = gca();
hf.background = -2;
hf.figure_size = [777,552];
bar(bp.packContPower,'black');
ylabel('Battery pack continuous power [kW]', 'FontSize', 2)
ha.x_ticks.labels = bc_manufacturer';
xgrid()
xs2png(hf, 'Battery_pack_cont_power.png')

disp('done')
```

Figure 6. Program for Plotting Pack Parameters

6. Results

By using Scilab the graphs for comparing the battery cells are generated. By analyzing the graphs, the suitable cell can be selected accordingly. Below is the result of the battery cells:

i. Battery Cell Capacity

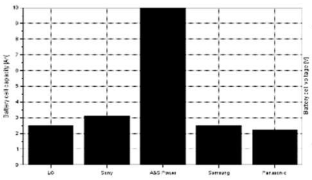

Fig 7. Battery Cell Capacity

ii. Battery Cell Voltages

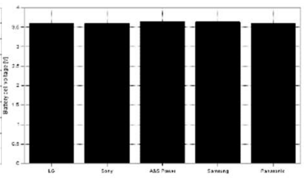

Fig 8. Battery Cell Voltages

iii. Energy Density – Gravimetric

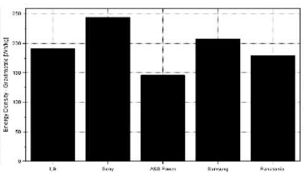

Fig 9. Energy Density – Gravimetric

iv. Energy Density – Volumetric

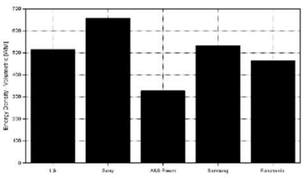

Fig 10. Energy Density – Volumetric

v. Battery Pack Capacity

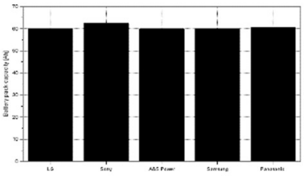

Fig 11. Battery Pack Capacity

vi. Battery Pack Continuous Current

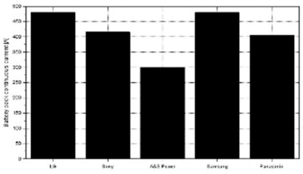

Fig 12. Battery Pack Continuous Current

vii. Battery Pack Continuous Power

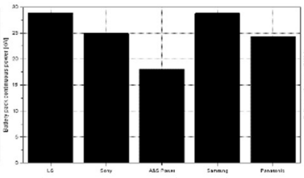

Fig 13. Battery Pack Continuous Power

viii. Battery Pack Energy

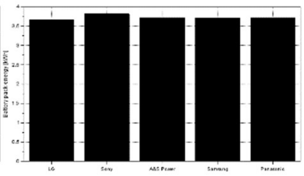

Fig 14. Battery Pack Energy

ix. Battery Pack Peak Current

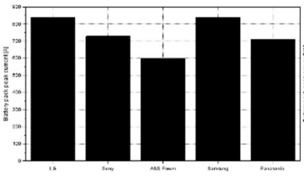

Fig 15. Battery Pack Peak Current

x. Battery Pack Peak Power

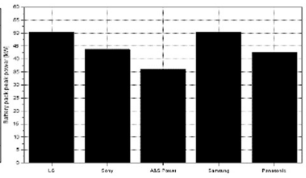

Fig 16. Battery Pack Peak Power

xi. Battery Pack Volume

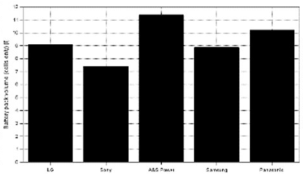

Fig 17. Battery Pack Volume

xii. Battery Pack Mass

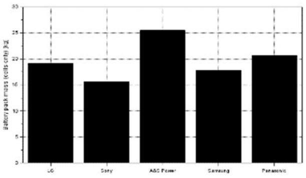

Fig 18. Battery Pack Mass

xiii. Total Number of Cells

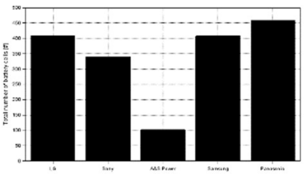

Fig 19. Total Number of Cells

An electric vehicle needs a good amount of acceleration and power to cruise at a constant speed so the battery pack should have a good continuous current and peak current. While a battery pack should be compact and lightweight. Thus, it should have high gravimetric and volumetric energy. By analyzing the graphs, the cell which provides a better combination of the tradeoffs can be selected.

7. Conclusions

The prime focus of the paper was on the comparison of different battery cells the application of electric vehicle battery packs. With the help of Scilab, the comparison was carried out by writing and executing the required programs for generating the graphs for the battery cell comparison. This method can be used for the comparison of any number of cells and parameters for a varied range of applications. The formulas and the method used for comparison are basic and easy to understand. Though this method does not elaborate on the state of charge of the battery. Yet, it can be effectively used for the primary stage of battery cell selection.

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