Battery dimensioning for Renault Zoe

Master's Degree in Automotive Engineering

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1 Introduction

Battery dimensioning is a critical aspect of electric vehicle (EV) development, directly influencing performance, range, safety, and overall vehicle integration. This document outlines the key factors in battery dimensioning of a Renault Zoe, a compact and widely popular EV, with a focus on producing a preliminary 3D design of the battery module or pack.

1. **Electrical Sizing of the battery: Voltage, Nominal Energy**
   The following electrical characteristics of the battery are chosen considering that these are the most common parameters for B-segment EV cars.

$NominalVoltage$	400 V	V
$Energy$	52.5 kWh	E
$Capacity$	131.25 Ah	Q

Table 1: Battery pack specifications

2. **Battery Cell Selection**
   LG Chem E63 lithium-ion (Li-ion) pouch cell with a Nominal Capacity of 65.6Ah and a Nominal Voltage of 3.60V.
3. **Battery Layout: Cell-to-Pack, Cell-to-Module, or Cell-to-Chassis**
   The structural arrangement of battery cells chosen is the **Cell-to-Module** with 10 modules connected in series.

$Number\ of\ module$	10	N
$Nominal\ Voltage$	40 V	V
$Nominal\ Energy$	5.25 kWh	E
$Capacity$	131.25 Ah	Q

Table 2: Cell-to-Module specifications

Furthermore, other factors such as gravimetric and volumetric energy density, thermal management system, and electrical connections are reported in the next chapters of this document.

2 Battery cell selection and battery layout

The cell type selected for this battery pack is a pouch cell, which has a cost in between the common cylindrical and the less adopted prismatic one. Its main advantages are high volumetric and gravimetric density due to their size and weight. The flat design allows for even heat distribution, even though it is challenging to well manage the cooling in automotive applications. Moreover, if the thermal management is not well-designed, the cell starts to swell due to gas generation inside of it, compromising the integrity of the battery back or the module where is installed. Therefore, the thin design makes the cell a bit flexible, so its mechanical vulnerability is higher than other cases, and generally has a shorter life cycle.
The selected cell is a LG Chem E63 lithium-ion (Li-ion) with a Nominal Capacity of $65.6Ah$ and a Nominal Voltage of $3.60V$ with a battery layout cell-to-module. This layout leads to an improved maintainability because it is easier and cheaper to change a single module, instead of the entire pack, if a pouch cell blows off due to swell, temperature or mechanical stresses.
In Figure 1 and Figure 2 the discussed cell is shown.

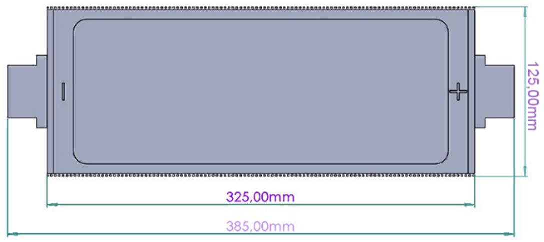

Figure 1: LG Chem $E63$ pouch cell front view

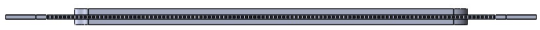

Figure 2: LG Chem $E63$ pouch cell lateral view

The entire pack is realised by a **10-module series connection** composed by a $11s2p$ connection of the cells, and a Nominal Capacity of $131.25Ah$, chosen to ensure the vehicle performance and range. The parameters of each single module are as in table 2.
To compute the series-parallel connections $11s2p$ $(XsYp)$ the following formulas has been used:

$$X = \frac{V}{NominalCellVoltage} = \frac{40V}{3.60V} = 11 \tag{1}$$

$$Y = \frac{Q}{NominalCellCapacity} = \frac{131.25Ah}{65.5Ah} = 2 \tag{2}$$

2.1 Cell specification

In the following table the specification of the LG Chem $E63$ pouch cell used in this project are reported.

Discharge Capacity	Under 25 °C, $2.50V - 4.20V$ Standard charge/ $21.6A$ discharge	Nominal $65.6Ah$ Minimum $64.6Ah$
Standard charge	Constant current Constant current and voltage End condition (current cut off) Temperature	$21.6A/4.05V$ $13.0A/4.20V$ $3.25A$ 25 ± 2 °C
Normal charge	Constant power Termination voltage adn power Temperature	$6.25W$ $4.157V/6.25W$ 10 °C – 50 °C
22kW fast charge	Constant power Termination voltage and power Temperature	Max. $114.25W$ $4.157V/6.25W$ 10 °C – 45 °C
43kW fast charge	Constant power Termination voltage and power Temperature	Max. $224W$ $4.157V/6.25W$ 25 °C – 45 °C
Charge at low temperatures	Constant power Termination voltage and power Temperature	Max. $69W$ at 0 °C Max. $46.9W$ at -10 °C Max. $11.7W$ at -20 °C $4.157V/13.13W$ at 0 °C $4.157V/5.26W$ at -10 °C $4.157V/2.60W$ at -20 °C -20 °C – 0 °C
Nominal Voltage	3.60	V
Voltage	$2.50 - 4.20$	V
Thickness	11.5 ± 0.2	mm
Weight	964.9 ± 8	g
Width	125	mm
Height	325	mm
Thickness	11.5	mm
Nominal Capacity at 0 °C	57.4	Ah
Nominal Capacity at 25 °C	63.5	Ah
Nominal Capacity at 45 °C	64.8	Ah

Table 3: LG Chem $E63$'s specifications

2.2 Cells configuration

In order to realise a battery pack with the chosen configuration and the desired specification, the Equation 1 is used to compute the number of the cells connected in series and the Equation 2 for the parallel connection. For the series connection the negative pole of the previous cell has to be connected with the positive pole of the next one. With this electrical connection the cells will share the same capacity, as well as the same current, and the voltage will be the sum of each cell's voltage. The parallel is used to increase the capacity of the entire battery pack by maintaining the same voltage.

In order to better manage the cables connection per each module, the cells are coupled in opposite direction for the series connection, linking just one pole per each cell (e.g. the positive pole of one cell with the negative pole of the second one). Pouch cells are tipically mounted under pressure, even though its thickness normally expand around $5 - 10\%$ due to the high temperature and the gasses produced inside of it. However, this type of cell is projected to work under high load condition, and for that reason the pouches tipically have a great volumetric energy density. Once connected 2-pairs of 11 series cells, to manage the parallel connection the negative terminal of the last series-block of the cells is connected with the negative terminal of the first cell of the other series-block. The same procedure is done for the positive terminal. The Figure 3 shows how the $11s2p$ cells are mounted by using symbol + for the positive pole and − for the negative one.

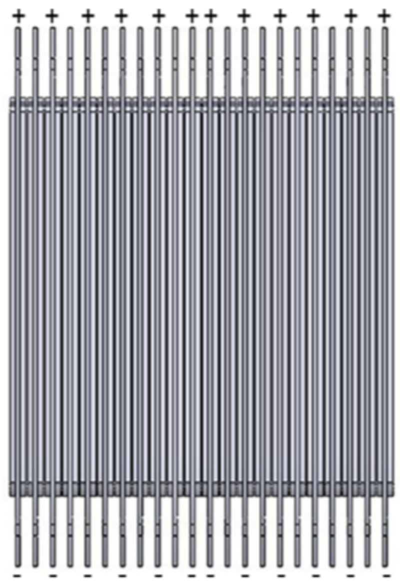

Figure 3: $11s2p$ cells configuration

3 Thermal management

Considering that batteries operate under demanding working conditions, a cooling system must be taken into account to avoid the swell due to the high temperatures. Various cooling system can be used, such as forced air cooling, surface cooling and edge cooling. The latter is commonly used and is one of the more efficient way to manage the heat transfer for the pouch cells. Considering that pouch cells are made from aluminium and other materials which have a high thermal conductivity, a cold plate is designed to be applied along the longest edge of the cells to dissipate a significant amount of heat. To achieve this, a pump is required to circulate an appropriate fluid through a tube within the cold plate. This type of system is referred to as **passive indirect liquid cooling**, as illustrated in Figure 4, which shows the cold plate developed for the module described in this document.

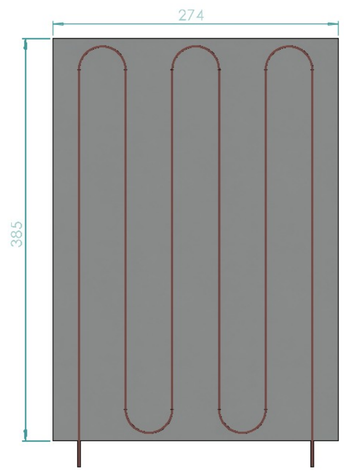

Figure 4: Cold plate - passive indirect fluid cooling system

Its thickness is 5 mm, and the holes through which the tube passes are 3 mm diameter. Width and height are such that the cold plate covers the entire $11s2p$ cells array, optimizing both the cooling system and the module volume.

4 3D-design

To design a 3D model of the discussed module, several factors must be taken into account. The cells are connected using busbars that are bonded to them, and these dimensions must be considered, along with the cooling system, a small gap with the upper case cover, and tolerances to facilitate ease of assembly. The material chosen for the module is the 6063 aluminium alloy with a density $d = 2.7\ \mathrm{g/cm^3}$. For these reasons, the total dimensions of the module are reported in Table 4.

Length	385	mm
Height	133	mm
Width	276	mm
Case Thickness	2.00	mm
Volume	$1.41 \cdot 10^7$	mm^3
Mass	27.2	kg

Table 4: Cell-to-Module specifications

The mass takes into account the weight of the case, cooling system, cells and everything is needed for the electrical connection. In Figure 5 and Figure 6 a 3D model of the module with its dimensions is shown. The positive terminal of the module is located on the front, meanwhile the negative one is on the other side.

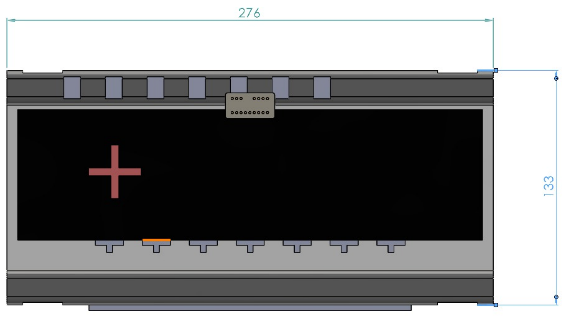

Figure 5: Cold plate - passive indirect fluid cooling system

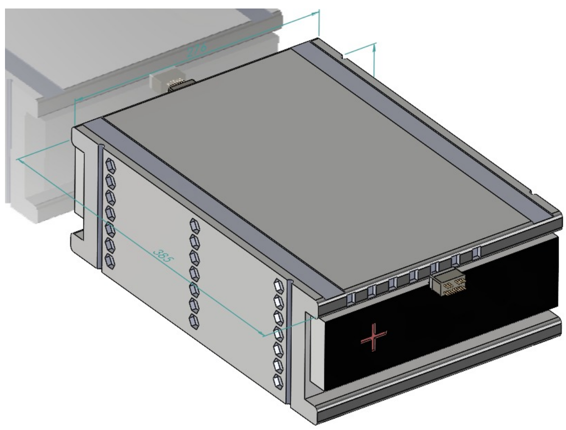

Figure 6: Cold plate - passive indirect fluid cooling system

5 Gravimetric and volumetric energy density

The **gravimetric energy density** is a parameter that defines how much energy a system contains in relation to its mass. It has been calculated for both the cells and module levels for comparison. Similarly, the **volumetric energy density** defines the amount of energy contained in the system in relation to its volume. High values of these two specifications indicate that the battery pack is well-optimized. It is also important to compare the energy density of the $11s2p$ cells configuration with that of the module to better understand whether it has been properly dimensioned.

The equations 3 and 4 could be used to compute these two values. The results are related to the module energy density.

$$d_g = \frac{E}{Mass} = \frac{52.5\ kWh}{27.2\ kg} = 1.93\ kWh/kg \tag{3}$$

$$d_V = \frac{E}{Volume} = \frac{52.5\ kWh}{0.0141\ m^3} = 3723\ kWh/m^3 \tag{4}$$

In the following Table 5 are reported the results for both cells and module in order to compare the dimensioning efficiency.

	Cells	Module	
d_g	2.48	1.93	kWh/kg
d_V	5108	3723	kWh/m^3

Table 5: Energy density comparison between cells and module

Considering these results, it is possible to compute the efficiency of the module dimensioning by using the following formulas:

$$\eta_g = 1 - \frac{2.48kWh/kg - 1.93kWh/kg}{2.48kWh/kg} = 0.778 \tag{5}$$

$$\eta_g = 1 - \frac{5108kWh/m^3 - 3723kWh/m^3}{5108kWh/m^3} = 0.729 \tag{6}$$

6 Conclusion

In conclusion, the battery dimensioning for the Renault Zoe has been a challenging yet rewarding process. The design aimed to optimize the balance between performance, safety, and efficiency, focusing on factors like voltage, energy, and cell configuration. The intricacies of selecting the right cell type has been explored, opting for LG Chem's E63 lithium-ion pouch cell, and the optimal layout, which is a 10-module series connection with a 11s2p configuration.

However, one of the main challenges was meeting the energy density goals while maintaining the structural integrity and thermal stability of the battery. Thermal management, in particular, was crucial due to the high operating temperatures of lithium-ion batteries. The use of a passive indirect liquid cooling system with a cold plate was selected to manage these temperatures, but further optimization could involve alternatives like graphite for better heat conduction.

Moreover, the volumetric and gravimetric energy densities, which are critical for vehicle range and efficiency, showed room for improvement. The system's energy density could be enhanced by refining the battery layout, such as possibly eliminating the cooling plate to free up more space, though this would require advanced thermal management techniques.

The calculated efficiencies of the gravimetric and volumetric energy densities showed that there is potential for improvement, with values of 77.8% and 72.9%, respectively. Thus, while the current design meets the specifications, there are still avenues for optimization in terms of both mass and volume efficiency.

In summary, the design is a solid foundation for the battery pack of the Renault Zoe, but ongoing research and innovation in thermal management, material selection, and battery chemistry could make the system more efficient and cost-effective in future iterations.