PSIM

TUTORIAL
Lithium-Ion Battery Model

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This tutorial describes how to use the lithium-ion battery model.

Some battery model parameters can be obtained from manufacturer datasheets, while others need to be obtained by trial-and-error. This tutorial describes how to obtain these parameters.

The parameters needed by the model are:

N_s	No. of cells in series
N_p	No. of cells in parallel
K_s	Voltage derating factor
K_p	Capacity derating factor
E_{rated}	Rated voltage, in V
E_{cut}	Discharge cut-off voltage, in V
Q_{rated}	Rated capacity, in Ah (ampere-hour)
R_{batt}	Internal resistance, in Ohm
I_{dischg}	Discharge current of the curve under which model parameters are obtained, in A
K_c	Capacity factor
E_{full}	Full (or maximum) battery voltage, in V
E_{top}	Exponential point voltage (voltage at the end of the exponential zone), in V
E_{nom}	Nominal voltage, in V
Q_{max}	Maximum capacity corresponding to the discharge cut-off voltage E_{cut}, in Ah
Q_{top}	Exponential point capacity (capacity at the end of the exponential zone), in Ah
Q_{nom}	Nominal capacity, in Ah
SOC	Initial state-of-charge

Parameters E_{rated}, E_{cut}, and Q_{rated}, can be directly read from manufacturer datasheet. Some other parameters can be obtained from the battery discharge curve.

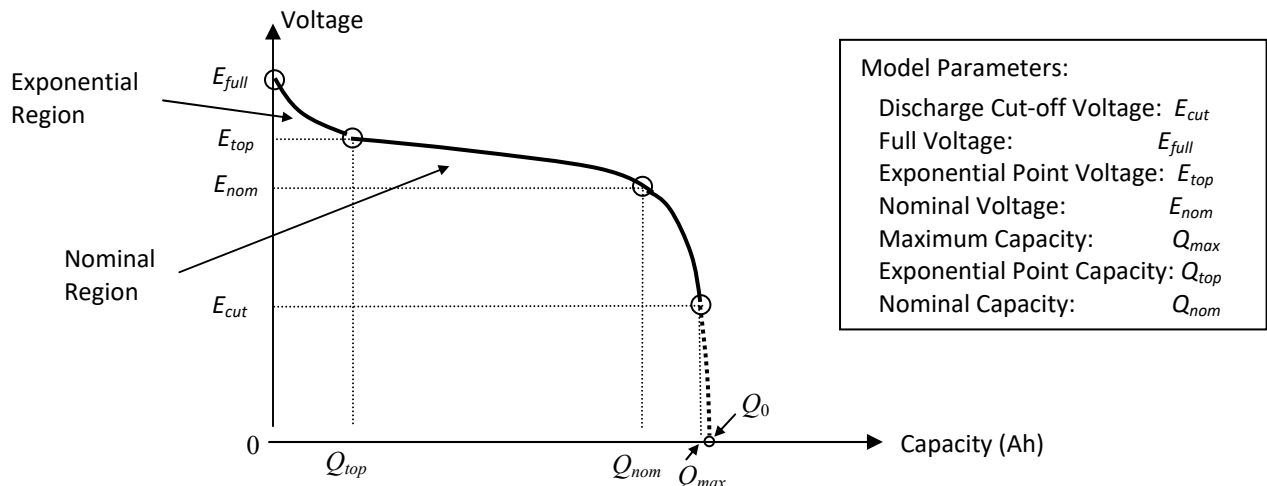A typical discharge curve is shown in Figure 1.

Fig. 1: Typical battery discharge curve

From a specific discharge curve, one can read values of E_{full}, E_{top}, E_{nom}, Q_{top}, Q_{nom}, and Q_{max}. Note that the values of E_{top}, Q_{top}, E_{nom}, and Q_{nom} are not exact as the transition points are often not defined exactly. One may try different values to obtain a better fit of the model characteristics to the actual characteristics.

The capacity factor is roughly the ratio between Q_0 (the capacity at 0V) and Q_{max}. It is a value close to 1, and it needs to be adjusted such that the battery voltage is equal to E_{cut} when SOC=0.

For parameters that are not provided in the datasheet, one may ask manufacturers for the information or make an initial guess and adjust it by trial-and-error.

In this tutorial, the rechargeable lithium-ion battery VL34570 from Saft is used to illustrate how to define the parameters to fine tune the battery model. The process involves the following steps:

- Enter the information from the datasheet.

- Make an initial guess of certain parameters from the discharge curve of the datasheet.

- Obtain the discharge and charge curves. Compare with the datasheet and experimental data for different operating conditions, and fine tune the parameters.

1. Entering Datasheet Information

Fig. 2 shows the image of the example manufacturer datasheet.

The first step is to obtain a battery profile based on the datasheet. The number of cells in the stack, as well as the derating factors are all set to 1 as the default.

Fig. 2: Saft VL-34570 Rechargeable lithium-ion battery electrical characteristics

The battery rating parameters can be read directly from the manufacturer's datasheet.

E$_{rated}$ = 3.7 V
Q$_{rated}$ = 5.4 Ah
E$_{cut}$ = 2.5 V

In this case, the datasheet does not provide the battery internal resistance. One may make an initial estimate from other Lithium-Ion batteries of similar ratings. We will assume the battery internal resistance as R_{batt} = 0.065 Ohm.

2. Estimating Parameter Values from the Discharge Curve

The discharge curve of the battery from the datasheet is shown below. From the discharge curve, one may make the initial estimate the parameters.
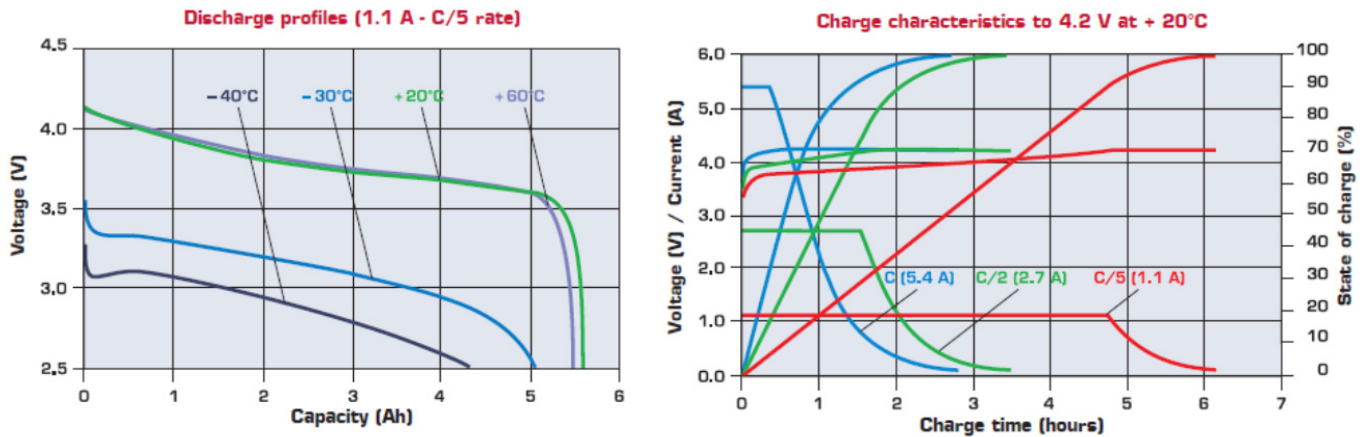

Fig. 3: Discharge and charge profile of the Saft VL34570 rechargeable lithium-ion battery

Using the +20° temperature discharge curve (1.1A), we have the initial readings of the following parameters:

E_{full} = 4.2 V	[full (maximum) battery voltage]
E_{top} = 3.75 V	[values at the point where the exponential zone ends]
Q_{top} = 2.5 Ah	
E_{nom} = 3.6 V	[values at the point where the nominal zone ends]
Q_{nom} = 5.2 Ah	
Q_{max} = 5.6 Ah	[capacity at the cut-off voltage of 2.5V]

The capacity factor K_c is set to 1.02. Note that except E_{full} and Q_{max}, these values are approximate. One should adjust these parameters to better fit the simulated curves with the datasheet curves or experimental results.

3. Fine Tuning the Parameters

Once the parameters are obtained, one can set up circuits to test the charging and discharging characteristics. A discharge test circuit is shown below.
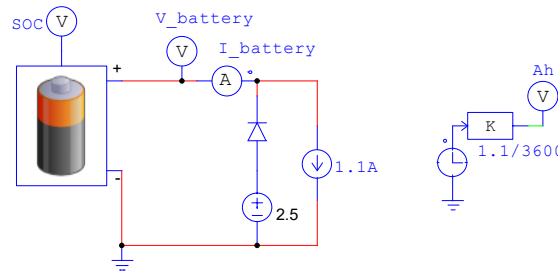

Fig. 4: A battery discharge test circuit

The circuit uses a 1.1A current source to discharge the battery that has a initial state of charge of 1. The time, in sec., is divided by 3600 to convert to hour and is multiplied to the 1.1A current to obtain the capacity Ah.

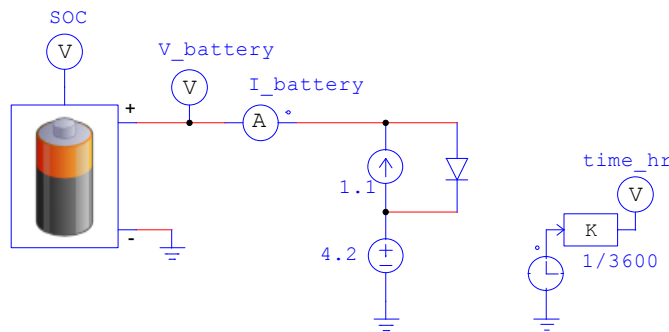A charge test circuit is shown below.

Fig. 5: A battery charge test circuit

Usually an actual battery charge circuit consists of control circuitry that regulates the charge current and battery voltage. The circuit above is an oversimplified version of a practical circuit.

The charge process consists of two stages: constant-current charging and constant-voltage charging. In the initial charging stage, the charging current is limited to 1.1A. When the voltage is close to the full voltage of 4.2V, it is constant-voltage charging.

Fig. 6 shows the simulation results of the discharging and charging characteristics based on the initial set of parameters.
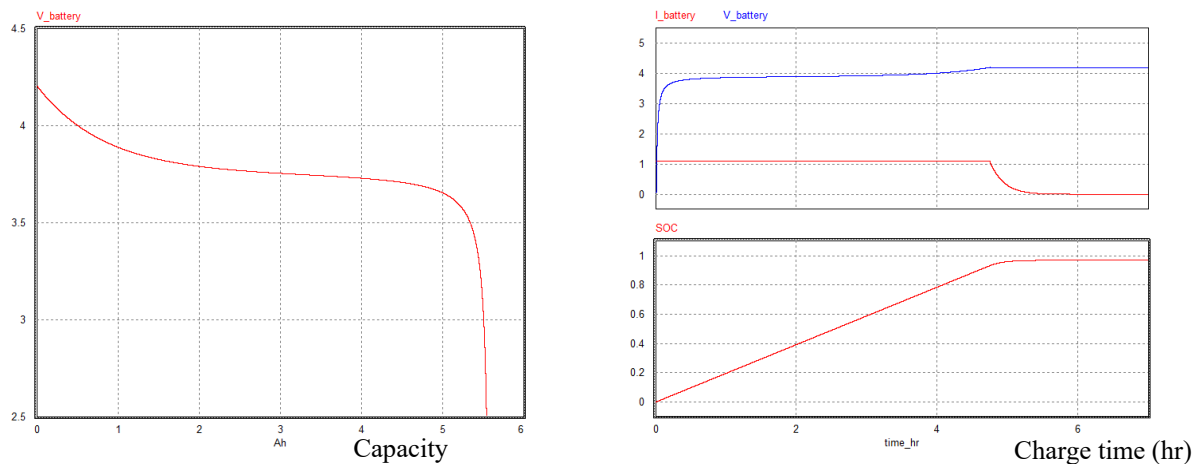

Fig. 6: Simulation results of the discharging and charging characteristics

From the inspection of the simulated discharge and charge curves, one can observe the followings:

- On the discharge curve, the turning corner at the end of the nominal zone is more rounded than the datasheet profile.

- On the charge curve, the state of charge (SOC) stays at around 0.97 (97%) while the voltage has reached the fully charged value. Also, the charge current is reduced to 0 at a faster rate than in the datasheet. This could be due to the oversimplified charge circuit.

Ideally, when charging the battery, the internal battery voltage should reach the maximum value when the state of charge (SOC) reaches 100%. When discharging the battery, the SOC would reach zero (0%) when the voltage is decreased to zero.

Some parameters may need to be adjusted to better fit the simulation curves with the datasheet curves.

Here are a few ways to adjust the parameters:

- Adjust the "top" point where the exponential zone ends

  For the same Q_{top}, the reading of the value E_{top} from the datasheet is approximate. A slightly higher reading would slow down the voltage change rate, especially in the beginning of the charge/discharge process.

- Adjust the "nom" point where the nominal zone ends

  At the nominal voltage E_{nom}, the reading Q_{nom} on the datasheet curve is approximate. A slightly higher reading would slow down the voltage change rate.

- Adjust the maximum capacity

  The state of charge (SOC) is calculated against the maximum capacity Q_{max}. If the value Q_{max} is estimated too high, it would result a false situation that the battery is not fully charged (SOC < 100%) when the internal battery voltage reaches the maximum value.

Also, if the value Q_{max} is too high, or the value Q_{nom} is too low, the corner at the end of the nominal zone in the discharge curve would be more rounded. Otherwise, the corner will be sharper.

- Adjust battery internal resistance

  The battery internal resistance affects the charging curve if the battery charger is constant-current constant-voltage. A larger resistance would move the transition point from constant-current to constant-voltage to a lower voltage value, causing the charger to stop charging the battery before it is fully charged.

Note that one may need a few iterations to obtain a good fit to the datasheet or experimental results.

4. Multi-Cell Battery Stack

In many applications, multiple batteries are stacked together, either in series to obtain higher output voltage, or in parallel to obtain higher capacity, or both.

In these cases, one can simply specify the number of batteries in series or in parallel. If the derating factors are known, one can also specify them. Otherwise the default derating factors are 1 (i.e. no derating).