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# **PSIM Tutorial**

## **How to Use Lithium-Ion Battery Model**

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

Some of the battery parameters can be obtained from manufacturer datasheets, while other parameters need to be obtained by trial-and-error. This tutorial describes how to estimate and adjust these parameters through an example.

The parameters needed by the model are:

$N_s$	No. of cells in series
$K_s$	Voltage derating factor
$N_p$	No. of cells in parallel
$K_p$	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
$E_{full}$	Full (or maximum) battery voltage, in V
$E_{top}$	Exponential point voltage (voltage at the end of the exponential zone), in V
$Q_{nom}$	Nominal voltage, in V
$Q_{max}$	Maximum capacity, 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.

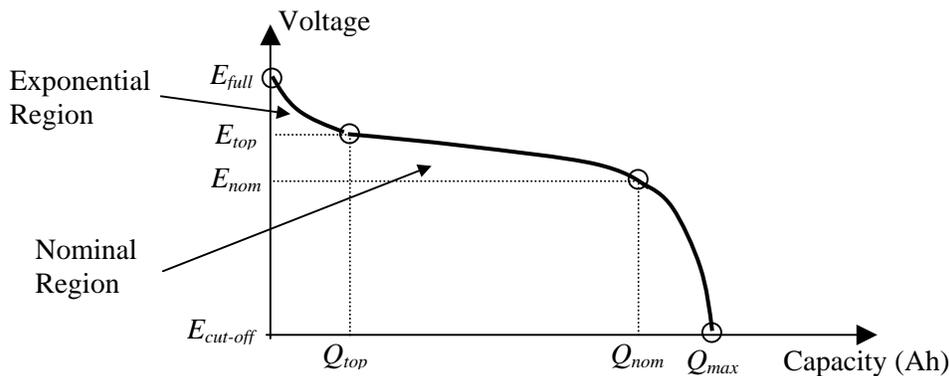


Fig. 1: Typical battery discharge curve

From the discharge curve, one can read values of  $E_{full}$ ,  $E_{top}$ ,  $E_{nom}$ ,  $Q_{top}$ ,  $Q_{nom}$ , and  $Q_{nom}$ . 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.

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.

Electrical characteristics	
Nominal voltage (under 1.1 A at 20°C)	3.7 V
Typical capacity (under 1.1 A at 20°C 2.75 V cut-off)	5.4 Ah
Operating conditions	
Charge method	Constant Current/ Constant Voltage
Maximum charge voltage	4.20 +/- 0.05 V
Maximum recommended charge current**	5.4 A (~C rate)
Charge temperature range*	- 20°C to + 60°C (- 4°F to +140°F)
Charge time at 20°C	To be set as a function of the charge current: C rate     ⇒ 2 to 3 h C/2 rate   ⇒ 3 to 4 h C/5 rate   ⇒ 5 to 7 h
Maximum continuous discharge current***	11 A (~2C rate)
Pulse discharge current	up to 21 A (~4C rate)
Discharge cut-off voltage	2.5 V
Discharge temperature range*	- 50°C to + 60°C (- 58°F to +140°F)

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

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

$$E_{rated} = 3.7 \text{ V}$$

$$Q_{rated} = 5.4 \text{ Ah}$$

$$E_{cut} = 2.5 \text{ V}$$

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  $R_{batt} = 0.05 \text{ Ohm}$ .

### 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.

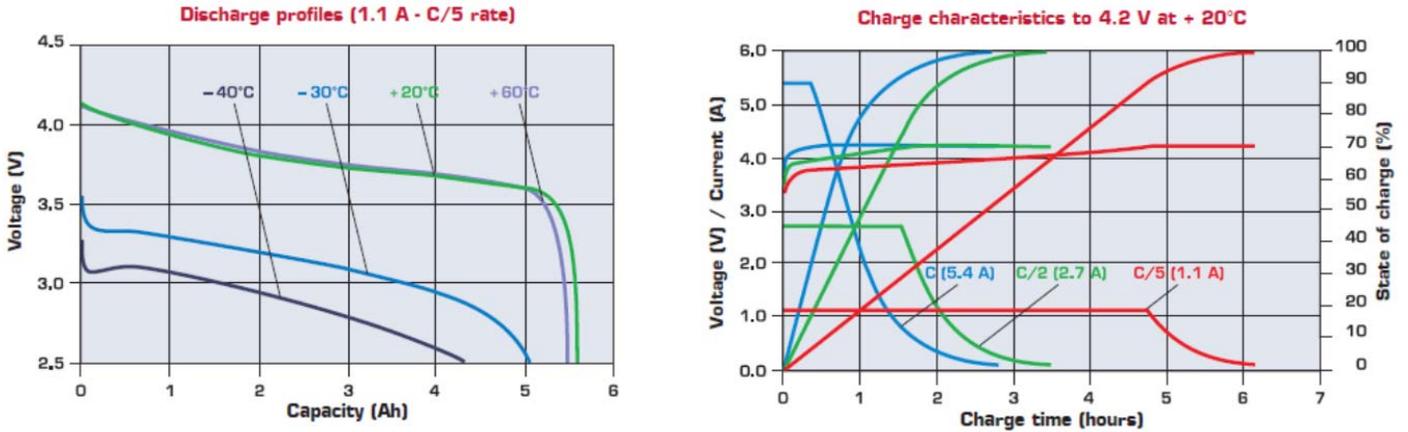


Fig. 3: Discharge and charge profile of the Saft VL34570 rechargeable lithium-ion battery  
 Using the +20° temperature discharge curve (1.1A), we have the initial readings of the following parameters:

$E_{full} = 4.2 \text{ V}$	[full (maximum) battery voltage]
$E_{top} = 3.9 \text{ V}$	[values at the point where the exponential zone ends]
$Q_{top} = 1.08 \text{ Ah}$	
$E_{nom} = 3.6 \text{ V}$	[values at the point where the nominal zone ends]
$Q_{nom} = 5.13 \text{ Ah}$	
$Q_{max} = 5.67 \text{ Ah}$	[capacity at the cut-off voltage]

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.

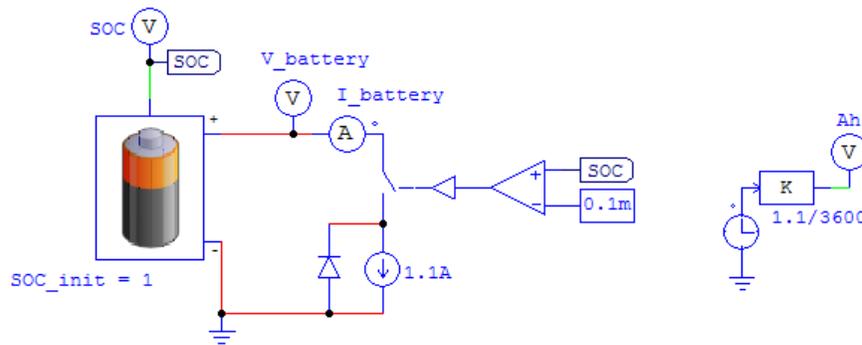


Fig. 4: A battery discharge test circuit

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.

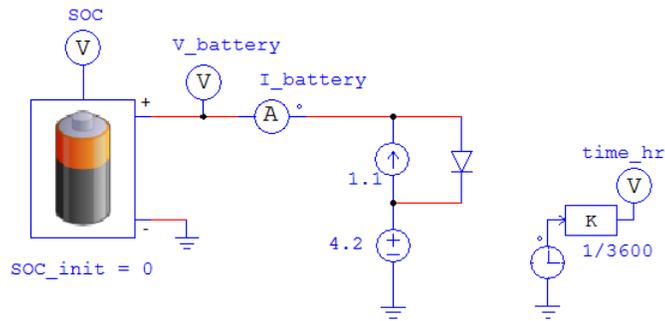


Fig. 5: A battery charge test circuit

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.

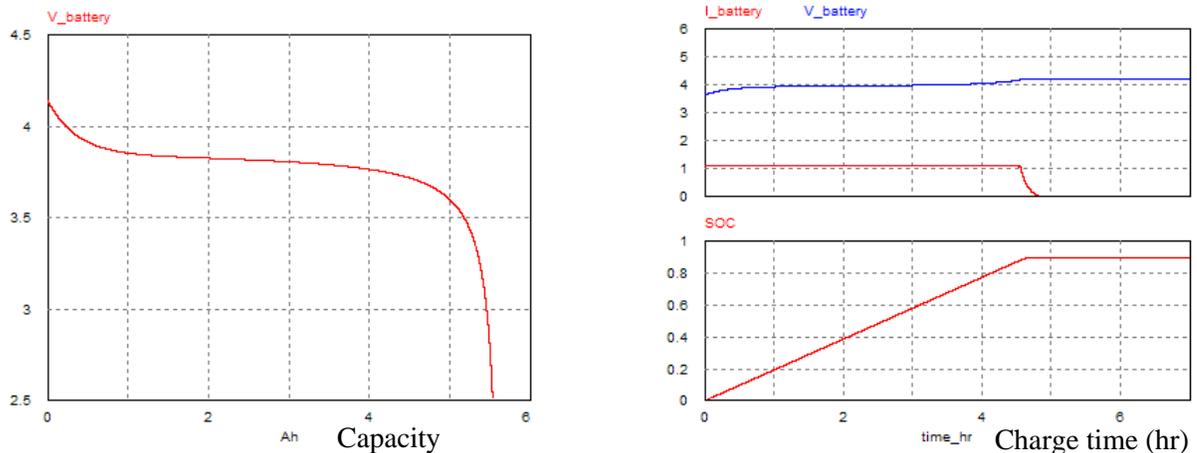


Fig. 6: Simulation results of the discharging and charging characteristics

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 0.9 (90%) 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%) before the voltage is decreased to the cut-off point.

The simulation results show that, with the initial parameter set, the battery voltage change rate is too fast or the SOC increase is too slow. Some parameters 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.

Based on these,  $Q_{nom}$  is slightly increased and  $Q_{max}$  is slightly decreased as follows:

$$Q_{nom} = 5.4 \text{ Ah}$$

$$Q_{max} = 5.56 \text{ Ah}$$

The discharge and charge curves obtained from this set of parameter are shown below.

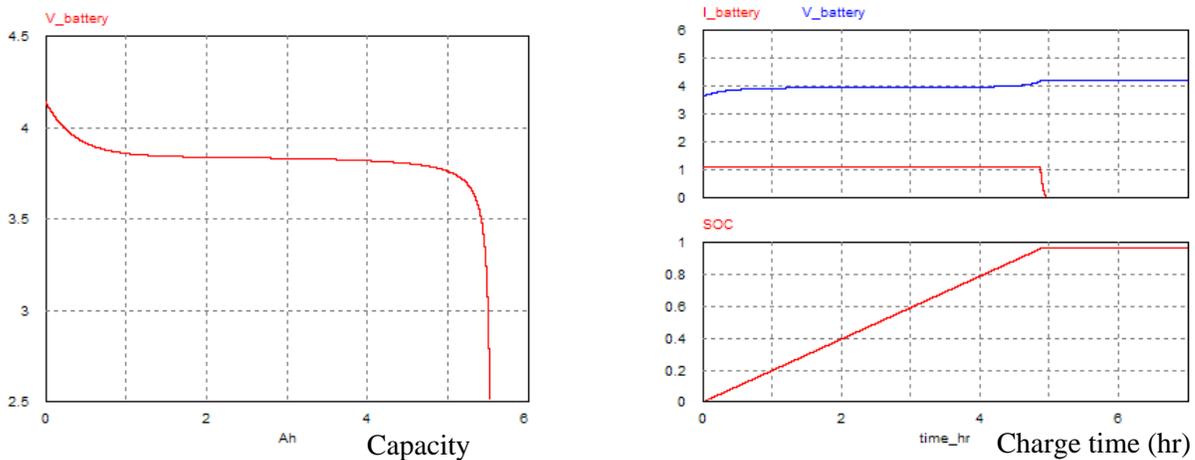


Fig. 7: Simulation results of the discharging and charging characteristics after parameter adjustment

These curves provide a better fit to the datasheet curves.

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

#### **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).