PSIM

TUTORIAL
Ultracapacitor Model

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This tutorial describes the ultracapacitor model. Unlike other models that are appropriate in simulating the charge/discharge process of a ultracapacitor in a short-to-medium period (in a few minutes), this model can model the charge/discharge process in a medium-to-long period (in hundreds of minutes).

The ultracapacitor model has the following parameters:

- Number of Cells in Series
- Number of Cells in Parallel
- Capacitance per Cell
- Coefficient K_v
- Resistance R_1
- Capacitance C_1
- Resistance R_2
- Capacitance C_2
- Resistance R_3
- Capacitance C_3
- Resistance R_4
- Maximum Voltage V_{rated}
- Initial Voltage

The parameters K_v, R_1, C_1, R_2, C_2, R_3, C_3, R_4, and V_{max} are all values for one cell.

The parameters K_v, R_1, and C_1 affect the short-term response (in seconds). The parameters R_2 and C_2 affect the short-to-medium term response (in minutes). The parameters R_3 and C_3 affect the medium-to-long term response (in hundreds of minutes). The parameter R_4 represents the losses due to capacitor self-discharge.

To determine the model parameters, information from the datasheet is needed. In addition, experimental measurement of the ultracapacitor voltage under a charging and discharging process is needed. The figure below shows the capacitor voltage V_c when it is charged by a constant current I_s from 0 to t_3, and at t_3, the charging current is removed.
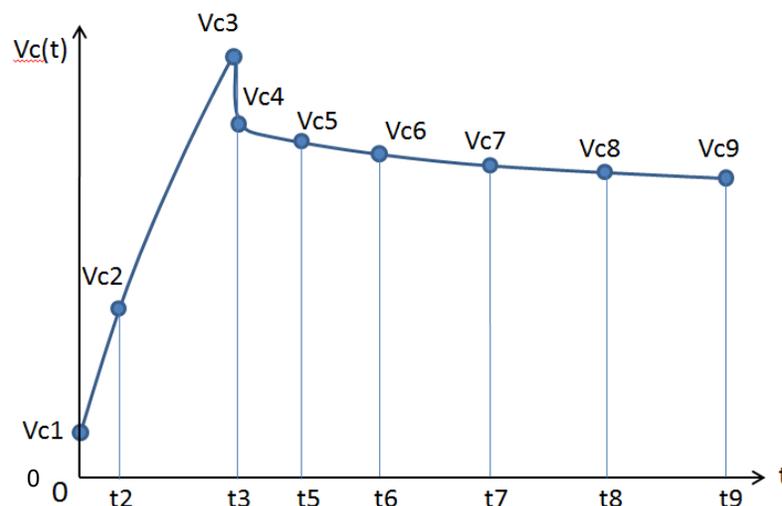
Parameters K_v, R_1, and C_1 are calculated based on the charging current and the capacitor voltage at 0, t_2 and t_3. Parameters R_2 and C_2 are calculated based on the capacitor voltage at t_3, t_5, and t_6. Parameters R_3 and C_3 are calculated based on the capacitor voltage at t_7, t_8, and t_9. The parameter R_4 is calculated from the datasheet using the leakage current.

Given the times and voltages as highlighted in the figure above, as well as the charge current, leakage current, and rated voltage, all the model parameters can be calculated. A tool called "Ultracapacitor Model Tool" is provided to calculate the model parameters.

Note that the parameters are for a single cell. When multiple cells are connected in series or in parallel, the model automatically takes into account the multiple cell configurations.

Ultracapacitor Model Tool

To facilitate the use of the ultracapacitor model, a parameter extraction tool called **Ultracapacitor Model Tool** is provided. It will do adjust the model parameters and do curve fitting so that simulated results match closely with the experimental data.

From the Utilities menu in PSIM, launch the tool, and the following window will appear:
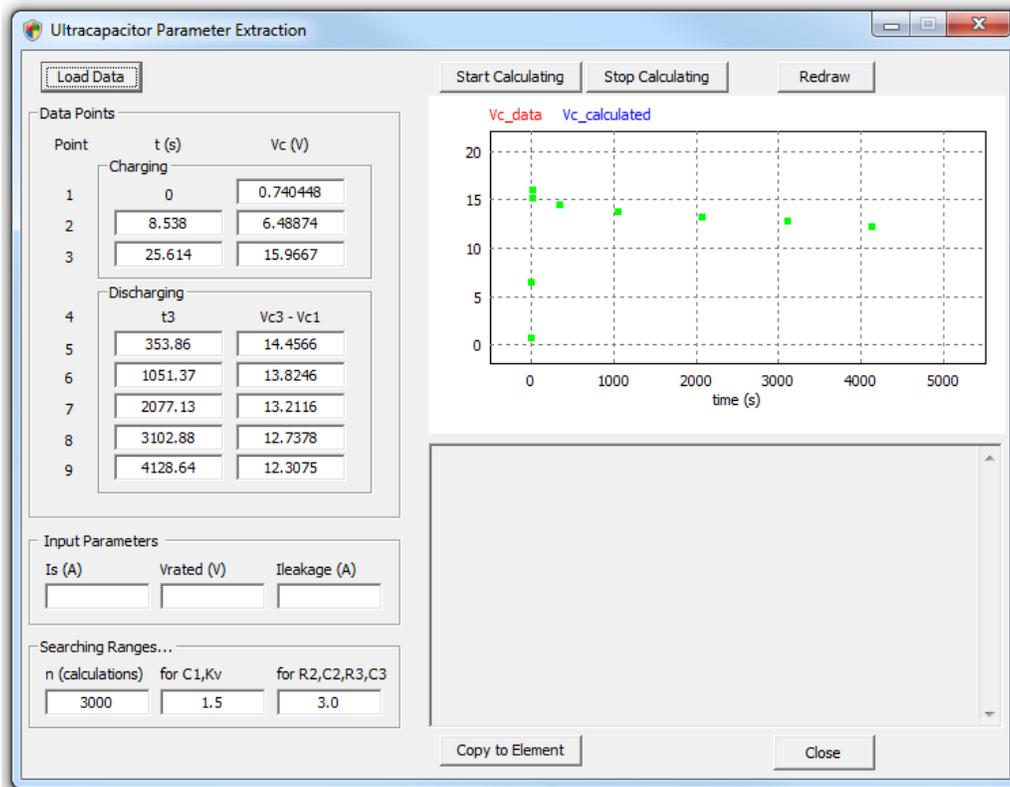
There are two ways to enter the experimental data. One way is to click on the button **Load Data** and load the experimental data from a text file. The file has the following format:

Time	Vc
0.1	0.76
0.2	0.78
0.3	0.80
… … …	

The labels in the first line "Time   Vc" are optional and can be omitted. It is ok that the first data point does not start from 0. If it does not start from 0, the tool will automatically shift the time so that the first point starts from 0.

Once the data is read, the tool will automatically determine the 9 points needed to do the curve fitting, and will load into the graph window and will be displayed as Vc_data in red.

Another way is to specify the 9 data points manually.

Beside the experimental data, one needs to specify the charging current I_s, the rated (or maximum) voltage V_{rated}, and the leakage current $I_{leakage}$.

The parameters under **Searching Ranges…** define the curve fitting calculation. For example, with the default setting, the calculation will perform at most 3000 iterations, from the current solution, parameters C1 and Kc will vary within 1/1.5 and 1.5 of the current solution, and parameters R2, C2, R3, and C3 will vary within 1/3 and 3 of the current solution for a new solution.

Once the data and parameters are entered, click on **Start Calculating** to start curve fitting. Results will be displayed in the window at the lower right, and calculated results will be plotted and compared with the experimental data. A key value to watch for is "Error(%)" which gives the curve fitting error.

Once satisfactory results are obtained, click on **Stop Calculating** to stop curve fitting. Record the model parameters. If the schematic of the ultracapacitor under study is open, one can copy the parameters automatically to the schematic by clicking on **Copy to Element**.

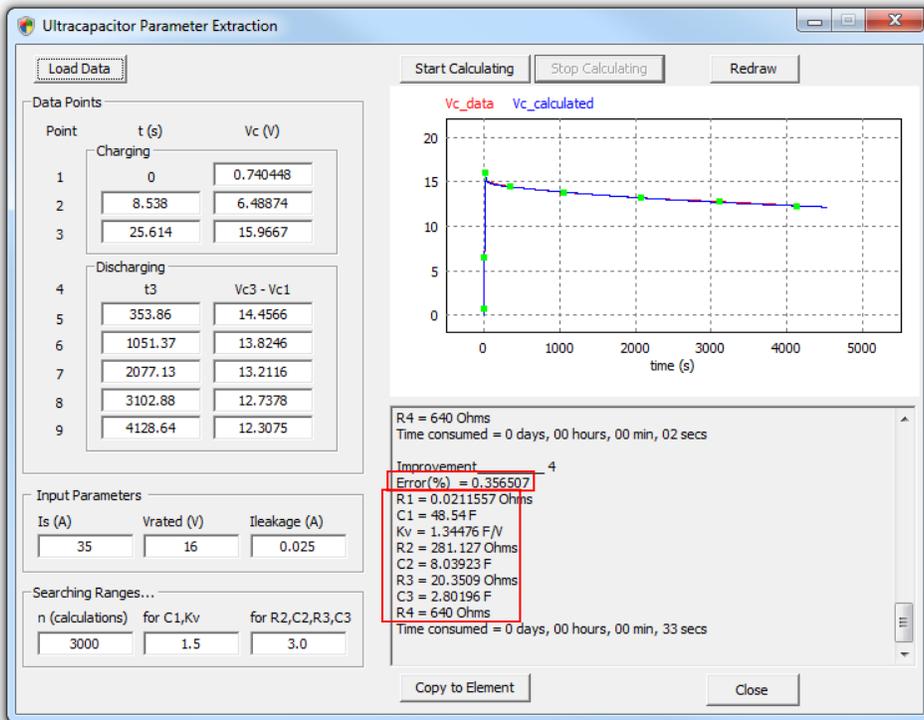**Example: Maxwell Ultracapacitor 58F 16V (model BMOD0058-E016-B0)**

The Maxwell 16V 58F ultracapacitor BMOD0058-E016-B0 is used as an example. From the manufacture datasheet, the following information is obtained:

Rated Capacitance:	58F
Rated Voltage:	16V
Leakage current at 25°C	25mA

Lab experiment of a single cell capacitor is conducted with a charge current of 35A. After the experimental data is loaded into the Ultracapacitor Model Tool, with the other parameters entered, the dialog window appears as follows. The experimental data is in red, and the 9 selected points are in green.
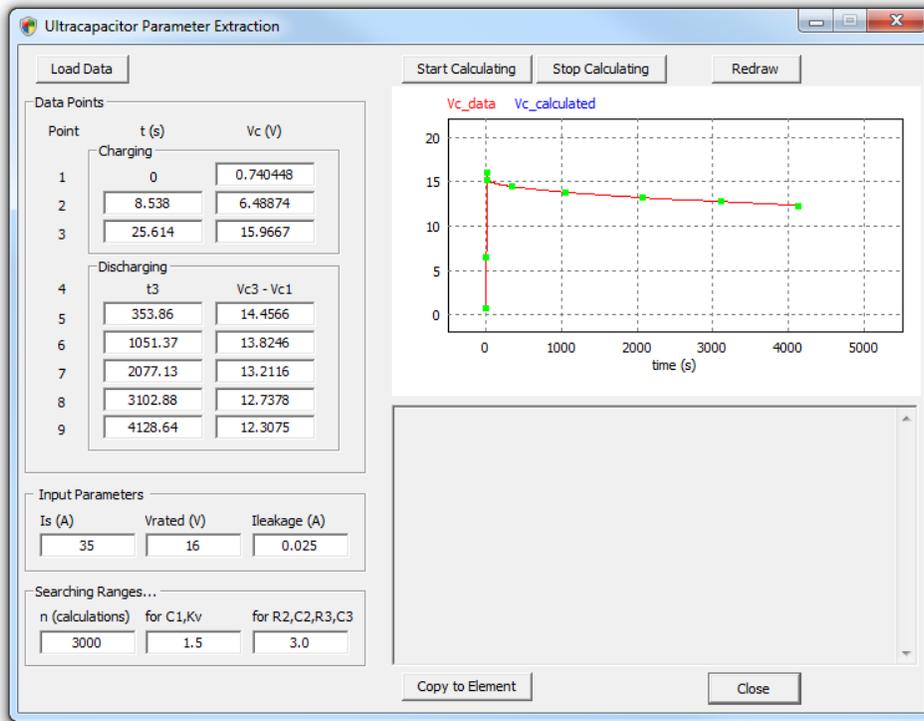
Click on **Start Calculating**. After less than a minute, the curve fitting error is around 0.36%. We would stop the calculation at this point. The dialog window is shown below.

A test circuit as shown below is set up to validate the model parameters obtained above.

The figures below show the comparison of the simulation result Vc_simu (in red) and the experimental result Vc_exp (in blue). The figure on the left shows the waveforms in the long range, and the figure on the right shows the close-up of the charging period and early discharging period.

It shows a very good match between the simulation result and the experimental result.

Other Ultracapacitor Model Parameters:

Model parameters of a few ultracapacitors are given below:

Maxwell ultracapacitor 3400F 2.85V (model BCAP-3400):

K_v = 772.923
R_1 = 0.00041
C_1 = 1763.49
R_2 = 1.2362
C_2 = 142.89
R_3 = 7.9553
C_3 = 333.922
R_4 = 158.333

Maxwell ultracapacitor 1200F 2.7V (model BCAP-1200):

K_v = 276
R_1 = 0.0103
C_1 = 890
R_2 = 1.7
C_2 = 86.4
R_3 = 12.1
C_3 = 150
R_4 = 1000

Epcos ultracapacitor 110F 2.7V (charging current 10A):

K_v = 29.11
R_1 = 0.01
C_1 = 89.03
R_2 = 17.5
C_2 = 13.72
R_3 = 1e6
C_3 = 1e-9
R_4 = 5000

Epcos ultracapacitor 200F 2.7V (charging current 10A):

K_v = 56.25
R_1 = 0.0089
C_1 = 158.05
R_2 = 8.77
C_2 = 27.55
R_3 = 1e6
C_3 = 1e-9
R_4 = 5000

Epcos ultracapacitor 350F 2.7V (charging current 25A):

K_v = 89.86
R_1 = 0.0048
C_1 = 232.52
R_2 = 5.56
C_2 = 43.19
R_3 = 1e6
C_3 = 1e-9
R_4 = 2500

Epcos ultracapacitor 600F 2.7V (charging current 33A):

K_v = 176.48
R_1 = 0.0028
C_1 = 454.49
R_2 = 3.1
C_2 = 77.44
R_3 = 1e6
C_3 = 1e-9
R_4 = 2500