**Battery Model in PSCAD/EMTDC**

Secondary electrochemical batteries (rechargeable batteries) are of great importance in power systems because they give the electric engineer a means for storing small quantities of energy in a way that is immediately available. Some of the main battery uses are:

* Batteries within Uninterruptable Power Supplies (UPS)
* Battery Energy Storage System (BESS) to be installed in power grids with the purpose of compensating active and reactive power (in this sense they are an extension of the SVCs, and therefore are sometimes called also SWVCs).
* Batteries of the main energy source of electric vehicles.

There are many types of batteries and many factors that affect battery performance. To predict the performance of batteries, different mathematical models exist. None of them are completely accurate nor do any include all necessary performance effecting factors.

This report introduces a battery component in PSCAD/EMTDC which is based on electrochemical battery model and tabulated battery data models. It includes the following sections:

* A brief introduction of the electrical characteristic of batteries
* The general battery component in PSCAD/EMTDC
* Example case to validate the component

**1. Electrical characteristics of batteries**

The main characteristics of battery are the charge and discharge characteristics. The discharge characteristic is shown as follow:

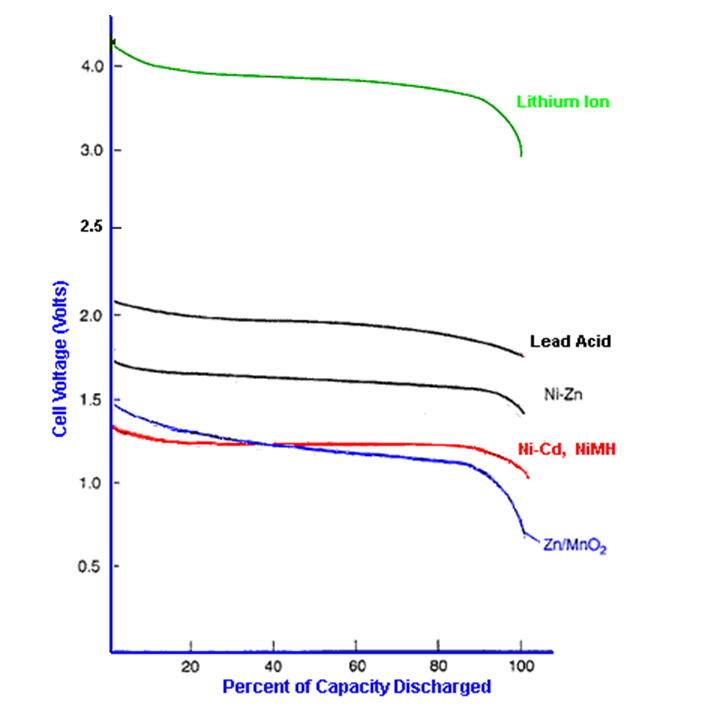


Figure Discharge characteristic of batteries

The charge characteristic has a very similar shape to that of discharge. For low C-rate charge and discharge currents, if superimposed, the two curves are almost the same (Figure. 2). Hence for the purposes of most system studies, the charge and discharge characteristic can be described by the same equation if the battery hysteresis effect is neglected.

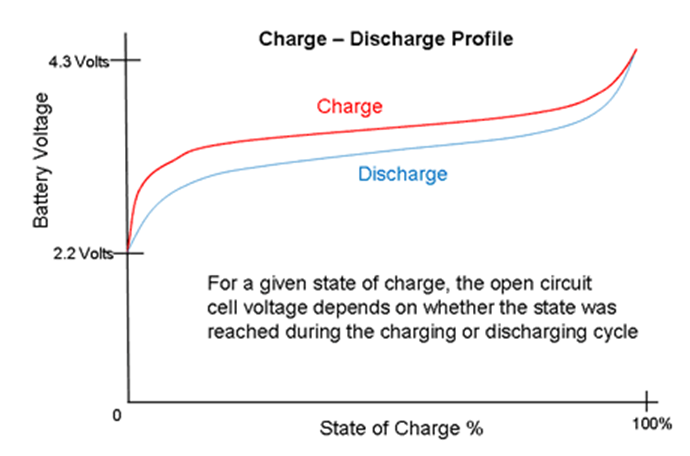


Figure Charge and discharge characteristic of batteries

The important terminology of batteries:

1. Rated capacity: the ampere-hours a fully charged battery can deliver at a specified rate (C/5 or C/20 rates are typically used here)
2. Nominal voltage: The voltage of the battery under normal operating conditions.
3. State of charge (SOC): An expression of the present battery capacity as a percentage of maximum capacity.
4. Charging rate (C rate): the amount of current that a battery can deliver for 1 hour from fully charged to the end of life. For a 100 Ah battery, 1C means the discharging current is 100A, 0.2C means 20A, 5C means 500A
5. Internal resistance: the Thevenin resistance within the battery

**2. Battery model in PSCAD/EMTDC**

The battery model created for PSACD is based on the method proposed in IEEE paper [1]. This method is a general approach in which an ideal controlled voltage source in series with a resistance is used to model the battery. At every time step the voltage of the controlled voltage source is computed based on the state of charge of the battery using two different methods.

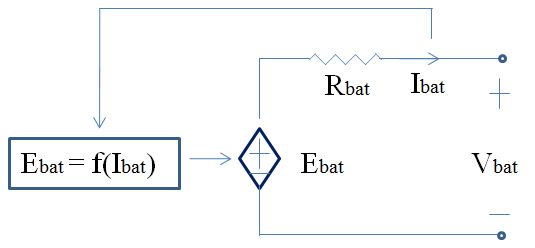


Figure 3 Equivalent circuit of batteries

The first method is based on a non-linear equation shown in Figure 4 that uses the actual state of the battery to calculate the no load voltage and the value of the resistance is assumed to be constant.



Figure 4 Non-linear battery model

In this equation:

*E*  No-load voltage (V)

*E0* Battery constant voltage (V)

*K* Polarization voltage (V)

*Q* Battery capacity (Ah)

 Actual battery charge (Ah)

*A* Exponential zone amplitude (V)

*B* Exponential zone time constant inverse (*Ah*)*−*1

*vbat*  Battery voltage (V)

*Rbat* Internal resistance (Ω)

*ibat* Battery current (A)

The battery voltage equation can be modified as follows in order to be expressed in terms of SOC instead of *it:*



This model is based on a few simplifying assumptions and has some limitation.

*1) Model assumptions:*

* During the charge and discharge cycles, the internal resistance is assumed to be constant.
* The amplitude of the current does not have any effect on the internal resistance
* The discharge characteristics curve of the battery is used to derive the battery parameters, since the discharge and charge characteristics are assumed to be the same.
* The amplitude of the current does not have any effect on the capacity of the battery (No Peukert effect).
* The temperature doesn’t change the model’s behavior.
* The Self-Discharge of the battery is not represented.
* Charge and discharge history does not affect battery characteristics (ie. No hysteresis)

*2) Model limitations:*

* The battery voltage cannot be negative and the maximum battery voltage is not limited.
* The capacity of the battery cannot be negative and the maximum capacity is not limited.

Therefore, if the battery is overcharged, the maximum SOC can be greater than 100%.

**2.1 Model parameters**

**Internal resistance:** Although the manufacturer provides the battery internal resistance in the datasheet, it is possible to calculate that based on the efficiency of the battery. Since the output voltage and consequently the efficiency of the battery is affected by internal resistance, therefore the internal resistance can be derived using the efficiency equation based on nominal voltage and rated capacity:



Assuming 

Then:



Based on ref [1], the best approximation for the efficiency of a 1.2 volts cell is 99.5% on average.

Other parameters of the battery can be derived using three points on the discharge curve available in the manufacturer’s datasheet of the battery. As shown in figure 5, the first point is the battery voltage where it is fully charged, the second one is the voltage and charge at the end of the exponential zone and the third one is voltage and charge at the end of the nominal zone.



Figure 5 Typical discharge curve at nominal current

The exponential part is calculated with the first two points as follows:

A: voltage drop during the exponential zone (V)



3/(B): Charge at the end of exponential zone (Ah)



The fully charged voltage (*EFull*) and the third point (End of nominal zone: *QNom* and *ENom*) can be used to calculate the polarization voltage *K*:



Then, the voltage constant *E*0 is deduced from the fully charged voltage:



This is a general approach to extract the model parameters of any battery types. However in this method the precision of the model parameters depends on the points chosen from the discharge curve.

There are four main cell chemistries in use for rechargeable batteries: [lead-acid](http://en.wikipedia.org/wiki/Lead-acid_cell), [nickel-cadmium](http://en.wikipedia.org/wiki/Nickel-cadmium_battery) (Ni-Cd), [nickel metal hydride](http://en.wikipedia.org/wiki/Nickel_metal_hydride_battery) (Ni-MH), and [lithium-ion](http://en.wikipedia.org/wiki/Lithium_ion_battery) (Li-ion). The discharge characteristics curve of each types are shown in Ref [1]. According to MATLAB (with an average efficiency of 99.5%) in order to form the voltage equation of these batteries, the model parameters can be obtained using Table 1.

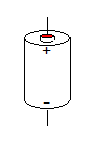
Table Battery parameters

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Fully charged voltage(% of nominal voltage) | Nominal discharge current(% of rated capacity) | Internal resistance | Nominal Capacity (% of rated capacity) | Exp voltage  current(% of rated capacity) | Exp capacity  Capacity (% of rated capacity) |
| Lead-Acid | 108 | 5 |  | 50 | 102.5 | 0.086 |
| Lithium-Ion | 116 | 20 |  | 98 | 103 | 85 |
| Nickel-Cadmium | 115 | 20 |  | 95 | 103 | 40 |
| Nickel-Metal-Hydride | 117 | 20 |  | 80 | 105 | 20 |

In PSCAD, the second method of battery modeling is using characteristics curves of the battery to compute the value of the controlled voltage source and internal resistance based on the actual state of charge of the battery. In this method SOC-voltage and SOC-Resistance curves are required to model the battery.

**2.2 The battery component in PSCAD**

The battery component in PSCAD is shown as bellow:



In this model + and – are the terminals of the battery. The data entry for this model can be either general user defined or characteristic curves as explained earlier. The internal output variables of the battery are the battery state of charge, voltage (kV) and current (kA).

## Input Parameters

Battery

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Battery Name |  | Text |  | Just an identifier. A name should be entered here to avoid compilation warnings. |
|  |  |  |  |  |
| Data Entry |  | Choice |  | Select **General User-Defined** or **Characteristics curves** |
|  |  |  |  |  |
| Nominal Voltage |  | REAL | Constant | Enter the nominal voltage of the battery [kV]. |
|  |  |  |  |  |
| Rated Capacity |  | REAL | Constant | Enter the rated capacity of the battery [kAh] |
|  |  |  |  |  |
| Initial State of Charge |  | REAL | Constant | Enter the initial state of charge of the battery (%) |
|  |  |  |  |  |
| Is this Battery Grounded |  | Choice |  | Select **YES** to connect this battery to the ground |
|  |  |  |  |  |

General Data Entry

NOTE: These properties are only enabled if Data Entry is set to **General User-Defined**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Fully Charged Voltage |  | REAL | Constant | Enter the fully charged voltage of the battery [kV]. |
|  |  |  |  |  |
| Nominal Capacity |  | REAL | Constant | Enter the nominal capacity of the battery [kAh]. |
|  |  |  |  |  |
| Internal Resistance |  | REAL | Constant | Enter the internal resistance of the battery [ohm]. |
|  |  |  |  |  |
| Nominal Discharge Current |  | REAL | Constant | Enter the nominal discharge current of the battery [kA] |
|  |  |  |  |  |
| Voltage at Exponential Point |  | REAL | Constant | Enter the voltage at exponential point [kV] |
|  |  |  |  |  |
| Capacity at Exponential Point |  | REAL | Constant | Enter the capacity at exponential point [kAh] |

Discharge Curve of Battery voltage

NOTE: These properties are only enabled if Data Entry is set to **Characteristics curves**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SOC point 1 |  | REAL | Constant | Enter the SOC of the first point in battery voltage curve[%] |
|  |  |  |  |  |
| Voltage point 1 |  | REAL | Constant | Enter the voltage of the first point in battery voltage curve[kV] |
|  |  |  |  |  |
| (SOC, Voltage)  Point# |  | REAL | Constant | Enter the remaining points of the battery voltage curve |

Discharge Curve of Internal Resistance

NOTE: These properties are only enabled if Data Entry is set to **Characteristics curves**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SOC point 1 |  | REAL | Constant | Enter the SOC of the first point in battery internal resistance curve[%] |
|  |  |  |  |  |
| R point 1 |  | REAL | Constant | Enter the resistance of the first point in battery internal resistance curve[ohm] |
|  |  |  |  |  |
| (SOC, R) Point# |  | REAL | Constant | Enter the remaining points of the battery voltage curve |

Output Internal Variables

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| State of Charge |  | REAL | Output | Name for state of Charge of the battery [%] |
|  |  |  |  |  |
| Battery current |  | REAL | Output | Name for the battery current [kA] |
|  |  |  |  |  |
| Battery voltage |  | REAL | Output | Name for the battery voltage [kV] |

**3. Model Example**

An example case is developed in order to test the charge and discharge process of the battery model. In this example a 120V, 6.5 Ah Nickel-Cadmium battery is used. In MATLAB, the discharge characteristics of this battery at nominal current and [6.5A, 13A, 32.5A] are shown in figure 6

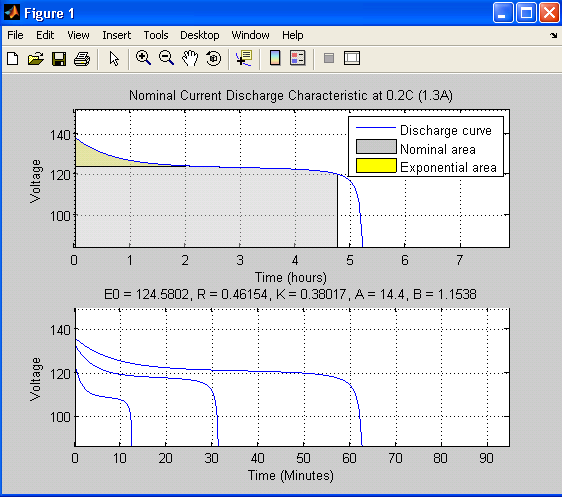


Figure discharge characteristics of MATLAB battery

The discharge characteristics of the same battery in PSCAD are presented in the following figures.



Figure Discharge characteristics at nominal current in PSCAD



Figure Discharge characteristics at 6.5A,13A,32.5A in PSCAD

In this example case a constant resistive load in parallel with a DC machine is connected to a 120V, 6.5Ah battery. The battery SOC is supposed to be between 40% and 80%. Therefore whenever the SOC is less than 40% in order to charge the battery a negative load torque is applied to the machine to force it to operate as a generator and provide the power for the load and the battery. Moreover, when the battery is charging as soon as the SOC reaches 80% then the machine operates as a motor to discharge the battery. The battery current can be controlled or limited by changing the load torque of the DC machine.

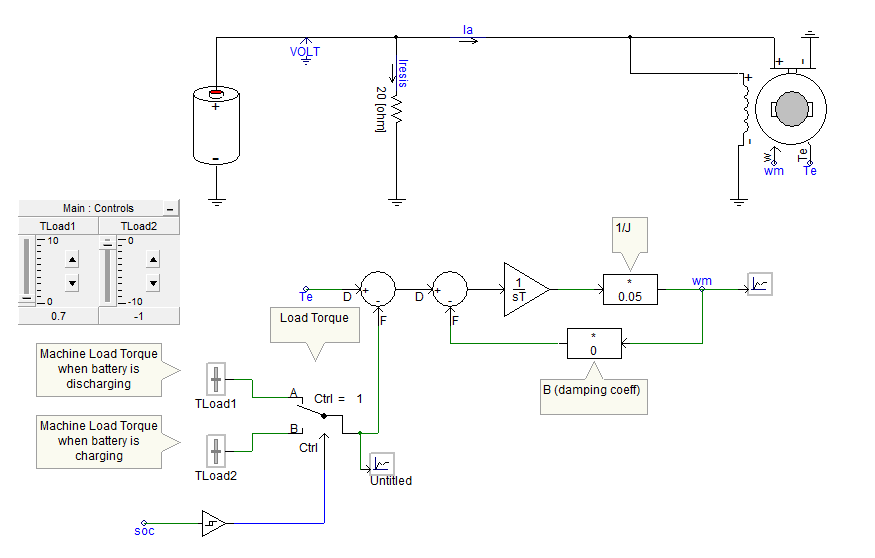


Figure Battery model example case in PSCAD (This case is similar to MATLAB battery example case.)



Figure charging and discharging process

Figure 9 and figure 10 show the circuit and the simulation results of charging and discharging process respectively.References

[1] Tremblay, O.; Dessaint, L.-A.; Dekkiche, A.-I.; , "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles," *Vehicle Power and Propulsion Conference, 2007. VPPC 2007. IEEE* , vol., no., pp.284-289, 9-12 Sept. 2007

[2] SimPowerSystems (MATLAB 2007) help