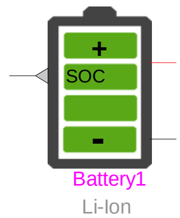
Battery



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1 Introduction

This device is a battery model. The battery is modelled as a controlled voltage source where the battery voltage and the State Of Charge (SOC) output given in % are calculated with control blocks according to the type of battery.

The development of this model is based on the references [1]-[7]. See also the list of references in the main reference [3].

2 Parameters

- **Battery type** Li-Ion, NiMH, NiCD, Lead-Acid.
- **Nominal voltage E_0** No-load voltage of the battery when fully charged, in V.
- **Initial state-of-charge SOC_0** State Of Charge at t=0 in %. Should not be greater than 100%.
- **SOC_{min}** Minimum state of charge in %
  Below this threshold, the battery cannot provide energy.
- **Nominal capacity Q_n** Nominal capacity of the battery in Ah.
- **Internal resistance R**
  Internal (series) resistance of the battery, in ΩAh/V. It is converted to Ohms using the base **E_0/Q_n**.
- **Self-discharge constant k_{sd}** Used to calculate parallel resistance, in %/day.

- **Exponential zone amplitude A** Amplitude of the hysteresis phenomenon, in pu, see [3]-[5]. The pu base is **E_0**.
- **Exponential zone constant B**
  Constant of the exponential zone used in the calculations of the hysteresis, in $(Ah)^{-1}$, see [3]-[5].
- **Polarization constant K**
  Models the phenomenon of nonlinear variation of open-circuit voltage (OCV), in pu. The pu base is **E_0/Q_n**.
- **Filter time-constant T_r** Constant (s) used in the transfer function of the current filter which is used for multiple other calculations such as the charge and discharge equations. The usage of filtered current is supported by experimental results that demonstrate a slow response to current.
- **Discharge time to obtain nominal capacity**
  This constant (hours) represents the time required to reach **Q_n**.

- **Peukert coefficient a**: Coefficient used to model the decrease of a battery's capacity with the rise of the discharge rate, also known as the Peukert effect.

The complete circuit model can be viewed by opening the subcircuit of this device.

3 Model equations

The model series resistance R_s is found from:

$$R_s = R\frac{E_0}{Q_n}$$

where R is input data in ΩAh/V.
The parallel resistance is found from:

$$R_p = 100\frac{E_0}{\frac{k_{sd}Q_n}{24}}$$

where k_{sd} is the self-discharge constant.
The SOC signal is calculated as follows in %:

$$SOC = 100\left(1-\frac{it}{Q_n}\right)$$

Each battery type is modeled by a unique combination of charge and discharge expressions. The battery is modeled as a controlled voltage source with the voltage v found from the battery type.

- The Lead-Acid battery:

Discharge: $v = E_0 - K\frac{Q_a}{Q_a-it}i^* - K\frac{Q_a}{Q_a-it}it + Exp(t)$

Charge: $v = E_0 - K\frac{Q}{it+0.1Q_a}i^* - K\frac{Q_a}{Q-it}it + Exp(t)$

- The Lithium-Ion battery:

Discharge: $v = E_0 - K\frac{Q_a}{Q_a-it}i^* - K\frac{Q_a}{Q_a-it}it + Ae^{-Bit}$

Charge: $v = E_0 - K\frac{Q_a}{it+0.1Q_a}i^* - K\frac{Q_a}{Q_a-it}it + Ae^{-Bit}$

- The Nickel-Cadmium and Nickel-Metal-Hydride battery:

Discharge: $v = E_0 - K\frac{Q_a}{Q_a-it}i^* - K\frac{Q_a}{Q_a-it}it + Exp(t)$

Charge: $v = E_0 - K\frac{Q_a}{|it|+0.1Q_a}i^* - K\frac{Q_a}{Q_a-it}it + Exp(t)$

Where:

- v is battery voltage
- i is battery current
- E_0 is the no-load voltage when fully charged
- K is the Polarization constant, it is given in pu and converted into V/Ah using the base E_0/Q_n. It is noticed that this conversion is not valid for resulting into Volts for all sections of the above equations. It is based on existing references and will be investigated further in a future EMTP release.
- i^* is the lower frequency component of the battery current, after the low pass filter with a time-constant T_r:

$$\frac{1}{T_r s + 1}$$

- it is the battery capacity in Ah
- Q_a is the maximum capacity calculated by the Peukert model:

$$Q_a = Q_n\left(\frac{Q_n}{ni}\right)^{a-1}$$

- n is discharge time of the battery to obtain nominal capacity
- Q_n is nominal capacity of the battery in Ah
- a is the Peukert coefficient

- Exp function is defined as follows:

$$\frac{dExp(t)}{dt} = B|i|[-Exp(t) + Au(t)]$$

- B is exponential zone constant in $(Ah)^{-1}$, the hours are converted into seconds for the above equation
- A is exponential zone amplitude in pu, it is converted to Volts using the base E_0.
- $u(t)$ is 1 when the current is negative (discharge mode) and 0 when the current is positive or zero (charge mode).

4 References

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