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Model-Based Investigation of Vehicle Electrical Energy Storage Systems

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In the recent years, more and more important research and development projects are aimed to the modernization of vehicle energy supply and to find an alternative of fossil energy sources. One of these alternatives is the family of vehicles powered by purely electric energy. Besides its advantages, the main disadvantage of this solution is that the storage of the necessary amount of electrical energy needed for the long term operation of the vehicles is not completely solved.
Therefore there is a rapid development in the field of batteries with small size and high storage capacity. An important prerequisite of development and testing of such batteries is the presence of a model suitable for the comparison of different battery types and describing the underlying physical mechanisms. Models used so far describe only the current-voltage characteristics without taking the various temperature circumstances into account.
The charging, discharging, and capacity parameters of batteries used for energy storage are highly temperature dependent, so temperature must be taken into consideration for the correct description of such batteries.
The proposed paper presents a general temperature dependent model of a family of batteries developed for vehicle electronic use. Besides the model derivation, the methodology and instruments developed for the correct measurements of the temperature dependent parameters are also presented together with a Matlab/Simulink block for the temperature dependent battery.

1. Introduction

Different approaches of modeling the thermal behavior electric energy storage systems can be found in the literature. These are typically linear, Vasebi et al. (2007), Doughty et al. (2002), Hu et al. (2011), or LPV models, Hu et al. (2010). The aim of this work is to create a more general approach, not assuming linear behavior. The measurement configuration is able to inspect nonlinear electrical two pole systems too. On the other hand our model also includes the cell surface temperature as model output, not only the electrical parameters. In our approach the result of the modeling procedure is a Matlab Simulink Model (extended with SimPower Systems) that has been parameterized based on the measurement database.

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2. Problem statement

The aim of this paper is to create a simplified battery model for simulation purposes. The simplified model we are intended to find polynomial relationship between the actual magnitude at an instant of the exact charging state and the connection point voltage values and the deviation of the environmental temperature and the surface temperature of the cell. With the help of this relationship it is possible to build model based simulations and to simulate the battery behavior in different thermal conditions, for example in a temperature controlled quick battery charger application, or a deploying characteristic of an electrical vehicle (EV) in very low temperature winter conditions. With the help of this method we can measure and build model for any electronic two poles, not only the linear ones (Supercapacitors, nonlinear batteries, etc.).

3. Measurement device

The measured battery is a TS-LFP60AHA $LiFePO_4$ Li ion battery which is generally used in electrical vehicles in different capacities from 40 to 200 Ah-s (1 Ah = 3600 As). The parameters of the cell can be seen in Table 1. In the measurement configuration the 60Ah version of the product family has been used.

Table 1: TS-LFP60AHA $LiFePO_4$ Li-ion battery parameters

Nominal Capacity	**Operation Voltage**	**Max. Charge Current**	**Max. Discharge Current**	**Standard Charge/ Discharge Current**
60 Ah	charge 4.25V discharge 2.5V	180A	constant current 180A Impulse current 600A	Charge ≤ 18A Discharge ≤ 18A
Cycle Life	**Temperature Durability of Case**	**Temperature Range**	**Self Discharge Rate**	**Weight**
0.8C ≥ 2000 0.7C ≥ 3000	≤ 250°C	Charge -25°C- +75°C Discharge -25°C- +75°C	≤ 3% Monthly	2.5kg

The measurement configuration consists of a power supply unit with 12V 20A capability, a programmable electronic load/current generator unit with 30V 30A capability. The configuration can be seen in Figure 1. Four signals have been measured and logged: voltage, charge/discharge current, the surface temperature of the battery and the environmental temperature. The resolution was 12 bit in the voltage and current values, and approx 0.1 degree in the temperature values. The sampling rate was 12 sample/minutes. We collected different variations with different constant charging and discharging current values, and in different thermal conditions. In our simplified model we are intended to find polynomial relationship between the actual magnitude at an instant of the exact charging state and the connection point voltage values and the deviation of the environmental temperature and the surface temperature of the cell.

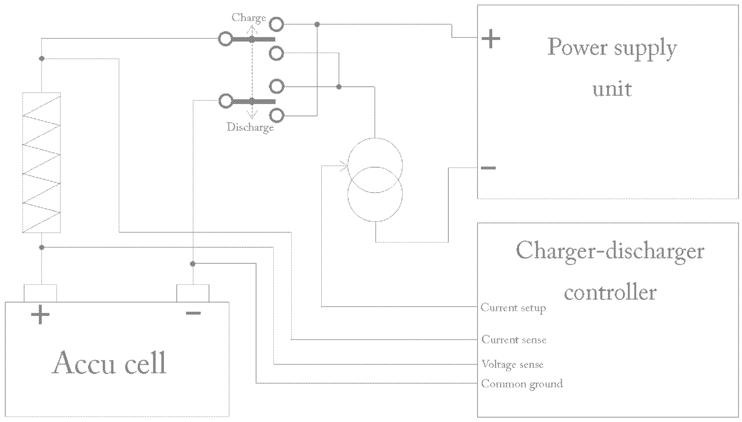

Figure 1: Measurement configuration

One of the collected databases with 10 A charging current and 25 °C enviroment temperature can be seen in Figure 2. These are raw unfiltered values plotted against time.

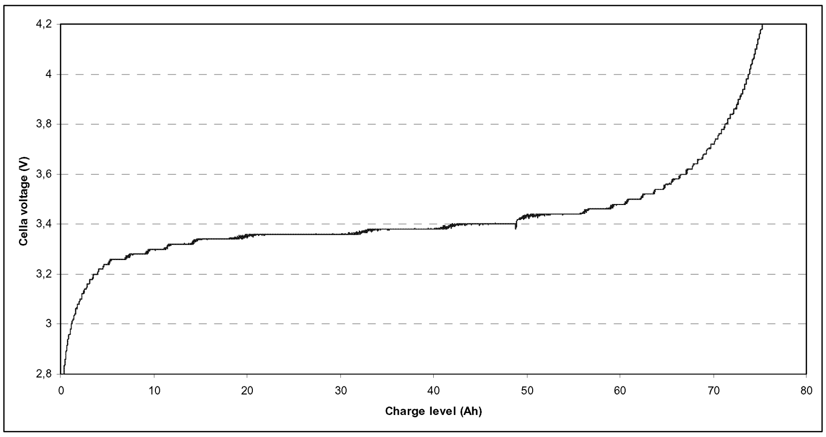

Figure 2: Measured voltage values (charge 10 A, Env. Temp. 25 °C)

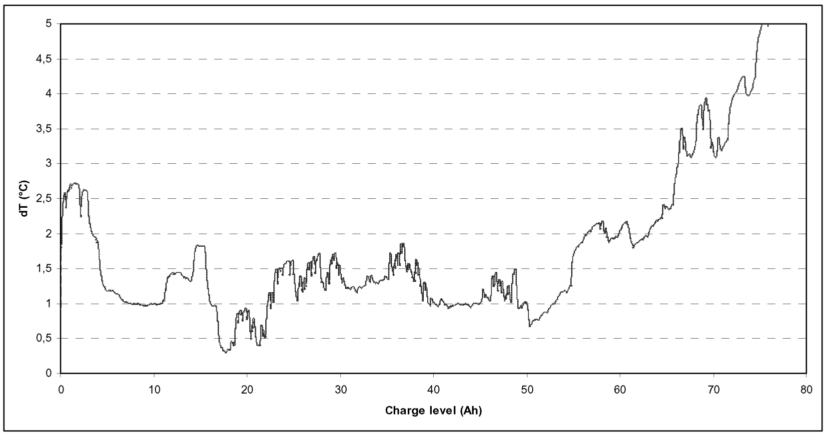

Figure 3: Measured temperature deviation (charge 1 0A, Env. Temp. 25 °C)

4. Matlab model of vehicle energy storage systems

The dynamical model of the battery has been implemented in Matlab Simulink using the Power Electronics Toolbox. The Simulink block scheme of the model is depicted in Figure 4. The unknown function relationships of the battery voltage with respect to battery charge and battery temperature with respect to battery charge and environmental temperature has been approximated using 5th and 3rd order polynomials, respectively.
The voltage relationship is given by the polynomial.

$$u(Q) = 1.4Q^5 - 2.59 \cdot 10^{-6} Q^4 + 1.8 \cdot 10^{-4} Q^3 - 0.006Q^2 + 0.084Q + 2.89 \quad (1)$$

while the temperature as a function of charge and environmental temperature is defined as

$$T(T_{env}, Q) = T_{env} + 2.02 \cdot 10^{-5} Q^3 - 7.82 \cdot 10^{-4} Q^2 + 0.02Q + 1.76 \quad (2)$$

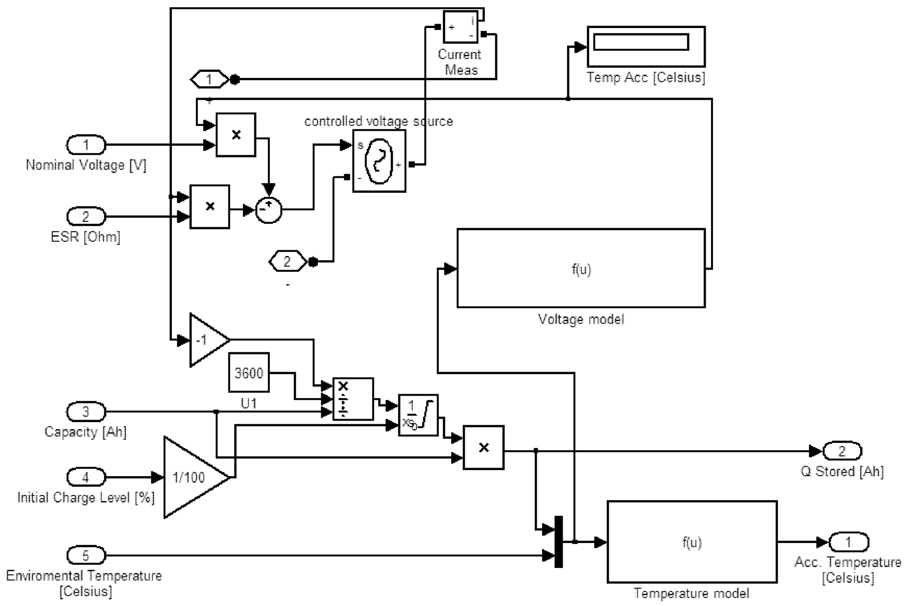

Figure 4: Matlab Simulink model of the system

The obtained Simulink model has been validated by exposing the system to the same cicumstances as the original battery, i.e. the measurement procedure has been implemented (see Figure 4.). The results can be seen in Figure 5.

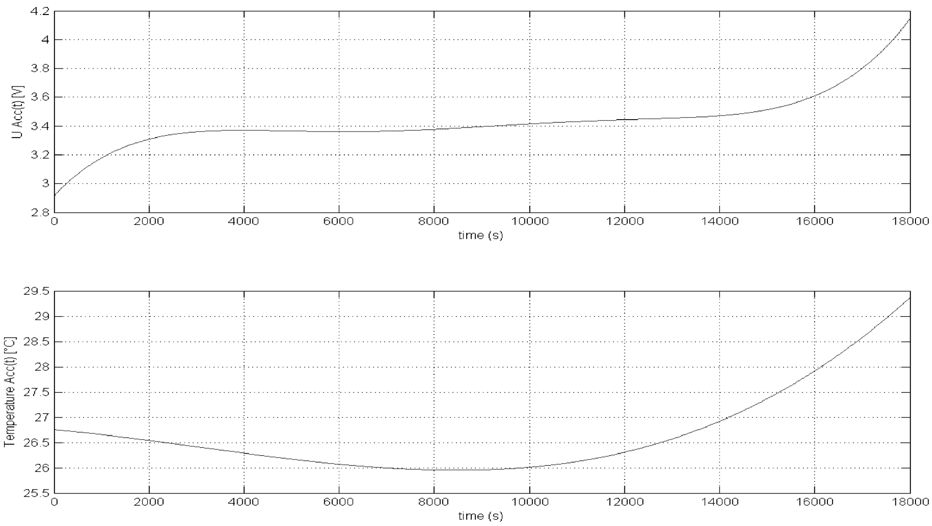

Figure 5: Battery voltage and temperature as a function of time

5. Conclusion

A general thermal model for a family of batteries has been developed for vehicle electronics applications. The model parameters are obtained from measurement data. Besides the model derivation, the methodology and instruments developed for the correct measurements of the temperature dependent parameters has also been presented together with a Matlab/Simulink model for the temperature dependent battery. Our future aim is to finalize the measurement at more working point to get more accurate Simulink model to use in our simulations.

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