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SPICE Modeling of Li-Ion Pouch Battery Cell Including Thermo-Electrochemical Effects

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The development of efficient, cheap, compact, and reliable storage systems is getting increasingly crucial. Special attention must be given to Li-Ion batteries, which stand out for the stability of their open-circuit voltage (V_{OC}), current capability, and compactness [1]. Such features make them suitable for a large scale of applications. Unfortunately, the design of electric/electronic systems embedding batteries as power supply/storage is still challenging because of the lack of simple and trustworthy circuital models accounting for complex thermo-electrochemical mechanisms.

In this abstract, a SPICE-compatible compact electrical model of batteries including thermal and chemical effects (hereinafter referred to as *macrocircuit*) is proposed (Fig. 1). The macrocircuit was customized on a Li-ion pouch cell battery in the NMC technology (schematically depicted in Fig. 2), its capacity being C=20 Ah; however, the model can be adapted to a generic product. First, in both the charge and discharge phases, self-heating effects are considered along with their impact on the overall electrical behavior of the system. Furthermore, for each simulation, the initial conditions of the state of charge (SoC) of the battery can be defined; the SoC can be then monitored during the simulation run.

The macrocircuit is composed by: (i) a core including a voltage generator V_{OC} and a passive network, the values of which are allowed to vary with both the SoC and the cell average temperature (T_{avg}); (ii) a thermal feedback block (TFB) based on Foster-I equivalent network, which provides T_{avg} as an output; (iii) some behavioral modeling blocks devoted to evaluate the SoC and the dissipated power (P_D). It must be remarked that P_D is given by the *algebraic sum* of two components, namely, the irreversible ($P_{D,irr}$) and the reversible ($P_{D,rev}$) one. While the former is always positive being it given by the Joule heating dissipation over the core, the latter accounts for the endothermic/exothermic chemical reactions – dictated by the entropic coefficient *dU/dT* – occurring in the battery; therefore, $P_{D,rev}$ can also be negative, thus reducing the overall P_D and providing cooling effects. The modeling of the above quantities was based on the meticulous experimental campaign conducted in [2].

In order to prove the accuracy of the macrocircuit, simulative results obtained in the OrCAD SPICE software package [3] were compared with the counterpart performed in the FEM environment, which was used as a reference. The 3-D structure and the corresponding multiphysics FEM problem was (i) calibrated by means of the experimental data shown in [4], and simulations were run in COMSOL [5].

Given the initial state of charge SoC_0=80% and T_{amb}=25°C, the discharge of the battery was emulated by defining an outgoing current at 4.5 C (i.e., 90 A). A good agreement between results carried out through the macrocircuit and FEM simulations was achieved in terms of dissipated power (Fig. 3), cell average temperature (Fig. 4), and voltage at the battery terminals (Fig. 5). It must be remarked that each FEM simulation required approximately 10 minutes, while a few seconds were needed by making use of the proposed model. As a further advantage, the model is prone to be adopted in complex SPICE simulations of circuits for applications in power electronics (such as DC/DC converters, inverters, and rectifiers) as well as to study the electrical connection of several pouch cells forming a battery pack.

References

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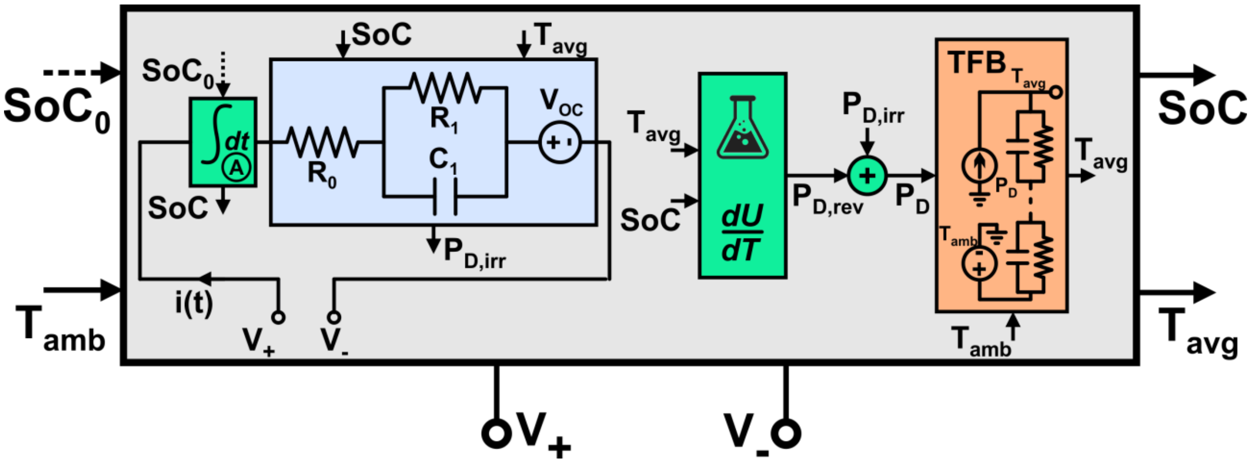

Figure 1: Schematic representation of the SPICE-compatible thermo-electrochemical macrocircuit of the battery (grey box). The equivalent circuit representing the core is shown in the light blue box. The green boxes include the behavioral modeling for the SoC and P_D evaluation. The TFB is shown in the orange box. Also highlighted are (i) the circuit terminals (V_+ and V_-), (ii) the input signals SoC_0 and T_{amb}, and (iii) the output signals T_{avg} and SoC to be monitored.

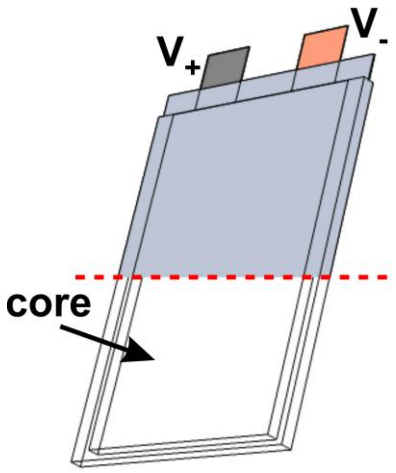

Figure 2: Depiction of the 3-D structure of the Li-Ion pouch cell battery under investigation built in the COMSOL Multiphysics environment.

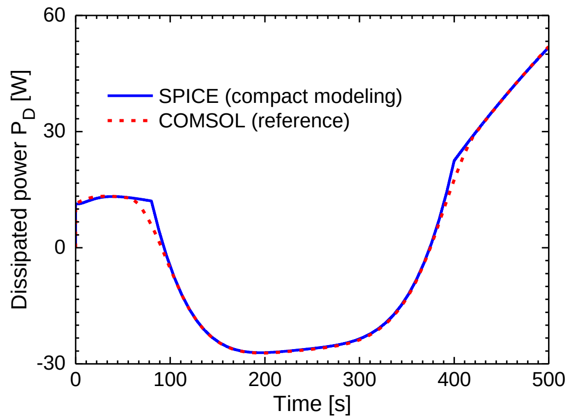

Figure 3. 500-second-long simulation results of the battery discharge (T_{amb}=25°C and SoC_0=80%). Comparison between the total dissipated power (i.e., $P_{D,rev}$+$P_{D,irr}$) obtained through the proposed model in OrCAD SPICE (solid blue line) and through 3-D FEM simulations in COMSOL (dashed red).

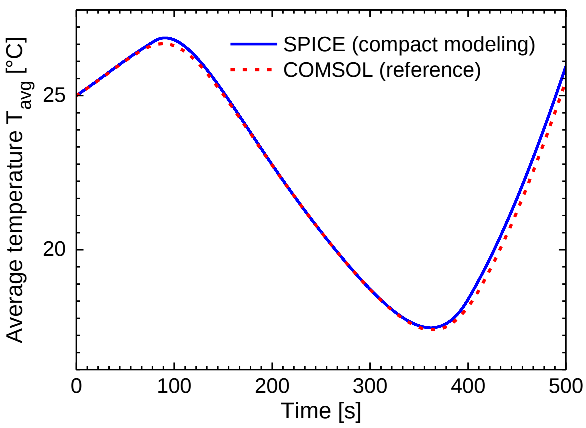

Figure 4. 500-second-long simulation results of the battery discharge (T_{amb}=25°C and SoC_0=80%). Comparison between the average battery temperature obtained through the proposed model in OrCAD SPICE (solid blue line) and through 3-D FEM simulations in COMSOL (dashed red).

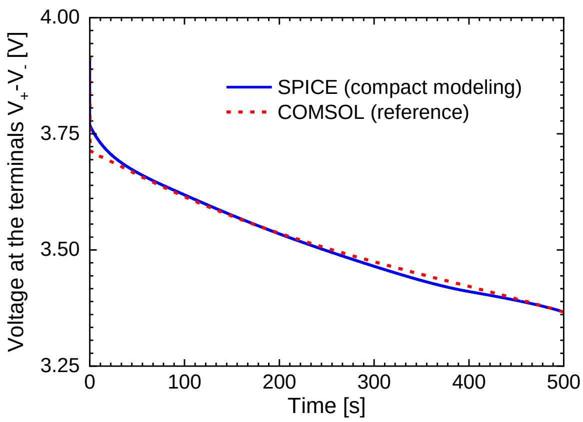

Figure 5. 500-second-long simulation results of the battery discharge (T_{amb}=25°C and SoC_0=80%). Comparison between the voltage at the battery terminals obtained through the proposed model in OrCAD SPICE (solid blue line) and through 3-D FEM simulations in COMSOL (dashed red).