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Direct Continuous-Time Linear Parameter-Varying System Identification of Li-ion Batteries

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1 Introduction

Equivalent circuit models (ECMs) are widely used for Li-ion battery modeling. Due to the nonlinearity of battery behaviors, ECM's parameters vary with the battery's state of charge (SOC). Identifying the physical parameters of the battery requires continuous-time (CT) identification of a linear parameter-varying (LPV) system. Existing CT-LPV approaches use numerical differentiation and iterative refinement that are prone to amplifying measurement noise. This work presents a novel CT-LPV method that can be run in a single shoot without differentiating signals. The LPV state-space model is transformed into an input-output (IO) model and is seen as a multiple-input single-output LTI system to which classical CT stable variable filter approaches can be applied. We demonstrated the efficacy of the developed method on a simulated battery.

2 Model description of Li-ion batteries

Li-ion batteries are commonly modeled using the equivalent circuit model shown in Figure 1. This model has the following state-space equations:

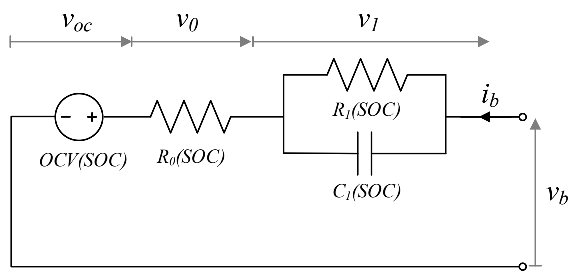

Figure 1: Equivalent circuit model

$$\dot{v}_1(t) = -\frac{1}{R_1(z(t))C_1(z(t))}v_1(t) + \frac{1}{C_1(z(t))}i_b(t) \quad (1)$$

$$v_b(t) = v_1(t) + R_0(z)i_b(t) + v_{oc}(z(t)), \quad (2)$$

where R_0, R_1, C_1 are continuous-time battery parameters, v_{oc} is the battery's open circuit voltage (OCV), and z is the state of charge (SOC) of the battery

$$z(t) = z(t_0) + \int_{t_0}^{t} \frac{1}{3600C} i_b(\tau)d\tau. \quad (3)$$

In practice, the OCV can be obtained from offline battery tests. This work aims to identify the continuous-time SOC-dependent model parameters of the battery from sampled input-output data.

3 Direct CT identification of battery parameters

The continuous-time LPV model can be equivalently transformed into an input-output (IO) model [1]. With parameters represented by a basis function of SOC, the obtained IO model is regarded as a multiple-input single-output linear time-invariant system with the following form:

$$v_d^{(1)}(t) = a_{10}v_d(t) + \sum_{l=1}^{\alpha} a_{1l} f_l(z(t)) v_d(t) + \sum_{i=0}^{1}\sum_{l=0}^{\beta} (b_{il} g_l(z(t)) i_b(t))^{(1-i)} \quad (4)$$

where $v_d = v_b - v_{oc}$. The resultant MISO LTI system can then be transformed into the Laplace domain as:

$$sV_d(s) = [A_1V_d](s) + s[B_0I_b](s) + [B_1I_b](s). \quad (5)$$

With a state variable filter $F(s) = \frac{1}{s+v}$, we can preserve and compute all model parameters with digital filters without numerical differentiation. The SOC-dependent parameters are solved for via least squares:

$$\min_{\theta} \|V_{d,m}^{f_1} - X\theta^{a_1,b_0,b_1}\|_F^2. \quad (6)$$

4 Results

The effectiveness of the developed method is validated via a simulated battery with the result shown in Figure 2.

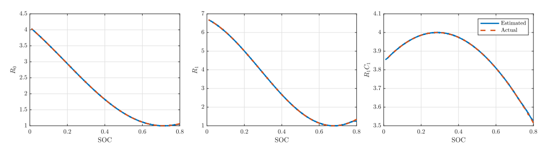

Figure 2: Battery parameter identification of a simulated battery

References

[1] R. Tóth, *Modeling and Identification of Linear Parameter-Varying Systems*, vol. 403. Springer, 2010.