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Electrochemical model parameter identification of a lithium-ion battery using particle swarm optimization method

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HIGHLIGHTS

- Four critical electrochemical model parameters of a Li-Ion battery were identified.
- A cost function was defined to minimize voltage error between model and test data.
- Particle swarm optimization methodology was utilized to minimize the cost function.
- Four sets of these critical model parameters were identified for the stated conditions.

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ABSTRACT

In this paper, a gradient-free optimization technique, namely particle swarm optimization (PSO) algorithm, is utilized to identify specific parameters of the electrochemical model of a Lithium-Ion battery with $LiCoO_2$ cathode chemistry. Battery electrochemical model parameters are subject to change under severe or abusive operating conditions resulting in, for example, over-discharged battery, over-charged battery, etc. It is important for a battery management system to have these parameter changes fully captured in a bank of battery models that can be used to monitor battery conditions in real time. Here the PSO methodology has been successfully applied to identify four electrochemical model parameters that exhibit significant variations under severe operating conditions: solid phase diffusion coefficient at the positive electrode (cathode), solid phase diffusion coefficient at the negative electrode (anode), intercalation/de-intercalation reaction rate at the cathode, and intercalation/de-intercalation reaction rate at the anode. The identified model parameters were used to generate the respective battery models for both healthy and degraded batteries. These models were then validated by comparing the model output voltage with the experimental output voltage for the stated operating conditions. The identified Li-Ion battery electrochemical model parameters are within reasonable accuracy as evidenced by the experimental validation results.

1. Introduction

Amongst all the alternative energy sources available for various propulsion applications such as plug-in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV), and electric vehicle (EV), Lithium-Ion (Li-ion) battery is considered to be the most promising [1]. Compared to the other alternative options for energy sources (such as Nickel–Cadmium, Nickel-Metal Hydride, etc.), Lithium-Ion batteries have some unique advantages such as higher specific energy, minimum memory effect, best energy-to-weight ratio, and low self-discharge when idle [2,3]. Based on these stated advantages, Li-Ion batteries are the leading candidate for the upcoming generation of automotive, aerospace, and other applications.

PHEV, HEV, and EV have been gaining more acceptance in recent years due to their lower emission rates and better fuel efficiency [4]. Performance of these transportation options are significantly dependent on the electrochemical energy sources, e.g. installed battery modules integrated with the vehicle powertrain. Depending on the user driving habits and the road conditions, these traction batteries undergo different operating conditions as the battery load demand changes. The safe operation of the entire battery

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Nomenclature

c_e	lithium ion concentration in the electrolyte phase
c_s	lithium ion concentration in the active materials in both electrodes
$\bar{c}_{s,i}$	volume-averaged concentration of a single particle
D_e	diffusivity at electrolyte phase
D_s	diffusivity at solid phase
$f_{c/a}$	mean molar activity coefficient
F	Faraday constant
i_e	current in the electrolyte phase
i_0	exchange current density
I	load current
j_n	molar ion fluxes between the active materials in electrodes and the electrolyte
L^-	length of negative electrode
L^+	length of positive electrode
n	number of active materials
R	universal gas constant
R_p	radius of the spherical particles
t_c^0	transference number
T	average internal temperature
U	open circuit potential
V	cell voltage
α_a	charge transfer coefficient in anode
α_c	charge transfer coefficient in cathode
γ	observer gain constant
ϕ_e	potential at electrolyte phase
ϕ_s	potential at solid phase
ε_e	volume fraction at electrolyte phase
ε_s	volume fraction at solid phase
η	over-potential for the reactions
ρ^{avg}	average density
κ	intercalation/de-intercalation reaction rate

module is always expected, as it is one of the most vital components of the stated vehicle configurations. But in reality, it is not always possible to maintain the desired safe and healthy operating conditions of the battery system for a number of reasons. For instance, battery can be overcharged during operation, or over-discharged at different rates. Moreover, battery degradation due to aging is another potential situation arising out of long-term cycling of the battery.

In HEVs, the onboard battery management system (BMS) is responsible for managing the rechargeable battery system by monitoring its state of charge (SOC), protecting the battery from unsafe operating zones, and reporting the diagnostic data to the operator while managing the battery operation. An accurate monitoring of the battery state is possible if the critical battery parameters can be reliably identified which can consequently lead to a better BMS. With this objective, identification of four critical battery parameters of an electrochemical battery model with $LiCoO_2$ cathode chemistry is developed in this work. It is to be noted that a $LiCoO_2$ cathode based Li-Ion battery offers high energy density compared to other Li-Ion battery chemistries such as $LiFePO_4$ cathode. Also, the electrochemical model of a Li-Ion battery captures a more realistic chemical kinetics and electro-dynamics in a cell compared to other modeling methodologies such as equivalent circuit model. Amongst all the parameters of the electrochemical model of Li-Ion battery, the principal reason for selecting these four parameters (e.g. solid phase diffusion coefficient at the cathode, solid phase diffusion coefficient at the anode, intercalation/de-intercalation reaction rate at the cathode, and intercalation/de-intercalation reaction rate at the anode) is that these parameters exhibit significant variations when the battery is subject to severe or abusive conditions such as overcharging, over-discharging, adverse environmental conditions, etc. [13].

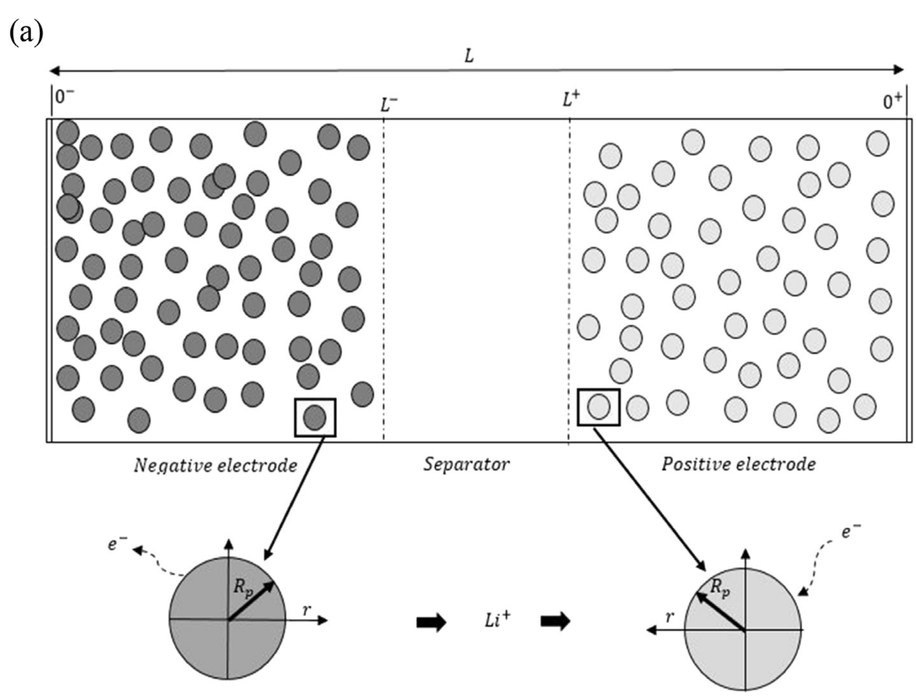

Fig. 1. (a) Schematic of Li-Ion battery geometry; (b) PSO algorithm flowchart.