Research on Parameter Identification Method of Lithium-ion Battery Model Based on Particle Swarm Optimization Algorithm

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ABSTRACT

Aiming at the problem of parameter selection and optimization of the mathematical model of lithium-ion battery, a method of using the particle swarm optimization (PSO) algorithm to optimize the parameters identification is proposed. The experimental results show that the algorithm has small average error and less time elapse, and the parameterization ability of the optimized parameters is improved. The speed and accuracy of the parameters of the battery model are improved, which solves the problem that the manual calibration is time-consuming and difficult to guarantee accuracy.

INTRODUCTION

Battery plays an important role in human’s industry and social life as energy storage device, lithium-ion battery has comparatively high energy density and stable characteristic during the process of charge and discharge. Therefore, its proportion in energy storage application increases rapidly. Lithium-ion battery is widely used in different power requirement area, such as smart phone, laptop, wearable smart devices and other low power degree application, as well as orbit satellite power, electric vehicle power, new energy storage power station and other high power demanding occasion.

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Battery management system (BMS) is essential part of lithium-ion battery power system, for improving battery performance, safety and reliability. The core function of BMS is to precisely estimate battery state, include state of charge and cycle life, whose accuracy depends on battery model. So far, there are several different types of lithium-ion battery model. Equivalence circuit model based on experimental outside electric characteristic, such as the venin model and PNGV model[1], these type model could simulate dynamic behavior at some degree by using RC circuit, but its high computation demanding limit the usage in real project, especially when the model has more order. Smart algorithm model based on machine learning, the typical one is three tier neural networks battery model, which can describe non-linear characteristic of battery[2]. However its anti-interference ability is weak, and can only be used in the scope of the original training data, this model rarely be taken in the real project. Mathemetic model coming from inner chemical reaction of battery, the representative model is Shepherd mathematic model[3], which builds the relationship of battery inner parameters from cathode and anode potential. The model can accurately reflect the discharge behavior of battery, and widely be used in battery state estimation.

Although the way to identify mathematic model parameters is relatively easy, the process to optimize parameters is very difficult and time-consuming. This paper will take PSO algorithm as basic method to identify and optimize the parameters of Shepherd mathematic battery model. PSO algorithm is a population-based iteration, which is the particle in the solution space to follow the optimal particle search. Whose advantage is simple, easy to implement, it is very suitable for the problem of optimal parameters seeking because of its natural real coding characteristic. This method can be used in battery mathematic model parameters offline calibration, could eliminate the limitation of mathematic model using in the project application.

CONVENTIONAL SHEPHERD MODEL PARAMETER IDENTIFICATION

Shepherd Lithium-ion Battery Model

Shepherd lithium-ion battery model is a mathematic description which is established from the principle of battery charge and discharge chemical reaction and characteristic of battery structure. Firstly, Shepherd model builds cathode potential energy equation as

\[ E_c = E_{sc} - K_c \left( \frac{Q_c}{Q_c - It} \right)i \]  

(1)

Where \( E_c \) is cathode potential during discharge; \( E_{sc} \) is a constant potential; \( K_c \) is the cathode coefficient of polarization; \( i \) is the active material current density; \( Q_c \) is the amount of available cathode active material expressed in units such as ampere hours; \( t \) is the time at any point during the discharge.
Similarly, anode can be described in Eq.(2).

$$E_a = E_{sa} - K_a \left( \frac{Q_a}{Q_a - it} \right)$$

(2)

Eq. (2) plus Eq. (1), Eq. (3) can be obtained.

$$E = E_s - K \left( \frac{Q}{Q - it} \right)$$

(3)

Where $Q=Q_a=Q_c$ is the available amount of active material; $E=E_a+E_c$ is the potential of the battery at any time $t$ during the discharge.

Because of the battery voltage drop at the beginning of discharge process, internal resistance is considered, Eq. (3) becomes

$$E = E_s - K \left( \frac{Q}{Q - it} \right)i - Ni$$

(4)

Where $N$, the internal resistance per unit area, is measured in ohm cm$^2$.

When Eq. (3) is evaluated mathematically, a set of curves is obtained, there are some differences by comparing to the actual battery discharge curves. In order to minimize the model error is to bring new factor to the Eq. (4), form the final equation

$$E = E_s - K \left( \frac{Q}{Q - it} \right)i - Ni + A \exp(-BQ^{-1}it) - Cit$$

(5)

Parameters Identification of Shepherd Lithium-ion Battery Model

According to Eq. (5), the Shepherd model parameters include $E_s, K, Q, N, A, B$ and $C$. But $A$, $B$ and $C$ just reflect the quick drop process at the discharge beginning, in order to reduce identification computational complexity, these three parameters identification don’t be considered in this paper. The way to identify other parameters shown in Figure 1 is to gain four feature points from two different discharge curves.

Each point is put into the Eq. (4), Eq. (6) can be built.
Figure 1. Model identification discharge curves.

Where $t_1$, $t_2$, $t_3$ and $t_4$ are the time points; $E_1$, $E_2$, $E_3$ and $E_4$ are the battery voltage of respective time points; the solutions of Eq. (6) are the value of model parameters.

### Parameters Identification Effect of Shepherd Lithium-ion Battery Model

After the four feature points are selected, the model parameters can be obtained by solving the equation set. This method is simple, but the fitting effect of the model depends on whether the feature points are appropriate. Select 500mA and 2000mA discharge curve as $i_a$ and $i_b$, the four feature points shown in Figure 2 are used to calculate the parameters. Plug the numerical data into Eq. (4), the comparison of actual discharges with points calculated from equations at $i_a$ and $i_b$ is shown in Fig. 3.

In Figure 3 the fitting effect of 500mA is not good, especially in the latter half of the curve. Therefore adjust the position of feature point 4 shown in Figure 4, and repeat the parameter identification. The fitting results are shown in Figure 5.
PARAMETERS IDENTIFICATION BASED ON PSO ALGORITHM

Basic PSO Algorithm

PSO put forward by Drs. Kennedy and Eberhart in 1995 is a global optimization evolutionary algorithm. This algorithm based on simulation of birds’ feeding behavior, make the group to achieve optimal through the collective collaboration between birds [4]. PSO is initialized to a group of random particles, and each
particle represents a candidate solution in the search-space. The optimal solution is found through iteration, and a fitness function according to the optimization objective is defined to determine the solution is good or bad. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. For particle $i$, its position represent as $x_i=[x_{i1}, x_{i2}, \ldots, x_{id}]$, its velocity represent as $v_i=[v_{i1}, v_{i2}, \ldots, v_{id}]$, its own best known position represent as $p_i=[p_{i1}, p_{i2}, \ldots, p_{id}]$ (called pbest), the entire swarm’s best known position represent as $g=[g1, g2, \ldots, gd]$ (called gbest). The calculating formula to update particle’s position and velocity is

$$
\begin{align*}
  v_{i+1}^t &= \omega v_i^t + c_1 r_1 (p_i^t - x_i^t) + c_2 r_2 (g^t - x_i^t) \\
  x_{i+1}^t &= x_i^t + v_{i+1}^t
\end{align*}
$$

(7)

Where $i=1,2,\ldots, M$, $M$ is the number of particles in the swarm; $t$ is the current iteration number; $\omega$ is the inertia weight, make the particles has a trend to expand the search-space[5]; $c_1$ and $c_2$ are learning factors, accelerate the particles’ movement toward $p_{\text{best}}$ and $g_{\text{best}}$; $r_1$ and $r_2$ are random numbers of uniform distribution on $[0, 1]$ in order to ensure the diversity of the population [6]. Particles update their position by continuous learning, eventually fly to the optimal solution in the search-space. The termination criterion can be number of iterations performed, or a solution with adequate fitness value is found.

The Parameter Identification Method of Lithium-ion Battery Model based on PSO Algorithm

The essence of parameter identification based on PSO, is to translate it into an optimization problem in parameter space. Then using the PSO algorithm for parallel search in the entire parameter space efficiently, in order to obtain optimal estimates of the system parameters. Regard the horizontal coordinates of four feature points (discharge capacity) as position vectors of the particle, and regard the mean absolute percentage error as fitness function. Specific steps are as follows:

1. Initialize the PSO parameters include the number of particles in the swarm, inertia weight, learning factors, maximum iteration number, search-space range, and the initial position and velocity of particles.

2. Calculate the initial fitness of particles, initialize the particles' best known position to their initial position, and update the swarm's best known position.

3. Update the particles' position, velocity, and fitness, then update the particles' best known position and the swarm's best known position.

4. While the termination criterion is not met, return to Step 3. If the maximum number of iterations has reached, calculate the lithium-ion battery model parameter according to the swarm's best known position.
Simulating Experiment

In order to make comparison with traditional model parameter identification method, select 500mA and 2000mA discharge curve as \( i_a \) and \( i_b \). Set the number of particles in the swarm at 20, inertia weight at 0.8, learning factors at 2, maximum iteration number at 20. The model parameters are identified by the standard particle swarm algorithm, and the results are shown in TABLE I.

The mathematical model of lithium-ion battery can be obtained by substituting parameter identification results into Eq. (4). The comparison of actual discharges with points calculated from equations is shown in Figure 6. The mean absolute percentage error of each iteration is shown in Figure 7. Therefore, using the PSO algorithm can determine the feature points’ position quickly and directly without manual adjustment, and obtain good fit.

**CONCLUSIONS**

Battery model parameters are the vital data of battery characteristics, are the essence to estimate battery real time capacity and life cycle. BMS works effectively based on the battery model parameters identification precisely. This paper identify and optimize lithium-ion shepherd battery model by using PSO algorithm, the experimental result shows the validity and stability of the method. The way proposed is mainly used in the battery state initial parameters calibration, how to identify and optimize online parameters dynamically is the next study goal.

**TABLE I. PARAMETER IDENTIFICATION RESULTS WITH PSO.**

<table>
<thead>
<tr>
<th>( E_s )</th>
<th>( K )</th>
<th>( Q )</th>
<th>( N )</th>
<th>Run Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>3225</td>
<td>0.0211</td>
<td>1505.3</td>
<td>0.0122</td>
<td>200s</td>
</tr>
</tbody>
</table>

Figure 6. Comparison of actual discharges with fitting curve used PSO.  
Figure 7. The mean absolute percentage error at different iterations.
REFERENCES