Measurement 120 (2018) 114–120

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Design and analysis of capacity models for Lithium-ion battery

Akhil Garg[a], Xiongbin Peng[a,*], My Loan Phung Le[b], Kapil Pareek[c], C.M.M. Chin[d]

[a] Intelligent Manufacturing Key Laboratory of Ministry of Education, Shantou University, Shantou, China
[b] Applied Physical Chemistry Laboratory, Department of Physical Chemistry, Faculty of Chemistry, University of Sciences, Viet Nam National University of Ho Chi Minh city (VNUHCM), Ho Chi Minh City, Viet Nam
[c] Centre for Energy and Environment, Malaviya National Institute of Technology, JLN Marg, Jaipur 302017, India
[d] Department of Mechanical Engineering, University of Nottingham, Malaysia Campus, Malaysia

ARTICLE INFO

Keywords:
Battery modelling
Electric vehicle
Genetic programming (GP)
Complexity
Battery capacity
Temperature
SRM

ABSTRACT

Past studies on battery models is focussed on formulation of physics-based models, empirical models and fusion models derived from the battery pack data of electric vehicle. It is desirable to have an explicit, robust and accurate models for battery states estimation in-order to ensure its proper reliability and safety. The present work conducts a brief survey on battery models and will propose the evolutionary approach of Genetic programming (GP) for the battery capacity estimation. The experimental design for GP simulation comprises of the inputs such as the battery temperature and the rate of discharge. Further, the seven objective functions in GP approach is designed by introducing the complexity based on the order of polynomial. This step will ensure the precise functions evaluation in GP and drives the evolutionary search towards its optimum solutions. The design and analysis of the GP based battery capacity models involves the statistical validation of the seven objective functions based on error metrics with 2-D and 3-D surface plots. The results conclude that the GP models using Structural risk minimization (SRM) objective function accurately estimate the battery capacity based on the variations of the inputs. 2-D and 3-D surface analysis of the GP model reveals the increasing–decreasing nature of temperature-battery capacity curve with temperature the dominant input. The battery capacity model obtained using SRM as an objective function in GP is robust and thus can be integrated in the electric vehicle system for monitoring its performance and ensure its safety.

1. Introduction

The research on battery-powered electric vehicles is the primary focus of experts to ensure sustainable, cleaner and noise-free environment [1–3]. The main unit responsible for transmission of power to vehicle is the battery pack. The main problems associated with the battery packs are overcharging, overheating, thermal runway, etc. Many modelling methods were developed to formulate the physics-based-models, the empirical models and the equivalent circuit models The main factors responsible for the problems is the abnormal voltage and abnormal temperature, which directly results in material degradation of battery and capacity fading and loss of cycle life [4]. In this context, a gamut of research studies [5–7] has been conducted classifying the modelling methods with their pros and cons for predicting battery/battery pack states [8–10]. The following is the important literature review conducted in area of battery models.

Basically, many review studies summarize that there exist three types of models [11]. Firstly, the empirical model based on only the data obtained from the experiments or simulation. These models have disadvantage of having the poor accuracy and does not incorporate physics into a model. Secondly, the models based on physics generally represents the fundamentals mechanisms taking place inside the battery. These models are known as electrochemical models or physics-based models. These are computationally expensive and the error accumulates over the time. The third category of models are equivalent circuit models which requires good understanding of circuit system in the battery pack. The broad discussion on these models were based on the two types of batteries: lead acid and lithium-ion [12–14]. The models are a part of battery management systems whose functions is to monitor and control the battery pack by the prediction of voltage, temperature distribution, battery SOC, battery SOH, etc. In this context, the review on key issues in battery management system was conducted and the findings were discussed [15–17].

Among the main issues in the battery management system, the emphasizes was paid to the prediction of SOC and SOH in real time. Past studies suggests that the prediction SOH is most difficult since it is difficult to visualize the mechanisms/material degradation inside battery in real time that results in capacity fading of the battery. In this

* Corresponding author.
E-mail address: xbpeng@stu.edu.cn (X. Peng).

https://doi.org/10.1016/j.measurement.2018.02.003
Received 26 September 2017; Received in revised form 31 January 2018; Accepted 1 February 2018
Available online 15 February 2018
0263-2241/

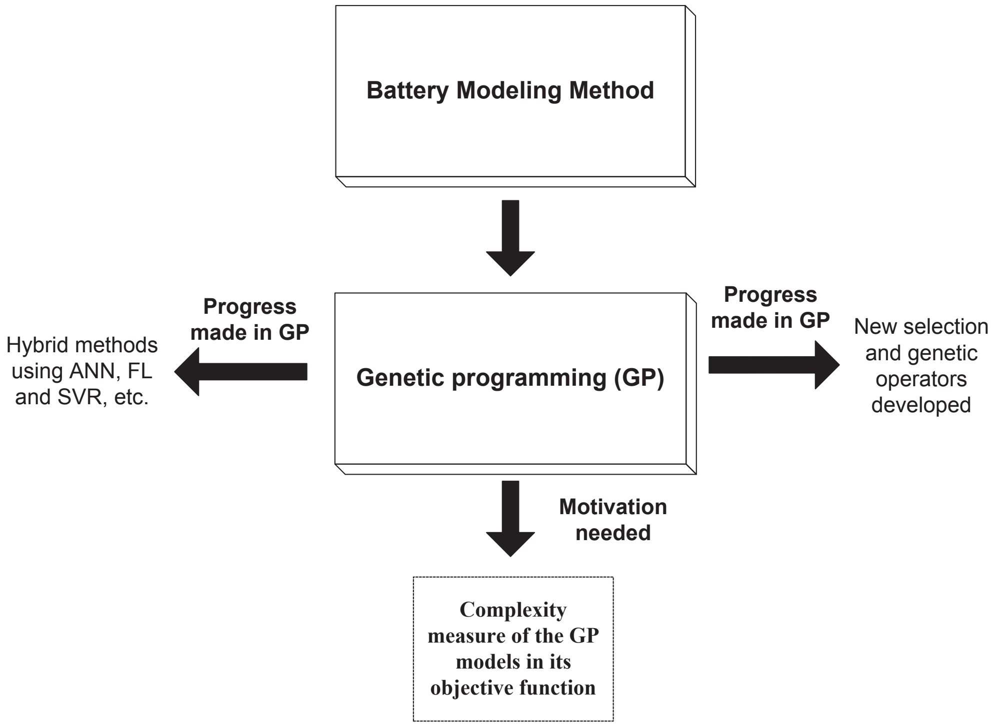

Fig. 1. Progress made in GP and dotted line box represent the current research focus in GP.

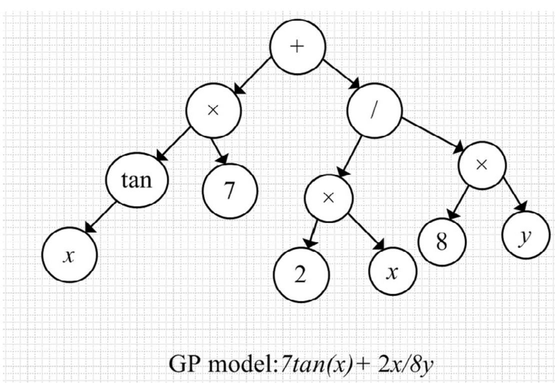

Fig. 2. GP model represented as a tree having complexity of 12 same as the number of nodes.

context, the theory of fuzzy mathematics in combination of human knowledge was used because it considers the imprecise information of battery [18].

Several prognostic and health management (PHM) methods for the battery states estimation were reviewed [19]. The methods were categorized into battery type, operating condition and driving conditions. The models were classified into empirical, physics-based, equivalent circuit models and fusion models [20,21]. A thorough review on the battery management system, vehicle energy management and the vehicle control was conducted by Cuma and Koroglu [14]. Battery management system comprises of the battery modelling methods, learning algorithms, controller, etc. Fundamental study on temperature and thermal life estimation, state of power estimation and recovery estimation methods are part of vehicle energy management system with objective to lower emissions and the higher efficiency. Besides, the vehicle control consists of methods for the prediction of orque, speed, range, slideslip angle, roll angle, road friction condition and the electric motor parameters with objective to ensure smooth vehicle control [22].

The critical review of the past studies reveals that the methods applied for battery modelling includes the physics-based modelling, empirical modelling based on artificial intelligence (AI) and the fusion modelling methods. Among these methods, the physics-based models developed using the finite element software's were used to understand the physical/chemical aspects at cell level. However, the knowledge attributes such as the performance and durability derived from these physics based models are difficult to be incorporated in the electric vehicle system since they are built on different languages/platforms. The fusion and AI based methods are mainly used for battery modelling to estimate the battery states such as the battery capacity, discharge capacity, SOC, SOH, SOF, temperature distribution, voltage, etc. for fault diagnosis and prognostics to mitigate the safety risk [14]. It was found that the AI based models can be integrated in the system however, their robustness and accuracy with respect to the input variations still possesses the main challenge. For e.g., Any systematic/non-systematic variations in the inputs such as the structure of the battery modelling method can directly influence the robustness of the models in context of any smaller variation in inputs values. In addition, the models built must represent explicitly the relationships between the battery capacity and the inputs. The pre-assumption of the model structure for the battery capacity introduces an uncertainty in the predictive ability of the model [23]. Therefore, it would be interesting to develop a robust approach that can explicit represent and estimate the battery capacity of the models based on the variations in temperature, rate of discharge rate and the structure of the modelling method.

In this context, the AI category of evolutionary approach of Genetic programming (GP) can be applied for generation of explicit models for battery capacity based on the given inputs [24]. Past studies in GP reveals that the state-of-the-art of the work was mainly on developing the new variants of GP by hybridising it with other methods such as the neural network, support vector regression and probabilistic based methods. New selection and genetic operators were developed to improve the evolutionary search mechanism [25–27]. To the best of authors knowledge, very few or hardly any research studies were found focussing on evaluation of the complexity measures in objective functions. The performance of the generated models depends highly on the objective functions chosen in GP. This is because the objective function