Assessment of Lithium-Ion Battery Degradation and its impact on ECM using Simulated Impedance Spectroscopy

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***Abstract*—This paper investigates Equivalent Circuit Model (ECM) based Impedance Spectroscopy to assess the state of Lithium-Ion Battery (LIB) Degradation. ECM parameter identification under different ageing mechanisms has been considered. The proposed technique is investigated using reference Electrochemical Impedance Spectroscopy (EIS) data obtained via a simulated LIB electrochemical model in the Python PyBAMM package. A Genetic Algorithm (GA) based optimization strategy is used to identify the ECM parameters for different ageing mechanisms with calendar ageing. The results show that the ECM is capable of capturing the LIB dynamics over a wide frequency range in addition to identifying the ECM parameter variations for specific degradation mechanisms.**

***Index Terms*—Lithium-ion battery, Battery Modelling, Equivalent Circuit Model, Electrochemical Impedance Spectroscopy**

I. Introduction

The demand for LIBs has increased significantly due to the rapid development in electric vehicles (EVs), as these vehicles primarily rely on LIBs for energy storage. Over the next decade, this demand is predicted to increase by 26%, reaching a market value of over USD 70 billion by 2026 [1]. As a result of this high demand and the high production cost of LIBs, significant attention has been given to reuse, recycle and disposal management of LIBs at the end of life (EoL) of EVs.

Reusing retired LIBs can have a significant economic and environmental impact. Typically, remaining capacity has a direct impact on the safer operation of them. In general, if the State of Health (SOH) of a battery falls below 80%, it is recommended that it should be retired due to a reduction in its capability to supply the power and energy requirement of the EV during operation [2]. Though these batteries are not suitable in EVs they can be still used in other applications such as energy storage systems which require lower surge power demands [2]. An accurate estimate of SOH is essential for battery usage in a new application in its second life. Therefore, an accurate SOH estimation and battery degradation analysis is crucial for its deployment in a repurposed application [3]–[5].

Model-based approaches have been used in past literature where electrochemical models and equivalent circuit models have been used frequently to analyze battery degradation and SOH estimation [6]. Physics-based modelling requires parameter identification using customized experiments, limiting the general use of this approach [7], [8]. Due to simple model structure and computational accuracy, Equivalent Circuit Models (ECMs) are widely used in Battery Managements System (BMS) design. For on-board battery state estimation such as SOC, SOH, and SOP, appropriate model structure and matching model parameters are essential. ECMs can be used to analyze the battery dynamic variations with different factors such as SOC, temperature, and degradation mechanisms [9]. In addition to its energy capacity, the battery's impedance can also be used as a gauge for its state of health. Previous research has focused on measuring impedance using an electrochemical impedance spectroscopy (EIS) [10]–[12].

In this paper, an ECM is used and its parameter variation under different SOC levels and degradation conditions are analysed based on reference EIS data obtained via a simulated LIB electrochemical model in the Python package PyBAMM. In the following sections, the fundamentals of ECM and the SOH estimation are presented followed by the methods and discussion of results.

II. LIB Equivalent Circuit Models

According to [13] ECM can be categorized as integer-order models (IOMs) and fractional-order models (FOMs) and selection of the appropriate model depend on the application.

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