Faculty of Engineering

STATE OF CHARGE ESTIMATION FOR AN ELECTRIC VEHICLE BATTERY

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Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

UNIVERSITI MALAYSIA SARAWAK

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STATE OF CHARGE ESTIMATION FOR AN ELECTRIC VEHICLE BATTERY

MORRIS GIBBSON ANAK TAMIN

A dissertation submitted in partial fulfilment
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ABSTRACT

The usage of electric vehicles has been increasing over the past decade globally. This is driven by the effort to reduce dependency of internal combustion engine (ICE) vehicles due to the global warming alerts by the environmental experts. As people began to explore the options of using electric vehicle (EV), the concern of battery or rather ‘battery anxiety’ has become a popular issue especially for new users transitioning from ICE vehicles to EV. State of charge (SOC) is the level of charge of a battery relative to the rated capacity and measured in percentage unit. It is the equivalent to the fuel level gauge for ICE vehicles. SOC cannot be measured directly because of the complexity of materials for different types of battery, thus it can only be estimated from measurement variables. Therefore, in this project which is State of Charge Estimation for Electric Vehicle Battery designed to estimate the SOC of a battery. The estimation of the SOC is crucial in the aspects of driving range estimation, battery health protection and to provide better charging routines. This project aims to simulate the battery SOC estimation with the Matrix Laboratory (MATLAB) Simulink and to compare the estimation methods and analyse the results from the simulation. Different methods will have different analysis on the SOC estimation due to external factors such as the battery model, the accuracy level, battery voltage, current, temperature and cell capacity.

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ABSTRAK

Penggunaan kenderaan elektrik telah meningkat sepanjang dekad yang lalu di seluruh dunia. Ini didorong oleh usaha mengurangkan kebergantungan kepada kenderaan enjin pembakaran dalaman berikutan amaran pemanasan global oleh pakar alam sekitar. Ketika orang ramai mula meneroka pilihan menggunakan kenderaan elektrik (EV), kebimbangan mengenai bateri atau lebih tepatnya 'kebimbangan bateri' telah menjadi isu popular terutamanya bagi pengguna baharu yang beralih daripada kenderaan ICE kepada EV. State of charge (SOC) ialah tahap cas bateri berbanding dengan kapasiti terkadar dan diukur dalam unit peratusan. Ia adalah bersamaan dengan tolok aras bahan api untuk kenderaan ICE. SOC tidak boleh diukur secara langsung kerana kerumitan bahan untuk pelbagai jenis bateri, oleh itu ia hanya boleh dianggarkan daripada pembolehubah ukuran. Oleh itu, dalam projek ini iaitu Anggaran Keadaan Caj untuk Bateri Kenderaan Elektrik direka untuk menganggar SOC sesuatu bateri. Anggaran SOC adalah penting dalam aspek anggaran jarak pemanduan, perlindungan kesihatan bateri dan untuk menyediakan rutin pengecasan yang lebih baik. Projek ini bertujuan untuk mensimulasikan anggaran SOC bateri dengan Simulink Makmal Matriks (MATLAB) dan membandingkan kaedah anggaran dan menganalisis keputusan daripada simulasi. Kaedah yang berbeza akan mempunyai analisis yang berbeza pada anggaran SOC disebabkan oleh faktor luaran seperti model bateri, tahap ketepatan, voltan bateri, arus, suhu dan kapasiti sel.

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LIST OF ABBREVIATIONS

Notations

ADAS: Advanced Driver Assistance Systems

BEV: Battery Electric Vehicles

BMS: Battery Management System

BYD: Build Your Dreams

CO2: Carbon Dioxide

EKF: Extended Kalman Filter

EV: Electric Vehicle

FPGA: Field-programmable gate arrays

GPU: Graphics Processing Unit

HEV: Hybrid Electric Vehicles

HVAC: Heating, Ventilation and Air Conditioning

ICE: Internal Combustion Engine

LEV: Light Electric Vehicles

KF: Kalman Filter

MATLAB: Matrix Laboratory

NOx: Nitrogen Oxide

OCV: Open Circuit Voltage

PETRONAS: Petroliam Nasional Berhad

PM: Particulate Matter

SOC: State of Charge

SOH: State of Health

V2G: Vehicle to Grid

VOC: Volatile Organic Compounds

CHAPTER 1

INTRODUCTION

1.1 Background

Battery is an important component for EVs. It can store energy that can be used to provide electrical power for the EV. Among the types of battery used in EVs are lead acid battery, nickel metal hydride and the most common type is lithium ion. Some EV models also use 12V battery like the ICE models to provide electrical power for low voltage components such as lights, infotainment display and the alarm system. The growth of EV sales across the world has allow car manufacturers to shift focus towards EV, especially battery electric vehicles (BEV) aside from the hybrid electric vehicles (HEV). As the importance of battery in EVs is highly emphasised by many, car manufacturers begin to invest in battery system.

The main battery system for EVs is different than their ICE counterparts as it is used to power the main powertrain of the vehicle. Thus, it can be observed that EVs normally will have larger battery capacity, especially for BEVs that relies fully on battery power. In most EVs, the SOC of the battery pack operates as a fuel gauge indication [1]. Many people misunderstood SOC as the clear indicator of their remaining battery percentage, however SOC cannot be measured directly. Therefore, the SOC of a battery is estimated as a clear indicator for the battery performance. Furthermore, SOC is crucial for EV users to properly plan their journey that includes charging time. SOC is also used for battery management system (BMS) that assists in maintaining and monitoring of the battery performance.

SOC estimation can be done with several methods such as coulomb counting method and Kalman filtering method. For coulomb counting method, it includes measuring of the charge flowing into and out of the battery. Then, based on the measured charge and total battery capacity, the SOC can be estimated. Additionally, the coulomb counting method for estimating SOC does depends a lot on how accurate the current sensor is [2] Coulomb counting can be used with batteries of all shapes and sizes, and it is often combined with other methods to get a more accurate estimate of SOC. Another method which is Kalman filtering in which the SOC is estimated by using a Kalman filter based on several input factors like as current, voltage, and temperature. The advantage is that it can be done very precisely and comprehensively [3]. The Kalman Filter principle block diagram is shown in Figure 1.1. This method constructs a state-space model, considers SOC to be an internal state of the system, determines the minimal variance estimation for SOC, and represents the battery as a system that is formed of an equation of state and an observation equation.

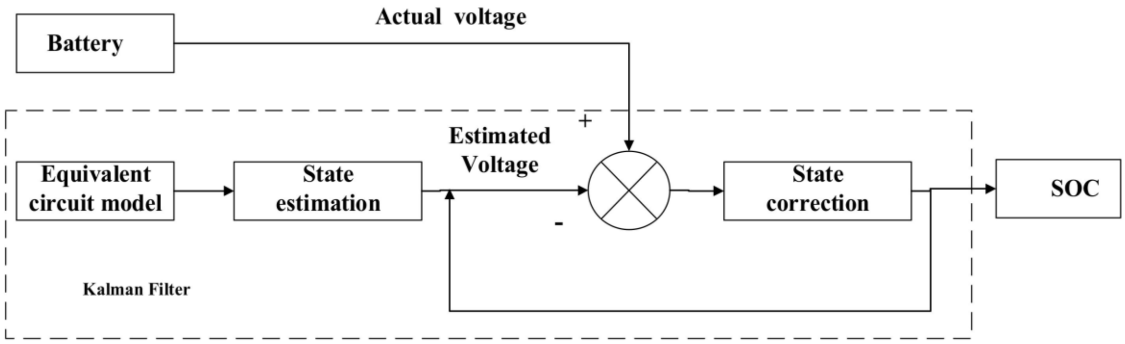

Figure 1.1: Kalman Filter principle

1.2 Problem Statement

Accurate SOC estimation is essential for a range of applications, including electric vehicles, portable devices, and renewable energy systems, since it allows the system to efficiently utilise the available battery capacity and increase the life of the battery. The accurate estimation of SOC can be affected by several factors. In the case of EVs, an accurate SOC estimation is important for several reasons, including optimising EV performance and range, enhancing charging efficiency, and assisting drivers in trip planning. Firstly, a battery's SOC is not immediately measurable. It can only be estimated using a variety of input factors, including current, voltage, temperature, and past SOC calculations. This is due to the battery's SOC is a relative measurement that expresses the amount of energy stored in the battery as a percentage of overall capacity. To calculate the SOC of a battery, it is vital to identify its capacity as well as the quantity of energy stored in it at any one time.

Next, the estimation of SOC can be complicated. Some SOC estimation techniques, such as machine learning algorithms, are complicated and may necessitate a large quantity of data and computer resources to train and execute. This makes them unsuitable for use in various situations. Another reason that SOC estimation can be complex is because the state of charge of a battery can change fast due to factors such as the rate of discharge or charging, battery temperature, and vehicle load. This makes precise real-time SOC measurement challenging. Furthermore, the accuracy of SOC estimation methods might be affected by the quality and consistency of the data utilised for training or estimation. For example, if the data is noisy or contains inaccuracies, the SOC estimate's accuracy may suffer.

Lastly, the model drift, also known as concept drift, is a phenomenon that occurs when the accuracy of a model or algorithm used for SOC estimation of an electric vehicle battery degrades over time. This can be caused by a few circumstances, including changes in the vehicle's operating conditions, battery degradation, or changes in the data used for training or estimation. For example, assume a SOC estimation model that has been trained using data from a battery that is relatively new and has not seen considerable degradation. If the battery begins to degrade over time, or if the vehicle is utilised in situations other than those for which it was initially built, the model's accuracy may begin to deteriorate. This is because the model was not trained on data that represents these changes, making it less capable of reliably predicting the battery's SOC under certain situations.

1.3 Objectives

The objectives of this project are:

- To design and simulate the battery SOC estimation using MATLAB Simulink for better battery performance monitoring and efficiency.
- To compare the SOC estimation methods from the simulation and analyse the results.

1.4 Project Significance

The intention of this project is to apply and compare the Kalman filter based method and coulomb counting method for SOC estimation for EV battery. The estimation methods will be compared and analysed for SOC estimation. The methods will be able to provide the representation of SOC that can be used in EVs. The information from the SOC is important for maximising an EV's performance and range since it allows the driver to know how much energy is available in the battery and plan trips accordingly. Besides that, it would help to improve EV safety by providing drivers with real-time battery information and alerting them if the battery is getting low and can be integrated to the vehicle's navigation system to help drivers reach the nearest charging station. This project can also improve the user experience of EVs by providing drivers with dependable and accurate information about the state of their battery, reducing battery anxiety and improving the overall driving experience.

1.5 Summary

This chapter consists of the research background, problem statement, objectives and project significant. As conclusion, the battery SOC estimation is significant for EV performance, monitoring and safety. It also serves valuable information for users to improve their user experience during driving.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

First, the electric vehicles will be presented. Next, the electric vehicle battery technologies available and additional new technology will be discussed. Furthermore, the state of charge estimation methods with relevant research works is presented.

2.2 Electric vehicles

Since the turn of the 21st century, numerous governments have vigorously discussed the problems associated with climate change or global warming. The negative effects of climate change, which is primarily driven by human activities, have been documented in many reports. Carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs) are just some of the air pollutants released into the atmosphere by motor vehicles powered by internal combustion engines like cars, trucks, and buses. The electrification of transportation is the most viable option to provide clean and efficient transportation, which is vital for the global sustainable development [4]. The air we breathe and the health of the public may suffer because of these emissions, and they also contribute to global warming. As people began to progress as a society, the need of personal transportation is more prevalent particularly in area where public transport is limited.

Electric vehicles had existed quite longer than we thought. The first electric vehicles were developed and utilised for short-distance travel in the early 19th century. These early EVs were powered by non-rechargeable primary cells and had limited range and top speeds. Due to their quiet operation and lack of pollution, electric vehicles gained popularity as a mode of urban transportation during the late 19th and early 20th centuries. However, the widespread adoption of EVs was hampered by the availability of electricity as well as the limited range and speed of electric vehicles compared to their gasoline-powered counterparts. At the beginning of the 20th century, electric vehicles must have appeared to be a strong contender for the future of road transportation [5]. Late in the 20th century, advancements in battery technology and rising concern about air pollution and climate change sparked renewed interest in electric vehicles. The 1990s saw the introduction of hybrid electric vehicles, which were powered by a combination of gasoline and electricity. This allowed for a longer range and the convenience of running on gasoline if necessary.

Battery electric vehicles have gained popularity in the 21st century due to the development of longer-range batteries and the expansion of charging infrastructure. BEVs have the potential for zero emissions and lower operating costs, but their limited driving range and high upfront costs limit their viability. Companies such as Tesla Inc. has played a significant role in promoting EVs and advancing their technology. The development of long-range BEV especially for their first in house designed car model which is the Model S in 2012. The car has the range of up to 420 km, making it the longest-range BEV by beating the Nissan Leaf at that time. The 70, 85, and 90 kilowatt-hour battery packs available for the Model S are technological marvels backed by an eight-year, unlimited-mileage warranty [6]. As the technology of EVs in general have been progressing throughout the years, car manufacturers have progressed in developing more EVs with longer range and faster charging speed.

Figure 2.1: Tesla's Supercharger Station

Tesla has made substantial investments in charging infrastructure in addition to developing BEVs with long ranges. To support the market adoption of EVs, it is anticipated that consumers will demand faster charging rates, especially for all-electric vehicles [7]. Superchargers, which can be shown in Figure 2.1, that was launched in 2012 is a global network of fast-charging stations installed by the company that allow Tesla owners to quickly charge their vehicles while travelling long distances. This has helped to overcome one of the primary obstacles to the widespread adoption of electric vehicles, namely the limited driving range and lack of charging infrastructure. The development of charging network has quickly adopted by many companies. In Malaysia, the charging network provided by companies such as JomCharge, ChargEV, Shell Recharge and Petroliam Nasional Berhad (PETRONAS) wholly owned subsidiary, Gentari has benefitted the EV owners around the country.

There are positive and negative effects of electric vehicles (EVs) on the energy system. Positively, electric vehicles can reduce reliance on fossil fuels and transportation emissions. They can also facilitate the integration of renewable energy sources into the grid by storing excess energy generated by wind and solar power. A sudden increase in EV adoption could strain the power grid and increase electricity demand, necessitating the construction of new power generation and transmission infrastructure. In addition, the increased use of EVs could increase peak electricity demand, resulting in higher prices for electricity consumers. The vehicle-to-grid (V2G) technology uses electric vehicles (EVs) as a power source and regulator in the power grid, while electricity from the grid can be used as a load and a source to the grid when necessary [8]. Charging stations for electric cars need to be put in a lot of places, which could help the local economy grows and create more job opportunities. Additionally, electric vehicles should add some welcome flexibility to the energy system. During the night, when the price of energy is low, electric vehicles act as pumped-storage units by storing energy and withdrawing it during peak demand periods, when the price is high [9]. Thus, vehicle owners can profit from the price differential and recoup a portion of their initial investment. Figure 2.2 illustrates the energy flow diagram for V2G technology.

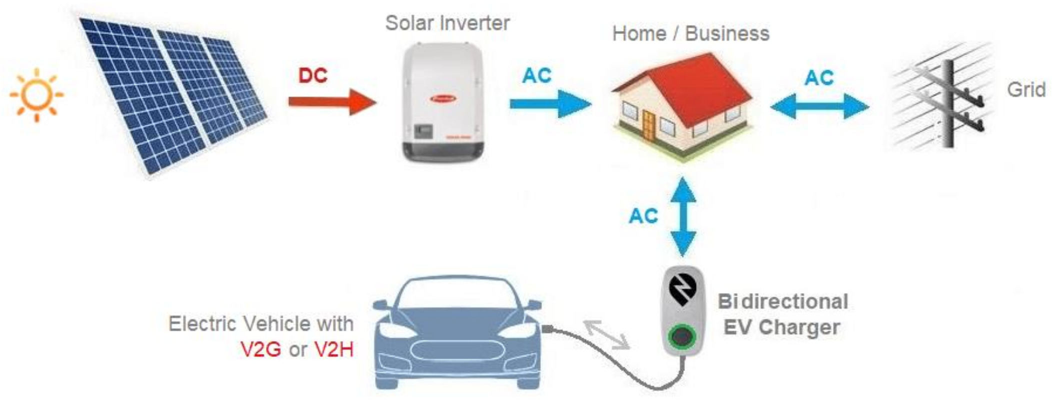

Figure 2.2: Vehicle to Grid energy flow diagram

The economic and employment gains currently enjoyed by foreign oil interests should instead go to domestic economies since electricity is basically a local product, not suited to long-distance commerce. New possibilities emerge for the grid as mobility becomes more dependent on energy. At least one thousand gigawatt hours (10 percent of the battery capacity of one hundred million vehicles, each with a one-hundred-kilowatt hour battery) is readily available from electric vehicles as a distributed energy resource. Demand response and grid storage are two areas where the potential of this decentralised energy resource has not been fully explored.

The adoption of electric vehicles is significantly aided by policies enacted by various levels of government. In the body of published work, numerous policy tools such as purchase subsidies, tax incentives, and exemptions from road tolls or congestion charges have been subjected to analysis and evaluation. The impact of these policies on consumer behaviour, market penetration, and the overall environmental benefits of EVs have been analysed by researchers. According to the findings of several studies, well-designed policies have the potential to significantly accelerate the adoption of electric vehicles (EVs) and contribute to the reduction of carbon emissions in the transportation sector.

In addition to this, researchers have investigated the efficacy of policies regarding the deployment of public charging infrastructure. It is essential for the widespread adoption of electric vehicles to have charging infrastructure readily available. In the body of research that has been done, various models for the development of charging infrastructure, such as public-private partnerships, financial incentives, and zoning regulations, have been analysed. These studies investigate how the accessibility of charging stations, user convenience, and the expansion of the electric vehicle market are affected by the policies that govern charging infrastructure.

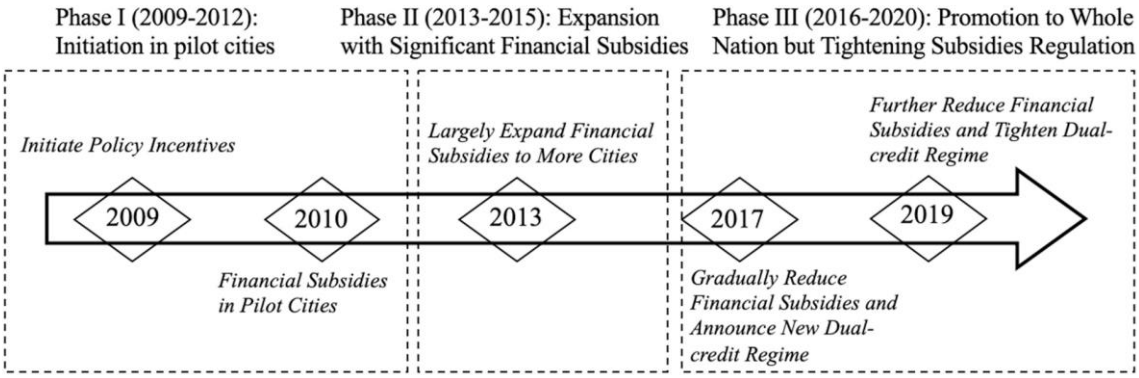

Figure 2.3: Milestones of EV policy in China

China has put into effect several regulations to encourage the widespread use of electric vehicles and their continued development. These all-encompassing policies are evidence of China's commitment to advancing the widespread use of electric vehicles as a method of providing environmentally responsible transportation. The move from Phase I to Phase III of China's national electric vehicle (EV) policy incentives is depicted in Figure 2.3, which can be found here. During Phase I, which took place between 2009 and 2012, the primary emphasis was placed on pilot projects in 25 different cities, and financial subsidies were provided, in most cases, for the public transportation sector [10].

During Phase II, which lasted from 2013 to 2015, the number of EV pilot projects was increased to 88 cities, and the amount of funding allocated to subsidies for the public and private transportation sectors was significantly increased. Domestic consumers were able to afford electric vehicles at prices that were comparable to those of conventional automobiles, which led to a rapid growth in the adoption of EVs during this phase. During this phase, improvements were made to both the infrastructure and the technical performance of high-end electric vehicle models.

During Phase III, which lasted from 2016 to 2020, the emphasis was placed on encouraging the development of electric vehicles across the country while also tightening the regulations governing subsidies. At the national level, the entire industrial chain of the electric vehicle (EV) industry was established and upgraded, and there was a shift toward promoting technological innovation and improving energy efficiency. The central government's financial support for electric vehicle development has been gradually decreasing, while at the same time, more stringent regulations have been put in place to guide and drive sustainable EV development. These government subsidies have been an essential factor in boosting investment, propelling industry expansion, and shortening the ramp-up time for the widespread adoption of electric vehicles in China. They have resulted in a substantial rise in EV sales, which has contributed to the EV market's explosion since the latter half of 2015.

Life cycle assessment (LCA) research has been conducted on an extensive scale to investigate the environmental impact of electric vehicles. A life cycle assessment, or LCA, is an evaluation of a product's impact on the environment throughout its entirety, from the extraction of raw materials to the product's use and eventual disposal. Comparative life cycle assessments (LCAs) between electric vehicles and conventional vehicles powered by internal combustion engines (ICEVs) have been conducted numerous times. Even when considering the various types of electricity generation that can be used for charging, the findings indicate that electric vehicles, in general, have lower life cycle emissions.

In addition, researchers have investigated the possible synergies that could exist between electric vehicles and renewable energy sources. Integration of electric vehicles (EVs) with the power grid by means of vehicle-to-grid (V2G) technology has garnered a lot of attention recently. The ability for electric vehicles (EVs) to act as energy storage systems and to provide grid services is made possible by V2G, which enables bidirectional power flow between EVs and the grid. Several studies have been conducted to investigate the environmental and economic benefits of V2G integration. These benefits include peak load shaving, grid stability, and the integration of renewable energy.

EV adoption addresses a variety of challenges, including those related to policy and the impact on the environment. The need for long-term policy stability to support sustained growth in the electric vehicle market, the need to ensure equitable access to charging infrastructure, and the need to address the environmental impact of battery manufacturing and disposal are some of these issues. Researchers and policymakers are still hard at work developing comprehensive policy frameworks that take these challenges