ANALYSIS AND MODELLING OF ULTRACAPACITOR

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Dedicated to my beloved parents

Rai bin Ngah Mat Ali & Rohani binti Jusoh

Siblings

Nor Arina binti Rai

Nor Raidah binti Rai

Muhamad Najmi bin Rai

Muhamad Hisyam bin Rai

and

All my friends in MEP programme

for their support and encouragement

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ABSTRACT

Ultracapacitor is one of most popular device for energy storage system because of it capability that have high charge/discharge efficiency, can operate at high current, have long life cycle and no chemical reaction involve in store and release of energy. Ultracapacitor modelling is important for the electrical system analysis and equipment design. An efficient and high accuracy model can help electrical engineers thoroughly understand ultracapacitor's characteristics. A commercial ultracapacitor cell is characterized under standard procedures to assess its performance. This project focuses on the analysis and modelling of ultracapacitor cell characteristic. Two experiments involve which are charging/discharging test and AC Impedance test. The charge / discharge test is to determine ultracapacitor cell ability on charge and discharge performance. AC impedance test/ Electrochemical impedance spectroscopy (EIS) is to measure the complex impedance of ultracapacitor. The purpose of the test is to determine capacitance and equivalent series resistance. Based on experiment result, parameters and analysis, the equivalent circuit model of ultracapacitor is proposed. After that, the proposed model is simulated with MATLAB/Simulink and EIS Spectrum Analyser for verification. Then, the simulation result carried out is analysed and compared with experiment results. Based on ultracapacitor characteristic, the electrical circuit modelling was present in this thesis and can be used for power electronic, backup memory, heavy transportation application, hybrid electric vehicles and as power back up for UPS application.

ABSTRAK

Ultracapacitor ialah satu daripada peranti paling popular untuk sistem simpanan tenaga disebabkan ia mempunyai keupayaan untuk mengecas/menyahcas pada kecekapan yang tinggi, boleh beroperasi pada arus yang tinggi, mempunyai kitaran umur yang panjang dan tiada tindak balas kimia terlibat dalam penyimpanan dan pembebasan tenaga. Model Ultracapacitor penting untuk analisis sistem elektrik dan reka bentuk peralatan. Kecekapan tinggi dan kejituan model boleh membantu jurutera elektrik memahami sifat ultracapacitor. Sel ultracapacitor komersial akan digunakan untuk ujikaji berdasarkan standart prosedur untuk menilai prestasinya. Projek ini menumpukan kepada analisis dan model sel ultracapacitor. Dua eksperimen terlibat iaitu ujian mengecas/menyahcas dan ujian arus ulang-alik galangan. Ujian mengecas/menyahcas adalah untuk menentukan kebolehan prestasi sel ultracapacitor mengecas/menyahcas. Ujian arus ulang-alik galangan / Elektrokimia Galangan Spektroskopi adalah untuk mengukur nilai kompleks galangan ultaracapacitor. Tujuan ujian ialah adalah untuk menentukan nilai rintangan siri setara dan nilai capcitor. Berdasarkan keputusan eksperimen, parameter dan analisis, model litar elektrik setara ultracapacitor dicadangkan. Selepas itu, model cadangan disimulasikan dengan MATLAB / Simulink and EIS Spectrum Analyser untuk pengesahan. Kemudian, keputusan simulasi yang dijalankan dianalisis dan dibandingkan dengan hasil ujian. Berdasarkan sifat ultracapacitor melalui ujian yang dijalankan, model litar elektrik dicadangan didalam tesis ini dan boleh digunakan untuk alatan elektronik kuasa, aplikasi pengangkutan, kenderaan hibrid elektrik dan aplikasi untuk alat bantuan ingatan.

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LIST OF ABBREVIATIONS

EDLC	-	Electrical Double Layer Capacitor
AC	-	Alternating Current
EIS	-	Electrochemical Impedance Spectroscopy
ESR	-	Electrical Series Resistance
H2SO4	-	Sulphuric Acid
KOH	-	Potassium Hydroxide/ calcium hydroxide
EPR	-	Electrical Parallel Resistance
NI	-	National Instrument
PGSTAT	-	Potentiostart/Galvanostart
FRA	-	Frequency Response Analyser
I	-	Current
V	-	Voltage
P	-	Power
UC		Ultracapacitor

LIST OF SYMBOLS

Q	-	Charge
R	-	Resistance
L	-	Inductance
C	-	Capacitance
Z	-	Impedance
π	-	Pi (3.141593)
f	-	Frequency
Ω	-	Ohm
F	-	Farad

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CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, ultracapacitor become an alternative and complementary device for energy storage system. Its ability to fast charge/discharge and long life cycle give an advantage of ultracapacitor in a lot of electrical and electronic application. Ultracapacitor also known as supercapacitor or electric double layer capacitor (ELDC) are one type of an electrochemical device that stores electrical charge in the electrical double layer surface.

The first electrical device using double layer charge storage was invented in 1957 by H.I. Becker from General Electric. Unfortunately, Becker's device was not practical because it is similar to a flooded battery with both electrodes need to immerse in a container of electrolyte and this device was never been commercialized [1]. As a rapid development in technology, a lot of researches have been done to produce an electric double layer capacitor. Varies type of ultracapacitor have been develop based on its application as electrical energy storages device in power electronic system, industrial application, heavy transportation application, hybrid electric vehicles, UPS system and memory backup application.

Ultracapacitor have become a popular device in many applications because of its characteristic that give advantages over other energy storage device. The energy density of the existing ultracapacitor range is about 1 to 10 Wh/kg and its power density range typically of 2000 to 20000 W/kg as compared to electrochemical batteries that have an energy density range about 100 Wh/kg but lower in power density range 100 to 500W/kg [2]. Furthermore, ultracapacitor have high efficiency, which can stand at higher current and temperature, have a long life cycle and an environmental friendly because it's not involve in any chemical reaction while store electrical energy as compare to other energy storage device.

1.2 Problem Statement

Ultracapacitor are being used in many applications in electrical and electronic application, as an energy storage device. Ultracapacitor modelling plays an important role for the electrical system analysis and equipment design. The ultracapacitor model can provide detail information and equivalent electrical circuit modelling of energy storage device. An efficiency and high accuracy model can help electrical engineer to understand ultracapacitor characteristics.

1.3 Objective

The main objective of this project is:

- To study the characteristic of ultracapacitor.

- To performed in lab testing for ultracapacitor using charge/discharge and AC Impedance test.

- To proposed an equivalent electrical circuit model of tested ultracapacitor.

- To simulate equivalent electrical circuit model using MATLAB/Simulink and EIS Spectrum Analyser.

1.4 Scope and Aim of Study

These projects focus on modelling of ultracapacitor characteristic. This project needs in lab test and model of the ultracapacitor equivalent circuit. It involves two parts which are in lab test of ultracapacitor characteristic and modelling of the ultracapacitor using the equivalent electrical circuit model. There are two types of in lab test require which is charge/discharge test and AC impedance test. The charge / discharge test is to determine ultracapacitor cell ability on charge and discharge performance. AC impedance test/ Electrochemical impedance spectroscopy (EIS) is to measure the complex impedance of ultracapacitor. Based on experiment result, parameters and analysis, the equivalent circuit model of ultracapacitor is proposed. After that, the proposed model is simulated with MATLAB/Simulink and EIS Spectrum Analyser for verification. Then, the simulation result carried out is analysed and compared with experimental results.

1.5 Report Outlines

The thesisconsists of five chapters. In the first chapter, it discusses the project background, problem statement, objectives, scope and report outline.

Chapter 2 presents background, characteristic of ultracapacitor, related work and an overview of ultracapacitor model and parameter identification method. The principle of ultracapacitor structure and material are explained in detail in this chapter.

In chapter 3, the focus is on detail description for in lab test carried out. It is clear and concise of work performed. This chapter describes the test circuit and method used to obtain lab data which will be used to develop ultracapacitor model.

In chapter 4, the lab result and equivalent electrical circuit modelling of ultracapacitor is attached. This chapter represented in the form of diagrams, waveform of test result and simulation result of ultracapacitor model. The comparison and analysis are made in order to achieve objectives. Analysis of data, such as discusses on the outcome of research in relation to the result are obtained.

Lastly, the conclusion about the project is written on the fifth chapter. It is also provide suggestions and recommendations for future work.

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