Faculty of Electrical Engineering

BATTERY CAPACITY ESTIMATION ANALYSIS BASED ON TIME-FREQUENCY DISTRIBUTION

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A thesis submitted in fulfilment of the requirements for the degree of Master of Science in Electrical Engineering

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DECLARATION

I declare that this thesis entitle "Battery Capacity Estimation Analysis Based On Time-Frequency Distribution" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for award of Master of Science in Electrical Engineering.

Signature : ……...............................

Supervisor Name : Prof Madya Dr. Abdul Rahim Bin Abdullah

Date :......................................

DEDICATION

I dedicate my dissertation work towards my family, my respectful and helpful supervisor, co-supervisor, examiners, collaboration lecturer and all my friends especially from Advanced Digital Signal Processing Group (ADSP) for their support cooperation in helping me to complete this research and thesis.

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ABSTRACT

The rising crude oil prices and awareness of environmental issues led to increasing the development of energy storage system. Due to this reason, rechargeable batteries are beneficial options for energy storage. Improper handling of the battery during the high discharge rate and overcharging will cause the premature failure to the battery. Obtaining an accurate data of battery parameter is important because it will avoid unexpected system interruption and prevent permanent damage to the internal structure of the batteries. This research presents the charging and discharging battery signals analysis using periodogram and time-frequency distribution (TFD) which is spectrogram. The analysis focuses on four types of batteries which are lead acid, nickel-cadmium, nickel-metal hydride and lithium-ion. The nominal voltage for batteries are used 6V and 12V while the capacities is in the range of 5Ah to 50Ah, respectively. The raw data of batteries charging and discharging signals are collected via simulation using MATLAB 2013 for various voltages and battery capacities. Then, the signals are transformed into periodogram and spectrogram. Periodogram represents signal in frequency domain while spectrogram represents signal in time-frequency representation (TFR). The signal parameters that estimated from the spectrogram are instantaneous voltage root mean square (V_{RMS}), instantaneous voltage direct current (V_{DC}) and instantaneous voltage alternating current (V_{AC}). The result shows the decreased voltage signal with an increased battery capacity. The highest voltage signal is at 5 Ah and the lower voltage signal at 50Ah. Besides, the battery capacities can be identified by using formula that have been defined by using the curve fitting tools from MATLAB. An equation is defined based on correlation between voltage alternating current (V_{AC}) and battery capacities (Ah). An experimental test also conducted to capture the real data for battery signals. The outcome of this research shows the application of spectrogram clearly give the information of the performance characteristic of battery at various operating conditions.

ABSTRAK

Kenaikan harga minyak mentah dan kesedaran mengenai isu-isu alam sekitar telah membawa kepada peningkatan pembangunan sistem penyimpanan tenaga. Oleh sebab ini, bateri boleh dicas semula adalah pilihan yang bermanfaat untuk penyimpanan tenaga. Pengendalian bateri yang tidak betul semasa kadar pelepasan yang tinggi dan pengecasan berlebihan akan menyebabkan kegagalan awal pada bateri. Memperolehi data yang tepat mengenai parameter bateri adalah penting kerana ia dapat mengelakkan gangguan sistem yang tidak dijangka dan mencegah kerosakan kekal kepada struktur dalaman bateri. Kajian ini membentangkan analisis isyarat mengecas dan menyahcas bateri menggunakan periodogram dan taburan masa frekuensi (TFD) iaitu spectrogram. Analisis ini memberi tumpuan kepada empat jenis bateri iaitu asid plumbum, nikel-kadmium nikel-logam hidrida dan lithium-ion. Voltan nominal yang digunakan untuk bateri ialah 6V dan 12V manakala kapasiti adalah dalam lingkungan 5Ah hingga 50Ah. Data isyarat mengecas dan menyahcas bateri dikumpulkan melalui simulasi menggunakan MATLAB 2013 untuk pelbagai voltan dan kapasiti bateri. Kemudian, isyarat diubah menjadi periodogram dan spectrogram. Periodogram mewakili isyarat dalam domain frekuensi manakala spectrogram mewakili isyarat dalam perwakilan masa-frekuensi (TFR). Parameter isyarat yang dianggarkan dari spectrogram ialah voltan punca min kuasa dua (V_{PMKD}), voltan arus terus (V_{AT}) dan voltan arus ulang alik (V_{AU}).Hasil daripada keputusan menunjukkan isyarat voltan menurun dengan peningkatan kapassiti bateri. Isyarat voltan yang tertinggi ialah 5A dan isyarat voltan yang rendah ialah 50Ah. Selain itu, kapasiti bateri boleh dianggarkan menggunakan formula yang telah ditentukan menggunakan alat pemasangan lengkung dari MATLAB. Persamaan ditakrifkan berdasarkan korelasi antara voltan arus ulang alik (V_{AU}) dan kapasit bateri (Ah). Ujian eksperimen juga dijalankan untuk mendapatkan data sebenar untuk isyarat bateri. Hasil kajian ini menunjukkan penggunaan spectrogram dengan jelas memberi ciri prestasi bateri pada pelbagai keadaan operasi.

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LIST OF ABBREVIATIONS

A	-	Ampere
Ah	-	Ampere hour
e	-	Electron
EKF	-	Extended Kalman filter
Exp	-	Exponential
FFT	-	Fast Fourier transform
FT	-	Fourier transform
H^+	-	Proton
H_2O	-	Water
H_2SO_4	-	Sulphuric acid
Hz	-	Frequency unit, Hertz
Li-ion	-	Lithium-ion
$LiCoO_2$	-	Lithium cobalt oxide
$LiMn_2O_4$	-	Lithium manganese oxide

$LiNiO_2$	-	Lithium nickel oxide
$LiPF_6$	-	Lithium hexafluorophosphate
LiC_6	-	Lithium graphite
Ni-CD	-	Nickel Cadmium
Ni-MH	-	Nickel-Metal Hydride
$Ni(OH)_2/NiOOH$	-	Nickel hydroxide/ nickel oxyhydroxide
O_2	-	Oxygen
Pb	-	Lead
PbO_2	-	Lead dioxide
SOC	-	State Of Charge
STFT	-	Short Time Fourier Transform
TFD	-	Time-frequency distribution
TFR	-	Time-frequency representation
V_{AC}	-	Voltage alternating current
V_{DC}	-	Voltage direct current
V_{RMS}	-	Voltage root means square
WT	-	Wavelet transform
$Zn\text{-}MnO_2$	-	Zinc-manganese dioxide

LIST OF SYMBOL

A	-	Ampere
Ah	-	Ampere hour
E_0	-	Battery constant voltage
t	-	Time
f	-	Frequency
f_1	-	Fundamental frequency
fr	-	Frequency resolution
fs	-	Frequency sampling
it	-	Actual battery charge
K	-	Polarization constant (V/Ah) or polarization resistance
N	-	Number of signal length
N_s	-	Number of samples
N_W	-	Number of window length
Q	-	Battery capacity
$S(t,f)$	-	Time-frequency distribution
$S_x(t,f)$	-	TFR of signal
T_r	-	Time resolution
V	-	Voltage
$V_{AC}(t)$	-	Voltage alternating

V_{dis}	-	Battery voltage during discharge process
$V_{DC}(t)$	-	Voltage direct current
$V_{RMS}(t)$	-	Instantaneous RMS voltage
$w(t)$	-	Window function
$x(t)$	-	Time domain signal

LIST OF PUBLICATIONS

A. Journal

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Batteries are one of the most successful creations in the history of mankind (Erdinc et al., 2009) . It plays an important role in future technology since it potentially to be applied as devices to store energy. Besides, it could not only used to store energy from various source and release the load during demand, but it also, supply enough power for the demand of electricity (Schainker, 2004). Many of today's technologies are powered by batteries such as portable electronic, uninterruptible power supply (UPS), renewable energy, and cars (Li et al., 2015). The battery used for each device is different, depending on the power requirements and for what they are used (Birkl and Howey, 2013).

Batteries are generally, divided into two categories, namely, non-rechargeable (or primary cell) and rechargeable (or secondary cell). A non-rechargeable battery is designed to be used once and discarded after it is depleted. Meanwhile, a rechargeable battery can be charged multiple times to refill its store of energy (Divya and stergaard, 2009).

Rechargeable batteries store energy by holding different electrochemically active materials together. Rechargeable batteries generate and store free electrons (electrical potential energy) for long periods of time and release them when needed (Subburaj and Bayne, 2014). Rechargeable batteries are characterized (in addition to their ability to be recharged) by high power density, good low-temperature, and high discharge rate. Their energy densities are generally lower than those of non-rechargeable batteries (Chuang, 2015).