VOL. 10, NO. 15, AUGUST 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

NICKEL-METAL HYDRIDE BATTERY ANALYSIS USING SPECTROGRAM

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ABSTRACT

Rechargeable battery plays an important role in future technology since it potentially to be applied as the energy storage element in technology applications. However, to improve the efficiency of the battery, the system needs an accurate information of the battery parameters. Thus, this paper presents the implementation of time-frequency analysis technique which is spectrogram to analyze battery charging and discharging of Nickel-Metal Hydride (Ni-MH). Signal of charging and discharging from the battery is translated into time-frequency representation (TFR) to estimate the signal parameters. The signal parameters are such as instantaneous of voltage root mean square, voltage direct current and voltage alternating current. Then, characteristics of the Ni-MH battery is calculated based on the signal parameters. This analysis focuses on Ni-MH battery with nominal voltage of 6 and 12V and their storage capacities from 5 to 50Ah, respectively. The results show that the analysis of charging and discharging of the Ni-MH battery using spectrogram is capable to identify the characteristics of the battery and a new formula to represent the relationship between battery storage capacity and voltage alternating current is present.

Keywords: spectrogram, nickel metal hydride, time-frequency, instantaneous RMS voltage.

INTRODUCTION

Nowadays, the main problem of our planet is energy; with fossil energy are not infinite sources, humanity are forced to develop other energy sources. Therefore, renewable energy systems were developed many years ago like battery system, which in addition to be a source for portable and replace fossil energy in many applications (Yao, 2013). In batteries, the energy compounds act as a storage medium and it converts chemical energy into electric energy. This is done by the transfer of electrons from one material to another through an electric circuit. This transfer results in the oxidation of a reducing agent (the anode) and the reduction of an oxidizer (cathode), a process called oxidation-reduction or REDOX. The term "oxidation" means that a material is losing electrons; the term "reduction" means that the material is gaining electrons (Divya, 2009 and Moubayed, 2008)

Nickel-Metal Hydride (Ni-MH) batteries are among the most used devices to store and deliver energy. The NiMH battery has become pervasive in today's technologies, climate, powering everything from cellular phones to hybrid electric vehicle. The Ni-MH battery started its life as an evolution from the Nickel hydrogen battery. It is an attractive replacement for the Nickel Cadmium (Ni-Cd) battery because of its low-cost, non-toxic, long cycle life and offers a higher specific energy (Pan, 2002).

Battery parameters are very important information to the users of the battery system. Normally, the manufacturer has the choices of building a battery for a long run time and low cost, but it will have a limited service life. Therefore, the analysis of battery signal is important to accurately identify the parameters of battery model in order to fulfill good battery management functions (Lee, 2011).

Different methods and analytical techniques have been used to identify battery parameters. For example, in (Moubayed, 2008) and (Yao, 2013) uses an equivalent circuit model to develop lead acid and lithium Ferro phosphate battery to identify the battery parameters. Besides that, (Daowd, 2013) use standard battery test for parameter estimation were represented with different battery models parameters estimation methods.

In this paper, the spectrogram is applied to represent the Nickel-Metal Hydride battery charging and discharging voltage signal in, jointly, time-frequency representation (TFR). From the TFR, parameters of the battery signals are estimated such as instantaneous of voltage root mean square, voltage direct current and voltage alternating current. Then, characteristics of the signals are calculated from the signal parameters and will be used to identify the nominal voltage and storage capacity of Ni-MH battery.

BATTERY

Nickel-Metal Hydride Battery

The rechargeable sealed nickel-metal hydride battery is a relatively new technology with characteristics similar to those of the sealed nickel-cadmium battery. The principal difference is that the nickel-metal hydride battery uses hydrogen, absorbed in a metal alloy, for the active negative material in place of the cadmium used in the nickel-cadmium battery (Pan, 2002). The metal hydride electrode has a higher energy density than the cadmium electrode. Therefore the amount of the negative electrode used in the nickel-metal hydride cell can be less than that used in the nickel-cadmium cell. This allows for a larger volume for the positive electrode, which results in a higher capacity or longer service life of the metal hydride battery (Viera, 2006). Furthermore, as the nickel-metal hydride battery is free of cadmium, it is considered more environmentally friendly than the nickel-cadmium battery and may reduce the problems associated with the disposal of rechargeable nickel batteries (Rongeat, 2006).

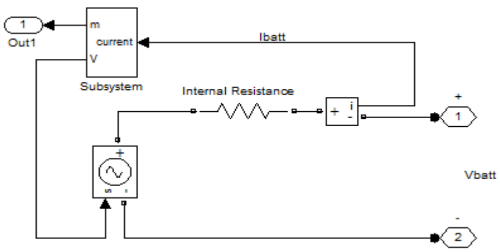

Figure-1. Battery Model.

This paper uses a Ni-MH battery model from MATLAB/SIMULINK to generate signals of battery charging and discharging where their equations can be expressed, respectively, as below:-

$$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{Q-it}i - R.i + Exp(t) \quad (1)$$

$$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{it-0,1.Q}i - R.i + Exp(t) \quad (2)$$

V = battery voltage (V)
E0 = battery constant voltage (V)
K = polarization resistance (Ω)
Q = battery capacity (Ah)
it = actual battery charge (Ah)
R = internal resistance (Ω)
i = actual battery current (A)

SPECTROGRAM

The spectrogram is the square magnitude of the short time Fourier transform (STFT) that represents a signal in three-dimensional of the signal energy with respect to time and frequency domain. This technique roughly reflects how frequency content changes over time (Ahmad, 2014).

$$S_x(t,f) = \left|\int_{-\infty}^{\infty} x(\tau)w(\tau - t)e^{-j2\pi f}dt\right|^2 \quad (3)$$

Where x (τ) is the input signal and w (t) is the window observation window.

SIGNAL PARAMETERS

In order to provide the information of the signal in time, the signal characteristic is estimated from the calculated TFR. The signal parameters are listed as instantaneous of voltage RMS, voltage direct current and voltage alternating current. The information from the signal parameters are then used to identify the Ni-MH battery nominal voltage and storage capacity (Norddin, 2013).

Instantaneous Voltage Root Mean Square

The instantaneous voltage RMS is the square root of the arithmetic mean of squares of the function of continuous waveform. It can be defined as (Abidin, 2012):

$$V_{rms}(t) = \sqrt{\int_0^{f_{\max}} S_x(t,f)df} \quad (4)$$

Where S_x *(t, f)* is the time-frequency distribution and fmax is the maximum frequency of interest.

Instantaneous Voltage Direct Current

The direct current voltage can be calculated as;

$$V_{DC}(t) = \sqrt{\int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_x(t,f)df} \quad (5)$$

Where V_{DC} (t) is direct current voltage, (Δf)/2 is power system frequency and S_x *(t, f)* is spectrogram.

Instantaneous Voltage Alternating Current

Instantaneous voltage alternating current, V_{AC} (t), consists of harmonic and non-harmonic distortion. The V_{AC} (t) can be defined as;

$$V_{AC}(t) = \sqrt{V_{rms}(t)^2 - V_{DC}(t)^2} \quad (6)$$

Where Vrms(t) is instantaneous voltage root means (RMS) and V_{DC}(t) is voltage direct current.

RESULT AND ANALYSIS DATA

The battery is simulated using MATLAB/SIMULINK. The simulation starts from zero charge and then continues to rise until 100% of the state of charge (SoC) is achieved. Then the battery is operating until it reaches 25% of discharge and then it is starts charging up to 100% again. The SoC is defined as the capacity still available in a battery cell. It is normally expressed as a percentage of the rated capacity of cell and a 0% SoC means empty battery while a 100% SoC means fully charged battery. The battery parameter for Ni-MH is assumed, that internal resistance is constant, no self-discharge, no memory effect and temperature have no effect on the parameter.

Figure-2 (a) and (b) shows, battery charging and discharging for Ni-MH battery.

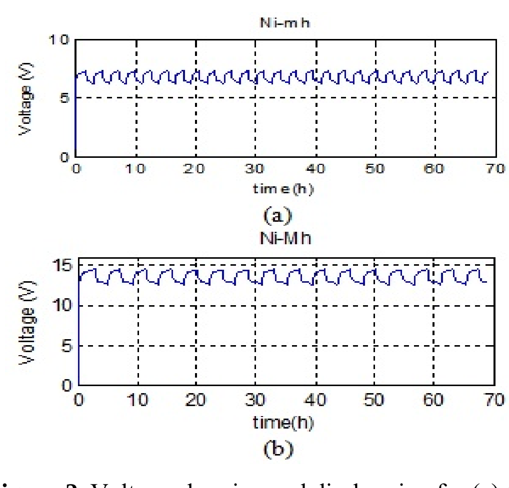

Figure-2. Voltage charging and discharging for (a) 6V with 10 Ah (b) 12V with 20Ah.

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ARPN Journal of Engineering and Applied Sciences

Based on Figures-3 (a) and (b), the contour of TFR detects 0 Hz for the frequency at DC component. The red line represents the highest amplitude and the blue line represent the lowest amplitude.

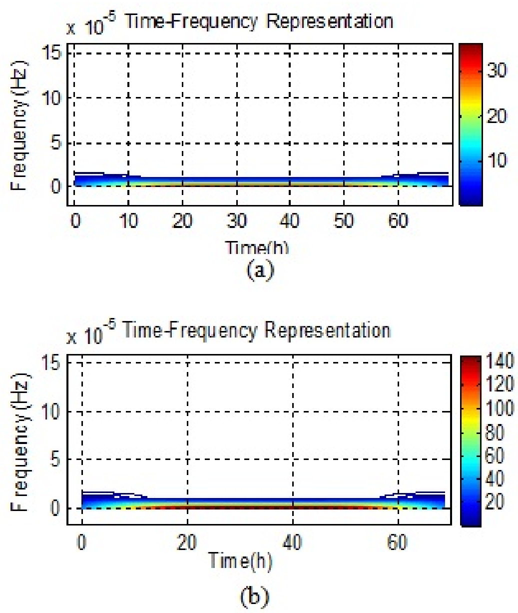


Figure-3. Time Frequency Representation (a) 6V with 10 Ah (b) 12V with 20Ah.

Figures-4 (a) and (b) show, the voltage RMS for 6V with 10Ah and 12V with 20Ah. The voltage RMS can be calculated using equation 4. From the calculation the value of 6V with 10Ah is 7.4280V while for 12V with 20Ah is 14.8294.

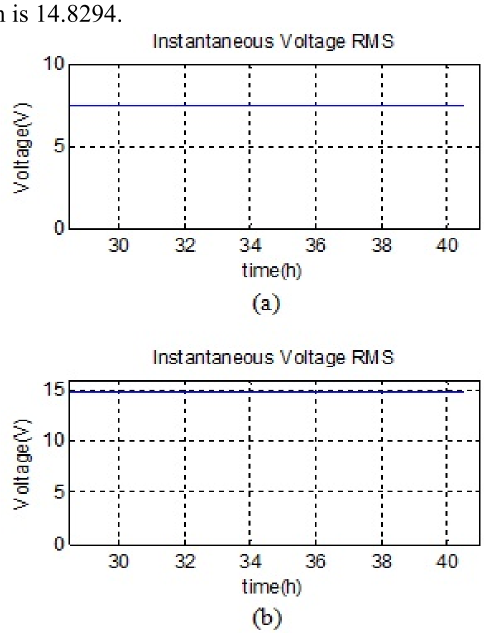


Figure-4. Voltage RMS (a) 6V with 10Ah (b) 12V with 20Ah.

The voltage DC for 6V and 12V battery are shown in Figures-5. The voltage DC represents the nominal battery voltage. The nominal value for 6V with 10Ah is 7.4152V while for the 12V with 20Ah the voltage value is 14.8304V.

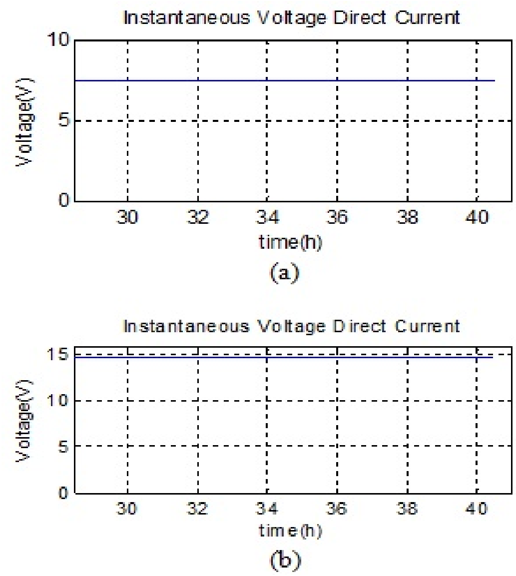


Figure-5. Voltage direct current (a) 6V with 10Ah (b) 12V with 20Ah.

By referring to Figures-5 (a) and (b), the graphs show the value of voltage alternating current for Ni-MH battery. For 6V with 10Ah, the value is 0.4359V while for 12V with 20Ah the value is 0.7304V.

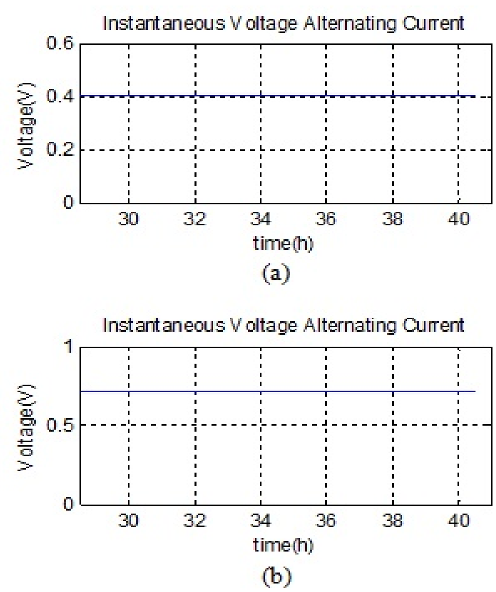
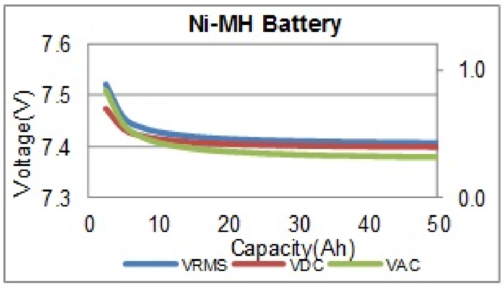
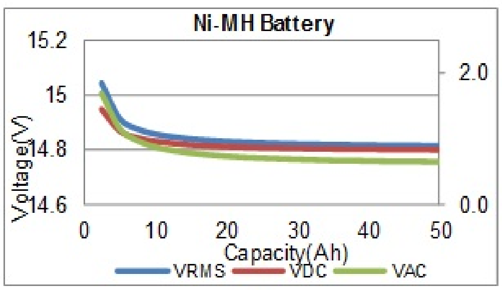


Figure-6. Voltage alternating current (a) 6V with 10Ah (b) 12V with 20Ah.

The spectrogram data of V_{rms} (t), V_{DC} (t) and V_{AC} (t) with various capacity storage is presented in figure 6. From the graph, the X-axis represents the storage capacity (Ah) while the Y-axis represents the instantaneous V_{rms} (t), V_{DC} (t) and V_{AC} (t). For 6V and 12V, the value for V_{rms} (t) are 7.4564V to 7.4071V and 14.9128V to 14.8141 while for V_{DC} (t) are from 7.4V to 7.5V and 14.9459V to 14.8V. The V_{AC} (t) value is calculated from both of V_{rms} (t) and V_{DC}(t) value using equation 6. From the V_{DC} value, the nominal battery voltage can be estimated.



(a)



(b)

Figure-6. Spectrogram data for (a) 6V with 10Ah (b) 12V with 20Ah.

Figure-7 shows, result for battery capacity. The graph is produced using equation 7 and to verify the performance, the mean absolute percentage error (MAPE) is used to identify the accuracy equation. From the graph, the Y-axis represents the storage capacity while the X-axis represents the V_{AC}. Thus, the storage capacity can be estimated.

$$Q = 800\exp(-5.5(V_{AC}) + 4.8 \tag{7}$$

Where Q is battery capacity and V_{AC} is alternating current voltage.

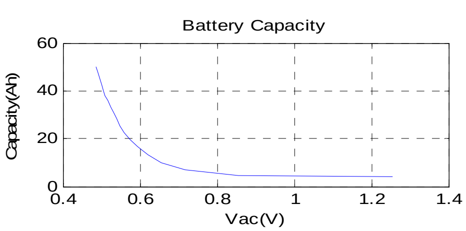


Figure-7. Battery storage capacity.

CONCLUSIONS

The result shows the characteristic of the signal through Time-frequency representation (TFR) which is by using a spectrogram technique to analyses the Ni-MH battery signal. The TFR is estimated to be able to identify signal parameter and then, based on the parameters, signal characteristic can be calculated. Next, the characteristic of Ni-MH battery can be identified. From the result, a new equation was produced to estimate the battery storage using equation 7.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and the Ministry of Higher Education (MOHE) for providing the research grant RAGS/2012/FKE/TK07/1 B00011 for this research.

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