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NICKEL-CADMIUM BATTERY ANALYSIS USING SPECTROGRAM

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ABSTRACT

Energy storage systems become crucial when power generated from power plant does not fulfill peak power load demand. Due to that reason, technologies such as rechargeable battery are beneficial options for energy storage system. The accurate data information about the battery parameter is important, to maintain the battery in a state in which it can fulfill the functional requirements of the application for which it was specified. This paper presents the application of spectrogram in battery signal analysis for Nickel-Cadmium (Ni-Cd). This paper focuses on the analysis of Ni-Cd battery with nominal battery voltage of 6 and 12V with the storage capacity from 5 to 50Ah, respectively. The signals from battery charging and discharging were then analyzed using MATLAB/SIMULINK to obtain the time-frequency representation (TFR). Based on the TFR, the estimation parameters such as instantaneous RMS voltage, instantaneous voltage direct current (V_{DC}) and instantaneous voltage alternating current (V_{AC}) were obtained to visualize the trend of battery signal performance. This study found that the nominal voltage and storage capacity for battery can be estimated through the V_{AC} parameter.

Keywords: nickel-cadmium, time-frequency distribution, instantaneous voltage RMS, instantaneous voltage direct current.

INTRODUCTION

The invention of the battery by Alessandro Volta over 200 years ago was one of those innovation leaps in technology that occur from time to time. Many of the technologies we rely on today are enabled by batteries, including cellular phones, laptop computers and cars. The type of battery for a device that used every day depends on the power requirements and how it is used (Bergveld, 2002).

A primary cell or non-rechargeable battery is designed to be used once and discarded after it is depleted while for secondary cell or rechargeable battery, it can be recharged multiple times to refill its store of energy (Divya, 2009). It stores energy by holding different electro-chemically active materials together. The batteries generate and store free electrons (electrical potential energy) for long periods of time and deliver that energy when the battery user demands it (Wen Yao, 2013).

Rechargeable or secondary battery plays important role in future technology since it potentially to be applied as the energy storage element in technology applications (Sparacino, 2012). However to improve the efficiency of the battery and even more the new batteries, the system needs the accurate information about the battery parameter which is used in many battery-operated industrial and commercial systems to make the battery-operation more efficient. Therefore, by identifying battery parameters, it will help ensure that its handling will be done safely and in accordance with regulations (Jiang, 2011).

Over recent years, some approaches were proposed with different parameter estimation methods. Among them, (Mauracher *et al*. 1997) develop dynamic modeling of lead acid battery using impedance spectroscopy to identify battery parameters. Besides that, (Wen. Yao *et al*. 2013) and (Maubayed *et al*. 2008) use an equivalent circuit model to develop lithium Ferro phosphate and lead acid battery to identify the battery parameters. (Mohamed *et al.* 2013) use standard battery test to estimate the parameters that represented with different battery model parameter estimation methods while (Livint *et al*., 2007) used the precise determination method of the parameters for the RC battery model but this technique has a lot mathematical expression for extracting the battery parameters. All of these methods are different according to its model battery, degree of complexity, or processing time for estimating the parameters.

The works describes in this paper presents the analysis of signal charging and discharging for nickel-cadmium (Ni-Cd) battery using time-frequency distribution (TFD) which is a spectrogram. Spectrogram is used to identify signal parameters and represent the signals in time-frequency representation (TFR). The parameter of a signal such as instantaneous voltage root mean square (RMS), voltage direct current (V_{DC}) and voltage alternating current (V_{AC}) was estimated from TFR. Then, based on these signal parameters, the signal characteristics can be calculated. The main advantages of this method that it can use for any battery model, as the user builds.

RECHARGEABLE BATTERY

Nickel-Cadmium (Ni-Cd) battery

Nickel–cadmium battery (Ni-Cd) is a type of rechargeable battery using nickel oxide hydroxide as cathode, metallic cadmium as a node, and potassium hydroxide (KOH) as an electrolyte. The abbreviation Ni-

ARPN Journal of Engineering and Applied Sciences

Cd is derived from the chemical symbols of nickel (Ni) and cadmium (Cd). Ni-Cd batteries have a matured technology and use in places where long service life and economy amidst difficult environmental conditions is required. Besides, it has a reputation for being robust and low cost. Due to its robustness, Ni-Cd batteries can be charged at a higher rate and thus a shorter time. However, they suffer from a memory effect, since they lose capacity if recharged before completely discharged.

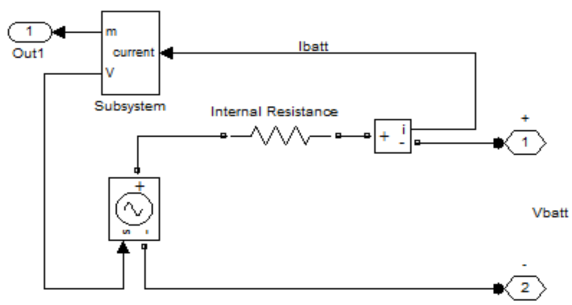

Figure-1. Battery model.

This paper uses a Ni-Cd battery model from MATLAB/SIMULINK to generate signals of battery charging and discharging where their equations can be expressed, respectively, as below (Melentjev, 2013 and Trembley, 2009) :-

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

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

The equation 1 is for battery discharge and whiles the equation 2 for battery charge of battery.

V = battery voltage (V)
E_0 = 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)

TIME-FREQUENCY ANALYSIS TECHNIQUE

Time-frequency analysis technique presents a three-dimensional plot of a signal in term of the signal energy or magnitude with respect to time and frequency. This study focuses on spectrogram to represent time-frequency for Ni-Cd battery (Ahmad, 2014).

Spectrogram

Spectrogram is one of the time-frequency distributions (TFD) that represents the signal energy with respect to time and frequency. The analysis technique is motivated by the limitation of FFT to cater non-stationary signals whose spectral characteristics change in time. The changes are from calculating of the frequency spectrum of compound signal windowed frames. Spectrogram can be defined as (Abdullah, 2013).

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

Where $x\ (\tau)$ is the input signal and $w\ (t)$ is the window observation window.

SIGNAL PARAMETERS

Parameters of the signal are estimated from the time-frequency distribution to recognize the signal information in time. These parameters are important to identify the nominal voltage and storage capacity for Ni-Cd battery (Abdullah, 2008).

Instantaneous voltage RMS

The instantaneous RMS voltage is the square root of the arithmetic mean of squares of the function of continuous waveform. It can define as (Norddin, 2013);

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

Where $S_x\ (t, f)$ is the time-frequency distribution and f_{max} is the maximum frequency of interest.

Instantaneous voltage direct current

The voltage direct current 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} is voltage direct current, $\Delta f/2$ is a power system frequency.

Instantaneous voltage alternating current

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

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

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

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RESULT AND ANALYSIS DATA

A simulation model is built in MATLAB/SIMULINK to evaluate the performance of the system. This simulation consists of Ni-Cd battery with voltage at 6 and 12V and various storage capacities in the range of 5 to 50Ah. The simulation starts with 0% and then continues to rise until 100% of State of Charge (SoC) is achieved. Then, the battery is put to work until it reaches 25% of discharge and its starts charging up to 100% again. The battery is charged and discharged with constant rated current. The battery were charged and discharged for several cycles.

Figure-2 (a) and (b) show the signal charging and discharging for Ni-Cd battery that used voltage at 6V with 25Ah and 12V with 35Ah.

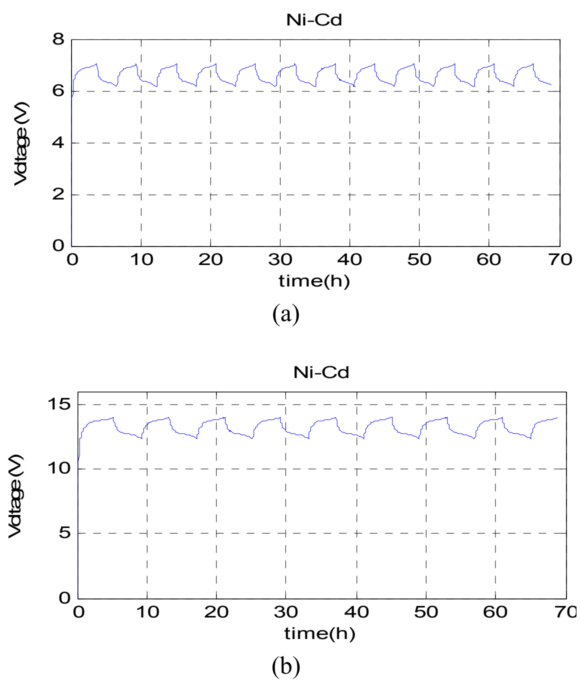

Figure-2. Voltage charging and discharging for (a) 6V with 25 Ah (b) 12V with 35Ah.

Figure-3 (a) and (b) shows the time-frequency representation of the Ni-Cd battery signal. The window size used is 1024. The battery has a 0Hz frequency. Frequency is inversely proportional to time-period. Time-period of the signal is defined as the time for which the signal repeats itself. The DC signals are constant and repeat itself at infinity. Therefore, as a time period is infinity, the frequency is zero. From the indicator, red color represents the highest magnitude while the blue color for the lowest amplitude.

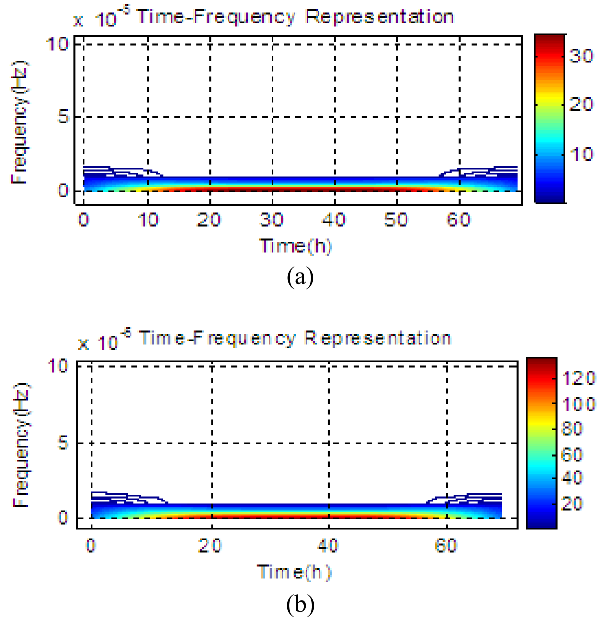

Figure-3. Time frequency representation (a) 6V with 25 Ah (b) 12V with 35Ah.

The signal parameters extracted from TFRs are shown in Figure-4 and 5. Figure-4 (a) and (b) show the value of RMS voltage for 6V with 25Ah and 12V with 35Ah while Figure-5 (a) and (b) show the voltage DC. The value for the voltage RMS are 7.2434 and 14.4746V and for the voltage DC is 7.2322V and 14.4635V. The value is calculated using equation 5 and 6.

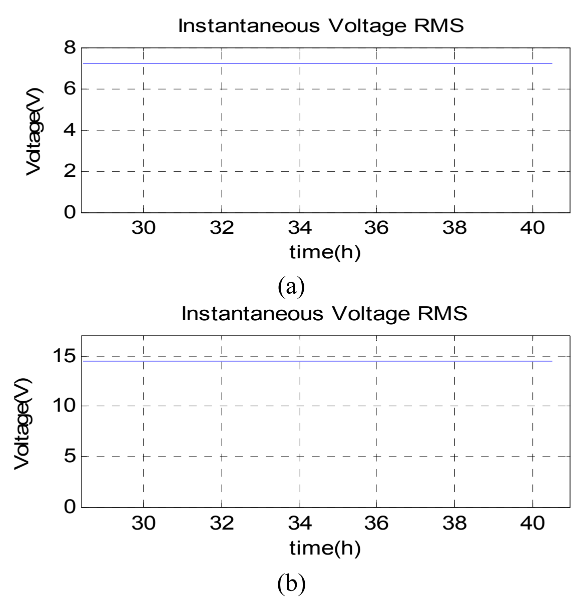

Figure-4. RMS voltage (a) 6V with 25 Ah (b) 12V with 35Ah.

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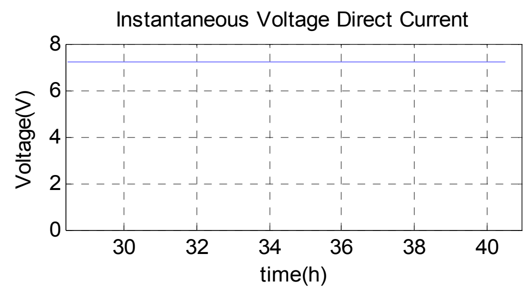
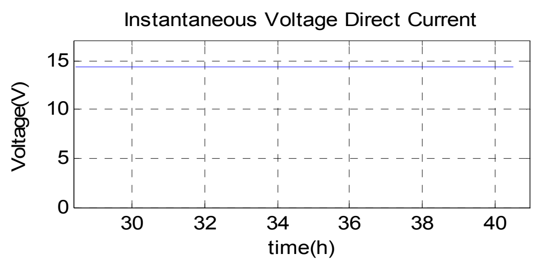


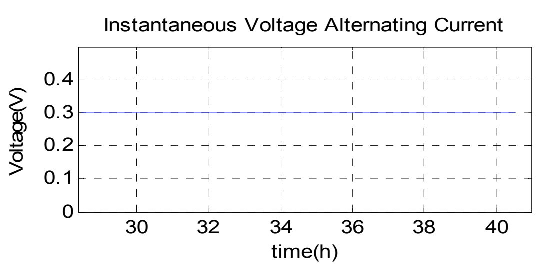
(a)



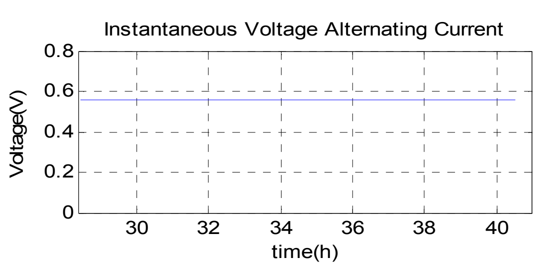
(b)

Figure-5. Direct current voltage (V_{DC}) (a) 6V with 25Ah (b) 12V with 35Ah.

Based on Figure-6 (a) and (b), the graphs show the value of alternating current (V_{AC}) for Ni-Cd battery. The V_{AC} resulting from the alternating value during the battery is charged and discharged. For 6V with 25Ah, the value is 0.2996 while for 12V with 35Ah the value is 0.5668. The voltage AC is calculated using equations 6.



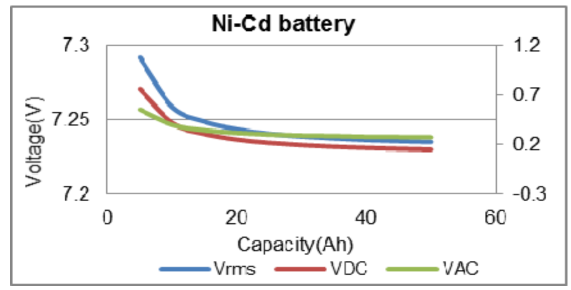
(a)



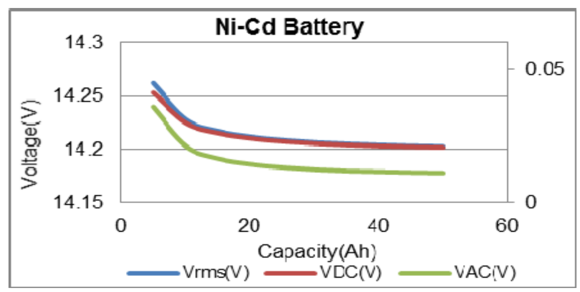
(b)

Figure-6. Alternating current voltage (V_{AC}) (a) 6V with 25Ah (b) 12V with 35Ah.

The signal characteristic of V_{rms}, V_{DC} and V_{AC} were identified. Figure-6 (a) and (b) shows, the overall results for V_{rms}, V_{DC} and V_{AC} for Ni-Cd battery of 6 and 12V. For 6V, the value for V_{rms} and V_{DC} are from 7.3166 to 7.2349V while for 12V the value is in the range of 14.4597V to 14.6334V. The V_{AC} for 6V is 0.8426V to 0.2561V while for 12V; the value is from 0.1598V to 0.5121V.



(a)



(b)

Figure-7. Graphical view of battery storage capacity

By referring on Figure-7, it shows the graphical view of battery storage capacity. The graph is produced using equation 7 and to verify the accuracy of the equation, mean absolute error percentage (MAPE) is used. Thus, the storage capacity of the batteries can be estimated. The battery capacity can be calculated as;

$$Q = 3995\exp(-11(V_{AC})) + 4 \quad (7)$$

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

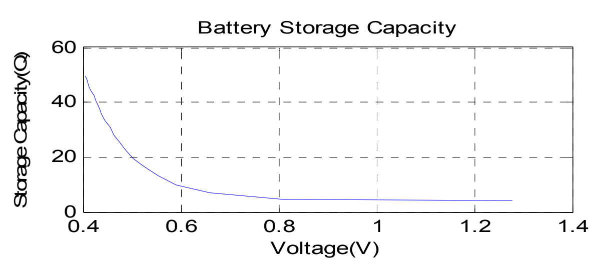


Figure-8. Battery storage capacity.

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CONCLUSIONS

The analysis of voltage signal from the battery charging and discharging for nickel-cadmium has been performed using spectrogram time-frequency analysis technique. From the result the nominal voltage, current and battery storage capacity can be identified and the new equation has been produced to estimate battery storage capacity using V_{AC} parameter.

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