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Battery Parameters Identification Analysis using Periodogram

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Abstract. Batteries are essential components of most electrical devices and one of the most important parameters in batteries is storage capacity. It represents the maximum amount of energy that can be extracted from the battery under certain specified condition. This paper presents the analysis of charging and discharging battery signal using periodogram. The periodogram converts waveform data from the time domain into the frequency domain and represents the distribution of the signal power over frequency. This analysis focuses on four types of batteries which are lead-acid (LA), lithium-ion (Li-ion), nickel-cadmium (Ni-Cd) and nickel-metal-hydride (Ni-MH). This paper used battery model from MATLAB/SIMULINK software and the nominal voltage of each battery is 6 and 12V while the capacity is 10 and 20Ah, respectively. The analysis is done and the result shows that varying capacity produce different power at a frequency and voltage at DC component.

Introduction

A battery today is a source of portable electronic device and one of the most successful inventions in history of mankind. The energy stored in these batteries is limited. Thus, it is important to apply this energy as efficient as possible, to extend the battery life [1]. Batteries are numerous varieties, but all of them share common flaws, such as low energy capacity versus size and poor performance in cold condition [2]. Also, there is a problem of battery capacity discharging, as effective capacity value is getting lower in time with such factors as temperature and battery improper handling speeding up the rate of the discharging process [3].

An accurate battery model in simulation platform is very important to design an efficient battery-powered system. This make the task of selecting the right battery type is important [4]. Different methods and analytical techniques have been used to identify battery parameters. The equivalent circuit model is commonly used by circuit designers to be applied in circuit simulator [5]. For example, L.W.Yao *et al* [6] and N.Maubayed et al [7] use an equivalent circuit model to develop lithium ferro phosphate and lead acid battery to identify the battery parameters. Besides that, M. Daowd *et al* [8] use standard battery test for parameters estimation were represented with different battery models parameters estimation methods.

For this paper, four of the common battery types were chosen, such lead-acid, nickel-cadmium, nickel-metal-hydride and lithium-ion. The periodogram is used to analyse the battery signal using the different capacity and nominal voltage. Firstly, the model is implemented in MATLAB/SIMULINK software using several standard Simulink block. Then, the output signal from battery charging and discharging was analysed using the periodogram. The periodogram converts waveform signal from the time domain into the frequency domain and represents the distribution of the waveform signal power over frequency [9].

Battery Model

In the literature, several studies have been reported regarding to Lead-Acid, Li-ion, Ni-Cd and Ni-Mh. The model is implemented in MATLAB/SIMULINK software using several standards Simulink blocks as shown in figure 1. The equation for each battery is used in the subsystem.

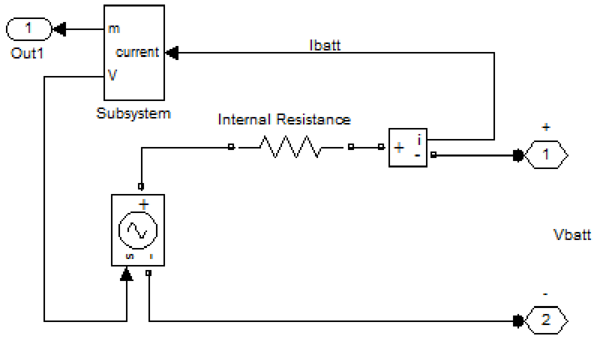


Fig.1: Battery model

The equations for the different type of battery can be expressed as [10];

Lead Acid

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

Lithium Ion

- Discharging $$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{Q-it}i - R.i + A.e^{(-B.it)} \quad (3)$$
- Charging $$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{it-0,1.Q}i - R.i + A.e^{(-B.it)} \quad (4)$$

Nickel Metal-Hybrid and Nickel-Cadmium

- Discharging $$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{Q-it}i - R.i + Exp(t) \quad (5)$$
- Charging $$V_{batt} = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{it-0,1.Q}i - R.i + Exp(t) \quad (6)$$

Where *Vbatt* is no load voltage, E_0 is battery constant voltage, K is the polarization voltage, Q is the battery capacity; *it* is the actual battery charge, A is the exponential zone amplitude, B is the exponential zone time constant inverse Ah^{-1}, Vbatt is the battery voltage, i is the battery current and R is the internal resistance.

Periodogram

The periodogram power spectrum estimate represents the distribution of the signal power over frequency. From the spectrum, the frequency sample values that correspond to the peak value. It is calculated based on the frequency representation of the discrete-time waveform. The periodogram is calculated for the voltage waveform as follows [11]:

$$S_v(f) = \left| \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} v(t)e^{-j2\pi ft}dt \right|^2 \quad (7)$$

Where $S_v(f)$ periodogram in the frequency domain and *v (t)* is the voltage waveform.

The DC voltage can be calculated from periodogram as follow;

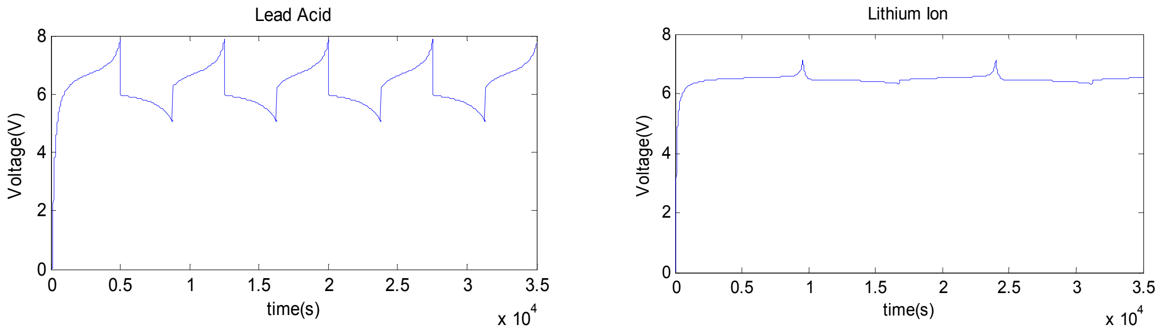
$$V_{DC}(t) = \sqrt{\int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_v(f)df} \quad (8)$$

Where V_{DC} is direct current voltage, $\frac{\Delta f}{2}$ is power system frequency and $S_v(f)$ is periodogram.

Results and Analysis Data

This simulation used different type of battery which is Lead-Acid, Li-ion, Ni-Cd and Ni-Mh. The simulation starts with zero charge and then continues to rise until 100% of State of Charge is achieved. Then the battery is put to work until it reaches 25% of discharge and its starts charging up to 100% again. Charging for each battery is done corresponding to the voltage and storage capacity.

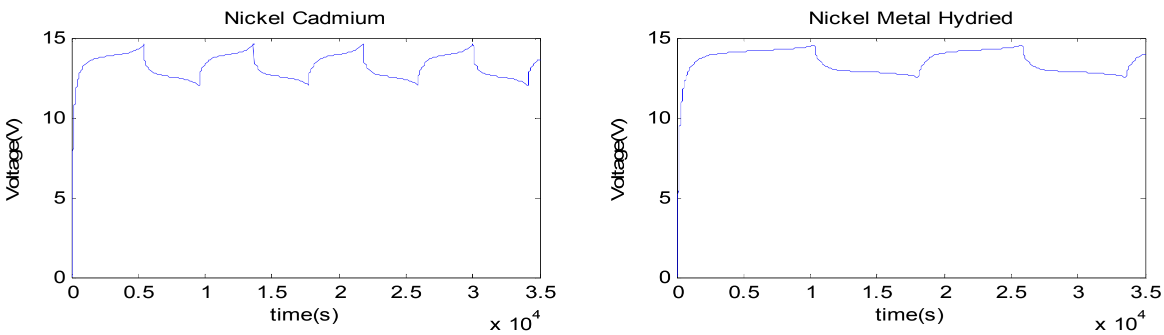
Figures 2 show the battery charging and discharging for Lead Acid and Li-ion. The graph produced is voltage versus time. The different type of battery will produce different forms of voltage. Both of the battery has different time to full charging and discharging. It is due to the difference storage capacity (Ah) of the battery. For the figures 2 (a) and (b) the voltage is approximate to 7.8V.



(a) (b)

Fig. 2: Voltage (a) Lead-Acid battery at 6V and 10Ah (b) Li-ion battery at 6V and 20 Ah

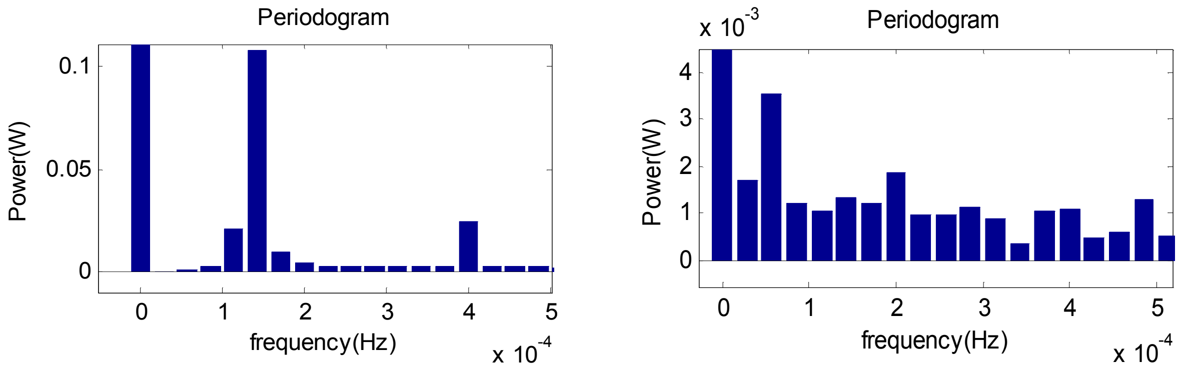
Based on figures 3 (a) and (b), the voltage for Ni-Cd and Ni-Mh battery is approximate to 14.8V but the time to full charge and discharge are different due to different storage capacity. The lead-acid battery need a short time to fully charge and discharge compared to Li-ion battery.



(a) (b)

Fig. 3, Voltage (a) Ni-Cd battery at 12V and 10Ah (b) Ni-MH battery at 12V and 20Ah

The diagram has shown in figures 4, shows the example of the periodogram for different battery types. In periodogram, Y-axis is representing the signal power and X-axis represents the frequency. The result of periodogram consists of different frequencies for 10 and 20 Ah respectively. The summary result for all data is presented in table 1.



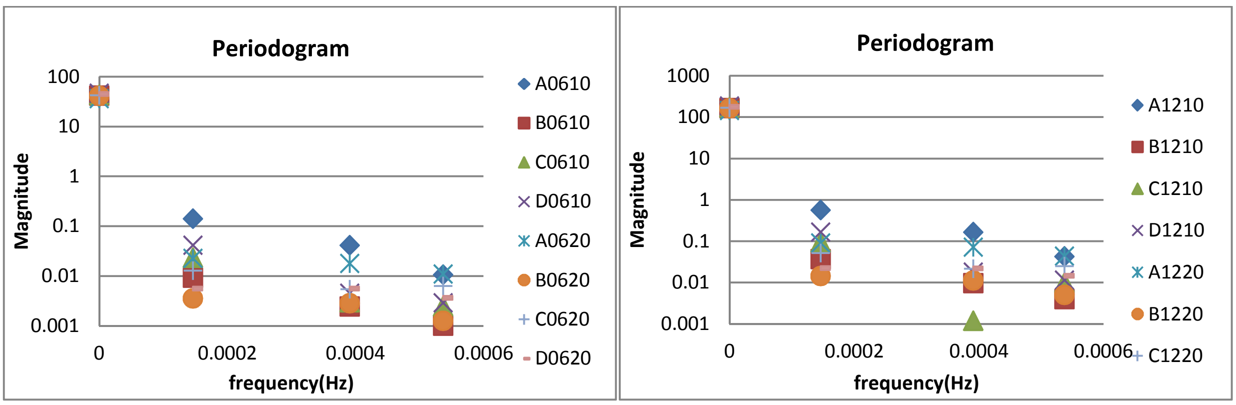
(a) (b)

Fig. 4, Periodogram (a) Lead-Acid battery (b) Li-ion battery

Table 1, Periodogram data

Capacity [Ah]		10			20		
Frequency [Hz]		f1	f2	f3	f1	f2	f3
		146 [μ]	391 [μ]	537 [μ]	146 [μ]	391[μ]	537 [μ]
Lead-Acid (A)	6 [V]	141 [m]	41.6 [m]	10.7 [m]	22.7 [m]	17.9 [m]	10.9 [m]
	12 [V]	564 [m]	166 [m]	42.9 [m]	90.6 [m]	71.5 [m]	43.6 [m]
Li-ion (B)	6 [V]	9.38 [m]	2.46 [m]	1.01 [m]	3.59 [m]	2.85 [m]	1.26 [m]
	12 [V]	37.5 [m]	9.84 [m]	4.05 [m]	14.4 [m]	11.4 [m]	5.05 [m]
Ni-Cd (C)	6 [V]	23.5 [m]	0.30 [m]	2.48 [m]	13.0 [m]	5.46 [m]	6.32 [m]
	12 [V]	93.9 [m]	1.20[m]	9.94 [m]	52.0 [m]	21.8 [m]	25.3 [m]
Ni-Mh (D)	6 [V]	41.3 [m]	4.49 [m]	2.90 [m]	5.68 [m]	5.61[m]	3.68 [m]
	12 [V]	165 [m]	18.0 [m]	11.6 [m]	22.7 [m]	22.4 [m]	14.7 [m]

Figures 5 shows, the periodogram result for 6 and 12V with 10Ah and 20Ah respectively. At DC component, the frequency is 0 Hz and the magnitude value range from 6V is 39W to 46.3W, while the magnitude for 12V is in the range of 156W to 180W. The magnitude is present in power form. After the magnitude was converted to V_{DC}, refer to Eq. 8, the value is approximate to the nominal voltage. By comparing both of the figures, the Ni-MH battery has higher magnitude value.



(a) (b)

Fig. 5, Periodogram (a) 6V with 10Ah and 20 Ah (b) 12V with 10Ah and 20Ah.

Conclusion

This paper presents an identification type of battery based on analysis of the periodogram power spectrum. According to the periodogram result, all types of battery have the same frequency (f1, f2, f3) with the same storage capacity but it's has different in term of power at the frequency. For the DC component the power depends on the type of battery, storage capacity and the nominal voltage at the battery. As a conclusion, the type of battery, storage capacity and voltage can be estimated using Periodogram and can be impelemented for battery parameters estimation system.

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