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Lead Acid Battery Analysis using Spectrogram

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Abstract. Battery is an alternative option that can be substituted for future energy demand. Numerous type of battery is used in industries to propel portable power and its makes the task of selecting the right battery type is crucial. These papers discuss the implementation of linear time-frequency distribution (TFD) in analysing lead acid battery signals. The time-frequency analysis technique selected is spectrogram. Based on, the time-frequency representations (TFR) obtain, the signal parameter such as instantaneous root mean square (RMS) voltage, direct current voltage (VDC) and alternating current voltage (VAC) are estimated. The parameter is essential in identifying signal characteristics. This analysis is focussing on lead-acid battery with nominal battery voltage of 6 and 12V and storage capacity from 5 until 50Ah, respectively. The results show that spectrogram technique is capable to estimate and identify the signal characteristics of Lead Acid battery.

Introduction

In today's world, the battery plays a vital role in local energy storage for a wide range of systems. In the aspect of technology, lead acid battery is the oldest type of rechargeable battery. The lead–acid battery was invented in 1859 by French physicist Gaston Planté [1-2]. The lead-acid is the most popular form of energy storage utilized because it has a higher energy density, wide availability and low cost [3].

Many type of battery are used in commerce to propel power and its make the task of selecting the right battery is crucial. Keep in mind that battery is undergo electrochemical process. Hence, it's a device that is slow to fill, holds relatively little storage capacity and has a defined life span [4]. Normally, the manufacturer has the choices of developing a battery for a long times and low cost, but it will have a limited service life. Therefore, the information of battery such as capacity storage, current and voltage are important in managing the energy consumption of the powered system. The analysis of battery signal is required to provide the right information of the battery [5].

Different methods and analytical techniques have been used to identify battery parameters. For example, M. Daowd *et al* [6] use standard battery test for parameters estimation were represented with different battery models parameters estimation methods. Besides that, L.W.Yao *et al* [4] and N.Maubayed et al [1] use an equivalent circuit model to develop lithium Ferro phosphate and lead acid battery to identify the battery parameters. However, this paper looks at use of time frequency analysis technique to analyse battery parameter.

This paper presents time-frequency distribution (TFD) which is spectrogram to analyse signals from charging and discharging of lead acid battery. The signal is generated using MATLAB/SIMULINK software using several standards Simulink blocks. Next, the spectrogram technique is used to represent the signal in time-frequency representation (TFR) to identify and determine the signal parameter. Then, based on the TFR, a set of parameter are calculated such as instantaneous voltage means square (RMS), direct current voltage (V_{DC}) and alternating current voltage (V_{AC}). This information is used to identify the signal parameter for Lead Acid battery [7].

Lead Acid Battery

The Lead Acid battery is made up of separator plates, lead plates, and lead oxide plates with a 35% sulphuric acid and 65% water solution. This solution is called electrolyte that causes a chemical reaction that produce electrons. When the battery discharges, the electrolyte dilutes and the sulphur deposits on the lead plates, while when it recharged the process reverses and the sulphur dissolves into the electrolyte. They can be recharged when one reverses the chemical reaction; it is what differentiates them from the electric batteries. This paper used lead-acid battery model from MATLAB/SIMULINK to generate signal for battery charging and discharging using equation below [1-2].

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

Where V_{batt} 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}

Parameter Estimation. Parameters of the signal such as instantaneous RMS voltage, direct current voltage (V_{DC}) and alternating current voltage (V_{AC}) are estimated from the time frequency representation (TFR) to identify the signal information. The information is important to detect the battery signals [8].

Spectogram. Spectogram 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 Fast Fourier Transform (FFT) to cater non-stationary signals whose spectral characteristic change in time. Spectogram can be defined as [9]:

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

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

Instantaneous RMS Voltage. Instantaneous RMS voltage is defined as the RMS voltage at power system frequency [10]. It can be calculated as;

$$V_{rms}(t) = \sqrt{\int_{-\frac{f_{max}}{2}}^{\frac{f_{max}}{2}} S_x(t,f)df} \tag{4}$$

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

Direct Current Voltage. The direct current voltage can be calculated as;

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

Where V_{DC} is direct current voltage, $\Delta f/2$ is power system frequency and $S_x(f)$ is spectrogram.

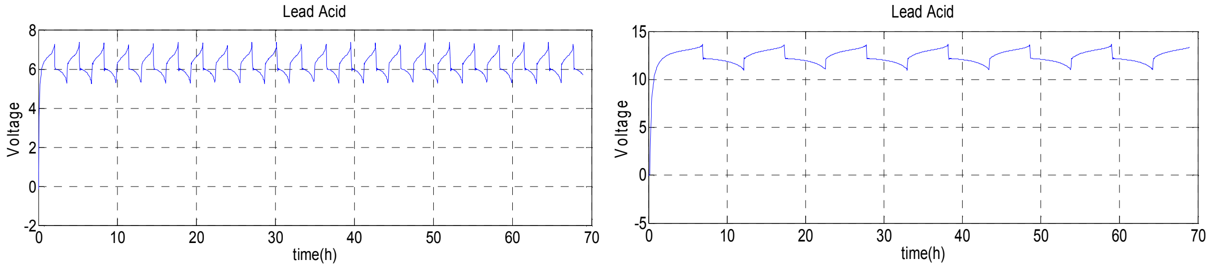
Altertenating Current Voltage. Instantenous voltage alternating current consists of harmonic and non-harmonic distortion.The V_{AC} can be defined as;

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

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

Results

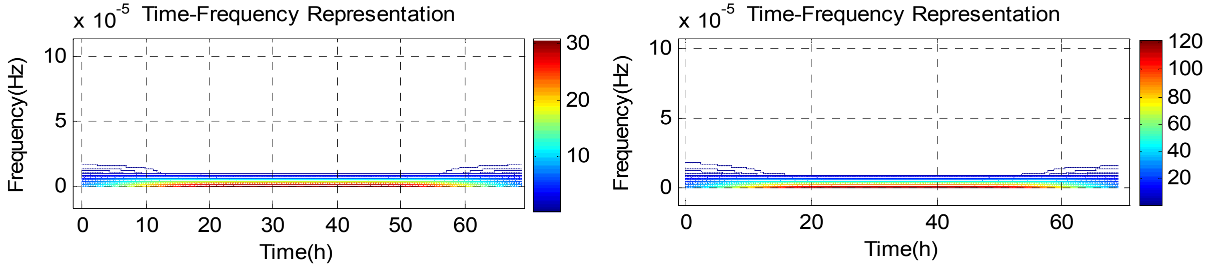
A simulation model is established using MATLAB/SIMULINK to evaluate the performance of the system. The simulation consists of lead acid battery with voltage at 6 and 12V and various storage capacities in the range of 5 to 50Ah. Figures 1 (a) and (b) shows the voltage charge and discharge with different voltage and capacity.



(a) (b)

Fig. 1 Voltage Charging and Discharging for (a) 6V with 15 Ah (b) 12V with 50Ah

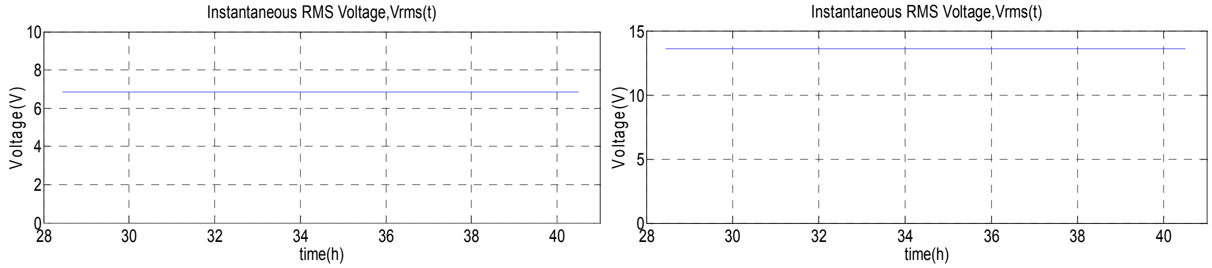
Figures 2 (a) and (b) shows the time and frequency of the lead acid battery signal using spectrogram. The red line represents the highest amplitude and the blue line represent the lowest amplitude. The signal consists of frequency at 0 Hz.



(a) (b)

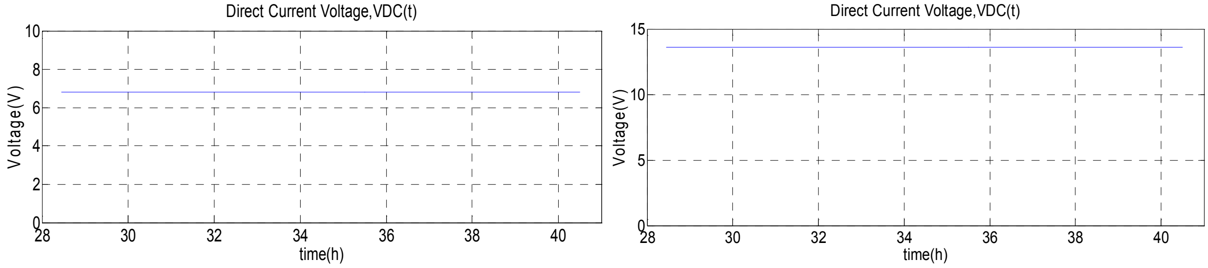
Fig. 2 Time Frequency Representation (a) 6V with 15 Ah (b) 12V with 50Ah

Based on figures 3(a) and (b), the RMS voltage of 6V with 15Ah is 6.8458V and for 12Vwith 50Ah is 13.6025Vrespectively. The RMS voltage can be calculated using equations 4. The DC voltage for 6V and 12V battery are shown in figures 4. The DC voltage represents the battery nominal voltage. The nominal value for 6V with 15Ah is 6.8248V while for the 12V with 50Ah the voltage value is 13.5846V. If the input is DC, then the RMS voltage will be the same as the DC voltage.



(a) (b)

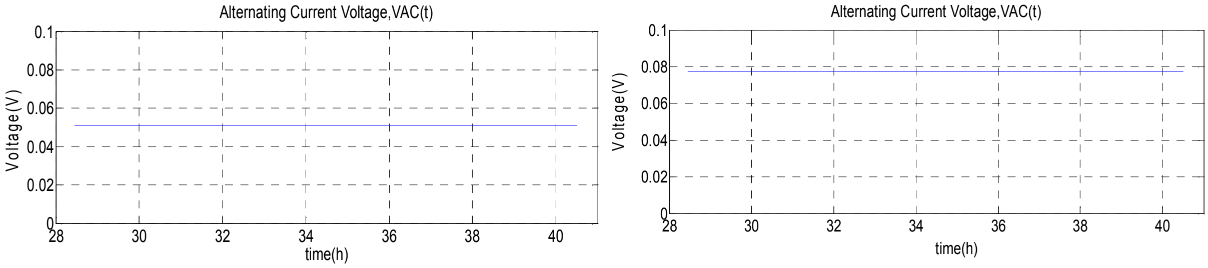
Fig. 3, RMS voltage (a) 6V with 15 Ah (b) 12V with 50Ah



(a) (b)

Fig. 4, Direct current voltage (V_{DC}) (a) 6V with 15Ah (b) 12V with 50Ah

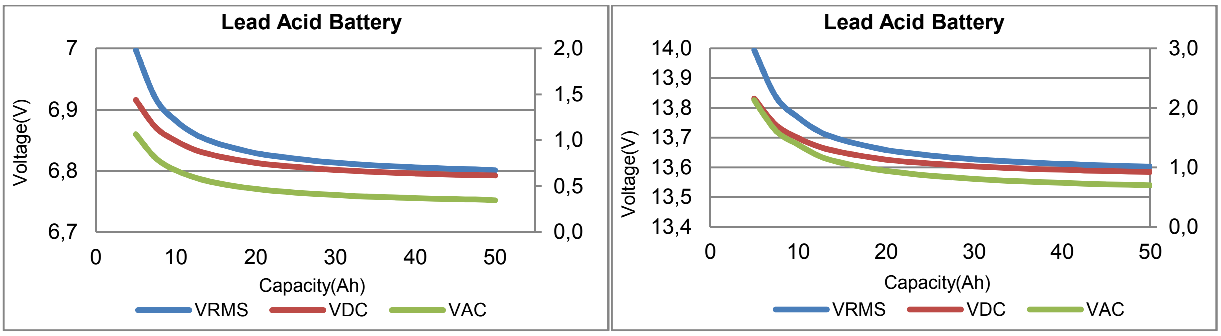
Refer to figures 5 (a) and (b), the graphs show the value of alternating current (V_{AC}) for Lead Acid battery. For 6V with 15Ah, the value is 0.5358V while for 12V with 50Ah the value is 0.6995V.



(a) (b)

Fig. 5 Alternating current voltage (V_{AC}) (a) 6V with 15Ah (b) 12V with 50Ah

The diagram shown in figures 6 (a) (b) shows the spectrogram results for "V_{rms}, V_{DC} and V_{AC} respectively". From the diagram, the Y-axis represents the V_{rms}, V_{DC} and V_{AC}, while the X-axis represents the storage capacity (Ah). For 6V, the value for V_{rms} and V_{DC} are from 6.7V to 6.9V while the value for 12V is in the range of 13.9V to 13.6V. So, from the V_{DC} value, the nominal battery voltage can be estimated.



(a) (b)

Fig. 6, Spectrogram for (a) 6V with 15Ah (b) 12V with 50Ah

Figure 7 shows, result for battery capacity. From the graph, Y-axis represents the storage capacity while X-axis represent the $V_{AC.}$ 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 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.

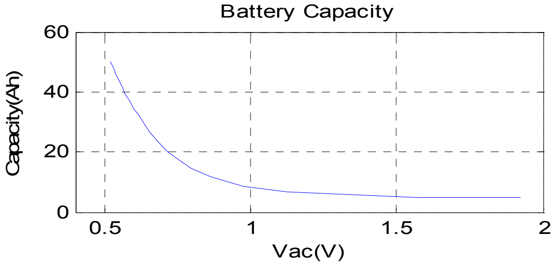


Fig. 7, Battery Capacity

Conclusion

The analysis and identification of parameter for lead acid battery is presented using TFD which is spectogram. From the parameter calculation, the TFR is estimated to be able to identify signal parameter and then, based on the parameters, signal characteristic can be calculated. The calculated parameter are instantaneous V_{rms}, V_{DC} and V_{AC}. Next, the characteristic of lead acid battery can be identified based on storage capacity and voltage. As a conclusion the identification of lead acid battery can be done by an estimation using spectrogram.

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