

Modeling of the Lead-Acid Battery with Different Load Current Profiles

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ABSTRACT

This paper presents the idea of modeling the Lead-acid battery for the changing Load current profile. A 12 V Lead-Acid battery was tested using the two different load profiles having amplitude 10 A. The small charging window was also kept to see the effect on the State of Charge (SoC) of the battery. The parameters of the battery like voltage variation, State of Charge –SoC, Depth of Charge (DoC) and Temperature in degree centigrade were also given the due consideration. The complete battery model was simulated in MATLAB/Simulink®. The total simulation time was 36000 second or 10 hours. The two different load profiles are considered to see the parameter variations.

1. Introduction

The energy storage options available in today's technological era, has given some new dimensions to the energy usage. Researchers and scientists are continuously working on improving the energy storage capacities of the grid. MWh and even GWh energy storage options are coming to the market on the regular basis. To strengthen the grid for the active or reactive power support, these energy storage options along with the Flexible AC Transmission System (FACTS) devices are also becoming attractive. The conventional batteries, ultracapacitors, flywheels, pumped hydro power plants, fuel cells are getting very attention. Over the all above storage options available, the batteries are frequently used option due to its cost, availability and to some extent the energy density. The battery technology is nothing new as is has been established since 1800 and may be prior to that [1-6]. One of the most prominent and in-use battery technologies is the Lead-Acid batteries. These batteries were and are has become a part of our day to day life particularly because of their lower cost and energy storage capacities. Although, the Lead-Acid batteries suffer from the disadvantages like environmental hazards and maintenance issues, the better option has still not become viable world-wide. Some other technologies like Zinc-air, Nickel Cadmium, Li-ion, Nickel Metal Hydride(Ni-MH), has also emerged in the recent years. A small comparison in the tabular form is presented hereunder.

Table-1
Comparison of the Battery Technologies

Battery Technology	Energy Density (Wh/kg)
Lead-Acid	35
Nickel-Cadmium	35
Nickel-Metal Hydride	50
Zinc-air	150
Lithium-ion	90

Source: batteryuniversity.com/learn/article/secondary_batteries

It is again very clear from the above table, that although Lead-acid and Nickel-Cadmium batteries have the energy densities less than the Nickel-Metal hydride and considerably lower than the Zinc-air or Lithium-ion batteries, the Lead-acid

batteries as were the pioneer in this field has remained on top till today with the Li-ion batteries have also covered the market in the past two decades [7]. This paper introduces the modeling of the Lead-Acid battery with its various parameters like load current, voltage variation, State of the Charge (SoC), Depth of the Charge (DoC) and the temperature variations over the time. The simulations in the MATLAB/Simulink® were carried out for the different load current patterns and results are justified by interpreting the graphs plotted on the basis of the simulations.

2. Modeling the Lead-acid battery

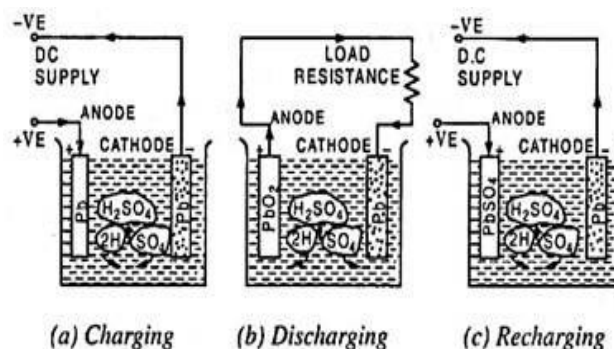


Figure 1 Construction, Operating Principle, Charging and Discharging of the Lead-Acid Batteries

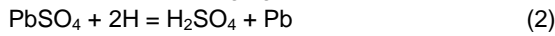
Source: engineeringnotes.com/electrical-engineering/batteries

The construction, Operating principle, Charging and Discharging of the conventional Lead-Acid battery is shown in Figure 1. With the process of sulphuric acid desolation, its molecules split up into hydrogen positive ions ($2H^+$) and sulphate negative ions (SO_4^{--}) and shift freely. When the two lead electrodes are engrossed in this solution and coupled to dc supply mains, the hydrogen ions being positively charged travel towards the electrode associated to the negative terminal of the supply mains (i.e., cathode) and as SO_4^{--} ions are negatively charged travel in the direction of the electrode connected to the positive terminal of the supply main (i.e., anode). Every positive hydrogen ion (H^+) attains the cathode get one electron from it, becomes atom of hydrogen and escapes out as hydrogen gas in the form of bubbles. Each of the negatively charged sulphate ion (SO_4^{--}) when reach at the

anode gives two electrons to it, reacts with water and forms sulphuric acid and oxygen. So, according to chemical reaction



The oxygen generated attacks the lead anode and hence it is converted in lead peroxide PbO_2 . Thus, during charging process, the lead cathode remains as lead but the lead anode gets changed into lead peroxide (PbO_2). On the same line the chemical reaction at the recharging process can be written as



This operation is very well known and it is available in the different literature [8]

Modeling the Lead-acid battery on this note was carried out by using the MATLAB/Simulink[®] and the complete simulation block diagram is shown in Figure 2 (at the end of the paper). Here, in the paper the due consideration is also given to the temperature effects as temperature also affects the performance of these Lead-Acid batteries.

3. Results and Discussion

3.1 Load/Charging Current profile 1

In the first profile of the load current the battery is first discharged at 10 A from 1000 seconds to 12000 seconds with the total simulation time of 36000 seconds (10 hours). In the next phase, the battery was recharged at initial rate of 5 A and then linearly converting the recharging process in the discharging process from 12000 seconds to 18000 seconds. Again the discharging current was reduced linearly to zero value from 18000 second to 28000 seconds. Thus, the complete profile was basically dynamic to see the effect on the model and most of the part was kept in the discharging area. The results are presented in figures 3(a) to 3(e). Figure 3 (a) shows the Load/Charging current profile, 3 (b) shows the terminal voltage variation for the given current profile.

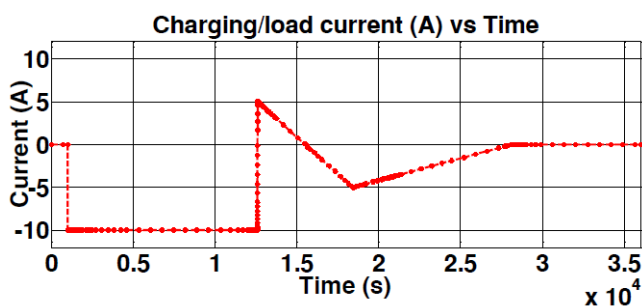


Figure 3 (a) Load Current Profile number 1

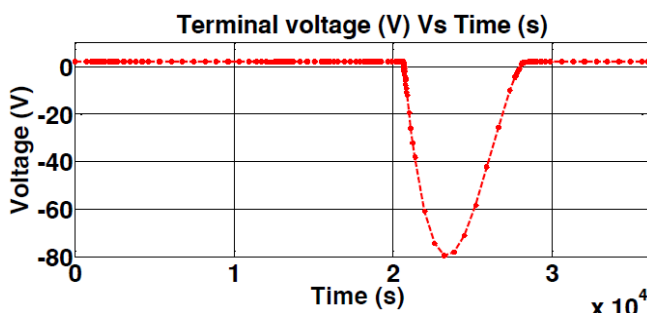


Figure 3(b) Voltage Variation for Load Current Profile number 1

The dip in the voltage is very much clear and figure 3 (c) presents the variation in the State of Charge (SoC) and the SoC is in the decrement mode apart from the small recharging process at 12000 second to 15000 second. The Depth of Charge in figure 3 (d) follows SoC curve and the temperature variation is also presented in figure 3(e).

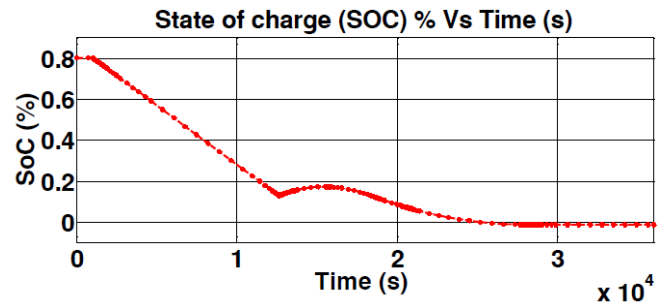


Figure 3(c) SoC Variation for Load Current Profile number 1

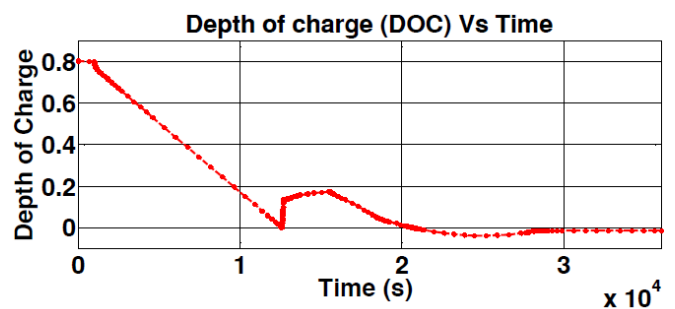


Figure 3(d) DoC Variation for Load Current Profile number 1

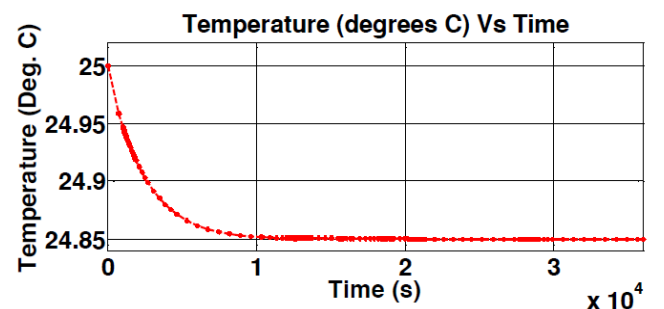


Figure 3(e) Temperature Variation for Load Current Profile number 1

3.2 Load/Charging Current profile 2

In the second profile of the load current the battery is first discharged linearly that goes from 1000 seconds to 12000 seconds. At 12000 seconds it becomes 10 A and suddenly jumps to zero value, again to get the linear discharge, and it is reaching at 10 A at 18000 seconds. The load is then gradually removed to from 18000 second to 27000 second to make it 0A. Thus, again the complete profile was basically dynamic to see the effect on the model and all of the part was kept in the discharging area. The results are presented in figures 4(a) to 4(e). Figure 4 (a) shows the Load/Charging current profile, 4 (b) shows the terminal voltage variation for the given current profile. The dip in the voltage is clearly visible and figure 4 (c) presents the variation in the State of Charge (SoC) and the SoC is in the decrement mode apart from the small time at 12000 second to 15000 second. The Depth of Charge in figure 4 (d) follows SoC curve and the temperature variation is also presented in figure 4(e)

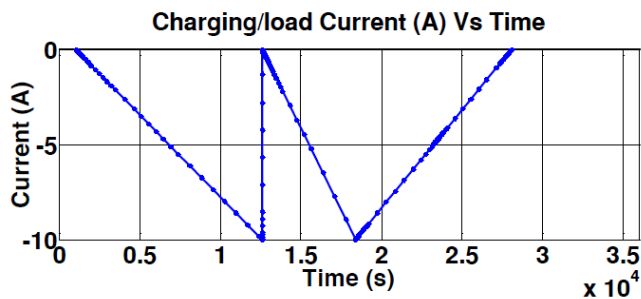


Figure 4(a) Load Current Profile number 2

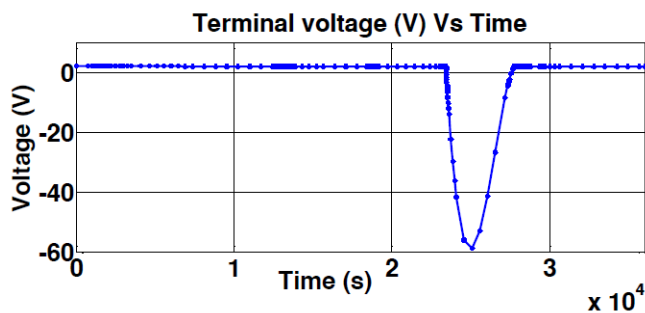


Figure 4(b) Voltage Variation for Load Current Profile number 2

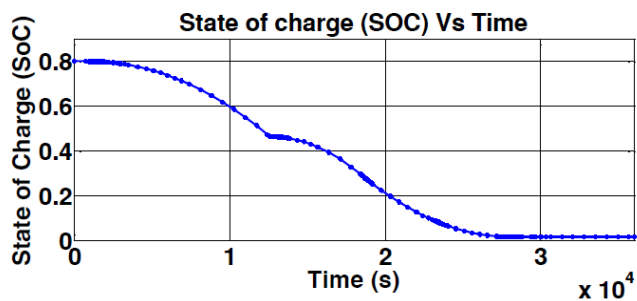


Figure 4(c) SoC Variation for Load Current Profile number 2

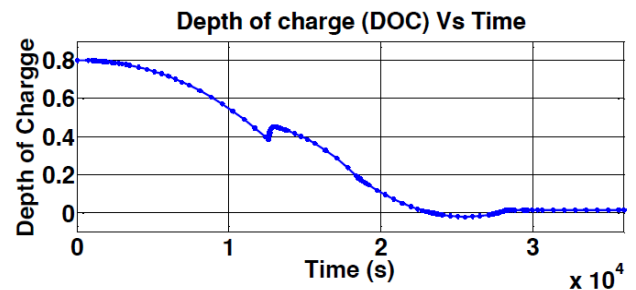


Figure 4(d) DoC Variation for Load Current Profile number 2

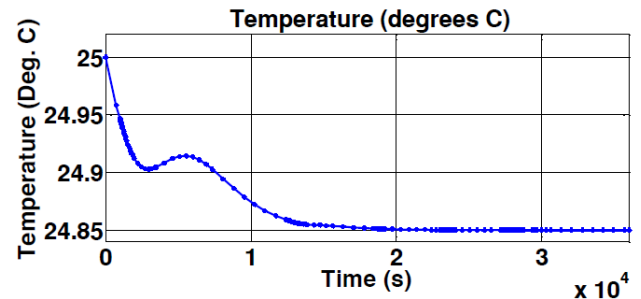


Figure 4(e) Temperature Variation for Load Current Profile number 2

4. Conclusion

The Lead-Acid battery with voltage 12 V was modeled with MATLAB/Simulink[®]. The complete simulation time was 36000 seconds or 10 hours. Two different load profiles of charging and discharging were considered. In the first load profile, with 10 A discharge current for most of the time, a small window for recharging was also kept and with the variation in SoC the model simulated gives the accurate results. The second load profile was a linearly increasing charging current profile and again the SoC and DoC variation were according to the standard practiced theory of the Lead-Acid batteries. Thus, the complete model and the simulated profiles are working satisfactorily.

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