Simulation of Regimes of Charge/Discharge in Batteries of Lead-Acid or of Lithium-Ion

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Abstract — **The paper is about a dynamic simulation of charge and discharge on two battery technologies: the lead-acid battery model, and the lithium-ion battery model. The simulation aim is to evaluate the performance of the two battery technologies. Additionally, for both batteries, the hysteresis between the charge and discharge voltage is analysed. Simulations reveal that the lead-acid battery has a significant higher hysteresis than the lithium-ion battery.**

Keywords: Battery model, energy storage, charge/discharge, Lead-acid battery, Li-ion battery, simulation.

I. INTRODUCTION

In the smart grid context, the renewable energy sources, namely wind and solar are likely to have a more significant role in the world energy supply in the upcoming years [1]. Among the renewable energy sources, wind and solar energy has ubiquity and abundance [2]. The smart grid is envisioned to take advantage of all available renewable technologies, namely the wind, PV and storage energy technologies to provide benefits to all stakeholders in the fields of efficient energy utilization and wide integration of renewable energy sources. However, due to the variable nature of the insolation, the energy storage technology could help to solve some issues during periods of low usage of electricity energy in order to use during periods of no insolation or of higher usage.

Storage of energy is regarded as an economic operational practice in order to develop an action for mitigation of the cost of electricity, for instances, for consumers when electric companies apply hourly pricing or for providing spinning reserve to maintain the power system frequency [2,3].

The significant role of the wind power in power systems in the upcoming years implies dealing with necessary actions for helping the stability of power systems. One action to be considered in wind farms is the ability to contribute to the black-start capability of the power system, i.e., the ability to recover from a total or partial shutdown within a timeframe without any external supply [2,4]. Total or partial shutdown recover can be treated by black-start capability given by auxiliary services, such as a battery storage unit connected at the end of the rectifier in order to maintain system reliability and supply continuity to the capacitors banks allowing for a successful black-start [2,4].

The lead-acid battery is used in automobiles and in small PV systems. Although having a low energy-to-weight ratio and a low energy-to-volume ratio, the ability to supply high currents and their low cost, allows that to be attractive for use in automobiles [5]. The lithium-ion battery is used in a variety of applications due to its high energy/power density and operating voltage. In the military it is used in communications and robotic applications [5].

The identification of all the battery parameters is a rather complicated technique called impedance spectroscopy. Shepherd developed a model to describe the electrochemical behavior of a battery in terms of the terminal voltage, open circuit voltage, internal resistance, discharge current and state-of-charge (SOC). Hence, the Shepherd model is used for battery discharge as well as for battery charge [5]. The SOC represents the energy content in the battery relative to the energy content upon full charge [6].

In this paper, a comparison between charge and discharge dynamics of two battery technologies: the lithium-ion battery model and the lead-acid battery model are considered. Additionally, for both batteries, the hysteresis between the charge and discharge voltage is analyzed.

II. MODELING

The modelling of batteries is a complex procedure and requires a detailed knowledge of electrochemistry. The models include the hysteresis voltage for the lead-acid battery or the lithium-ion battery.

The lithium-ion battery discharge model $i^* > 0$ [7] is given by,

$$V_{bat} = E_0 - \frac{K_1 Q\, i^*}{Q - it} - \frac{K_2 Q\, it}{Q - it} + A e^{-B\, it}\,, \tag{1}$$

where V_{bat} is the battery voltage, E_0 is the constant voltage, K_1 is polarization resistance (Ω), Q is the maximum battery capacity, K_2 is the polarization constant (V/Ah), i is the battery current, A is the exponential voltage, B is the exponential capacity, it is the extracted capacity.

The lead-acid battery discharge model [5] is given by,

$$V_{bat} = E_0 - \frac{K_1 Q i^*}{Q - it} - \frac{K_2 Q it}{Q - it} + L^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot 0\right), \qquad (2)$$

In (1) and (2) the exponential function represents the hysteresis for the battery during charge and discharge cycles. The exponential voltage increases when battery is charging, no matter the SOC of the battery. When the battery is discharging the exponential voltage decreases immediately.

III. SIMULATION RESULTS

The mathematical model for the lithium-ion battery the one and for the lead-acid battery is implemented in Matlab/Simulink [8]. The data for the batteries are: the battery voltage value of 48 V; the power load considered is constant with the value of 1.5 kW; the battery is fully at the maximum voltage value of 52.26 V; the initial SOC value of 80%; the ambient temperature value of 25ºC.

The voltage hysteresis of the lithium-ion battery [8] is shown in Figure 1.

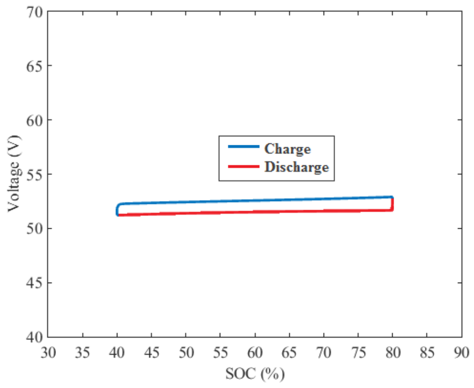

Fig. 1. Lithium-ion battery: voltage hysteresis.

The voltage hysteresis of the lead-acid battery [8] is shown in Figure 2.

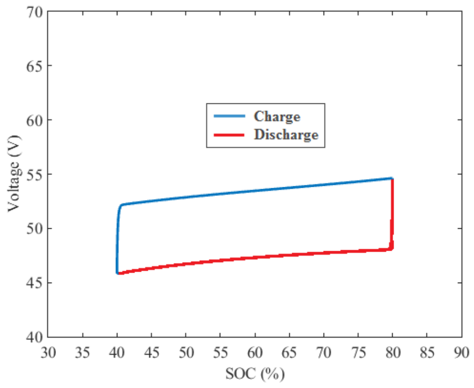

Fig. 2. Lead-acid battery: voltage hysteresis.

For the lithium-ion battery, Figure 1 reveal that during the discharge the voltage hysteresis varies between 51.65 V and 51.2 V, while during the charge the voltage hysteresis varies between 51.8 V and 54.6 V. For the lead-acid battery, Figure 2 reveal that during the discharge the voltage hysteresis varies between 48 V and 45.82 V, while during the charge the voltage hysteresis varies between 48.87 V and 54.6 V. The simulation results reveals that the SOC during the discharge process for the lithium-ion battery is faster than the lead-acid battery, however during charging the lithium-ion battery is faster than the lead-acid battery.

IV. CONCLUSION

The hysteresis depends on the battery type. Simulations reveal that the lead-acid battery has a significant higher hysteresis than the lithium-ion battery.

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