Characterization of battery for energy storage applications – lead acid battery, lithium battery, vanadium redox flow battery, and capacitor

Chih-Lung Hsieh[1], Yen-Ting Liu[2], Kan-Lin Hsueh[2], Ju-Shei Hung[3]

1. Institute of Nuclear Energy Research, Taoyuan, Taiwan
2. Dept. Energy Eng., National United University, Miaoli, Taiwan
3. Dept. Chem. Eng., National United University, Miaoli, Taiwan

The purpose of this study is to measure the charge/discharge characteristics of four different components for energy storage application. They are lead acid battery, lithium battery, vanadium redox flow battery, and capacitor. The voltage–current (E-I) curves were measured at different state of charge (SOC). Except the E-I curve of capacitor, the E-I curves of batteries were depending on their SOC. Capacitor can be charge/discharge quickly but it store small amount of energy. Large energy can be stored in the batteries.

Energy storage is an critical technology as the renewable energy, smart grid, distributed power generation, and energy management becomes popular. Several electrochemical components are considered for grid scale energy storage application. They are lead acid battery, nickel/cadmium battery, nickel/metal hydride battery, lithium battery, sodium/sulfur battery, redox flow battery, capacitor, and others. Lead acid battery, lithium battery, vanadium redox flow battery, and capacitor were very attractive and they were used in many MW scale demonstration sites. The purpose of this study is to measure the charge/discharge characteristics of four different components for energy storage application.

Lead acid battery, lithium battery, and capacitors were commercial products. Vanadium redox flow battery was built in our lab. These components have difference size and energy storage capacity. To make a fair comparison, we measure their charge/discharge characteristics at fixed state-of-charge (SOC), 0%, 25%, 50%, 75%, and 100% as shown on Fig. 1. Characteristics measured were voltage-current (E-I) curves and voltage-time (E-t) curves at constant charge discharge current. Constant charge/discharge currents were used to charge or discharge the component to a given SOC.

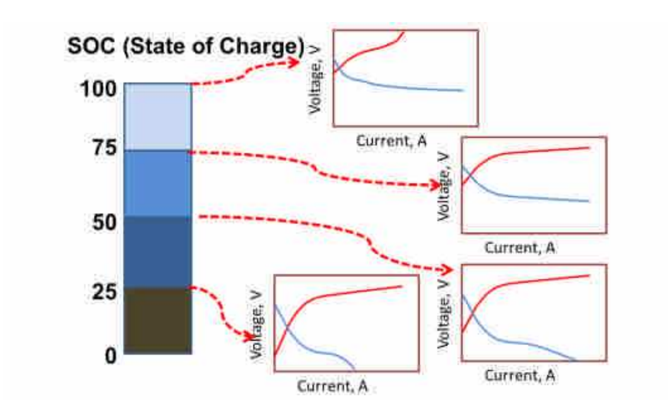

Fig. 1 Schematic presentation of sharge/discharge E-I curves were measured at different SOCs.

Figure 2 is a typical measured results of E-I curves of a lead acid battery (YUASA, NP4-6). It has a normal voltage of 6 V and capacity of 4 Ah. The battery power was drained at 0.5 A till the cell voltage down to 3.0 V. The E-I curve was recorded by linear scanning amperometry at scanning rate of 0.01 A/s. The battery is then charge at 0.5 A for 2 hours. The SOC was assumed reached 25%. The E-I curve was then recorded. This procedure was carried out for SOC at 50%, 75%, and 100%. When cell voltage reached 7.0 V during charge was considered as 100% SOC. Curves shown on Fig. 2 was measured result of laed acid battery. These curves can be described by following equations. Where the I·R accounts for internal resistance. Last term of equation [1] is the voltage cahge due to acitvation over-potential.

During Charge

$$E = E_o + \frac{RT}{nF}\ln\left(\frac{1}{[SO_4^{=}]^2\,[H^+]^4}\right) + I\cdot R + i_o \exp[\frac{\alpha nF}{RT}(\eta)] \qquad [1]$$

During Discharge

$$E = E_o - \frac{RT}{nF}\ln\left(\frac{1}{[SO_4^{=}]^2\,[H^+]^4}\right) - I\cdot R - i_o \exp[\frac{\alpha nF}{RT}(\eta)]$$

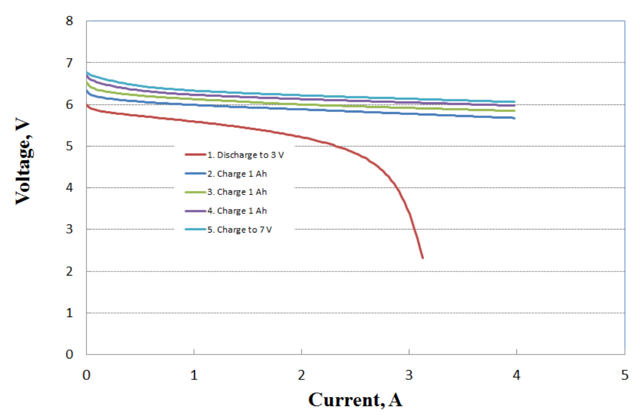

Fig. 2 E-I curves of lead acid battery at different SOCs during charge cycle.

Similar analysis were carried out for lithium battery, vanadium redox flow battery, and capacitor. Except the E-I curve of capacitor, the E-I curves of batteries were depending on their SOC. Equation similar to Eq [1] can be used to describe the E-I curve behavior of lead acid battery, lithium battery, and vanadium redox flow battery. Capacitor can be charge/discharge quickly but it store small amount of energy. Large energy can be stored in the batteries.

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