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산업용 리튬 이온 배터리 용량산정에 영향을 미치는 요소 분석

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Factors Affecting the Sizing of Lithium-Ion Stationary Battery

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Abstract - Currently, lead-acid batteries are used in Nuclear Power Plants for DC power. Although they have proved to be reliable over the years, lithium-ion batteries have a higher energy density and would be useful in extending battery backup time while occupying a much smaller area. In this paper, factors that need to be considered to determine the capacity of stationary lithium-ion batteries are investigated and reviewed.

1. Introduction

The nuclear industry has taken useful steps over the years to improve the ability of nuclear plants to cope during extended loss of power. Lithium-ion battery is recommended as an alternative for lead-acid battery due to its high energy density. Korea Electric Association published KEPIC EEG 1400, 'Installation design and installation of lithium-ion batteries for station applications' on December 31, 2017. It describes how to size lithium-ion stationary batteries but does not take into account all the characteristics of lithium ion batteries. A recent study [1] proposes a lithium-ion stationary battery capacity sizing formula for establishment of a design standard. This study seeks to review and analyze lithium-ion battery characteristics necessary in utilizing the proposed lithium-ion battery sizing formula.

2. Factors Affecting Lithium-Ion Stationary Battery Sizing

2.1 Nominal Cell Voltage

Nominal voltage is the voltage measured when the battery has discharged 50% of its total energy based on a 0.2C discharge rate. A battery with a higher energy density is obtained for a material with a higher voltage and a higher capacity since the energy of a battery depends on its voltage and its capacity. The lithium-ion battery cell typically operates in the range of 2.5V to 4.2V as shown in table 1 [2].

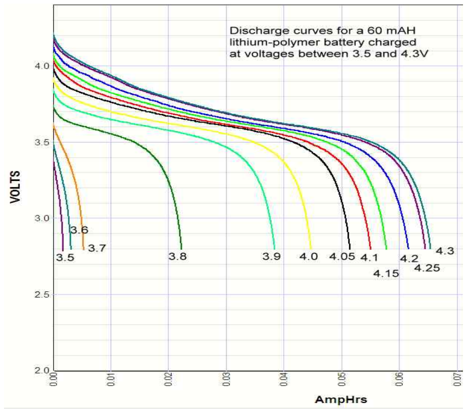
2.2 Charging Voltage and State of Charge

There is approximately a linear relationship between the state of charge (SOC) of the lead-acid battery and its open circuit voltage (OCV). The Lithium-ion battery however, does not have a linear relationship between the OCV and SOC [3]. Most batteries have a distinct charge voltage. Below that voltage battery is not charged, and if voltage is slightly higher, battery is fully charged although it may take a long time. However, for lithium-ion batteries the amount of charging depends on the voltage as shown in Figure 1 [4]. Continuing to charge a fully charged battery could cause a fire due to overcharging. To prevent overcharge, charge voltage should be controlled during the charging process.

In float charging, current entry beyond full charge is prevented by choosing a charge voltage less than cut-off voltage which depends on the cell's exact electrochemistry and temperature. [5]

<Table 1> Lithium-Ion battery voltages

Battery Type	Voltage(V)			Applications
	Min	Nom	Max	
$LiCoO_2$	3.0	3.6	4.2	Phones, tablets
$LiMn_2O_4$	3.0	3.7	4.2	Medical devices
$LiNiMnCoO_2$	3.0	3.6	4.2	Electrical vehicles, industrial
$LiFePO_4$	2.5	3.2	3.65	High current loads
$LiNiCoAlO_2$	3.0	3.6	4.2	Industrial, tram
$Li_4Ti_5O_{12}$	1.8	2.4	2.85	UPS, tram



<Figure 1> Charging voltage and discharge capacity of Lithium-Ion battery

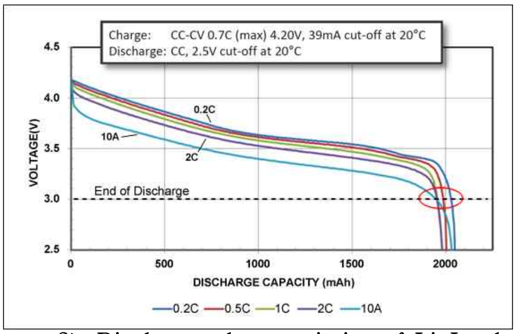
2.3 Discharge Current and Discharge Capacity

The discharge characteristics of lead-acid batteries, are represented by the following Peukert's law.

$$t = \frac{Qp}{I^k} \tag{1}$$

Where;
Qp: Discharge capacity when discharging at 1A [Ah]
I: Discharge current [A]
t: Discharge time to reach discharge terminating voltage [s]
k:: Constant, approximately 1.3

On the other hand, the lithium-ion battery has a k-constant close to unity. This means that the discharge capacity of the battery does not vary greatly depending on the magnitude of the discharge current and exhibits good discharge characteristics at high currents as shown in Fig.2 [6].



<Figure 2> Discharge characteristics of Li-Ion battery

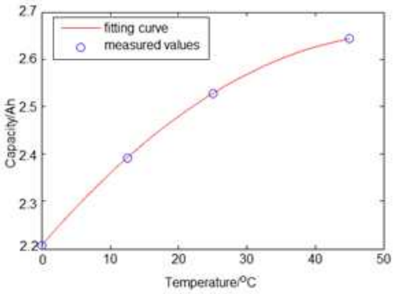
2.4 Operating Temperature and Discharge Capacity

Lithium-ion batteries are capable of operating over a relatively wide temperature range. They are more affected by temperature during charging as shown in table 2 [7].

<Table 2> Permissible temperature for battery operation

Accumulator form	Charging Temp.[℃]	Discharge Temp.[℃]	Charging Notice
Lead-acid	-20~50	-20~50	<0.3C at below freezing point
NiCd, NiMH	0~45	-20~65	75% charge at 45 ℃
Li-ion	0~45	-20~60	Don't charge at <0℃

According to the experiment of [8], where a graphite/$LiNixCoyMnzO_2$ cell with a nominal voltage 3.6 V and nominal capacity 2.5 Ah was tested, predicting the battery capacity from the ambient temperature is possible as in figure 3 below.



<Figure 3> Fitting capacity result at 0~45°C

2.5 Charging Cycle and Capacity Retention

An experiment tested with nickel manganese cobalt oxide-type lithium-ion cell shows the different capacity retention result after cycling depend on discharge current and room temperature as shown in Fig.4 [9].

3. Battery Capacity Calculation Formula

The following is the capacity and dimension sizing method for lithium-ion battery proposed in the study [1].

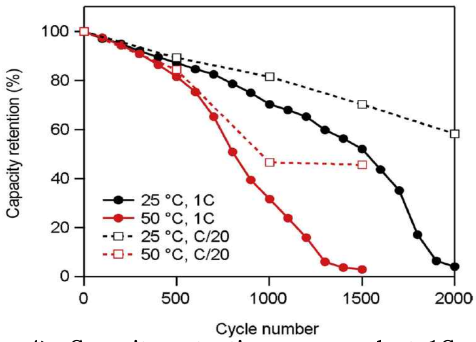
$$Fs = Fd \times Sf \qquad (3)$$

where; Fs is the capacity required by DC loads [Wh];
Fd is the battery capacity uncorrected for temperature, aging, and design margin etc.
Sf is the capacity correction factor

and,

$$Sf = (1+df)\times(1+tf)\times(1+cf)\times(1+af)\times(1+if) \qquad (4)$$

where df is the design margin;
tf is the temperature correction factor;
cf is the state of charge correction;
af is the aging compensation;
if is the inverter loss (for UPS battery).



<Figure 4> Capacity retention measured at 1C and C/20 at 25 °C as a function of cycle number

4. Conclusion

The lithium-ion battery characteristics discussed in this paper should be considered in determining stationary battery capacity. The calculation formula may be applicable in determining the capacity of stationary lithium ion batteries for establishment of a design standard for lithium-ion battery should specify the requirements for above reviewed factors.

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[References]

[1] Choong-koo Chang; M. Sulley, Lithium-ion Stationary Battery Capacity Sizing Formula for the Establishment of Industrial Design Standard, J. Electr Eng Technol. 2018;13 (6):2561-2567.

[2] Types of Lithium-ion, Battery University http://batteryuniversity.com/learn/article/types_of_lithium_ion

[3] M. Coleman; C. K. Lee; C. Zhu; W. G. Hurley, State-of-charge determination from EMF voltage estimation: using impedance, terminal voltage, and current for lead-acid and lithium-ion batteries, IEEE Transactions on Industrial Electronics, vol. 54, no. 5, 2007, pp. 2550-2557.

[4] How does capacity correlate with charge voltage for lithium ion batteries?, http://www.powerstream.com/ lithium-ion-charge-voltage.htm

[5] https://www.electronicsweekly.com/market-sectors/ power/float-charging-lithium-ion-cells-2006-02/

[6] BU-501a: Discharge Characteristics of Lithium-ion Batteries http://batteryuniversity.com/learn/article/discharge characteristics _li

[7] Charging at High and Low Temperature, http://batteryuniversity.com/learn/article/charging_at_high_and_low_ temperatures

[8] S. Yang; C. Deng; Y. Zhang; Y. He, State of Charge Estimation for Lithium-Ion Battery with a Temperature-Compensated Model. Energies 2017, 10, 1560.

[9] T. Matsudaa; K. Andoa; M. Myojina; M. Matsumotob; T. Sanadab; N. Takaob; H. Imaib; D. Imamuraa, Investigation of the influence of temperature on the degradation mechanism of commercial nickel manganese cobalt oxide-type lithium-ion cells during long-term cycle tests, Journal of Energy Storage, 21 (2019) 665-671