Online State-of-health(SOH) estimation for a $LiMn_2O_4$ cell based on fuzzy-logic

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ABSTRACT

This paper investigates a new approach based on the fuzzy-logic controlled methodology that is suitable for analyzing and evaluating large format $LiMn_2O_4$ cell performance via online state-of-health (SOH) estimation for energy storage system (ESS) applications. First of all, the values of the cell resistance R and maximum cell capacity Q_{max} are calculated from three factors such as voltage, current, and time that were measured by discharging/charging sequence. Then, using two values R and Q_{max} previously calculated, present SOH of an arbitrary $LiMn_2O_4$ cell can be estimated using the defined fuzzy-logic inference system. The main advantage of this approach is wide parameters tuning possibility for good correspondence of SOH decay with other accurate estimation method and the possibility to perform suitable online SOH estimation.

1. Introduction

Fig. 1: $LiMn_2O_4$ cell and ESS of Samsung SDI.

These days, an accurate and reliable knowledge of state-of-health (SOH) absolutely need to be considered in battery management system (BMS) in order to guarantee the overall system performance for energy storage system (ESS) applications of Fig. 1[1]. In this work, a new method based on application of fuzzy-logic rules set is described, which is suitable for analyzing and evaluating SOH esti-mation of large format $LiMn_2O_4$ cell. Two parameters namely maximum cell capacity Q_{max} and resistance R were calculated and used for SOH estimation. Using these para-meters, current SOH of an arbitrary $LiMn_2O_4$ cell can be estimated with the help of fuzzy-logic controller. Proposed method allows relatively simple, online SOH determination without the need for great amount of learning data and the need for exact battery system model. Verification result shows the fuzzy-logic approach is clearly appropriate for reliable SOH estimation. The approach has been validated by experimental results conducted on prismatic $LiMn_2O_4$ cell that had a rated capacity of 60Ah produced by Samsung SDI.

2. Two parameters online calculation

In this approach, SOH can be calculated by mixing these parameters of a fresh cell. Two types of aging were pre-viously considered, cell degradation during storage (calendar

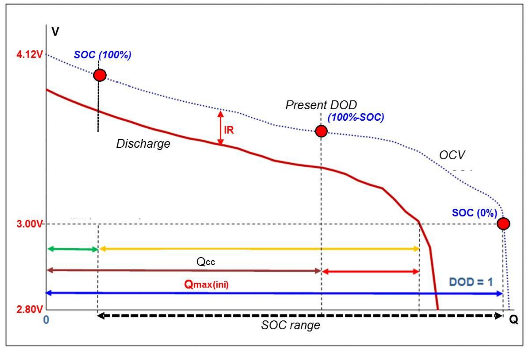

Fig. 2: Relation between the capacities in the discharge progress.

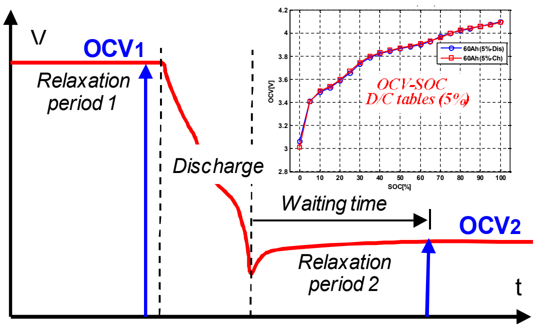

Fig. 3: Method for the Q_{max} calculation and updating.

-life test), when environmental conditions play an important role and cell degradation during cycling (cycling-life test). We determined that a cell reaches its end of life (SOH=0) when the resistance R increase 1.6 times of its initial value (R_{aged}=1.6R), or the maximum cell capacity Q_{max} decreases to 0.8 of its initial value (Q_{aged}=0.8Q_{max}).

2.1. Q_{max} and R calculation

The main capacity values and its interrelations during discharge are graphically represented and expressed in Fig. 2. In this work, Q_{max} is updated after the rela-xation modes, using OCV measurements in two relaxation modes separated by charge or discharge as expressed in (1) and (2) (Fig. 3). Minimum difference between DOD_1 and DOD_2 for these equations is taken as 36% of Q_{max}. If Q_{passed} is larger than 36% of Q_{max}, updated Q_{max} can be calculated. After determination of DOD based on the OCV-SOC relation, the resistance R can be calculated and updated at predetermined SOC points (3).

$$Q_{max} = \frac{Q_{passed}}{\mathrm{DOD}_1(\mathrm{OCV}_1) - \mathrm{DOD}_2(\mathrm{OCV}_2)} \quad (1)$$

$$Q_{passed} = \sum_{\mathrm{DOD}_1}^{\mathrm{DOD}_2} \mathrm{I}\Delta t \ \ (discharge) \quad (2)$$

$$R(SOC) = \frac{OCV(SOC) - V_{present}}{I} \quad (3)$$

2.2. Battery operation states

In order to obtain the SOC information for Q_{max} and R estimation, following procedure such as states as equilibrium, relaxation, and charge/discharge states is used. Conditions

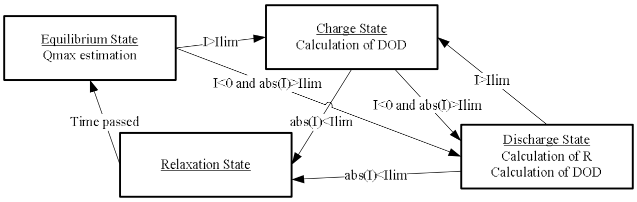

Fig. 4: Relation between the capacities in the discharge progress.

If R is good Q_{max} is good then SOH is good. If R is bad then SOH is bad. If Q_{max} is bad then SOH is bad.

Table1: Linguistic rules for Suzeno-based fuzzy logic system for SOH determination

And method (Min), Or method (Max), Implication (Min), Aggregation (Max), Defuzzification (Centroid)

Table2: Logical function methods

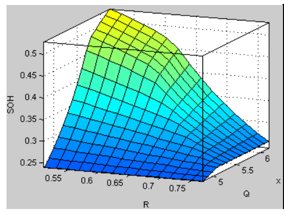

Fig. 5: Fuzzy surfaces SOH from Q_{max} and R (3D surface)

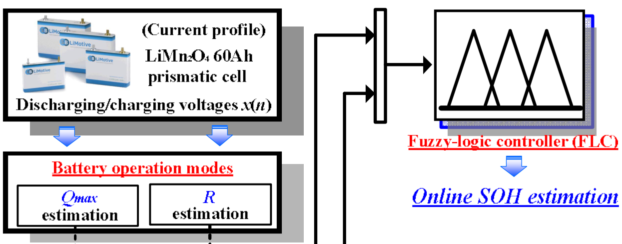

Fig. 6: Fuzzy surfaces SOH from Q_{max} and R (3D surface)

for transitions between these modes are described using flow-charge in Fig. 4. Note that during initialization it should be assigned some predefined Q_{max} value, so it would then seek for its real value.

3. Fuzzy-logic based control methodology

Three variables and rules interconnection between them were described. With 2-inputs and 1-output, fuzzy-logic system based on Sugeno reasoning was developed to model the relationship between two factors (Q_{max} and R) and SOH of the cell. Each parameter is described in terms of 'bad' or 'good', so logical implication rules are given in linguistic from Table 1. After strong consideration and feasibility testing, following logical function methods were chosen and listed in Table 2. Membership functions curves for each value are chosen according to best linearity in terms of given experimental data. As shown in Fig. 5, the model output can be additionally shown as 3D surface, where 3 axes correspond to input/output parameters, so given input values it is possible to find output SOH. Fig. 6 shows the schematic diagram of the proposed approach.

4. Verification

Note that actually resistance has dependence on working condition (C-rate and temperature), but in the proposed work, it will be neglected to the extent that C-rate contribution itself is really small in terms of introduced error, and ESS systems usually operate at room temperatures. Model based on cell capacity measured during fully discharge/charge is used for verification. It employs capacity measurements taken during calendar life battery tests. It employs data taken at relatively large time intervals of

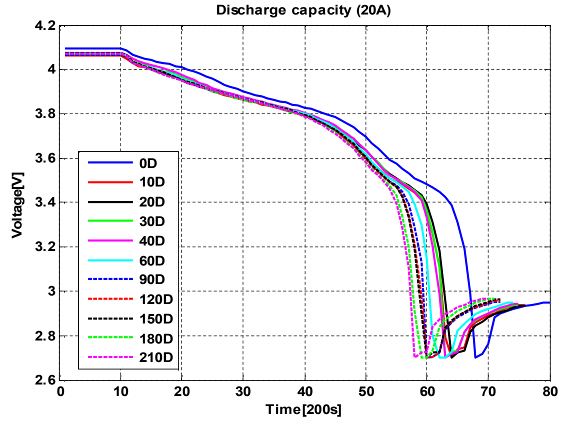

Fig. 7: Discharging curves for obtaining discharge capacity measured by calendar-life test

Days	Capacity[Ah]	Days	Capacity[Ah]
0D	62.911	90D	56.516
10D	61.216	120D	55.408
20D	60.288	150D	54.726
30D	59.378	180D	53.912
40D	58.569	210D	53.243
60D	57.483		

Table3: Logical function methods

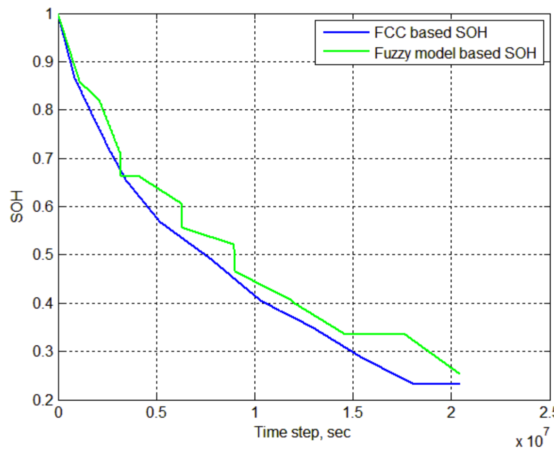

Fig. 8: Verification for online SOH estimation of an arbitrary battery.

0days, 10dyas, 20days, etc. up to 210 days (Fig. 7 and Table 3). It is possible to calculate SOH using the data measured by calendar-life test. For an arbitrary discharging/charging current profile, verification result between reference data (interpolation) and fuzzy-logic based model data is presented in Fig. 8. The results have high degree of consistency between them. Fuzzy logic with implementation of Q_{max} and R calculation provides great flexibility in terms of fine tuning and online SOH estimation.

5. Conclusion

In this work, fuzzy logic-controlled methodology for online SOH estimation of the ESS system is newly introduced.

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Reference

[1] H. Qian et. Al., *A high-efficiency grid-tie battery energy storage system*, IEEE Transactions on Industrial Electronics, ISSN 0278-0046, 26(2011), 886-895.