Study on test and assessment of low voltage ride through characteristics of electrochemical energy storage system

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Abstract. In this paper, it is focused on test and assessment of low voltage ride through characteristics of electrochemical energy storage system. Based on the national standard GB/T 36547-2018: technical rule for electrochemical energy storage system connected to power grid, this paper proposes a test and evaluation method for the low voltage ride through characteristics of EESS, and carries out a case analysis based on test data of experimental system to verify the feasibility and effectiveness of the method.

1. Introduction
In recent years, with the large-scale promotion and application of wind power, photovoltaic power generation and other new energy power generation technologies, the proportion of renewable energy installed capacity in the total installed capacity of the power system is also growing [1]. Due to the influence of wind speed, light and other natural resources, the output of new energy generation is intermittent, random and fluctuating [2]. With the large-scale growth of renewable energy generation installed capacity, the demand for flexible regulation of power system is also growing. In order to improve the flexible regulation ability of the system and promote the consumption of renewable energy, in addition to the construction of large-scale pumped storage power station, the electrochemical energy storage system (EESS) represented by batteries has also been widely used in the power system [3].

Based on the national standard GB/T 36547-2018: technical rule for EESS connected to power grid, this paper proposes a test and evaluation method for the low voltage ride through (LVRT) characteristics of EESS, and carries out a case analysis based on the test data to verify the feasibility and effectiveness of the method.

2. Technical requirement of LVRT for EESS
According to the requirements of the national standard GB/T 36547-2018 [4]: for the EESS connected to the power grid of 6kv~10 (20) kV and above, when the voltage of grid-connection point is below 85% of the rated voltage, the electrochemical ESS shall have the low voltage ride through capability as shown in Figure 1. When the voltage of grid-connection point is at or above the contour line of curve 1, the EESS shall operate continuously without disconnection; when the voltage of grid-connection point is below the contour line of curve 1, the EESS is allowed to be disconnected from the electric network.
Figure 1. Cure of LVRT.

The fault types and assessment voltage of LVRT of EESS are shown in Table 1.

| Fault Type                                      | Assessment Voltage                              |
|------------------------------------------------|-------------------------------------------------|
| Three phase short circuit fault                 | line voltage of grid-connection point           |
| Two phase short circuit fault                   | line voltage of grid-connection point           |
| Single phase to ground short circuit fault      | line voltage of grid-connection point           |

3. Test method of LVRT for EESS

3.1. Test condition

Passive reactor should be used for the detection device to simulate grid voltage drop, and the principle of voltage drop generating device is shown in Figure 2. The detection device shall meet the following requirements:

1. The device shall be able to simulate three-phase symmetrical voltage drop, phase to phase voltage drop and single-phase voltage drop.

2. Where current limiting reactor X1 and short-circuit reactor are adjustable, the device shall be able to generate voltage drop of different depth at point a. The ratio of reactance value to resistance value (X/R) shall be greater than 10.

3. The three-phase symmetrical short-circuit capacity shall be more than 3 times of the total rated power of the converter provided for the energy storage system.

4. Switch S1 and S2 shall use mechanical circuit breaker or power electronic switch.

5. The voltage drop time and recovery time shall be less than 20 ms.
3.2. Test steps
Set the parameters, fault types and voltage drop time of the voltage drop device according to the requirements of the national standard GB/T 36547-2018. The specific test steps are as follows [5]:

(1) Put the energy storage system into operation and test it under the charging and discharging conditions of $0.1P_N$~$0.3P_N$ and rated power respectively.

(2) Control voltage sag generator to carry out three-phase symmetrical voltage sag and no-load randomly selected asymmetrical voltage sag.

(3) At least 5 drop points shall be selected for testing, including $0\%U_N$ and $20\%U_N$ drop points. Other points shall be distributed in the three intervals of $(20\% \sim 50\%U_N)$, $(50\% \sim 75\%)U_N$ and $(75\% \sim 90\%)U_N$, and the drop time shall be selected according to the curve required by GB/T 36547-2018.

(4) At least record the voltage, current waveform, active power, reactive power curve and other data of the energy storage system from 10 seconds before the voltage drop to 6 seconds after the voltage returns to normal.

(5) All test points shall be repeated twice.

4. Assessment of LVRT characteristic for EESS
Taking the three-phase short-circuit recording data of an EESS experimental system at 35kV side as an example, the calculation of various technical indicators of low-voltage ride through and the analysis and evaluation of grid connection compliance are carried out. Figure 3 (a) shows the waveform of three-phase voltage instantaneous value during three-phase short circuit on 35kV side of the energy storage station. To facilitate observation, the waveforms during voltage drop ($9.22 \sim 9.25s$) and during voltage recovery ($10.79 \sim 10.84s$) after clearing the three-phase short-circuit fault are amplified as shown in Figure 3.
To extract the fundamental component of three-phase voltage instantaneous value waveform and three-phase current instantaneous value waveform, and then extract the positive sequence component, the specific steps are as follows:

1. Use the Fourier transform to extract the fundamental component, as shown in formula (1):

$$u_{a,\text{cos}} = \frac{2}{T} \int_{t-T}^{t} u_a(t) \cos(2\pi f_t t) dt$$

$$u_{a,\text{sin}} = \frac{2}{T} \int_{t-T}^{t} u_a(t) \sin(2\pi f_t t) dt$$

(1)

2. The positive sequence component of fundamental wave is extracted by positive and negative sequence transformation, as shown in formula (2):

$$\begin{bmatrix} U_1 \\ U_2 \\ U_0 \end{bmatrix} = \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

(2)

Where, $a = e^{j\frac{2\pi}{3}} = -\frac{1}{2} + j\frac{\sqrt{3}}{2}, \quad a^2 = e^{-j\frac{2\pi}{3}} = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$.

Taking three-phase current as an example, the fundamental positive sequence current (blue line), fundamental negative sequence current (green line) and fundamental zero sequence current (red line) can be extracted by using the above steps, as shown in Figure 4. The analysis shows that during the three-phase symmetrical short-circuit fault, the fault current is mainly positive sequence component, and the negative sequence current component will be rapidly attenuated in the voltage recovery phase.

![Figure 4. Positive sequence / negative sequence / zero sequence current waveform (effective value)](image)

Further, the active power and reactive power of the positive sequence component of the fundamental wave can be obtained by using formula (3), and the waveform is shown in Figure 5. The analysis shows that during the fault period, the storage power station injects a certain amount of reactive power into the grid to play a role of voltage support. Figure 6 shows the active power recovery waveform during voltage recovery after clearing the three-phase short circuit fault.
Based on the requirements of national standard GB/T 36547-2018, the main technical indicators of low voltage ride through are defined as follows:

1. Active power recovery time: \( t_p = t_{2r} - t_{1l} \);
2. Active power recovery rate: \( k_p = \frac{P_{2r} - P_{1l}}{t_{2r} - t_{1l}} \);
3. Average injection value of reactive current during fault: \( I_q = \frac{\int_{t_{1l}}^{t_{2r}} I_q(t)\,dt}{t_{2r} - t_{1l}} \);
4. Reactive power response time: \( t_{q, res} = t_{1r} - t_0 \);
5. Continuous injection time of reactive current: \( t_{last} = t_{2r} - t_{1r} \).

Based on the above evaluation indexes, the technical parameters during low voltage ride through are calculated as shown in Table 2. The results show that the energy storage system meets the technical requirements of national standard GB/T 36547-2018 for low voltage ride through.

| Index Type                              | Index Value |
|-----------------------------------------|-------------|
| Voltage drop depth                      | 0.2 p.u.    |
| Fault duration                          | 1575 ms     |
| Active power recovery time              | 40 ms       |
| Active power recovery rate              | 12.17 p.u./s|
| Average injection value of reactive current during fault | 0.41 p.u. |
| Reactive power response time            | 68 ms       |
| Continuous injection time of reactive current | 1508 ms    |

5. Conclusion
In this paper, the test and evaluation method for the LVRT characteristics of EESS are presented, which is based on the national standard GB/T 36547-2018: technical rule for electrochemical energy storage system connected to power grid. The research shows that the test and evaluation of the LVRT characteristics of EEES is helpful to standardize the interface characteristics of grid-connected EEES and provide guarantee for the full use of EEES to support the flexible regulation of power system.
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