

# IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications

IEEE Standards Coordinating Committee 21

Sponsored by the  
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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USA

**IEEE Std 2030.3™-2016**

# IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications

Sponsor

**IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics,  
Dispersed Generation, and Energy Storage**

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**Abstract:** Applications of electric energy storage equipment and systems (ESS) for electric power systems (EPSs) are covered. Testing items and procedures, including type test, production test, installation evaluation, commissioning test at site, and periodic test, are provided in order to verify whether ESS applied in EPSs meet the safety and reliability requirements of the EPS. Grid operators, ESS manufactures, and ESS operators are for whom this standard is established.

**Keywords:** commissioning test, electric energy storage equipment, electric energy storage systems, electric power systems, IEEE 2030.3™, installation evaluation, periodic test, production test, test procedure, type test

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## Introduction

This introduction is not part of IEEE Std 2030.3-2016, IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications.

Energy storage equipment and systems (ESS) that connect to an electric power system (EPS) shall meet the requirements specified in related IEEE standards. Standardized test procedures are necessary to establish and verify compliance with those requirements. These test procedures need to provide both repeatable results, at independent test locations, and have flexibility to accommodate the variety of storage technologies and applications.

This guide is comprised of 10 clauses and two annexes. The main content includes type tests, production tests, installation evaluations, commissioning tests at site, and periodic tests.

Despite the fact that ESS applied in an EPS are at discharging state (acting as power sources) or at charging state (acting as load), ESS shall comply with the planning and operation requirements of the grid. This standard aims to provide the test items and procedures for the ESS applied in EPSs to verify whether the relevant characteristic parameters of the integrated ESS are in accordance with the technical requirements of the EPSs.

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# IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications

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## 1. Overview

### 1.1 Scope

The test items and procedures of electric energy storage equipment and systems (ESS) for electric power system (EPS) applications, including type test, production test, installation evaluation, commissioning test at site, and periodic tests are as follows:

- Type tests covering all necessary test items of ESS applied in EPSs.
- Production tests, including quality inspection and test of ESS before shipment.
- Installation evaluation shall be carried out after field installation of ESS.
- Commissioning tests shall be carried out on site when the field installation of ESS are complete and before they are officially put into operation.
- Periodic tests shall be periodically carried out after ESS are officially applied in the EPS.

ESS can either be a single piece of equipment with all functions or an integrated set of equipment with specific functions. A single piece of equipment shall go through type tests, production tests, installation evaluation, and commissioning tests as a whole. Each piece of an integrated set of equipment shall go through type tests and

production tests based on its specific function, and then the whole set of equipment shall go through the installation evaluation and commissioning tests after field assembly and integration of the equipment.

## 1.2 Purpose

Despite of the fact that ESS applied in EPS are at the discharging state (acting as power sources) or at charging state (acting as load), they shall comply with the planning and operation requirements of the grid. This standard aims to provide the test items and test procedures for ESS applied in EPSs to verify whether the relevant characteristic parameters of the integrated ESS are in accordance with the technical requirements of the EPS, as follows:

- The type test is the first step for the integration test of ESS, generally used to verify the design principle and the design rating of the product, and reflect the operation condition of the product.
- Production tests include the quality inspection and test of the ESS before shipment, which is used to verify whether the manufacturing quality and deviation meet the specific requirements.
- Installation evaluation is the inspection and evaluation of the outer connection of ESS, grounding, isolation, electrical connection correctness, etc. This shall be carried out after field installation of ESS.
- Commissioning tests shall be carried out on site when field installations of ESS are complete and before they are officially put into operation. These tests aim to verify whether the technical indexes of ESS are in accordance with the operation requirements after delivery and installation.
- Periodic tests aim to inspect operation safety and reliability of ESS, which shall be periodically carried out after ESS have been officially applied in EPSs.

The measured and analyzed results of each test obtained by applying the standard shall be repeatable, traceable, and independent from the test environment and location. The test results can provide meaningful references for manufacturers, users, ESS operators, and grid operators in order to evaluate the performance and quality of ESS applied in EPSs.

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61000-4-2, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.<sup>1</sup>

IEC 61000-4-3, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4, Electromagnetic compatibility (EMC)—Part 4-4: Testing and measurement techniques—Electrical fast transient/burst immunity test.

IEC 61000-4-5, Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

<sup>1</sup>IEC publications are available from the Sales Department of the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department of the American National Standards Institute (<http://www.ansi.org>).

IEC 61000-4-6, Electromagnetic compatibility (EMC)—Part 4-6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields.

IEEE Std 1547™, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.<sup>2,3</sup>

IEEE Std 1547.1™, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

IEEE Std C37.09™, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE C37.06, American National Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.

### 3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* could be consulted for any undefined terms of this document.<sup>4</sup>

#### 3.1 Definitions

**energy storage equipment and systems (ESS):** The energy storage systems in this standard include energy storage equipment and any units connected with the energy storage equipment, for instance, the power conversion units, the energy management units, and related monitoring and control systems.

**simulated electric power system (EPS):** An emulator imitates the expected electrical powers from a utility power source. Where appropriate, an actual EPS can replace the simulated EPS.

#### 3.2 Acronyms and abbreviations

|                    |                                                      |
|--------------------|------------------------------------------------------|
| BMS                | battery management system                            |
| EPS                | electric power system                                |
| ESS                | energy storage equipment and systems                 |
| EUT                | equipment under test                                 |
| LVRT               | low-voltage ride through                             |
| PCC                | point of common coupling                             |
| PCS                | power conversion system                              |
| SOC                | state of charge                                      |
| SOC <sub>max</sub> | maximum working load state specified by manufacturer |
| SOC <sub>min</sub> | minimum working load state specified by manufacturer |
| TRD                | total rated-current distortion                       |
| V <sub>max</sub>   | maximum dc working voltage specified by manufacturer |

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<sup>4</sup>*IEEE Standards Dictionary Online* is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

$V_{\min}$  minimum dc working voltage specified by manufacturer  
 $V_{\text{nom}}$  for ac, means nominal working voltage appointed by manufacturer; for dc, means average of  $V_{\max}$  and  $V_{\min}$

## 4. General

### 4.1 Testing items

Test methods of ESS working in conjunction with EPSs shall include type tests, production tests, installation evaluations, commissioning tests, and periodic tests. Test items are shown in Table 1. ESS can either be a single piece of equipment with all functions or a set of equipment units with each individual unit having a specific function. In the latter case, each piece of equipment shall go through corresponding tests individually according to its specific function. The test overview is shown in Figure 1.

**Table 1—ESS test items**

| No. | Test items                               | Type tests | Production tests | Commissioning tests | Periodic tests |
|-----|------------------------------------------|------------|------------------|---------------------|----------------|
| 1   | Temperature stability                    | √          |                  |                     |                |
| 2   | State of charge (SOC)                    | √          |                  |                     | √              |
| 3   | Conversion efficiency                    | √          |                  |                     |                |
| 4   | Response time                            | √          |                  |                     | √              |
| 5   | Ramp-rate                                | √          |                  |                     | √              |
| 6   | Synchronization                          | √          | √                | √                   |                |
| 7   | Reconnection after abnormal condition    | √          | √                |                     |                |
| 8   | Harmonics                                | √          |                  |                     | √              |
| 9   | Flicker                                  | √          |                  |                     |                |
| 10  | Voltage unbalance                        | √          |                  |                     |                |
| 11  | Open phase                               | √          |                  |                     |                |
| 12  | Overcurrent                              | √          | √                |                     |                |
| 13  | DC injection                             | √          |                  |                     |                |
| 14  | Response to abnormal voltage condition   | √          | √                |                     | √              |
| 15  | Response to abnormal frequency condition | √          | √                |                     | √              |
| 16  | Unintentional islanding                  | √          | √                | √                   |                |
| 17  | Low-voltage ride through (LVRT)          | √          | √                |                     |                |
| 18  | Interconnection integrity                | √          |                  |                     |                |
| 19  | Continuous operation                     | √          | √                |                     |                |
| 20  | Stop charging/discharging                | √          |                  | √                   |                |

### 4.2 Application

For power-grid operation, test results based on this standard could be used to evaluate whether the relevant characteristic parameters of ESS are in accordance with the planning and operation requirements of the EPS. If the ESS are at discharging state, energy delivers from the ESS to the EPS. Hence, grid operators shall focus on the supporting capability of ESS, such as synchronization, active power ramping, response to abnormal condition, etc. When ESS are at charging state, grid operators shall pay more attention to the influences that could be caused by an ESS and may affect the grid, such as power quality, response to abnormal condition of the grid, etc.

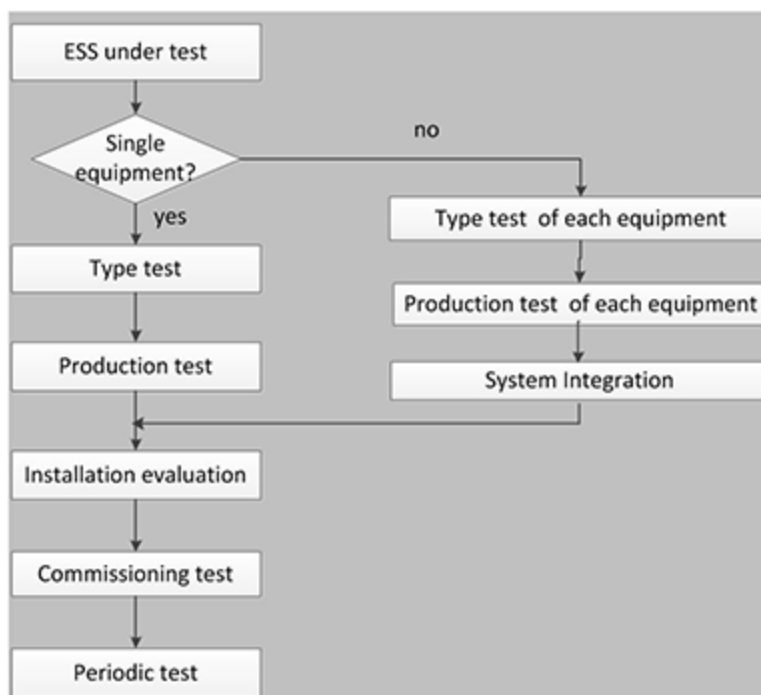


**Figure 1—Test overview**

For the interests of ESS manufacturers, this standard provides test items and test procedures to evaluate the performance and quality of ESS, such as temperature stability tests, reliability tests of the equipment, state of charge (SOC) tests, conversion efficiency tests, and active power ramping capability tests, etc. These test results can provide reference and basis for ESS manufacturers in order to improve the performance and quality of products.

For ESS operators, this standard provides the procedures to verify the specific performance indices [e.g., unintentional islanding protection and low-voltage ride through (LVRT)] and grid-connected operation characteristics (e.g., power quantity, energy conversion efficiency, ramping rate) under charging and discharging states. These test results could be used as references for the ESS operator to improve their operation.

Table 2 shows the relevant test items for different related parties, including the grid operator, ESS manufacturers, and ESS operators.

**Table 2—Test items for relevant shareholders**

| No. | Test items                            | Grid operators | ESS manufacturers | ESS operators |
|-----|---------------------------------------|----------------|-------------------|---------------|
| 1   | Temperature stability                 |                | √                 | √             |
| 2   | SOC                                   | √              | √                 | √             |
| 3   | Conversion efficiency                 |                | √                 | √             |
| 4   | Response time                         | √              |                   |               |
| 5   | Ramp-rate                             | √              |                   |               |
| 6   | Synchronization                       | √              |                   |               |
| 7   | Reconnection after abnormal condition | √              |                   |               |
| 8   | Harmonics                             | √              |                   | √             |
| 9   | Flicker                               | √              |                   | √             |
| 10  | Voltage unbalance                     | √              |                   | √             |

Table continues

**Table 2—Test items for relevant shareholders (continued)**

| No. | Test items                               | Grid operators | ESS manufacturers | ESS operators |
|-----|------------------------------------------|----------------|-------------------|---------------|
| 11  | Open phase                               | √              |                   | √             |
| 12  | Overcurrent                              | √              | √                 | √             |
| 13  | DC injection                             | √              |                   | √             |
| 14  | Response to abnormal voltage condition   | √              |                   |               |
| 15  | Response to abnormal frequency condition | √              |                   |               |
| 16  | Unintentional islanding                  | √              | √                 | √             |
| 17  | LVRT                                     | √              | √                 | √             |
| 18  | Interconnection integrity                | √              |                   | √             |
| 19  | Continuous operation test                |                | √                 | √             |
| 20  | Stop charging/discharging                | √              |                   |               |

## 5. General technical requirements

### 5.1 Accuracy of the test result

The test results according upon this standard shall be effective to verify the performance of the tested ESS as requested by the manufacturers and within the manufacturer's specified accuracy.

### 5.2 Test environment

The test environment shall be maintained within an acceptable range of environmental conditions specified by the manufacturer. If the environment conditions are out of the specified range, the test shall be terminated and restart after the adjustment of the test environment.

### 5.3 Accuracy and calibration of the instruments for test

The instruments used for testing ESS shall be calibrated periodically and these calibrations shall be traceable. The accuracy of instruments used in the test shall be capable and appropriate for performing the tests.

### 5.4 Equipment information

ESS manufacturers shall provide technical documents for every relevant device and equipment and connection requirements necessary to conduct the tests. Special requirements shall be stated, such as the concerns of shielded cables or special cables, maximum cable length, the use of filters, and the correct bonding to functional earth (grounding). Manufacturers shall provide additional devices or equipment necessary for conducting the tests.

If ESS consist of several equipment units, each unit shall have relevant technical documents, for instance, qualification, safety certificates, type test reports, and production tests reports.

The tested ESS shall have product codes and nameplates.

### 5.5 Test report

The test results shall be documented in a test report. The report shall specifically and unambiguously present all relevant information from the tests (e.g., load conditions, conductor type, routing, functional description, and acceptance criteria).

In the test report, the performed test procedures shall be described in detail and any modifications or exemptions shall be justified. The test report shall include all critical information for rerunning the test, and reproduce the same results, when the test follows the indications of this standard.

## 5.6 Technical requirement of the test system

### 5.6.1 Technical conditions of a simulated EPS

When using the simulated EPS, the following requirements shall be satisfied:

- a) The simulated EPS source shall be capable of confirming the manufacturer's stated performance.
- b) The total harmonic distortion (THD) of the simulated EPS shall be less than 50% of that required by the quality standard of local power systems.
- c) During the tests, the steady-state voltage of the simulated EPS source shall not exceed  $\pm 1\%$  of the normal voltage.
- d) Voltage deviation shall be less than  $\pm 3\%$  of the nominal voltage.
- e) Frequency deviation value shall be less than  $\pm 0.01\text{Hz}$ .
- f) For multiphase simulated area EPSs that provide a neutral connection, the phase-to-neutral voltages shall be balanced within  $\pm 3\%$  of the nominal value and the phase displacement shall be within  $\pm 3^\circ$ .
- g) For multiphase simulated area EPSs without a neutral connection, the phase-to-phase voltage balance shall be  $\pm 3\%$  of the amplitude of the nominal value.
- h) The simulated EPS shall be capable of adjusting  $\pm 3\%$  of nominal voltage within one cycle.
- i) The simulated EPS shall be capable of adjusting  $\pm 0.1\%$  of rated frequency within one cycle.

### 5.6.2 Measurement system requirements

Each measurement shall have an uncertainty of no more than 0.5 times the specified accuracies of the tested ESS. The equipment used for measuring shall be capable of confirming the product performance stated by the manufacturer.

## 6. Type tests

The type test is mainly used to verify the design principle and ratings of the ESS. If the ESS consist of several different equipment units, the corresponding type test shall be carried out for each unit according to its specific function.

If any critical characteristics of the ESS are changed and could influence the performance of the ESS, the type test shall be re-performed. These characteristics could be related to design, manufacturing processes, components, materials and firmware.

### 6.1 Temperature stability test

#### 6.1.1 Purpose

The purpose of the test is to verify whether the ESS applied in the EPS is capable of fully functioning within a specified temperature range, and relevant parameters shall be within an accuracy range as stated by the manufacturer.

The test consists of two sections: the storage temperature test and the operation temperature test. The storage temperature test verifies that the ESS shall be stored without damage under the temperature condition stated by the manufacturer. The operational temperature test verifies whether the ESS are capable of functioning under the operational temperature conditions specified by manufacturers and its performance shall be achieved close to an accuracy stated by the manufacturer.

When the results obtained from both tests have met the storage and operational requirements specified by the manufacturer respectively, the subsequent type tests can be carried out.

### 6.1.2 Storage temperature test

The test shall be carried out under the temperature condition stated by the manufacturer.

When the tested ESS are at power-off state, they shall be placed for at least 72 h at the maximum, normal and minimum temperature conditions as stated by the manufacturer. If the normal temperature is not stated, the weighted average of the maximum and minimum temperatures could be used. Then, place the tested ESS under room-temperature conditions. The tested ESS shall be able to function normally when they resume to room temperature.

If the tested ESS are composed of several equipment units, each unit shall go through the storage temperature test respectively. If every equipment unit satisfies the requirements, the ESS could be considered as meeting the requirements as a whole.

To ensure the equipment reach the required temperature, the temperature shall be stable at room temperature. Usually, temperature becomes stable after 2.5 h at minimum. When the deviations of three successive temperature readings of 30 min intervals are within 1 °C, the temperature is considered stable.

### 6.1.3 Operation temperature test

In order to ensure that the tested ESS have reached the desired temperature, the temperature values shall be recorded every 30 min. The temperature is considered stable when the deviations of three successive temperature readings are within 1 °C. For the lowest operating temperature, the tested ESS should remain powered off until the temperature is stable. Test temperature and function shall be selected as follows:

- a) *Selection of test temperature:* The ESS shall be tested at the minimum, normal (if the normal temperature is not stated, the weighted average of the maximum and minimum temperatures shall be used.) and maximum temperature stated by the manufacturer, respectively. If non-linear phenomena are found during the test, additional tests under selected points between minimum and maximum temperature shall be performed.
- b) *Selection of test function:* The trip and reset parameters shall be measured within the test temperature range stated by the manufacturer, including voltage, current, power, phase angle, frequency, and time parameter. It is not necessary to test all functions of the ESS, only those likely to be affected by temperature. The tested ESS shall be able to properly perform the protection function stated by the manufacturer.
- c) Every function or parameter selected in step b) shall be tested three times at every test temperature point selected in step a).

## 6.2 State of charge (SOC) test

The purpose of the test is to measure the actual storage capacity of the energy storage battery pack and evaluate the accuracy of charging quantity indicated by the battery management system (BMS).

The procedure for Test 1, the fully charging/discharging test, is as follows:

- a) Connect the measuring devices to the point of common coupling (PCC) between the tested ESS and the EPS or simulated EPS.
- b) The tested ESS shall discharge to the minimum SOC stated by the manufacturer.
- c) Based on the charging condition and steps stated by the manufacturer, record the charging quantity in Table 3 until the maximum SOC stated by the manufacturer has been reached.
- d) Based on the discharging condition and steps stated by the manufacturer, record the discharging quantity in Table 3 until the minimum SOC stated by the manufacturer has been reached.

NOTE—The charging quantity may not be equal to the discharging quantity, because of the conversion losses during the charging and discharging processes.

- e) Calculate the differences of the charging quantity and the discharging quantity and record the value in the Table 3.
- NOTE—The charging quantity should be slightly higher than the discharging quantity. Otherwise, the measuring instruments and methods used should be reconsidered.
- f) Repeat steps c) to e) at least eight times. Using Table 3, to calculate the average value of the charging quantity  $\bar{C}_c$ , the average value of the discharge quantity  $\bar{C}_d$ , and the difference between the two  $\bar{D}$ . The following percentage values also need to be calculated:

- 1) Charging quantity deviation:

$$\frac{\bar{C}_c - C_{\text{stated}}}{C_{\text{stated}}} \times 100\% \quad \bar{C}_c = \frac{\sum_{i=1}^8 C_{c-i}}{8}$$

- 2)  $C_{\text{stated}}$ : the capacity stated by the manufactures

- 3) Discharging quantity deviation  $D_d$ :

$$D_d = \frac{\bar{C}_d - C_{\text{stated}}}{C_{\text{stated}}} \times 100\% \quad \bar{C}_d = \frac{\sum_{i=1}^8 C_{d-i}}{8}$$

- 4) Charging and discharging quantity deviation  $D$ :  $D = \frac{\bar{D}}{C_{\text{stated}}} \times 100\%$

$$\begin{aligned} \bar{D} &= \frac{\sum_{i=1}^8 D_i}{8} \\ &= \frac{\sum_{i=1}^8 (D_{c-i} - D_{d-i})}{8} \end{aligned}$$

The procedure for Test 2, the proportionally charging/discharging test, is as follows:

- a) Charge the battery pack at a rated charging current stated by the manufacturer, until the SOC reach setting points in turn (typical setting points are 10%, 25%, 50%, 75%, 90%; e.g.,  $\text{SOC}_n = 10\%$ , then  $\text{SOC}_{n+1} = 25\%$ ;  $\text{SOC}_n = 25\%$ , then  $\text{SOC}_{n+1} = 50\%$ ).
- b) Measure and record the charging quantity absorbed by the battery pack from  $\text{SOC}_n$  to the next  $\text{SOC}_{n+1}$ .
- c) Discharge the battery pack at rated discharging current stated by the manufacturer, until the SOC reach setting points in turn (such as 90%, 75%, 50%, 25% and 10%).

- d) Measure and record the discharging quantity released by the battery pack from  $SOC_{n+1}$  to the next adjacent  $SOC_n$ .
- e) Repeat step a) to step d) four times, and record the test results in Table 4 and Table 5, take the average value of measurement results of charging quantity between adjacent SOC points, and record it as the average measurement value of charging quantity  $\bar{C}_m$ .
- f) Calculate  $C_c$  (calculation value of charging quantity):  $C_c = (SOC_{n+1} - SOC_n)C_n$ , where  $C_n$  is the nominal capacity specified by the manufacture.
- g) Calculate the difference between  $\bar{C}_m$  and  $C_c$ , which shall meet the accuracy requirement stated by the manufacturer.

Use Table 3, Table 4, and Table 5 to record the charging quantity of the tested ESS.

**Table 3—Charging quantity record table**

| Test number | Actual measured charging quantity      |  |
|-------------|----------------------------------------|--|
| 1           | Charging quantity, $C_{c\_1}$          |  |
|             | Discharging quantity, $C_{d\_1}$       |  |
|             | Deviation, $D_1 = C_{c\_1} - C_{d\_1}$ |  |
| 2           | Charging quantity, $C_{c\_2}$          |  |
|             | Discharging quantity, $C_{d\_2}$       |  |
|             | Deviation, $D_2 = C_{c\_2} - C_{d\_2}$ |  |
| 3           | Charging quantity, $C_{c\_3}$          |  |
|             | Discharging quantity, $C_{d\_3}$       |  |
|             | Deviation, $D_3 = C_{c\_3} - C_{d\_3}$ |  |
| 4           | Charging quantity, $C_{c\_4}$          |  |
|             | Discharging quantity, $C_{d\_4}$       |  |
|             | Deviation, $D_4 = C_{c\_4} - C_{d\_4}$ |  |
| 5           | Charging quantity, $C_{c\_5}$          |  |
|             | Discharging quantity, $C_{d\_5}$       |  |
|             | Deviation, $D_5 = C_{c\_5} - C_{d\_5}$ |  |
| 6           | Charging quantity, $C_{c\_6}$          |  |
|             | Discharging quantity, $C_{d\_6}$       |  |
|             | Deviation, $D_6 = C_{c\_6} - C_{d\_6}$ |  |

Table continues

**Table 3—Charging quantity record table (continued)**

| Test number                                         | Actual measured charging quantity      |  |
|-----------------------------------------------------|----------------------------------------|--|
| 7                                                   | Charging quantity, $C_{c\_7}$          |  |
|                                                     | Discharging quantity, $C_{d\_7}$       |  |
|                                                     | Deviation, $D_7 = C_{c\_7} - C_{d\_7}$ |  |
| 8                                                   | Charging quantity, $C_{c\_8}$          |  |
|                                                     | Discharging quantity, $C_{d\_8}$       |  |
|                                                     | Deviation, $D_8 = C_{c\_8} - C_{d\_8}$ |  |
| Average charging quantity                           | $\bar{C}_c = \sum_{i=1}^8 C_{c\_i}$    |  |
| Average discharging quantity                        | $\bar{C}_d = \sum_{i=1}^8 C_{d\_i}$    |  |
| Average charging/<br>discharging quantity deviation | $\bar{D} = \frac{\sum_{i=1}^8 D_i}{8}$ |  |

**Table 4—Charging quantity test record table**

| SOC interval                                                  |   | 10%~25%                    | 25%~50%                    | 50%~75%                    | 75%~90%                    |
|---------------------------------------------------------------|---|----------------------------|----------------------------|----------------------------|----------------------------|
| Measure-<br>ment value<br>of charging<br>quantity             | 1 |                            |                            |                            |                            |
|                                                               | 2 |                            |                            |                            |                            |
|                                                               | 3 |                            |                            |                            |                            |
|                                                               | 4 |                            |                            |                            |                            |
| Average measurement value of<br>charging quantity $\bar{C}_m$ |   |                            |                            |                            |                            |
| Calculation value of charging<br>quantity $C_c$               |   | $(25\% - 10\%) \times C_n$ | $(50\% - 25\%) \times C_n$ | $(75\% - 50\%) \times C_n$ | $(90\% - 75\%) \times C_n$ |
| Deviation ( $\bar{C}_m - C_c$ )                               |   |                            |                            |                            |                            |

**Table 5—Discharging quantity test record table**

| SOC interval                                                     |   | 90%~75%                    | 75%~50%                    | 50%~25%                    | 25%~10%                    |
|------------------------------------------------------------------|---|----------------------------|----------------------------|----------------------------|----------------------------|
| Measurement<br>value of discharg-<br>ing quantity                | 1 |                            |                            |                            |                            |
|                                                                  | 2 |                            |                            |                            |                            |
|                                                                  | 3 |                            |                            |                            |                            |
|                                                                  | 4 |                            |                            |                            |                            |
| Average measurement value of<br>discharging quantity $\bar{C}_m$ |   |                            |                            |                            |                            |
| Calculation value of discharging<br>quantity $C_c$               |   | $(90\% - 75\%) \times C_n$ | $(75\% - 50\%) \times C_n$ | $(50\% - 25\%) \times C_n$ | $(25\% - 10\%) \times C_n$ |
| Deviation ( $\bar{C}_m - C_c$ )                                  |   |                            |                            |                            |                            |

Charging quantity  $C$  of the battery is defined as:

$$C = \int I dt (Ah)$$

where

- $I$  is the charging/discharging current, with unit  $A$
- $t$  is the charging/discharging time correspondently, with unit  $h$

## 6.3 Conversion efficiency test

### 6.3.1 PCS conversion efficiency test

The power conversion system (PCS) is an important part of ESS in a power system, which can realize ac and dc conversion between the ESS and the ac grid bidirectionally. The purpose of this test is to test energy conversion efficiency of the PCS.

Test 1 (PCS test in inverter mode) sets the PCS of the tested ESS in inverter mode as follows:

- a) Connect the PCS as an inverter according to the instruction and specification provided by the manufacturer (see [Figure 2](#)).

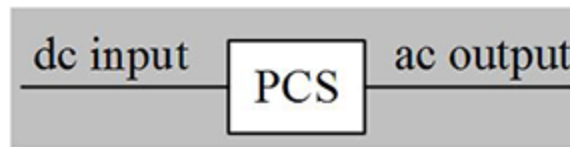


**Figure 2—PCS in inverter mode**

- b) Set the input and output voltage of the PCS to nominal value and the frequency of the power supply at the ac side to nominal value. Adjust the input power supply until the output power of the PCS reaches the rated level. Operate the PCS for at least 30 min at rated output power.
- c) Adjust the input and output voltage of the PCS to the displayed value in Row A of [Table 6](#).
- d) Adjust the input power of the PCS to 100% as shown in [Table 6](#).
- e) When the temperature of the PCS is stable, record the environment temperature and the tested ESS temperature, and measure and record three groups of input voltage ( $U_{dc}$ ), input current ( $I_{dc}$ ), output voltage, and output power ( $P_o$ ), respectively.
- f) Calculate the input power according to the formula  $P_{in} = U_{dc} I_{dc}$ .
- g) When measuring the output power in a three-phase three-wire system, choose any one of the three wiring methods shown in [Figure 3](#). Output power  $P_o$  is the algebraic sum of the two power meter readings.

For three-phase four-wire systems, connect the three power meters as shown in [Figure 4](#). The output power  $P_o$  is the sum of the three power meter readings.

Repeat Steps d) to e) at the input power levels of 75%, 50%, 25%, respectively, and record the results correspondingly

- h) To test Condition B to C in [Table 6](#), repeat Step c) to f); the test shall be carried out from maximum power to minimum power