

---

---

**Electrically propelled road vehicles —  
Test specification for lithium-ion  
traction battery packs and systems —**

**Part 4:  
Performance testing**

*Véhicules routiers à propulsion électrique — Spécifications d'essai  
pour packs et systèmes de batterie de traction aux ions lithium —*

*Partie 4: Essais de performance*



STANDARDSISO.COM : Click to view the full PDF of ISO 12405-4:2018



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2018

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Fax: +41 22 749 09 47  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

# Contents

|                                                                             | Page      |
|-----------------------------------------------------------------------------|-----------|
| Foreword .....                                                              | v         |
| Introduction .....                                                          | vi        |
| <b>1 Scope .....</b>                                                        | <b>1</b>  |
| <b>2 Normative references .....</b>                                         | <b>1</b>  |
| <b>3 Terms and definitions .....</b>                                        | <b>1</b>  |
| <b>4 Symbols and abbreviated terms .....</b>                                | <b>4</b>  |
| 4.1 Symbols .....                                                           | 4         |
| 4.2 Abbreviated terms .....                                                 | 5         |
| <b>5 General requirements .....</b>                                         | <b>6</b>  |
| 5.1 General conditions .....                                                | 6         |
| 5.1.1 Prerequisites .....                                                   | 6         |
| 5.1.2 Accuracy of measurement equipment and measured values .....           | 6         |
| 5.2 Test sequence plan .....                                                | 7         |
| 5.3 Tests .....                                                             | 7         |
| 5.4 Preparation of battery pack and system for bench testing .....          | 7         |
| 5.4.1 Preparation of battery pack .....                                     | 7         |
| 5.4.2 Preparation of battery system .....                                   | 8         |
| <b>6 General tests .....</b>                                                | <b>8</b>  |
| 6.1 Preconditioning cycles .....                                            | 8         |
| 6.1.1 Purpose .....                                                         | 8         |
| 6.1.2 Test procedures .....                                                 | 8         |
| 6.2 Standard Cycle (SC) .....                                               | 9         |
| 6.2.1 Purpose .....                                                         | 9         |
| 6.2.2 Test procedures .....                                                 | 9         |
| <b>7 Performance tests .....</b>                                            | <b>10</b> |
| 7.1 Energy and capacity at RT .....                                         | 10        |
| 7.1.1 Purpose .....                                                         | 10        |
| 7.1.2 Test procedures .....                                                 | 11        |
| 7.1.3 Determination of rated capacity .....                                 | 12        |
| 7.2 Energy and capacity at different temperatures and discharge rates ..... | 13        |
| 7.2.1 Purpose .....                                                         | 13        |
| 7.2.2 Test procedure .....                                                  | 13        |
| 7.2.3 Requirements .....                                                    | 20        |
| 7.3 Power and internal resistance .....                                     | 20        |
| 7.3.1 Purpose .....                                                         | 20        |
| 7.3.2 Pulse power characterization profile .....                            | 20        |
| 7.3.3 Test procedure .....                                                  | 27        |
| 7.3.4 Requirements .....                                                    | 31        |
| 7.4 No load SOC loss .....                                                  | 31        |
| 7.4.1 Purpose .....                                                         | 31        |
| 7.4.2 Test procedure .....                                                  | 32        |
| 7.4.3 Test sequence .....                                                   | 33        |
| 7.4.4 Requirement .....                                                     | 35        |
| 7.5 SOC loss at storage .....                                               | 35        |
| 7.5.1 Purpose .....                                                         | 35        |
| 7.5.2 Test procedure .....                                                  | 36        |
| 7.5.3 Test sequence .....                                                   | 36        |
| 7.5.4 Requirement .....                                                     | 36        |
| 7.6 Cranking power at low temperature .....                                 | 37        |
| 7.6.1 Purpose .....                                                         | 37        |
| 7.6.2 Test procedure .....                                                  | 37        |
| 7.6.3 Requirement .....                                                     | 38        |

|                              |                                                                            |           |
|------------------------------|----------------------------------------------------------------------------|-----------|
| 7.7                          | Cranking power at high temperature.....                                    | 38        |
| 7.7.1                        | Purpose.....                                                               | 38        |
| 7.7.2                        | Test procedure.....                                                        | 38        |
| 7.7.3                        | Requirement.....                                                           | 39        |
| 7.8                          | Energy efficiency.....                                                     | 40        |
| 7.8.1                        | Purpose.....                                                               | 40        |
| 7.8.2                        | Test description.....                                                      | 40        |
| 7.8.3                        | Test procedure.....                                                        | 40        |
| 7.8.4                        | Requirement.....                                                           | 42        |
| 7.8.5                        | Calculation example for energy efficiency test.....                        | 42        |
| 7.9                          | Energy efficiency at fast charging.....                                    | 42        |
| 7.9.1                        | Purpose.....                                                               | 42        |
| 7.9.2                        | Test procedure.....                                                        | 42        |
| 7.9.3                        | Requirement.....                                                           | 44        |
| 7.10                         | Cycle life.....                                                            | 44        |
| 7.10.1                       | Purpose.....                                                               | 44        |
| 7.10.2                       | Test procedure.....                                                        | 45        |
| 7.10.3                       | Requirement.....                                                           | 60        |
| 7.10.4                       | Calculation example for cycle life test for high-power battery system..... | 61        |
| <b>Annex A (informative)</b> | <b>Battery pack and system and overview on tests.....</b>                  | <b>62</b> |
| <b>Annex B (informative)</b> | <b>Examples of data sheets for battery pack and system testing.....</b>    | <b>67</b> |
| <b>Annex C (informative)</b> | <b>Example of test conditions.....</b>                                     | <b>71</b> |
| <b>Bibliography</b>          | <b>.....</b>                                                               | <b>72</b> |

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. [www.iso.org/directives](http://www.iso.org/directives)

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received. [www.iso.org/patents](http://www.iso.org/patents)

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

This document cancels and replaces ISO 12405-1:2011 and ISO 12405-2:2012 by summarizing the test specifications.

## Introduction

Lithium-ion-based battery systems are an efficient alternative energy storage system for electrically propelled vehicles. The requirements for lithium-ion based battery systems for use as a power source for the propulsion of electric road vehicles are significantly different from those batteries used for consumer electronics or stationary usage.

This document provides specific test procedures for lithium-ion battery packs and systems specially developed for propulsion of road vehicles. This document specifies such tests and related requirements to ensure that a battery pack or system is able to meet the specific needs of the automobile industry. It enables vehicle manufactures to choose test procedures to evaluate the characteristics of a battery pack or system for their specific requirements.

ISO 12405 specifies test procedures for lithium-ion battery packs and systems which are connected to the electric propulsion system of electrically propelled vehicles.

The objective of ISO 12405 is to specify standard test procedures for the basic characteristics of performance, reliability and electrical functionality of lithium-ion battery packs and systems and to assist the user in comparing the test results achieved for different battery packs or systems.

NOTE 1 The general safety relevant tests and requirements are given in ISO 6469-1<sup>1)</sup>.

NOTE 2 Environmental conditions and testing will be given in the future ISO 19453-6<sup>2)</sup>.

For specifications for battery cells, see IEC 62660-1 to 3.

---

1) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

2) Under preparation. Stage at the time of publication: ISO/CD 19453-6.

# Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —

## Part 4: Performance testing

### 1 Scope

This document specifies test procedures for the basic characteristics of performance, reliability and electrical functionality for the battery packs and systems for either high-power or high-energy application. Unless otherwise stated, the test applies to both applications.

NOTE 1 Typical applications for high-power battery packs and systems are hybrid electric vehicles (HEVs) and some type of fuel cell vehicles (FCVs).

NOTE 2 Typical applications for high-energy battery packs and systems are battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and some type of fuel cell vehicles (FCVs).

NOTE 3 Testing on cell level is specified in IEC 62660 series.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6469-1<sup>3)</sup>, *Electrically propelled road vehicles — Safety specifications — Part 1: On-board rechargeable energy storage system (RESS)*

ISO 6469-3<sup>4)</sup>, *Electrically propelled road vehicles — Safety specifications — Part 3: Protection of persons against electric shock*

### 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

#### 3.1

##### **battery control unit** **BCU**

electronic device that controls, manages, detects or calculates electric and thermal functions of the *battery system* (3.3) and that provides communication between the battery system and other vehicle controllers

Note 1 to entry: See A.3.1 for further explanations.

3) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

4) Under preparation. Stage at the time of publication: ISO/DIS 6469-3.

### 3.2

#### **battery pack**

energy storage device that includes cells or cell assemblies normally connected with *cell electronics* (3.5), power supply circuits and overcurrent shut-off device, including electrical interconnections, interfaces for external systems

Note 1 to entry: See A.2 for further explanations.

Note 2 to entry: Examples of external systems are cooling, voltage class B, auxiliary voltage class A and communication.

### 3.3

#### **battery system**

energy storage device that includes cells or cell assemblies or *battery pack*(s) (3.2) as well as electrical circuits and electronics

Note 1 to entry: See A.3.2 and A.3.3 for further explanations. Battery system components can also be distributed in different devices within the vehicle.

Note 2 to entry: Examples of electronics are the BCU and contactors.

### 3.4

#### **capacity**

total number of ampere hours that can be withdrawn from a fully charged *battery pack* (3.2) under specified conditions

### 3.5

#### **cell electronics**

electronic device that collects and possibly monitors thermal or electric data of cells or cell assemblies and contains electronics for cell balancing, if necessary

Note 1 to entry: The cell electronics can include a cell controller. The functionality of cell balancing can be controlled by the cell electronics or by the BCU.

### 3.6

#### **customer**

party that is interested in using the *battery pack* or system and therefore orders or performs the test

EXAMPLE A vehicle manufacturer.

### 3.7

#### **device under test**

##### **DUT**

*battery pack* or *battery system*

### 3.8

#### **electric drive**

combination of a traction motor, power electronics and their associated controls for the conversion of electric to mechanical power and vice versa

### 3.9

#### **electrically propelled vehicle**

vehicle with one or more *electric drive*(s) (3.8) for vehicle propulsion

### 3.10

#### **energy density**

amount of stored energy related to the *battery pack* (3.2) or *system* (3.3) volume

Note 1 to entry: The *battery pack* or system includes the cooling system, if any, to the point of a reversible attachment of the coolant lines or air ducts, respectively.

Note 2 to entry: Energy density is expressed in watt hours per litre (Wh/l).

**3.11****energy round trip efficiency**

ratio of the net d.c. energy delivered by a DUT during a discharge test to the total d.c. energy required to restore the initial SOC by a standard charge

Note 1 to entry: The net d.c. energy is expressed as watt hours (Wh) discharge and the total d.c. energy is expressed as watt hours (Wh) charge.

**3.12****high-energy battery pack and system**

*battery pack* (3.2) and *system* (3.3) using cells, which have the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT lower than 10

Note 1 to entry: Typically high-energy battery packs and systems are designed for applications in BEVs and PHEVs.

Note 2 to entry: The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (Wh).

**3.13****high-power battery pack and system**

*battery pack* (3.2) and *system* (3.3) using cells, for which the numerical ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT equal to or higher than 10

Note 1 to entry: Typically high-power battery packs and systems are designed for applications in HEVs and FCVs.

Note 2 to entry: The allowed electric power output is expressed as power in watts (W) and the electric energy output is expressed as energy in watt hours (Wh).

**3.14****maximum working voltage**

highest value of a.c. voltage (rms) or of d.c. voltage which may occur in an electric system under any normal operating conditions according to the supplier's specifications, disregarding transients

**3.15****overcurrent protection**

protection intended to operate when the current is in excess of a predetermined value

**3.16****rated capacity**

supplier's specification of the total number of ampere hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature and discharge cut-off voltage

**3.17****room temperature**

RT

temperature of  $(25 \pm 2) ^\circ\text{C}$

**3.18****sign of battery current**

discharge current is specified as positive and the charge current as negative

**3.19****specific energy**

amount of stored energy related to the *battery pack* (3.2) or *system* (3.3) mass

Note 1 to entry: The mass of battery pack or system includes the mass of the temperature conditioning system if any up to the point of a reversible attachment of the coolant lines or air ducts and the coolant mass.

Note 2 to entry: Specific energy is expressed in watt hours per kilogram (Wh/kg).

### 3.20

#### state of charge

##### SOC

available capacity in a battery pack or system expressed as a percentage of *rated capacity* (3.15)

### 3.21

#### top off charge

additional charge which eliminates possible SOC reduction after SCH at RT followed by thermal equilibration at a different temperature

### 3.22

#### supplier

party that provides battery systems and packs

EXAMPLE A battery manufacturer.

### 3.23

#### voltage class A

classification of an electric component or circuit with a *maximum working voltage* (3.14) of  $\leq 30$  V a.c. (rms) or  $\leq 60$  V d.c., respectively

Note 1 to entry: See ISO 6469-3.

### 3.24

#### voltage class B

classification of an electric component or circuit with a *maximum working voltage* (3.14) of  $> 30$  and  $\leq 1\,000$  V a.c. (rms) or  $> 60$  and  $\leq 1\,500$  V d.c., respectively

Note 1 to entry: See ISO 6469-3.

## 4 Symbols and abbreviated terms

### 4.1 Symbols

|                     |                                                                                                                        |
|---------------------|------------------------------------------------------------------------------------------------------------------------|
| $C_{\text{fade}}$   | Capacity fade                                                                                                          |
| $C_{\text{rt},t0}$  | Rated 1 C capacity at BOL                                                                                              |
| $I_{\text{c,max}}$  | maximum continuous charge current specified by the supplier for energy efficiency at fast charging testing             |
| $I_{\text{d,max}}$  | maximum continuous discharge current specified by the supplier for energy and capacity testing                         |
| $I_{\text{dp,max}}$ | maximum discharge pulse current specified by the supplier for power, internal resistance and energy efficiency testing |
| $T_{\text{max}}$    | maximum temperature                                                                                                    |
| $T_{\text{min}}$    | minimum temperature                                                                                                    |
| $T$                 | Time                                                                                                                   |

## 4.2 Abbreviated terms

|        |                                                                                                                                                                         |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| a.c.   | alternating current                                                                                                                                                     |
| BCU    | battery control unit                                                                                                                                                    |
| BEV    | battery electric vehicle                                                                                                                                                |
| BOL    | beginning of life                                                                                                                                                       |
| C      | capacity, expressed in ampere hours (Ah)                                                                                                                                |
| nC     | current rate equal to n times the one hour discharge capacity expressed in ampere (e.g. 3C is equal to three times the 1 h current discharge rate, expressed in ampere) |
| d.c.   | direct current                                                                                                                                                          |
| DUT    | device under test                                                                                                                                                       |
| EODV   | End-of-discharge-voltage                                                                                                                                                |
| EUCAR  | European Council for Automotive Research                                                                                                                                |
| FCV    | fuel cell vehicle                                                                                                                                                       |
| HEV    | hybrid electric vehicle                                                                                                                                                 |
| IEC    | International Electrotechnical Commission                                                                                                                               |
| ISO    | International Organization for Standardization                                                                                                                          |
| Li     | lithium                                                                                                                                                                 |
| Li-ion | lithium-ion                                                                                                                                                             |
| OCV    | Open Circuit Voltage                                                                                                                                                    |
| PHEV   | plug-in hybrid electric vehicle                                                                                                                                         |
| PSD    | power spectral density                                                                                                                                                  |
| RESS   | rechargeable energy storage system                                                                                                                                      |
| rms    | root mean square                                                                                                                                                        |
| RT     | room temperature ( $25 \pm 2$ ) °C                                                                                                                                      |
| SC     | standard cycle                                                                                                                                                          |
| SCH    | standard charge                                                                                                                                                         |
| SDCH   | standard discharge                                                                                                                                                      |
| SOC    | state of charge                                                                                                                                                         |
| USABC  | United States Advanced Battery Consortium                                                                                                                               |

## 5 General requirements

### 5.1 General conditions

#### 5.1.1 Prerequisites

A battery pack or system to be tested according to this document shall fulfil the following requirements:

- The electrical safety design and safety requirements shall comply with the requirements given in ISO 6469-1<sup>5)</sup> and ISO 6469-3<sup>6)</sup>.
- The necessary documentation for operation and needed interface parts for connection to the test equipment (i.e. connectors, plugs including cooling, communication) shall be delivered together with the DUT.

A battery system shall enable the specified tests, i.e. via specified test modes implemented in the BCU, and shall be able to communicate with the test bench via common communication buses.

The battery pack subsystem as a DUT shall comprise all parts specified by the customer (e.g. including mechanical and electrical connecting points for mechanical test).

If not otherwise specified, before each test the DUT shall be equilibrated at the test temperature. The thermal equilibration is reached if during a period of 1 h without active cooling the deviations between test temperature and temperature of all cell temperature measuring points are lower than  $\pm 2$  K.

If not otherwise specified, each charge and each SOC change shall be followed by a rest period of 30 min.

#### 5.1.2 Accuracy of measurement equipment and measured values

The accuracy of external measurement equipment shall be at least within the following tolerances:

- voltage  $\pm 0,5$  %
- current  $\pm 0,5$  %
- temperature  $\pm 1$  K

The overall accuracy of externally controlled or measured values, relative to the specified or actual values, shall be at least within the following tolerances:

- voltage  $\pm 1$  %
- current  $\pm 1$  %
- temperature  $\pm 2$  K
- time  $\pm 0,1$  %
- mass  $\pm 0,1$  %
- dimensions  $\pm 0,1$  %

All values (time, temperature, current and voltage) shall be noted at least every 5 % of the estimated discharge and charge time, except if it is noted otherwise in the individual test procedure.

5) Under preparation. Stage at the time of publication: ISO/DIS 6469-1.

6) Under preparation. Stage at the time of publication: ISO/DIS 6469-3.

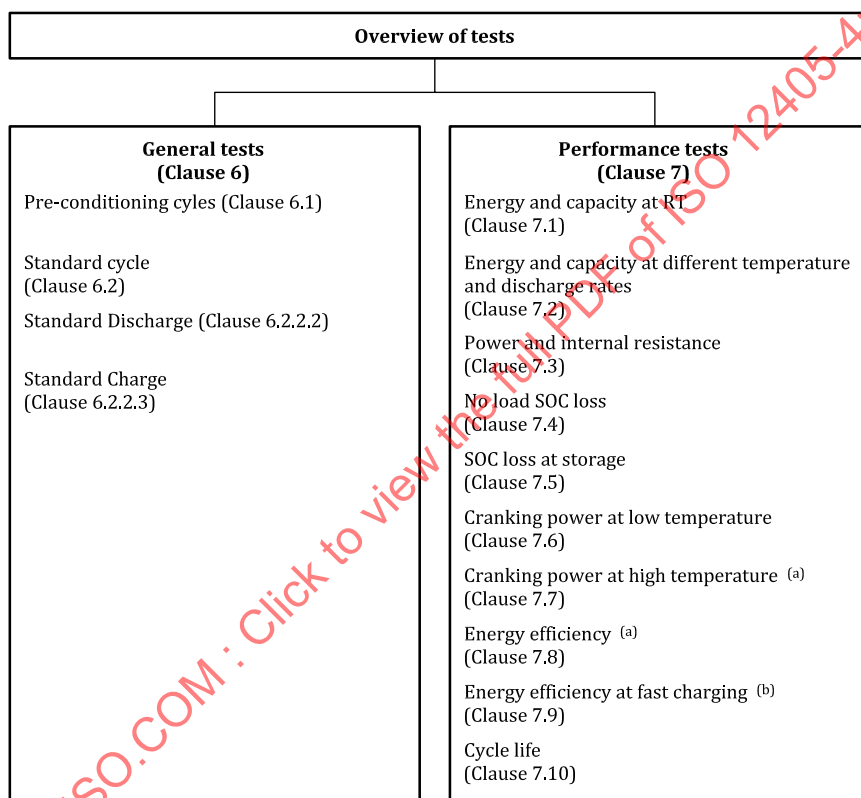
## 5.2 Test sequence plan

The test sequence for an individual battery pack or system, or a battery pack subsystem shall be based on agreement between the customer and supplier with consideration of tests in 5.3.

An example for a list of test conditions to be agreed between customer and supplier is provided in Table C.1 for high-power battery packs and systems or in Table C.2 for high-energy battery packs and systems.

## 5.3 Tests

An overview of the tests is given in Figure 1 where the references to the specific subclauses are also given. Annex B provides examples for collection of test data.



### Key

- a The test applies only to high-power battery packs and systems.
- b The test applies only to high-energy battery packs and systems.

Figure 1 — Test sequence

## 5.4 Preparation of battery pack and system for bench testing

### 5.4.1 Preparation of battery pack

If not otherwise specified, the battery pack shall be connected with voltage class B if any, and voltage class A connections to the test bench equipment. Contactors, available voltage, current and temperature data shall be controlled according to the supplier's requirements and according to the given test specification by the test bench equipment. The passive overcurrent protection shall be operational in the battery pack. Active overcurrent protection shall be maintained by the test bench equipment, if necessary, via disconnection of the battery pack main contactors. The cooling device may be connected to the test bench equipment and operated according to the supplier's requirements.

#### 5.4.2 Preparation of battery system

If not otherwise specified, the battery system shall be connected with voltage class B, if any, and voltage class A and cooling connections to the test bench equipment. The battery system shall be controlled by the BCU, the test bench equipment shall follow the operational limits provided by the BCU via bus communication. The test bench equipment shall maintain the on/off requirements for the main contactors and the voltage, current and temperature profiles according to the requested requirements of the given test procedure. The battery system cooling device and the corresponding cooling loop at the test bench equipment shall be operational according to the controls by the BCU, unless otherwise specified in the given test procedure. The BCU shall enable the test bench equipment to perform the requested test procedure within the battery system operational limits. If necessary, the BCU program shall be adapted by the supplier for the requested test procedure. The active and passive overcurrent protection shall be operational by the battery system. Active overcurrent protection shall be maintained by the test bench equipment, too, if necessary via request of disconnection of the battery system main contactors.

### 6 General tests

#### 6.1 Preconditioning cycles

##### 6.1.1 Purpose

The DUT shall be conditioned by performing some electrical cycles, before starting the real testing sequence, in order to ensure an adequate stabilization of the battery pack or system performance.

This test applies to battery packs and systems.

##### 6.1.2 Test procedures

###### 6.1.2.1 High-power battery pack and system

For high-power battery packs and systems the procedure shall be the following:

- The test shall be performed at RT.
- The discharges shall be performed at 2 C or at a different current if suggested and/or used by the supplier in testing before delivery. The charging shall be performed according to the recommendations of the supplier.
- Five consecutive preconditioning cycles shall be performed. Fewer cycles may be agreed between the customer and supplier.
- At the end of discharge, the battery pack or system voltage shall not go below the minimum voltage recommended by the supplier.
- The battery pack or system shall be considered “preconditioned” if the discharged capacity during two consecutive discharges does not change by a value greater than 3 % of the rated capacity (30 min discharge or other discharge process adopted during test according to supplier indications). If the discharge process is equal to that used by the supplier on the same battery pack or system during factory tests, the data from the second cycle may be compared directly with the data from the supplier.
- If the precondition requirements cannot be fulfilled, the customer and supplier shall agree on further procedure.

NOTE The discharge rate of 2 C is used in order to shorten the preconditioning.

### 6.1.2.2 High-energy battery pack and system

For high-energy battery packs and systems the procedure shall be the following:

- The test shall be performed at RT.
- The discharges shall be performed at C/3 or at a different current if suggested and/or used by the supplier in testing before delivery. The charging shall be performed according to the recommendations of the supplier.
- Three consecutive preconditioning cycles shall be performed. If agreed between customer and supplier, only two cycles shall be performed.
- At end of discharge, the battery pack or system voltage shall not go below the minimum voltage recommended by the supplier (the minimum voltage is the lowest voltage under discharge without irreversible damage).
- The battery pack or system shall be considered as “preconditioned” if the discharged capacity during two consecutive discharges does not change by a value greater than 3 % of the rated capacity. If the discharge process is equal to that used by the supplier on the same battery pack or system during factory tests, the data from the second cycle can be compared directly with the data from the supplier.
- If the preconditioning requirements cannot be fulfilled, customer and supplier shall agree on further procedure.

## 6.2 Standard Cycle (SC)

### 6.2.1 Purpose

The purpose of the standard cycle (SC) is to ensure the same initial condition for each test of a battery pack or system. A standard cycle (SC), as described below, shall be performed prior to each test.

This test applies to battery packs and systems.

### 6.2.2 Test procedures

#### 6.2.2.1 General

The standard cycle (SC) shall be performed at RT. The SC shall comprise a standard discharge (SDCH), see [6.2.2.2](#), followed by a standard charge (SCH), see [6.2.2.3](#).

If, for any reason, the time interval between the end of the SC and the start of a new test is longer than 3 h, the SC shall be repeated.

#### 6.2.2.2 Standard discharge (SDCH)

##### 6.2.2.2.1 High-power battery pack and system

Discharge rate:

- 1 C or other specific discharge rate according to the specifications given by the supplier.

Discharge limit:

- According to the specifications given by the supplier.

Rest period after discharge to reach a stable condition:

- 30 min or a thermal equilibration at RT of the DUT is reached.

#### 6.2.2.2.2 High-energy battery pack and system

Discharge rate:

- C/3 or other specific discharge rate according to the specifications given by the supplier.

Discharge limit:

- According to the specifications given by the supplier.

Rest period after discharge to reach a stable condition:

- 30 min or a thermal equilibration at RT of the DUT is reached.

#### 6.2.2.3 Standard charge (SCH)

##### 6.2.2.3.1 High-power battery pack and system

Charge procedure and end of charge criteria:

- According to the specifications given by the supplier. The specifications shall cover end of charge criteria and time limits for the overall charging procedure.

Rest period after charge:

- 30 min.

##### 6.2.2.3.2 High-energy battery pack and system

Charge procedure and end of charge criteria:

- C/3 or another specific charge rate according to the specifications given by the supplier. The specifications shall cover end of charge criteria and time limits for the overall charging procedure.
- In any case, the total charge procedure shall be completed within 8 h.

Rest period after charge:

- 60 min.

## 7 Performance tests

### 7.1 Energy and capacity at RT

#### 7.1.1 Purpose

This test measures DUT capacity in A·h at constant current discharge rates.

For high-power battery packs and systems, the constant current discharge rates shall be corresponding to the suppliers rated 1 C capacity in A·h (e.g., if the rated one hour discharge capacity is 10 A·h, the discharge rate is 10 A). The one hour rate (1 C) is used as reference for static capacity and energy measurement and as a standard rate for high-power battery pack and system level testing. In addition, if applicable, the 10 C and the maximum permitted C rate shall be performed for capacity determination to meet the high-power system requirements. Discharge shall be terminated on supplier-specified discharge voltage limits depending on discharge rates and temperature.

For high-energy battery packs and systems the constant current discharge rates shall be corresponding to the suppliers rated C/3 capacity in A·h (e.g., if the rated three hour discharge capacity is 45 A·h, the discharge rate is 15 A). The three hour rate (C/3) is used as reference for static capacity and energy measurement and as a standard rate for pack and high-energy system level testing. In addition, if

applicable, the 1C, 2C and the maximum permitted C rate shall be performed for capacity determination to meet the high-energy system requirements. Discharge shall be terminated on supplier specified discharge voltage limits depending on discharge rates and temperature.

This test applies to battery packs and systems.

## 7.1.2 Test procedures

### 7.1.2.1 High-power battery pack and system

The test shall be performed at RT with the discharge rates of 1 C, 10 C and the maximum C rate as permitted by the supplier (the maximum C rate corresponds to  $I_{d,max}$ ).

The test sequence shall be performed as specified in [Table 1](#).

**Table 1 — Test sequence energy and capacity test at RT for high-power battery packs and systems**

| Step | Procedure                | Test temperature |
|------|--------------------------|------------------|
| 1.1  | Thermal equilibration    | RT               |
| 1.2  | Standard charge (SCH)    | RT               |
| 1.3  | Standard cycle (SC)      | RT               |
| 2.1  | Discharge at 1 C         | RT               |
| 2.2  | Standard charge (SCH)    | RT               |
| 2.3  | Discharge at 1 C         | RT               |
| 2.4  | Standard charge (SCH)    | RT               |
| 2.5  | Discharge at 10 C        | RT               |
| 2.6  | Standard charge (SCH)    | RT               |
| 2.7  | Discharge at 10 C        | RT               |
| 2.8  | Standard charge (SCH)    | RT               |
| 2.9  | Discharge at $I_{d,max}$ | RT               |
| 2.10 | Standard charge (SCH)    | RT               |
| 2.11 | Discharge at $I_{d,max}$ | RT               |
| 2.12 | Standard charge (SCH)    | RT               |
| 3.1  | Standard cycle (SC)      | RT               |

The SCH procedure shall follow [6.2.2.3.1](#).

The SC procedure shall follow [6.2](#).

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermally equilibrated at the required ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

### 7.1.2.2 High-energy battery pack and system

The test shall be performed at RT with the discharge rates C/3, 1C, 2C (if 2C is less than  $I_{d,max}$ ) and the maximum C rate as permitted by the supplier.

The test sequence shall be performed as specified in [Table 2](#).

**Table 2 — Test sequence energy and capacity test at RT for high-energy battery packs and systems**

| Step | Procedure                | Ambient temperature |
|------|--------------------------|---------------------|
| 1.1  | Thermal equilibration    | RT                  |
| 1.2  | Standard charge (SCH)    | RT                  |
| 1.3  | Standard cycle (SC)      | RT                  |
| 2.1  | Discharge at C/3         | RT                  |
| 2.2  | Standard charge (SCH)    | RT                  |
| 2.3  | Discharge at C/3         | RT                  |
| 2.4  | Standard charge (SCH)    | RT                  |
| 2.5  | Discharge at 1C          | RT                  |
| 2.6  | Standard charge (SCH)    | RT                  |
| 2.7  | Discharge at 1C          | RT                  |
| 2.8  | Standard charge (SCH)    | RT                  |
| 2.9  | Discharge at 2C          | RT                  |
| 2.10 | Standard charge (SCH)    | RT                  |
| 2.11 | Discharge at 2C          | RT                  |
| 2.12 | Standard charge (SCH)    | RT                  |
| 2.13 | Discharge at $I_{d,max}$ | RT                  |
| 2.14 | Standard charge (SCH)    | RT                  |
| 2.15 | Discharge at $I_{d,max}$ | RT                  |
| 2.16 | Standard charge (SCH)    | RT                  |
| 3.1  | Standard cycle (SC)      | RT                  |

The standard charge (SCH) procedure shall follow [6.2.2.3.2](#).

The standard cycle (SC) procedure shall follow [6.2](#).

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermally equilibrated at the requested ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

### 7.1.3 Determination of rated capacity

#### 7.1.3.1 High-power battery pack and system

If the 1 C capacity obtained during testing at [7.1.2.1](#) step no. 2.3 in [Table 1](#) differs more than 5 % from the suppliers 1 C specification, this measured 1 C capacity shall be used as rated capacity and shall be the basis value for all further discharge current requirements, i.e. the value for C in each discharge current calculation,  $nC$ , shall be based on the measured 1 C capacity.

The following data shall be reported:

- current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following standard charge;
- discharged capacity, in A·h, energy in Wh and average power in W at each discharge test;
- charged capacity in A·h, energy in Wh and average power in W following each discharge test;
- energy round-trip efficiency at each discharge test;

- discharged energy in Wh as a function of SOC at each discharge test (in % of rated capacity);
- EODV of all available cell voltage measuring points for all performed discharge tests;
- determined 1 C rated capacity which is taken as basic value for all further discharge current requirements.

NOTE Capacity data are also used for the later calculation of capacity fades (see [7.10.2.1.8](#)).

### 7.1.3.2 High-energy battery pack and system

If the C/3 capacity obtained during testing at [7.1.2.2](#) step no. 2.1 in [Table 2](#) differs more than 5 % from the suppliers C/3 specification, this measured C/3 capacity shall be used as rated capacity and shall be the basis value for all further discharge current requirements, i.e. the value for C in each discharge current calculation  $nC$  shall be based on the measured C/3 capacity.

The following data shall be reported:

- current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following standard charge;
- discharged capacity in Ah, energy in Wh and average power in W at each discharge test;
- charged capacity in Ah, energy in Wh and average power in W following each discharge test;
- energy round trip efficiency at each discharge test;
- discharged energy in Wh as a function of SOC at each discharge test (in % of rated capacity);
- the EODV of all available cell voltage measuring points for all performed discharge tests;
- determined C/3 rated capacity which is taken as basic value for all further discharge current requirements.

NOTE Capacity data are also used for the later calculation of capacity fades (see [7.10.2.2.6](#)).

## 7.2 Energy and capacity at different temperatures and discharge rates

### 7.2.1 Purpose

This test characterizes the capacity at different temperatures at three different constant current discharge rates. The different discharge rates shall be performed in a sequence before the ambient temperature is changed and the test shall be repeated after the new temperature is achieved.

### 7.2.2 Test procedure

#### 7.2.2.1 High-power battery pack and system

The test shall be performed at three different temperatures (40 °C, 0 °C and -18 °C) with the discharge rates 1 C, 10 C and the maximum C rate as permitted by the supplier (the maximum C rate corresponds to  $I_{d,max}$ ).

The test sequence shall be performed as specified in [Table 3](#).

**Table 3 — Test sequence energy and capacity test at different temperature and discharge rates for high-power battery packs and systems**

| Step | Procedure                | Test temperature |
|------|--------------------------|------------------|
| 1.1  | Thermal equilibration    | RT               |
| 1.2  | Standard charge (SCH)    | RT               |
| 1.3  | Standard cycle (SC)      | RT               |
| 2.1  | Thermal equilibration    | 40 °C            |
| 2.2  | Top off charge           | 40 °C            |
| 2.3  | Discharge at 1 C         | 40 °C            |
| 2.4  | Standard charge (SCH)    | 40 °C            |
| 2.5  | Discharge at 1 C         | 40 °C            |
| 3.1  | Thermal equilibration    | RT               |
| 3.2  | Standard charge (SCH)    | RT               |
| 3.3  | Standard cycle (SC)      | RT               |
| 4.1  | Thermal equilibration    | 40 °C            |
| 4.2  | Top off charge           | 40 °C            |
| 4.3  | Discharge at 10 C        | 40 °C            |
| 4.4  | Standard charge (SCH)    | 40 °C            |
| 4.5  | Discharge at 10 C        | 40 °C            |
| 5.1  | Thermal equilibration    | RT               |
| 5.2  | Standard charge (SCH)    | RT               |
| 5.3  | Standard cycle (SC)      | RT               |
| 6.1  | Thermal equilibration    | 40 °C            |
| 6.2  | Top off charge           | 40 °C            |
| 6.3  | Discharge at $I_{d,max}$ | 40 °C            |
| 6.4  | Standard charge (SCH)    | 40 °C            |
| 6.5  | Discharge at $I_{d,max}$ | 40 °C            |
| 7.1  | Thermal equilibration    | RT               |
| 7.2  | Standard charge (SCH)    | RT               |
| 7.3  | Standard cycle (SC)      | RT               |
| 8.1  | Thermal equilibration    | 0 °C             |
| 8.2  | Top off charge           | 0 °C             |
| 8.3  | Discharge at 1 C         | 0 °C             |
| 8.4  | Standard charge (SCH)    | 0 °C             |
| 8.5  | Discharge at 1 C         | 0 °C             |
| 9.1  | Thermal equilibration    | RT               |
| 9.2  | Standard charge (SCH)    | RT               |
| 9.3  | Standard cycle (SC)      | RT               |
| 10.1 | Thermal equilibration    | 0 °C             |
| 10.2 | Top off charge           | 0 °C             |
| 10.3 | Discharge at 10 C        | 0 °C             |
| 10.4 | Standard charge (SCH)    | 0 °C             |
| 10.5 | Discharge at 10 C        | 0 °C             |
| 11.1 | Thermal equilibration    | RT               |
| 11.2 | Standard charge (SCH)    | RT               |
| 11.3 | Standard cycle (SC)      | RT               |

Table 3 (continued)

| Step | Procedure                | Test temperature |
|------|--------------------------|------------------|
| 12.1 | Thermal equilibration    | 0 °C             |
| 12.2 | Top off charge           | 0 °C             |
| 12.3 | Discharge at $I_{d,max}$ | 0 °C             |
| 12.4 | Standard charge (SCH)    | 0 °C             |
| 12.5 | Discharge at $I_{d,max}$ | 0 °C             |
| 13.1 | Thermal equilibration    | RT               |
| 13.2 | Standard charge (SCH)    | RT               |
| 13.3 | Standard cycle (SC)      | RT               |
| 14.1 | Thermal equilibration    | -18 °C           |
| 14.2 | Top off charge           | -18 °C           |
| 14.3 | Discharge at 1 C         | -18 °C           |
| 14.4 | Standard charge (SCH)    | -18 °C           |
| 14.5 | Discharge at 1 C         | -18 °C           |
| 15.1 | Thermal equilibration    | RT               |
| 15.2 | Standard charge (SCH)    | RT               |
| 15.3 | Standard cycle (SC)      | RT               |
| 16.1 | Thermal equilibration    | -18 °C           |
| 16.2 | Top off charge           | -18 °C           |
| 16.3 | Discharge at 10 C        | -18 °C           |
| 16.4 | Standard charge (SCH)    | -18 °C           |
| 16.5 | Discharge at 10 C        | -18 °C           |
| 17.1 | Thermal equilibration    | RT               |
| 17.2 | Standard charge (SCH)    | RT               |
| 17.3 | Standard cycle (SC)      | RT               |
| 18.1 | Thermal equilibration    | -18 °C           |
| 18.2 | Top off charge           | -18 °C           |
| 18.3 | Discharge at $I_{d,max}$ | -18 °C           |
| 18.4 | Standard charge (SCH)    | -18 °C           |
| 18.5 | Discharge at $I_{d,max}$ | -18 °C           |
| 19.1 | Thermal equilibration    | RT               |
| 19.2 | Standard charge (SCH)    | RT               |
| 19.3 | Standard cycle (SC)      | RT               |

The SCH procedure shall follow [6.2.2.3.1](#).

The SC procedure shall follow [6.2](#).

The value “n” for the discharge rate nC shall be based on the rated capacity provided by the supplier and according to the 1 C test results, as described in test procedure [7.1.2.1](#), respectively.

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermally equilibrated at the required ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

NOTE The SCH for top-off enables recharging of the DUT in order to compensate for energy losses that can occur during temperature equilibration.

### 7.2.2.2 High-energy battery pack and system

The test shall be performed at least at four different temperatures (40 °C, 0 °C, –10 °C and –18 °C, the test at  $T_{\min}$  shall be optional) with the discharge rates C/3, 1C, 2C and the maximum C rate as permitted by the supplier (the maximum C rate corresponds to  $I_{d,\max}$ ).

The test sequence shall be performed as specified in [Table 4](#).

**Table 4 — Test sequence energy and capacity test at different temperature and discharge rates for high-energy battery packs and systems**

| Step | Procedure                 | Ambient temperature |
|------|---------------------------|---------------------|
| 1.1  | Thermal equilibration     | RT                  |
| 1.2  | Standard charge (SCH)     | RT                  |
| 1.3  | Standard cycle (SC)       | RT                  |
| 2.1  | Thermal equilibration     | 40 °C               |
| 2.2  | Top off charge            | 40 °C               |
| 2.3  | Discharge at C/3          | 40 °C               |
| 2.4  | Standard charge (SCH)     | 40 °C               |
| 2.5  | Discharge at C/3          | 40 °C               |
| 3.1  | Thermal equilibration     | RT                  |
| 3.2  | Standard charge (SCH)     | RT                  |
| 3.3  | Standard cycle (SC)       | RT                  |
| 4.1  | Thermal equilibration     | 40 °C               |
| 4.2  | Top off charge            | 40 °C               |
| 4.3  | Discharge at 1C           | 40 °C               |
| 4.4  | Standard charge (SCH)     | 40 °C               |
| 4.5  | Discharge at 1C           | 40 °C               |
| 5.1  | Thermal equilibration     | RT                  |
| 5.2  | Standard charge (SCH)     | RT                  |
| 5.3  | Standard cycle (SC)       | RT                  |
| 6.1  | Thermal equilibration     | 40 °C               |
| 6.2  | Top off charge            | 40 °C               |
| 6.3  | Discharge at 2C           | 40 °C               |
| 6.4  | Standard charge (SCH)     | 40 °C               |
| 6.5  | Discharge at 2C           | 40 °C               |
| 7.1  | Thermal equilibration     | RT                  |
| 7.2  | Standard charge (SCH)     | RT                  |
| 7.3  | Standard cycle (SC)       | RT                  |
| 8.1  | Thermal equilibration     | 40 °C               |
| 8.2  | Top off charge            | 40 °C               |
| 8.3  | Discharge at $I_{d,\max}$ | 40 °C               |
| 8.4  | Standard charge (SCH)     | 40 °C               |
| 8.5  | Discharge at $I_{d,\max}$ | 40 °C               |
| 9.1  | Thermal equilibration     | RT                  |
| 9.2  | Standard charge (SCH)     | RT                  |
| 9.3  | Standard cycle (SC)       | RT                  |
| 10.1 | Thermal equilibration     | 0 °C                |
| 10.2 | Top off charge            | 0 °C                |

Table 4 (continued)

| Step | Procedure                | Ambient temperature |
|------|--------------------------|---------------------|
| 10.3 | Discharge at C/3         | 0 °C                |
| 10.4 | Standard charge (SCH)    | 0 °C                |
| 10.5 | Discharge at C/3         | 0 °C                |
| 11.1 | Thermal equilibration    | RT                  |
| 11.2 | Standard charge (SCH)    | RT                  |
| 11.3 | Standard cycle (SC)      | RT                  |
| 12.1 | Thermal equilibration    | 0 °C                |
| 12.2 | Top off charge           | 0 °C                |
| 12.3 | Discharge at 1C          | 0 °C                |
| 12.4 | Standard charge (SCH)    | 0 °C                |
| 12.5 | Discharge at 1C          | 0 °C                |
| 13.1 | Thermal equilibration    | RT                  |
| 13.2 | Standard charge (SCH)    | RT                  |
| 13.3 | Standard cycle (SC)      | RT                  |
| 14.1 | Thermal equilibration    | 0 °C                |
| 14.2 | Top off charge           | 0 °C                |
| 14.3 | Discharge at 2C          | 0 °C                |
| 14.4 | Standard charge (SCH)    | 0 °C                |
| 14.5 | Discharge at 2C          | 0 °C                |
| 15.1 | Thermal equilibration    | RT                  |
| 15.2 | Standard charge (SCH)    | RT                  |
| 15.3 | Standard cycle (SC)      | RT                  |
| 16.1 | Thermal equilibration    | 0 °C                |
| 16.2 | Top off charge           | 0 °C                |
| 16.3 | Discharge at $I_{d,max}$ | 0 °C                |
| 16.4 | Standard charge (SCH)    | 0 °C                |
| 16.5 | Discharge at $I_{d,max}$ | 0 °C                |
| 17.1 | Thermal equilibration    | RT                  |
| 17.2 | Standard Charge (SCH)    | RT                  |
| 17.3 | Standard cycle (SC)      | RT                  |
| 18.1 | Thermal equilibration    | -10 °C              |
| 18.2 | Top off charge           | -10 °C              |
| 18.3 | Discharge at C/3         | -10 °C              |
| 18.4 | Standard charge (SCH)    | -10 °C              |
| 18.5 | Discharge at C/3         | -10 °C              |
| 19.1 | Thermal equilibration    | RT                  |
| 19.2 | Standard charge (SCH)    | RT                  |
| 19.3 | Standard cycle (SC)      | RT                  |
| 20.1 | Thermal equilibration    | -10 °C              |
| 20.2 | Top off charge           | -10 °C              |
| 20.3 | Discharge at 1C          | -10 °C              |
| 20.4 | Standard charge (SCH)    | -10 °C              |
| 20.5 | Discharge at 1C          | -10 °C              |
| 21.1 | Thermal equilibration    | RT                  |

Table 4 (continued)

| Step | Procedure                | Ambient temperature |
|------|--------------------------|---------------------|
| 21.2 | Standard charge (SCH)    | RT                  |
| 21.3 | Standard cycle (SC)      | RT                  |
| 22.1 | Thermal equilibration    | -10 °C              |
| 22.2 | Top off charge           | -10 °C              |
| 22.3 | Discharge at 2C          | -10 °C              |
| 22.4 | Standard charge (SCH)    | -10 °C              |
| 22.5 | Discharge at 2C          | -10 °C              |
| 23.1 | Thermal equilibration    | RT                  |
| 23.2 | Standard charge (SCH)    | RT                  |
| 23.3 | Standard cycle (SC)      | RT                  |
| 24.1 | Thermal equilibration    | -10 °C              |
| 24.2 | Top off charge           | -10 °C              |
| 24.3 | Discharge at $I_{d,max}$ | -10 °C              |
| 24.4 | Standard charge (SCH)    | -10 °C              |
| 24.5 | Discharge at $I_{d,max}$ | -10 °C              |
| 25.1 | Thermal equilibration    | RT                  |
| 25.2 | Standard Charge (SCH)    | RT                  |
| 25.3 | Standard cycle (SC)      | RT                  |
| 26.1 | Thermal equilibration    | -18 °C              |
| 26.2 | Top off charge           | -18 °C              |
| 26.3 | Discharge at C/3         | -18 °C              |
| 26.4 | Standard charge (SCH)    | -18 °C              |
| 26.5 | Discharge at C/3         | -18 °C              |
| 27.1 | Thermal equilibration    | RT                  |
| 27.2 | Standard charge (SCH)    | RT                  |
| 27.3 | Standard cycle (SC)      | RT                  |
| 28.1 | Thermal equilibration    | -18 °C              |
| 28.2 | Top off charge           | -18 °C              |
| 28.3 | Discharge at 1C          | -18 °C              |
| 28.4 | Standard charge (SCH)    | -18 °C              |
| 28.5 | Discharge at 1C          | -18 °C              |
| 29.1 | Thermal equilibration    | RT                  |
| 29.2 | Standard charge (SCH)    | RT                  |
| 29.3 | Standard cycle (SC)      | RT                  |
| 30.1 | Thermal equilibration    | -18 °C              |
| 30.2 | Top off charge           | -18 °C              |
| 30.3 | Discharge at 2C          | -18 °C              |
| 30.4 | Standard charge (SCH)    | -18 °C              |
| 30.5 | Discharge at 2C          | -18 °C              |
| 31.1 | Thermal equilibration    | RT                  |
| 31.2 | Standard charge (SCH)    | RT                  |
| 31.3 | Standard cycle (SC)      | RT                  |
| 32.1 | Thermal equilibration    | -18 °C              |
| 32.2 | Top off charge           | -18 °C              |

Table 4 (continued)

| Step | Procedure                | Ambient temperature |
|------|--------------------------|---------------------|
| 32.3 | Discharge at $I_{d,max}$ | -18 °C              |
| 32.4 | Standard charge (SCH)    | -18 °C              |
| 32.5 | Discharge at $I_{d,max}$ | -18 °C              |
| 33.1 | Thermal equilibration    | RT                  |
| 33.2 | Standard charge (SCH)    | RT                  |
| 33.3 | Standard cycle (SC)      | RT                  |
| 34.1 | Thermal equilibration    | $T_{min}$           |
| 34.2 | Top off charge           | $T_{min}$           |
| 34.3 | Discharge at C/3         | $T_{min}$           |
| 34.4 | Standard charge (SCH)    | $T_{min}$           |
| 34.5 | Discharge at C/3         | $T_{min}$           |
| 35.1 | Thermal equilibration    | RT                  |
| 35.2 | Standard charge (SCH)    | RT                  |
| 35.3 | Standard cycle (SC)      | RT                  |
| 36.1 | Thermal equilibration    | $T_{min}$           |
| 36.2 | Top off charge           | $T_{min}$           |
| 36.3 | Discharge at 1C          | $T_{min}$           |
| 36.4 | Standard charge (SCH)    | $T_{min}$           |
| 36.5 | Discharge at 1C          | $T_{min}$           |
| 37.1 | Thermal equilibration    | RT                  |
| 37.2 | Standard charge (SCH)    | RT                  |
| 37.3 | Standard cycle (SC)      | RT                  |
| 38.1 | Thermal equilibration    | $T_{min}$           |
| 38.2 | Top off charge           | $T_{min}$           |
| 38.3 | Discharge at 2C          | $T_{min}$           |
| 38.4 | Standard charge (SCH)    | $T_{min}$           |
| 38.5 | Discharge at 2C          | $T_{min}$           |
| 39.1 | Thermal equilibration    | RT                  |
| 39.2 | Standard charge (SCH)    | RT                  |
| 39.3 | Standard cycle (SC)      | RT                  |
| 40.1 | Thermal equilibration    | $T_{min}$           |
| 40.2 | Top off charge           | $T_{min}$           |
| 40.3 | Discharge at $I_{d,max}$ | $T_{min}$           |
| 40.4 | Standard charge (SCH)    | $T_{min}$           |
| 40.5 | Discharge at $I_{d,max}$ | $T_{min}$           |
| 41.1 | Thermal equilibration    | RT                  |
| 41.2 | Standard charge (SCH)    | RT                  |
| 41.3 | Standard cycle (SC)      | RT                  |

The standard charge (SCH) procedure at the different temperatures shall follow [6.2.2.3.2](#).

The standard cycle (SC) procedure shall follow [6.2](#).

The value for the C discharge rate shall be based on the rated capacity provided by the supplier and according to the C/3 test results as described in test procedure [7.1](#) Energy and capacity test at RT, respectively.

All discharge tests shall be terminated at the supplier's discharge voltage limits.

After discharge, the DUT shall rest at least for 30 min or shall be thermal equilibrated at the requested ambient temperature or a fixed time period shall be used to allow for thermal equilibration before starting the next step in the test sequence.

The test procedure with the ambient temperature  $T_{\min}$  ( $-20\text{ °C} \geq T_{\min} \geq -40\text{ °C}$ ) within step 34.1 to 41.3 in [Table 4](#) shall be optional.

NOTE Top off charge enables the DUT to be recharged in order to compensate for energy losses that can occur during temperature equilibration.

### 7.2.3 Requirements

The following data shall be reported:

- current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following standard charge;
- discharged capacity in A·h, energy in W·h and average power in W at each discharge test;
- charged capacity in A·h, energy in W·h and average power in W following each discharge test;
- energy round trip efficiency at each discharge test;
- discharged energy in W·h as a function of SOC at each discharge test (in % of rated capacity);
- a diagram regarding the EODV dispersion of the cells at each discharge test.

## 7.3 Power and internal resistance

### 7.3.1 Purpose

The power and internal resistance test is intended to determine the dynamic power capability, the ohmic resistance for discharge and charge conditions as well as the OCV of the DUT as a function of SOC and temperatures according to a realistic load profile derived from vehicle driving operation.

The test procedure for the high-power battery packs and systems combines the FreedomCAR “Hybrid Pulse Power Characterization Test” (see Reference [3]) and the EUCAR “Internal Resistance, Open Circuit Voltage and Power Determination Test” (see Reference [2]).

This test applies to battery packs and systems.

### 7.3.2 Pulse power characterization profile

#### 7.3.2.1 High-power battery pack and system

The objective of this profile is to demonstrate the discharge pulse power (0,1 s, 2 s, 10 s and 18 s) and regenerative charge pulse power (0,1 s, 2 s and 10 s) capabilities at various SOC. The test protocol uses constant current at levels derived from the supplier's maximum rated pulse discharge current  $I_{dp,max}$  at the test temperature. In agreement with the customer, this value may be reduced. Only in the case where the DUT reaches the discharge voltage limit during discharge, shall the current be reduced such that the battery terminal voltage is maintained at the discharge voltage limit throughout the 18 s discharge pulse. The current of the regenerative charge pulse shall be kept constant and shall be calculated as 75 % of the discharge pulse current. Only in the case where the DUT reaches during charging the charge voltage limit, shall the current be reduced such that the battery terminal voltage is maintained at the charge voltage limit throughout the 10 s regenerative charge pulse.

The test profile shall consist of an 18 s discharge pulse followed by a 40 s rest period to allow the measurement of the cell polarization resistance. After the 40 s rest period, a 10 s charge pulse with

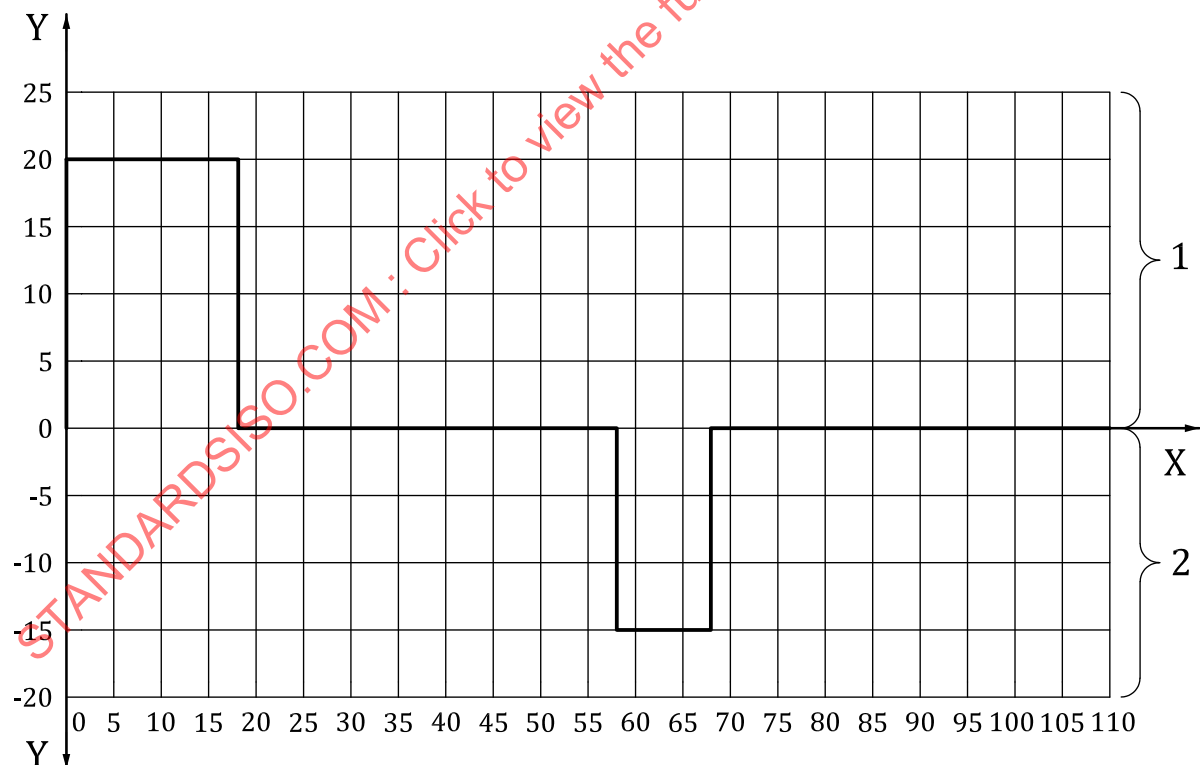
75 % current rate of the discharge pulse shall be performed to determine the regenerative charge capabilities. After the charge pulse, a rest period of 40 s shall follow (for timing and current, see [Table 5](#) and [Figure 2](#)).

NOTE For the testing of battery systems, the BCU delivers, e.g. depending on actual temperature and SOC of the DUT, the maximum allowed operating limits of the DUT via bus communication to enable the test bench equipment to maintain the DUT at all times in specified operating conditions. For the testing of battery packs, the supplier is requested to deliver all necessary operating limits for the DUT in order to adjust the test bench equipment to maintain the DUT at all times in specified operating conditions.

**Table 5 — Pulse power characterization profile**

| Time increment<br>s | Time cumulative<br>s | Current            |
|---------------------|----------------------|--------------------|
| 0                   | 0                    | 0                  |
| 18                  | 18                   | $I_{dp,max}$       |
| 40                  | 58                   | 0                  |
| 10                  | 68                   | $-0,75 I_{dp,max}$ |
| 40                  | 108                  | 0                  |

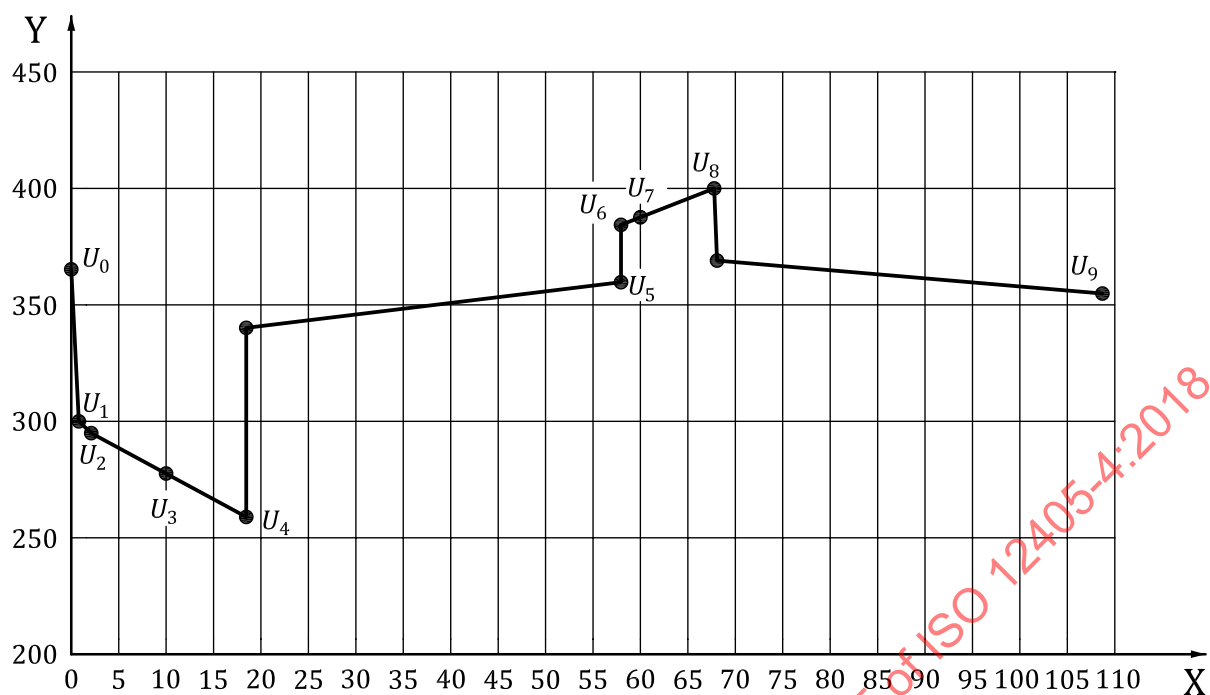
[Figure 2](#) shows an example where the maximum rated discharge pulse current,  $I_{dp,max}$ , is 20 C. The discharge current is specified as positive and the charge current as negative. The maximum rated discharge pulse current,  $I_{dp,max}$ , for the pulse power characterization profile shall be specified by the supplier.



**Key**

|   |                  |   |           |
|---|------------------|---|-----------|
| X | time (s)         | 1 | discharge |
| Y | current (C rate) | 2 | charge    |

**Figure 2 — Pulse power characterization profile — Current**

**Key**

X time (s)

Y voltage (V) of pack or system (example)

**Figure 3 — Pulse power characterization profile — Voltage**

NOTE The voltage values in Figure 3 are an example and expressed for pack or system level. Values can differ depending on battery chemistry, temperature, SOC, etc.

For the peak power, regenerative power and resistance determination, the battery terminal voltage and current shall be measured at the times given in Table 6.

If the test equipment cannot provide the current value with the requested accuracy at the time of 100 ms after a change in the current profile, no related values for power and resistance shall be calculated for this specific test step.

**Table 6 — Measured voltages and currents**

| Time, $t$<br>s | Voltage | Current | Current value      |
|----------------|---------|---------|--------------------|
| 0              | $U_0$   | $I_0$   | 0                  |
| 0,1            | $U_1$   | $I_1$   | $I_{dp,max}$       |
| 2              | $U_2$   | $I_2$   | $I_{dp,max}$       |
| 10             | $U_3$   | $I_3$   | $I_{dp,max}$       |
| 18             | $U_4$   | $I_4$   | $I_{dp,max}$       |
| 58             | $U_5$   | $I_5$   | 0                  |
| 58,1           | $U_6$   | $I_6$   | $-0,75 I_{dp,max}$ |
| 60             | $U_7$   | $I_7$   | $-0,75 I_{dp,max}$ |
| 68             | $U_8$   | $I_8$   | $-0,75 I_{dp,max}$ |
| 108            | $U_9$   | $I_9$   | 0                  |

The following calculations for resistance and power shall be performed according to Table 7.

Table 7 — Calculation of resistance and power

| Value                        | Equation                          | $\Delta t$<br>s |
|------------------------------|-----------------------------------|-----------------|
| 0,1 s discharge resistance   | $Ri_{0,1s,dch} = (U_0 - U_1)/I_1$ | 0,1             |
| 2 s discharge resistance     | $Ri_{2s, ch} = (U_0 - U_2)/I_2$   | 2               |
| 10 s discharge resistance    | $Ri_{10s,dch} = (U_0 - U_3)/I_3$  | 10              |
| 18 s discharge resistance    | $Ri_{18s,dch} = (U_0 - U_4)/I_4$  | 18              |
| Overall discharge resistance | $Ri_{dch} = (U_5 - U_4)/I_4$      | 40              |
| 0,1 s charge resistance      | $Ri_{0,1s,cha} = (U_5 - U_6)/I_6$ | 0,1             |
| 2 s charge resistance        | $Ri_{2s,cha} = (U_5 - U_7)/I_7$   | 2               |
| 10 s charge resistance       | $Ri_{10s,cha} = (U_5 - U_8)/I_8$  | 10              |
| Overall charge resistance    | $Ri_{cha} = (U_9 - U_8)/I_8$      | 40              |
| 0,1 s discharge power        | $P_{0,1s,dch} = U_1 \times I_1$   | 0,1             |
| 2 s discharge power          | $P_{2s,dch} = U_2 \times I_2$     | 2               |
| 10 s discharge power         | $P_{10s,dch} = U_3 \times I_3$    | 10              |
| 18 s discharge power         | $P_{18s,dch} = U_4 \times I_4$    | 18              |
| 0,1 s regenerative power     | $P_{0,1s,cha} = U_6 \times I_6$   | 0,1             |
| 2 s regenerative power       | $P_{2s,cha} = U_7 \times I_7$     | 2               |
| 10 s regenerative power      | $P_{10s,cha} = U_8 \times I_8$    | 10              |
| Open circuit voltage         | $U_{OCV} = U_0$                   |                 |

### 7.3.2.2 High-energy battery pack and system

The objective of this profile is to demonstrate the discharge pulse power (0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s) and regenerative charge pulse power (0,1 s, 2 s, 10 s and 20 s) capabilities at various SOC and temperatures. The test protocol uses constant current at levels derived from the supplier's maximum rated pulse discharge current  $I_{dp,max}$  at the test temperature. In agreement with the customer, this value can be reduced. Only in case the DUT reaches the discharge voltage limit during discharge, the current shall be reduced such that the battery terminal voltage is maintained at the discharge voltage limit throughout the 120 s discharge pulse. The current of the regenerative charge pulse shall be kept constant and shall be calculated as 75 % of the discharge pulse current. Only in case the DUT reaches the charge voltage limit during charging, the current shall be reduced such that the battery terminal voltage is maintained at the charge voltage limit throughout the 20 s regenerative charge pulse.

The test profile shall start with an  $I_{dp,max}$  discharge pulse for 18 s followed by a  $0,75I_{dp,max}$  discharge pulse for additional 102 s followed by a 40 s rest period to allow the measurement of the cell polarization resistance. After the rest period, a 20 s charge pulse with 75 % current rate of the  $I_{dp,max}$  discharge pulse shall be performed to determine the regenerative charge capabilities. After the charge pulse, a rest period of 40 s shall follow (for timing and current see also [Table 8](#) and [Figure 4](#)).

NOTE For testing of battery systems the BCU delivers, e.g. depending on actual temperature and SOC of the DUT, the maximum allowed operating limits of the DUT via bus communication to enable the test bench equipment to maintain the DUT always in the specified operating conditions. For testing of battery packs, the supplier is requested to deliver all necessary operating limits for the DUT in order to adjust the test bench equipment to maintain the DUT always in the specified operating conditions.

Table 8 — Pulse power characterization profile

| Time increment<br>[s] | Cumulative time<br>[s] | Current            |
|-----------------------|------------------------|--------------------|
| 0                     | 0                      | 0                  |
| 18                    | 18                     | $I_{dp,max}$       |
| 102                   | 120                    | $0,75 I_{dp,max}$  |
| 40                    | 160                    | 0                  |
| 20                    | 180                    | $-0,75 I_{dp,max}$ |
| 40                    | 220                    | 0                  |

Figure 4 shows an example with a maximum rated pulse discharge current  $I_{dp,max}$ . The discharge current is specified as positive and the charge current as negative. The maximum rated pulse discharge current  $I_{dp,max}$  for the pulse power characterization profile has to be specified by the supplier.

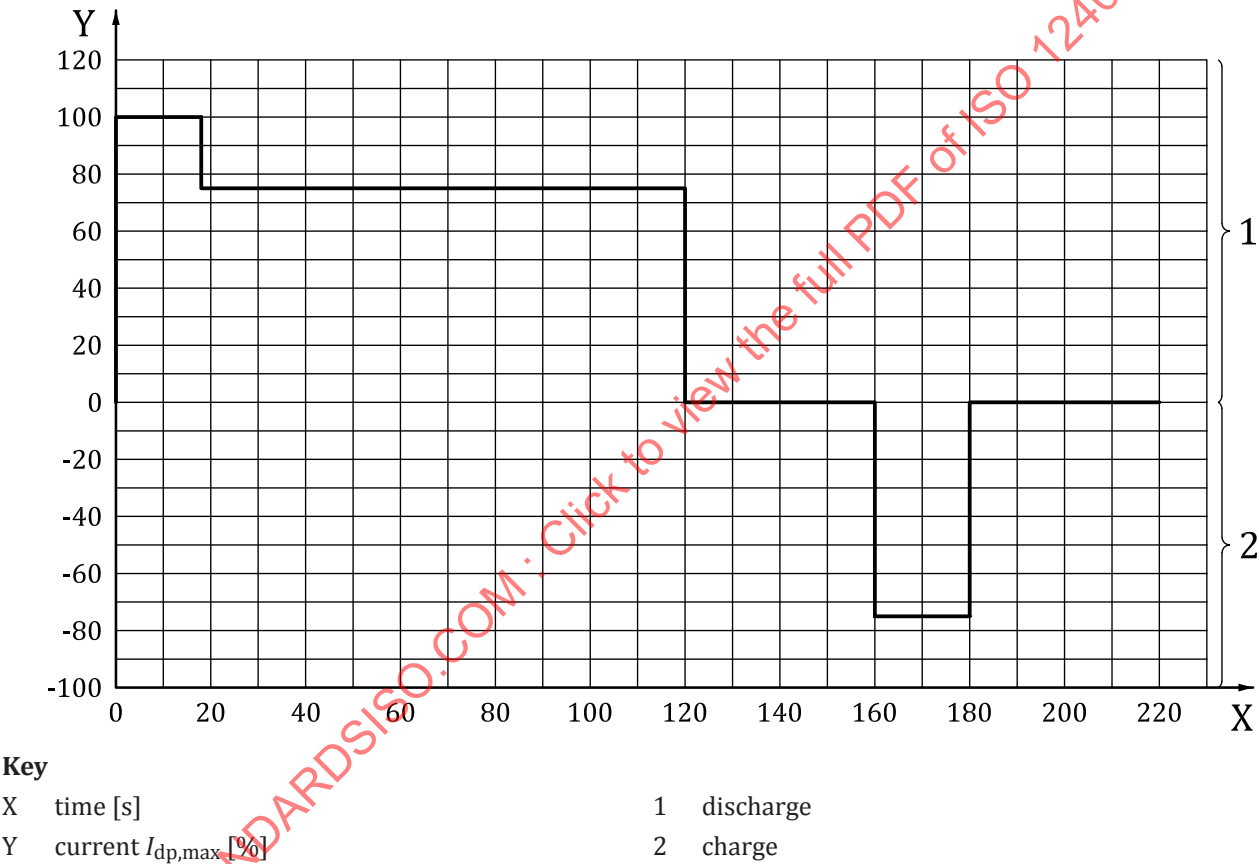
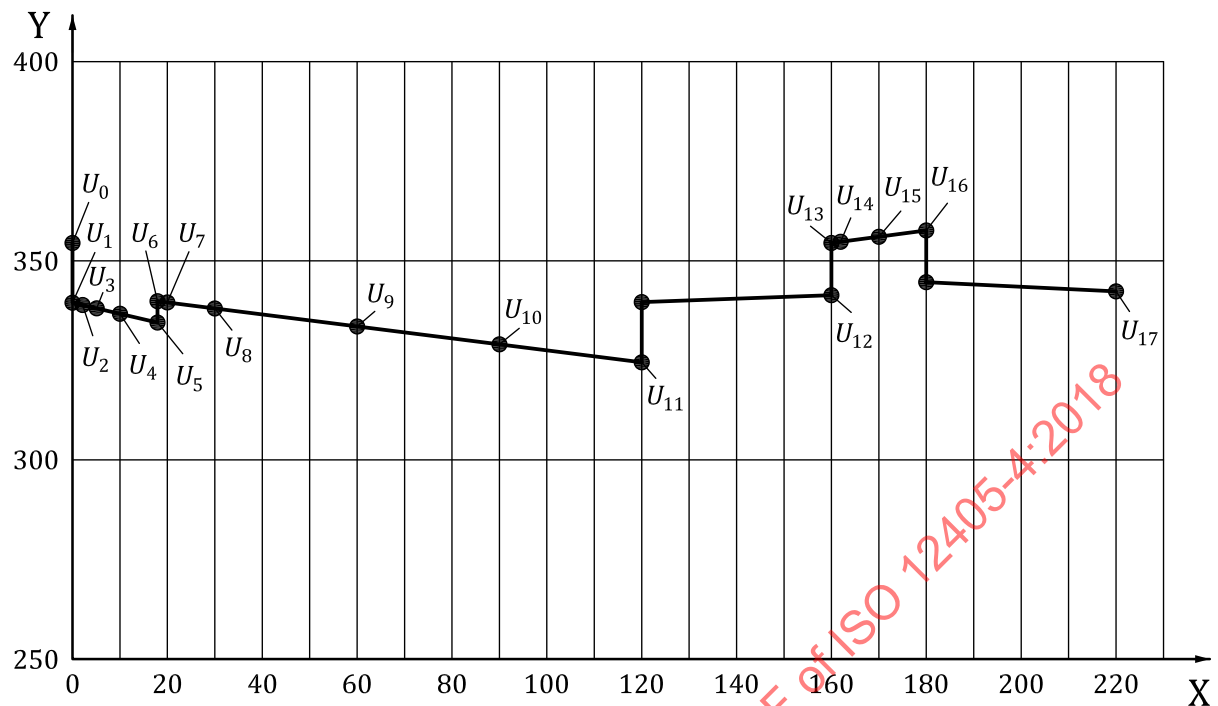


Figure 4 — Pulse power characterization profile — Current

**Key**

X time [s]

Y voltage of pack or system (example) [V]

**Figure 5 — Pulse power characterization profile — Voltage**

NOTE The voltage values in Figure 5 are an example and expressed for pack or system level. Values can differ depending on battery chemistry, temperature, SOC, etc.

For the peak power, regenerative power and resistance determination, the battery terminal voltage and current shall be measured at the times given in Table 9.

If the test equipment cannot provide the current value with the requested accuracy at the time of 100 ms after a change in the current profile, no related values for power and resistance shall be calculated for this specific test step.

**Table 9 — Measured voltages and currents**

| Time<br>[s] | Current<br>value  | Voltage  | Current  |
|-------------|-------------------|----------|----------|
| 0           | 0                 | $U_0$    | $I_0$    |
| 0,1         | $I_{dp,max}$      | $U_1$    | $I_1$    |
| 2           | $I_{dp,max}$      | $U_2$    | $I_2$    |
| 5           | $I_{dp,max}$      | $U_3$    | $I_3$    |
| 10          | $I_{dp,max}$      | $U_4$    | $I_4$    |
| 18          | $I_{dp,max}$      | $U_5$    | $I_5$    |
| 18,1        | $0,75 I_{dp,max}$ | $U_6$    | $I_6$    |
| 20          | $0,75 I_{dp,max}$ | $U_7$    | $I_7$    |
| 30          | $0,75 I_{dp,max}$ | $U_8$    | $I_8$    |
| 60          | $0,75 I_{dp,max}$ | $U_9$    | $I_9$    |
| 90          | $0,75 I_{dp,max}$ | $U_{10}$ | $I_{10}$ |

Table 9 (continued)

| Time<br>[s] | Current<br>value   | Voltage  | Current  |
|-------------|--------------------|----------|----------|
| 120         | $0,75 I_{dp,max}$  | $U_{11}$ | $I_{11}$ |
| 160         | 0                  | $U_{12}$ | $I_{12}$ |
| 160,1       | $-0,75 I_{dp,max}$ | $U_{13}$ | $I_{13}$ |
| 162         | $-0,75 I_{dp,max}$ | $U_{14}$ | $I_{14}$ |
| 170         | $-0,75 I_{dp,max}$ | $U_{15}$ | $I_{15}$ |
| 180         | $-0,75 I_{dp,max}$ | $U_{16}$ | $I_{16}$ |
| 220         | 0                  | $U_{17}$ | $I_{17}$ |

The following calculations for resistance and power shall be performed according to [Table 10](#).

Table 10 — Calculation of resistance and power

| Value                        | Formula                                        | $\Delta t$<br>[s] |
|------------------------------|------------------------------------------------|-------------------|
| 0,1 s discharge resistance   | $R_{i\ 0,1s,dch} = (U_0 - U_1) / I_1$          | 0,1               |
| 2 s discharge resistance     | $R_{i\ 2s,dch} = (U_0 - U_2) / I_2$            | 2                 |
| 5 s discharge resistance     | $R_{i\ 5s,dch} = (U_0 - U_3) / I_3$            | 5                 |
| 10 s discharge resistance    | $R_{i\ 10s,dch} = (U_0 - U_4) / I_4$           | 10                |
| 18 s discharge resistance    | $R_{i\ 18s,dch} = (U_0 - U_5) / I_5$           | 18                |
| 18,1 s discharge resistance  | $R_{i\ 18,1s,dch} = (U_0 - U_6) / I_6$         | 18,1              |
| 20 s discharge resistance    | $R_{i\ 20s,dch} = (U_0 - U_7) / I_7$           | 20                |
| 30 s discharge resistance    | $R_{i\ 30s,dch} = (U_0 - U_8) / I_8$           | 30                |
| 60 s discharge resistance    | $R_{i\ 60s,dch} = (U_0 - U_9) / I_9$           | 60                |
| 90 s discharge resistance    | $R_{i\ 90s,dch} = (U_0 - U_{10}) / I_{10}$     | 90                |
| 120 s discharge resistance   | $R_{i\ 120s,dch} = (U_0 - U_{11}) / I_{11}$    | 120               |
| Overall discharge resistance | $R_{i\ dch} = (U_{12} - U_{11}) / I_{11}$      | 40                |
| 0,1 s charge resistance      | $R_{i\ 0,1s,cha} = (U_{12} - U_{13}) / I_{13}$ | 0,1               |
| 2 s charge resistance        | $R_{i\ 2s,cha} = (U_{12} - U_{14}) / I_{14}$   | 2                 |
| 10 s charge resistance       | $R_{i\ 10s,cha} = (U_{12} - U_{15}) / I_{15}$  | 10                |
| 20 s charge resistance       | $R_{i\ 20s,cha} = (U_{12} - U_{16}) / I_{16}$  | 20                |
| Overall charge resistance    | $R_{i\ cha} = (U_{16} - U_{17}) / I_{17}$      | 20                |
| 0,1 s discharge power        | $P_{0,1s,dch} = U_1 \times I_1$                | 0,1               |
| 2 s discharge power          | $P_{2s,dch} = U_2 \times I_2$                  | 2                 |
| 5 s discharge power          | $P_{5s,dch} = U_3 \times I_3$                  | 5                 |
| 10 s discharge power         | $P_{10s,dch} = U_4 \times I_4$                 | 10                |
| 18 s discharge power         | $P_{18s,dch} = U_5 \times I_5$                 | 18                |
| 18,1 s discharge power       | $P_{18,1s,dch} = U_6 \times I_6$               | 18,1              |
| 20 s discharge power         | $P_{20s,dch} = U_7 \times I_7$                 | 20                |
| 30 s discharge power         | $P_{30s,dch} = U_8 \times I_8$                 | 30                |
| 60 s discharge power         | $P_{60s,dch} = U_9 \times I_9$                 | 60                |
| 90 s discharge power         | $P_{70s,dch} = U_{10} \times I_{10}$           | 90                |
| 120 s discharge power        | $P_{120s,dch} = U_{11} \times I_{11}$          | 120               |
| 0,1 s charge power           | $P_{0,1s,cha} = U_{13} \times I_{13}$          | 0,1               |
| 2 s charge power             | $P_{2s,cha} = U_{14} \times I_{14}$            | 2                 |

**Table 10** (continued)

| Value                | Formula                              | $\Delta t$<br>[s] |
|----------------------|--------------------------------------|-------------------|
| 10 s charge power    | $P_{10s,cha} = U_{15} \times I_{15}$ | 10                |
| 20 s charge power    | $P_{20s,cha} = U_{16} \times I_{16}$ | 20                |
| Open circuit voltage | $U_{OCV} = U_{17}$                   |                   |

### 7.3.3 Test procedure

#### 7.3.3.1 High-power battery pack and system

The test shall be performed at five different temperatures (40 °C, RT, 0 °C, –10 °C and –18 °C) and shall cover an SOC range of 80 % to 20 % within five steps (80 %, 65 %, 50 %, 35 %, 20 %), whereas the last step at 20 % SOC shall only be performed if the maximum discharge current of the DUT is equal to or less than a 10 C current rate in order to avoid a deep discharge of the DUT.

- Prior to each test temperature, the DUT shall be conditioned at RT in accordance with the thermal equilibration requirements provided in 5.1, followed by an SCH as provided in 6.2.2.3.1 for top off and an SC as provided in 6.2.
- Then, the DUT shall be conditioned at the specified test temperature in accordance with the thermal equilibration requirements provided in 5.1, followed by an SCH as provided in 6.2.2.3.1. The SCH is required in order to condition the DUT to 100 % SOC at the specified test temperature prior to the pulse power characterization test profile.
- In the next step, the fully charged DUT shall be discharged with a 1 C rate to the initial SOC of 80 % followed by a minimum 30 min rest period.
- Then, the pulse power characterization profile as described in 7.3.2.1 shall be performed.
- The next SOC steps (65 %, 50 %, 35 % and 20 %) shall be reached by a 1 C discharge followed by a 30 min rest period. Then, the pulse power characterization profile as described in 7.3.2.1 shall be performed at each mentioned SOC step.

NOTE The last step at 20 % SOC is performed only if possible.

- At the end of the pulse power characterization profile, at the 20 % SOC level, the SCH shall be performed.

Data sampling, especially for DUT voltage and current shall be performed with an adequate sampling rate, e.g. 10 ms.

The complete test sequence shall be performed as specified in Table 11.

**Table 11 — Test sequence power and internal resistance test**

| Step | Procedure                    | Test temperature |
|------|------------------------------|------------------|
| 1.1  | Thermal equilibration        | RT               |
| 1.2  | Top off charge               | RT               |
| 1.3  | Standard cycle (SC)          | RT               |
| 2.1  | Thermal equilibration        | RT               |
| 2.2  | Top off charge               | RT               |
| 2.3  | Pulse power characterization | RT               |
| 2.4  | Standard charge (SCH)        | RT               |
| 3.1  | Thermal equilibration        | RT               |

Table 11 (continued)

| Step | Procedure                    | Test temperature |
|------|------------------------------|------------------|
| 3.2  | Top off charge               | RT               |
| 3.3  | Standard cycle (SC)          | RT               |
| 4.1  | Thermal equilibration        | 40 °C            |
| 4.2  | Top off charge               | 40 °C            |
| 4.3  | Pulse power characterization | 40 °C            |
| 4.4  | Standard charge (SCH)        | 40 °C            |
| 5.1  | Thermal equilibration        | RT               |
| 5.2  | Top off charge               | RT               |
| 5.3  | Standard cycle (SC)          | RT               |
| 6.1  | Thermal equilibration        | 0 °C             |
| 6.2  | Top off charge               | 0 °C             |
| 6.3  | Pulse power characterization | 0 °C             |
| 6.4  | Standard charge (SCH)        | 0 °C             |
| 7.1  | Thermal equilibration        | RT               |
| 7.2  | Top off charge               | RT               |
| 7.3  | Standard cycle (SC)          | RT               |
| 8.1  | Thermal equilibration        | -10 °C           |
| 8.2  | Top off charge               | -10 °C           |
| 8.3  | Pulse power characterization | -10 °C           |
| 8.4  | Standard charge (SCH)        | -10 °C           |
| 9.1  | Thermal equilibration        | RT               |
| 9.2  | Top off charge               | RT               |
| 9.3  | Standard cycle (SC)          | RT               |
| 10.1 | Thermal equilibration        | -18 °C           |
| 10.2 | Top off charge               | -18 °C           |
| 10.3 | Pulse power characterization | -18 °C           |
| 10.4 | Standard charge (SCH)        | -18 °C           |
| 11.1 | Thermal equilibration        | RT               |
| 11.2 | Top off charge               | RT               |
| 11.3 | Standard cycle (SC)          | RT               |
| 12.1 | Thermal equilibration        | RT               |
| 12.2 | Top off charge               | RT               |
| 12.3 | Pulse power characterization | RT               |
| 12.4 | Standard charge (SCH)        | RT               |

- The SCH procedure at the different temperatures shall follow [6.2.2.3.1](#).
- The SC procedure shall follow [6.2](#).
- All discharge tests shall be terminated at the supplier's discharge voltage limits.

NOTE The SCH for top off enables the recharging of the DUT in order to compensate for energy losses that can occur during temperature equilibration.

### 7.3.3.2 High-energy battery pack and system

The test shall be performed at six different temperatures (40 °C, RT, 0 °C, -10 °C, -18 °C and -25 °C) and shall cover a SOC range of 90 % to 20 % within five steps (90 %, 70 %, 50 %, 35 %, 20 %) whereas the

last step at 20 % SOC shall only be performed if the maximum discharge current of the DUT is equal to or less than a 5C current rate in order to avoid a deep discharge of the DUT.

- Prior to each test temperature, the DUT shall be conditioned at RT according to the thermal equilibration requirements provided in 5.1 followed by a standard charge (SCH) as provided in 6.2.2.3.2 for top off and a standard cycle (SC) as provided in 6.2.
- Then the DUT shall be conditioned at the specified test temperature according to the thermal equilibration requirements provided in 5.1 followed by a standard charge (SCH) as provided in 6.2.2.3.2. The standard charge (SCH) is requested in order to condition the DUT to 100 % SOC at the specified test temperature prior to the pulse power characterization test profile.
- In the next step, the fully charged DUT shall be discharged with a C/3 rate to the initial SOC of 90 % followed by a minimum 30 min rest period.

NOTE A 108 s discharge with a C/3 rate will decrease the SOC level by 1 %.

- Then the pulse power characterization profile as described in 7.3.2.2 shall be performed.
- The next SOC steps (70 %, 50 %, 35 %, and 20 %<sup>7)</sup>) shall be reached by a C/3 discharge followed by a 30 min rest period. Then the pulse power characterization profile as described in 7.3.2.2 shall be performed at each mentioned SOC step.

NOTE The amount of electric charge [Ah] withdrawn during the previous power characterization profile needs to be taken into account when adjusting the SOC level to the next following step by a C/3 discharge.

- At the end of the pulse power characterization profile at the 20 % SOC level, the standard charge (SCH) shall be performed.
- Data sampling, especially for DUT voltage and current, shall be performed with an adequate sampling rate for the profile described in Figure 5 and Table 9. A minimum of 10 measuring points per step are required.
- The complete test sequence shall be performed as specified in Table 12.

**Table 12 — Test sequence power and internal resistance test**

| Step | Procedure                    | Ambient temperature |
|------|------------------------------|---------------------|
| 1.1  | Thermal equilibration        | RT                  |
| 1.2  | Top off charge               | RT                  |
| 1.3  | Standard cycle (SC)          | RT                  |
| 2.1  | Thermal equilibration        | RT                  |
| 2.2  | Top off charge               | RT                  |
| 2.3  | Pulse power characterization | RT                  |
| 2.4  | Standard charge (SCH)        | RT                  |
| 3.1  | Thermal equilibration        | RT                  |
| 3.2  | Top off charge               | RT                  |
| 3.3  | Standard cycle (SC)          | RT                  |
| 4.1  | Thermal equilibration        | 40 °C               |
| 4.2  | Top off charge               | 40 °C               |
| 4.3  | Pulse power characterization | 40 °C               |
| 4.4  | Standard charge (SCH)        | 40 °C               |
| 5.1  | Thermal equilibration        | RT                  |
| 5.2  | Top off charge               | RT                  |

7) If possible.

Table 12 (continued)

| Step | Procedure                    | Ambient temperature |
|------|------------------------------|---------------------|
| 5.3  | Standard cycle (SC)          | RT                  |
| 6.1  | Thermal equilibration        | 0 °C                |
| 6.2  | Top off charge               | 0 °C                |
| 6.3  | Pulse power characterization | 0 °C                |
| 6.4  | Standard charge (SCH)        | 0 °C                |
| 7.1  | Thermal equilibration        | RT                  |
| 7.2  | Top off charge               | RT                  |
| 7.3  | Standard cycle (SC)          | RT                  |
| 8.1  | Thermal equilibration        | -10 °C              |
| 8.2  | Top off charge               | -10 °C              |
| 8.3  | Pulse power characterization | -10 °C              |
| 8.4  | Standard charge (SCH)        | -10 °C              |
| 9.1  | Thermal equilibration        | RT                  |
| 9.2  | Top off charge               | RT                  |
| 9.3  | Standard cycle (SC)          | RT                  |
| 10.1 | Thermal equilibration        | -18 °C              |
| 10.2 | Top off charge               | -18 °C              |
| 10.3 | Pulse power characterization | -18 °C              |
| 10.4 | Standard charge (SCH)        | -18 °C              |
| 11.1 | Thermal equilibration        | RT                  |
| 11.2 | Top off charge               | RT                  |
| 11.3 | Standard cycle (SC)          | RT                  |
| 12.1 | Thermal equilibration        | -25 °C              |
| 12.2 | Top off charge               | -25 °C              |
| 12.3 | Pulse power characterization | -25 °C              |
| 12.4 | Standard charge (SCH)        | -25 °C              |
| 13.1 | Thermal equilibration        | RT                  |
| 13.2 | Top off charge               | RT                  |
| 13.3 | Standard cycle (SC)          | RT                  |
| 14.1 | Thermal equilibration        | RT                  |
| 14.2 | Top off charge               | RT                  |
| 14.3 | Pulse power characterization | RT                  |
| 14.4 | Standard charge (SCH)        | RT                  |

- The standard charge (SCH) procedure at the different temperatures shall follow [6.2.2.3.2](#).
- The standard cycle (SC) procedure shall follow [6.2](#).
- All discharge tests shall be terminated at the supplier's discharge voltage limits.

NOTE Top off charge enables the DUT to be recharged in order to compensate for energy losses that can occur during temperature equilibration.

### 7.3.4 Requirements

#### 7.3.4.1 High-power battery pack and system

The following data shall be delivered by using the equations described in [7.3.2.1](#):

- discharge power for 0,1 s, 2 s, 10 s and 18 s peaks as a function of SOC and temperature;
- regenerative power for 0,1 s, 2 s and 10 s peaks as a function of SOC and temperature;
- discharge resistance for 0,1 s, 2 s, 10 s and 18 s peaks as well as the overall resistance as a function of SOC and temperature;
- charge resistance for 0,1 s, 2 s and 10 s peaks as well as the overall resistance as a function of SOC and temperature;
- open circuit voltage as a function of SOC and temperature;
- deviation from first and last test at RT, if any;
- if it is necessary to reduce the charge or discharge current due to voltage limits, the calculated internal resistance values shall be marked clearly in the test report and in the result tables.

#### 7.3.4.2 High-energy battery pack and system

The following data shall be delivered by using the equations described in [7.3.2.2](#):

- discharge power for 0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s peaks as a function of SOC and temperature;
- regenerative power for 0,1 s, 2 s, 10 s and 20 s peaks as a function of SOC and temperature;
- discharge resistance for 0,1 s, 2 s, 5 s, 10 s, 18 s, 18,1 s, 20 s, 30 s, 60 s, 90 s and 120 s peaks as well as the overall resistance as a function of SOC and temperature;
- charge resistance for 0,1 s, 2 s, 10 s and 20 s peaks as well as the overall resistance as a function of SOC and temperature;
- open circuit voltage as a function of SOC and temperature;
- deviation from first and last test at RT, if any;
- temperature versus time of the DUT at the specified tests;
- if the charge or discharge current had to be reduced due to voltage limits, the calculated internal resistance values shall be marked clearly in the protocol and in the result tables.

### 7.4 No load SOC loss

#### 7.4.1 Purpose

The purpose of this test is to measure the SOC loss of a battery system if it is not used for an extended period of time. This test refers to a scenario that a vehicle is in parking mode without charging for a longer time period and therefore the battery system could not be placed on charge. The no load SOC loss, if it occurs, may be due to self-discharge, which is normally temporary, or to other mechanisms that could produce permanent or semi-permanent loss of SOC.

This test applies to battery systems only.

## 7.4.2 Test procedure

### 7.4.2.1 High-power battery system

The no-load SOC loss shall be measured with a complete and fully operational battery system. The BCU shall be supplied with the necessary auxiliary power (e.g. 12 V d.c. power supply) in order to be able to control necessary battery system functions during the rest period, for example:

- a) battery system cell balancing, and
- b) periodical BCU wake-up activities.

The no-load SOC loss rate(s) shall include any possible parasitic or operational discharge contribution of the cell balancing circuitry itself beyond the inherent self-discharge rate of the battery cells themselves.

The no-load SOC loss rate of the battery system shall be measured for three different rest periods and at two different temperatures. The battery system is discharged to 80 % SOC (or to an SOC agreed between the supplier and customer) and then left at open circuit for a certain time. The BCU shall be able to perform control activities (e.g. cell balancing and regular wake-up activities). After the rest period, the remaining SOC shall be determined by a 1 C discharge at RT.

The tests shall be performed in a temperature-controlled test chamber at the given temperatures according to the test sequence in [Table 13](#) and [Table 14](#). Before each test cycle at a given temperature, the battery shall be kept at the test temperature for a minimum of 12 h. This period can be reduced if thermal equilibration is reached, specified as less than 4 K change among individual cell temperatures during an interval of 1 h.

Temperatures: RT and 40 °C.

Standard cycle: to ensure that each test is done with the battery system in the same initial condition, an SC (see [6.2](#)) shall be performed prior to each test;

Discharge rate: discharge the battery system to 80 % SOC (or to an SOC agreed between the supplier and customer) at 1 C rate;

Rest period: 24 h (1 d), 168 h (7 d) and 720 h (30 d);

Auxiliary energy: auxiliary energy consumption (e.g. 12 V d.c. level) for the BCU and, if required, for other battery system electronics shall be measured continuously and expressed in watt hours (W·h) for each rest period.

### 7.4.2.2 High-energy battery system

The no load SOC loss shall be measured with a complete and fully operational battery system. The BCU shall be supplied with the necessary auxiliary power (e.g. 12 V d.c. power supply) in order to be able to control necessary battery system functions during the rest period, for example:

- battery system cell balancing;
- periodical BCU wake-up activities.

The no load SOC loss rate[s] shall include any possible parasitic or operational discharge contribution of the cell balancing circuitry itself beyond the inherent self-discharge rate of the battery cells themselves.

The no load SOC loss rate of the battery system shall be measured for three different rest periods and at two different temperatures. The battery system shall be conditioned to 100 % SOC by a standard cycle (SC) and then left at open circuit for a certain time. The BCU shall be able to perform control activities (e.g. cell balancing, regular wake-up activities). After the rest period, the remaining SOC shall be determined by a C/3 discharge at RT.

The tests shall be performed in a temperature controlled test chamber at the given temperatures according to the test sequence in [Table 15](#) and [Table 16](#). Before each test cycle at a given temperature, the battery shall be kept at the test temperature for a minimum of 12 h. This period can be reduced if thermal equilibration is reached, specified as less than 4 K change among individual cell temperatures during an interval of 1 h.

|                   |                                                                                                                                                                                                                                                     |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Temperatures:     | RT and 40 °C.                                                                                                                                                                                                                                       |
| Standard cycle:   | To ensure that each test is done with the battery system in the same initial condition, an SC (see <a href="#">6.2</a> ) shall be performed prior to each test.                                                                                     |
| Discharge rate:   | No discharge after the SC requested, the battery system shall be at 100 % SOC. If supplier and customer agreed to a lower SOC, the battery system shall be discharged after the SC at a C/3 rate to adjust the agreed SOC prior to the rest period. |
| Rest period:      | 48 h (2 d), 168 h (7 d) and 720 h (30 d).                                                                                                                                                                                                           |
| Auxiliary energy: | The auxiliary energy consumption (e.g. 12 V d.c. level) for the BCU and, if required, for other battery system electronics shall be measured continuously and expressed in W·h for each rest period.                                                |

NOTE The test can be performed in sequence with a single DUT or in parallel with multiple DUTs.

### 7.4.3 Test sequence

#### 7.4.3.1 High-power battery system

1st test sequence: Rest period at RT

**Table 13 — Test sequence no-load SOC loss at RT**

| Step | Procedure                                            | Test temperature |
|------|------------------------------------------------------|------------------|
| 1.1  | Thermal equilibration                                | RT               |
| 1.2  | Standard charge (SCH)                                | RT               |
| 1.3  | Standard cycle (SC)                                  | RT               |
| 1.4  | Discharge 1 C to 80 % SOC                            | RT               |
| 1.5  | Rest period with open power supply circuit for 24 h  | RT               |
| 1.6  | Standard cycle (SC)                                  | RT               |
| 1.7  | Discharge 1 C to 80 % SOC                            | RT               |
| 1.8  | Rest period with open power supply circuit for 168 h | RT               |
| 1.9  | Standard cycle (SC)                                  | RT               |
| 1.10 | Discharge 1 C to 80 % SOC                            | RT               |
| 1.11 | Rest period with open power supply circuit for 720 h | RT               |
| 1.12 | Standard cycle (SC)                                  | RT               |

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

2nd test sequence: rest period at 40 °C (or higher according to agreement between the supplier and customer)

**Table 14 — Test sequence no-load SOC loss at 40 °C (or higher)**

| Step | Procedure                                            | Test temperature  |
|------|------------------------------------------------------|-------------------|
| 2.1  | Thermal equilibration                                | RT                |
| 2.2  | Standard charge (SCH)                                | RT                |
| 2.3  | Standard cycle (SC)                                  | RT                |
| 2.4  | Discharge 1 C to 80 % SOC                            | RT                |
| 2.5  | Rest period with open power supply circuit for 24 h  | 40 °C (or higher) |
| 2.6  | Thermal equilibration                                | RT                |
| 2.7  | Standard cycle (SC)                                  | RT                |
| 2.8  | Discharge 1 C to 80 % SOC                            | RT                |
| 2.9  | Rest period with open power supply circuit for 168 h | 40 °C (or higher) |
| 2.10 | Thermal equilibration                                | RT                |
| 2.11 | Standard cycle (SC)                                  | RT                |
| 2.12 | Discharge 1 C to 80 % SOC                            | RT                |
| 2.13 | Rest period with open power supply circuit for 720 h | 40 °C (or higher) |
| 2.14 | Thermal equilibration                                | RT                |
| 2.15 | Standard cycle (SC)                                  | RT                |

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

#### 7.4.3.2 High-energy battery system

1st test sequence: Rest period at RT

**Table 15 — Test sequence no load SOC loss at RT**

| Step | Procedure                                          | Ambient temperature |
|------|----------------------------------------------------|---------------------|
| 1.1  | Thermal equilibration                              | RT                  |
| 1.2  | Standard charge (SCH)                              | RT                  |
| 1.3  | Standard cycle (SC)                                | RT                  |
| 1.4  | Rest period at open power supply circuit for 48 h  | RT                  |
| 1.5  | Standard cycle (SC)                                | RT                  |
| 1.6  | Rest period at open power supply circuit for 168 h | RT                  |
| 1.7  | Standard cycle (SC)                                | RT                  |
| 1.8  | Rest period at open power supply circuit for 720 h | RT                  |
| 1.9  | Standard cycle (SC)                                | RT                  |

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

NOTE The remaining capacity will be measured within steps 1.5, 1.7 and 1.9 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

2nd test sequence: Rest period at 40 °C (or higher according to agreement between supplier and customer)

**Table 16 — Test sequence no load SOC loss at 40 °C (or higher)**

| Step | Procedure                                          | Ambient temperature |
|------|----------------------------------------------------|---------------------|
| 2.1  | Thermal equilibration                              | RT                  |
| 2.2  | Standard charge (SCH)                              | RT                  |
| 2.3  | Standard cycle (SC)                                | RT                  |
| 2.4  | Rest period at open power supply circuit for 48 h  | 40 °C (or higher)   |
| 2.5  | Thermal equilibration                              | RT                  |
| 2.6  | Standard cycle (SC)                                | RT                  |
| 2.7  | Rest period at open power supply circuit for 168 h | 40 °C (or higher)   |
| 2.8  | Thermal equilibration                              | RT                  |
| 2.9  | Standard cycle (SC)                                | RT                  |
| 2.10 | Rest period at open power supply circuit for 720 h | 40 °C (or higher)   |
| 2.11 | Thermal equilibration                              | RT                  |
| 2.12 | Standard cycle (SC)                                | RT                  |

All discharge tests shall be terminated if the supplier's requested discharge voltage limits are reached.

NOTE The remaining capacity will be measured within steps 2.6, 2.9 and 2.12 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

#### 7.4.4 Requirement

##### 7.4.4.1 High-power battery system

The remaining 1 C energy and SOC from the initial 80 % SOC shall be reported. The loss of energy and SOC after each rest period shall be expressed as a percentage of the initial 80 % SOC.

The auxiliary energy consumption (12 V d.c. level) for the BCU and, if required for other battery system electronics, shall be expressed in watt hours (Wh) for each rest period.

A graph, including data for the three rest periods and the two test temperatures, showing residual capacity versus rest period, shall be presented.

##### 7.4.4.2 High-energy battery system

The remaining C/3 energy and SOC from the initial 100 % SOC shall be reported. The loss of energy and SOC after each rest period shall be expressed as a percentage of the initial 100 % SOC.

The auxiliary energy consumption (12 V d.c. level) for the BCU and if required for other battery system electronics shall be expressed in W·h for each rest period.

A graph, including data for the three rest periods and the two test temperatures, showing residual capacity versus rest period shall be presented.

### 7.5 SOC loss at storage

#### 7.5.1 Purpose

The purpose of this test is to measure the SOC loss at storage of a battery system if it is stored for an extended period of time. This test refers to a scenario when the battery system is shipped from a supplier to a customer. This SOC loss at storage, if it occurs, may be due to self-discharge, which is normally temporary, or to other mechanisms that could produce permanent or semi-permanent loss of SOC.

This test applies to battery systems only.

## 7.5.2 Test procedure

The SOC loss at storage behaviour shall be measured with a complete battery system. During the storage period, all battery system terminals shall be disconnected (e.g. voltage class B connections, voltage class A connection, cooling). The service disconnect device, if any, shall be disconnected.

The SOC loss at storage of the battery system shall be measured after a 720 h (30 d) rest period at 45 °C ambient temperature with an initial SOC of 50 % or higher, if agreed between supplier and customer. The remaining SOC after the storage period shall be determined by a 1C discharge for high-power battery systems or a C/3 discharge for high-energy battery systems.

The SOC loss at storage test shall be performed in a temperature controlled test chamber according to the test sequence in [Table 17](#).

|                     |                                                                                                                                                                                                            |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Temperature:        | 45 °C.                                                                                                                                                                                                     |
| Standard cycle:     | To ensure that each test is done with the battery system in the same initial condition, an SC (see <a href="#">6.2</a> ) shall be performed prior to the SOC loss at storage test.                         |
| Discharge rate:     | Discharge the high-power battery system to 50 % SOC at 1 C rate or<br>Discharge the high-energy battery system to 50 % SOC at C/3 rate.<br>A higher SOC value can be agreed between supplier and customer. |
| Rest period:        | 720 h (30 d).                                                                                                                                                                                              |
| Auxiliary energy:   | During the storage period, all connections at the battery system are disconnected.                                                                                                                         |
| Service disconnect: | The service disconnect device, if any, shall be disconnected.                                                                                                                                              |

## 7.5.3 Test sequence

**Table 17 — Test sequence capacity loss at storage**

| Step | Procedure                                                                                                                     | Ambient temperature |
|------|-------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 1    | Thermal equilibration                                                                                                         | RT                  |
| 2    | Standard charge (SCH)                                                                                                         | RT                  |
| 3    | Standard cycle (SC)                                                                                                           | RT                  |
| 4    | High-power battery systems: discharge 1C to 50 % SOC<br>High-energy battery systems: discharge C/3 to 50 % SOC                | RT                  |
| 5    | Rest period for 720 h, all voltage class B and voltage class A terminals are disconnected, service disconnect is disconnected | 45 °C               |
| 6    | Thermal equilibration                                                                                                         | RT                  |
| 7    | Standard cycle (SC)                                                                                                           | RT                  |

All discharge tests shall be terminated if the suppliers requested discharge voltage limits are reached.

NOTE The remaining SOC will be measured within step 7 during the standard discharge (SDCH) test, which is the first part of the standard cycle (SC) test.

## 7.5.4 Requirement

### 7.5.4.1 High-power battery system

The remaining 1 C energy and SOC from the initial 50 % SOC shall be reported. The loss of energy and SOC after the rest period shall be expressed as a percentage of the initial 50 % SOC.

#### 7.5.4.2 High-energy battery system

The remaining C/3 energy and SOC from the initial SOC shall be reported. The loss of energy and SOC after the rest period shall be expressed as a percentage of the initial SOC.

### 7.6 Cranking power at low temperature

#### 7.6.1 Purpose

The cranking power test at low temperatures is intended to measure the power capability at low temperatures. The relevant temperatures shall be  $-18\text{ }^{\circ}\text{C}$  and, if agreed between the supplier and customer, also  $-30\text{ }^{\circ}\text{C}$ . The aim is to generate a database of time-dependent power output at low temperatures.

This test applies to high-power battery systems only.

#### 7.6.2 Test procedure

The test for cranking power at  $-18\text{ }^{\circ}\text{C}$  shall be performed at the lowest SOC level permitted, as specified by the supplier according to the test sequence in [Table 18](#).

**Table 18 — Test sequence cranking power at low temperature ( $-18\text{ }^{\circ}\text{C}$ )**

| Step | Procedure                                                                                                                                                                                                                                                  | Test temperature              |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| 1.1  | Thermal equilibration                                                                                                                                                                                                                                      | RT                            |
| 1.2  | Standard charge (SCH)                                                                                                                                                                                                                                      | RT                            |
| 1.3  | Standard cycle (SC)                                                                                                                                                                                                                                        | RT                            |
| 1.4  | Discharge the fully charged DUT at a 1 C discharge rate to 20 % SOC or the lowest SOC level allowable as specified by the supplier (minimum SOC)                                                                                                           | RT                            |
| 1.5  | Thermal equilibration                                                                                                                                                                                                                                      | $-18\text{ }^{\circ}\text{C}$ |
| 1.6  | Set constant voltage of test bench to the lowest permitted system discharge voltage level according to the supplier's recommendation for 5 s and monitor the power versus time profile. The maximum current shall not exceed the supplier's specification. | $-18\text{ }^{\circ}\text{C}$ |
| 1.7  | Rest period with open power supply circuit for 10 s                                                                                                                                                                                                        | $-18\text{ }^{\circ}\text{C}$ |
| 1.8  | Repeat steps 1.6 to 1.7 twice                                                                                                                                                                                                                              | $-18\text{ }^{\circ}\text{C}$ |
| 1.9  | Thermal equilibration                                                                                                                                                                                                                                      | RT                            |
| 1.10 | Standard charge (SCH)                                                                                                                                                                                                                                      | RT                            |

The sampling rate for test data during testing shall be  $\leq 50\text{ ms}$ .

If agreed between the supplier and customer, the test for cranking power shall also be performed at  $-30\text{ }^{\circ}\text{C}$  at the lowest SOC level permitted, as specified by the supplier according to the test sequence in [Table 19](#).

**Table 19 — Test sequence cranking power at low temperature ( $-30\text{ }^{\circ}\text{C}$ )**

| Step | Procedure                                                                                                                                        | Test temperature              |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| 2.1  | Thermal equilibration                                                                                                                            | RT                            |
| 2.2  | Standard charge (SCH)                                                                                                                            | RT                            |
| 2.3  | Standard cycle (SC)                                                                                                                              | RT                            |
| 2.4  | Discharge the fully charged DUT at a 1 C discharge rate to 20 % SOC or the lowest SOC level allowable as specified by the supplier (minimum SOC) | RT                            |
| 2.5  | Thermal equilibration                                                                                                                            | $-30\text{ }^{\circ}\text{C}$ |

Table 19 (continued)

| Step | Procedure                                                                                                                                                                                                                                                  | Test temperature |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 2.6  | Set constant voltage of test bench to the lowest permitted system discharge voltage level according to the supplier's recommendation for 5 s and monitor the power versus time profile. The maximum current shall not exceed the supplier's specification. | −30 °C           |
| 2.7  | Rest period with open power supply circuit for 10 s                                                                                                                                                                                                        | −30 °C           |
| 2.8  | Repeat steps 2.6 to 2.7 twice                                                                                                                                                                                                                              | −30 °C           |
| 2.9  | Thermal equilibration                                                                                                                                                                                                                                      | RT               |
| 2.10 | Standard charge (SCH)                                                                                                                                                                                                                                      | RT               |

The sampling rate for test data during testing shall be  $\leq 50$  ms.

Table 20 — Voltage limits for cranking power at low temperature

| Time increment<br>s | Cumulative time<br>s | Applicable DUT voltage<br>V               |
|---------------------|----------------------|-------------------------------------------|
| 5                   | 5                    | Lowest permitted system discharge voltage |
| 10                  | 15                   | Open power supply circuit                 |
| 5                   | 20                   | Lowest permitted system discharge voltage |
| 10                  | 30                   | Open power supply circuit                 |
| 5                   | 35                   | Lowest permitted system discharge voltage |
| 10                  | 45                   | Open power supply circuit                 |

The profile pulses shall be performed for the full 5 s duration (even if the test power has to be limited to stay within the minimum permitted discharge voltage) to permit the later calculation of low-temperature cranking power capability (see [Table 20](#)).

### 7.6.3 Requirement

The results shall be delivered as graphic representations of power versus time profiles, including current, voltage and temperature values.

## 7.7 Cranking power at high temperature

### 7.7.1 Purpose

The test for cranking power at high temperature is intended to measure power capabilities at a high temperature of 50 °C or the maximum temperature specified by the supplier. The aim is to generate a database of time-dependent power output at high temperatures.

This test applies to high-power battery systems only.

### 7.7.2 Test procedure

The test for cranking power at 50 °C shall be performed at the lowest SOC level permitted as specified by the supplier according to the test sequence in [Table 21](#).

**Table 21 — Test sequence cranking power at high temperature (50 °C)**

| Step | Procedure                                                                                                                                                                                                                                                  | Test temperature                                         |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|
| 1.1  | Thermal equilibration                                                                                                                                                                                                                                      | RT                                                       |
| 1.2  | Standard charge (SCH)                                                                                                                                                                                                                                      | RT                                                       |
| 1.3  | Standard cycle (SC)                                                                                                                                                                                                                                        | RT                                                       |
| 1.4  | Discharge the fully charged DUT at a 1 C discharge rate to 20 % SOC or the lowest SOC level allowable as specified by the supplier (minimum SOC).                                                                                                          | RT                                                       |
| 1.5  | Thermal equilibration                                                                                                                                                                                                                                      | 50 °C<br>(or max. temperature specified by the supplier) |
| 1.6  | Set constant voltage of test bench to the lowest permitted system discharge voltage level according to the supplier's recommendation for 5 s and monitor the power versus time profile. The maximum current shall not exceed the supplier's specification. | 50 °C<br>(or max. temperature specified by the supplier) |
| 1.7  | Rest period with open power supply circuit for 10 s                                                                                                                                                                                                        | 50 °C<br>(or max. temperature specified by the supplier) |
| 1.8  | Repeat steps 1.6 to 1.7 twice                                                                                                                                                                                                                              | 50 °C<br>(or max. temperature specified by the supplier) |
| 1.9  | Thermal equilibration                                                                                                                                                                                                                                      | RT                                                       |
| 1.10 | Standard charge (SCH)                                                                                                                                                                                                                                      | RT                                                       |
| 1.11 | Standard cycle (SC)                                                                                                                                                                                                                                        | RT                                                       |

The sampling rate for test data during testing shall be  $\leq 50$  ms.

**Table 22 — Voltage limits for cranking power at high temperature**

| Time increment<br>s | Time cumulative<br>s | Applicable DUT voltage and current<br>V and A                                     |
|---------------------|----------------------|-----------------------------------------------------------------------------------|
| 5                   | 5                    | Lowest permitted system discharge voltage and maximum permitted discharge current |
| 10                  | 15                   | Open circuit                                                                      |
| 5                   | 20                   | Lowest permitted system discharge voltage and maximum permitted discharge current |
| 10                  | 30                   | Open circuit                                                                      |
| 5                   | 35                   | Lowest permitted system discharge voltage and maximum permitted discharge current |

The profile pulses according to [Table 22](#) shall be performed for the full 5 s duration (even if it is necessary to limit the test power to stay within the minimum permitted discharge voltage) to permit the later calculation of the cranking power capability at high temperature.

### 7.7.3 Requirement

The results shall be delivered as graphic representations of power versus time profiles including current, voltage and temperature values.

## 7.8 Energy efficiency

### 7.8.1 Purpose

The purpose of the energy efficiency test is to determine the battery system round-trip efficiency by calculation from a charge balanced pulse profile. For high-power battery system, the energy efficiency of the used battery system has a significant influence on the overall vehicle efficiency. It directly affects the fuel consumption and emission levels of a vehicle equipped with a high-power battery system.

This test applies to high-power battery systems only.

### 7.8.2 Test description

The test simulates the following driving situation: for acceleration, for example on to a highway or during the overtaking process, the vehicle driver requests the maximum vehicle power (max. battery discharge power). Following that, there is a cruising phase without battery performance for an assumed time of 40 s. After that, there is a regenerative braking period assumed for 10 s to recharge the battery. Of course, the actual demands are different because the drive systems of the vehicle suppliers differ, but for reasons of comparison and evaluation of battery pack and system, it is a common base.

### 7.8.3 Test procedure

The following conditions apply:

- RT, 40 °C, 0 °C;
- three different SOC: 65 %, 50 %, 35 %;
- 30 min rest period before each power pulse sequence application for equilibrium;
- adequate rest period (see general conditions in 5.1) after temperature change for thermal equilibration;
- current profile for energy efficiency characterization as described in Table 23.

**Table 23 — Energy efficiency test profile**

| Time increment<br>s | Time cumulative<br>s | Current<br>A                |
|---------------------|----------------------|-----------------------------|
| 0                   | 0                    | 0                           |
| 12                  | 12                   | 20 C or $I_{dp,max}$        |
| 40                  | 52                   | 0                           |
| 16                  | 68                   | -15 C or $-0,75 I_{dp,max}$ |
| 40                  | 108                  | 0                           |

The charge balance (A·h) during this current profile pulse sequence shall be neutral. That means the recharged capacity shall be exactly the same as the discharged capacity before. In case of voltage limitations and current degradations during the power pulse sequence, only the charge neutral periods shall be evaluated. This case shall be indicated clearly in the reported results.

Evaluation:

- energy during discharge pulse: integration of voltage and discharge current over time;
- energy during charge pulse: integration of voltage and charge current over time.

The efficiency,  $\eta$ , expressed as a percentage, is calculated as the ratio of the energy during the discharge pulse divided by the energy of the charge pulse, as given in following equation:

$$\eta = \frac{\left| \int_{t_{\text{start}}}^{t_{\text{end}}} U \times I_{\text{discharge}} \times dt \right|}{\left| \int_{t_{\text{start}}}^{t_{\text{end}}} U \times I_{\text{charge}} \times dt \right|} \times 100$$

Expected values are between 75 % and 90 %, depending on chemistry and system.

The energy efficiency test shall be performed according to the test sequence in [Table 24](#).

**Table 24 — Test sequence energy efficiency test**

| Step | Procedure                                             | Test temperature |
|------|-------------------------------------------------------|------------------|
| 1.1  | Thermal equilibration                                 | RT               |
| 1.2  | Standard charge (SCH)                                 | RT               |
| 1.3  | Standard cycle (SC)                                   | RT               |
| 2.1  | Discharge with 1 C to SOC 65 %                        | RT               |
| 2.2  | Rest period for 30 min with open power supply circuit | RT               |
| 2.3  | Energy efficiency test at SOC 65 %                    | RT               |
| 2.4  | Discharge with 1 C to SOC 50 %                        | RT               |
| 2.5  | Rest period for 30 min with open power supply circuit | RT               |
| 2.6  | Energy efficiency test at SOC 50 %                    | RT               |
| 2.7  | Discharge with 1 C to SOC 35 %                        | RT               |
| 2.8  | Rest period for 30 min with open power supply circuit | RT               |
| 2.9  | Energy efficiency test at SOC 35 %                    | RT               |
| 3.1  | Standard cycle (SC)                                   | RT               |
| 3.2  | Thermal equilibration                                 | 40 °C            |
| 4.1  | Discharge with 1 C to SOC 65 %                        | 40 °C            |
| 4.2  | Rest period for 30 min with open power supply circuit | 40 °C            |
| 4.3  | Energy efficiency test at SOC 65 %                    | 40 °C            |
| 4.4  | Discharge with 1 C to SOC 50 %                        | 40 °C            |
| 4.5  | Rest period for 30 min with open power supply circuit | 40 °C            |
| 4.6  | Energy efficiency test at SOC 50 %                    | 40 °C            |
| 4.7  | Discharge with 1 C to SOC 35 %                        | 40 °C            |
| 4.8  | Rest period for 30 min with open power supply circuit | 40 °C            |
| 4.9  | Energy efficiency test at SOC 35 %                    | 40 °C            |
| 5.1  | Thermal equilibration                                 | RT               |
| 5.2  | Standard cycle (SC)                                   | RT               |
| 5.3  | Thermal equilibration                                 | 0 °C             |
| 6.1  | Discharge with 1 C to SOC 65 %                        | 0 °C             |
| 6.2  | Rest period for 30 min with open power supply circuit | 0 °C             |
| 6.3  | Energy efficiency test at SOC 65 %                    | 0 °C             |
| 6.4  | Discharge with 1 C to SOC 50 %                        | 0 °C             |
| 6.5  | Rest period for 30 min with open power supply circuit | 0 °C             |

Table 24 (continued)

| Step | Procedure                                             | Test temperature |
|------|-------------------------------------------------------|------------------|
| 6.6  | Energy efficiency test at SOC 50 %                    | 0 °C             |
| 6.7  | Discharge with 1 C to SOC 35 %                        | 0 °C             |
| 6.8  | Rest period for 30 min with open power supply circuit | 0 °C             |
| 6.9  | Energy efficiency test at SOC 35 %                    | 0 °C             |
| 7.1  | Thermal equilibration                                 | RT               |
| 7.2  | Standard charge (SCH)                                 | RT               |
| 7.3  | Standard cycle (SC)                                   | RT               |

The sampling rate for test data during testing shall be  $\leq 50$  ms.

#### 7.8.4 Requirement

The following data shall be reported: energy efficiency at SOC 65 %, 50 % and 35 % for the test temperatures RT, 40 °C and 0 °C.

#### 7.8.5 Calculation example for energy efficiency test

Based on a fictive 300 V battery with 6 A·h capacity, the results shall correspond (estimated) to the following data:

- discharge/charge during 12 s discharge at 20C: 0,4 A·h;
- electrical power assist (e.g.): 32,40 kW;
- regenerative power (e.g.): 39,60 kW;
- SOC swing: 6,667 %;
- energy output during 12 s discharge at 20C (e.g.): 108 W·h;
- energy input during 16 s charge at 15C (e.g.): 132 W·h;
- energy efficiency 81,8 %.

NOTE These values seem realistic, appearing during typical acceleration or boost phases during driving.

### 7.9 Energy efficiency at fast charging

#### 7.9.1 Purpose

The purpose of the energy efficiency at fast charging test is to determine the battery system behaviour and the energy efficiency at different fast charging levels. For high-energy battery systems, the energy efficiency also at fast charging of the used battery system has a significant influence on the overall vehicle efficiency.

This test applies to high-energy battery systems only.

#### 7.9.2 Test procedure

The test shall be performed with battery systems at RT, 0 °C and  $T_{\min}$  and three different fast charging levels (1C, 2C and  $I_{C,\max}$ ). After thermal equilibration and conditioning of the DUT by a standard cycle, the DUT first shall be discharged via a standard discharge followed in the next step by a fast charge with a starting current of 1C, 2C and  $I_{C,\max}$ . The charge rate, the maximum charge current  $I_{C,\max}$  and the minimum ambient test temperature  $T_{\min}$  shall follow the requirements delivered by the supplier.

The test sequence shall be performed as specified in [Table 25](#).

**Table 25 — Test sequence energy efficiency at fast charging test**

| Step | Procedure                                           | Ambient temperature |
|------|-----------------------------------------------------|---------------------|
| 1.1  | Thermal equilibration                               | RT                  |
| 1.2  | Standard charge (SCH)                               | RT                  |
| 1.3  | Standard cycle (SC)                                 | RT                  |
| 2.1  | Standard discharge (SDCH)                           | RT                  |
| 2.2  | Fast charge with 1C                                 | RT                  |
| 2.3  | Rest period for 60 min at open power supply circuit | RT                  |
| 2.4  | Standard cycle (SC)                                 | RT                  |
| 2.5  | Standard discharge (SDCH)                           | RT                  |
| 2.6  | Fast charge with 2C                                 | RT                  |
| 2.7  | Rest period for 60 min at open power supply circuit | RT                  |
| 2.8  | Standard cycle (SC)                                 | RT                  |
| 2.9  | Standard discharge (SDCH)                           | RT                  |
| 2.10 | Fast charge with $I_{c,max}$                        | RT                  |
| 2.11 | Rest period for 60 min at open power supply circuit | RT                  |
| 3.1  | Standard cycle (SC)                                 | RT                  |
| 3.2  | Thermal equilibration                               | 0 °C                |
| 4.1  | Standard discharge (SDCH)                           | 0 °C                |
| 4.2  | Fast charge with 1C                                 | 0 °C                |
| 5.1  | Thermal equilibration                               | RT                  |
| 5.2  | Standard charge (SC) for top off                    | RT                  |
| 5.3  | Standard cycle (SC)                                 | RT                  |
| 5.4  | Thermal equilibration                               | 0 °C                |
| 6.1  | Standard discharge (SDCH)                           | 0 °C                |
| 6.2  | Fast charge with 2C                                 | 0 °C                |
| 7.1  | Thermal equilibration                               | RT                  |
| 7.2  | Standard charge (SC) for top off                    | RT                  |
| 7.3  | Standard cycle (SC)                                 | RT                  |
| 7.4  | Thermal equilibration                               | 0 °C                |
| 8.1  | Standard discharge (SDCH)                           | 0 °C                |
| 8.2  | Fast charge with $I_{c,max}$                        | 0 °C                |
| 9.1  | Thermal equilibration                               | RT                  |
| 9.2  | Standard charge (SC) for top off                    | RT                  |
| 9.3  | Standard cycle (SC)                                 | RT                  |
| 9.4  | Thermal equilibration                               | $T_{min}$           |
| 10.1 | Standard discharge (SDCH)                           | $T_{min}$           |
| 10.2 | Fast charge with $I_{c,max}$                        | $T_{min}$           |
| 11.1 | Thermal equilibration                               | RT                  |
| 11.2 | Standard charge (SC) for top off                    | RT                  |
| 11.3 | Standard cycle (SC)                                 | RT                  |

The standard charge (SCH) procedure at the different temperatures shall follow [6.2.2.3](#).

The standard cycle (SC) procedure shall follow [6.2](#).

All discharge tests shall be terminated at the supplier's discharge voltage limits.

All fast charge tests shall follow or shall be terminated at the supplier's requested limits.

The sampling rate for test data during testing shall be  $\leq 50$  ms.

Calculate energy efficiency for the following SOC's:

- from SOC at discharge test termination to the next rounded SOC decade and each following 10 % SOC increment up to the SOC level at fast charge termination,
- from each rounded SOC decade following the discharge test termination to each following 10 % SOC increment up to the SOC level at fast charge termination,

based on measured voltage and current data for each standard discharge and the following fast charge test. Use the following formula for calculation of the requested energy efficiency values:

$$\eta = \frac{\int_{t_{\text{start}}}^{t_{\text{end}}} U \cdot I_{\text{discharge}} \cdot dt}{\int_{t_{\text{start}}}^{t_{\text{end}}} U \cdot I_{\text{charge}} \cdot dt} \times 100 [\%]$$

### 7.9.3 Requirement

The following data shall be reported:

- current, voltage, DUT temperature and ambient temperature versus time at each discharge test and the following fast charge;
- discharged capacity in Ah, energy in Wh and average power in W at each discharge test;
- charged capacity in Ah, energy in Wh and average power in W following each discharge test;
- the EODV of all available cell voltage measuring points for all performed discharge tests;
- energy efficiency for specified  $\Delta$ SOCs at each standard discharge – fast charge test.

## 7.10 Cycle life

### 7.10.1 Purpose

In addition to other ageing factors (i.e. time, temperature), the energy throughput has a significant influence on the lifetime of a battery.

For choosing a relevant ageing profile concerning the energy throughput, the real conditions during driving shall be considered. That means the applied power profiles for battery systems for dynamic discharge applications and in addition the proposed SOC swing for battery systems for charge-depleting followed by charge-sustaining applications shall cover the vehicle demands in a proper way. In order to get reliable and significant data for lifetime prediction, it is important that supplier and customer agree on the basic data of the test profiles.

On the other hand, the battery system shall not be stressed too much. Therefore the thermal management and monitoring of the battery system is mandatory, and certain rest phases are needed for equilibrium and cell balancing.

This test applies to battery systems only.

## 7.10.2 Test procedure

### 7.10.2.1 High-power battery system

#### 7.10.2.1.1 Preparation

During the test, it is necessary to maintain the DUT temperature, using its cooling equipment, within a temperature range of between RT and 40 °C (i.e. RT during rest periods, certain higher temperatures during operation). If requested by the supplier, additional rest periods may be placed between the cycles in order to keep the DUT within the designated temperature range.

The cycle life test is performed by combining two test profiles, one is the “discharge-rich profile”, where the discharge amount is slightly larger than the charge amount, as shown in [Table 26](#) and [Figure 6](#), and another one is the “charge-rich profile”, where the charge amount is slightly larger than the discharge amount, as shown in [Table 27](#) and [Figure 7](#).

The SOC swing range shall be defined by the customer; otherwise, the cycle life test shall be performed between 30 % and 80 % SOC.

By combining the two profiles, the SOC swing range can be utilized over the cycling test. The cycle life test shall be started from the upper limit of SOC with the discharge-rich profile and once SOC reaches the lower limit or the battery voltage reaches the lower voltage limit specified by the supplier, the profile shall be switched to the charge-rich profile and continued until the upper SOC limit or voltage limit is reached (see [Figure 8](#)).

The SOC limit for altering the profiles can be detected by one of the following:

- SOC calculated, i.e. by the BCU;
- number of cycles ( $\Delta$ SOC per cycle equal to 1,944 %);
- ampere hours (A·h), counted by external measurement;
- battery voltage upper and lower limit defined by the supplier.

After 22 h of cycling, 2 h of rest shall be taken to allow certain equilibrium within the cell chemistry and to bring all cells to a voltage balanced status (this is normally performed by the integrated cell voltage balancing circuitry), followed by the performance check.

## 7.10.2.1.2 Test profile cycle life test

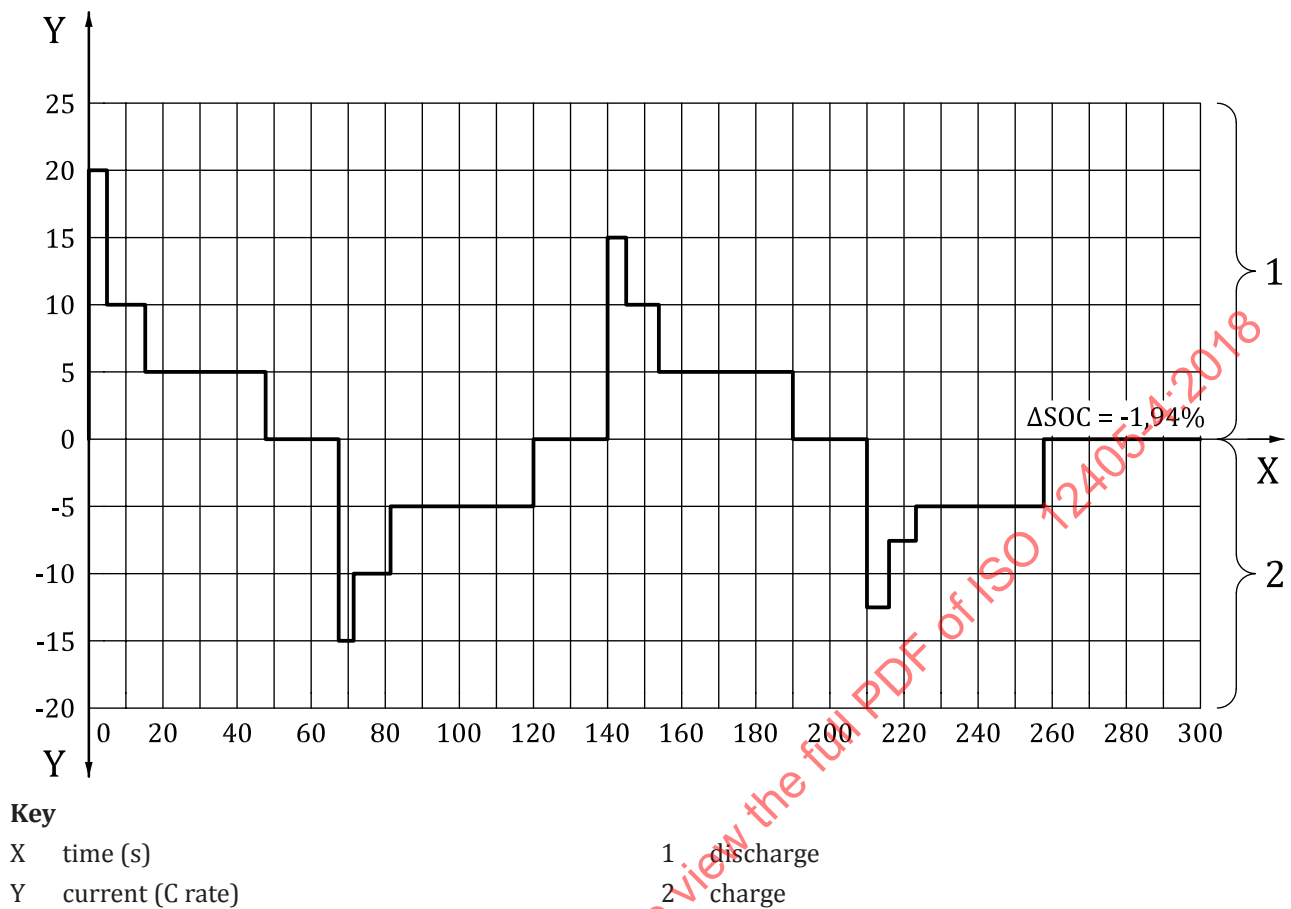


Figure 6 — Current profile for cycle life test — Discharge-rich profile

Table 26 — Times and current profile — Discharge-rich profile

| Time increment<br>s | Time cumulative<br>s | Current<br>C rate | Accumulated $\Delta SOC$<br>% |
|---------------------|----------------------|-------------------|-------------------------------|
| 5                   | 5                    | 20                | -2,778                        |
| 10                  | 15                   | 10                | -5,556                        |
| 32                  | 47                   | 5                 | -10,000                       |
| 20                  | 67                   | 0                 | -10,000                       |
| 5                   | 72                   | -15               | -7,917                        |
| 10                  | 82                   | -10               | -5,139                        |
| 37                  | 119                  | -5                | 0,000                         |
| 20                  | 139                  | 0                 | 0,000                         |
| 5                   | 144                  | 15                | -2,083                        |
| 10                  | 154                  | 10                | -4,861                        |
| 37                  | 191                  | 5                 | -10,000                       |
| 20                  | 211                  | 0                 | -10,000                       |
| 5                   | 216                  | -12,5             | -8,264                        |

Table 26 (continued)

| Time increment<br>s | Time cumulative<br>s | Current<br>C rate | Accumulated $\Delta$ SOC<br>% |
|---------------------|----------------------|-------------------|-------------------------------|
| 7                   | 223                  | -7,5              | -6,806                        |
| 35                  | 258                  | -5                | -1,944                        |
| 42                  | 300                  | 0                 | -1,944                        |

NOTE 1 Because of different time delays and slow rates of various battery testers which are used, no pulses shorter than 5 s are defined.

A requested C rate according to Table 26 shall be limited to the maximum current specified by the supplier. If so, the corresponding time increment shall be increased in order to achieve the requested  $\Delta$ SOC value. This results in an increased cumulative time for the discharge-rich profile.

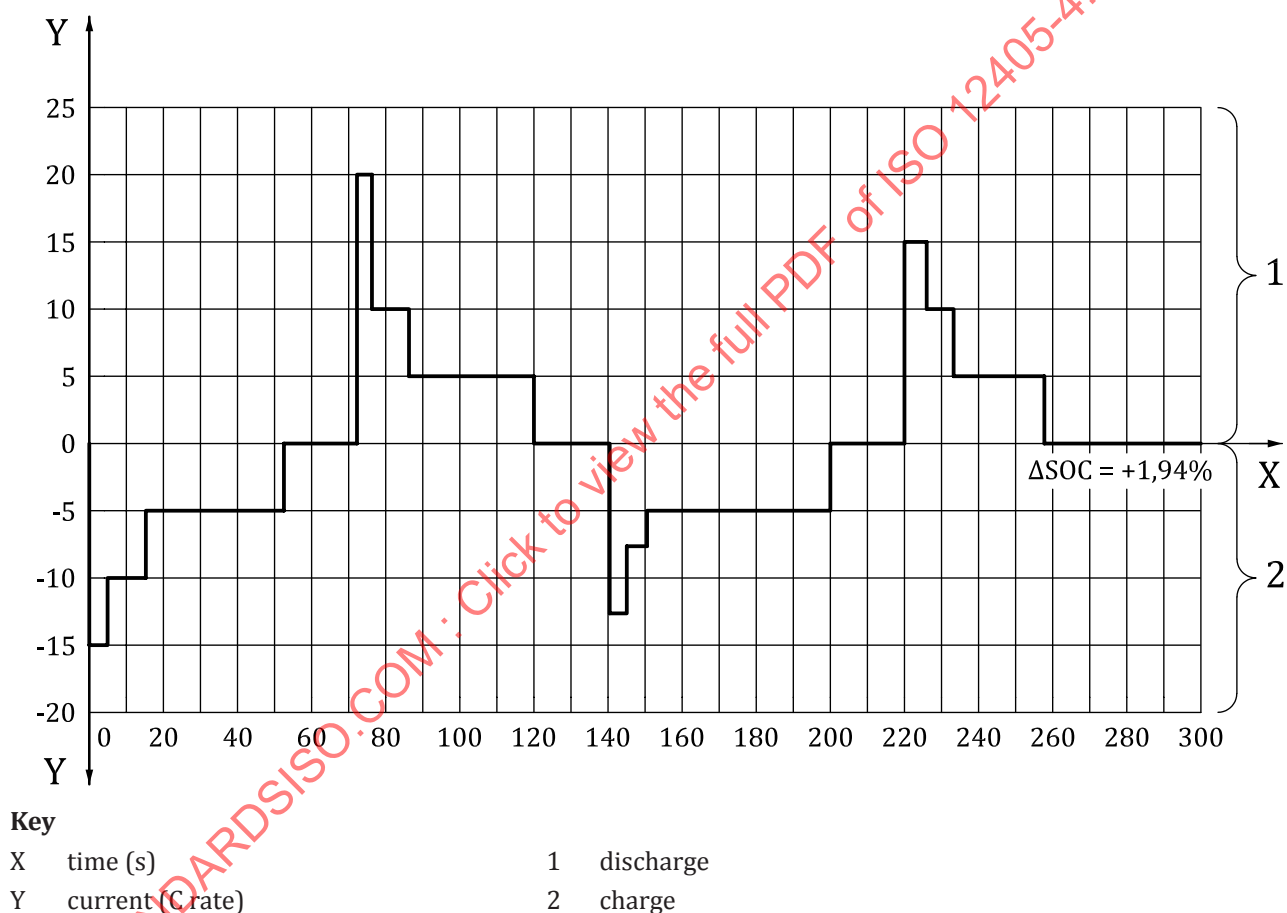


Figure 7 — Current profile for cycle life test — Charge-rich profile

Table 27 — Times and current profile — Charge-rich profile

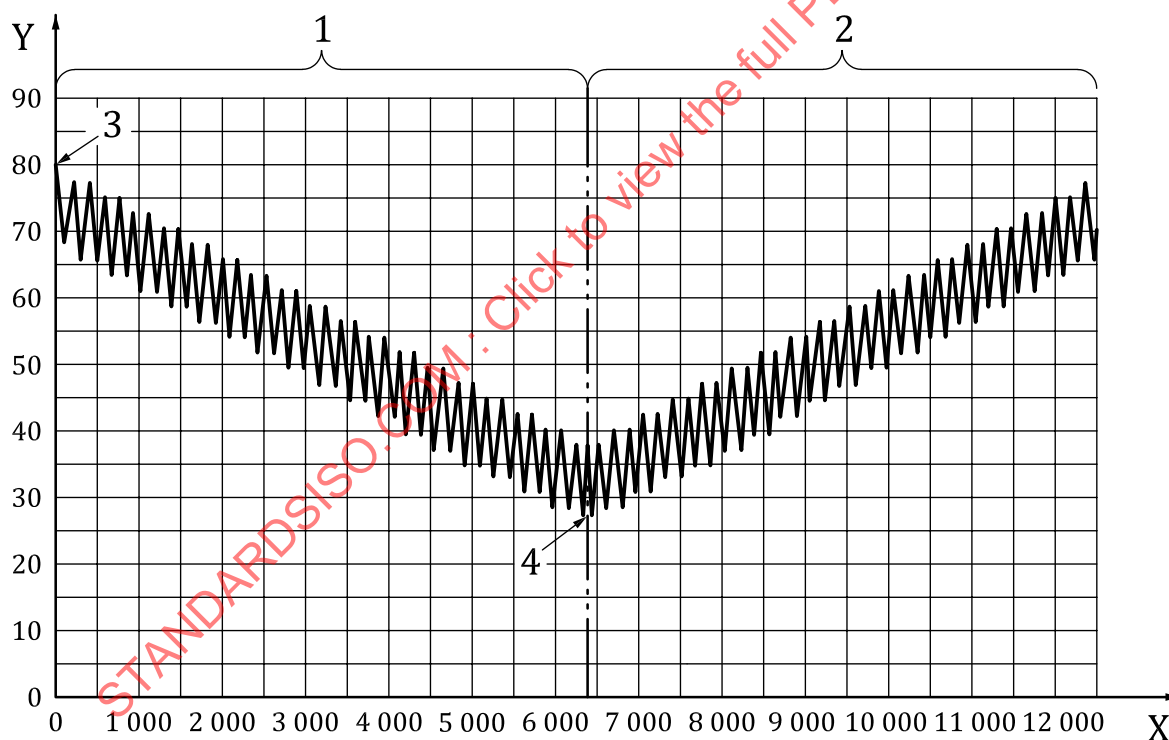
| Time increment<br>s | Time cumulative<br>s | Current<br>C rate | Accumulated $\Delta$ SOC<br>% |
|---------------------|----------------------|-------------------|-------------------------------|
| 5                   | 5                    | -15               | 2,083                         |
| 10                  | 15                   | -10               | 4,861                         |
| 37                  | 52                   | -5                | 10,000                        |
| 20                  | 72                   | 0                 | 10,000                        |
| 5                   | 77                   | 20                | 7,222                         |
| 10                  | 87                   | 10                | 4,444                         |

Table 27 (continued)

| Time increment<br>s | Time cumulative<br>s | Current<br>C rate | Accumulated $\Delta$ SOC<br>% |
|---------------------|----------------------|-------------------|-------------------------------|
| 32                  | 119                  | 5                 | 0,000                         |
| 20                  | 139                  | 0                 | 0,000                         |
| 5                   | 144                  | -12,5             | 1,736                         |
| 7                   | 151                  | -7,5              | 3,194                         |
| 49                  | 200                  | -5                | 10,000                        |
| 20                  | 220                  | 0                 | 10,000                        |
| 5                   | 226                  | 15                | 7,917                         |
| 10                  | 235                  | 10                | 5,139                         |
| 23                  | 258                  | 5                 | 1,944                         |
| 42                  | 300                  | 0                 | 1,944                         |

NOTE 2 Because of different time delays and slow rates of various battery testers which are used, no pulses shorter than 5 s are defined.

A requested C rate according to Table 27 shall be limited to the maximum current specified by the supplier. If so, the corresponding time increment shall be increased in order to achieve the requested  $\Delta$ SOC value. This results in an increased cumulative time for the charge-rich profile.



#### Key

|   |                         |   |                                   |
|---|-------------------------|---|-----------------------------------|
| X | time (s)                | 2 | charge-rich profiles              |
| Y | SOC (%)                 | 3 | initial SOC = 80 %                |
| 1 | discharge-rich profiles | 4 | cycle turning point at SOC = 30 % |

NOTE At SOC = 30 % is the cycle turn point.

Figure 8 — Typical SOC swing by combination of discharge-rich and charge-rich profiles

### 7.10.2.1.3 Test sequence cycle life test

Table 28 — Test sequence for cycle life test

| Step | Procedure                                                                                                                                                                                                                      | Test temperature |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 1    | Thermal equilibration                                                                                                                                                                                                          | RT               |
| 2    | Standard cycle (SC)                                                                                                                                                                                                            | RT               |
| 3    | Standard cycle (SC) for 1 C capacity determination                                                                                                                                                                             | RT               |
| 4    | Standard discharge (SCH) to 80 % SOC or other upper limit SOC defined by the customer                                                                                                                                          | RT               |
| 5    | Cycling by the discharge-rich profile until:<br>SOC 30 % or other lower limit SOC defined by the customer;<br>battery voltage reaches lower limit defined by the supplier                                                      | RT               |
| 6    | Cycling by the charge-rich profile until:<br>SOC 80 % or other upper limit SOC defined by the customer; battery voltage reaches upper limit defined by the supplier                                                            | RT               |
| 7    | Repeat steps 5 and 6 for 22 h                                                                                                                                                                                                  | RT               |
| 8    | Each day after 22 h of cycling and at the end of the charge-rich profile:<br>the rest period for equilibration of cell voltages and temperature shall be agreed between the supplier and customer                              | RT               |
| 9    | Every week after 7 days of cycling, perform power test with the following test sequence:<br>thermal equilibration;<br>standard charge (SCH);<br>standard cycle (SC);<br>pulse power characterization;<br>standard charge (SCH) | RT               |
| 10   | Continue with step 4, but every two weeks continue with step 2 in order to perform 1 C capacity determination                                                                                                                  | RT               |

### 7.10.2.1.4 Conditions

The following apply.

- Ambient: start at RT in a temperature chamber with adequate safety equipment.
- SOC range should be 30 % to 80 % or in a range agreed between the customer and supplier.
- 2 h rest period after 22 h of cycling for equilibrium and cell balancing.
- It is necessary that the designated (or comparable) battery system cooling operate.
- During cycling, the DUT electronic shall assure that no cell limits are exceeded, by achieving voltage limits as specified by the supplier. The current shall be reduced automatically to avoid any electrical and functional operation.

### 7.10.2.1.5 Monitoring and data logging

All available voltage and temperature sensor data shall be monitored and logged. The amount of stored data may be reduced by logging only during selected (critical) parts of the test sequences.

Cumulated capacity which corresponds to the  $\Delta$ SOC shall be recorded in order to compare with the SOC value given by the BCU.

#### 7.10.2.1.6 SOC determination

Due to ageing during the cycling test, a capacity loss is expected. Therefore, it is very important to provide a clear procedure to determine SOC over the whole test period. The rated capacity, determined in [5.1](#) specifies the range between 100 % SOC (fully charged) and 0 % SOC (fully discharged). For adjustment of the SOC values, the 100 % value shall be taken as the basis.

#### 7.10.2.1.7 End of test criteria

The cycle life test shall be terminated according to any of the following end-of-test criteria:

- the cycle life test profile cannot be performed any longer, for instance because limits are reached;
- the requirements of the parameter check between the life cycle test profile sequences according to [Table 28](#) step 9 can no longer be fulfilled;
- by agreement between the supplier and customer.

#### 7.10.2.1.8 Capacity fade

The change of dischargeable capacity from the BOL value (measured according to energy and capacity test at *RT*; see [7.1](#)) to some later point in time shall be reported periodically as capacity fade. The capacity fade,  $C_{\text{fade}}$ , shall be expressed as a percentage of the initial BOL capacity (1 C at *RT*) as shown in following Equation:

$$C_{\text{fade}} = 100 \times \left( 1 - \frac{C_{\text{rt,tx}}}{C_{\text{rt,t0}}} \right)$$

where

- $C_{\text{fade}}$  is the capacity fade, in per cent;
- $C_{\text{rt,tx}}$  is the 1 C capacity at current test;
- $C_{\text{rt,t0}}$  is the rated 1 C capacity at BOL.

#### 7.10.2.2 High-energy battery system

The procedure delivers two sets of test procedures, dedicated to battery systems used in dynamic discharge applications followed by a complete charging procedure, see [7.10.2.2.1](#), and for battery systems used in dynamic discharge applications followed first by a charge sustainable operation within a moderate SOC swing and then followed by a complete charging procedure, see [7.10.2.2.2](#). Supplier and customer shall agree on the relevant test procedure based on the dedicated application requirements for the battery system.

##### 7.10.2.2.1 Battery systems for dynamic discharge applications

###### 7.10.2.2.1.1 Preparation

During the test, it is necessary to maintain the DUT temperature by its cooling equipment within a temperature range between *RT* and 40 °C (i.e. *RT* during rest periods, certainly higher during operation). If requested by the supplier, additional rest periods can be placed between the cycles in order to keep the DUT within the designated temperature range.

The cycle test is performed by combining two test profiles: one is the “dynamic discharge power profile A”, where the amount of discharged energy is significantly lower than the “dynamic discharge power profile B”. The profiles are shown in [Figure 9](#) and [Figure 10](#). The data of the profiles are shown in [Table 30](#) and [Table 31](#) accordingly.

The SOC range shall be defined by the customer, otherwise the cycle test shall be performed between 100 % and 20 % SOC.

The cycle test shall be started from the upper limit of SOC with a sequence by performing the dynamic discharge power profile A, followed by the dynamic discharge power profile B and then followed by the dynamic discharge power profile A until SOC reaches the lower limit or the battery voltage reaches the lower voltage limit specified by the supplier. Within the next step, the battery system shall be charged according to the supplier's recommendation to the upper limit of SOC with the requirement to maintain the total time for the discharge-charge cycle including a rest time for cell balancing to 8 h. This sequence of dynamic discharge power profiles including charging shall be repeated during the following 28 d. After these cycling activities the capacity and pulse power characterization tests shall be performed to determine the current status of the battery system. After this performance testing, the life cycling testing shall be continued until the test has been terminated according to the specified criteria; see end of test criteria in [7.10.2.2.5](#).

The SOC limit can be detected by one of the following:

- SOC calculated, i.e. by the BCU for a battery system test;
- Ah counted by external measurement;
- battery voltage upper and lower limits defined by the supplier.

#### 7.10.2.2.1.2 Test sequence battery system cycle life test for dynamic discharge applications

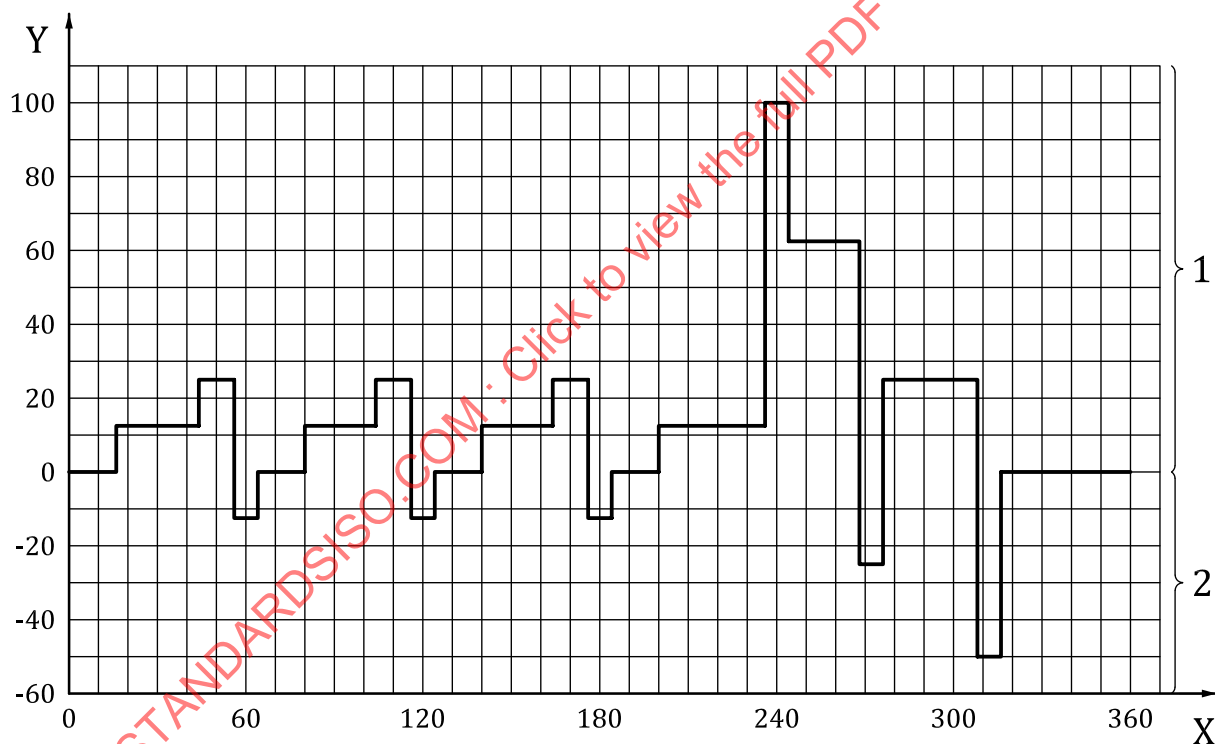
**Table 29 — Test sequence battery system cycle life test for dynamic discharge applications**

| Step | Procedure                                                                                                                                                                                                                                                                                                                                                                                | Ambient temperature |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 1    | Thermal equilibration                                                                                                                                                                                                                                                                                                                                                                    | RT                  |
| 2    | Standard cycle (SC)                                                                                                                                                                                                                                                                                                                                                                      | RT                  |
| 3    | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                                                                                                                                                                                       | RT                  |
| 4    | Thermal equilibration                                                                                                                                                                                                                                                                                                                                                                    | -10 °C              |
| 5    | Top off charge                                                                                                                                                                                                                                                                                                                                                                           | -10 °C              |
| 6    | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                                                                                                                                                                                       | -10 °C              |
| 7    | Thermal equilibration                                                                                                                                                                                                                                                                                                                                                                    | RT                  |
| 8    | Standard cycle (SC)                                                                                                                                                                                                                                                                                                                                                                      | RT                  |
| 9    | Cycling by performing the sequence of dynamic discharge power profile A, followed by the dynamic discharge power profile B and then followed by the dynamic discharge power profile A until: <ul style="list-style-type: none"> <li>— SOC 20 % or other lower limit SOC defined by customer is reached</li> <li>— Battery voltage reaches lower limit defined by the supplier</li> </ul> | RT                  |
| 10   | Charging to 100 % SOC as defined by the supplier with the following requirements: <ul style="list-style-type: none"> <li>— Charging including cell balancing activities and rest time shall be finished at least 8 h after starting the dynamic discharge profile A</li> </ul>                                                                                                           | RT                  |
| 11   | Repeat steps 9 to 10 for a total of 28 d                                                                                                                                                                                                                                                                                                                                                 |                     |
| 12   | Thermal equilibration                                                                                                                                                                                                                                                                                                                                                                    | RT                  |
| 13   | Standard cycle (SC)                                                                                                                                                                                                                                                                                                                                                                      | RT                  |
| 14   | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                                                                                                                                                                                       | RT                  |
| 15   | Thermal equilibration                                                                                                                                                                                                                                                                                                                                                                    | RT                  |
| 16   | Top off charge                                                                                                                                                                                                                                                                                                                                                                           | RT                  |
| 17   | Pulse power characterization                                                                                                                                                                                                                                                                                                                                                             | RT                  |
| 18   | Standard charge (SCH)                                                                                                                                                                                                                                                                                                                                                                    | RT                  |

Table 29 (continued)

| Step | Procedure                                                  | Ambient temperature |
|------|------------------------------------------------------------|---------------------|
| 19   | Every 8 weeks continue with step 20, otherwise with step 9 |                     |
| 20   | Thermal equilibration                                      | -10 °C              |
| 21   | Top off charge                                             | -10 °C              |
| 22   | Standard cycle (SC) for C/3 capacity determination         | -10 °C              |
| 23   | Thermal equilibration                                      | RT                  |
| 24   | Standard cycle (SC)                                        | RT                  |
| 25   | Thermal equilibration                                      | -10 °C              |
| 26   | Top off charge                                             | -10 °C              |
| 27   | Pulse power characterization                               | -10 °C              |
| 28   | Thermal equilibration                                      | RT                  |
| 29   | Standard cycle (SC)                                        | RT                  |
| 30   | Continue with step 9                                       | RT                  |

## 7.10.2.2.1.3 Test profiles for cycle life test



## Key

|   |                           |   |           |
|---|---------------------------|---|-----------|
| X | time [s]                  | 1 | discharge |
| Y | fraction of $P_{max}$ [%] | 2 | charge    |

Figure 9 — Profile for cycle life test — Dynamic discharge power profile A

Table 30 — Time and power data — Dynamic discharge power profile A

| Step | Time increment<br>[s] | Time cumulative<br>[s] | Fraction of max. power<br>[%] |
|------|-----------------------|------------------------|-------------------------------|
| 1    | 16                    | 16                     | 0                             |
| 2    | 28                    | 44                     | +12,5                         |
| 3    | 12                    | 56                     | +25                           |
| 4    | 8                     | 64                     | -12,5                         |
| 5    | 16                    | 80                     | 0                             |
| 6    | 24                    | 104                    | +12,5                         |
| 7    | 12                    | 116                    | +25                           |
| 8    | 8                     | 124                    | -12,5                         |
| 9    | 16                    | 140                    | 0                             |
| 10   | 24                    | 164                    | +12,5                         |
| 11   | 12                    | 176                    | +25                           |
| 12   | 8                     | 184                    | -12,5                         |
| 13   | 16                    | 200                    | 0                             |
| 14   | 36                    | 236                    | +12,5                         |
| 15   | 8                     | 244                    | +100                          |
| 16   | 24                    | 268                    | +62,5                         |
| 17   | 8                     | 276                    | -25                           |
| 18   | 32                    | 308                    | +25                           |
| 19   | 8                     | 316                    | -50                           |
| 20   | 44                    | 360                    | 0                             |

In this profile, the max. power shall be the power value  $P_{10s,dch}$ , measured in the power and internal resistance test as described in 7.3 at RT, 35 % SOC and  $t = 10$  s unless customer and supplier have agreed on a reduction of this power value.

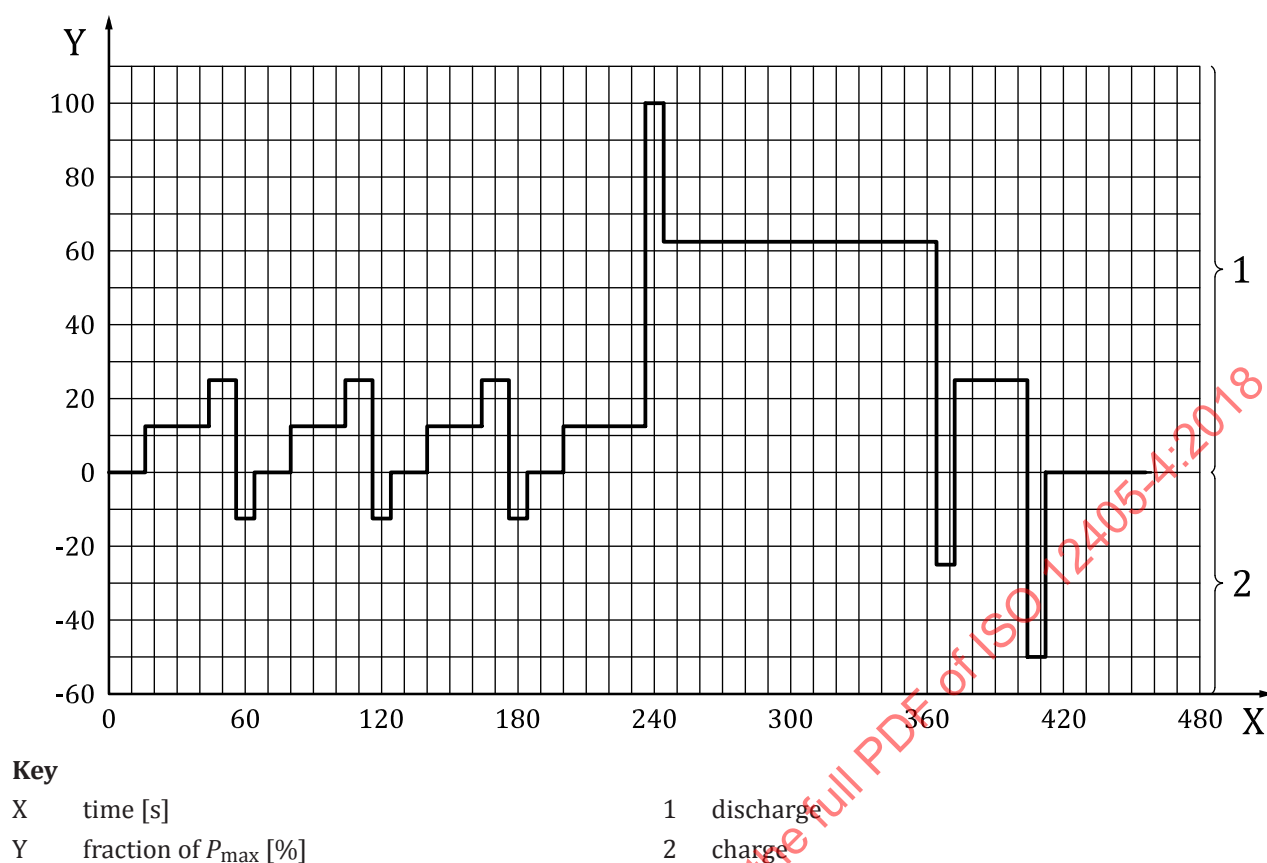


Figure 10 — Profile for cycle life test — Dynamic discharge power profile B

Table 31 — Time and power data — Dynamic discharge power profile B

| Step | Time increment<br>[s] | Time cumulative<br>[s] | Fraction of max. power<br>[%] |
|------|-----------------------|------------------------|-------------------------------|
| 1    | 16                    | 16                     | 0                             |
| 2    | 28                    | 44                     | +12,5                         |
| 3    | 12                    | 56                     | +25                           |
| 4    | 8                     | 64                     | -12,5                         |
| 5    | 16                    | 80                     | 0                             |
| 6    | 24                    | 104                    | +12,5                         |
| 7    | 12                    | 116                    | +25                           |
| 8    | 8                     | 124                    | -12,5                         |
| 9    | 16                    | 140                    | 0                             |
| 10   | 24                    | 164                    | +12,5                         |
| 11   | 12                    | 176                    | +25                           |
| 12   | 8                     | 184                    | -12,5                         |
| 13   | 16                    | 200                    | 0                             |
| 14   | 36                    | 236                    | +12,5                         |
| 15   | 8                     | 244                    | +100                          |
| 16   | 120                   | 364                    | +62,5                         |
| 17   | 8                     | 372                    | -25                           |

**Table 31** (continued)

| Step | Time increment<br>[s] | Time cumulative<br>[s] | Fraction of max. power<br>[%] |
|------|-----------------------|------------------------|-------------------------------|
| 18   | 32                    | 404                    | +25                           |
| 19   | 8                     | 412                    | -50                           |
| 20   | 44                    | 456                    | 0                             |

In this profile, the max. power shall be the power value  $P_{10s,dch}$ , measured in the power and internal resistance test as described in 7.3 at RT, 35 % SOC and  $t = 10$  s unless customer and supplier have agreed on a reduction of this power value.

#### 7.10.2.2.1.4 Conditions

- Ambient: start at RT in a temperature chamber with adequate safety equipment.
- Designated (or comparable) battery cooling system shall operate.
- During cycling, the DUT electronic shall ensure that no cell limits will be exceeded, by achieving voltage limits as specified by the supplier. The current has to be reduced automatically to avoid any electrical and functional operation.

#### 7.10.2.2.2 Battery systems for charge-depleting followed by charge-sustaining applications

##### 7.10.2.2.2.1 Preparation

During the test, it is necessary to maintain the DUT temperature by its cooling equipment within a temperature range between RT and 40 °C (i.e. RT during rest periods, certainly higher during operation). If requested by the supplier, additional rest periods can be placed between the cycles in order to keep the DUT within the designated temperature range.

The cycle test is performed by combining the power profile cycling for charge-depleting applications as described in 7.10.2.2.1 and a charge-sustaining cycle composed of a “plug-in charge-rich profile” where the charge amount is slightly larger than the discharge amount, and a “plug-in discharge-rich profile” where the discharge amount is slightly larger than the charge amount, as shown in Figure 11 and Figure 12. Their data are shown in Table 33 and Table 34 accordingly.

The cycle test shall be started from the upper limit of SOC by performing the power profile cycling for charge-depleting applications as described in 7.10.2.2.1 until SOC reaches the lower limit for the charge-depleting operation of 30 % SOC or as specified by the customer, followed by a sequence of the plug-in charge-rich current profile and the plug-in discharge-rich current profile. The SOC swing range during the charge-sustaining cycling shall be defined by the customer, otherwise the cycle test shall be performed between 35 % and 25 % SOC for the following 2 h. Within the next step, the battery system shall be charged according to the supplier's recommendation to the upper limit of SOC with the requirement to maintain the total time for the discharge-charge cycle including a rest time for cell balancing to 8 h. This sequence of dynamic discharge profiles including charging shall be repeated during the following 28 d. After these cycling activities the capacity and pulse power characterization tests shall be performed to determine the current status of the battery system. After the performance testing, the life cycling testing shall be continued until the test has been terminated according to the specified criteria; see end of test criteria in 7.10.2.2.5

The SOC limit for altering the profiles can be detected by one of the following:

- SOC calculated, i.e. by the BCU for a battery system test;
- A·h counted by external measurement;
- battery voltage upper and lower limit defined by the supplier.

### 7.10.2.2.2.2 Test sequence battery system cycle life test for charge-depleting followed by charge-sustaining applications

**Table 32 — Test sequence battery system cycle life test for charge-depleting followed by charge-sustaining applications**

| Step | Procedure                                                                                                                                                                                                             | Ambient temperature |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 1    | Thermal equilibration                                                                                                                                                                                                 | RT                  |
| 2    | Standard cycle (SC)                                                                                                                                                                                                   | RT                  |
| 3    | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                    | RT                  |
| 4    | Thermal equilibration                                                                                                                                                                                                 | -10 °C              |
| 5    | Top off charge                                                                                                                                                                                                        | -10 °C              |
| 6    | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                    | -10 °C              |
| 7    | Thermal equilibration                                                                                                                                                                                                 | RT                  |
| 8    | Standard cycle (SC)                                                                                                                                                                                                   | RT                  |
| 9    | Cycling by performing the power profile cycling for charge-depleting applications as described in 7.10.2.2.1 until:<br>— SOC 30 % or other lower limit SOC defined by customer is reached                             | RT                  |
| 10   | Cycling by the plug-in charge-rich current profile until:<br>— SOC 35 % or other upper limit SOC defined by customer<br>— Battery voltage reaches upper limit defined by the supplier                                 | RT                  |
| 11   | Cycling by the plug-in discharge-rich current profile until:<br>— SOC 25 % or other lower limit SOC defined by the customer<br>— Battery voltage reaches lower limit defined by the supplier                          | RT                  |
| 12   | Repeat steps 10 to 11 for 2 h                                                                                                                                                                                         |                     |
| 13   | Charge to 100 % SOC as defined by the supplier with the following requirements:<br>— Charging including cell balancing activities and rest time shall be finished at least 8 h after starting the cycling with step 9 | RT                  |
| 14   | Repeat steps 9 to 13 for a total of 28 d                                                                                                                                                                              |                     |
| 15   | Thermal equilibration                                                                                                                                                                                                 | RT                  |
| 16   | Standard cycle (SC)                                                                                                                                                                                                   | RT                  |
| 17   | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                    | RT                  |
| 18   | Thermal equilibration                                                                                                                                                                                                 | RT                  |
| 19   | Top off charge                                                                                                                                                                                                        | RT                  |
| 20   | Pulse power characterization                                                                                                                                                                                          | RT                  |
| 21   | Standard charge (SCH)                                                                                                                                                                                                 | RT                  |
| 22   | Every 8 weeks continue with step 23, otherwise with step 9                                                                                                                                                            |                     |
| 23   | Thermal equilibration                                                                                                                                                                                                 | -10 °C              |
| 24   | Top off charge                                                                                                                                                                                                        | -10 °C              |
| 25   | Standard cycle (SC) for C/3 capacity determination                                                                                                                                                                    | -10 °C              |
| 26   | Thermal equilibration                                                                                                                                                                                                 | RT                  |
| 27   | Standard cycle (SC)                                                                                                                                                                                                   | RT                  |
| 28   | Thermal equilibration                                                                                                                                                                                                 | -10 °C              |
| 29   | Top off charge                                                                                                                                                                                                        | -10 °C              |
| 30   | Pulse power characterization                                                                                                                                                                                          | -10 °C              |

Table 32 (continued)

| Step | Procedure             | Ambient temperature |
|------|-----------------------|---------------------|
| 31   | Thermal equilibration | RT                  |
| 32   | Standard cycle (SC)   | RT                  |
| 33   | Continue with step 9  | RT                  |

## 7.10.2.2.2.3 Test profiles for cycle life test

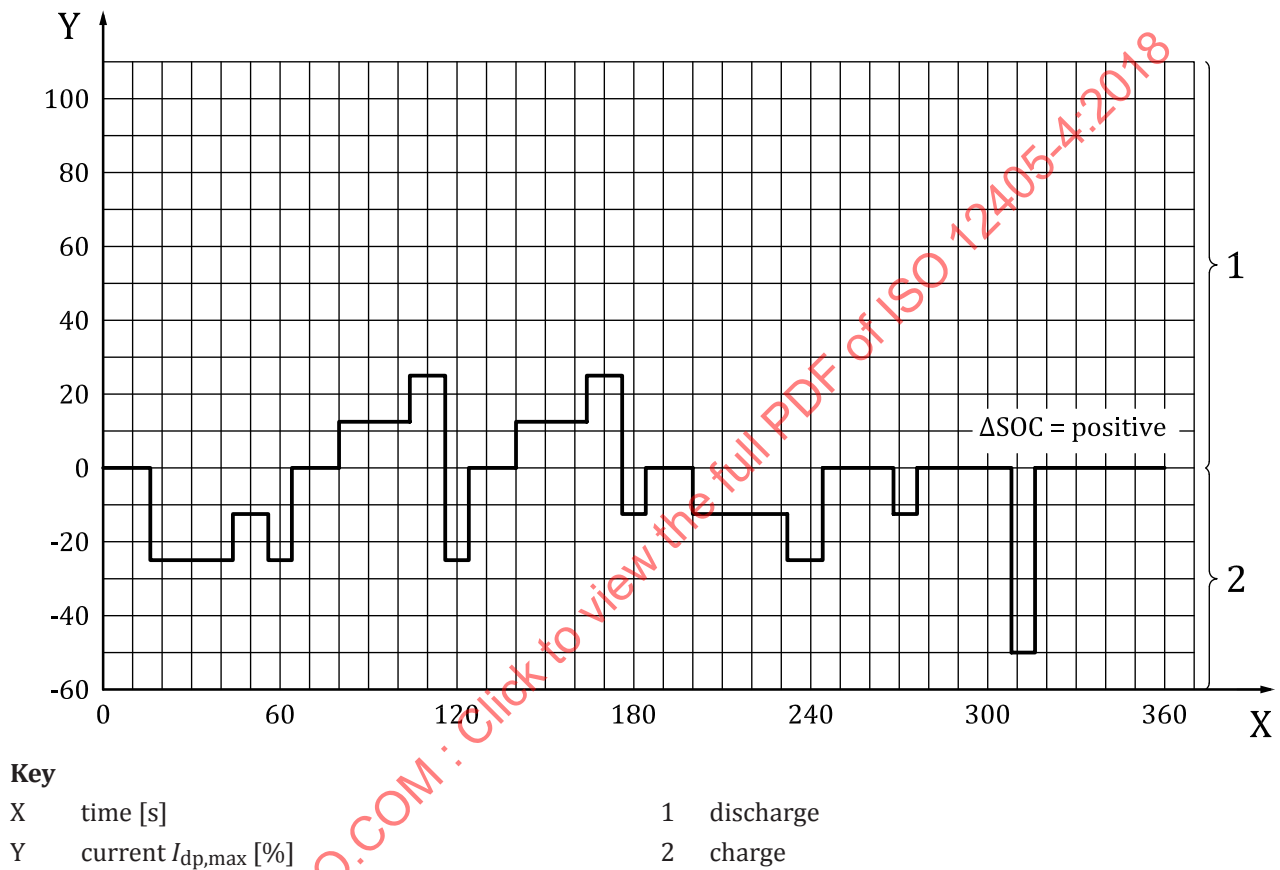


Figure 11 — Profile for cycle life test — Plug-in charge-rich current profile

Table 33 — Time and current data — Plug-in charge-rich current profile

| Step | Time increment<br>[s] | Time cumulative<br>[s] | Fraction of $I_{max}$<br>[%] |
|------|-----------------------|------------------------|------------------------------|
| 1    | 16                    | 16                     | 0                            |
| 2    | 28                    | 44                     | -25                          |
| 3    | 12                    | 56                     | -12,5                        |
| 4    | 8                     | 64                     | -25                          |
| 5    | 16                    | 80                     | 0                            |
| 6    | 24                    | 104                    | +12,5                        |
| 7    | 12                    | 116                    | +25                          |
| 8    | 8                     | 124                    | -25                          |
| 9    | 16                    | 140                    | 0                            |
| 10   | 24                    | 164                    | +12,5                        |

Table 33 (continued)

| Step | Time increment<br>[s] | Time cumulative<br>[s] | Fraction of $I_{\max}$<br>[%] |
|------|-----------------------|------------------------|-------------------------------|
| 11   | 12                    | 176                    | +25                           |
| 12   | 8                     | 184                    | -12,5                         |
| 13   | 16                    | 200                    | 0                             |
| 14   | 32                    | 232                    | -12,5                         |
| 15   | 12                    | 244                    | -25                           |
| 16   | 24                    | 268                    | 0                             |
| 17   | 8                     | 276                    | -12,5                         |
| 18   | 32                    | 308                    | 0                             |
| 19   | 8                     | 316                    | -50                           |
| 20   | 44                    | 360                    | 0                             |

NOTE Because of different time delays and slew rates of various battery testers which will be used, no shorter pulses than 5 s are defined.

In this profile,  $I_{\max}$  shall be the maximum rated pulse discharge current  $I_{dp,\max}$  at RT, as specified by the supplier, see 7.3.2.

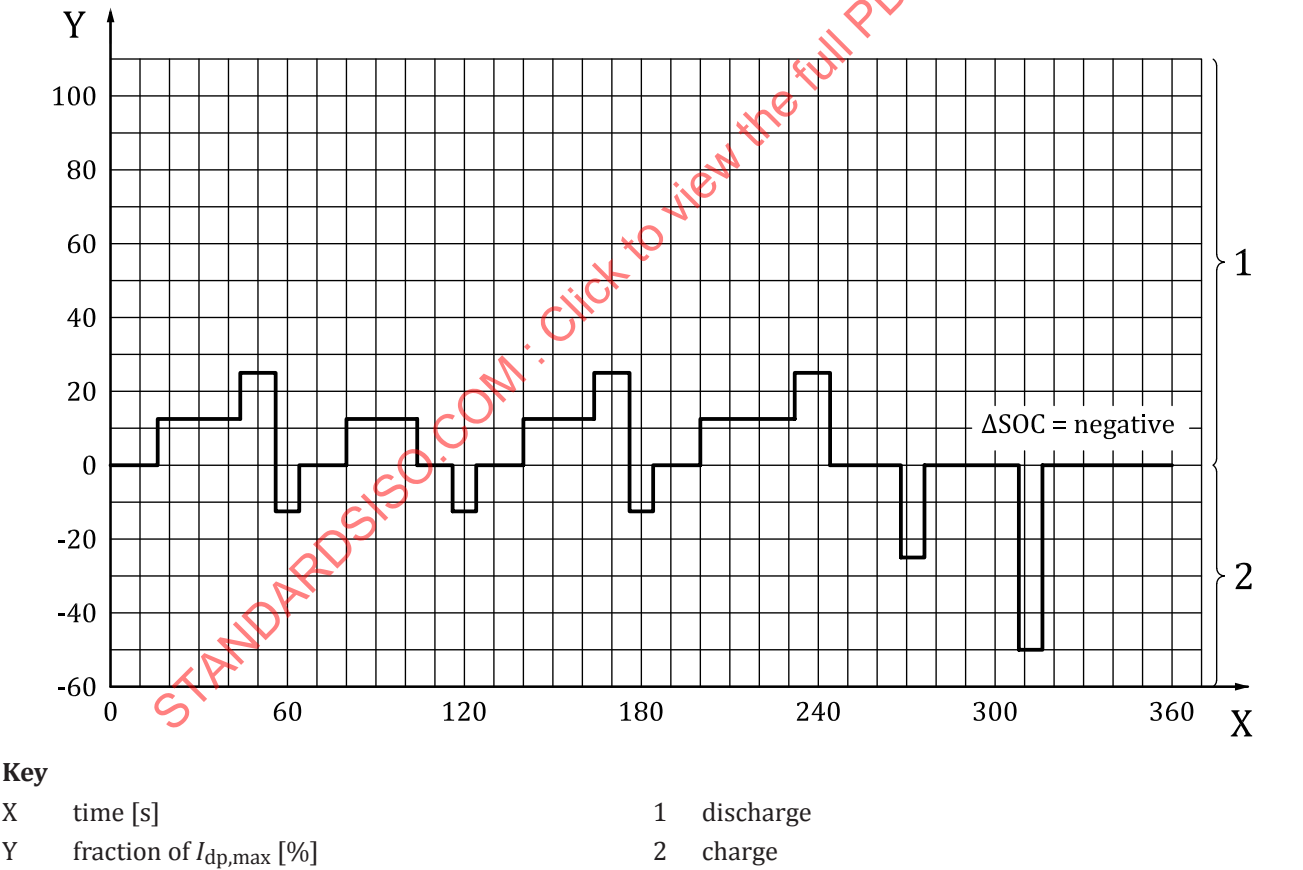


Figure 12 — Profile for cycle life test — Plug-in discharge-rich current profile