BS EN 62660-1:2011

BSI Standards Publication

Secondary lithium-ion cells for the propulsion of electric road vehicles

Part 1: Performance testing

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National foreword

This British Standard is the UK implementation of EN 62660-1:2011. It is identical to IEC 62660-1:2010.

The UK participation in its preparation was entrusted to Technical Committee PEL/21, Secondary cells and batteries.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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EUROPEAN STANDARD

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EN 62660-1

July 2011

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English version

Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing
(IEC 62660-1:2010)

Eléments d'accumulateurs lithium-ion pour la propulsion des véhicules routiers électriques -
Partie 1: Essais de performance
(CEI 62660-1:2010)

Lithium-Ionen-Sekundärzellen für den Antrieb von Elektrostraßenfahrzeugen -
Teil 1: Prüfung des Leistungsverhaltens
(IEC 62660-1:2010)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 21/728/FDIS, future edition 1 of IEC 62660-1, prepared by IEC TC 21, Secondary cells and batteries, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62660-1 on 2011-01-20.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-10-20
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-01-20

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62660-1:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 62660-2 NOTE Harmonized as EN 62660-2.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-482	-	International Electrotechnical Vocabulary - Part 482: Primary and secondary cells and batteries	-	-
IEC 61434	-	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Guide to the designation of current in alkaline secondary cell and battery standards	EN 61434	-

CONTENTS

INTRODUCTION

The commercialisation of electric road vehicles including battery, hybrid and plug-in hybrid electric vehicles has been accelerated in the global market, responding to the global concerns on CO_2 reduction and energy security. This, in turn, has led to rapidly increasing demand for high-power and high-energy density traction batteries. Lithium-ion batteries are estimated to be one of the most promising secondary batteries for the propulsion of electric vehicles. In the light of rapidly diffusing hybrid electric vehicles and emerging battery and plug-in hybrid electric vehicles, a standard method for testing performance requirements of lithium-ion batteries is indispensable for securing a basic level of performance and obtaining essential data for the design of vehicle systems and battery packs.

This standard is to specify performance testing for automobile traction lithium-ion cells that basically differ from the other cells including those for portable and stationary applications specified by the other IEC standards. For automobile application, it is important to note the usage specificity; i.e. the designing diversity of automobile battery packs and systems, and specific requirements for cells and batteries corresponding to each of such designs. Based on these facts, the purpose of this standard is to provide a basic test methodology with general versatility, which serves a function in common primary testing of lithium ion cells to be used in a variety of battery systems.

This standard is associated with ISO 12405-1-and ISO 12405-2[1].

IEC 62660-2 specifies the reliability and abuse testing for lithium-ion cells for electric vehicle application.

1 Under consideration.

SECONDARY LITHIUM-ION CELLS FOR THE PROPULSION OF ELECTRIC ROAD VEHICLES –

Part 1: Performance testing

1 Scope

This part of IEC 62660 specifies performance and life testing of secondary lithium-ion cells used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).

The objective of this standard is to specify the test procedures to obtain the essential characteristics of lithium-ion cells for vehicle propulsion applications regarding capacity, power density, energy density, storage life and cycle life.

This standard provides the standard test procedures and conditions for testing basic performance characteristics of lithium-ion cells for vehicle propulsion applications, which are indispensable for securing a basic level of performance and obtaining essential data on cells for various designs of battery systems and battery packs.

NOTE 1 Based on the agreement between the manufacturer and the customer, specific test conditions may be selected in addition to the conditions specified in this standard. Selective test conditions are described in Annex A.

NOTE 2 The performance tests for the electrically connected lithium-ion cells may be performed with reference to this standard.

NOTE 3 The test specification for lithium-ion battery packs and systems is defined in ISO 12405-1 and ISO 12405-2 (under consideration).

2 Normative references

The following referenced documents are indispensable for the application 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.

IEC 60050-482, *International Electrotechnical Vocabulary – Part 482: Primary and secondary cells and batteries*

IEC 61434, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Guide to the designation of current in alkaline secondary cell and battery standards*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-482 and the following apply.

3.1
battery electric vehicle
BEV
electric vehicle with only a traction battery as power source for vehicle propulsion

3.2
hybrid electric vehicle
HEV
vehicle with both a rechargeable energy storage system and a fuelled power source for propulsion

3.3
rated capacity
quantity of electricity C_3 Ah (ampere-hours) for BEV and C_1 Ah for HEV declared by the manufacturer

3.4
reference test current
$\boldsymbol{I_t}$
current in amperes which is expressed as

I_t (A) = C_n (Ah)/ 1 (h)

where

C_n is the rated capacity of the cell ;

n is the time base (hours).

3.5
room temperature
temperature of 25 °C ± 2 K

3.6
secondary lithium ion cell
secondary single cell whose electrical energy is derived from the insertion/extraction reactions of lithium ions between the anode and the cathode

NOTE 1 The secondary cell is a basic manufactured unit providing a source of electrical energy by direct conversion of chemical energy. The cell consists of electrodes, separators, electrolyte, container and terminals, and is designed to be charged electrically.

NOTE 2 In this standard, cell or secondary cell means the secondary lithium ion cell to be used for the propulsion of electric road vehicles.

3.7
state of charge
SOC
available capacity in a battery expressed as a percentage of rated capacity

4 Test conditions

4.1 General

The details of the instrumentation used shall be provided in any report of results.

4.2 Measuring instruments

4.2.1 Range of measuring devices

The instruments used shall enable the values of voltage and current to be measured. The range of these instruments and measuring methods shall be chosen so as to ensure the accuracy specified for each test.

For analogue instruments, this implies that the readings shall be taken in the last third of the graduated scale.

Any other measuring instruments may be used provided they give an equivalent accuracy.

4.2.2 Voltage measurement

The resistance of the voltmeters used shall be at least 1 M Ω /V.

4.2.3 Current measurement

The entire assembly of ammeter, shunt and leads shall be of an accuracy class of 0,5 or better.

4.2.4 Temperature measurements

The cell temperature shall be measured by use of a surface temperature measuring device capable of an equivalent scale definition and accuracy of calibration as specified in 4.2.1. The temperature should be measured at a location which most closely reflects the cell temperature. The temperature may be measured at additional appropriate locations, if necessary.

The examples for temperature measurement are shown in Figure 1. The instructions for temperature measurement specified by the manufacturer shall be followed.

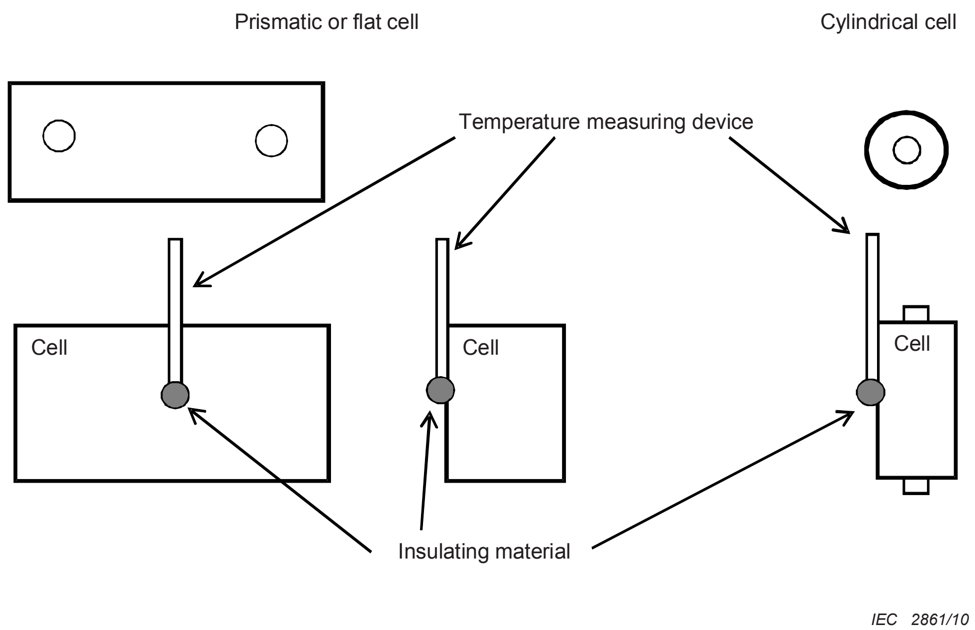


Figure 1 – Example of temperature measurement of cell

4.2.5 Other measurements

Other values including capacity and power may be measured by use of a measuring device, provided that it complies with 4.3.

4.3 Tolerance

The overall accuracy of controlled or measured values, relative to the specified or actual values, shall be within these tolerances:

a) ±0,1 % for voltage;

b) ±1 % for current;

c) ± 2 K for temperature;

d) ±0,1 % for time;

e) ±0,1 % for mass;

f) ±0,1 % for dimensions.

These tolerances comprise the combined accuracy of the measuring instruments, the measurement technique used, and all other sources of error in the test procedure.

4.4 Test temperature

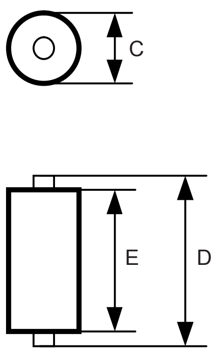
If not otherwise defined, before each test the cell shall be stabilized at the test temperature for a minimum of 12 h. This period can be reduced if thermal stabilization is reached. Thermal stabilization is considered to be reached if after one interval of 1 h, the change of cell temperature is lower than 1 K.

Unless otherwise stated in this standard, cells shall be tested at room temperature using the method declared by the manufacturer.

5 Dimension measurement

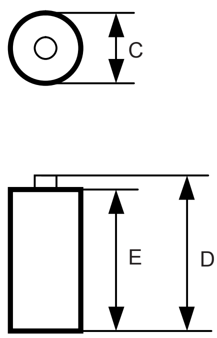
The maximum dimension of the total width, thickness or diameter, and length of a cell shall be measured up to three significant figures in accordance with the tolerances in 4.3.

The examples of maximum dimension are shown in Figures 2a to 2f.



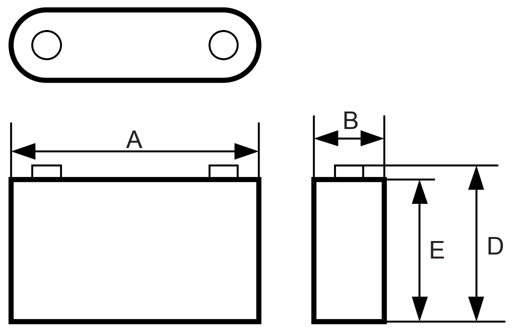
IEC 2862/10

Figure 2a – Cylindrical cell (1)



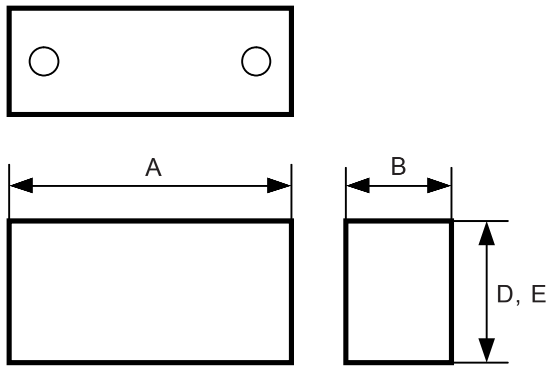
IEC 2863/10

Figure 2b – Cylindrical cell (2)



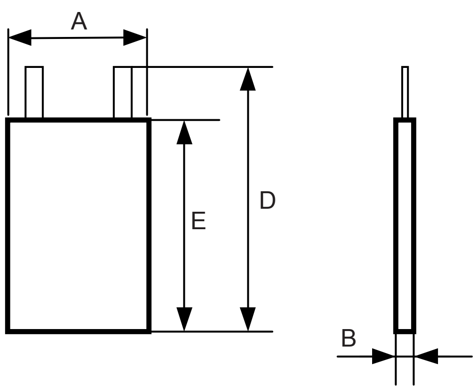
IEC 2864/10

Figure 2c – Prismatic cell (1)



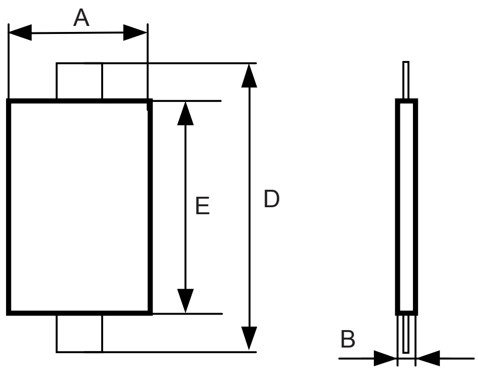
IEC 2865/10

Figure 2d – Prismatic cell (2)



IEC 2866/10

Figure 2e – Flat cell (1)



IEC 2867/10

Figure 2f – Flat cell (2)

Key

A total width

B total thickness

C diameter

D total length (including terminals)

E total length (excluding terminals)

Figure 2 – Examples of maximum dimension of cell

6 Mass measurement

Mass of a cell is measured up to three significant figures in accordance with the tolerances in 4.3.

7 Electrical measurement

During each test, voltage, current and temperature shall be recorded.

7.1 General charge conditions

Unless otherwise stated in this standard, prior to electrical measurement test, the cell shall be charged as follows.

Prior to charging, the cell shall be discharged at room temperature at a constant current described in Table 1 down to a end-of-discharge voltage specified by the manufacturer. Then, the cell shall be charged according to the charging method declared by the manufacturer at room temperature.

7.2 Capacity

Capacity of cell shall be measured in accordance with the following steps.

Step 1 − The cell shall be charged in accordance with 7.1.

After recharge, the cell temperature shall be stabilized in accordance with 4.4.

Step 2 − The cell shall be discharged at specified temperature at a constant current I_t (A) to the end-of-discharge voltage that is provided by the manufacturer. The discharge current and temperatures indicated in Table 1 shall be used.

NOTE Selective test conditions are shown in Table A.1 in Annex A.

The method of designation of test current I_t is defined in IEC 61434.

Table 1 – Discharge conditions

	Discharge current A	
Temperature °C	**BEV application**	**HEV application**
0	1/3 I_t	1 I_t
25		
45		

Step 3 − Measure the discharge duration until the specified end-of discharge voltage is reached, and calculate the capacity of cell expressed in Ah up to three significant figures.

7.3 SOC adjustment

The test cells shall be charged as specified below. The SOC adjustment is the procedure to be followed for preparing cells to the various SOCs for the tests in this standard.

Step 1 - The cell shall be charged in accordance with 7.1.

Step 2 - The cell shall be left at rest at room temperature in accordance with 4.4.

Step 3 - The cell shall be discharged at a constant current according to Table 1 for $(100 - n)/100 \times 3$ h for BEV application and $(100 - n)/100 \times 1$ h for HEV application, where n is SOC (%) to be adjusted for each test.

7.4 Power

7.4.1 Test method

The test shall be carried out in accordance with the following procedure.

a) Mass measurement

   Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimension of the cell shall be measured as specified in Clause 5.

c) Current-voltage characteristic test

Current-voltage characteristics shall be determined by measuring the voltage at the end of the 10 second pulse, when a constant current is discharged and charged under the conditions specified below.

1) SOC shall be adjusted to 20 %, 50 %, and 80 % according to the procedure specified in 7.3.
2) The cell temperature at test commencement shall be set to 40 °C, 25 °C, 0 °C, and –20 °C.
3) The cell is charged or discharged at each value of the current corresponding to the respective rated capacity level, and the voltage is measured at the end of the 10 s pulse. The range of the charge and discharge current shall be specified by the manufacturer, and the standard measurement interval shall be 1 s. If the voltage after 10 s exceeds the discharge lower limit voltage or charge upper limit voltage, the measurement data shall be omitted.

NOTE The charge/discharge limits at low temperature specified by the manufacturer should be taken into account.

Table 2 shows examples of charge and discharge current according to the applications. If it is required, the maximum current for charge and discharge is specified by the cell manufacturer (I_{max}). This value can be reduced according to the agreement with the customer. The maximum charge and discharge current can be applied after the measurement at 5 I_t for BEV application and 10 I_t for HEV application. I_{max} value changes depending on SOC, test temperature and charge or discharge state.

Table 2 – Examples of charge and discharge current

Application	**Charge and discharge current** A				
BEV	1/3 I_t	1 I_t	2 I_t	5 I_t	I_{max}
HEV	1/3 I_t	1 I_t	5 I_t	10 I_t	I_{max}

4) 10-min rest time shall be provided between charge and discharge pulses as well as between discharge and charge pulses. However, if the cell temperature after 10 min is not within 2 K of test temperature, it shall be cooled further; alternatively, the rest time duration shall be extended and it shall be inspected whether the cell temperature then settles within 2 K. The next discharging or charging procedure is then proceeded with.
5) The test is performed according to the scheme shown in Figure 3a and Figure 3b.

NOTE 1 Selective test conditions are shown in Table A.2 in Annex A.

NOTE 2 The current-voltage characteristic line can be obtained by straight-line approximation using the measured values of current and voltage, from which I_{max} and power can be calculated. The slope of this line shows the internal resistance of cell.

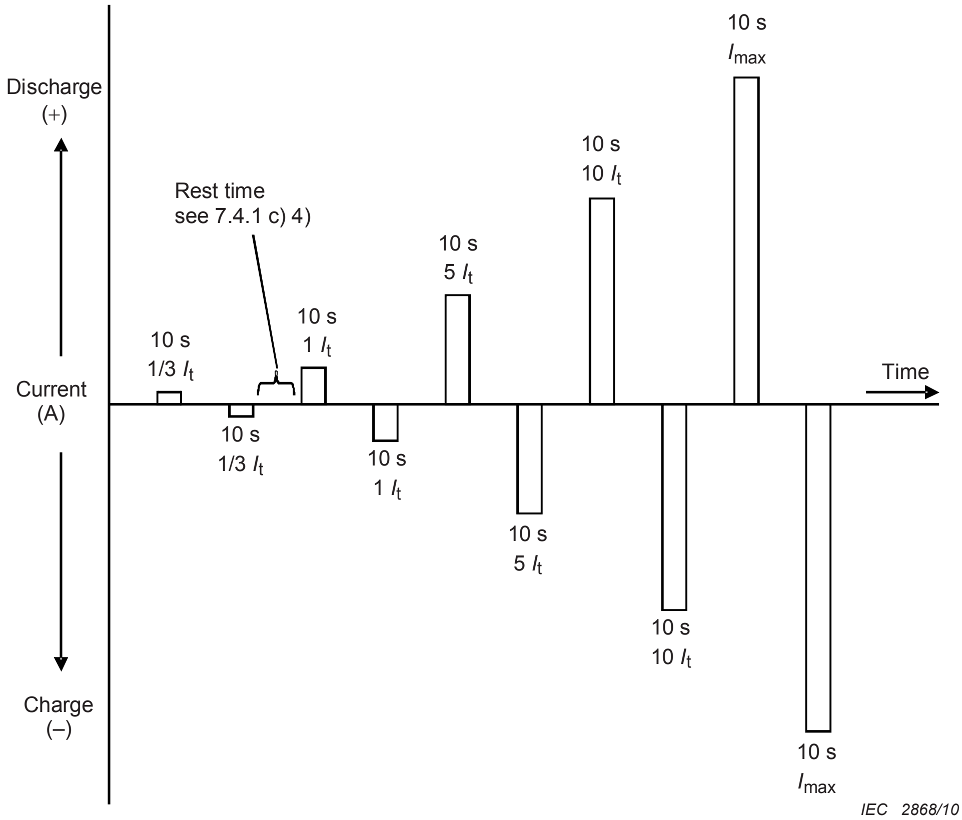


Figure 3a – Test order of the current-voltage characteristic test for HEV application

(continued overleaf)

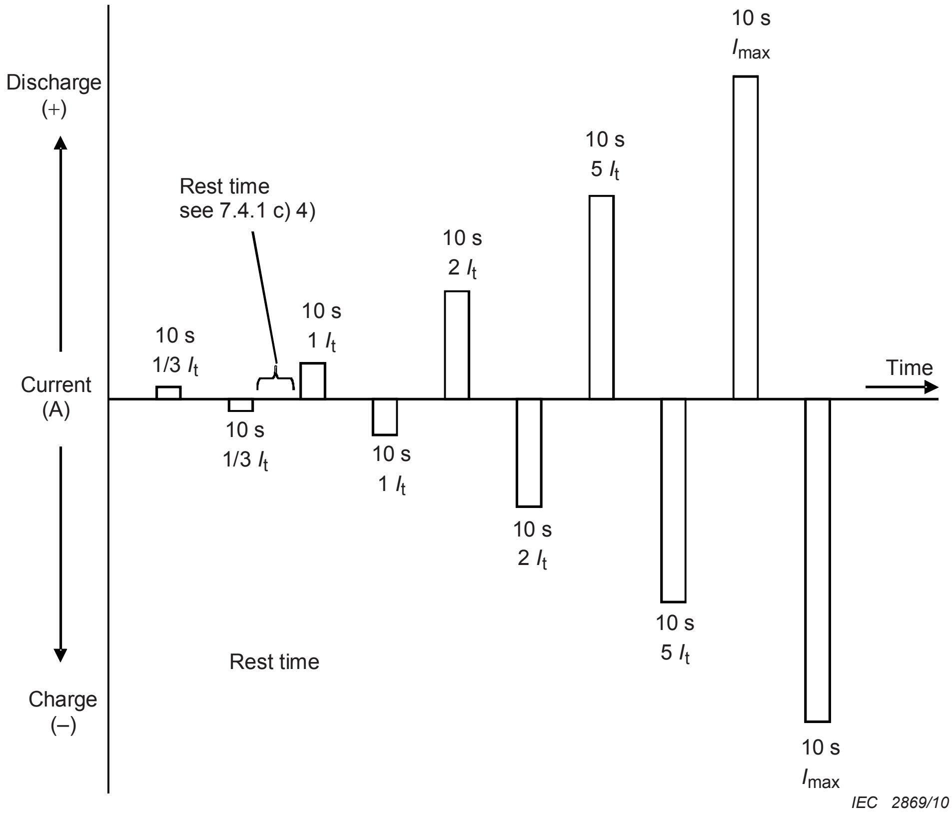


Figure 3b – Test order of the current-voltage characteristic test for BEV application

Figure 3 – Test order of the current-voltage characteristic test

7.4.2 Calculation of power density

7.4.2.1 Power

The power shall be calculated according to equation (1) and rounded to 3 significant figures.

$$P_d = U_d \times I_{dmax} \quad (1)$$

where

P_d is the power (W);

U_d is the measured voltage at the end of the 10 s pulse of I_{dmax} discharge (V);

I_{dmax} is the maximum discharge current which is specified by the manufacturer (A).

If P_d is an estimated value, it shall be stated.

7.4.2.2 Power density per unit mass

Mass power density is calculated from equation (2), and is rounded to 3 significant figures.

$$\rho_{pd} = \frac{P_d}{m} \quad (2)$$

where

ρ_{pd} is the power density (W/kg);

P_d is the power (W);

m is the mass of cell (kg).

7.4.2.3 Power density per unit volume

Volumetric power density shall be calculated from equation (3), and is rounded to 3 significant figures.

$$\rho_{pvlm} = \frac{P_d}{V} \tag{3}$$

where

ρ_{pvlm} is the volumetric power density (W/l);

P_d is the power (W);

V is the volume of cell (l).

The volume of a prismatic or a flat cell is given by the product of its total height excluding terminals, width, and length, and that of a cylindrical cell is given by the product of the cross section of the cylinder and its total length excluding terminals.

7.4.3 Calculation of regenerative power density

7.4.3.1 Regenerative power

Regenerative power shall be calculated according to equation (4) and rounded to three significant figures.

$$P_c = U_c \times I_{cmax} \tag{4}$$

where

P_c is the regenerative power (W);

U_c is the measured voltage at the end of the 10 s pulse of I_{cmax} charge (V);

I_{cmax} is the maximum charge current specified by the manufacturer (A).

If P_c is an estimated value, it shall be stated.

7.4.3.2 Regenerative power density per unit mass

Regenerative power density per unit mass shall be calculated from equation (5) and is rounded to three significant figures.

$$\rho_{pc} = \frac{P_c}{m} \tag{5}$$

where

ρ_{pc} is the regenerative power density (W/kg);

P_c is the regenerative power (W);

m is the mass of cell (kg).

7.4.3.3 Regenerative power density per unit volume

Volumetric regenerative power density is calculated from equation (6) and is rounded to three significant figures.

$$\rho_{\text{pvlmc}} = \frac{P_c}{V} \tag{6}$$

where

ρ_{pvlmc} is the volumetric regenerative power density (W/l);

P_c is the regenerative power (W);

V is the volume of cell (l).

The volume of a prismatic or a flat cell is given by the product of its total height excluding terminals, width, and length, and that of a cylindrical battery is given by the product of the cross section of the cylinder and its total length excluding terminals.

7.5 Energy

7.5.1 Test method

Mass energy density (Wh/kg) and volumetric energy density (Wh/l) of cells in a certain current discharge of 1/3 I_t A for BEV application and 1 I_t A for HEV application shall be determined according to the following procedure.

a) Mass measurement

Mass of the cell shall be measured as specified in Clause 6.

b) Dimension measurement

Dimension of the cell shall be measured as specified in Clause 5.

c) Capacity measurement

Capacity of the cell shall be determined in accordance with 7.2 at room temperature.

d) Average voltage calculation

The value of the average voltage during discharging in the above capacity test shall be obtained by integrating the discharge voltage over time and dividing the result by the discharge duration. The average voltage is calculated in a simple manner using the following method: Discharge voltages U_1, U_2, ..., U_n are noted every 5 s from the time the discharging starts and voltages that cut off the end of discharge voltage in less than 5 s are discarded. The average voltage U_{avr} is then calculated in a simplified manner using equation (7) up to three significant figures by rounding off the result.

$$U_{\text{avr}} = \frac{U_1 + U_2 + \cdot\ \cdot\ \cdot + U_n}{n} \tag{7}$$

NOTE Values provided by measurement devices may be used, if sufficient accuracy can be achieved.

7.5.2 Calculation of energy density

7.5.2.1 Energy density per unit mass

The mass energy density shall be calculated using equation (8) and equation (9) up to three significant figures by rounding off the result.

$$W_{\text{ed}} = C_d U_{\text{avr}} \tag{8}$$

where

W_{ed} is the electric energy of cell (Wh);

C_d is the discharge capacity (Ah) at 1/3 I_t (A) for BEV or 1 I_t (A) for HEV;

U_{avr} is the average voltage during discharging (V).

$$\rho_{ed} = \frac{W_{ed}}{m} \tag{9}$$

where

ρ_{ed} is the mass energy density (Wh/kg);

W_{ed} is the electric energy of cell (Wh);

m is the mass of cell (kg).

7.5.2.2 Energy density per unit volume

The volumetric energy density shall be calculated using equation (10) up to three significant figures by rounding off the result.

$$\rho_{evlmd} = \frac{W_{ed}}{V} \tag{10}$$

where

ρ_{evlmd} is the volumetric energy density (Wh/l);

W_{ed} is the electric energy of cell (Wh);

V is volume of cell (l).

The volume of prismatic cell shall be given by the product of the total height excluding terminals, width, and length of the cell, and that of cylindrical cells shall be given by the product of the cylindrical cross-sectional area and the total length excluding terminals.

7.6 Storage test

7.6.1 Charge retention test

The charge retention characteristics of cell at a 50 % SOC shall be determined according to the following procedure.

Step 1 - The cell shall be charged in accordance with 7.1.

Step 2 - The cell shall be discharged to 50 % SOC in accordance with the method specified in 7.3. Then, the cell shall be stabilized at test temperature for 1 h.

Step 3 - Discharge the cell to the end-of-discharge voltage at a discharge current of 1/3 I_t (A) for BEV application and 1 I_t (A) for HEV application and at room temperature. This discharge capacity is C_b.

Step 4 - Repeat steps 1 and 2.

Step 5 - The cell shall be stored for 28 days at an ambient temperature 45 °C ± 2 K.

Step 6 - Discharge the cell at a constant current of 1/3 I_t (A) for BEV application and 1 I_t (A) for HEV application at room temperature until end-of-discharge voltage, and then measure the capacity of cell. This discharge capacity is C_r.

Charge retention ratio shall be calculated according to equation (11).

$$R = \frac{C_r}{C_b} \times 100 \qquad (11)$$

where

R is the charge retention ratio (%);

C_r is the capacity of cell after storage (Ah);

C_b is the capacity of cell before storage (Ah).

7.6.2 Storage life test

The storage life of a cell shall be determined according to the following procedure.

Step 1 - Determine the capacity, power density and regenerative power density of cell in accordance with 7.1, 7.2 and 7.4.

Step 2 - Adjust the SOC of cell to 100 % for BEV application, and to 50 % for HEV application in accordance with 7.3. The cell shall then be stored for 42 days at an ambient temperature 45 °C ± 2 K.

Step 3 - Following the storage of step 2, the cell shall be kept at room temperature according to 4.4 and discharged at a constant current of 1/3 I_t (A) for BEV application and 1 I_t (A) for HEV application, down to the end-of discharge voltage specified by the manufacturer. Then, measure the capacity of cell. This discharge capacity is the retained capacity (Ah).

Step 4 - Repeat step1, step 2 and step 3 for 3 times.

The capacity, power density, regenerative power density and retained capacity measured in step1 and step 3 shall be reported.

If the cell is stored at room temperature during the test for rest such as for test timing adjustment, the total time of such rest shall be reported.

7.7 Cycle life test

The cycle life test shall be performed to determine the degradation character of cell by charge and discharge cycles.

NOTE 1 The cycle life test sequence is shown in Annex B.

NOTE 2 Selective test conditions are shown in Table A.3 in Annex A.

7.7.1 BEV cycle test

The cycle life performance of cell for BEV application shall be determined by the following test methods.

7.7.1.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity, dynamic discharge capacity, and power as the initial performance of cell.

– Capacity

The capacity shall be measured as specified in 7.2 at 25 °C ± 2 K.

– The dynamic discharge capacity C_D

The dynamic discharge capacity C_D shall be measured at 25 °C ± 2 K and 45 °C ± 2 K.

The dynamic discharge capacity is defined by the time integrated value of charge and discharge current confirmed by the following test: Discharge the fully charged cell repeatedly by the dynamic discharge profile A specified in Table 3 and Figure 4 until the voltage reaches the lower limit specified by the manufacturer.

– Power

The power shall be measured as specified in 7.4 at 25 °C ± 2 K, 50 % SOC.

7.7.1.2 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

a) Temperature

The ambient temperature shall be 45 °C ± 2 K. At the start of charge and discharge cycle, cell temperature shall be 45 °C ± 2 K.

b) Charge and discharge cycle

A single cycle is determined as the repetition of the following steps from 1 to 4. The rest time between each step shall be less than 4 h.

The cycle shall be continuously repeated for 28 days. Then, measure the performance of the cell as specified in 7.7.1.2 c). This procedure shall be repeated until the test termination specified in 7.7.1.2 d).

Step 1 - The cell shall be fully discharged by the method specified by the manufacturer.

Step 2 - The cells shall be fully charged by the method specified by the manufacturer. The charge time shall be less than 12 h.

Step 3 - Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 4 until the discharged capacity reaches equivalent to 50 % ± 5 % of the initial dynamic discharge capacity C_D at 45 °C.

If the voltage reaches the lower limit specified by the manufacturer during step 3, the test shall be discontinued notwithstanding the stipulation in 7.7.1.2 d), and the cell performance shall be measured at this point as specified in 7.7.1.2 c).

If the temperature of cell reaches the upper limit specified by the manufacturer during step 3, the duration of charge/discharge step 20 in Table 3 can be extended to an appropriate value. The actual duration time shall be reported.

In this profile, the test power shall be calculated using equation (12)

$$P_{max} = NW_{ed} \quad (12)$$

where

P_{max} is the test power (W);

N is a value (1/h) of vehicle required maximum power of cell (W) divided by energy of cell (Wh);

NOTE The value of N = 3/h is an example based on the specifications of commercialized BEVs.

W_{ed} is the electric energy of cell at room temperature (Wh).

If the value derived from equation (12) is larger than the maximum power of cell specified by the manufacturer, the test power shall be defined as 80 % of the maximum power at room temperature and at 20 % SOC specified by the manufacturer. Power value actually used shall be reported.

Table 3 – Dynamic discharge profile A for BEV cycle test

Charge/discharge step	Duration s	Ratio to test power %	Charge/discharge
1	16	0,0	-
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	–12,5	Charge
5	16	0,0	-
6	24	+12.5	Discharge
7	12	+25,0	Discharge
8	8	–12,5	Charge
9	16	0,0	-
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	–12,5	Charge
13	16	0,0	-
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	24	+62,5	Discharge
17	8	-25,0	Charge
18	32	+25,0	Discharge
19	8	–50,0	Charge
20	44	0,0	-

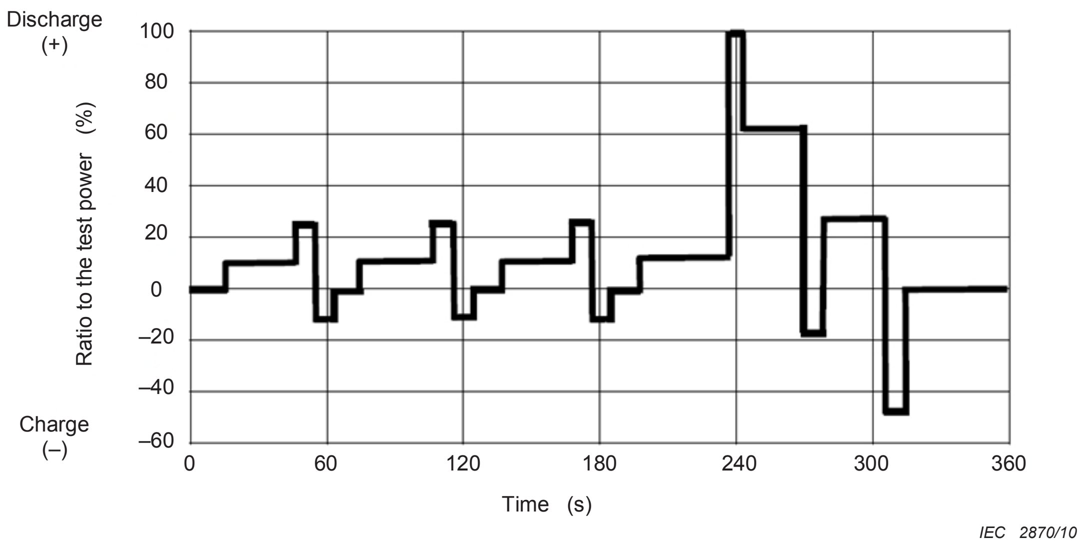


Figure 4 – Dynamic discharge profile A for BEV cycle test

Step 4 - Discharge the cell following the dynamic discharge profile B (hill climbing profile) specified in Table 4 and Figure 5 for one time. The test power shall be calculated using equation (12).

If the voltage reaches the lower limit specified by the manufacturer during step 4, the test shall be discontinued notwithstanding the stipulation in 7.7.1.2 d), and the cell performance shall be measured at this point as specified in 7.7.1.2 c).

If the battery voltage frequently reaches the lower limit voltage during charge/discharge step 16, the discharge power and duration can be changed appropriately. The actual test values shall be reported accordingly.

Table 4 – Dynamic discharge profile B for BEV cycle test

Charge/discharge step	Duration s	Ratio to test power %	Charge/discharge
1	16	0,0	-
2	28	+12,5	Discharge
3	12	+25,0	Discharge
4	8	–12,5	Charge
5	16	0,0	-
6	24	+12.5	Discharge
7	12	+25,0	Discharge
8	8	–12,5	Charge
9	16	0,0	-
10	24	+12,5	Discharge
11	12	+25,0	Discharge
12	8	–12,5	Charge
13	16	0,0	-
14	36	+12,5	Discharge
15	8	+100,0	Discharge
16	120	+62,5	Discharge
17	8	–25,0	Charge
18	32	+25,0	Discharge
19	8	–50,0	Charge
20	44	0,0	-

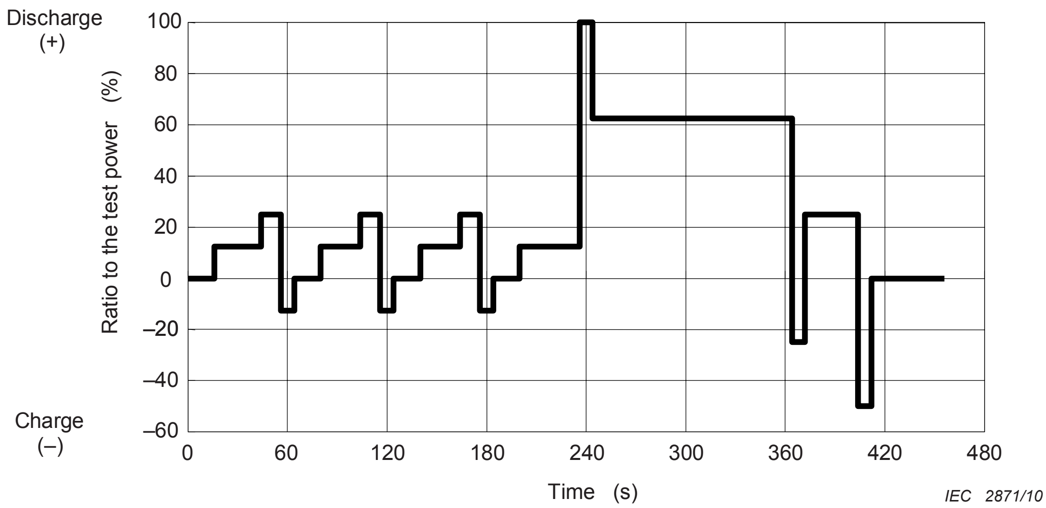


Figure 5 – Dynamic discharge profile B for BEV cycle test

Step 5 - Discharge the cell following the dynamic discharge profile A specified in Table 3 and Figure 4 until the overall discharge capacity including step 3 and step 4 reaches equivalent to 80 % of initial C_D at 45 °C.

If the temperature of cell reaches the upper limit specified by the manufacturer during step 5, the duration of charge/discharge step 20 in Table 3 can be extended to an appropriate value. The actual duration time shall be reported.

If the voltage reaches the lower limit specified by the manufacturer during step 5, the test shall be discontinued notwithstanding the stipulation in 7.7.1.2 d), and the cell performance shall be measured at this point as specified in 7.7.1.2 c).

c) Periodical measurement of performance

After every completion of the repetition from step 1 to step 5 for 28 test days, the performance of cell shall be measured as specified in 7.7.1.1. The accumulated time from step 1 to step 4 in 7.7.1.2 b) shall also be reported. The dynamic discharge capacity shall be measured at 25 °C ± 2 K only.

d) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise back to 7.7.1.2 a) and repeat the test.

Condition A – The test sequence from 7.7.1.2 a) to 7.7.1.2 c) is repeated 6 times.

Condition B – When any of the performance measured in 7.7.1.2 c) is decreased to less than 80 % of the initial value.

Condition C – The temperature of cell reaches the upper limit agreed between the manufacturer and the customer during the test.

The number of implemented times of each profile and cycle during the test shall be reported.

7.7.2 HEV cycle test

The cycle life performance of cell for HEV application shall be determined by the following test methods.

7.7.2.1 Measurement of initial performance

Before the charge and discharge cycle test, measure the capacity and power as the initial performance of cell.

– Capacity

The capacity shall be measured as specified in 7.2 at 25 °C ± 2 K.

– Power

The power shall be measured as specified in 7.4 at 25 °C ± 2 K, 50 % SOC.

7.7.2.2 Profile switching voltage

Before the cycle life test, set switching voltages at which discharge-rich profile and charge-rich profile specified in 7.7.2.3 c) shall be switched over.

a) Switching voltage from discharge-rich profile to charge-rich profile

Adjust the SOC of cell to 30 % according to 7.3, and then perform the cycle test with discharge-rich profile at 45 °C for one time. The lowest voltage achieved during this test shall be the switching voltage from discharge-rich profile to charge-rich profile. If the achieved lowest voltage is lower than the manufacturer's specified lower limit voltage, the latter shall be the switching voltage. The manufacturer's recommended SOC of cell may be used additionally.

b) Switching voltage from charge-rich profile to discharge-rich profile

Adjust the SOC of cell to 80 % according to 7.3, and then perform the cycle test with charge-rich profile at 45 °C for one time. The highest voltage achieved during this test shall be the switching voltage from charge-rich profile to discharge-rich profile. If the achieved highest voltage is higher than the manufacturer's specified upper limit voltage, the latter shall be used as switching voltage. The manufacturer's recommended SOC of cell may be used additionally.

7.7.2.3 Charge and discharge cycle

The charge and discharge cycle test shall be performed as follows.

a) Temperature

The ambient temperature shall be maintained at 45 °C ± 2 K in accordance with 4.4 during the test. At the start of charge and discharge cycle, cell temperature shall be 45 °C ± 2 K in accordance with 4.2.4.

b) Adjustment of SOC before charge and discharge cycle

The cells shall be left at a temperature of 45 °C ± 2 K, and be adjusted to 80 % SOC or the SOC agreed between the manufacturer and the customer within an interval of 16 h to 24 h, in accordance with 7.3. If 80 % SOC is not used, the used SOC shall be reported.

c) Charge and discharge cycle

The procedure from step 1 to step 4 shall be continuously repeated until the test termination specified in 7.7.2.3 e). During the test, the performance of the cell shall be measured periodically as specified in 7.7.2.3 d).

If the temperature of cell reaches the upper limit specified by the manufacturer during the test, the duration of charge/discharge step 16 in Table 5 and Table 6 can be extended to an appropriate duration time. The actual duration time shall be reported.

Step 1 - Charge and discharge cycle shall be carried out repeatedly through the discharge-rich profile given by Table 5 and Figure 6 until the cell voltage reaches to the switching voltage set in 7.7.2.2 a) (see Figure 8).

Step 2 - Charge and discharge cycle shall be carried out repeatedly through the charge-rich profile given by Table 6 and Figure 7 until the cell voltage reaches to the switching voltage set in 7.7.2.2 b) (see Figure 8).

Step 3 - Repeat step 1 and step 2 for 22 h.

Step 4 - Rest the cell for 2 h.

Table 5 – Discharge-rich profile for HEV cycle test

Charge/discharge step	Duration s	Current I_t A	Charge/discharge
1	5	20	Discharge
2	10	10	Discharge
3	32	5	Discharge
4	20	0	-
5	5	–15	Charge
6	10	–10	Charge
7	37	–5	Charge
8	20	0	-
9	5	15	Discharge
10	10	10	Discharge
11	37	5	Discharge
12	20	0	-
13	5	–12,5	Charge
14	7	–7,5	Charge
15	35	–5	Charge
16	42	0	-

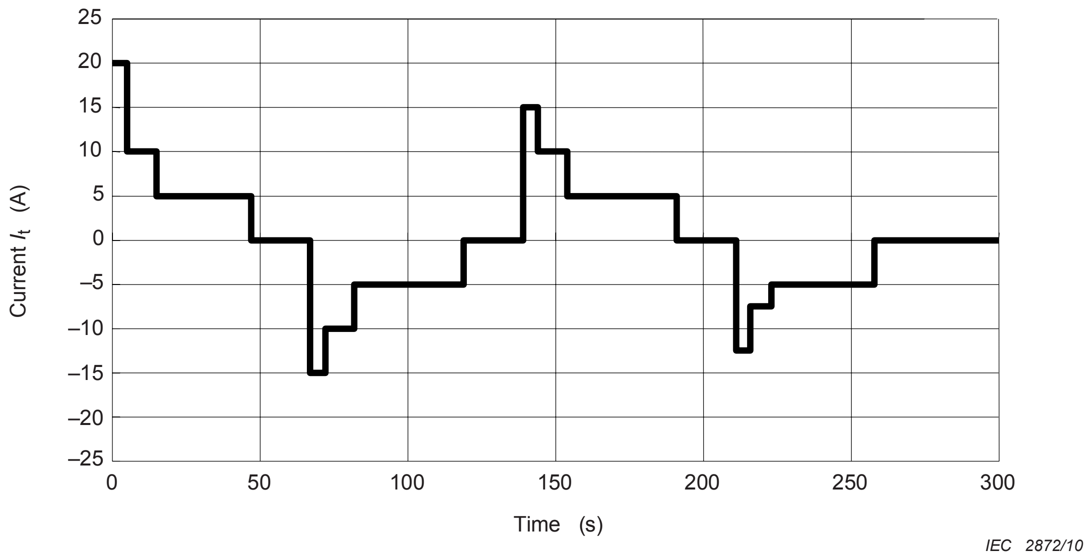


Figure 6 – Discharge-rich profile for HEV cycle test

If the maximum current specified by the manufacturer is below 20 I_t, the manufacturer's specified maximum current may by used at charge/discharge step 1, along with replacing the current at charge/discharge step 6 with 1/2 of the manufacturer's specified maximum current.

Table 6 – Charge-rich profile for HEV cycle test

Charge/discharge step	Duration s	Current I_t A	Charge/discharge
1	5	–15	Charge
2	10	–10	Charge
3	37	–5	Charge
4	20	0	-
5	5	20	Discharge
6	10	10	Discharge
7	32	5	Discharge
8	20	0	-
9	5	–12,5	Charge
10	7	–7,5	Charge
11	49	-5	Charge
12	20	0	-
13	5	15	Discharge
14	10	10	Discharge
15	23	5	Discharge
16	42	0	-

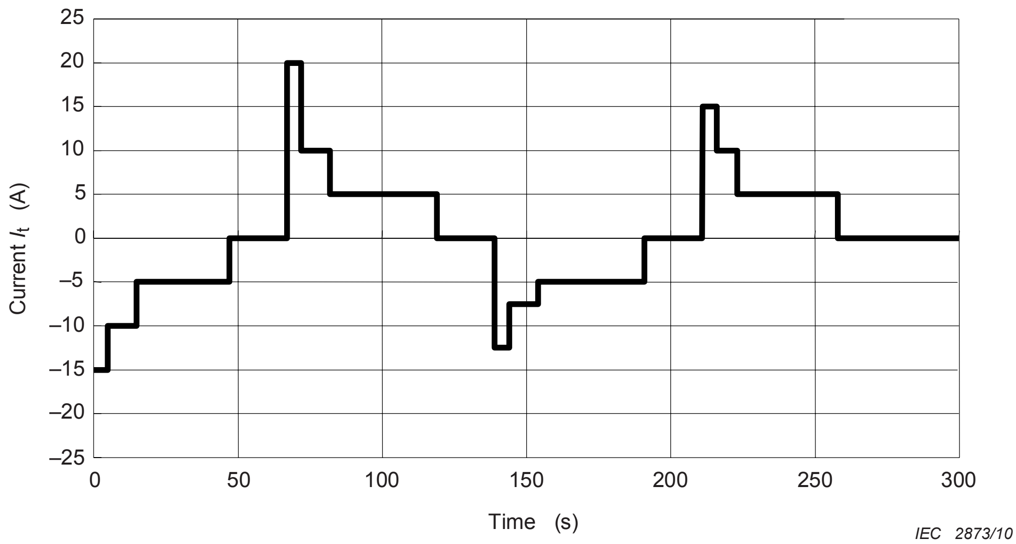


Figure 7 – Charge-rich profile for HEV cycle test

If the maximum current specified by the manufacturer is below 20 I_t, the manufacturer's specified maximum current may by used at charge/discharge step 5, along with replacing the current at charge/discharge step 2 with 1/2 of the manufacturer's specified maximum current.

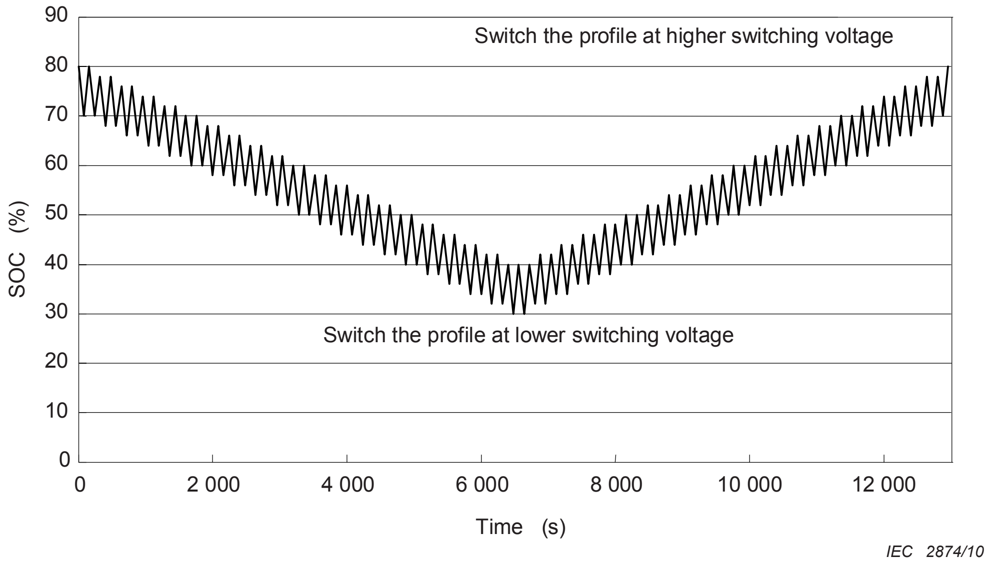


Figure 8 – Typical SOC swing by combination of two profiles for HEV cycle test

d) Periodical measurement of performance

After every completion of the procedure from step 1 to step 4 for 7 days, the power of cell shall be measured as specified in 7.7.2.1. The capacity of cell shall be measured every 14 days as specified in 7.7.2.1.

e) Termination of test

The cycle life test shall be terminated when either of the following conditions is satisfied. Otherwise back to 7.7.2.3 a) and repeat the test.

Condition A – The test in 7.7.2.3 c) is repeated for a total of 6 months.

Condition B – When either of the performance measured in 7.7.2.3 d) is decreased to less than 80 % of the initial value.

The number of times of each profile implementation and that the switching voltages are reached shall be reported.

7.8 Energy efficiency test

Energy efficiency of cells shall be determined by two common tests as specified in 7.8.1 and either of tests described in 7.8.2 and 7.8.3.

7.8.1 Common tests

7.8.1.1 Test for normal conditions

This test is applicable to cells used in HEVs and BEVs. The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.
b) Discharge the cell by the method specified in 7.2 at room temperature.
c) Energy efficiency test at 100 % SOC:
   1) leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.2 at room temperature.

d) Energy efficiency test at 70 % SOC:

1) leave the cell at rest for 4 h, and then charge it to 70 % SOC by the method recommended by the manufacturer;

2) leave the cell at rest for 4 h, and then discharge it by the method specified in 7.2 at room temperature.

e) Calculation of the discharge electric quantity and charge electric quantity

The electric quantity during the discharge and charge can be calculated using the following method: read the discharge and charge currents *I* at intervals of *s* seconds ($s \leq 30$) from the start of the discharge; then, calculate the discharge electric quantity Q_d and charge electric quantity Q_c using equation (13).

$$Q = \frac{I_1 + I_2 + \cdots + I_n}{\frac{3600}{s}} \quad (13)$$

where

Q is discharge electric quantity or charge electric quantity (Ah);

I_n is discharge current value or charge current value at n point of measured intervals (A).

f) Calculation of the discharge electric energy and charge electric energy.

The electric energy during the discharge and charge can be calculated using the following method: read the discharge currents *I* and the discharge voltages *V* at intervals of *s* seconds ($s \leq 30$) from the start of discharge; then, calculate the discharge electric energy and charge electric energy using equation (14).

$$W = \frac{I_1U_1 + I_2U_2 + \cdots + I_nU_n}{\frac{3600}{s}} \quad (14)$$

where

W is discharge electric energy or charge electric energy (Wh);

I_n is charge current value or discharge current value at n point of measured intervals (A);

U_n is discharge voltage value at n point of measured intervals (V).

g) Calculation of energy efficiency

Determine the coulomb efficiency using equation (15) and the energy efficiency using equation (16).

$$\eta_c = \frac{Q_d}{Q_c} 100 \quad (15)$$

where

η_c is coulomb efficiency (%);

Q_d is discharge electric quantities in 7.8.1 (Ah);

Q_c is charge electric quantities in 7.8.1 (Ah).

$$\eta_e = \frac{W_d}{W_c} 100 \tag{16}$$

where

η_e is energy efficiency (%);

W_d is discharge electric energies in 7.8.1 (Wh);

W_C is charge electric energies in 7.8.1 (Wh).

NOTE Values provided by measurement devices may be used, if sufficient accuracy can be achieved.

7.8.1.2 Test by temperature

This test is applicable to cells used in HEVs and BEVs. The test shall be carried out in accordance with the following procedure.

The test shall be carried out at the test temperatures of –20 °C ± 2 K, 0 °C ± 2 K, and 45 °C ± 2 K.

a) Full charge at room temperature.
b) Thermal equilibration of the cell at the test temperature, and start testing after a minimum of 16 h and a maximum 24 h.
c) Discharge the cell by the method specified in 7.2 at each test temperature.
d) Energy efficiency test at 100 % SOC:
    1) at each test temperature, leave the cell at rest for 4 h, and then charge it to 100 % SOC by the method recommended by the manufacturer;
    2) leave the battery at rest for 4 h, and then discharge it by the method specified in 7.2.
e) Calculate discharge electric quantity and charge electric quantity using equation (13).
f) Calculate discharge electric energy and charge electric energy using equation (14).
g) Calculate coulomb efficiency and energy efficiency using equation (15) and equation (16).

NOTE The charge/discharge limits at low temperature specified by the manufacturer should be taken into account.

7.8.2 Test for cells of BEV application

This test is applicable to cells used in BEVs, and intended to determine the energy efficiency of cells under fast charging conditions. The test shall be carried out in accordance with the following procedure.

a) The cell shall be left at rest at room temperature for a minimum of 1 h and a maximum of 4 h after full charge. The test shall then be commenced.
b) Discharge the cell by the method specified in 7.2.
c) Energy efficiency test at 80 % SOC:
    1) leave the cell at rest for 4 h, and then charge it to 80 % SOC at 2 I_t. If the voltage reached the upper limit voltage specified by the manufacturer, charging shall be terminated;

NOTE Selective test conditions are shown in Table A.4 in Annex A.

    2) leave the cell at rest for more than 4 h until the cell has attained the test temperature, and then discharge it by the method specified in 7.2.
d) Calculate discharge electric quantity and charge electric quantity using equation (13).
e) Calculate discharge electric energy and charge electric energy using equation (14).
f) Calculation of energy efficiency.

Determine the Coulomb efficiency using equation (17) and the energy efficiency using equation (18).

$$\eta_{c1} = \frac{Q_{d1}}{Q_{c1}} 100 \tag{17}$$

where

η_{c1} is coulomb efficiency (%);

Q_{d1} is discharge electric quantities in 7.8.2 (Ah);

Q_{c1} is charge electric quantities in 7.8.2 (Ah).

$$\eta_{e1} = \frac{W_{d1}}{W_{c1}} 100 \tag{18}$$

where

η_{e1} is energy efficiency (%);

W_{d1} is discharge electric energies in 7.8.2 (Wh);

W_{c1} is charge electric energies in 7.8.2(Wh).

7.8.3 Energy efficiency calculation for cells of HEV application

This paragraph is applicable to cells used in HEVs.

a) Calculation of the charge electric energy and discharge electric energy.

Calculate the charge and discharge electric energy from the results of the test specified in 7.4 using equation (19) and equation (20). Round off the resulting values to three significant figures.

Read current values and voltage values at regular intervals from the current and voltage data collected during the charge and discharge cycles, which correspond to the charge and discharge patterns of duration 10 I_t × 10 s. Use the standard measurement interval of 1 s. When the battery voltage after 10 s exceeds the discharge lower limit voltage or the charge upper limit voltage, perform the test using the current value in the lower stage of Table 1, and report the current value that was actually observed.

$$W_{C2} = \frac{I_{C1}U_{C1} + I_{C2}U_{C2} + \cdot\ \cdot\ \cdot + I_{Cn}U_{Cn}}{3\,600} \tag{19}$$

where

W_{C2} is charge electric energy (Wh);

I_{cn} is charge current value at n point of measured intervals (A);

U_{cn} is charge voltage value at n point of measured intervals (V).

$$W_{d2} = \frac{I_{d1}U_{d1} + I_{d2}U_{d2} + \cdots + I_{dn}U_{dn}}{3\,600} \tag{20}$$

where

W_{d2} is discharge electric energy (Wh);

I_{dn} is discharge current value at n point of measured intervals (A);

U_{dn} is discharge voltage value at n point of measured intervals (V).

b) Calculation of energy efficiency

Determine the energy efficiency using equation (21).

$$\eta_{e2} = \frac{W_{d2}}{W_{c2}} 100 \qquad (21)$$

where

η_{e2} is energy efficiency (%);

W_{d2} is discharge electric energy (Wh);

W_{C2} is charge electric energy (Wh).

Annex A
(informative)

Selective test conditions

This annex provides additional and selective conditions for the capacity test specified in 7.2, the power tests in 7.4, the cycle life test in 7.7, and energy efficiency test in 7.8.2. The test conditions "r" are specified in this standard. In addition, the test conditions "a" as shown in Table A.1, Table A.2, Table A.3 and Table A.4 may be selected based on the agreement between the manufacturer and the customer.

Table A.1 – Capacity test conditions

		–20 °C	0 °C	25 °C	45 °C
BEV application	0,2 I_t	a	a	a	a
	1/3 I_t	a	r	r	r
	1 I_t	a	a	a	a
	5 I_t	a	a	a	a
HEV application	0,2 I_t	a	a	a	a
	1/3 I_t	a	a	a	a
	1 I_t	a	r	r	r
	10 I_t	a	a	a	a
	I_{dmax}	a	a	a	a

If the data deviation is larger than that of 1 I_t and 1/3 I_t, it shall be indicated.

Table A.2 – Power test conditions

		–20 °C	0 °C	25 °C	40 °C
BEV application	20% SOC	a	a	r	a
	50% SOC	r	r	r	r
	80% SOC	a	a	r	a
HEV application	20% SOC	a	a	r	a
	50% SOC	r	r	r	r
	80% SOC	a	a	r	a

Table A.3 – Cycle life test conditions

	25 °C	45 °C
BEV application	a	r
HEV application	a	r

Table A.4 – Conditions for energy efficiency test for BEV application

SOC	Charge Current	
80 %	2 I_t	r
Manufacturer's recommended SOC	Manufacturer's recommended current	a

Annex B
(informative)

Cycle life test sequence

This annex provides the test sequences of cycle life tests specified in 7.7. The test sequence and concept of BEV cycle are shown in Figure B.1 and Figure B.2. The test sequence of HEV cycle test is shown in Table B.1.

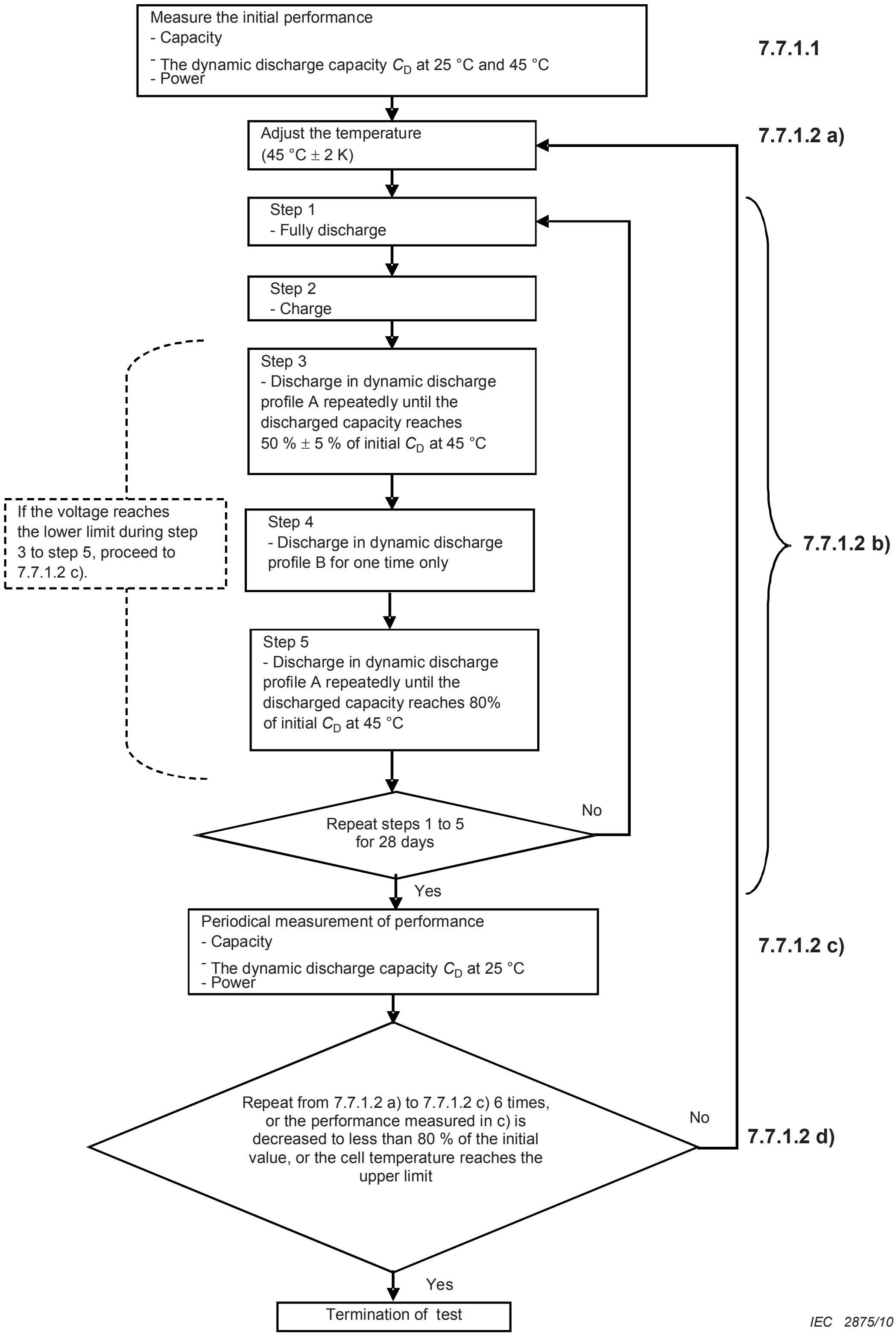


Figure B.1 – Test sequence of BEV cycle test

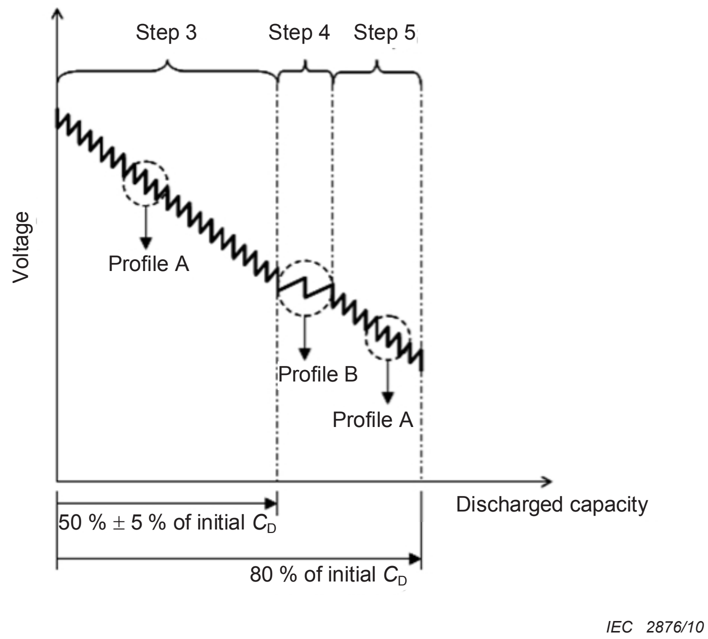


Figure B.2 – Concept of BEV cycle test

Table B.1 – Test sequence of HEV cycle test

		Test procedure	Temperature
7.7.2.1		Measure the initial performance - Capacity - Power	Room temperature
7.7.2.2 a)		Set the switching voltage from discharge-rich profile to charge-rich profile	45 °C ± 2 K
7.7.2.2 b)		Set the switching voltage from charge-rich profile to discharge-rich profile	
7.7.2.3 a)		Adjust the temperature to 45 °C ± 2 K	45 °C ± 2 K
7.7.2.3 b)		Adjust the SOC to 80 %	
7.7.2.3 c)	**Step 1**	Repeat the cycle in discharge-rich profile until the switching voltage set in 7.7.2.2 a)	
	Step 2	Repeat the cycle in charge-rich profile until the switching voltage set in 7.7.2.2 b)	
	Step 3	Repeat step 1 and step 2 for 22 h	
	Step 4	Rest for 2 h	
		Repeat the procedure from step 1 to step 4.	
7.7.2.3 d)		Periodical measurement of performance - Capacity (every 14 days) - Power (every 7 days)	Room temperature
7.7.2.3 e)		Terminate the test when either of the following conditions is satisfied. If not satisfied, back to 7.7.2.3 a). - Repeat 7.7.2.3 c) 6 months - Either of the performance measured in 7.7.2.3 d) is decreased to less than 80 % of the initial value.	-

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