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Electric double-layer capacitors for use in hybrid electric vehicles – Test methods for electrical characteristics

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ELECTRIC DOUBLE-LAYER CAPACITORS FOR USE IN HYBRID ELECTRIC VEHICLES – TEST METHODS FOR ELECTRICAL CHARACTERISTICS

FOREWORD

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International Standard IEC 62576 has been prepared by IEC technical committee 69: Electric road vehicles and electric industrial trucks.

This second edition cancels and replaces the first edition published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) information on applicability of this document has been added in Clause 1;
b) the definitions of some terms in Clause 3 have been improved;
c) the description of test procedures in Clause 4 has been clarified;
d) information on endurance cycling test has been added (Annex E).

The text of this International Standard is based on the following documents:

CDV	Report on voting
69/486/CDV	69/539/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The electric double-layer capacitor (EDLC capacitor) is used as an promising energy storage system for hybrid electric vehicles (HEVs). EDLC Capacitor-installed HEVs electric vehicles have begun to be are commercialized with an eye to improving fuel economy by recovering regenerative energy, and by peak power assistance during acceleration, etc. Although standards for EDLC capacitors already exists (IEC 62391 series), those for HEVs electric vehicles involve patterns of use, usage environment, and values of current that are quite different from those assumed in the existing standards. Standard evaluation and test methods will be useful for both auto manufacturers and capacitor suppliers to speed up the development and lower the costs of such EDLCs capacitors. With these points in mind, this document aims to provide basic and minimum specifications in terms of the methods for testing electrical characteristics, and to create an environment that supports the expanding market of HEVs electric vehicles and large capacity EDLCs capacitors. Additional practical test items to be standardized should be reconsidered after technology and market stabilization of EDLCs capacitors for HEVs electric vehicles. In terms of Regarding endurance, which is important in practical use, just a basic concept is set forth in the informative annexes.

ELECTRIC DOUBLE-LAYER CAPACITORS FOR USE IN HYBRID ELECTRIC VEHICLES – TEST METHODS FOR ELECTRICAL CHARACTERISTICS

1 Scope

This document describes the methods for testing electrical characteristics of electric double-layer capacitor cells (hereinafter referred to as "capacitor") used for peak power assistance in hybrid electric vehicles.

All the tests in this document are type tests.

This document can also be applicable to the capacitor used in idling reduction systems (start and-stop systems) for the vehicles.

This document can also be applicable to the capacitor modules consisting of more than one cell.

NOTE Annex E provides information on endurance cycling test.

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 60068-1:1988, *Environmental testing – Part 1: General and guidance*~~
~~Amendment 1(1992)~~

There are no normative references in this document.

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 http://www.iso.org/obp

~~**3.1**~~
~~**reference temperature**~~
~~reference temperature (°C) to be used in the test~~

3.1
ambient temperature
~~ambient~~ temperature of the air~~ surrounding space~~ in~~ which a~~ the immediate vicinity of a capacitor~~ is placed~~

3.2
applied voltage
voltage (V) applied between the terminals of a capacitor

3.3
calculation end voltage
voltage (V) at a selected end point for calculating the characteristics including capacitance under a state of voltage decrease during discharge

~~**3.4**~~
~~**lower category temperature**~~
~~lowest ambient temperature that a capacitor is designed to operate continuously~~

3.4
calculation start voltage
voltage (V) at a selected start point for calculating the characteristics including capacitance under a state of voltage decrease during discharge

3.5
capacitance
ability of a capacitor to store electrical charge (F)

3.6
charge accumulated electrical energy
amount of charged energy (J) accumulated from the beginning to the end of charging

3.7
charge current
I_c
current (A) required to charge a capacitor

3.8
charging efficiency
efficiency under specified charging conditions, and ratio (%) of stored energy to charge accumulated electrical energy

Note 1 to entry: This value is calculated from the internal resistance of a capacitor.

Note 2 to entry: Refer to Formula C.8.

3.9
constant voltage charging
~~method of charging a capacitor at specified voltage continuously~~ charging during which the voltage is maintained at a constant value regardless of charge current or temperature

3.10
discharge accumulated electrical energy
amount of discharged energy (J) accumulated from the beginning to the end of discharging

3.11
discharge current
I_d
current (A) required to discharge a capacitor

3.12
discharging efficiency
efficiency under specified discharging conditions, and ratio (%) of discharge accumulated electrical energy to stored energy

Note 1 to entry: This value is calculated from the internal resistance of a capacitor.

Note 2 to entry: Refer to Formula C.10.

3.13
electric double-layer capacitor
capacitor
device that stores electrical energy using a double layer in an electrochemical cell, and whose positive and negative electrodes are of the same material

Note 1 to entry: The electrolytic capacitor is not included in capacitor of this document.

3.14
energy efficiency
E_f
ratio (%) of discharge accumulated electrical energy to charge accumulated electrical energy under specified charging and discharging conditions

~~**3.15**~~
~~**nominal capacitance**~~
~~C_N~~
~~nominal capacitance value (C_N) to be used in design and measurement condition setting (*F*), generally, at the reference temperature~~

3.15
internal resistance
combined resistance (Ω) of constituent material specific resistance and inside connection resistance of a capacitor

3.16
maximum power density
P_{dm}
~~maximum power density (W/kg or W/l) that can be recovered from a charged capacitor. Generally, it is calculated by using the internal resistance and the rated voltage~~ greatest electrical power output of a capacitor per mass (W/kg) or volume (W/l)

3.17
nominal internal resistance
R_N
nominal value of the internal resistance (R_N) to be used in design and measurement condition setting (Ω), generally at the ambient temperature

3.18
post-treatment ~~**(recovery)**~~
discharging and storage of a capacitor under specified ambient conditions (temperature, humidity, and pressure) after tests

Note 1 to entry: Generally, post-treatment implies that a capacitor is discharged and stored until its inner temperature attains thermal equilibrium with the surrounding temperature before its electrical characteristics are measured.

3.19
pre-conditioning
charging and discharging and storage of a capacitor under specified ambient conditions (temperature, humidity, and pressure) before testing.

Note 1 to entry: Generally, pre-conditioning implies that a capacitor is discharged and stored until its inner temperature attains thermal equilibrium with the surrounding temperature, before its electrical characteristics are measured.

~~**3.20**~~
~~**voltage treatment**~~
~~voltage application before measurement of a capacitor's electrical characteristics~~

~~NOTE Generally, this treatment is applied to a capacitor that has been stored for a long time or to a capacitor whose history is not clear.~~

3.20
rated voltage
U_R
maximum DC voltage (V) that may be applied continuously for a certain time under the upper category temperature to a capacitor so that a capacitor can exhibit specified demand characteristics

Note 1 to entry: This voltage is the setting voltage in capacitor design.

Note 2 to entry: The endurance test using the rated voltage is described in Annex A.

3.21
ambient temperature
temperature of air in the vicinity of the device under test, in this document (25 ± 2) °C

3.22
stored energy
energy (J) stored in a capacitor

3.23
upper category temperature
highest ambient temperature ~~that~~ at which a capacitor is designed to operate continuously

3.24
voltage maintenance characteristics
~~voltage maintenance characteristics of a capacitor when its terminals are open after charging~~
ability of a capacitor to maintain the voltage, with its terminals open, after a specified time period subsequent to the charging

3.25
voltage maintenance rate
ratio of voltage maintenance
ratio of the voltage at the open-ended terminals to the charge voltage after a specified time period subsequent to the charging of a capacitor

~~**3.27**~~
~~**power density**~~
~~electrical power per unit mass (W/kg) or per unit volume (W/l) that can be recovered from a charged capacitor~~

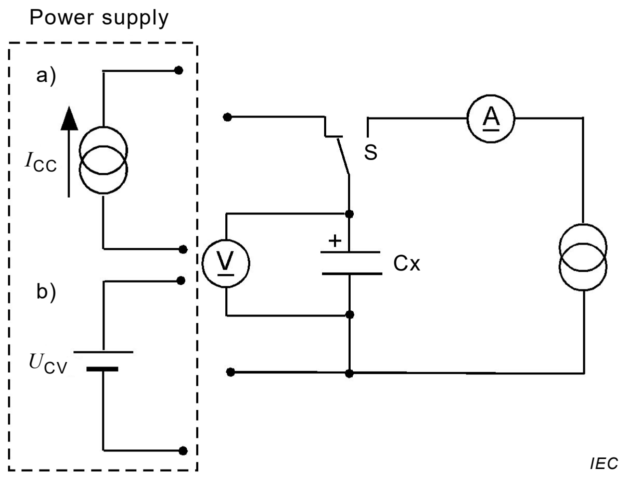
~~**3.28**~~
~~**rated power density**~~
~~specified maximum power density (W/kg or W/l). Generally, it is calculated by using the nominal internal resistance and the rated voltage~~

4 Tests ~~and measurement procedures~~ methods

4.1 Capacitance, internal resistance, and maximum power density

4.1.1 Circuit for measurement

The capacitance and the internal resistance shall be measured by using the constant current and constant voltage charging and the constant current discharging ~~methods~~. Figure 1 shows the basic circuit to be used for the measurement.



Key

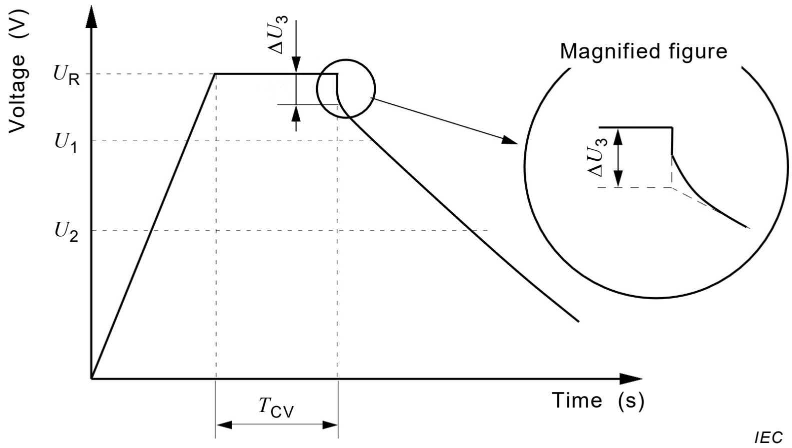
I_{CC}	constant-current
U_{CV}	constant-voltage
(A)	DC ammeter
(V)	DC voltage recorder
S	changeover switch
Cx	capacitor under test
(constant current discharger symbol)	constant current discharger
a)	constant current charging
b)	constant voltage charging

Figure 1 – Basic circuit for measuring capacitance, internal resistance and maximum power density

4.1.2 Test equipment

The test equipment shall be capable of constant current charging, constant voltage charging, constant current discharging, and continuous measurement of the current and the voltage between the capacitor terminals in time-series as shown in Figure 2. The test equipment shall be able to set ~~and measure~~ the current and the voltage with the accuracy equal to ±1 % or less, and to measure the current and voltage with accuracy equal to ±0,1 %.

The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency, set the duration of constant voltage charge, and provide a discharge current corresponding to the specified discharge efficiency. The DC voltage recorder shall be capable of conducting measurements and recording with a ~~5 mV resolution and~~ sampling interval of ~~100~~ 10 ms or less.



Key

U_R rated voltage (V)

U_1 calculation start voltage (V)

U_2 calculation end voltage (V)

ΔU_3 voltage drop (V)

T_{CV} constant voltage charging duration (s)

Figure 2 – Voltage–time characteristics between capacitor terminals in capacitance and internal resistance measurement

4.1.3 Measurement procedure

Measurements shall be carried out in accordance with the following procedures using the test equipment specified in 4.1.2.

a) Pre-conditioning

Before measurement, the capacitors shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ~~reference~~ ambient temperature~~, set at 25 °C ± 2 °C, as specified in 5.2 in IEC 60068-1,~~ or that specified by the related standards.

NOTE 1 The heat equilibrium time, which provides a reference for the soaking time, is described in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up in the following manner.

1) Set the constant current I_c for charging. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance R_N. The current value is calculated by $I_c = U_R/38R_N$. The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the maximum voltage for constant current charging as the rated voltage U_R.
3) Set the duration of constant voltage charging T_{cv} to 300 s.
4) Set the constant current discharge value. This value shall allow for a 95 % discharging efficiency based on the capacitor's nominal internal resistance R_N, and is calculated by $I_d = U_R/40R_N$.

   The constant current value or the discharging efficiency may be changed according to the agreement between the customer and the supplier.
5) Set the sampling interval to ~~100~~ 10 ms or less, and set the test-equipment so as to measure the voltage drop characteristics up to 0,5 U_R.

d) Test

According to the set-up in 4.1.3 c), charge and discharge the sample in the following order, and measure the voltage between the capacitor terminals as shown in Figure 2:

– constant current charging up to U_R;
– constant voltage charging at U_R for 300 s;
– constant current discharging down to 0,4 U_R.

~~4.1.4 Measurement~~

~~After the setting as specified above, the voltage-time characteristics between capacitor terminals as shown in Figure 2 shall be measured.~~

4.1.4 Calculation method for capacitance

The capacitance C shall be calculated using Formula (1) based on the voltage-time characteristics between capacitor terminals obtained in 4.1.4.

NOTE This calculation method is called "energy conversion capacitance method".

$$C = \frac{2W}{(0{,}9U_R)^2 - (0{,}7U_R)^2} \quad (1)$$

where

C is the capacitance (F) of capacitor;

W is the measured discharged energy (J) from calculation start voltage (0,9 U_R) to calculation end voltage (0,7 U_R);

U_R is the rated voltage (V).

4.1.5 Calculation method for internal resistance

The internal resistance R shall be calculated using Formula (2) based on the voltage-time characteristics between capacitor terminals obtained in 4.1.4.

$$R = \frac{\Delta U_3}{I_d} \quad (2)$$

where

R is the internal resistance (Ω) of capacitor;

I_d is the discharge current (A);

ΔU_3 is the voltage drop (V).

To obtain ΔU_3, apply the straight-line approximation to the voltage drop characteristics from the calculation start voltage (0,9 U_R) to the calculation end voltage (0,7 U_R) by using the least squares method. Obtain the intercept (voltage value) of the straight line at the discharge start time. ΔU_3 is the difference of voltages (V) between the intercept voltage value and the set value of constant voltage charging.

NOTE This calculation method is called "least squares internal resistance method".

4.1.6 Calculation method for maximum power density

The maximum power density P_{dm} is calculated by using the internal resistance value calculated in 4.1.5 and Formula (3).

NOTE This calculation method is called "matched impedance power density method".

$$P_{dm} = \frac{0{,}25 U_R^2}{RM} \tag{3}$$

where

P_{dm} is the maximum power density of capacitor (W/kg or W/l);

U_R is the rated voltage (V);

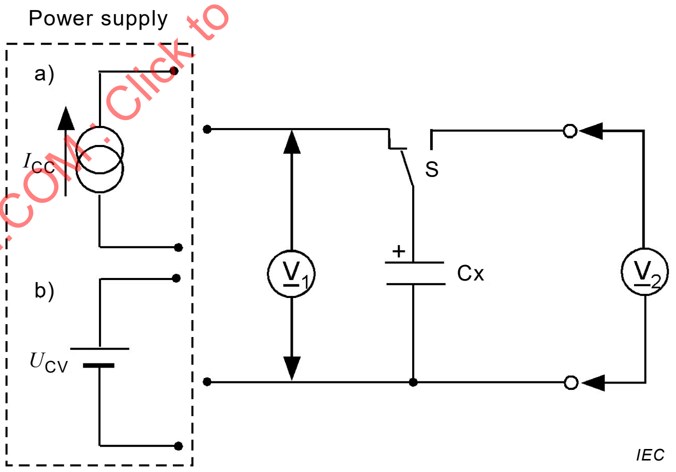
R is the calculated internal resistance (Ω);

M is the mass or volume of capacitor (kg or l).

4.2 Voltage maintenance characteristics

4.2.1 Circuit for measurement

Figure 3 shows the basic circuit for measuring the voltage maintenance characteristics.



Key

I_{CC} constant-current

U_{CV} constant-voltage

V1 V2 DC voltmeter

S changeover switch

Cx capacitor under test

a) constant current charging

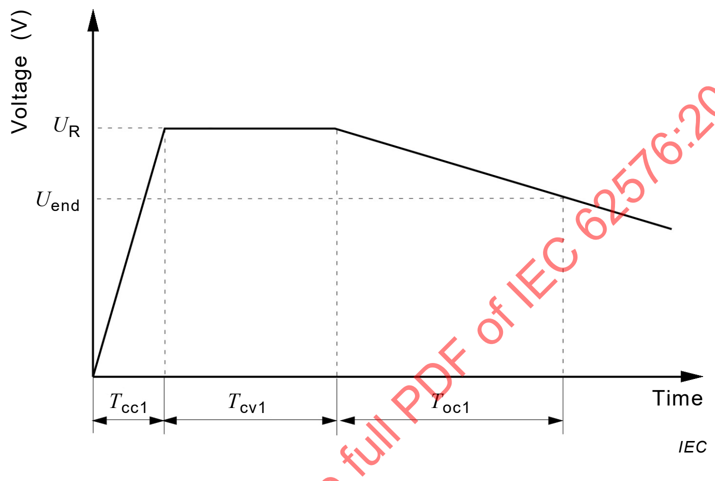
b) constant voltage charging

Figure 3 – Basic circuit for measuring the voltage maintenance characteristics

4.2.2 Test equipment

The test equipment shall be capable of constant current charging, constant voltage charging, and continuous measurement of the voltage between the capacitor terminals in time-series as shown in Figure 4. The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency and set the duration of constant voltage charging. The test equipment shall be able to set and measure the current and the voltage by the accuracy equal to ±1 % or less.

The DC voltage recorders V1 and V2 shall have a resolution of 5 mV or less for voltage measurement. The input impedance of the recorder shall be sufficiently high so that measurement errors are negligible.



Key

U_R	rated voltage (V)
T_{cc1}	charging duration with 95 % efficiency (s)
T_{cv1}	duration of constant voltage charging (s)
T_{oc1}	~~duration of measurement~~ soaking time (h)
U_{end}	voltage when T_{OC1} is 72 h (V)

Figure 4 – Time characteristics of voltage between capacitor terminals in voltage maintenance test

4.2.3 Measurement procedures

The measurements shall be carried out in accordance with the following procedures using the test equipment specified in 4.2.2.

a) Pre-conditioning

Before measurement, the capacitors shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ~~reference~~ ambient temperature~~, set at 25 °C ± 2 °C, as specified in 5.2 in IEC 60068-1,~~ or that specified by the related standards.

NOTE 1 The heat equilibrium time, which provides a reference for the soaking time, is described in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up in the following manner.

1) Set the constant current value for charging. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance. The current value is calculated by $I_c = U_R/38R_N$.

The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the maximum voltage for constant current charging to the rated voltage U_R.

3) Set the duration of constant voltage charging T_{cv1} to 300 s.

~~4) After specified charging duration, set the capacitor terminals open.~~

c) Test

1) According to the setup in 4.2.3 c), charge the sample in the following order:
   – constant current charging up to U_R;
   – constant voltage charging at U_R for 300 s.

2) Open the capacitor terminals, and after 72 h, measure the voltage between the capacitor terminals.

~~4.2.4 Measurement~~

~~After the setting as specified above, measure the voltage between capacitor terminals when T_{OC1} in Figure 4 is 72 h.~~

4.2.4 Calculation of voltage maintenance rate

The voltage maintenance rate A is calculated by Formula (4).

$$A = \frac{U_{end}}{U_R} \times 100 \tag{4}$$

where

A is the voltage maintenance rate (%);

U_{end} is the voltage between open capacitor terminals after 72 h (T_{OC1}) has elapsed;

U_R is the rated voltage (V).

4.3 Energy efficiency

4.3.1 Circuit for test

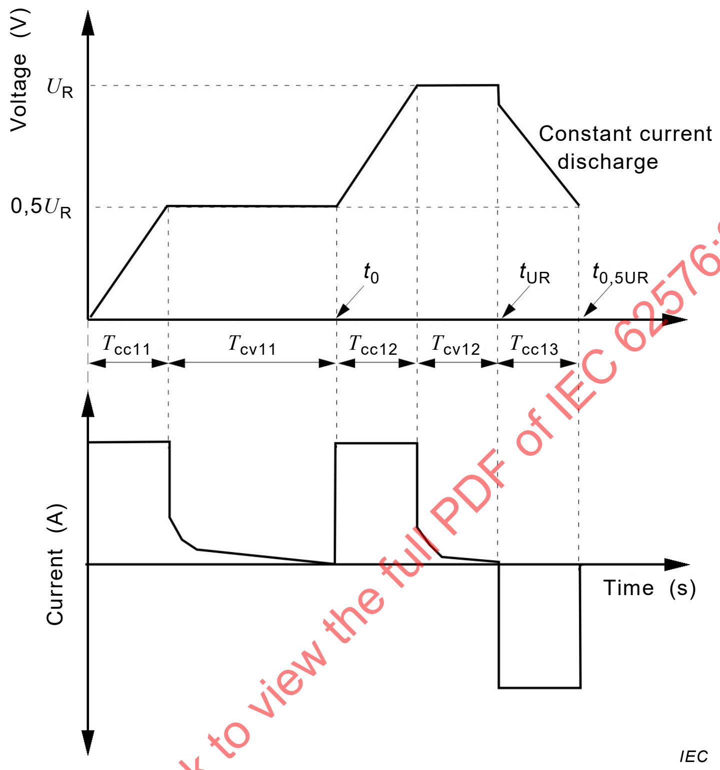
The energy efficiency test shall be conducted by the constant current charging and discharging. Figure 1 shows the basic circuit required for this test.

4.3.2 Test equipment

~~The test equipment shall be as specified in 4.1.2.~~

The test equipment shall be capable of constant current charging, constant voltage charging, constant current discharging, and continuous measurement of the current and the voltage between the capacitor terminals in time-series as shown in Figure 5. The test equipment shall be able to set and measure the current and the voltage ~~by the~~ with an accuracy equal to ±1 % or less.

The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency, set the duration of constant voltage charge, and provide a discharge current corresponding to the specified discharge efficiency. The DC voltage recorder shall be capable of conducting measurements and recording with a 5 mV resolution and sampling interval of 100 ms or less.



Key

U_R	rated voltage (V)
T_{CC11}	constant current charging duration (s) up to $0,5U_R$
T_{CV11}	constant voltage charging duration (s) ~~up to~~ at $0,5U_R$
T_{CC12}	constant current charging duration (s) up to U_R
T_{CV12}	constant voltage charging duration (s) at U_R
T_{CC13}	constant current discharging duration (s) from U_R to $0,5\ U_R$

Figure 5 – Voltage-time characteristics between capacitor terminals in charging/discharging efficiency test

4.3.3 Measurement procedures

The measurements shall be carried out in accordance with the following procedures by using the test equipment specified in 4.3.2.

a) Pre-conditioning

Before measurement, the capacitor shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ~~reference~~ ambient temperature~~, set at 25 °C ± 2 °C, as specified in 5.2 in IEC 60068-1,~~ or that specified by the related standards.

NOTE 1 The heat equilibrium time which provides a reference for the soaking time is in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up as follows.

1) Set the constant current for charging from 0 V to 0,5 U_R and from 0,5 U_R to U_R. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance R_N. The current value is calculated by $I_c = U_R/38R_N$.

   The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

   NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the duration of constant voltage charging T_{CV11} at 0,5 U_R to 300 s, and T_{cv12} at U_R to 10 s.

3) Set the constant current discharge value. This value shall allow for a 95 % discharging efficiency based on the capacitor's nominal internal resistance R_N and is calculated by $I_d = U_R/40R_N$.

   The constant current value or the discharging efficiency may be changed according to the agreement between the customer and the supplier.

   NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

4) ~~Discharging can be deemed complete when the voltage between the capacitor terminals reaches 0,5 U_R.~~

d) Test

1) According to the set-up in 4.3.3 c), charge and discharge the sample in the following order:
   – constant current charging up to 0,5 U_R;
   – constant voltage charging at 0,5 U_R for 300 s;
   – constant current charging from 0,5 U_R up to U_R;
   – constant voltage charging at U_R for 10 s;
   – constant current discharging down to 0,4 U_R.

2) Obtain the charge accumulated electrical energy during T_{CC12} and T_{CV12} and the discharge accumulated electrical energy during T_{CC13}.

~~4.3.4 Measurement~~

~~After setting up the test equipment as mentioned above, test the following: constant current charging up to 0,5 U_R, constant voltage charging at 0,5 U_R, constant current charging up to U_R, constant voltage charging at U_R, and constant current discharging down to 0,5 U_R in that order. Obtain the charge accumulated electrical energy from 0,5 U_R (during T_{CC12} and T_{CV12}) and the discharge accumulated electrical energy during discharging T_{CC13}.~~

4.3.4 Calculation of energy efficiency

The energy efficiency E_f can be obtained by Formula (5) based on the voltage-time and current-time characteristics between 0,5 U_R to U_R.

$$E_f = \frac{W_d}{W_c} \times 100 \tag{5}$$

where

E_f is the energy efficiency (%);

W_d is the discharged electrical energy (J) during T_{CC13} period;

W_c is the charged electrical energy (J) during T_{cc12} plus T_{cv12} period.

W_d can be obtained by Formula (6).

$$W_d = \int_{t_0}^{t_{0,5U_R}} I_d U(t) dt \tag{6}$$

W_c can be obtained by Formula (7).

$$W_c = \int_{t_0}^{t_{U_R}} I_c U(t) dt \tag{7}$$

Annex A
(informative)

Endurance test: continuous application of rated voltage at high temperature

A.1 General

Annex A describes the endurance test for continuous application of rated voltage at high temperature that is a factor to define the rated voltage in 3.20.

A.2 Test procedure

A.2.1 Test condition

Unless otherwise specified by related standards, the test conditions shall be as follows.

– Test temperature: upper category temperature.
– Applied voltage: rated voltage.
– Test duration: 1 000 h.

A.2.2 Test procedure

a) Pre-conditioning

Before measurement, the capacitors shall be fully discharged and then incubated for 2 h to 6 h under the ~~reference~~ ambient temperature~~, which shall be set at 25 °C ± 2 °C, as specified in 5.2 in IEC 60068-1~~.

b) Initial measurements

The capacitance and the internal resistance shall be measured according to the procedure specified in 4.1.

c) Testing

Place the capacitors in a chamber at the upper category temperature and apply the rated voltage for the specified duration. Charging up to the specified rated voltage shall be carried out by applying a current that provides 95 % charging efficiency based on the nominal internal resistance of the capacitors.

The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

d) Post-treatment (recovery)

After the test is complete, remove the capacitors from the test chamber, discharge completely and soak them ~~in~~ at the ~~reference~~ ambient temperature~~, set at 25 °C ± 2 °C, as specified in 5.2 in IEC 60068-1~~ for 2 h to 6 h.

e) Final measurement

Apart from visual inspection, the capacitance and the internal resistance of the capacitors shall be measured in accordance with the procedure of 4.1, and the rates of change from their initially measured values shall be obtained.

A.2.3 Judgment criteria

Unless otherwise specified by delivery contract between the parties, it is advisable that the capacitance change rate ΔC and internal resistance change rate ΔR shall conform with the following values.

$$\Delta C = \left| \frac{C_f - C_i}{C_i} \right| \times 100 \leq 20\%$$

where

C_i is the initial capacitance (F) before the test;

C_f is the capacitance (F) after the test.

$$\Delta R = \left| \frac{R_f - R_i}{R_i} \right| \times 100 \leq 50\%$$

where

R_i is the initial internal resistance (Ω) before the test;

R_f is the internal resistance (Ω) after the test.

Annex B
(informative)

Heat equilibrium time of capacitors

B.1 General

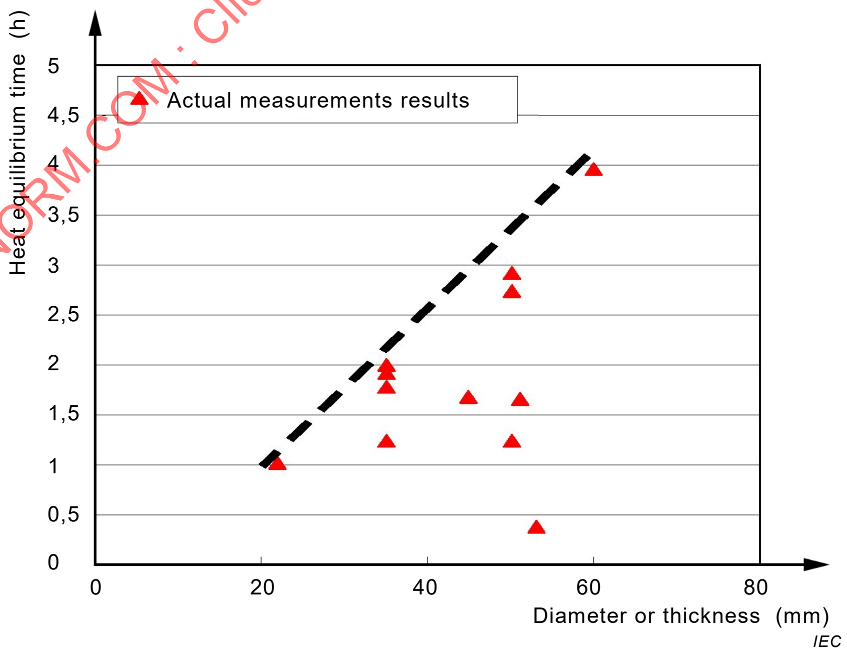
Annex B describes the heat equilibrium time of capacitors, as a reference in determining the soaking time for pre-treatment.

B.2 Heat equilibrium time of capacitors

~~Presuming that the heat equilibrium time, which is the time required for the central portion of a capacitor to reach the temperature difference from the external temperature within 1 °C, is dependent on the external dimensions of the capacitor, the temperature changes in the central portions of capacitors was verified.~~

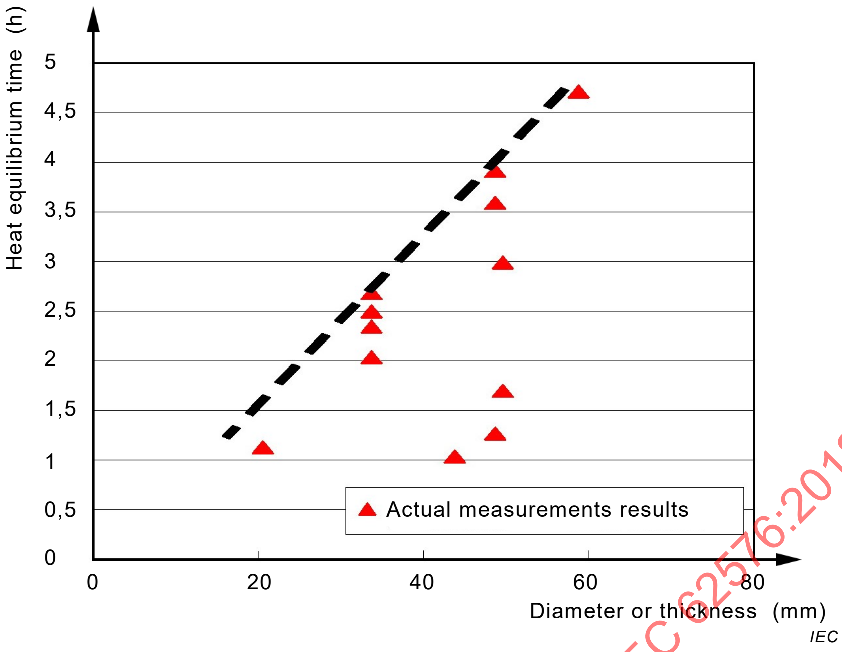
The heat equilibrium time is the time required for the central portion of a capacitor to reach the ambient temperature ±1 K. It is predicted that this time depends on the external dimensions of the capacitor.

The resultant data were obtained by verifying the heat equilibrium time of the central portions of capacitors that were subjected to a certain environmental temperature. As a result, it was observed that the equilibrium time was proportional to the magnitudes of the external dimensions such as diameter for cylindrical capacitors and thickness (thinnest side) for cubic capacitors. Figure B.1 shows the heat equilibrium times of the capacitors when soaked to normal room temperature from a high temperature. Figure B.2 shows the heat equilibrium time of the capacitors when soaked to normal room temperature from a low temperature. In these figures, the dotted straight lines indicate the presumed longest heat equilibrium time. It is advisable to use these dotted straight lines as soaking time for pre-conditioning. Figure B.3 a) and B.3 b) show the actual measured temperature changes in the capacitors' central portions.



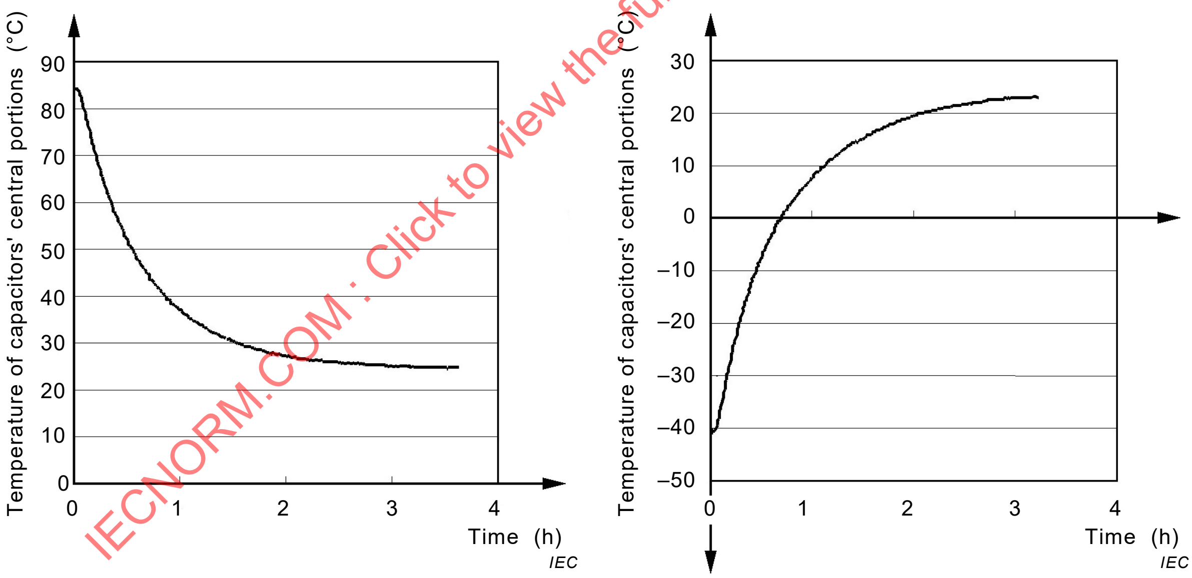
The dotted straight line indicates the presumed longest heat equilibrium time.

Figure B.1 – Heat equilibrium times of capacitors (from 85 °C→ to 25 °C)



The dotted straight line indicates the presumed longest heat equilibrium time.

Figure B.2 – Heat equilibrium times of capacitors (from −40 °C → to 25 °C)



a) Temperature changes of capacitors' central portions (from 85 °C to 25 °C)

b) Temperature changes of capacitors' central portions (from −40 °C to 25 °C)

The capacitors' dimensions are ∅51 mm × L 125 mm.

Figure B.3 – Temperature changes of capacitors' central portions

Annex C
(informative)

Charging/discharging efficiency and measurement current

C.1 General

Annex C describes the general concept regarding the charging and discharging efficiency and measured current, which are specified in 4.1.3, 4.2.3, and 4.3.3.

C.2 Charging efficiency, discharging efficiency, and current

Charge Q after charging or discharging for time t at a constant current I, stored energy W, and energy L lost by resistance R are given by Formulas (C.1), (C.2), and (C.3), respectively.

$$Q = It \tag{C.1}$$

$$W = \frac{Q^2}{2C} \tag{C.2}$$

$$L = I^2 Rt = \frac{RQ^2}{t} \tag{C.3}$$

When a capacitor is charged or discharged to its full capacity at a constant current according to Formula (C.2) or (C.3), respectively, the energy efficiency P_c for charging or P_d for discharging is given by Formula (C.4) or (C.5), respectively, where R is the internal resistance and C is the capacitance of the capacitor.

$$P_c = \frac{W}{W+L} = \frac{t}{t+2RC} \tag{C.4}$$

$$P_d = \frac{W-L}{W} = 1 - \frac{2RC}{t} \tag{C.5}$$

In this document, the efficiency for charging or discharging is proposed as 95 % after considering the exothermal effect and time consumption for the measurement. The time t required for charging at 95 % efficiency is given by Formula (C.6) derived from Formula (C.4).

$$t = 38RC \tag{C.6}$$

Charge Q stored in a capacitor is given as a product of capacity C and charging voltage U, thus leading to Formula (C.7). Current I_c for 95 % charging is given by Formula (C.8) derived from Formulas (C.1), (C.6), and (C.7).

$$Q = CU \tag{C.7}$$

$$I_c = \frac{U}{38R} \tag{C.8}$$

Similarly, the time t needed for 95 % discharging is given by Formula (C.9) derived from Formula (C.5), and the current I_d needed for 95 % discharging is given by Formula (C.10).

$$t = 40RC \tag{C.9}$$

$$I_d = \frac{U}{40R} \tag{C.10}$$

Formulas (C.8) and (C.10) are suggested for determining the value of the current for the charging or discharging test. Once the value of the charging/discharging current is determined, the maximum output at the target efficiency can be calculated.

Annex D
(informative)

Procedures for setting the measurement current of capacitor with uncertain nominal internal resistance

D.1 General

Annex D describes the current setting procedures with uncertain nominal internal resistance (see 4.1.3, 4.2.3, and 4.3.3).

D.2 Current setting procedures for measurement of capacitor

When the nominal value of internal resistance of a capacitor is uncertain, the current for the measurement of the capacitor with 95 % charging efficiency and 95 % discharging efficiency can be set according to the following procedures.

a) Using the estimated value of the internal resistance, measure the time characteristic of the voltage between the capacitor terminals according to the procedure described in 4.1.3, and then calculate the internal resistance according to the description in 4.1.5.

   ~~NOTE~~ When the internal resistance is unpredictable, it is recommended to temporarily set the charging and discharging currents as 30 A.

b) Using the internal resistance value calculated by step a) above, measure the time characteristic of the voltage between the capacitor terminals according to the procedure described in 4.1.4 and calculate the internal resistance according to the description in 4.1.6.

c) Repeat the above procedures until the difference between the calculated internal resistance value and the previous value becomes less than 10 % of the previous value.

   However, when ΔU_3 becomes greater than 0,1 U_R, follow procedures a) to c) with a smaller current and then perform the measurements. When the calculated internal resistance is a negative value, follow procedures a) to c) with a larger current and then perform the measurements.

D.3 Example of setting current for determining capacitor characteristics

Table D.1 shows examples of setting the measurement current. The setting was performed in the order of the setting conditions shown in Table D.1.

Table D.1 – Example of setting current for measurement of capacitor

Setting condition	Internal resistance value used for setting mΩ	Charging current A	Discharging current A	Calculated capacitance F	Calculated internal resistance mΩ
1	1,5 (estimated)	47,4	45,0	1 297	4,6
2	4,6 (calculated with the result of no. 1)	15,4	14,7	1 351	5,0
3	5,0 (calculated with the result of no. 2)	14,2	13,5	1 351	5,0

Annex E
(informative)

Endurance cycling test

E.1 General

The endurance cycling test for the capacitor may be carried out by the following procedure.

NOTE The purpose of the endurance cycling test is to demonstrate the performance of the capacitor under the conditions which will actually occur in service.

E.2 Test method

E.2.1 Test temperature

Test temperature is upper category temperature specified by the manufacturer. Test temperature is measured at the capacitor cell case.

E.2.2 Test equipment

The charge and discharge device is capable of charging and discharging the capacitor with the constant current as specified in E.2.3.

During the charge and discharge cycles, the voltage-time curves of all capacitor cells within the test set-up are monitored.

E.2.3 Preconditioning

The capacitor is charged up to U_R and conducts the constant voltage charging for 30 min. Then the capacitor is discharged through a suitable discharge device. The capacitor is placed in the environment at the ambient temperature for a suitable soak period for thermal equalization.

E.2.4 Initial measurements

The capacitance and internal resistance of the capacitor is measured in accordance with 4.1.

E.2.5 Test steps

Unless otherwise specified, the test consists of the following steps, repeating c) through f) continuously (See Figure E.1) until the end of test criteria is reached:

a) charge up to U_R with constant current of 5 mA/F per cell;

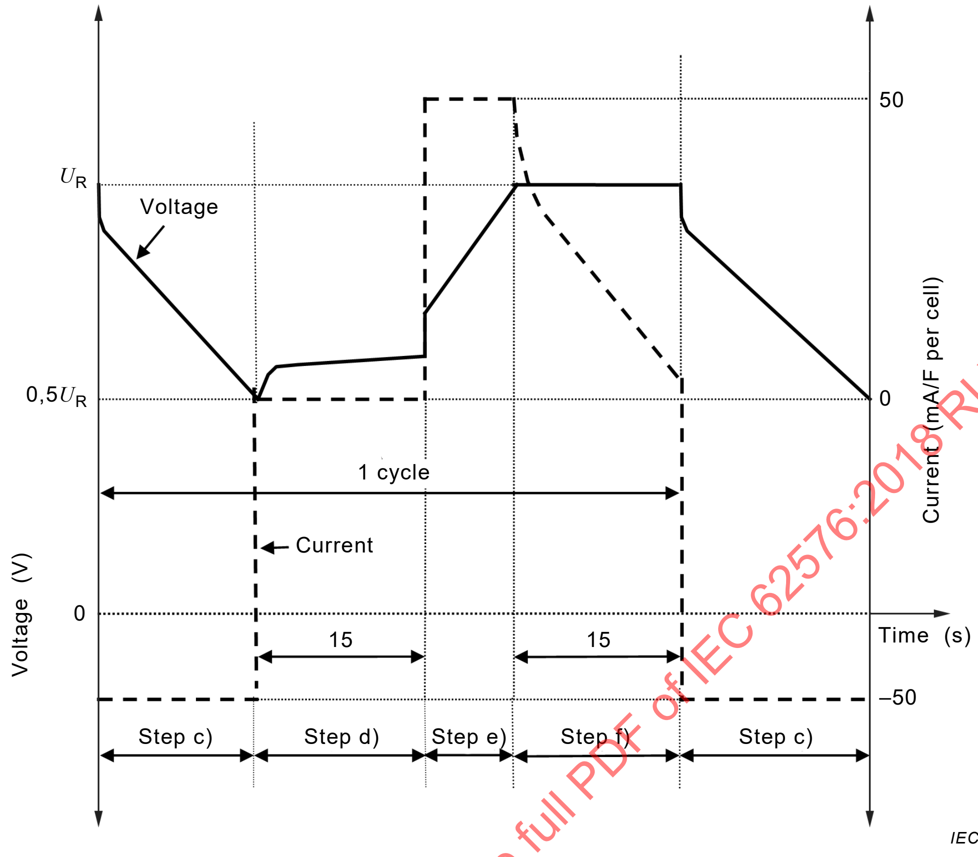
b) continue the constant voltage charging at U_R for 30 min;

c) discharge down to 0,5 U_R with constant current of 50 mA/F per cell;

d) pause for 15 s without charging current;

e) charge up to U_R with constant current of 50 mA/F per cell;

f) hold for 15 s at constant voltage U_R.



NOTE Current curve in step f) is not the specified value, but shows the result of constant voltage applied.

Figure E.1 – Endurance cycling test steps

E.2.6 Test

The capacitor is connected to the charge and discharge device, then start test steps as specified in E.2.3. When the capacitor has reached the test temperature, the cooling/heating conditions are adjusted so that stabilisation is achieved at this test temperature. After this initial stabilization no changes in cooling/heating temperature are permitted.

The capacitance and internal resistance of the capacitor can be obtained while the test step (cycling) is in operation by monitoring voltage-time curves and analysing them. The initial capacitance and internal resistance during cycling is taken after the capacitor has reached the thermal equlibrium.

NOTE The capacitance and internal resistance measurements during cycling might differ from the initial measurement as specified in E.2.4 and final measurement as specified in E.2.5 due to a different measurement current.

E.2.7 End of test criteria

The test is finished for a capacitor cell, when the measured value during cycling reaches one of the following criteria:

– capacitance reaches 80 % of its initial value; or
– internal resistance reaches 150 % of its initial value.

The test may be finished before the specified end of test criteria is achieved depending upon the agreement between manufacturer and purchaser.

E.2.8 Post-treatment

The capacitor is placed in the environment at the ambient temperature for a suitable soak period for thermal equalization (see Annex B).

E.2.9 Final measurement

The capacitance and internal resistance of the capacitor is measured in accordance with 4.1.

E.2.10 Acceptance criteria

The number of cycles reached is within the range as agreed between the manufacturer and the customer.

Unless otherwise specified, the capacitance is not less than 80 % of the initial measured value and the internal resistance does not exceed 150 % of the specified value.

No visible damage and no electrolyte leakage is observed.

Bibliography

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~~IEC 62391-1:2006, *Fixed electric double-layer capacitors for use in electronic equipment – Part 1: Generic specification* (available in English only)~~

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IEC 62576

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Electric double-layer capacitors for use in hybrid electric vehicles – Test methods for electrical characteristics

Condensateurs électriques à double couche pour véhicules électriques hybrides – Méthodes d'essai des caractéristiques électriques

IEC 62576:2018-02(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRIC DOUBLE-LAYER CAPACITORS FOR USE IN HYBRID ELECTRIC VEHICLES – TEST METHODS FOR ELECTRICAL CHARACTERISTICS

FOREWORD

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International Standard IEC 62576 has been prepared by IEC technical committee 69: Electric road vehicles and electric industrial trucks.

This second edition cancels and replaces the first edition published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) information on applicability of this document has been added in Clause 1;
b) the definitions of some terms in Clause 3 have been improved;
c) the description of test procedures in Clause 4 has been clarified;
d) information on endurance cycling test has been added (Annex E).

The text of this International Standard is based on the following documents:

CDV	Report on voting
69/486/CDV	69/539/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The electric double-layer capacitor (capacitor) is used as an energy storage system for vehicles. Capacitor-installed electric vehicles are commercialized with an eye to improving fuel economy by recovering regenerative energy, and by peak power assistance during acceleration, etc. Although standards for capacitors already exists (IEC 62391 series), those for electric vehicles involve patterns of use, usage environment, and values of current that are quite different from those assumed in the existing standards. Standard evaluation and test methods will be useful for both auto manufacturers and capacitor suppliers to speed up the development and lower the costs of such capacitors. With these points in mind, this document aims to provide basic and minimum specifications in terms of the methods for testing electrical characteristics, and to create an environment that supports the expanding market of electric vehicles and large capacity capacitors. Additional practical test items to be standardized should be reconsidered after technology and market stabilization of capacitors for electric vehicles. Regarding endurance, which is important in practical use, just a basic concept is set forth in the informative annexes.

ELECTRIC DOUBLE-LAYER CAPACITORS FOR USE IN HYBRID ELECTRIC VEHICLES – TEST METHODS FOR ELECTRICAL CHARACTERISTICS

1 Scope

This document describes the methods for testing electrical characteristics of electric double-layer capacitor cells (hereinafter referred to as "capacitor") used for peak power assistance in hybrid electric vehicles.

All the tests in this document are type tests.

This document can also be applicable to the capacitor used in idling reduction systems (start and-stop systems) for the vehicles.

This document can also be applicable to the capacitor modules consisting of more than one cell.

NOTE Annex E provides information on endurance cycling test.

2 Normative references

There are no normative references in this document.

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 http://www.iso.org/obp

3.1
ambient temperature
temperature of the air, in the immediate vicinity of a capacitor

3.2
applied voltage
voltage (V) applied between the terminals of a capacitor

3.3
calculation end voltage
voltage (V) at a selected end point for calculating the characteristics including capacitance under a state of voltage decrease during discharge

3.4
calculation start voltage
voltage (V) at a selected start point for calculating the characteristics including capacitance under a state of voltage decrease during discharge

3.5
capacitance
ability of a capacitor to store electrical charge (F)

3.6
charge accumulated electrical energy
amount of charged energy (J) accumulated from the beginning to the end of charging

3.7
charge current
I_c
current (A) required to charge a capacitor

3.8
charging efficiency
efficiency under specified charging conditions, and ratio (%) of stored energy to charge accumulated electrical energy

Note 1 to entry: This value is calculated from the internal resistance of a capacitor.

Note 2 to entry: Refer to Formula C.8.

3.9
constant voltage charging
charging during which the voltage is maintained at a constant value regardless of charge current or temperature

3.10
discharge accumulated electrical energy
amount of discharged energy (J) accumulated from the beginning to the end of discharging

3.11
discharge current
I_d
current (A) required to discharge a capacitor

3.12
discharging efficiency
efficiency under specified discharging conditions, and ratio (%) of discharge accumulated electrical energy to stored energy

Note 1 to entry: This value is calculated from the internal resistance of a capacitor.

Note 2 to entry: Refer to Formula C.10.

3.13
electric double-layer capacitor
capacitor
device that stores electrical energy using a double layer in an electrochemical cell, and whose positive and negative electrodes are of the same material

Note 1 to entry: The electrolytic capacitor is not included in capacitor of this document.

3.14
energy efficiency
E_f
ratio (%) of discharge accumulated electrical energy to charge accumulated electrical energy under specified charging and discharging conditions

3.15
internal resistance
combined resistance (Ω) of constituent material specific resistance and inside connection resistance of a capacitor

3.16
maximum power density
P_{dm}
greatest electrical power output of a capacitor per mass (W/kg) or volume (W/l)

3.17
nominal internal resistance
R_N
nominal value of the internal resistance (R_N) to be used in design and measurement condition setting (Ω), generally at the ambient temperature

3.18
post-treatment
discharging and storage of a capacitor under specified ambient conditions (temperature, humidity, and pressure) after tests

Note 1 to entry: Generally, post-treatment implies that a capacitor is discharged and stored until its inner temperature attains thermal equilibrium with the surrounding temperature before its electrical characteristics are measured.

3.19
pre-conditioning
charging and discharging and storage of a capacitor under specified ambient conditions (temperature, humidity, and pressure) before testing.

Note 1 to entry: Generally, pre-conditioning implies that a capacitor is discharged and stored until its inner temperature attains thermal equilibrium with the surrounding temperature, before its electrical characteristics are measured.

3.20
rated voltage
U_R
maximum DC voltage (V) that may be applied continuously for a certain time under the upper category temperature to a capacitor so that a capacitor can exhibit specified demand characteristics

Note 1 to entry: This voltage is the setting voltage in capacitor design.

Note 2 to entry: The endurance test using the rated voltage is described in Annex A.

3.21
ambient temperature
temperature of air in the vicinity of the device under test, in this document (25 ± 2) °C

3.22
stored energy
energy (J) stored in a capacitor

3.23
upper category temperature
highest ambient temperature at which a capacitor is designed to operate continuously

3.24
voltage maintenance characteristics
ability of a capacitor to maintain the voltage, with its terminals open, after a specified time period subsequent to the charging

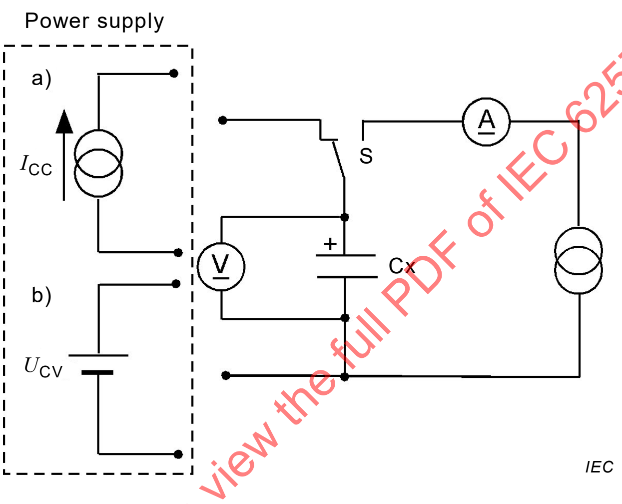
3.25
voltage maintenance rate
ratio of voltage maintenance
ratio of the voltage at the open-ended terminals to the charge voltage after a specified time period subsequent to the charging of a capacitor

4 Tests methods

4.1 Capacitance, internal resistance, and maximum power density

4.1.1 Circuit for measurement

The capacitance and the internal resistance shall be measured by using the constant current and constant voltage charging and the constant current discharging. Figure 1 shows the basic circuit to be used for the measurement.



Key

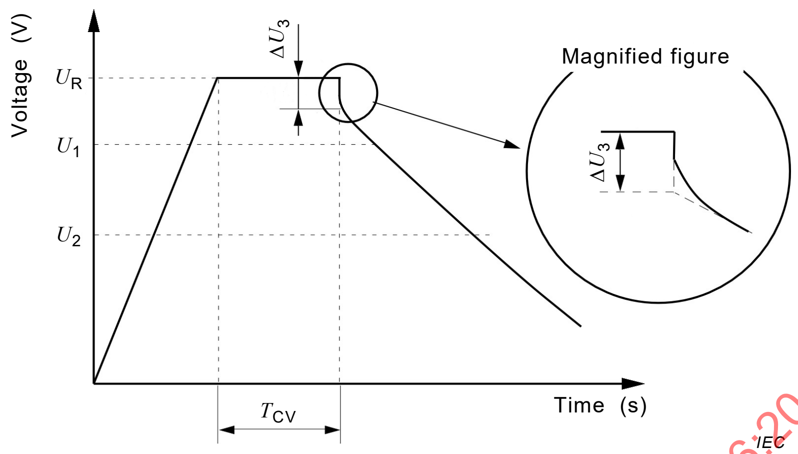
I_{CC} constant-current
U_{CV} constant-voltage
(A) DC ammeter
(V) DC voltage recorder
S changeover switch
Cx capacitor under test
(constant current discharger symbol) constant current discharger
a) constant current charging
b) constant voltage charging

Figure 1 – Basic circuit for measuring capacitance, internal resistance and maximum power density

4.1.2 Test equipment

The test equipment shall be capable of constant current charging, constant voltage charging, constant current discharging, and continuous measurement of the current and the voltage between the capacitor terminals in time-series as shown in Figure 2. The test equipment shall be able to set the current and the voltage with the accuracy equal to ±1 % or less, and to measure the current and voltage with accuracy equal to ±0,1 %.

The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency, set the duration of constant voltage charge, and provide a discharge current corresponding to the specified discharge efficiency. The DC voltage recorder shall be capable of conducting measurements and recording with a sampling interval of 10 ms or less.



Key

U_R rated voltage (V)

U_1 calculation start voltage (V)

U_2 calculation end voltage (V)

ΔU_3 voltage drop (V)

T_{CV} constant voltage charging duration (s)

Figure 2 – Voltage–time characteristics between capacitor terminals in capacitance and internal resistance measurement

4.1.3 Measurement procedure

Measurements shall be carried out in accordance with the following procedures using the test equipment specified in 4.1.2.

a) Pre-conditioning

Before measurement, the capacitors shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ambient temperature or that specified by the related standards.

NOTE 1 The heat equilibrium time, which provides a reference for the soaking time, is described in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up in the following manner.

1) Set the constant current I_c for charging. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance R_N. The current value is calculated by $I_c = U_R/38R_N$. The constant current value or the

charging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the maximum voltage for constant current charging as the rated voltage U_R.

3) Set the duration of constant voltage charging T_{cv} to 300 s.

4) Set the constant current discharge value. This value shall allow for a 95 % discharging efficiency based on the capacitor's nominal internal resistance R_N, and is calculated by $I_d = U_R/40R_N$.

   The constant current value or the discharging efficiency may be changed according to the agreement between the customer and the supplier.

5) Set the sampling interval to 10 ms or less, and set the test-equipment so as to measure the voltage drop characteristics up to 0,5 U_R.

d) Test

According to the set-up in 4.1.3 c), charge and discharge the sample in the following order, and measure the voltage between the capacitor terminals as shown in Figure 2:

– constant current charging up to U_R;
– constant voltage charging at U_R for 300 s;
– constant current discharging down to 0,4 U_R.

4.1.4 Calculation method for capacitance

The capacitance C shall be calculated using Formula (1) based on the voltage-time characteristics between capacitor terminals obtained in 4.1.4.

NOTE This calculation method is called "energy conversion capacitance method".

$$C = \frac{2W}{(0{,}9U_R)^2 - (0{,}7U_R)^2} \quad (1)$$

where

C is the capacitance (F) of capacitor;

W is the measured discharged energy (J) from calculation start voltage (0,9 U_R) to calculation end voltage (0,7 U_R);

U_R is the rated voltage (V).

4.1.5 Calculation method for internal resistance

The internal resistance R shall be calculated using Formula (2) based on the voltage-time characteristics between capacitor terminals obtained in 4.1.4.

$$R = \frac{\Delta U_3}{I_d} \tag{2}$$

where

R is the internal resistance (Ω) of capacitor;

I_d is the discharge current (A);

ΔU_3 is the voltage drop (V).

To obtain ΔU_3, apply the straight-line approximation to the voltage drop characteristics from the calculation start voltage (0,9 U_R) to the calculation end voltage (0,7 U_R) by using the least squares method. Obtain the intercept (voltage value) of the straight line at the discharge start time. ΔU_3 is the difference of voltages (V) between the intercept voltage value and the set value of constant voltage charging.

NOTE This calculation method is called "least squares internal resistance method".

4.1.6 Calculation method for maximum power density

The maximum power density P_{dm} is calculated by using the internal resistance value calculated in 4.1.5 and Formula (3).

NOTE This calculation method is called "matched impedance power density method".

$$P_{dm} = \frac{0,25 U_R^2}{RM} \tag{3}$$

where

P_{dm} is the maximum power density of capacitor (W/kg or W/l);

U_R is the rated voltage (V);

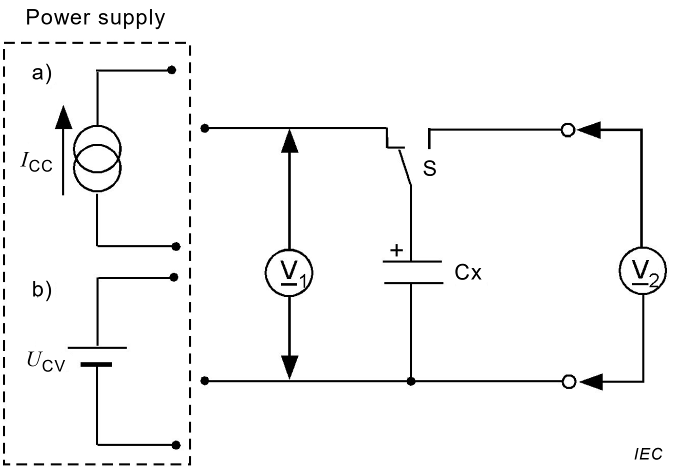
R is the calculated internal resistance (Ω);

M is the mass or volume of capacitor (kg or l).

4.2 Voltage maintenance characteristics

4.2.1 Circuit for measurement

Figure 3 shows the basic circuit for measuring the voltage maintenance characteristics.



Key

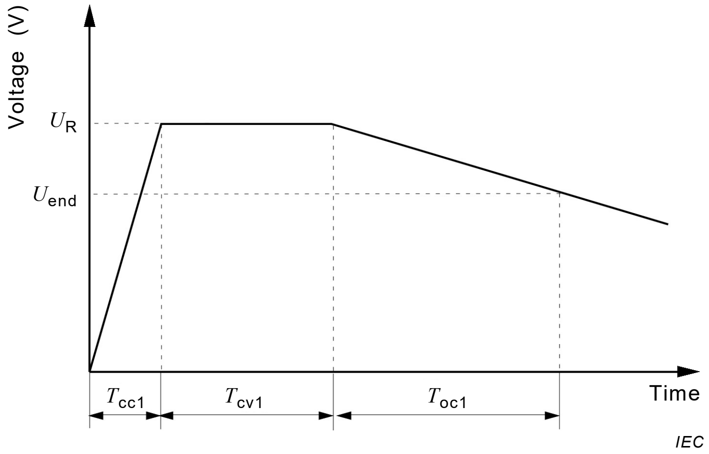
I_{CC}	constant-current
U_{CV}	constant-voltage
V1 V2	DC voltmeter
S	changeover switch
Cx	capacitor under test
a)	constant current charging
b)	constant voltage charging

Figure 3 – Basic circuit for measuring the voltage maintenance characteristics

4.2.2 Test equipment

The test equipment shall be capable of constant current charging, constant voltage charging, and continuous measurement of the voltage between the capacitor terminals in time-series as shown in Figure 4. The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency and set the duration of constant voltage charging. The test equipment shall be able to set and measure the current and the voltage by the accuracy equal to ±1 % or less.

The DC voltage recorders V1 and V2 shall have a resolution of 5 mV or less for voltage measurement. The input impedance of the recorder shall be sufficiently high so that measurement errors are negligible.



Key

U_R	rated voltage (V)
T_{cc1}	charging duration with 95 % efficiency (s)
T_{cv1}	duration of constant voltage charging (s)
T_{oc1}	soaking time (h)
U_{end}	voltage when T_{OC1} is 72 h (V)

Figure 4 – Time characteristics of voltage between capacitor terminals in voltage maintenance test

4.2.3 Measurement procedures

The measurements shall be carried out in accordance with the following procedures using the test equipment specified in 4.2.2.

a) Pre-conditioning

Before measurement, the capacitors shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ambient temperature or that specified by the related standards.

NOTE 1 The heat equilibrium time, which provides a reference for the soaking time, is described in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up in the following manner.

1) Set the constant current value for charging. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance. The current value is calculated by $I_c = U_R/38R_N$.

The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the maximum voltage for constant current charging to the rated voltage U_R.

3) Set the duration of constant voltage charging T_{cv1} to 300 s.

d) Test

1) According to the setup in 4.2.3 c), charge the sample in the following order:
   – constant current charging up to U_R;
   – constant voltage charging at U_R for 300 s.

2) Open the capacitor terminals, and after 72 h, measure the voltage between the capacitor terminals.

4.2.4 Calculation of voltage maintenance rate

The voltage maintenance rate A is calculated by Formula (4).

$$A = \frac{U_{end}}{U_R} \times 100 \qquad (4)$$

where

A is the voltage maintenance rate (%);

U_{end} is the voltage between open capacitor terminals after 72 h (T_{OC1}) has elapsed;

U_R is the rated voltage (V).

4.3 Energy efficiency

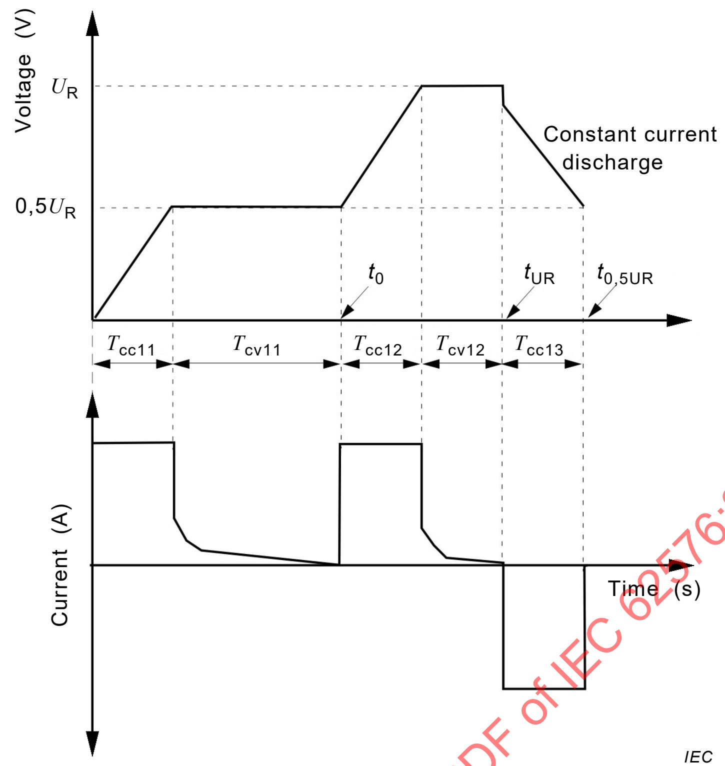
4.3.1 Circuit for test

The energy efficiency test shall be conducted by the constant current charging and discharging. Figure 1 shows the basic circuit required for this test.

4.3.2 Test equipment

The test equipment shall be capable of constant current charging, constant voltage charging, constant current discharging, and continuous measurement of the current and the voltage between the capacitor terminals in time-series as shown in Figure 5. The test equipment shall be able to set and measure the current and the voltage with an accuracy equal to ±1 % or less.

The power supply shall provide the constant charge current for the capacitor charge with 95 % efficiency, set the duration of constant voltage charge, and provide a discharge current corresponding to the specified discharge efficiency. The DC voltage recorder shall be capable of conducting measurements and recording with a 5 mV resolution and sampling interval of 100 ms or less.



Key

U_R	rated voltage (V)
T_{CC11}	constant current charging duration (s) up to 0,5U_R
T_{CV11}	constant voltage charging duration (s) at 0,5U_R
T_{CC12}	constant current charging duration (s) up to U_R
T_{CV12}	constant voltage charging duration (s) at U_R
T_{CC13}	constant current discharging duration (s) from U_R to 0,5 U_R

Figure 5 – Voltage-time characteristics between capacitor terminals in charging/discharging efficiency test

4.3.3 Measurement procedures

The measurements shall be carried out in accordance with the following procedures by using the test equipment specified in 4.3.2.

a) Pre-conditioning

Before measurement, the capacitor shall be fully charged and fully discharged, and then incubated for 2 h to 6 h under the ambient temperature or that specified by the related standards.

NOTE 1 The heat equilibrium time which provides a reference for the soaking time is in Annex B.

NOTE 2 Charging and discharging can be repeated if necessary until the capacity and internal resistance are stabilized.

EXAMPLE

Charge and discharge the sample using the current specified by the manufacturer in the following order:

1) fully discharge;
2) charge up to U_R;
3) discharge down to 0,5 U_R;
4) repeat 2) and 3) ten times.

b) Sample setting

Fit the sample capacitors with the test equipment.

c) Test equipment setup

Unless otherwise specified by related standards, the test equipment shall be set up as follows.

1) Set the constant current for charging from 0 V to 0,5 U_R and from 0,5 U_R to U_R. At this current, the capacitors shall be able to charge with 95 % charging efficiency based on their nominal internal resistance R_N. The current value is calculated by $I_c=U_R/38R_N$.

The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

2) Set the duration of constant voltage charging T_{CV11} at 0,5 U_R to 300 s, and T_{cv12} at U_R to 10 s.

3) Set the constant current discharge value. This value shall allow for a 95 % discharging efficiency based on the capacitor's nominal internal resistance R_N and is calculated by $I_d = U_R/40R_N$.

The constant current value or the discharging efficiency may be changed according to the agreement between the customer and the supplier.

NOTE The general concept for 95 % charging or discharging efficiency is described in Annex C. When the rated value of internal resistance of a capacitor is uncertain, the current for the measurement can be set according to the advisable procedures described in Annex D.

d) Test

1) According to the set-up in 4.3.3 c), charge and discharge the sample in the following order:

– constant current charging up to 0,5 U_R;

– constant voltage charging at 0,5 U_R for 300 s;

– constant current charging from 0,5 U_R up to U_R;

– constant voltage charging at U_R for 10 s;

– constant current discharging down to 0,4 U_R.

2) Obtain the charge accumulated electrical energy during T_{CC12} and T_{CV12} and the discharge accumulated electrical energy during T_{CC13}.

4.3.4 Calculation of energy efficiency

The energy efficiency E_f can be obtained by Formula (5) based on the voltage-time and current-time characteristics between 0,5 U_R to U_R.

$$E_f = \frac{W_d}{W_c} \times 100 \quad (5)$$

where

E_f is the energy efficiency (%);

W_d is the discharged electrical energy (J) during T_{CC13} period;

W_c is the charged electrical energy (J) during T_{cc12} plus T_{cv12} period.

W_d can be obtained by Formula (6).

$$W_{\mathrm{d}} = \int_{t_0}^{t_{0,5U_{\mathrm{R}}}} I_{\mathrm{d}} U(t) dt \tag{6}$$

W_{c} can be obtained by Formula (7).

$$W_{\mathrm{c}} = \int_{t_0}^{t_{U_{\mathrm{R}}}} I_{\mathrm{c}} U(t) dt \tag{7}$$

Annex A
(informative)

Endurance test: continuous application of rated voltage at high temperature

A.1 General

Annex A describes the endurance test for continuous application of rated voltage at high temperature that is a factor to define the rated voltage in 3.20.

A.2 Test procedure

A.2.1 Test condition

Unless otherwise specified by related standards, the test conditions shall be as follows.

– Test temperature: upper category temperature.
– Applied voltage: rated voltage.
– Test duration: 1 000 h.

A.2.2 Test procedure

a) Pre-conditioning

Before measurement, the capacitors shall be fully discharged and then incubated for 2 h to 6 h under the ambient temperature.

b) Initial measurements

The capacitance and the internal resistance shall be measured according to the procedure specified in 4.1.

c) Testing

Place the capacitors in a chamber at the upper category temperature and apply the rated voltage for the specified duration. Charging up to the specified rated voltage shall be carried out by applying a current that provides 95 % charging efficiency based on the nominal internal resistance of the capacitors.

The constant current value or the charging efficiency may be changed according to the agreement between the customer and the supplier.

d) Post-treatment (recovery)

After the test is complete, remove the capacitors from the test chamber, discharge completely and soak them at the ambient temperature for 2 h to 6 h.

e) Final measurement

Apart from visual inspection, the capacitance and the internal resistance of the capacitors shall be measured in accordance with the procedure of 4.1, and the rates of change from their initially measured values shall be obtained.

A.2.3 Judgment criteria

Unless otherwise specified by delivery contract between the parties, it is advisable that the capacitance change rate ΔC and internal resistance change rate ΔR shall conform with the following values.

$$\Delta C = \left| \frac{C_f - C_i}{C_i} \right| \times 100 \leq 20\,\%$$

where

C_i is the initial capacitance (F) before the test;

C_f is the capacitance (F) after the test.

$$\Delta R = \left| \frac{R_f - R_i}{R_i} \right| \times 100 \leq 50\,\%$$

where

R_i is the initial internal resistance (Ω) before the test;

R_f is the internal resistance (Ω) after the test.

Annex B
(informative)

Heat equilibrium time of capacitors

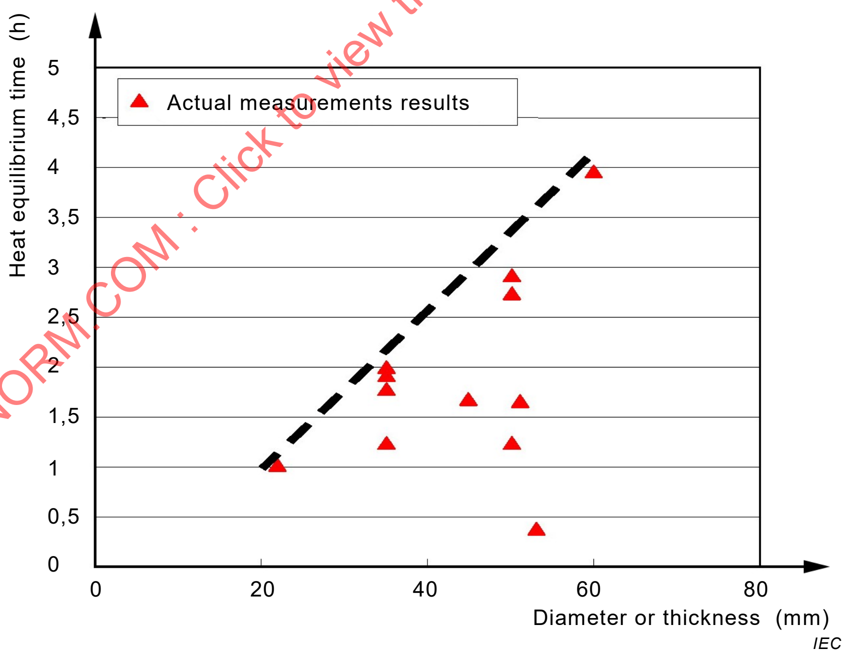
B.1 General

Annex B describes the heat equilibrium time of capacitors, as a reference in determining the soaking time for pre-treatment.

B.2 Heat equilibrium time of capacitors

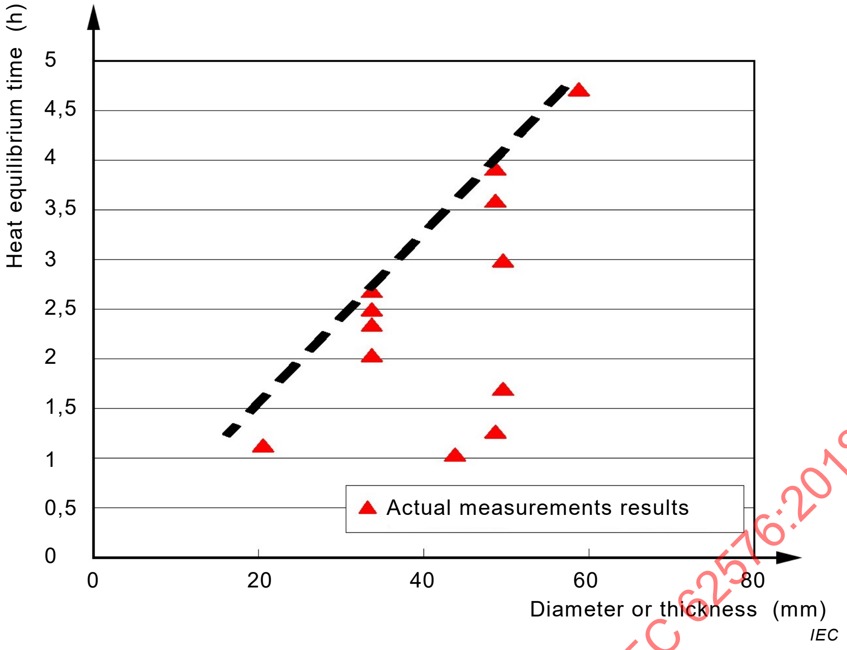
The heat equilibrium time is the time required for the central portion of a capacitor to reach the ambient temperature ±1 K. It is predicted that this time depends on the external dimensions of the capacitor.

The resultant data were obtained by verifying the heat equilibrium time of the central portions of capacitors that were subjected to a certain environmental temperature. As a result, it was observed that the equilibrium time was proportional to the magnitudes of the external dimensions such as diameter for cylindrical capacitors and thickness (thinnest side) for cubic capacitors. Figure B.1 shows the heat equilibrium times of the capacitors when soaked to normal room temperature from a high temperature. Figure B.2 shows the heat equilibrium time of the capacitors when soaked to normal room temperature from a low temperature. In these figures, the dotted straight lines indicate the presumed longest heat equilibrium time. It is advisable to use these dotted straight lines as soaking time for pre-conditioning. Figure B.3 a) and B.3 b) show the actual measured temperature changes in the capacitors' central portions.



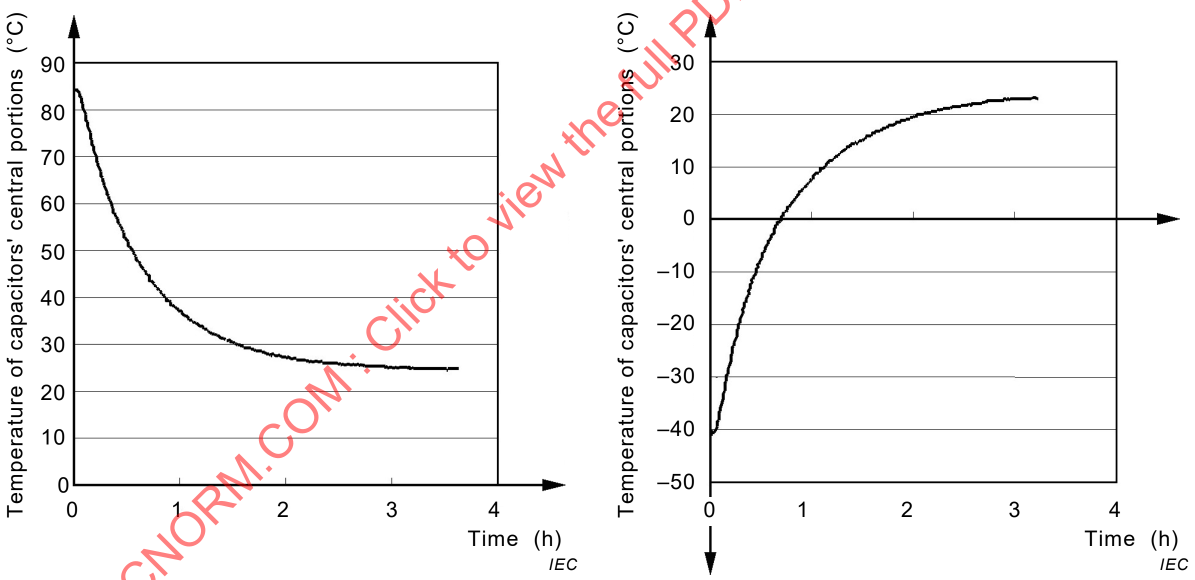
The dotted straight line indicates the presumed longest heat equilibrium time.

Figure B.1 – Heat equilibrium times of capacitors (from 85 °C to 25 °C)



The dotted straight line indicates the presumed longest heat equilibrium time.

Figure B.2 – Heat equilibrium times of capacitors (from −40 °C to 25 °C)



a) Temperature changes of capacitors' central portions (from 85 °C to 25 °C)

b) Temperature changes of capacitors' central portions (from −40 °C to 25 °C)

The capacitors' dimensions are ∅51 mm × L 125 mm.

Figure B.3 – Temperature changes of capacitors' central portions

Annex C
(informative)

Charging/discharging efficiency and measurement current

C.1 General

Annex C describes the general concept regarding the charging and discharging efficiency and measured current, which are specified in 4.1.3, 4.2.3, and 4.3.3.

C.2 Charging efficiency, discharging efficiency, and current

Charge Q after charging or discharging for time t at a constant current I, stored energy W, and energy L lost by resistance R are given by Formulas (C.1), (C.2), and (C.3), respectively.

$$Q = It \tag{C.1}$$

$$W = \frac{Q^2}{2C} \tag{C.2}$$

$$L = I^2 Rt = \frac{RQ^2}{t} \tag{C.3}$$

When a capacitor is charged or discharged to its full capacity at a constant current according to Formula (C.2) or (C.3), respectively, the energy efficiency P_c for charging or P_d for discharging is given by Formula (C.4) or (C.5), respectively, where R is the internal resistance and C is the capacitance of the capacitor.

$$P_c = \frac{W}{W + L} = \frac{t}{t + 2RC} \tag{C.4}$$

$$P_d = \frac{W - L}{W} = 1 - \frac{2RC}{t} \tag{C.5}$$

In this document, the efficiency for charging or discharging is proposed as 95 % after considering the exothermal effect and time consumption for the measurement. The time t required for charging at 95 % efficiency is given by Formula (C.6) derived from Formula (C.4).

$$t = 38RC \tag{C.6}$$

Charge Q stored in a capacitor is given as a product of capacity C and charging voltage U, thus leading to Formula (C.7). Current I_c for 95 % charging is given by Formula (C.8) derived from Formulas (C.1), (C.6), and (C.7).

$$Q = CU \tag{C.7}$$

$$I_c = \frac{U}{38R} \tag{C.8}$$

Similarly, the time t needed for 95 % discharging is given by Formula (C.9) derived from Formula (C.5), and the current I_d needed for 95 % discharging is given by Formula (C.10).

$$t = 40RC \tag{C.9}$$

$$I_d = \frac{U}{40R} \tag{C.10}$$

Formulas (C.8) and (C.10) are suggested for determining the value of the current for the charging or discharging test. Once the value of the charging/discharging current is determined, the maximum output at the target efficiency can be calculated.

Annex D
(informative)

Procedures for setting the measurement current of capacitor with uncertain nominal internal resistance

D.1 General

Annex D describes the current setting procedures with uncertain nominal internal resistance (see 4.1.3, 4.2.3, and 4.3.3).

D.2 Current setting procedures for measurement of capacitor

When the nominal value of internal resistance of a capacitor is uncertain, the current for the measurement of the capacitor with 95 % charging efficiency and 95 % discharging efficiency can be set according to the following procedures.

a) Using the estimated value of the internal resistance, measure the time characteristic of the voltage between the capacitor terminals according to the procedure described in 4.1.3, and then calculate the internal resistance according to the description in 4.1.5.

   When the internal resistance is unpredictable, it is recommended to temporarily set the charging and discharging currents as 30 A.

b) Using the internal resistance value calculated by step a) above, measure the time characteristic of the voltage between the capacitor terminals according to the procedure described in 4.1.4 and calculate the internal resistance according to the description in 4.1.6.

c) Repeat the above procedures until the difference between the calculated internal resistance value and the previous value becomes less than 10 % of the previous value.

   However, when ΔU_3 becomes greater than 0,1 U_R, follow procedures a) to c) with a smaller current and then perform the measurements. When the calculated internal resistance is a negative value, follow procedures a) to c) with a larger current and then perform the measurements.

D.3 Example of setting current for determining capacitor characteristics

Table D.1 shows examples of setting the measurement current. The setting was performed in the order of the setting conditions shown in Table D.1.

Table D.1 – Example of setting current for measurement of capacitor

Setting condition	Internal resistance value used for setting mΩ	Charging current A	Discharging current A	Calculated capacitance F	Calculated internal resistance mΩ
1	1,5 (estimated)	47,4	45,0	1 297	4,6
2	4,6 (calculated with the result of no. 1)	15,4	14,7	1 351	5,0
3	5,0 (calculated with the result of no. 2)	14,2	13,5	1 351	5,0

Annex E
(informative)

Endurance cycling test

E.1 General

The endurance cycling test for the capacitor may be carried out by the following procedure.

NOTE The purpose of the endurance cycling test is to demonstrate the performance of the capacitor under the conditions which will actually occur in service.

E.2 Test method

E.2.1 Test temperature

Test temperature is upper category temperature specified by the manufacturer. Test temperature is measured at the capacitor cell case.

E.2.2 Test equipment

The charge and discharge device is capable of charging and discharging the capacitor with the constant current as specified in E.2.3.

During the charge and discharge cycles, the voltage-time curves of all capacitor cells within the test set-up are monitored.

E.2.3 Preconditioning

The capacitor is charged up to U_R and conducts the constant voltage charging for 30 min. Then the capacitor is discharged through a suitable discharge device. The capacitor is placed in the environment at the ambient temperature for a suitable soak period for thermal equalization.

E.2.4 Initial measurements

The capacitance and internal resistance of the capacitor is measured in accordance with 4.1.

E.2.5 Test steps

Unless otherwise specified, the test consists of the following steps, repeating c) through f) continuously (See Figure E.1) until the end of test criteria is reached:

a) charge up to U_R with constant current of 5 mA/F per cell;

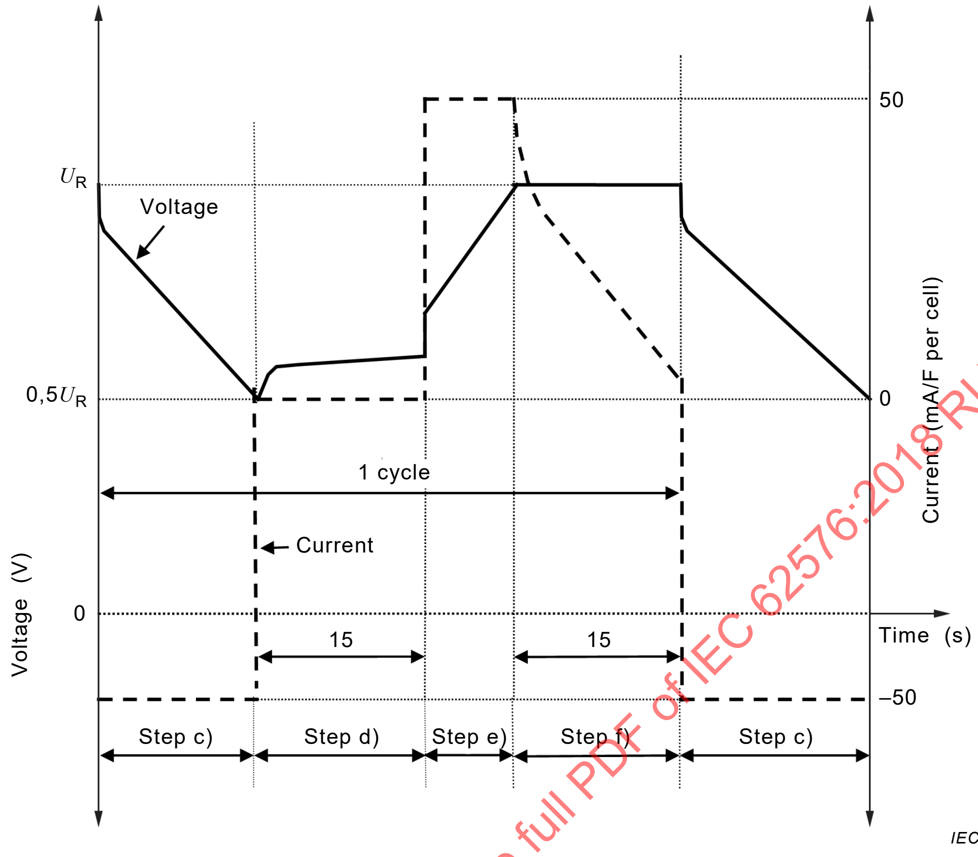
b) continue the constant voltage charging at U_R for 30 min;

c) discharge down to 0,5 U_R with constant current of 50 mA/F per cell;

d) pause for 15 s without charging current;

e) charge up to U_R with constant current of 50 mA/F per cell;

f) hold for 15 s at constant voltage U_R.



NOTE Current curve in step f) is not the specified value, but shows the result of constant voltage applied.

Figure E.1 – Endurance cycling test steps

E.2.6 Test

The capacitor is connected to the charge and discharge device, then start test steps as specified in E.2.3. When the capacitor has reached the test temperature, the cooling/heating conditions are adjusted so that stabilisation is achieved at this test temperature. After this initial stabilization no changes in cooling/heating temperature are permitted.

The capacitance and internal resistance of the capacitor can be obtained while the test step (cycling) is in operation by monitoring voltage-time curves and analysing them. The initial capacitance and internal resistance during cycling is taken after the capacitor has reached the thermal equilibrium.

NOTE The capacitance and internal resistance measurements during cycling might differ from the initial measurement as specified in E.2.4 and final measurement as specified in E.2.5 due to a different measurement current.

E.2.7 End of test criteria

The test is finished for a capacitor cell, when the measured value during cycling reaches one of the following criteria:

– capacitance reaches 80 % of its initial value; or
– internal resistance reaches 150 % of its initial value.

The test may be finished before the specified end of test criteria is achieved depending upon the agreement between manufacturer and purchaser.

E.2.8 Post-treatment

The capacitor is placed in the environment at the ambient temperature for a suitable soak period for thermal equalization (see Annex B).

E.2.9 Final measurement

The capacitance and internal resistance of the capacitor is measured in accordance with 4.1.

E.2.10 Acceptance criteria

The number of cycles reached is within the range as agreed between the manufacturer and the customer.

Unless otherwise specified, the capacitance is not less than 80 % of the initial measured value and the internal resistance does not exceed 150 % of the specified value.

No visible damage and no electrolyte leakage is observed.

Bibliography

IEC 61881-3:2012, *Railway applications – Rolling stock equipment – Capacitors for power electronics – Part 3: Electric double-layer capacitors*
IEC 61881-3:2012/AMD1:2013

IEC 62391 (all parts), *Fixed electric double layer capacitors for use in electric and electronic equipment*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CONDENSATEURS ÉLECTRIQUES À DOUBLE COUCHE POUR VÉHICULES ÉLECTRIQUES HYBRIDES – MÉTHODES D'ESSAI DES CARACTÉRISTIQUES ÉLECTRIQUES

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Cette deuxième édition annule et remplace la première édition parue en 2009. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) des informations sur le champ d'application du présent document ont été ajoutées dans l'Article 1;
b) les définitions de certains termes de l'Article 3 ont été améliorées;
c) la description des procédures d'essai de l'Article 4 a été clarifiée;

d) des informations sur l'essai cyclique d'endurance ont été ajoutées (Annexe E).

Le texte de cette Norme internationale est issu des documents suivants:

CDV	Rapport de vote
69/486/CDV	69/539/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

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INTRODUCTION

Le condensateur électrique à double couche (condensateur) est utilisé comme système de stockage d'énergie pour les véhicules. Des véhicules électriques équipés de condensateurs sont commercialisés dans le but de réduire la consommation de carburant grâce à la récupération des énergies et à l’assistance en puissance de crête lors de l’accélération, etc. Bien qu’il existe déjà des normes sur les condensateurs (série IEC 62391), celles sur les véhicules électriques mettent en œuvre des modèles d'utilisation, un environnement d'utilisation et des valeurs de courant qui sont assez différents de ceux qui sont prévus dans les normes existantes. Des méthodes d'essai et d'évaluation normalisées sont utiles tant aux constructeurs automobiles qu’aux fournisseurs de condensateurs pour accélérer le développement et la réduction des coûts de ces condensateurs. Dans cette perspective, la présente norme a pour but de fournir des spécifications minimales et de base relatives aux méthodes d’essai des caractéristiques électriques et de créer un environnement favorable au développement du marché des véhicules électriques et des condensateurs de grande capacité. Il convient de réexaminer des points d’essai pratiques complémentaires à normaliser après la stabilisation de la technologie et du marché des condensateurs pour les véhicules électriques. En ce qui concerne l’endurance, considérée comme importante dans l’utilisation pratique, seule la notion fondamentale est énoncée dans les annexes informatives.

CONDENSATEURS ÉLECTRIQUES À DOUBLE COUCHE POUR VÉHICULES ÉLECTRIQUES HYBRIDES – MÉTHODES D'ESSAI DES CARACTÉRISTIQUES ÉLECTRIQUES

1 Domaine d'application

Le présent document décrit les méthodes d'essai des caractéristiques électriques des cellules de condensateur électrique à double couche (ci-après dénommé "condensateur") utilisées pour l'assistance en puissance de crête dans les véhicules électriques hybrides.

Tous les essais décrits dans le présent document sont des essais de type.

Le présent document peut également s'appliquer aux condensateurs utilisés dans les systèmes de réduction de la marche au ralenti (systèmes de mise en veille) pour les véhicules.

Le présent document peut également s'appliquer aux modules de condensateurs constitués de plusieurs cellules.

NOTE L'Annexe E donne des informations relatives à l'essai cyclique d'endurance.

2 Références normatives

Le présent document ne contient aucune référence normative.

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
température ambiante
température de l'air dans l'environnement immédiat d'un condensateur

3.2
tension appliquée
tension (V) appliquée entre les bornes d'un condensateur

3.3
tension de fin de calcul
tension (V) à un point choisi pour la fin du calcul des caractéristiques, comprenant notamment la capacité dans des conditions d'affaiblissement de la tension pendant la décharge

3.4
tension de début de calcul
tension (V) à un point choisi pour le début du calcul des caractéristiques, comprenant notamment la capacité dans des conditions d'affaiblissement de la tension pendant la décharge

3.5
capacité
aptitude d'un condensateur à emmagasiner une charge électrique (F)

3.6
énergie électrique accumulée pendant la charge
quantité d'énergie (J) chargée, accumulée du début à la fin de la mise en charge

3.7
courant de charge
I_c
courant (A) exigé pour charger un condensateur

3.8
rendement de charge
rendement dans des conditions de charge spécifiées et rapport (en pour cent) de l'énergie emmagasinée à l'énergie accumulée pendant la charge

Note 1 à l'article: Cette valeur est calculée à partir de la résistance interne d'un condensateur.

Note 2 à l'article: Se référer à la Formule C.8.

3.9
charge à tension constante
mise en charge au cours de laquelle la tension est maintenue à une valeur constante quel(le) que soit le courant ou la température de la charge

3.10
énergie électrique accumulée pendant la décharge
quantité d'énergie (J) déchargée, accumulée du début à la fin de la décharge

3.11
courant de décharge
I_d
courant (A) exigé pour décharger un condensateur

3.12
rendement de décharge
rendement dans des conditions de décharge spécifiées et rapport (en pour cent) de l'énergie accumulée pendant la décharge à l'énergie emmagasinée

Note 1 à l'article: Cette valeur est calculée à partir de la résistance interne d'un condensateur.

Note 2 à l'article: Se référer à la Formule C.10.

3.13
condensateur électrique à double couche
condensateur
dispositif qui emmagasine de l'énergie électrique à l'aide d'une double couche dans une cellule électrochimique et dont les électrodes positive et négative sont fabriquées avec le même matériau

Note 1 à l'article: Les condensateurs traités dans le présent document ne comprennent pas les condensateurs électrolytiques.

3.14
rendement en énergie
E_f
rapport (en pour cent) de l'énergie électrique accumulée pendant la décharge à l'énergie électrique accumulée pendant la charge dans des conditions de mise en charge et de décharge spécifiées

3.15
résistance interne
résistance (Ω) combinée de la résistance spécifique au matériau constituant le condensateur et de la résistance des connexions internes d'un condensateur

3.16
puissance volumique maximale
P_{dm}
puissance de sortie maximale d'un condensateur par masse (W/kg) ou par volume (W/l)

3.17
résistance interne nominale
R_N
valeur nominale de la résistance interne (R_N) à utiliser lors de la conception et de l'établissement des conditions de mesure (Ω), en général à température ambiante

3.18
post-traitement
décharge et entreposage d'un condensateur dans des conditions ambiantes spécifiées (température, humidité et pression) après les essais

Note 1 à l'article: En règle générale, le post-traitement implique de décharger et d'entreposer le condensateur jusqu'à ce que sa température interne ait atteint l'équilibre thermique avec la température ambiante, avant de mesurer ses caractéristiques électriques.

3.19
préconditionnement
charge, décharge et entreposage d'un condensateur dans des conditions ambiantes spécifiées (température, humidité et pression) avant les essais

Note 1 à l'article: En règle générale, le préconditionnement implique de décharger et d'entreposer le condensateur jusqu'à ce que sa température interne ait atteint l'équilibre thermique avec la température ambiante, avant de mesurer ses caractéristiques électriques.

3.20
tension assignée
U_R
tension (V) continue maximale pouvant être appliquée en continu à un condensateur pendant une certaine durée, à la température de catégorie supérieure, de sorte que le condensateur puisse afficher des caractéristiques de puissance spécifiées

Note 1 à l'article: Cette tension est la tension de réglage nominale du condensateur.

Note 2 à l'article: L'essai d'endurance utilisant la tension assignée est décrit à l'Annex A.

3.21
température ambiante
température de l'air à proximité du dispositif en essai, dans le présent document, c'est-à-dire à (25 ± 2) °C

3.22
énergie emmagasinée
énergie (J) emmagasinée dans un condensateur

3.23
température de catégorie supérieure
température ambiante maximale au-delà de laquelle le fonctionnement en continu d'un condensateur n'est pas prévu

3.24
caractéristiques de maintien de la tension
capacité d'un condensateur à maintenir la tension lorsque ses bornes sont ouvertes après un laps de temps spécifié consécutif à la mise en charge

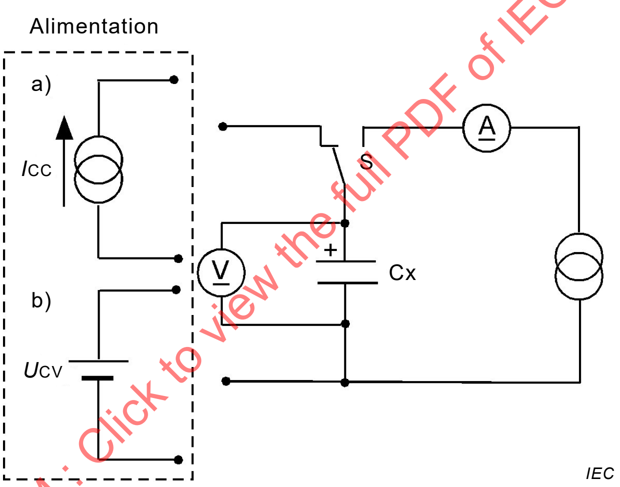
3.25
taux de maintien de la tension
rapport de maintien de la tension
rapport entre la tension aux bornes ouvertes et la tension de charge après un laps de temps spécifié consécutif à la mise en charge d'un condensateur

4 Méthodes d'essai

4.1 Capacité, résistance interne et puissance volumique maximale

4.1.1 Circuit utilisé pour le mesurage

La capacité et la résistance interne doivent être mesurées en utilisant la charge à courant constant et à tension constante et la décharge à courant constant. La Figure 1 représente le circuit de base à utiliser pour le mesurage.



Légende

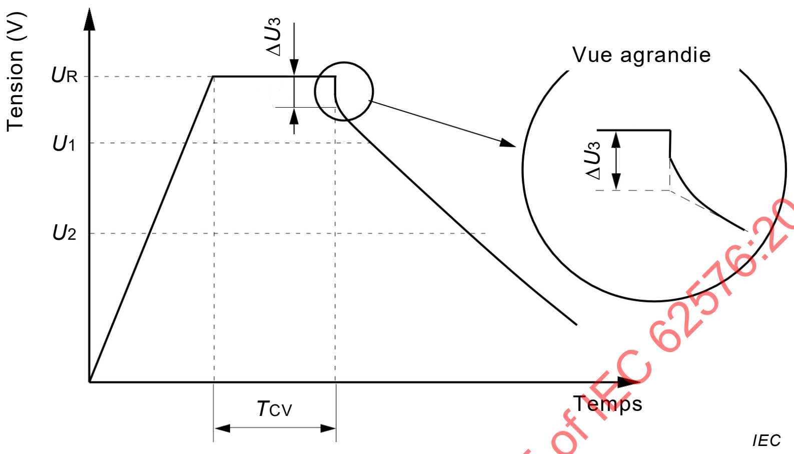
I_{CC}	alimentation stabilisée en courant
U_{CV}	alimentation stabilisée en tension
Ⓐ	ampèremètre à courant continu
Ⓥ	voltmètre enregistreur à courant continu
S	commutateur
Cx	condensateur en essai
(symbole)	déchargeur à courant constant
a)	charge à courant constant
b)	charge à tension constante

Figure 1 – Circuit de base pour le mesurage de la capacité, de la résistance interne et de la puissance volumique maximale

4.1.2 Équipement d'essai

L'équipement d'essai doit être capable d'effectuer la mise en charge à courant constant, la mise en charge à tension constante, la décharge à courant constant et le mesurage en continu du courant et de la tension entre les bornes du condensateur, en séries chronologiques, comme représenté à la Figure 2. L'équipement d'essai doit être capable de régler le courant et la tension avec une exactitude inférieure ou égale à ±1 % et de mesurer le courant et la tension avec une exactitude égale à ±0,1 %.

L'alimentation électrique doit fournir un courant de charge constant pour la mise en charge du condensateur, avec un rendement de 95 %, régler la durée de charge à tension constante et fournir un courant de décharge correspondant au rendement de décharge spécifié. Le voltmètre enregistreur à courant continu doit être capable de procéder aux mesurages et à l'enregistrement selon un intervalle d'échantillonnage de 10 ms ou moins.



Légende

U_R tension assignée (V)

U_1 tension de début de calcul (V)

U_2 tension de fin de calcul (V)

ΔU_3 chute de tension (V)

T_{CV} durée de charge à tension constante (s)

Figure 2 – Caractéristiques de tension par rapport au temps entre les bornes du condensateur lors du mesurage de la capacité et de la résistance interne

4.1.3 Mode opératoire de mesure

Les mesurages doivent être effectués conformément aux modes opératoires suivants, en utilisant l'équipement d'essai spécifié en 4.1.2.

a) Préconditionnement

Avant le mesurage, les condensateurs doivent être complètement chargés et complètement déchargés, puis placés en étuve pendant 2 h à 6 h à température ambiante ou à celle spécifiée par les normes connexes.

NOTE 1 Le temps d'équilibrage thermique, qui sert de référence à la durée d'imprégnation, est décrit à l'Annexe B.

NOTE 2 La mise en charge et la mise en décharge peuvent être répétées si nécessaire jusqu'à stabilisation de la capacité et de la résistance interne.

EXEMPLE

Charger et décharger l'échantillon à l'aide du courant spécifié par le fabricant en suivant les étapes suivantes:

1) décharger complètement;

2) charger jusqu'à U_R;

3) décharger jusqu'à 0,5 U_R;

4) répéter les étapes 2) et 3) dix fois.

b) Mise en place de l'échantillon

Installer les condensateurs d'essai dans l'équipement d'essai.

c) Configuration de l'équipement d'essai

Sauf spécification contraire dans les normes connexes, l'équipement d'essai doit être configuré comme suit.

1) Régler le courant constant I_c pour la mise en charge. À ce courant, les condensateurs doivent être capables de charger avec un rendement de charge de 95 %, basé sur leur résistance interne nominale R_N. La valeur du courant est calculée à l'aide de l'équation $I_c = U_R/38R_N$. La valeur du courant constant ou le rendement de charge peut être modifié(e) selon l'accord conclu entre le client et le fournisseur.

NOTE Le concept général de rendement de charge ou de décharge de 95 % est décrit à l'Annexe C. Lorsque la valeur assignée de la résistance interne d'un condensateur est incertaine, le courant utilisé pour le mesurage peut être réglé conformément aux modes opératoires recommandés décrits à l'Annexe D.

2) Régler la tension maximale pour la charge à courant constant à la tension assignée U_R.

3) Régler la durée de charge à tension constante T_{cv} à 300 s.

4) Régler la valeur de décharge à courant constant. Cette valeur doit assurer un rendement de décharge de 95 %, en fonction de la résistance interne nominale du condensateur R_N. Cette valeur est calculée à l'aide de l'équation $I_d = U_R/40R_N$.

   La valeur du courant constant ou le rendement de décharge peut être modifié(e) selon l'accord conclu entre le client et le fournisseur.

5) Régler l'intervalle d'échantillonnage à 10 ms ou moins et régler l'équipement d'essai de façon à mesurer les caractéristiques de chute de tension jusqu'à 0,5 U_R.

d) Essai

Conformément à la configuration décrite en 4.1.3 c), charger et décharger l'échantillon en suivant les étapes suivantes et mesurer la tension entre les bornes du condensateur comme représenté à la Figure 2:

– charge à courant constant jusqu'à U_R;

– charge à tension constante à U_R pendant 300 s;

– décharge à courant contant jusqu'à 0,4 U_R.

4.1.4 Méthode de calcul de la capacité

La capacité C doit être calculée à l'aide de la Formule (1) en fonction des caractéristiques de tension par rapport au temps entre les bornes du condensateur, telles que mesurées en 4.1.4.

NOTE La méthode décrite ici est la "méthode de calcul de la capacité de conversion d'énergie".

$$C = \frac{2W}{(0{,}9U_R)^2 - (0{,}7U_R)^2} \quad (1)$$

où

C est la capacité (F) du condensateur;

W est l'énergie (J) déchargée, mesurée de la tension de début de calcul (0,9 U_R) à la tension de fin de calcul (0,7 U_R);

U_R est la tension assignée (V).

4.1.5 Méthode de calcul de la résistance interne

La résistance interne R doit être calculée à l'aide de la Formule (2) en fonction des caractéristiques de tension par rapport au temps entre les bornes du condensateur, telles que mesurées en 4.1.4.

$$R = \frac{\Delta U_3}{I_d} \quad (2)$$

où

R est la résistance (Ω) interne du condensateur;

I_d est le courant de décharge (A);

ΔU_3 est la chute de tension (V).

Pour obtenir ΔU_3, appliquer l'approximation linéaire aux caractéristiques de chute de tension, de la tension de début de calcul (0,9 U_R) à la tension de fin de calcul (0,7 U_R), en utilisant la méthode des moindres carrés. Obtenir l'ordonnée à l'origine (valeur de la tension) de la droite au temps correspondant au démarrage de la décharge. ΔU_3 est la différence des tensions (V) entre la valeur de la tension à l'origine et la valeur de réglage de la charge à tension constante.

NOTE La méthode décrite ici est le "calcul de la résistance interne par la méthode des moindres carrés".

4.1.6 Méthode de calcul de la puissance volumique maximale

La puissance volumique maximale P_{dm} est calculée en utilisant la valeur de résistance interne calculée en 4.1.5 et à l'aide de la Formule (3).

NOTE La méthode décrite ici est la "méthode de calcul de la puissance volumique à impédance adaptée".

$$P_{dm} = \frac{0{,}25U_R^{\ 2}}{RM} \quad (3)$$

où

P_{dm} est la puissance volumique maximale du condensateur (W/kg ou W/l);

U_R est la tension assignée (V);

R est la résistance interne calculée (Ω);

M est la masse ou volume du condensateur (kg ou l).

4.2 Caractéristiques de maintien de la tension

4.2.1 Circuit utilisé pour le mesurage

La Figure 3 représente le circuit de base utilisé pour le mesurage des caractéristiques de maintien de la tension.