National B1 event

24 September 2025

“Connecting the past to the future”

Track 3. HVDC

cigre

For power system expertise

CIGRE PARIS SESSION 2024

cigre

Tutorial:

HV DC Cables, Technical Brochures 852, 853

Presented by: Frank de Vries
National Committee B1 member
Mob.: +31 621899571
Email: frank.de.vries@tennet.eu

cigre
For power system expertise

Prepared by:
Davide Pietribiasi
Roberto Gaspari
Alessandro Trolli
Roman Svoma

Table of contents

- Scope of Work of B1.62 (testing recommendation for DC extruded cable systems)
- Main changes with respect to TB 496
- Technical basis and test overview

- Scope of Work of B1.66 (testing recommendation for DC lapped cable systems)
- Main changes with respect to Electra 189

- Main differences between TB 852 and TB 853

- Conclusions

Scope of Work of B1.62

WG B1.62 Members

Members

Anne Catherine Sartieaux	BE
Christian Szczepakski	BE
Christian Frhone	DE
Roland Zhang Dongping	DE
Yannis Corlu	FR
Pierre Mirebeau	FR
Mandana Taleb (replaced)	FR
Stefano Franchi Bononi, **Convenor**	IT
Andrea Pelizzoni	IT
Davide Pietribiasi, **Secretary**	IT

Yoshihiro Tanaka	JP
Quentin Eyassutier	NO
Roberto Gaspari	NO
Jerome Joseph Mattalana	NO
Amirhossein Abbasi	SE
Johan Fredrik Falth	SE
Rosemary Urban King	UK
Roman Svoma	UK
Stuart William	UK

Corresponding Members

Herry Horton	CA
Mingli Fu	CN
Jinghui Gao	CN

Lee Su Kill	KR
Jung Chae kyun	KR

Background & General scope

In order to address HVDC extruded cable systems development and qualification Cigré SC B1 issued:

- in February 2003, the TB 219 which was addressing HVDC extruded cable systems up to 250 kV;
- In April 2012, the TB 496 which was addressing HVDC extruded cable systems up to 500 kV;

Few years later commercially available HVDC extruded systems above 500 kV were emerging. Today there is:

- Laboratory experience on cable systems at voltages up to and including 640 kV;
- contracts awarded at a voltage level up to 525 kV.

Furthermore, extruded technologies, using not only cross-linked material, but also un-cross-linked or partially cross-linked materials, with or without fillers, have been introduced and in some case installed.

Therefore, technical guidelines are required to take account of both higher rated voltage level and all the different technologies.

Terms of Reference

Solid insulated cable systems for the voltage class up to, and including, 800 kV.
WG had to cover:

1. Review of Test loop heating (see TB 496 1.5.5)
2. Review of Superimposed impulses test (TB 496: chapters 3.5 and 4.4.3)
3. Review of PQ test sequence (TB 496 chapter 3.4)
4. Review of Routine Tests (TB 496 Chapter 5)
5. Review of Sample Tests (TB 496 Chapter 6)

6. Assessment whether TB 303 is enough to define what means “significant change” in a cable system, in order to know when a PQ/Type Test has to be performed.

7. Definition of Rated and Max Voltage
8. Definition of Transient phenomena for HVDC cables in case of fault (Temporary Over Voltage)
9. Definition of voltage levels for Type, Prequalification (PQ) and Commissioning Tests, avoiding unnecessarily high test voltage
10. Definition of an extension of qualification test shorter than PQ for peculiar application

Working Group Deliverables & duration

Deliverables

- Technical Brochure and Executive summary in Electra
- Tutorial

Time Schedule:

- Start: February 2018
- Final Report: February 2021

Actual:

- Start: April 2018
- Final Report: October 2021

Main changes with respect to TB 496

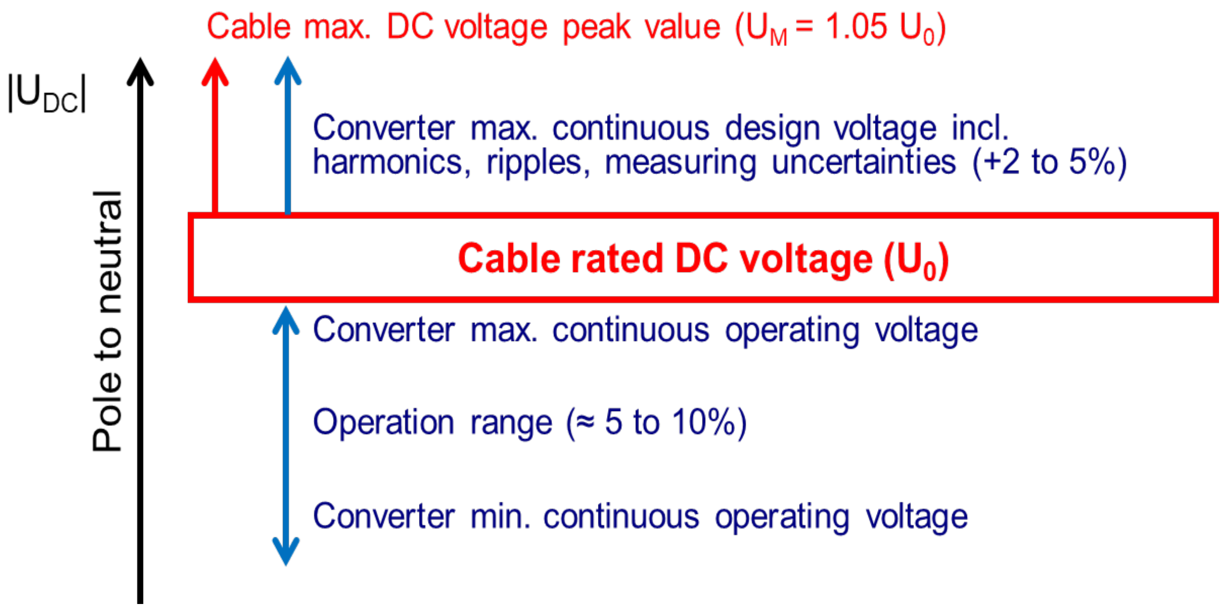
New Definitions

- **DC voltage class:**
  - HVDC: $U_0 \leq$ 400 kV and average stress ≤ 20 kV/mm
  - EHVDC: U_0 > 400 kV or average stress > 20 kV/mm
- **Joints:**
  - Flexible joint
  - Rigid joint
  - Factory joint
  - Flexible/Rigid Repair joint
  - Flexible/Rigid Field joint
  - Asymmetric joint
  - An interface joint
  - A transition joint

New Definitions

- **Material:**
  - LXLPE (low crosslink polyethylene)
  - Thermoplastic insulations

- **Max Dc Voltage:**
  - 1.05 U_0



New Definitions

- **Installation conditions**
  - Test object is installed in setups mimicking the operational installation
  - Test object is installed in a controlled environment /ambient
- $\boldsymbol{\Delta T_{min}}$
  - The minimum temperature difference over the cable insulation in steady state at $T_{cond,max}$ (not including semiconducting screens) at which the cable is designed to operate.
  - It is relevant for EHVDC systems only.

New guide for the selection of test procedures in case of changes in a qualified cable system

- A series of tests is recommended to reduce the time to market and the overall qualification cost of improvements by considering expected innovations in cable technology. In each

- The same philosophy as for HVAC cable systems by TB 303.

- 50 modifications are addressed covering the design, material and process related to cable, factory and pre-moulded joint, and termination.

- Two events were evaluated: the case of different cleanliness grades of insulation compounds, and the case of an interface joint *i.e.* a joint between two different qualified extruded cable systems.

Type of modification * M: change in material; P: change in manufacturing process; D: change in design (construction); DL: change in electrical design stress level		*M**	*P**	*D**	*DL**	Routine Tests		Sample Tests		Type Test		Prequalification Test		Extension of Qualification Test		Thermal Stability Test		Technical comment
The type of modification and the tests to be performed are marked with an "x" in the corresponding cell.						HVDC	EHVDC	HVDC	EHVDC	HVDC	EHVDC	HVDC	EHVDC	HVDC	EHVDC	HVDC	EHVDC	
Cable *Conductor*	Larger cross-section ≤20%, same metal, Laplace conductor and insulation screen field lower or equal		x	x	x					x[1]	x[1]							
	Larger cross-section >20%, same metal, Laplace conductor and insulation screen field lower or equal		x	x	x					x[1]	x[1]			x	x			

New guidance on examination of cable and accessories

A list of possible types of deterioration, encountered during a visual inspection (Appendix I):

- Damage to the conductor which could have a detrimental effect on the cable performance;
- Harmful indentations in the cable core(s), sharp indentations of the semi-conductive screen;
- Presence of corrosion on metallic parts, e.g. metallic screen and connections;
- Indication of possible mechanical degradation in the dielectric parts;
- Indication of possible electrical degradation in primary insulation of accessory and cable;
- Indication of thermal degradation (all components);
- Cracking or damage to the insulation;
- Damage on the cable sheath;
- Leak or emission of insulating fluid;
- Significant change in dimensions which could have a detrimental effect on the cable or accessory performance.

New Thermal Stability Test (TST)

The Thermal Stability Test (TST) is aimed at demonstrating the thermal stability of the cable and **to highlight**, if present, the possibility of **an undesirable thermal run-away** of the proposed solution.

Generally, the dielectric losses are directly related to the dielectric conductivity, the localized electric field and the localized insulation temperature.

Thermal run-away occurs when:

- **the conductor joule heat** due to the load current **produces more heat than the cable and surroundings can dissipate**.
- **dielectric losses lead to an increase of localized temperatures**. As a consequence of the temperature increase, the dielectric losses further increase;

These unstable situations could lead to an uncontrolled and possibly **catastrophic temperature increase**.

During the thermal stability test the temperature increase of the test sample shall be compared to the thermal behaviour of the reference cable, where dielectric losses do not occur since the electrical field is negligible, to check whether the thermal behaviour significatively differs among the two objects.

New Extension of Qualification Test (EQT)

The Extension of Qualification Test (EQT) is part of the scope of tests to verify the long-term performance **of a previously qualified cable system**, when **substantial changes** are implemented on a previously qualified cable system. More than one accessory of different design/type can be inserted in the test loop for an extension of the Qualification test.

A **substantial change** is defined as that which might adversely affect the performance of the cable system. The supplier should provide a detailed case, including test evidence, if modifications are introduced, which are claimed not to constitute a substantial change. **A chapter titled "Guide for the selection of test procedures in case of changes in a qualified cable system" is included in the TB** and it can be used to support customers or suppliers in this work.

New Temporary Over voltage (TOV) Test

According to the work of CIGRE JWG B4/B1/C4.73, two new overvoltage's can be experienced on HVDC and EHVDC cable systems on top of conventional lightning and switching impulses: **very slow front overvoltages with same polarity** to actual DC voltage and **oscillating overvoltages with opposite polarity** peaks to actual DC voltage.

The intention of the tests is to verify that these special conditions together with the cable system design give acceptable results. **It is not the intention that all tests described are automatically part of testing regime** for HVDC and EHVDC cable systems, but more an exception to study and/or address project specific issues or **for engineering information**.

Technical basis & Test overview

DC voltage factors

	Prequalification Test	Extension of qualification Test	Type Test
Design Life, t_0 (years)	40	40	40
Test Duration, t_1 (days)	360	82	30
Test Voltage Aging Factor, K_1	$\sqrt[10]{40 \cdot 365/360}$=1,45	$\sqrt[10]{40 \cdot 365/82}$=1,68	$\sqrt[10]{40 \cdot 365/30}$=1,85

Duration of tests

- Evaluation of resistivity and the time constants (τ) of current insulation materials.
- Compared to TB496, time constants slightly updated.
- *Higher resistivity materials may be developed, and a review of test block durations may be required in the future*

Duration of tests

Temperature (°C)	ε (F/m)	ρ (Ω.m)	Time for stability, 10 τ (hours)
20	$2x10^{-11}<\varepsilon< 3x10^{-11}$	$10^{15}< \rho< 5x10^{16}$	$55<10\ \tau < 4300$
60	$2x10^{-11}<\varepsilon< 3x10^{-11}$	$10^{13}<\rho< 5x10^{14}$	$0,6< 10\ \tau< 43$
90	$2x10^{-11}< \varepsilon< 3x10^{-11}$	$10^{13}<\rho< 10^{14}$	$0.6< 10\ \tau < 8.3$

Condition	Temperature	Testing time (Days)	Time for stability, 10 τ (Days)
Zero load (Prequalification Test)	Ambient temperature (20±15 °C)	At least 120	$2.3<10\ \tau < 180$
Zero load (Extension of qualification Test)	Ambient temperature (20±15 °C)	At least 6 days	$2.3<10\ \tau < 180$
48 hours Load Cycle (Type Approval)	At least maximal conductor temperature (60 °C to 90 °C depending on manufacturer design)	1 (heating period)	$0.03<10\ \tau<1.8$

Heating methods and temperature drop calculation

- External heating in combination with conductor heating possible.
- Two heating methods for the test (Appendix E):
  - Using a reference cable
  - Measurement of the surface temperature and calculation of conductor temperature
- Method to calculate temperature drop across the insulation (Annex D)

$$\Delta T_I = \Delta T_{Meas}\left(\frac{R_{TIns}}{R_{TMeas}}\right) = \Delta T_{Meas}\left(\frac{R_{TIns}}{R_{TIns} + R_{TAdds}}\right)$$

Where:

R_{TIns}: Thermal Resistance of the insulation

R_{TMeas}: Thermal Resistance of all layers between the temperature probes

R_{TAdds}: Thermal Resistance of all layers between the temperature probes, except the insulation layer

Prequalification Test (PQT), Extended qualification Test (EQT) and Type Test (TT) programs

- The PQT is intended to indicate the long-term performance of the insulation of the complete cable system.
  - It is carried out once, unless there is a substantial change in the cable system with respect to materials, manufacturing processes, construction design, thermal and electrical design stress level.
    - §10 "GUIDE FOR THE SELECTION OF TEST PROCEDURES IN CASE OF CHANGES IN A QUALIFIED CABLE SYSTEM" can be used to support customers or suppliers in this work.
  - An armoured cable prequalified according to this recommendation prequalifies an unarmoured cable and vice versa.
  - Where appropriate, mechanical preconditioning may be considered before starting the Prequalification Test

- The EQT shall be performed when substantial changes are implemented on a previously qualified cable system.
  - Guidance about what substantial changes require an EQT can be found in §10 "Guide for the selection of test procedures in case of changes in a qualified cable system" included in the TB.
  - If the Extension of Qualification test isn't associated with a Type test in §10, proper mechanical preconditioning shall be applied.

- The TT is made before supplying on a general commercial basis a type of cable system covered by this recommendation, to demonstrate satisfactory performance characteristics to meet the intended application.

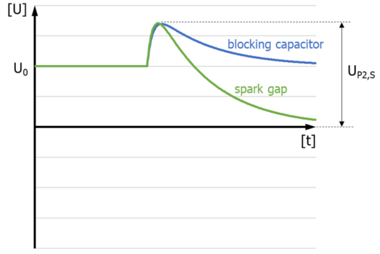
Prequalification Test: test sequence

Test sequence for Voltage Source Converter, VSC

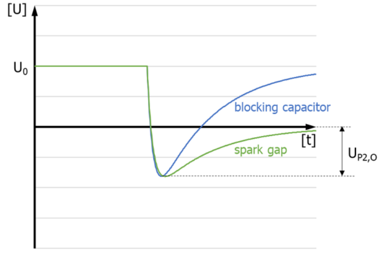
	LC	LC	HL	HL	ZL	LC	LC	S/IMP
Number of cycles or days	40 cycles	40 cycles	40 days	40 days	120 days	40 cycles	40 cycles	Not applicable
Test Voltage	+	-	+	-	-	+	-	$U_{P2,O} = 1.2\,U_0$
	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	$U_{P1} = 2.1\,U_0$

Test sequence for Line Commutated Converter, LCC

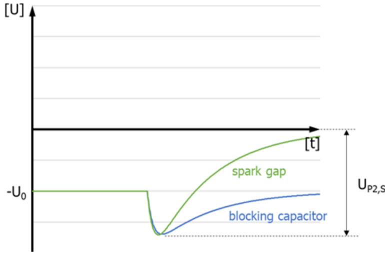
	LC	LC	LC+PR	HL	HL	ZL	LC	LC	LC+PR	S/IMP
Number of cycles or days	30 cycles	30 cycles	20 cycles	40 days	40 days	120 days	30 cycles	30 cycles	20 cycles	Not applicable
Test Voltage	+	-		+	-	-	+	-		$U_{P2,O} = 1.2\,U_0$
	U_{TP1}	U_{TP1}	U_{TP2}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP2}	$U_{P1} = 2.1\,U_0$



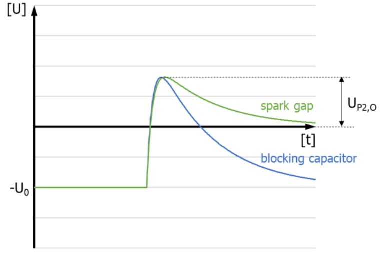
VSC, same polarity positive SI



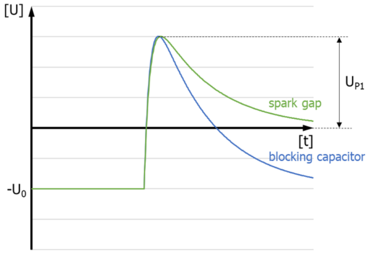
LCC or VSC, opposite polarity negative SI



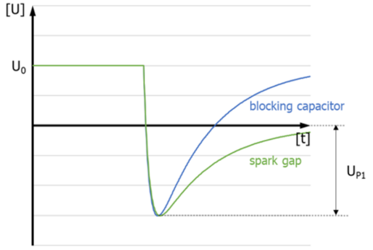
VSC, same polarity negative SI



LCC or VSC, opposite polarity postiive SI



LCC or VSC, postive LI



LCC or VSC, negative LI

Overview of PQT, EQT, TT sequences for VSC convertor technology

Prequalification test sequence for Voltage Source Converter, VSC, U_{TP1} = 1,45 U_o

	LC	LC	HL	HL	ZL	LC	LC	S/IMP
Number of cycles or days	40 cycles	40 cycles	40 days	40 days	120 days	40 cycles	40 cycles	Not applicable
Test Voltage	+	-	+	-	-	+	-	$U_{P2,O} = 1.2\,U_0$ $U_{P1} = 2.1\,U_0$
	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	

Extended qualification test sequence for Voltage Source Converter, VSC, U_{EQ1} = 1,68 U_o

	LC	LC	HL	HL	ZL	LC	LC	S/IMP
Number of cycles or days	10 cycles	10 cycles	18 days	18 days	6 days	10 cycles	10 cycles	Not applicable
Test Voltage	+	-	+	-	-	+	-	$U_{P2,O} = 1.2\,U_0$ $U_{P1} = 2.1\,U_0$
	U_{EQ1}	U_{EQ1}	U_{EQ1}	U_{EQ1}	U_{EQ1}	U_{EQ1}	U_{EQ1}	

Type test sequence for Voltage Source Converter, VSC, U_T = 1,85 U_o

	Mech precon.	LC	LC	LC48	S/IMP	DC
Number of cycles/days or duration	Not applicable	8 cycles	8 cycles	3 cycles	Not applicable	2 hours
Test Voltage		-	+	+	$U_{P2,O}$ U_{P1}	-
		U_T	U_T	U_T		U_T

FINAL IMPULSE SUPERIMPOSED TESTS

- The test may be carried out on the whole test assembly.
- For long circuits (typically >100m), the front time of LI may be increased up to 8 µs to comply with overshoot requirements as such oscillations are not present in actual installations and might be harmful for the test objects.
  - This doesn't have a significant impact on cable voltage withstand value.

Type Test: Additional test for accessories

- Joints with or without screen interruption
- Accessories for cable screen interruption and/or earth connection
- Terminations with sectionalizing insulation
- Composite insulators for outdoor terminations

Test sequence	Joints without screen or metal sheath interruption		Joints with screen or metal sheath interruption		Accessories for cables without a screen or metal sheath/screen interruption		Accessories for cables with a screen or metal sheath/screen interruption		Terminations with sectionalising insulation	Composite insulators for outdoor terminations
	J.3 Water immersion		J.3 Water immersion		J.3 Water immersion		J.3 Water immersion		J.4	J.5
	With	With-out	With	With-out	With	With-out	With	With-out		
- 20 thermal cycles with or without voltage	X	X	X	X	X	X	X	X		
- Water immersion (20 thermal cycles)	X	-	X	-	X	-	X	-		
DC withstand test between screen and earth	X		X		X		X		X	
DC withstand test between screen and screen			X				X			
LI withstand test between screen and earth	X		X		X		X		X	
LI withstand test between screen and screen			X				X			
internal pressure test										X
Cantilever load test										X
Examination	X		X		X		X		X	X

Thermal Stability Test

TEST OBJECTS

Each test assembly shall consist of **at least 10 m of cable** between terminations and at least 5 m between adjacent accessories where joints are included.

Factory joints shall be submitted to the thermal stability test. The presence of other accessories within the test sample are optional.

TEST ARRANGEMENT

The test is carried out independently from the Prequalification or Type Test, possibly but not necessarily on a separate length of cable from the one subject to either the Prequalification or Type Test.

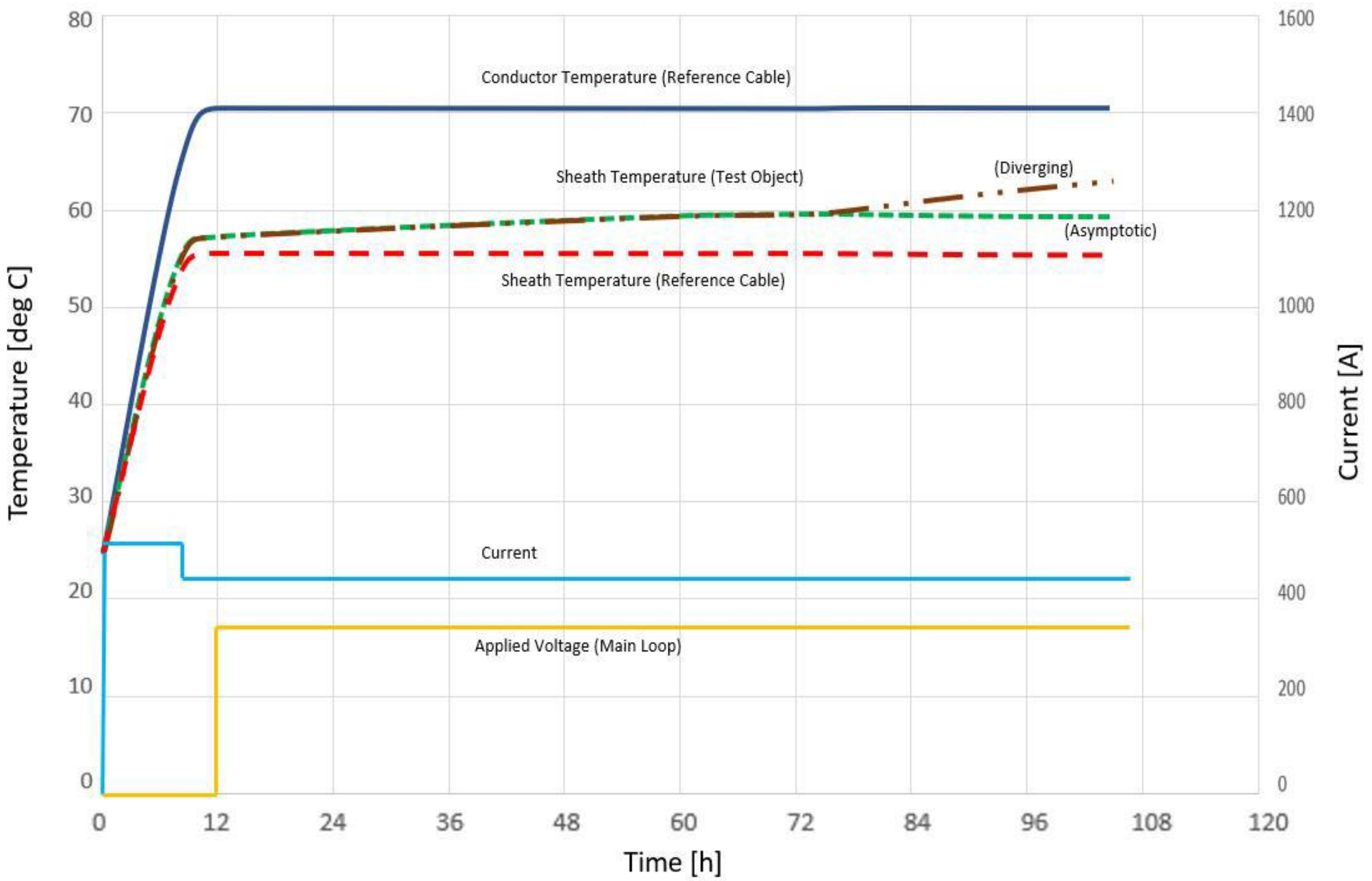
Thermal Stability Test

TEST CONDITIONS

- $T_{cond,max}$
- ΔT_{min}
- $U_{TP1} = 1.45 \cdot U_0$

For minimum 120h, maximum 240h at steps of 24h.

Successful completion of the thermal stability test is obtained if the temperature difference between test object sheath and reference cable sheath doesn't diverge by more than 4 K in the last 4 days and 2 K in the last 3 days.



Temporary Over Voltage (TOV) Test

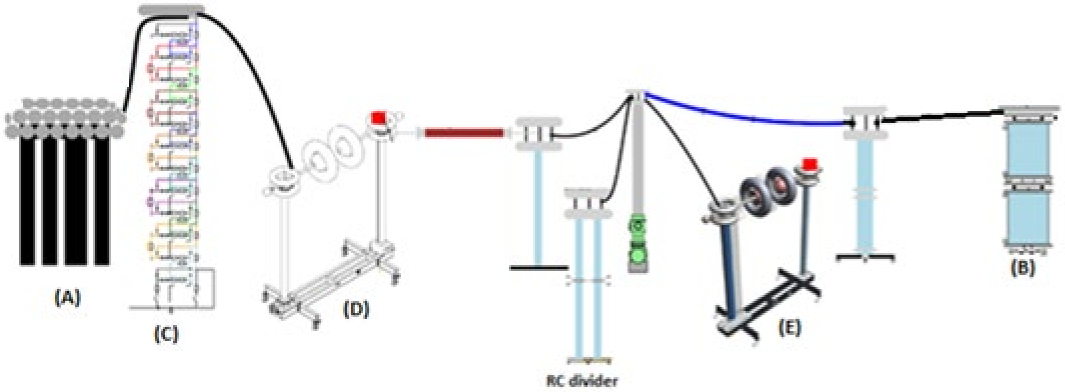
The intention of the tests is to verify that these special conditions together with the cable system design give acceptable results. It is not the intention that all tests described are automatically part of testing regime for HVDC and EHVDC cable systems, but more an exception to study and/or address project specific issues or for engineering information.

PRECONDITIONING

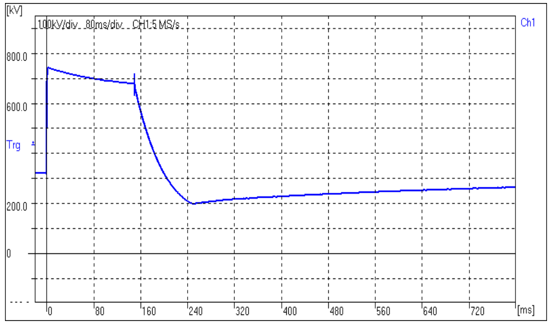
- Five "24 hours" load cycles at negative polarity at U_T
- Five "24 hours" load cycles at positive polarity at U_T

TEST PROCEDURE

- the test object at $+U_0$, 10 consecutive TOVs to $+U_1$;
- the test object at $-U_0$, 10 consecutive TOVs to $-U_1$.

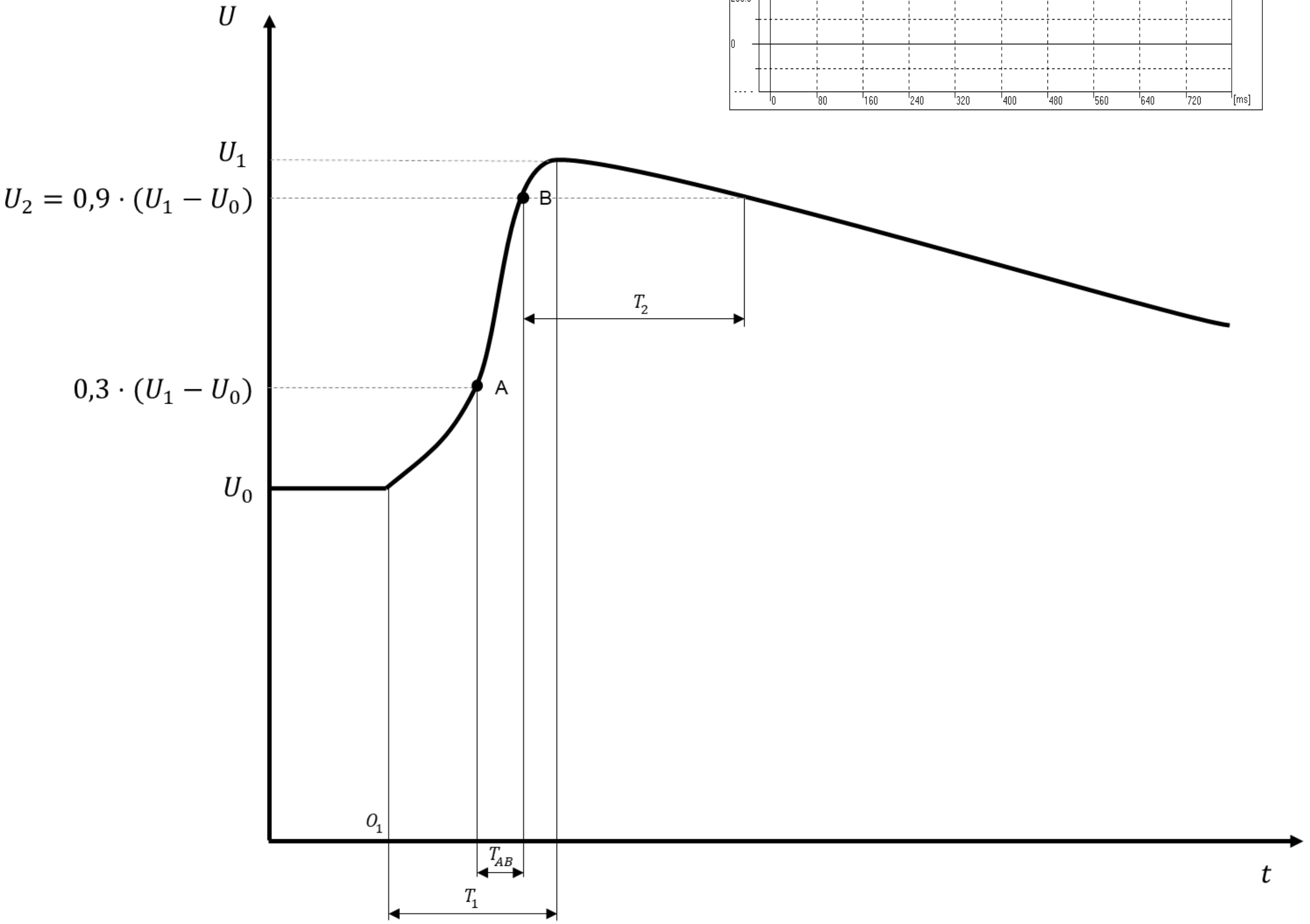


Temporary Over Voltage (TOV) Test



Very slow front temporary overvoltage

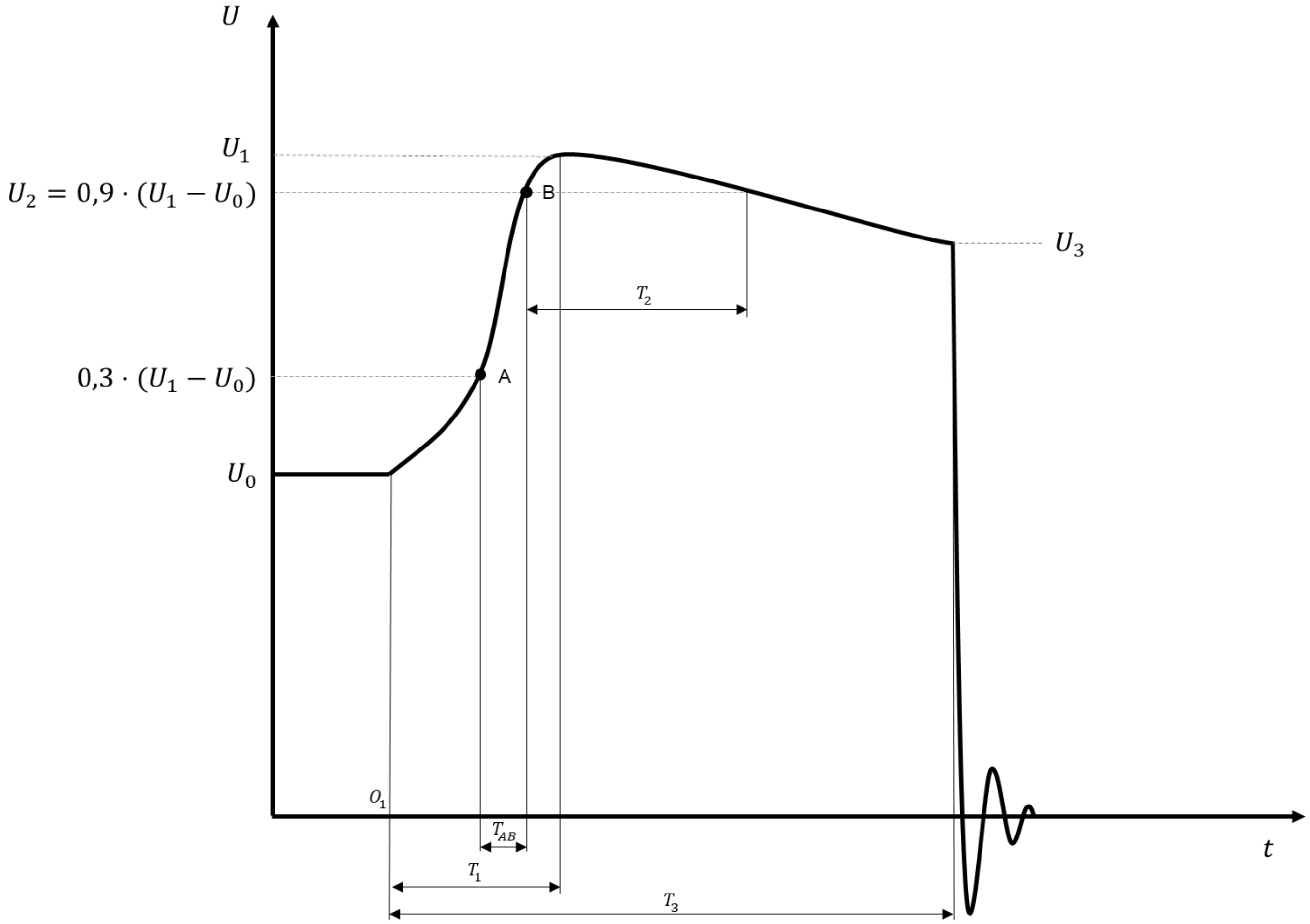
- time to peak, T_1: time interval from the true origin to the time of maximum value of a switching-impulse voltage, in the range of 1÷3 ms
- plateau time, T_2: time interval during which the switching-impulse voltage exceeds 90 % of its maximum value, in the range of 10÷150 ms



Temporary Over Voltage (TOV) Test

Very slow front temporary overvoltage with copped tail

time to chopping, T_3: time interval from the true origin to the instant of chopping

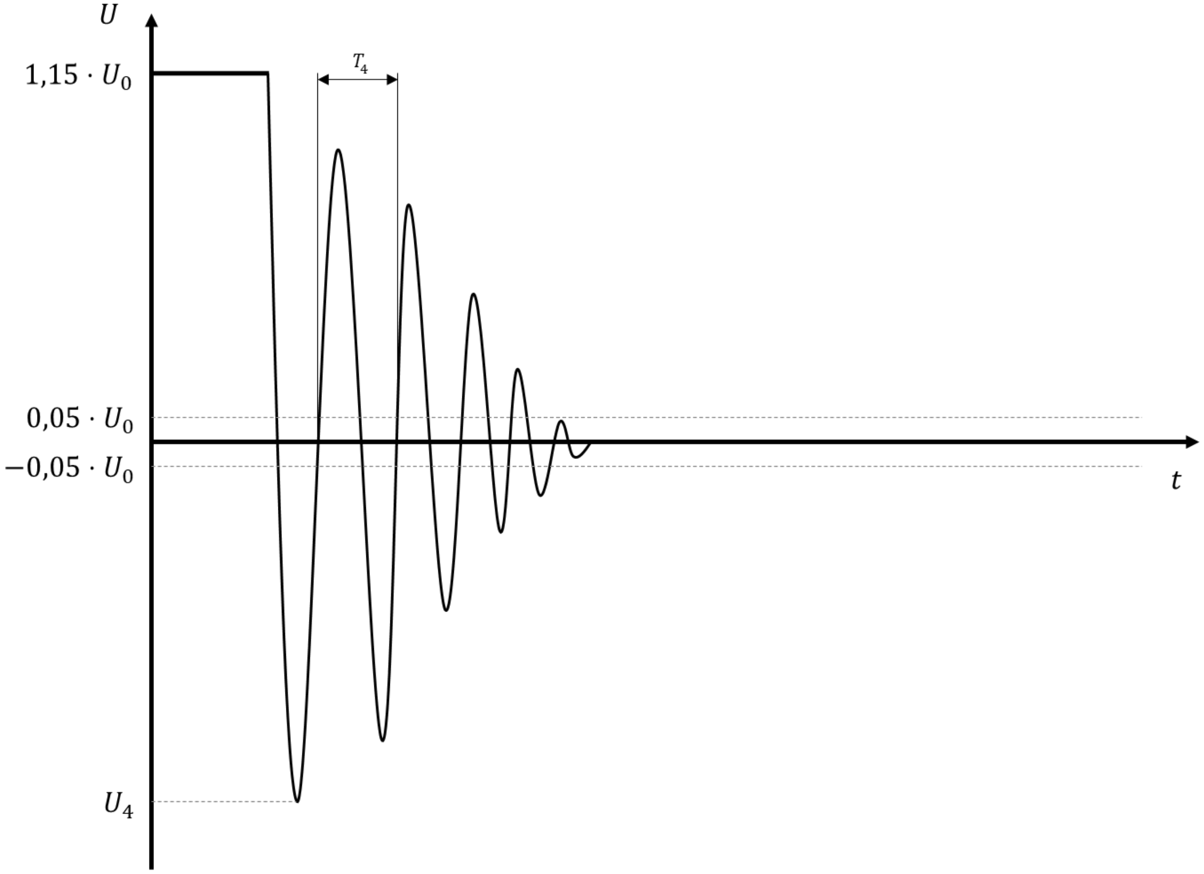


Temporary Over Voltage (TOV) Test

Zero crossing damped temporary overvoltage

first opposite oscillation peak value, U_4: peak value of the first oscillation after sample discharge

zero crossing damped temporary overvoltage period, T_4 : time interval between two damped oscillations



Type Test: Return cable

Mainly No changes with TB 496.

- Mechanical preconditioning
- Thermo-mechanical preconditioning
  - 24 daily cycles, without any requirement on ΔT_{max}
  - No voltage applied
- AC voltage test at
  - 1.15 x $U_{RC,AC}$ at power frequency for 30 minutes
  - Ambient temperature
- Lightning impulse withstand test at relevant test voltages
- Cable with integrated return conductor
  - For such a design, the return path function should be tested together with the power transmission cable in an integrated test program
  - The test program shall be agreed between customer and supplier

New tests introduced in Type and Sample Tests

- Selection of insulation system material tests
- Covering new materials

Test	Material	Application for HVDC	Application for EHVDC
By-products using TGA	XLPE, LXLPE insulation	*	Type Test Sample Test
By-products using Chromatography	XLPE, LXLPE insulation	*	Type Test Sample Test
Manufacturer' selected method	Insulation all	-	*
Volume resistivity	Semi-conductive	Type Test Sample Test	Type Test Sample Test
Mechanical properties	XLPE, LXLPE, Thermoplastic insulation	Type Test	Type Test
Pressure test	Thermoplastic insulation	Type Test Sample Test	Type Test Sample Test
Hot set test	XLPE, LXLPE insulation	Type Test Sample Test	Type Test Sample Test
DSC	XLPE, LXLPE, Thermoplastic insulation	-	-
Shrinkage	XLPE, LXLPE, Thermoplastic insulation	-	-
Conductivity	XLPE, LXLPE, Thermoplastic insulation	-	-
By-product content of semi-conductive layers of the insulation system.	XLPE, LXLPE	-	-

*To be discussed between manufacturer and customer

Routine Test: transmission cables

- **AC voltage test**
  - The applied AC test voltage shall be agreed between manufacturer and customer.
  - As a guidance, the maximum Laplace field stress of 20 kV/mm for a duration of 30 minutes for HVDC cables and 23 kV/mm for a duration of 60 minutes for EHVDC cables.
  - The frequency of the AC test voltage shall be in the range 10 Hz to 500 Hz for submarine cables and 49 Hz to 61 Hz for land cables.
- **DC voltage test**
  - Negative polarity DC voltage equal to U_T, 1 hour at ambient temperature.
- **Electrical test on over sheath of the cable**
  - If required according to the routine electrical test specified in IEC 60229.
- **Time Domain Reflectometry (TDR) measurement**

Routine Tests: cable accessories

- The main insulation of prefabricated accessories shall undergo AC voltage (if applicable) and DC routine tests according to either 1), 2) or 3) below:

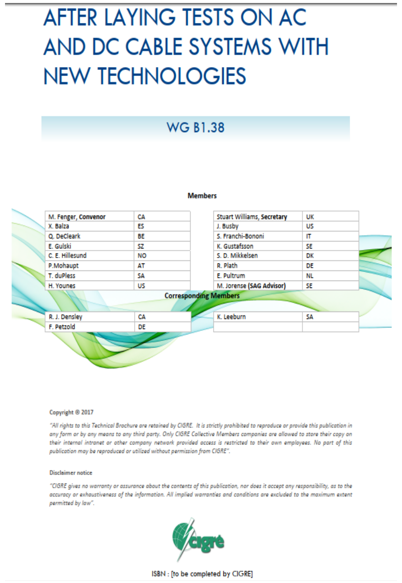
1) on the main insulation of prefabricated accessories installed on cable;
2) by using a host accessory into which a component of an accessory is substituted for test;
3) by using a simulated accessory rig in which the electrical stress environment of a main insulation component is reproduced.

After Installation Test

No changes with TB 496. The tests are always:

- High voltage test
  - Power cable: negative polarity DC voltage of U_{TP1} for 1 hour.
  - Metallic return cable: negative polarity DC voltage that has been agreed between the supplier and the customer for 1 hour
- Test on polymeric sheaths: for underground cables only in accordance with IEC 60229
- Time Domain Reflectometry (TDR) measurement: for engineering information and to obtain a "fingerprint" of the wave propagation characteristics of the cable.

Additional after installation tests can be agreed between manufacturer and customer with reference to TB 841.


AFTER LAYING TESTS ON AC AND DC CABLE SYSTEMS WITH NEW TECHNOLOGIES

WG B1.38

Members

M. Fenger, **Convenor**	CA	Stuart Williams, **Secretary**	UK
X. Balza	ES	J. Busby	US
Q. DeCleark	BE	S. Franchi-Bononi	IT
E. Gulski	SZ	K. Gustafsson	SE
C. E. Hillesund	NO	S. D. Mikkelsen	DK
P.Mohaupt	AT	R. Plath	DE
T. duPless	SA	E. Pultrum	NL
H. Younes	US	M. Jorense **(SAG Advisor)**	SE

Corresponding Members

R. J. Densley	CA	K. Leeburn	SA
F. Petzold	DE		

ISBN : [to be completed by CIGRE]

Scope of Work of B1.66

WG B1.66 Members, deliverables and time schedule

Members

CHINA	Haitian Wang
FRANCE	Benjamin Pailler
FRANCE	David Dubois
GERMANY	Kok Bun Tse
ITALY	Gianni Miramonti*
ITALY	Giuseppe Lagrotteria
ITALY	Alessandro Trolli
JAPAN	Vincent Foo
NORWAY	**Gunnar Evenset, Convenor**
NORWAY	Lars Lervik
NORWAY	Nora Kristjansdottir, Secretary
SWEDEN	Ola Hansson
UK	Roman Svoma

*replaced by Guiseppe Lagrotteria in 2019

Corresponding members

CHINA	Chen Zhengzheng
KOREA	Kim Seong-Weon
UK	Gregory Tzemis

Deliverables

- Technical Brochure and Executive summary in Electra
- Tutorial

Time Schedule

- Start: April 2018
- Final Report: October 2021

Terms Of Reference

Scope:

Test recommendations for lapped cable systems for the voltage class up to and including 800 kV.

The WG will cover:

1. Review of definitions
2. Review of references
3. Review of existing test requirements in Electra No 189/218.
4. Consideration of the introduction of test requirements for operation of lapped DC cables with voltage source converters
5. Combining the test requirements from Electra No. 189/218 and any new requirements from the work into a technical brochure The WG may benefit from collaboration with WG B1.62, JWG B4/C1.65 and JWG B4/B1/C4.73

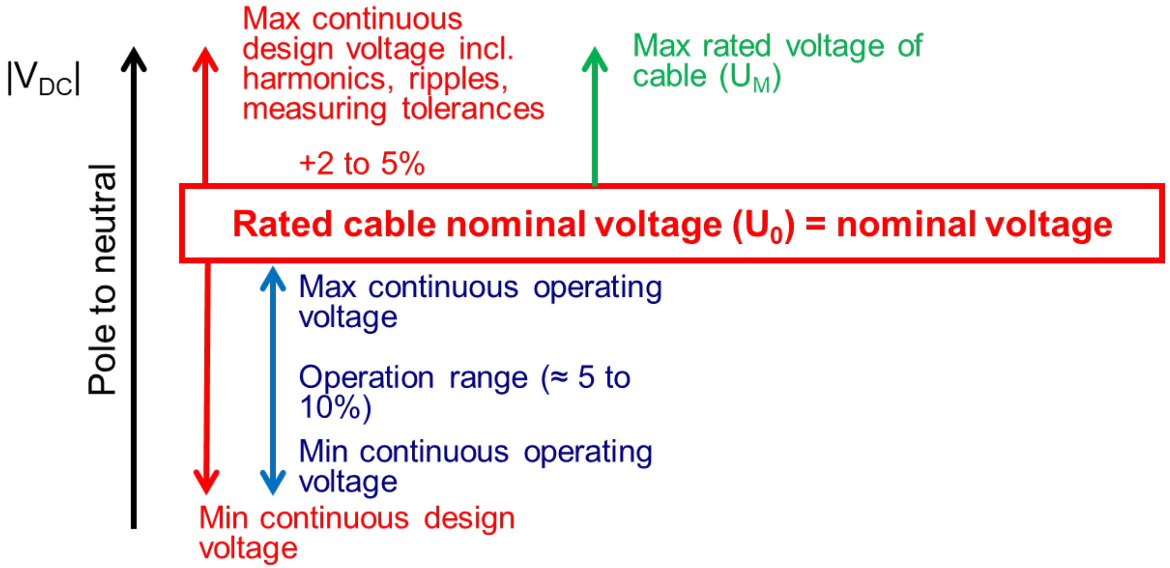
Main changes with respect to Electra 189/218

Main changes with respect to Electra 189/218

- NEW voltage definitions
- NEW development tests
- NEW prequalification test
- NEW test for extension of qualification
- NEW type test requirements
- NEW sample tests
- NEW special temporary overvoltage test
- NEW extended duration of FAT and after installation HV test

NEW voltage definitions

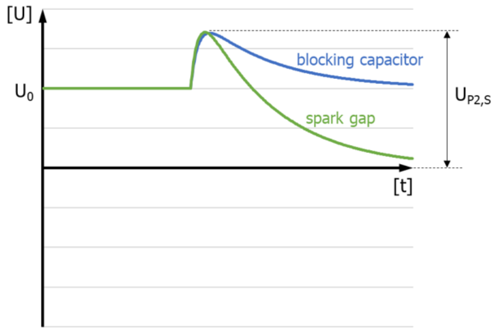
U_0	is the rated DC voltage between conductor and core screen for which the cable and accessories are designed, see Figure.
U_M	is the maximum DC voltage including ripples, harmonics and measuring tolerances between conductor and core screen for which the cable system is designed. For the scope of this recommendation $U_M = 1.05 * U_0$, see Figure.



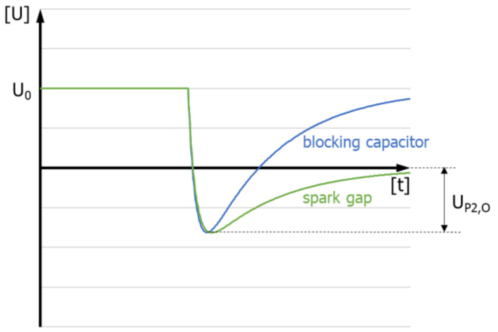
NOTE: The definition of U_0 is not the same as in TB 684 – Recommended voltages for DC grids [B23]. U_0 is in this brochure defined as the maximum continuous operation voltage excluding harmonics, ripple and measuring tolerances since these parameters are project specific.
U0 is used for test purposes and does not change the HVDC system voltage levels. Test voltages are also affected by ripple up to a maximum of 3% and measurement uncertainties which are acceptable in covering the operational stress including ripple and measuring tolerances.

NEW voltage definitions

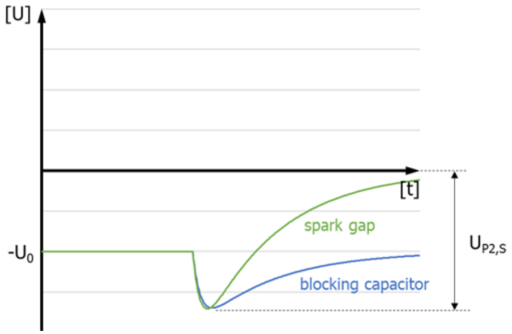
$U_{P2,S}$	is 1.15 * the maximum absolute peak value (see Figure) of the switching impulse voltage, which the cable system can experience when the impulse has the same polarity as the actual DC voltage.
$U_{P2,O}$	is 1.15 * the maximum absolute peak value (see Figure) of the switching impulse voltage which the cable system can experience when the impulse has the opposite polarity to the actual DC voltage.



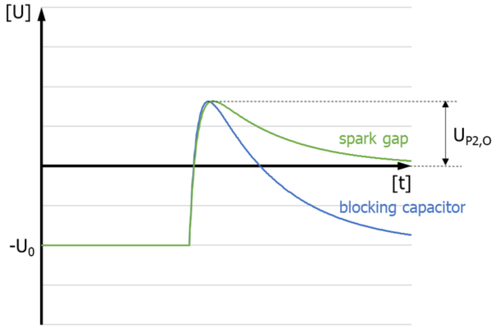
VSC, same polarity positive SI



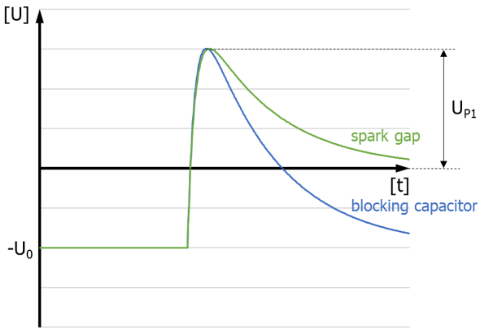
LCC or VSC, opposite polarity negative SI



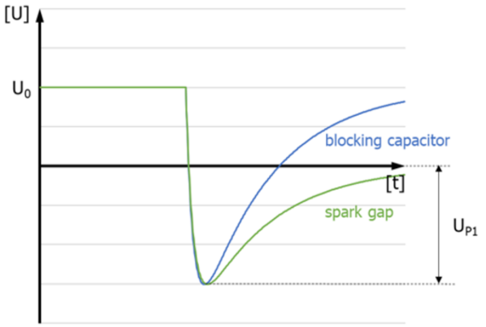
VSC, same polarity negative SI



LCC or VSC, opposite polarity postiive SI



LCC or VSC, postive LI



LCC or VSC, negative LI

NEW Development tests

The manufacturer should complete all analyses and development testing prior to commencing the prequalification test/type test.

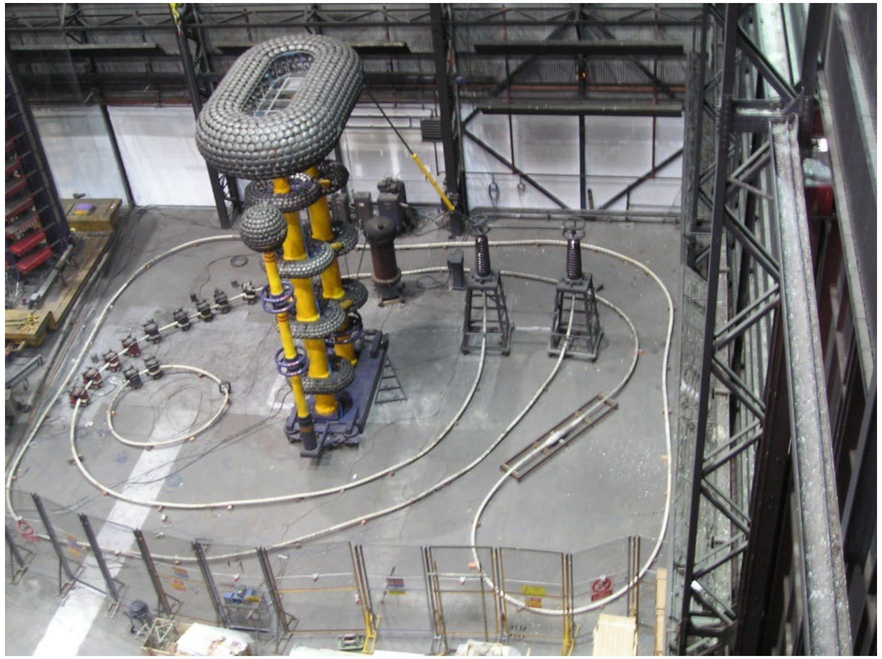
The precise nature and extent of development work and analyses shall be left to the discretion of the manufacturer, but may include the following:

- evaluation of the materials and processes employed. Such evaluations would normally include lapping tensions, cable handling properties, electrical resistivity assessments, breakdown tests, impregnation tests, etc.
- analysis of the electric stress distribution within the cable system insulation for a range of typical installation and loading conditions.
- assessment of the long-term stability, possibly involving factory experiments to assess the ageing effects of various parameters, e.g., electrical stress, temperature, environmental conditions etc.
- Compatibility between materials needs to be part of the development program.
- Assessment of the cable systems ability to withstand transient overvoltages.
- Tests done to verify no axial oil flow for type tests, PQ tests and EQ tests.

NEW Prequalification tests

- Prequalification tests are for new insulating materials and are not intended for kraft paper insulated mass-impregnated/pressurized cables from manufacturers with previous service experience.
- The prequalification test is intended to indicate the long-term performance of the complete cable system.
- The prequalification tests need only be carried out once unless there is a substantial change in the cable system with respect to materials, manufacturing processes, construction or design parameters.
- A range of approval is proposed in the TB.
- Approximately 100 m of cable including complete accessories.
- Minimum duration is 360 days.

- The normal sequence of tests shall be as follows:
  - Long duration voltage test;
  - Superimposed impulse voltage test;
  - Examination.



TB 496 tutorial

NEW Prequalification tests

LCC test sequence

	LC	LC	LC+PR	HL	HL	ZL	LC	LC	LC+PR	S/IMP
Number of cycles or days	30 cycles	30 cycles	20 cycles	40 days	40 days	120 days	30 cycles	30 cycles	20 cycles	Not applicable
Test Voltage	+	-		+	-	-	+	-		$U_{P2,O} = 1.2*U_0$ $U_{P1} = 1.8*U_0$*
	U_{TP1}	U_{TP1}	U_{TP2}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP2}	

VSC test sequence

	LC	LC	HL	HL	ZL	LC	LC	S/IMP
Number of cycles or days	40 cycles	40 cycles	40 days	40 days	120 days	40 cycles	40 cycles	Not applicable
Test Voltage	+	-	+	-	-	+	-	$U_{P2,O} = 1.2*U_0$
	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	U_{TP1}	$U_{P1} = 1.8*U_0$*

LC=Load Cycle, HL=High Load, ZL=Zero Load, S/IMP=Superimposed Impulse Test.

* If required

NOTE: If the insulation system is sensitive to low ambient temperature it should be considered to perform some of the load cycles at low ambient temperature.

NEW Extension of qualification for mass-impregnated cables

- Kraft paper insulated mass-impregnated cables have been developed in steps from 100 kV voltage level to 525 kV which are in service today.
- Development has been verified by type testing and extended type tests and the experience from this stepwise development has been good.
- A test is introduced for extension of qualification for mass-impregnated cables to support further development of the technology.
- Substantial changes to MI cables (kraft paper insulated) will not result in a prequalification test, but an extended type test.
- The extended type test is only applicable if actual operating conditions are significantly different from previous service experience. A range of approval is proposed in the TB.

NEW Extension of qualification for mass-impregnated cables

The extended type test is only applicable if actual operating conditions are significantly different from previous service experience, such as:

- if conductor temperature exceeds previous experience by more than 5^{o}C
- if insulation material changes (change of insulation compound or kraft paper material specifications resulting in change of physical, electrical or chemical properties)
- if maximum steady state electrical stress and the transient electrical stress during polarity reversals (if LCC) exceeds previous experience by more than 5 %
- Voltage level >10 % compared to previous experience.

NEW Extension of qualification for mass-impregnated cables

The extended type test should be executed as follows:

For LCC: Type test as specified in §5 – followed by 84 daily load cycles with 1000 polarity reversals at 1.25 * U_0. Polarity reversal every 2nd hour. The test should be performed at high ambient temperature and at $T_{cond, max}$ and ΔT_{max}.

For VSC: Type test as specified in §5 – followed by 84 daily load cycles at 1.4 U_0. The test should be performed at high ambient temperature and at $T_{cond, max}$ and ΔT_{max}.

If the system is tested for LCC applications it will also qualify the system for VSC applications.

Examination of the cable system shall be done according to §5.8.

https://site.ieee.org/norway-pes/files/2015/10/IEEE_HVDC_121115_LarsLervikNexans.pdf

NEW Type test introduced for VSC systems

- Type test requirements have been modified to allow cable systems to be qualified for operation with voltage source converters without polarity reversals.

Electrical load cycle test:

LCC	VSC
• Ten "24 hours" load cycles at negative polarity at U_T; • Ten "24 hours" load cycles at positive polarity at U_T; • Ten "24 hours" load cycles with polarity reversal cycles at U_{TP1}.	• Fifteen "24 hours" load cycles at negative polarity at U_T; • Fifteen "24 hours" load cycles at positive polarity at U_T.

Superimposed impulse voltage test, switching surge withstand test:

LCC	VSC
• the test object at U_0, 10 consecutive impulses to $-U_{P2,O}$; • the test object at $-U_0$, 10 consecutive impulses to $U_{P2,O}$.	• the test object at U0, 10 consecutive impulses to $U_{P2,S}$; • the test object at U0, 10 consecutive impulses to $-U_{P2,O}$; • the test object at -U0, 10 consecutive impulses to $-U_{P2,S}$; • the test object at -U0, 10 consecutive impulses to $U_{P2,O}$.

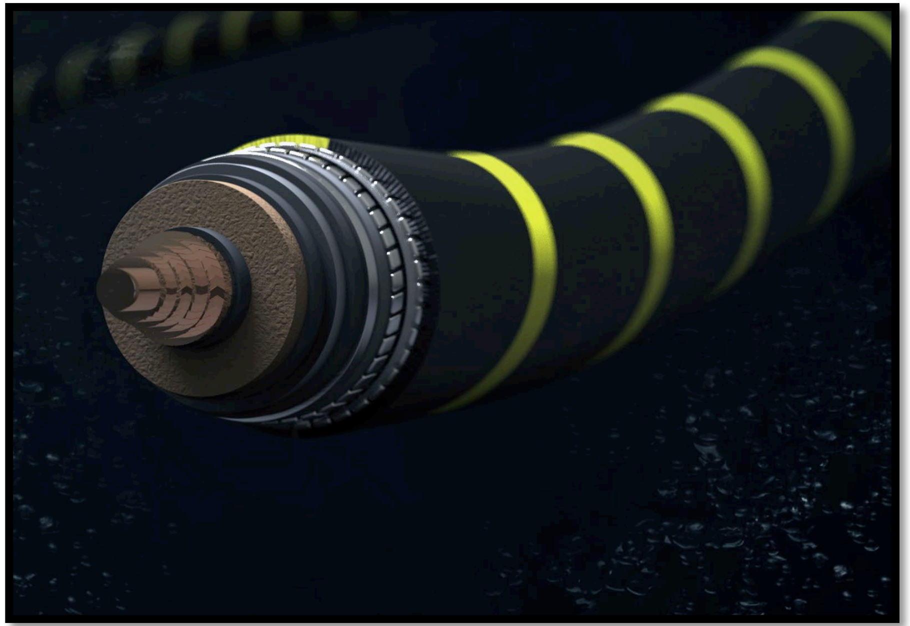
- A cable system qualified according to this recommendation for LCC is also qualified for VSC provided the switching impulse withstand tests at $\pm U_{P2,S}$ voltage levels are carried out.
- A cable system qualified according to this recommendation for VSC is not qualified for LCC.

NEW Type tests

Non-electrical type tests

The following non-electrical type tests are now included and described

- Longitudinal water penetration test for non-pressurised cables. The purpose of the test is to assess the longitudinal water penetration properties of each design.
- Measurement of specific thermal resistivity of insulation system. The purpose of the test is to verify the specific thermal resistivity of the insulation system at maximum conductor temperature used in ampacity calculations.



northsealink.com

NEW Routine tests

- Routine tests chapter is re-arranged from Electra 189.
- Test duration for intermediate high voltage test and factory acceptance test (FAT) is increased from ***15 to 30 minutes***.
- References to routine test on terminations included
- Tests on factory joints recommended

NEW Sample tests

Change from Electra 189. Sample tests are now listed in a separate chapter.

- Tests made by the manufacturer on samples of complete cable or components taken from a complete cable or accessory at a specified frequency to check that the finished product meets the specified requirements.

- The following new test are described in the TB
  - Measurement of thickness of insulation and non-metallic sheath
  - Measurement of thickness of metallic sheath
  - Measurement of diameters, if required
  - Conductor examination
  - Check of insulation
  - Check of construction at FAT

NEW Special temporary overvoltage test

According to the work of CIGRE JWG B4/B1/C4.73 [B19], two new overvoltages can be experienced on HVDC cable systems on top of conventional lightning and switching impulses:
very slow front overvoltages with same polarity to actual DC voltage and
oscillating overvoltages with opposite polarity peaks to actual DC voltage.

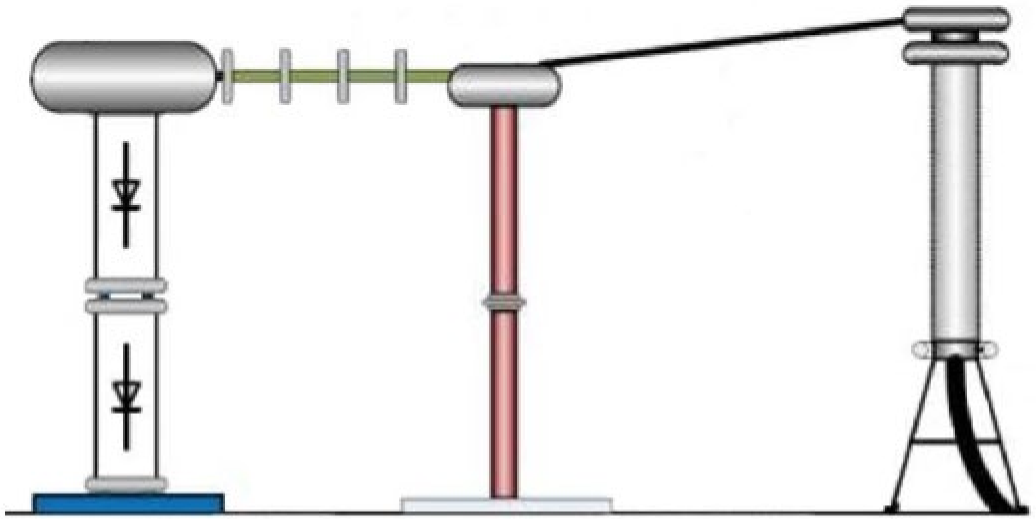
The intention of the tests is to verify that these special conditions together with the cable system design give acceptable results.
The tests are intended only to investigate the system limits; therefore, the test values (namely voltage, time and number of applied overvoltages) shall not be considered as design parameters for insulation coordination.

NEW After installation test

Every delivery length of cable shall be submitted to a negative DC voltage equal to the test voltage defined for the load cycle test U_{TP} and applied between conductor and sheath for **30 minutes** (increased from 15 minutes).

Included:

- More detailed description for TDR fingerprint.
- Test duration extended from 15 minutes to 30 minutes.
- Outer sheath test of land cables.



Source: TB 841

Main differences between TB 852 and TB 853

Main differences between WG B1.62 and B1.66

The two WGs met several times before the issuance of the respective TBs in order to align them as much as possible. The intrinsic differences between the two technologies, solid-insulation and lapped insulation cables, however, led to some substantial differences in the TBs.
In the case of extruded cables, particular attention must be paid to polarization phenomena and the consequent formation, in the insulation volume, of space charges capable of distorting the electrical field.
For cables with taped insulation, on the other hand, particular attention must be paid to the behaviour of the insulation system itself and its ability to maintain unaltered electrical performance even when subjected to thermal stress that induce displacement of the compound impregnating the papers (or the laminate).
The most significant differences are related to:

- DEFINITIONS:
    - HVDC and EHVDC;
    - Transition joints.
- TESTS:
    - Sequences and heating cycles definition for all Type Test, EQT and PQT;
    - need to carry out PQT;
    - Thermal stability test required only for cable with solid insulation (TB 852)
    - Testing at low and high temperature for lapped insulation
- EXTENSION OF QUALIFICATION TEST
    - Detailed guidance for selection of procedure in case of changes in a qualified cable system given by TB 852.

Conclusions

Conclusions

- Two updated test recommendations for DC cable systems ≤ 800 kV have been prepared
  - **Extruded insulation systems** (increased from < 500 kV) **Cigre TB852**
  - **Lapped insulation systems** (no change in voltage level) **Cigre TB853**
- The recommendations have been aligned where relevant
  - Some differences are required because of the properties of the insulation systems and previous experience
- The recommendations have addressed the results from JWG B4/B1/C4.73 “Surge and extended overvoltage testing of HVDC Cable Systems” by proposing a “special temporary overvoltage test”
- The updated recommendations provide a good basis for testing and future development of DC cable systems up to and including 800 kV

Thank you for your attention!

Presented by: Frank de Vries
Member of National Committee B1
Mob.: +31 621899571
Email: frank.de.vries@tennet.eu

Prepared by: Roberto Gaspari
Technoplatform Manager Monitoring & Digitalization
Mob.: +47 909 74 904
Email: Roberto.gaspari@nexans.com

Medium Voltage DC Cable Systems

B1 WG 82

Conveiner Paul Knapp

cigre

For power system expertise

Scope

The WG will explore and attempt to cover the following items:

1. **Existing experiences and applications for MVDC cables**
2. **System Requirements**

   a) Losses & Efficiency to be determined by cost, voltage drop and/or CO_2 emissions

   b) Operation Conditions, cable ratings, overload capacity, fault current and durations, wet/dry installations

   c) Fault clearance strategies – single disconnect, reclose strategy, system fault in converter and other constraints in line with JWG C6/B4-37.

1. **Recommendation of boundary of HV/MV & AC/DC material (where and when DC specific solution material/ accessories become relevant/required)**
2. **Review of existing HVDC & MVAC cable standard(s) for recommendation to MVDC cable system**
3. **Operations, Safety & Maintenance**

Expected publication of Technical Brochure 2026