CIGRE

# CIGRE UK Webinar Tutorial:

# HVDC Cables, Technical Brochures 852 and more

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For power system expertise

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- Main differences between TB 852 and TB 853

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# *New Definitions*

*Added to TB 496*

# *New Definitions*

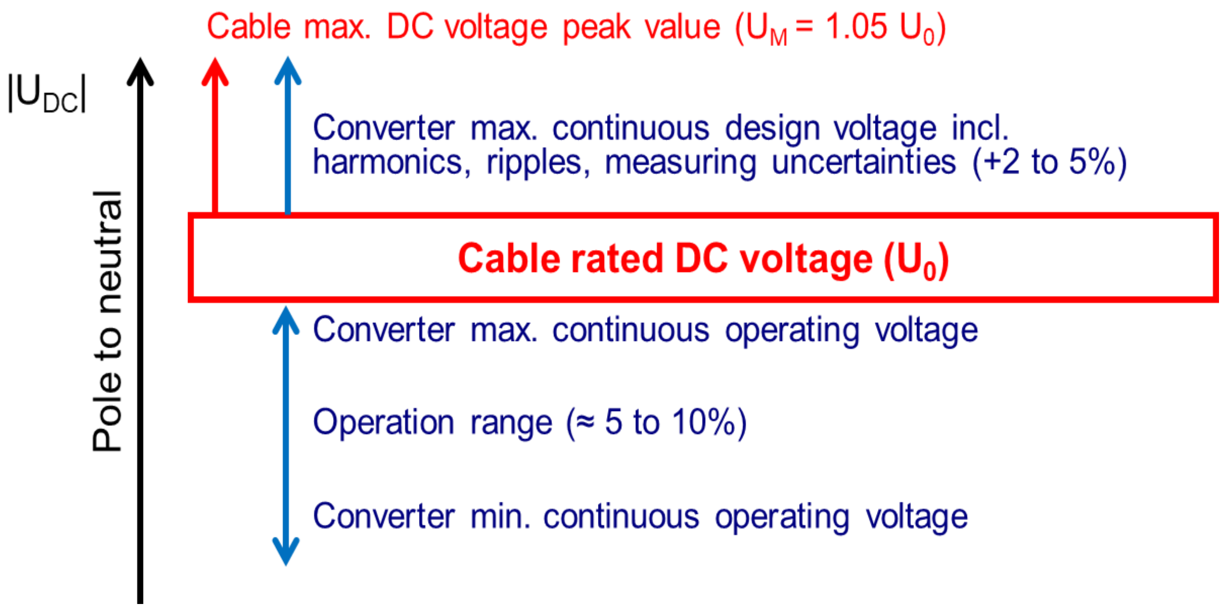
- **DC voltage classes**
  - HVDC: $U_0$≤ 400 kV and average stress ≤ 20 kV/mm
  - EHVDC: $U_0$ > 400 kV or average stress > 20 kV/mm
- **Joints**
  - Flexible joint
  - Rigid joint
  - Factory joint
  - Flexible/Rigid Repair joint
  - Flexible/Rigid Field joint
  - Asymmetric joint
  - **Interface joint**
  - Transition joint

*Added to TB 496*

# New Definitions

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

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



*Added to TB 496*

# 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

## *Technical basis*

# DC voltage factors

- Based on available V-t characteristics for DC operation
- Inverse power law provided a conservative basis for the work
- A value of **n = 10** was selected in **TB 496 and kept in TB 852** since **no significant finding allowed to modify this approach today**

$$V^n \cdot t = const$$

where:

*V* : voltage

*t* : time

*n* : life exponent from V-t characteristics

$$V_{dc} = V_0 \cdot K_1$$

where:

$V_0$ : system voltage

$K_1$ : test voltage ageing factor

# *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, $K_1$ | $\sqrt[10]{40 \cdot \frac{365}{360}} = 1.45$ | $\sqrt[10]{40 \cdot \frac{365}{82}} = $ **1.68** | $\sqrt[10]{40 \cdot \frac{365}{30}} = 1.85$ |

# *Duration of tests*

- Evaluation of resistivity and the time constants ($\tau$) 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**

| Temperature (°C) | $\varepsilon$ (F/m) | $\rho$ ($\Omega$.m) | Time for stability, 10 $\tau$ (hours) |
|---|---|---|---|
| **20** | $2\times10^{-11}<\varepsilon< 3\times10^{-11}$ | $10^{15}< \rho< 5\times10^{16}$ | $55<10\ \tau < 4300$ |
| **60** | $2\times10^{-11}<\varepsilon< 3\times10^{-11}$ | $10^{13}<\rho< 5\times10^{14}$ | 0,6< 10 $\tau$< 43 |
| **90** | $2\times10^{-11}< \varepsilon< 3\times10^{-11}$ | $10^{13}<\rho< 10^{14}$ | $0.6< 10\ \tau < 8.3$ |

| Condition | Temperature | Testing time (Days) | Time for stability, 10 $\tau$ (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

# *Qualification Tests overview*

Changed from TB 496

# Prequalification Test

- Same scope, range of approval and test sequence as in TB496
- **Better specified "*Substantial change*"** in §10 "*Guide for the selection of test procedures in case of changes in a qualified cable system*"

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 | + | - | | + | - | - | + | - | | $U_{P2,O} = 1.2\,U_0$ |
| | $U_{TP1}$ | $U_{TP1}$ | $U_{TP2}$ | $U_{TP1}$ | $U_{TP1}$ | $U_{TP1}$ | $U_{TP1}$ | $U_{TP1}$ | $U_{TP2}$ | $U_{P1} = 2.1\,U_0$ |

## 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.

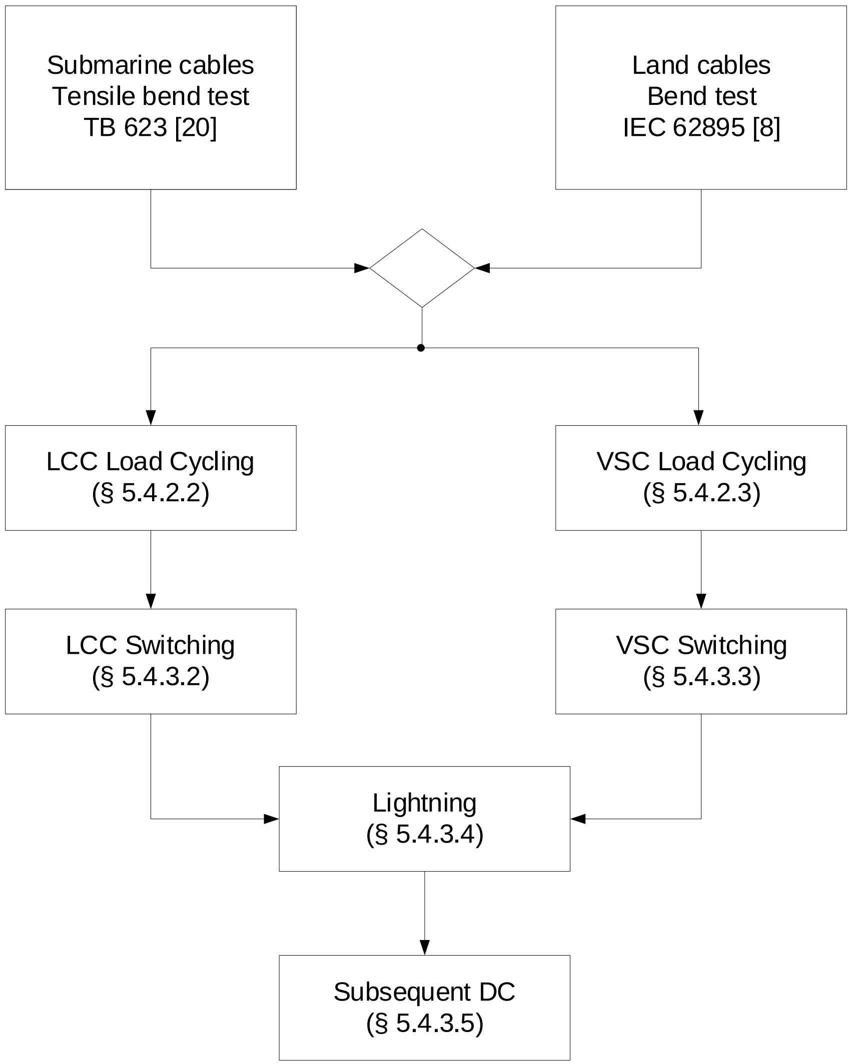
*Changed from TB 496*

# Type Test: Overview

Tests 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.

**No changes from TB496 to Electrical test sequence**.

**Updated mechanical test sequence** (in accordance with latest Standards and Recommendations) **and additions to non-electrical tests and tests on accessories**.



*Changed from TB 496*

# *Type Test: Non-Electrical & Mechanical test*

## Non-Electrical Tests

- Applicable non-electrical tests as specified in IEC 62895
- Water penetration test as specified in IEC 62895 for land cables
- Water integrity testing as specified in TB 623 for Submarine cables
- **By-products content in insulation material**
- **Pressure test of thermoplastic insulation**
- **Hot set test of cross-linked insulation**

## Mechanical Tests

- Mechanical preconditioning (bending) as specified in IEC 62895 for **Land** cable systems
  - The bending radius shall be the smallest between the inner diameter of the drum and the minimum installation radius and the bending radius defined in IEC 62895.
- Mechanical tests as specified in TB 623 for **Submarine** Cable systems

*Added to TB 496*

# *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 |

*No changes from TB 496*

# *Type Test: Return cable*

- Mechanical preconditioning
- Thermo-mechanical preconditioning
  - 24 daily cycles, without any requirement on $\Delta T_{max}$
  - 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

*Added to TB 496*

# *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:

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

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.

*Added to TB 496*

# *Thermal Stability Test (TST)*

**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.

*Added to TB 496*

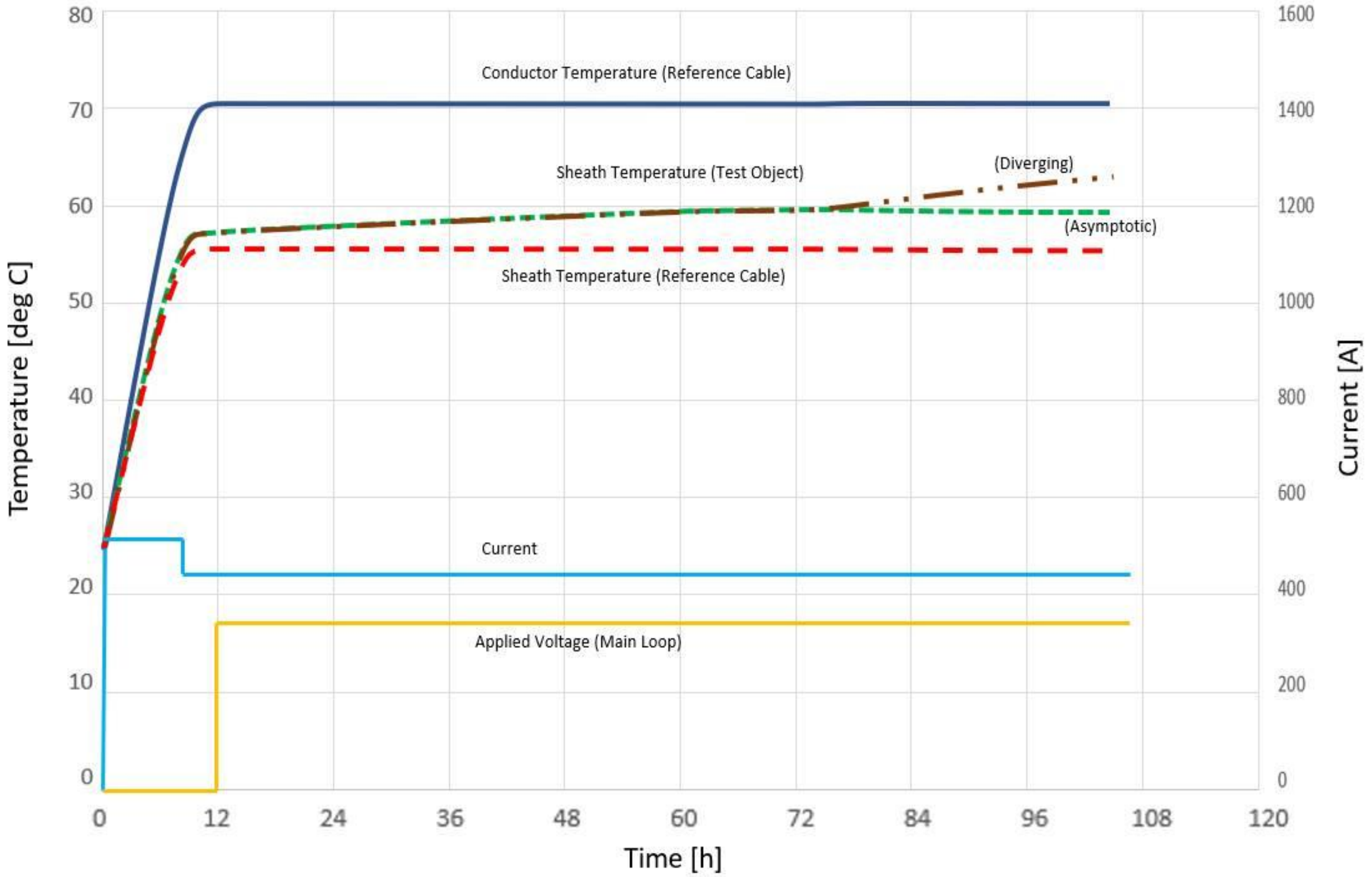
# *Thermal Stability Test (TST)*

**TEST CONDITIONS**

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

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.



*Added to TB 496*

# *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.

*Added to TB 496*

# Extension of Qualification Test (EQT)

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.

LCC test sequence ($U_{EQ1} = 1.68U_0$, $U_{EQ2} = 1.37U_0$):

| | LC | LC | LC+PR | HL | HL | ZL | LC | LC | LC+PR | S/IMP |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of cycles or days** | 4 cycles | 4 cycles | 12 cycles | 18 days | 18 days | 6 days | 4 cycles | 4 cycles | 12 cycles | Not applicable |
| **Test Voltage** | + | - | | + | - | - | + | - | | $U_{P2,O} = 1.2\,U_0$ |
| | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ2}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ2}$ | $U_{P1}' = 2.1\,U_0$ |

VSC test sequence ($U_{EQ1} = 1.68U_0$):

| | 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** | + | - | + | - | - | + | - | $U_{P2,O} = 1.2\,U_0$ |
| | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{EQ1}$ | $U_{P1}' = 2.1\,U_0$ |

*Added to TB 496*

# 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<br>* 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<br>*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 | | | |

*Added to TB 496*

# *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.

# *Verification Tests (routine, sample and after installation) overview*

# 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.

*No changes from TB 496*

# *Routine Tests: Factory joints of submarine cables*

- AC voltage test, if applicable
  - Test procedure and requirement as per cable
- PD measurement, if applicable
  - Test procedure and requirement as per cable
- DC voltage test
  - Test procedure and requirement as per cable
- X-ray inspection

*No changes from TB 496*

# *Routine Tests: Repair joint for submarine cables*

- If the joint consists of pre-fabricated insulation components
  - The procedures according to prefabricated joint, as closely as possible

- If the joint is not built up by any pre-fabricated components
  - The manufacturer and customer shall agree on the most practical solution

*No changes from TB 496*

# *Routine Tests: Return cables or conductors*

- AC testing is to be preferred for the testing of return conductors.
- The voltage level and time of application shall be agreed between the supplier and customer.
- If due to long manufacturing lengths AC testing is impractical.
  - A suitable DC voltage, agreed between supplier and customer, shall be applied.
  - It is recommended that the DC voltage test be no lower than the highest of either $2.5 \cdot U_{RC,DC}$ or 25 kV, the voltage shall be applied between conductor and metallic sheath for 1 hour.

*Changed from TB 496*

# *Sample Tests: Transmission cables*

- For materials which are not considered by IEC 62895 or this Technical Brochure, the test program shall be agreed between manufacturer and customer.
- The frequency of tests according to IEC62895 except for "Water penetration test, if applicable" for submarine cables, which shall be in accordance with agreed quality control procedures.
- In the absence of such an agreement, one test shall be made for contracts with a cable length up to 50 km and one additional test every additional 100 km delivered cable length.

- Conductor examination
- Measurement of electrical resistance of conductor and of metallic screen/sheath
- Measurement of capacitance
- Measurement of thickness of insulation and non-metallic sheath
- Measurement of thickness of metallic sheath and/or dimension of screen wires
- Measurement of diameters, if required
- By-products content on insulation material
- Volume resistivity of semiconductive screens
- Pressure test of thermoplastic insulation
- Hot set test of cross-linked insulation
- Impulse voltage test
- Water penetration test, if applicable
- Adhesion and peel strength of the laminated metal foil of cables with longitudinally applied metal tape or foil, bonded to the oversheath, if applicable

*Added to TB 496*

# *Sample Tests: Prefabricated joints and terminations*

- **Tests on components**
  - The characteristics of each component shall be verified, either through test reports or through internal tests.
  - The manufacturer of a given accessory shall provide a list of the tests to be performed on each type of component, indicating the frequency of each test.
  - The components shall be inspected against their drawings. There shall be no deviation outside the declared tolerances.
  - **As components differ from one supplier to another, it is not possible to define common Sample Tests on components in this recommendation.**
- **Tests on complete accessory**
  - **For accessories where the main insulation is routine tested, no electrical Sample Test is required.**
  - For accessories where the main insulation cannot be routine tested, the voltage test shall be carried out by the manufacturer on a fully assembled accessory.
- **Examples of main insulations that are not routine tested are insulations taped and/or moulded on site.**

*No changes from TB 496*

# *Sample Tests: Factory joints for submarine cables*

- Sample Tests shall be performed on one factory core joint only, prior to starting manufacture of the joints.
- A sample of at least 10 m of cable and a factory joint shall be prepared for the tests.
- If the factory joint is type tested under the contract,

Tensile test

PD measurement and AC voltage test

- If applicable to the insulation system.
- After restoring the outer semiconductive layer and the metallic ground conductor or outer sheath.
- In accordance with the manufacturer quality assurance procedures.

Impulse voltage test

Hot set test for insulation where applicable

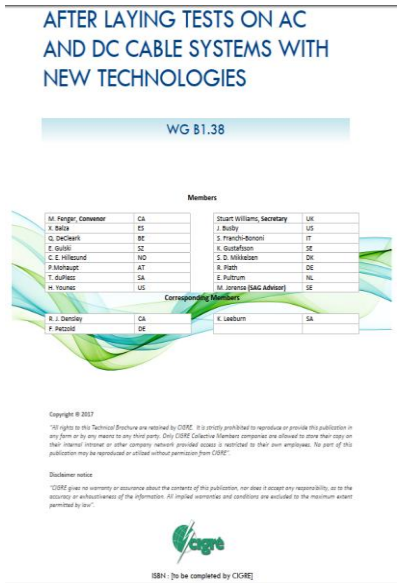
*No changes from TB 496*

# *Sample Tests: Repair and field molded joints*

- **Repair joints**
  - Not applicable for repair joints (submarine cable systems).
- **Field moulded joints**
  - The Sample Test sequence frequency and procedure is recommended in IEC 62895.
  - The same tests as prescribed for “factory joints of submarine cables” are applicable.

# After Installation Test

- 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.


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

WG B1.38

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ISBN : [to be completed by CIGRE]

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

# *Special Tests overview*

*Added to TB 496*

# *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**.

*Added to TB 496*

# *Temporary Over Voltage (TOV) Test*

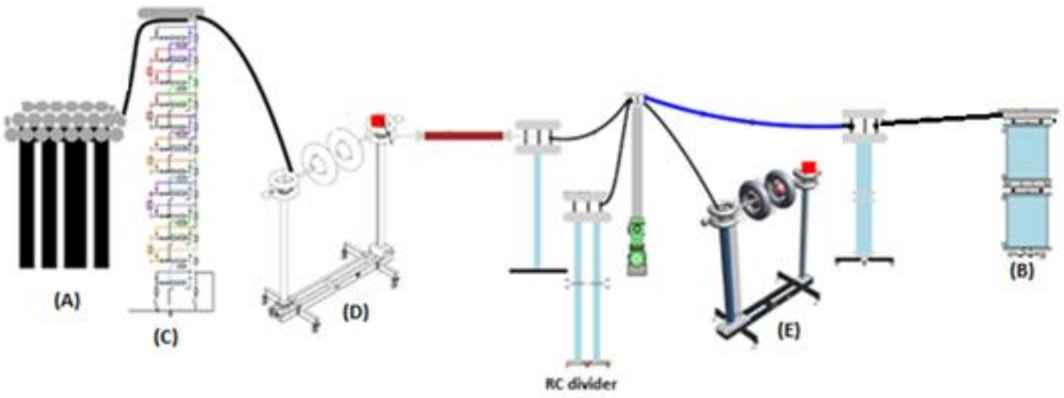
The intention of the tests is to verify that these special conditions together with the cable system design give acceptable results. It is not the intention that all tests described are automatically part of testing regime for HVDC and EHVDC cable systems, but more an exception to study and/or address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

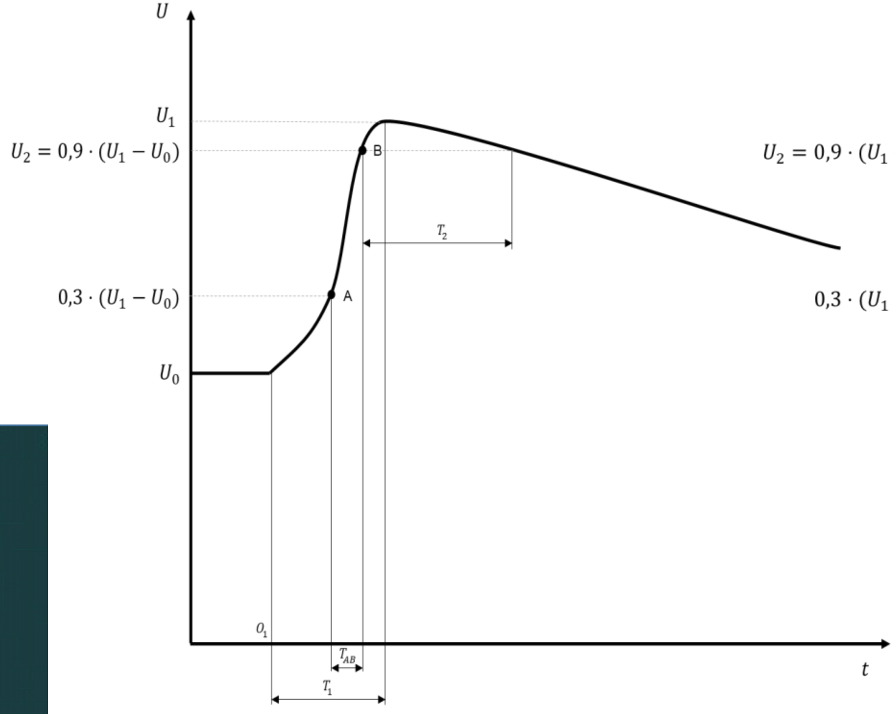
- the test object at $+U_0$, 10 consecutive TOVs to $+U_1$;
- the test object at $-U_0$, 10 consecutive TOVs to $-U_1$.



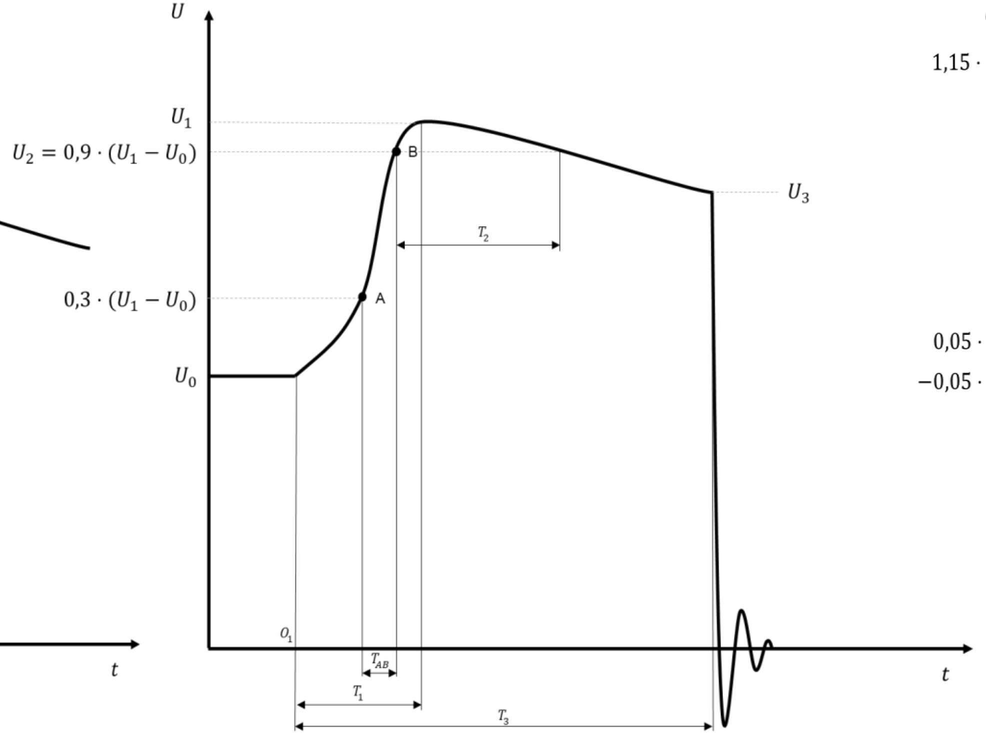
Added to TB 496

# Temporary Over Voltage (TOV) Test

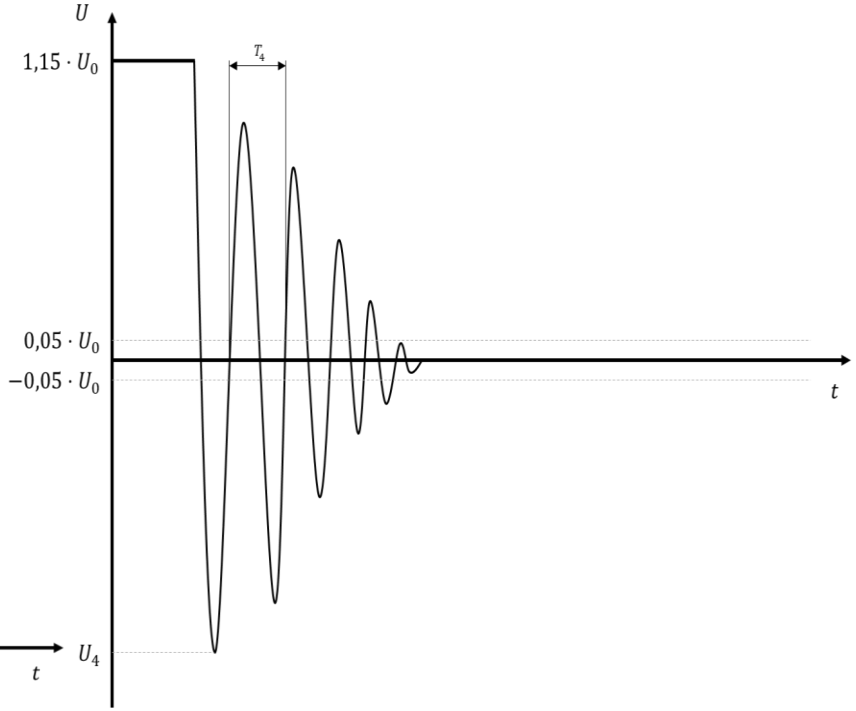
**Very slow front temporary overvoltage**




**Very slow front temporary overvoltage with chopped tail**




**Zero crossing damped temporary overvoltage**



# *Conclusions*

# *Conclusions*

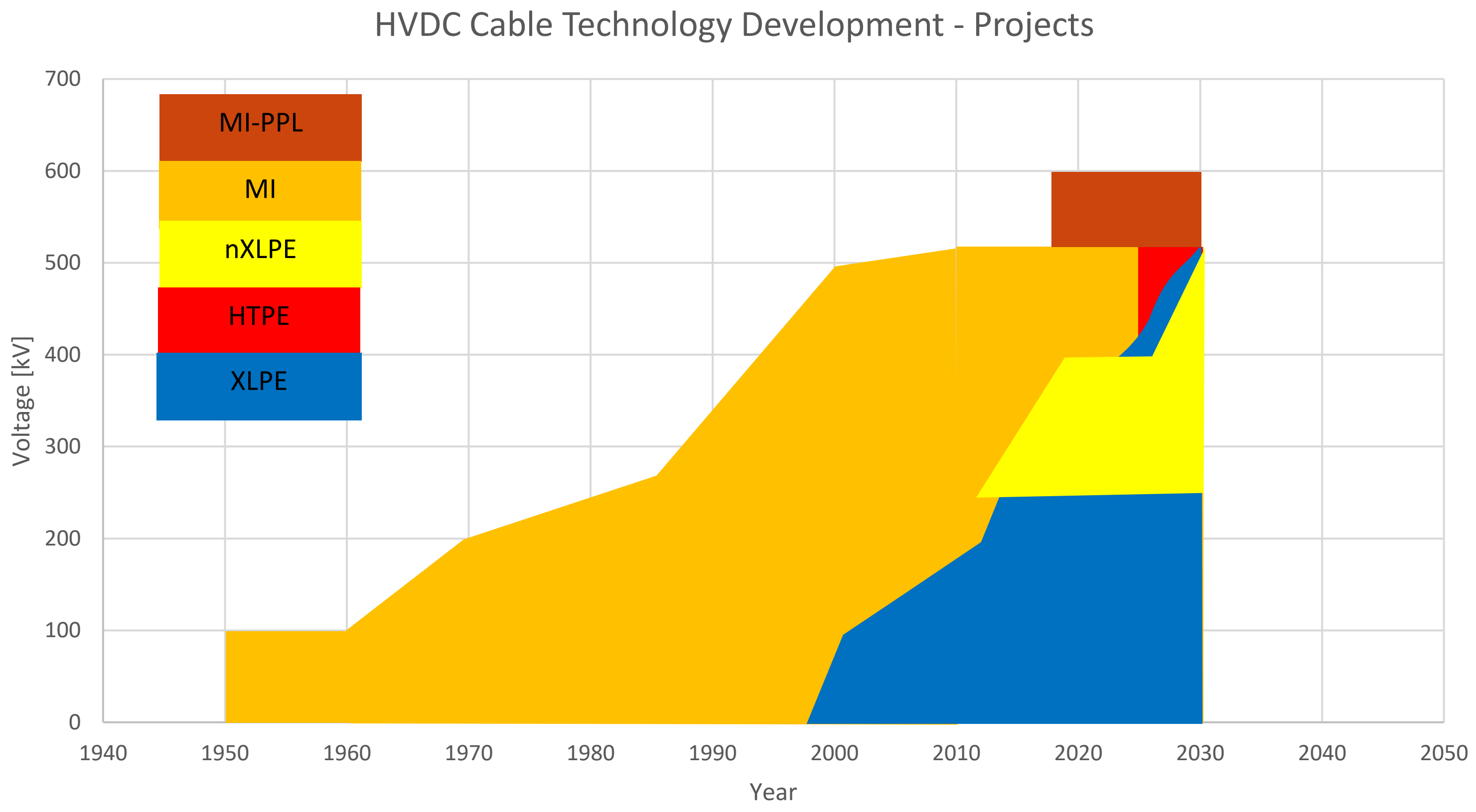
- Updated test recommendation for DC extruded cable systems ≤ 800 kV have been prepared
  - **Extruded insulation systems** (increased from < 500 kV)
- The recommendations have been aligned where relevant
  - Some differences are required because of the properties of the insulation systems and previous 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”

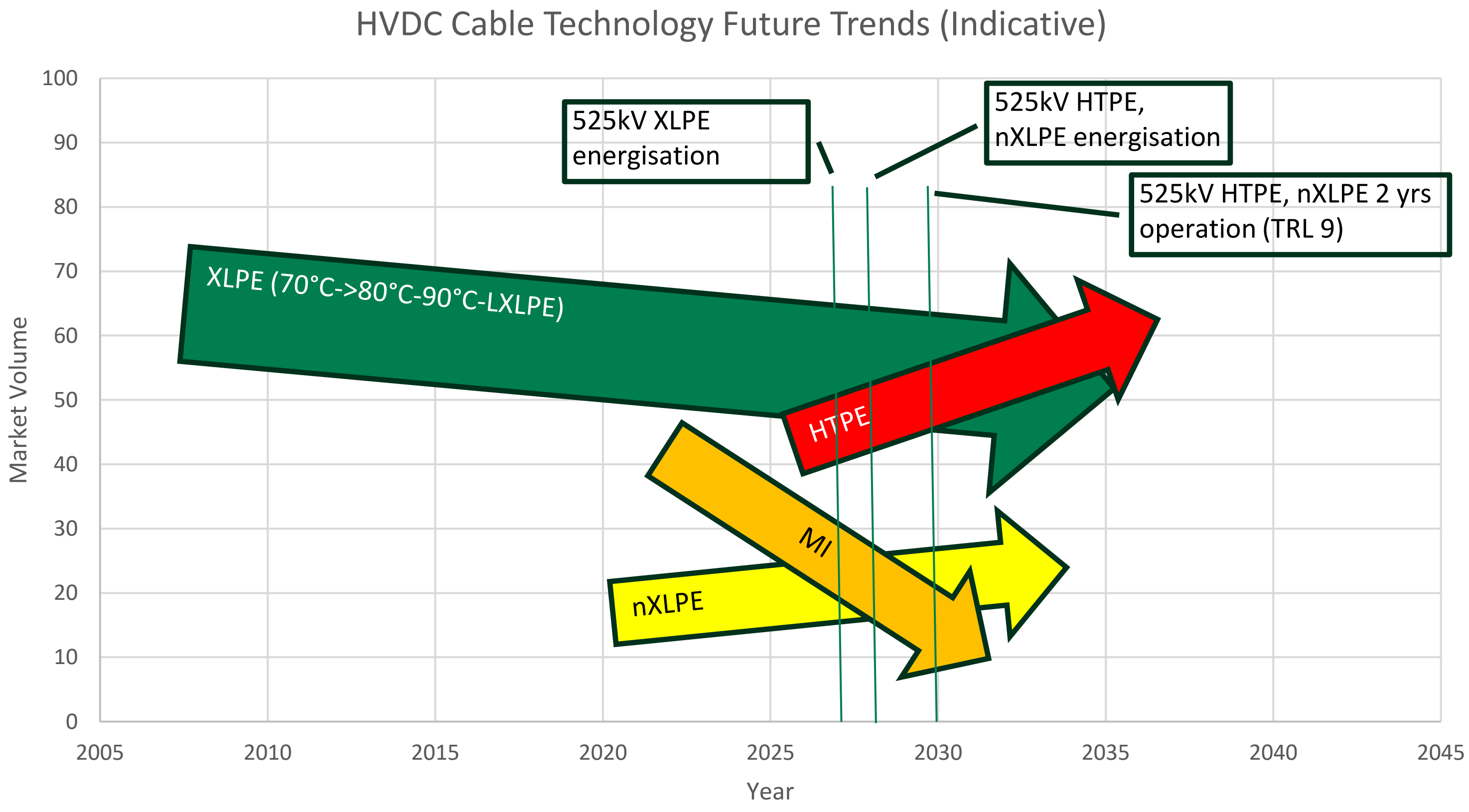
- The updated recommendations provide a good basis for testing and future development of DC cable systems up to and including 800 kV

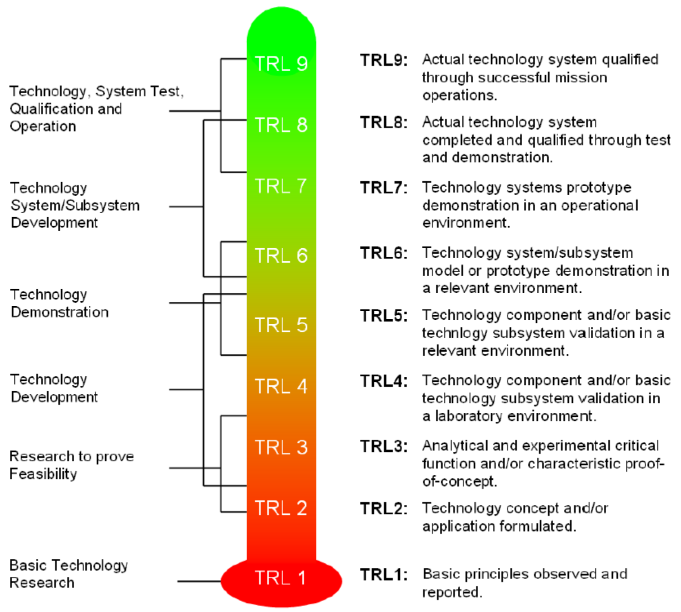
# Thank you for your attention!

# Technology Trends – Personal View

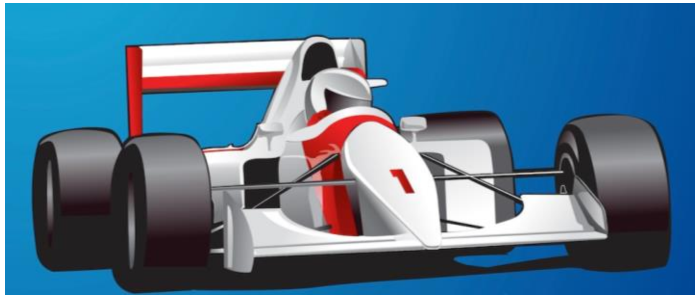


# Future Trends – Personal View

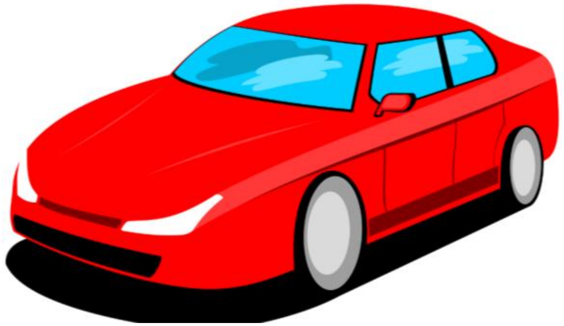


# AC vs DC comparison



- AC Electrical Stress (simple – Laplace)
- 25 years of 400kV-500kV extruded cable project experience
- Design Life - Verified
- Failure Rate – Established although some new failure mechanisms still found and RCA still identify:
  - Manufacture/Quality
  - Design
  - Installation/Construction
- Specifications – IEC/CIGRE
- Current Thermal Ratings – Developed
- Supply Chain – Developed new



- DC Electrical stress – complex, function of temperature and stress
- DC Stress varies with time due to time constants
- Materials – Higher performance
- Tighter Quality Required
- Higher level of degassing
- Affected by moisture to a greater degree than AC
- Accessories – complex design 3D effects of temperature and stress
- TOV – affected by system design
- AC transients under failure
- Current Thermal Ratings/Installation – higher risk due to stress Inversion
- Specification/Qualification (CIGRE and land IEC)
- Failure Rate at 525kV ?
- Design Life – high confidence on materials in service at 150kV-400kV
- Supply Chain - Developing

*Questions*