ENTSO-E Assessment

Framework for 525 kV HVDC Land and Submarine Cable Systems

Version 1.0 - Draft for Stakeholder Consultation
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Executive Summary

This document presents the ENTSO-E assessment on testing and (pre-)qualification of 525 kV high voltage direct current (HVDC) land and submarine cable systems. It has been developed in response to the European Commission Grid Action Plan and as part of ENTSO-E contribution to Action Point 1.3 of the Joint Roadmap Towards Future Proof Grids.

The objective of this assessment is to provide a common technical basis for transmission system operators for electricity when assessing cable systems intended for European projects, while ensuring harmonisation with IEC standards and CIGRE recommendations and maintaining a high level of technical confidence.

Action Point 1.3 identified the need to review diverging qualification and testing practices for HVDC cable systems and mandated ENTSO-E together with Europacable to assess harmonisation potential and propose pragmatic approaches for pre-qualification, type testing and extension of qualification.

This document constitutes the formal technical output of ENTSO-E experts and is intended for use by:

- Transmission system operators for electricity and project teams.
- Cable manufacturers.
- Procurement and contracting authorities.
- European institutions and regulatory bodies.
- Other stakeholders involved in offshore and onshore grid development.

It establishes minimum common requirements while allowing for project specific conditions related to installation environment, system operation and regulatory obligations. The document sets out:

- An assessment on a potential harmonisation of testing and qualification programme.
- Common principles for range of approval and extension of qualification.
- A transparent qualification decision process.
- Annexes capturing technical discussions.

The framework is designed to support coordinated application by TSOs and to provide a stable technical reference for manufacturers and other stakeholders involved in European HVDC infrastructure projects.

So far ENTSO-E achieved a good level of harmonisation on the prequalification and type testing programs and the extension of the CIGRE TB 852 range of approval tables, however at the time of this first draft publication, detailed internal review work by several TSOs is still ongoing and harmonisation will continue.

1. References and Definitions

The following international and European standards and technical recommendations were reviewed by the working group and constitute the primary technical reference set underpinning this assessment framework

1. All HVDC cable system relevant IEC, DIN IEC and EN standards, such as IEC 62895, DIN IEC 62895, IEC 62067, IEC 60840
2. All HVDC cable system relevant CIGRE Technical Brochures, such as TB 490, TB 496, TB 623, TB 758 and TB 852
3. Common Technical Specification for 525 kV HVDC Cable Systems (developed by RTE, Elia, 50Hertz, Amprion, Red Eléctrica)
4. Technical Specification: Extruded Cables for HVDC Underground Application above 320 kV up to 525 kV (developed by the German TSOs: 50Hertz, Amprion, TenneT and TransnetBW)
5. Other TSO individual specifications and approaches

Acronyms

The acronyms below are used throughout this document:

EPDM:	Ethylene Propylene Diene Monomer rubber
EQT:	Extension of Prequalification Test
FIMT:	Fibre in Metallic Tube
FOC:	Fibre Optic Cable
GIS:	Gas insulated switchgear
HVAC:	High Voltage Alternating Current
HVDC:	High Voltage Direct Current
NCR:	Non Conformity Report
PQT:	Prequalification Tests
sTr test:	Special Transient Voltage Test
SWAS:	Smooth Welded Aluminium Sheath
TSO:	Transmission System Operator
TST:	Thermal Stability Test
TT:	Type Test
VSC:	Voltage Source Converter
WSAF:	Wire Screen with Aluminium Foil
XLPE:	Cross Linked Polyethylene

Definitions

- Symmetric joint: Joint connecting two cables with the same design including cross-section, conductor material, insulation system and metallic screen type
- Asymmetric joint: Joint connecting two cables with the same insulation system but of different design such as different conductor cross-sections or conductor materials
- Interface joint: Joint connecting different extruded insulation technologies or cables produced by different manufacturers

- Sectionalised joint: Joint where the metallic screen/sheath and insulation screen are electrically interrupted
- Straight joint: Joint where the metallic screen/sheath and insulation screen are not electrically interrupted
- Production line: All machinery related to the manufacturing of the different layers of the power cable within a factory
- Extrusion line: All machinery related to the manufacturing of the insulation system (inner semiconducting screen, insulation layer and outer semiconducting screen) on one specific machine

2. Introduction

This document describes the evaluation results of nine European TSOs to achieve more harmonization on prequalification and type testing programs, including the application of range of approval, for HVDC underground and submarine cable systems.

Chapter 3 describes the background, the objectives and scope of work, the work approach and relevant information sources and involved stakeholders. Chapter 4 gives the harmonisation potential for prequalification and type testing programs. Chapter 5 shows an harmonised TSO's view on how to deal with extension of qualification, by applying the same principles of range of approval defined in CIGRE TB 852. The general conclusions and next steps are given in chapter 6 and chapter 7. In the Annexes, more detailed information is given on the harmonisation.

3. Objectives and scope

3.1. Background

The work leading to this assessment framework was initiated to address differences observed in testing and qualification practices across European projects and to establish a shared technical basis between TSOs and manufacturers.

3.2. Objectives

The objective of the ENTSO-E working group is to assess harmonisation potential for prequalification and type testing programs of the different TSOs in Europe. The work also includes harmonisation on how to deal with extension of qualification and the interpretation of the range of approval guidelines as given by CIGRE TB 852.

Harmonisation on cable design aspects and construction is not part of the evaluation as this is very country specific and depending on the environmental conditions and application. Europacable agreed not seeing this as a significant issue.

The topic of how to deal with new extrusion lines is also not discussed. The TSOs decided not to include this in the assessment as there is a CIGRE Taskforce B1.97 dealing with this topic with participation of the relevant experts (see chapter 3.4).

3.3. Scope of work

The work focusses on:

- Extruded underground and submarine HVDC power cables for voltage levels up to and including 525 kV.
- Accessories including various types of joints (e.g. factory joints, submarine rigid (repair) joints, underground joints (sectionalised and straight), underground to submarine transition joints, etc.) and terminations (indoor, outdoor and GIS).

At a later stage the harmonisation potential for HVAC power cable systems will be evaluated.

3.4. Overlap with CIGRE TF B1.97

The work of ENTSO-E has an overlap with CIGRE Taskforce B1.97. The scope of this taskforce is to improve range of approval tables for AC and DC cable systems (as provided by TB 852 and TB 303) and to give clarity on how to deal with new or modified extrusion lines. It is the aim to publish several CIGRE articles, probably in the first half of 2027. Three members from the ENTSO-E working group are also active in this CIGRE TF and take care of information exchange between both groups. The ENTSO-E position and harmonisation on range of approval is used as input for the CIGRE work.

3.5. Evaluation approach

To evaluate the harmonisation potential the following steps were conducted since the summer of 2025 up to the writing of this document.

- Two interactive sessions with Europacable to better understand their concerns and ideas.
- Preparation of a comparison table for prequalification and type testing programs as used by the different TSOs in Europe.
- Harmonisation sessions for prequalification and type testing programs by multiple online and physical workshops.
- Harmonisation sessions for range of approval by multiple online and physical workshops.
- Draft report and internal review sessions.

During the works, harmonisation between ENTSO-E and CIGRE TF B1.97 took place to avoid double work.

3.6. Involved stakeholders

- TSOs participating in the ENTSO-E working group: 50Hertz, Amprion, Elia, Red Eléctrica, RTE, Svenska Kraftnet, TenneT, Terna, TransnetBW.
- ENTSO-E Taskforce Supply Chain & Public Procurement.
- Europacable.

- CIGRE TF B1.97.

4. Harmonisation on prequalification and type testing programs

This chapter describes the evaluation of the different prequalification and type testing programs both for underground and submarine HVDC cable systems and the potential for further harmonisation. For the evaluation, ENTSO-E created a detailed comparison table where the approaches of each individual TSO were registered.

The comparison was done for underground and submarine HVDC cable systems. The table was divided in different categories:

- Prequalification test (PQT) program:
  - Requirements for test loop configuration and objects.
  - Test items and sequence for electrical testing.
  - Interruptions and re-testing.
- Type test (TT) program:
  - Requirements for test loop configuration and objects.
  - Test items and sequence for non-electrical and electrical testing.
  - Interruptions and re-testing.

At the start of the evaluation, the comparison tables revealed the different approaches used by TSOs. For instance, German TSOs referring to DIN IEC while others refer to international versions of the standards.

Based on multiple discussions (online and physical) the working group found major harmonisation potential for the prequalification test program. The results can be found in Annex 1 to this document.

Harmonisation of the type test program on European level seems to be more complex, especially when it comes to submarine cables. For underground cables there is potential for further harmonisation, even if different approaches may be driven by local conditions and project specific requirements. Nevertheless ENTSO-E is of the opinion that harmonising of PQ test programs has higher priority, considering the long test duration

The achieved harmonisation for prequalification and type testing programs is given in table 1 below.

Table 1: Result of the evaluation

	Total number of items that was evaluated	Harmonised after (and before) evaluation	Still under discussion	Details
PQ testing program	21	15 (4)	6	See Annex 1
Type testing program	63	24 (10)	39	-

5. Harmonisation on the application of range of approval.

This chapter summarises the ENTSO-E evaluation of the range of approval table as provided by CIGRE TB 852. This range of approval table describes the tests that need to be performed to extend prequalification, in case the cable system, production process or field application (e.g. stresses) have undergone a modification.

The evaluation was done for both underground and submarine HVDC cable systems, where the German 4TSO HVDC underground cable specification and 5TSO HVDC submarine and underground cable specification were both used as starting point for the discussion.

The working group evaluated the approach of each TSO against the range of approval guidelines of the CIGRE TB 852, (based on experiences in past projects). Multiple gaps, unclarities and insufficient guidelines were observed from the TSOs' point of view (see Table 2 below). In total 122 evaluation items were identified.

Table 2 TSO view on CIGRE TB 852 range of approval

TSO view on CIGRE TB 852 range of approval	#Items
TB852 guidance is sufficient and can remain unchanged	39
TB852 guidance is insufficient or unclear and needs to be changed	24
Gaps observed. Additional guidance is needed	59

What can be observed is that many gaps are identified especially for HVDC cable accessories. ENTSO-E is of the opinion that more attention is needed for accessories, since most of the problems lie with HVDC cable accessories. The range of approval table in TB 852 is mainly focussing on the HVDC cable itself.

Another topic of discussion is the extension of qualification test (EQT) program of CIGRE TB 852. ENTSO-E is of the opinion that the number of load cycles used for the EQT is too little and not in line with the CIGRE TB 303. This topic needs further discussion within ENTSO-E and CIGRE.

A complete and detailed ENTSO-E Range of approval table can be found in Annex 2 to this document.

The same ENTSO-E Range of approval table is shared with the CIGRE TF B1.97. This taskforce will use the table as input for further technical discussions.

6. Conclusion

At the start of the evaluation, the comparison tables revealed the different approaches used by TSOs. For instance, German TSOs referring to DIN IEC standards while the other TSOs refer

to IEC standards. Based on multiple discussions (online and physical) the working group found major harmonisation potential for the prequalification test program.

Harmonisation of the type test program on European level seems to be more complex, especially when it comes to submarine cables. For underground cables there is potential for further harmonisation, even if different approaches may be driven by local conditions and project specific requirements. Nevertheless ENTSO-E is of the opinion that harmonising of PQ test programs has higher priority, considering the long test duration

The working group achieved a good harmonisation on a broad extension of the CIGRE TB 852 range of approval tables. Detailed internal review work by several TSOs is still ongoing in some parts of the table.

7. Next steps

The ENTSO-E working group will take the following actions to come to further harmonization between TSOs and implementation of the achieved harmonisation. The following actions are planned.

- Further internal harmonisation session for the range of approval table.
- Discussion of open topics with Europacable.
- Request for review by additional TSOs within ENTSO-E.
- Providing input to and review the outcome of the CIGRE TF B1.97.
- Implementation of the harmonised results in the TSO specific project specifications.
- Communication towards the sector by presenting on an international platform (i.e. CIGRE).
- Create an ENTSO-E prequalification test specification for HVDC cable systems (if deemed feasible).
- Harmonisation evaluation for HVAC underground and submarine cable systems test programs.

Annex A Results of harmonisation sessions for prequalification testing program of Underground and Submarine HVDC Cable Systems

Harmonised PQ Test Program - 525 kV HVDC Cable Systems

Legend: Green = harmonised Yellow = Open item / still under discussion

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
Test objects and loop					
Test objects and loop	Total cable length	approx. 100 m	approx. 100 m	approx. 100 m	Harmonised. All TSOs within the working group use 100 m, according to IEC standards and CIGRE recommendation.
	Min. cable length between accessories	5 m	10 m	10 m	Harmonised. Working group agreed to 10 m between accessories, according to (DIN) IEC 62895. Working group is of the opinion that there is length enough in the 100 m long test loop to reach 10 m between accessories. This completely eliminates longitudinal thermal influences as well.
	Min. uninterrupted length of tested cable	10 m	no additional requirement	no additional requirement	Harmonised. All TSOs within the working group use 10 m, according to CIGRE TB852.
	Fixation	not specified	not specified	not specified	Item is still open. Fixation is joint design and supplier specific. This needs more discussion in the working group.
	FAT of test objects prior to assembly	not specified	not specified	not specified	Harmonised. Working group agreed that this should be required for new/future PQT. Not mandatory for already performed PQ tests. There is a big incentive for manufacturers to perform

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
					routine and sample tests in order to reach successful PQT results.
	Test objects (Underground cable system)	Large conductor cross sections of cable are recommended. Test objects not specifically defined but loop shall include complete cable system. Range of approval applies.	Range of approval applies.	Range of approval applies.	Item is still open and needs further discussion within the working group. In particular a discussion is ongoing on the number of test objects to include.
	Test objects (Submarine cable system)	Large conductor cross sections of cable are recommended. Test objects not specifically defined but loop shall include complete cable system. RoA applies.	Not applicable to submarine systems.	Not applicable to submarine systems.	Item is still open and needs further discussion within the working group. In particular a discussion is ongoing on the number of test objects to include.
	Temperature monitoring / Dummy loop	Min. 5 m reference loop. Sensors: 3 conductor, 2 sheath on ref loop; 3 sheath on hottest spot of loop. Temp. diff. central conductor sensor to others <2K. Heating current diff. within 1%.	Min. 5 m reference loop. Sensors: 3 conductor, 3 metal screen, 1 sheath on ref loop; 1 sheath on loop. Temp. diff. <2K. Heating current diff. within 1%.	Same as IEC 62895.	Item is still open and needs further discussion with Europacable.

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
	Crosslinking by-product concentration measurement	Not for PQ test. Only for TT as reference for Sample Testing. 4×3 specimens for TGA or alternatively 1×3 specimens for Chromatography.	Not specified.	Not for PQ test. Only for TT as reference for Sample Testing. No test procedure specified.	Item is still open and needs further discussion with Europacable.
	Insulation thickness verification	Voltage to be adjusted in case of 5–15% deviation to nominal value.	Voltage to be adjusted in case of 5–10% deviation.	Voltage to be adjusted in case of 5–10% deviation.	Harmonised. Working group agreed to follow (DIN) IEC 62895.
Test Sequence					
Test Sequence	Mechanical preconditioning (Underground cable)	Optional. Bending test with diameter calculated considering ODs of cable and conductor and inner diameter of drum. Afterwards visual examination and adhesion/peel strength test.	Bending test with diameter calculated considering ODs of cable and conductor. Afterwards visual examination and adhesion/peel strength test.	Same as IEC 62895.	Harmonised. Working group agreed that for new/future PQTs this test shall be done prior to electrical testing, either according to Cigré TB852 or (DIN) IEC 62895.
	Mechanical preconditioning (Submarine cable)	Optional.	Standard not applicable to	Standard not applicable to submarine systems.	Harmonised. Mechanical preconditioning shall be done prior to electrical testing, at least once per manufacturing location. Shall include: Tensile bending test (CIGRE TB623 §5.2), Tensile test

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
			submarine systems.		(CIGRE TB623 §5.5), Bending test (CIGRE TB852 §5.4.1). Working group proposes 200 m water depth as a starting point. Not applicable when qualifying a new extrusion line.
	Attenuation measurement (after mech. preconditioning)	not specified	not specified	not specified	Harmonised. Not a strict requirement but highly recommended after mechanical preconditioning (PQT) to identify problems early. For the type test, attenuation measurement is a strict requirement.
	Sheath test (Underground cable)	Optional only.	Mandatory.	Mandatory.	Harmonised. The sheath test is mandatory for new PQ tests. Existing PQ tests without sheath test may be accepted. DIN IEC requires sheath test to verify correct manufacturing and installation of the loop.
	AC & PD voltage test	not specified	not specified	not specified	Harmonised. AC+PD test on total test loop is highly recommended but not mandatory. Individual components may be subject to AC+PD as part of routine test/FAT prior to assembly of PQT loop.
	Long duration voltage test	Minimum duration 360 days.	Minimum duration 360 days.	Minimum duration 360 days.	Harmonised. All working group members agree to follow (DIN) IEC 62895 and CIGRE TB852. One TSO additionally requires space charge measurements according to IEEE 1732 (before and after load cycles), without acceptance criteria. PQT already performed without space charge measurements could be acceptable.
	Superimposed impulse voltage test	SI test with opposite polarity. LI test optional. Test on complete loop or cable samples with min. 30 m	SI test with opposite polarity. LI test optional.	SI test with opposite AND same polarity. LI test mandatory. Test on complete	Most working group members harmonised to follow CIGRE TB852 §4.5. SIMP shall always include LI test. One TSO deviates and requires SI and LI for same and opposite polarity. SI on same polarity

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
		active length including all relevant accessories.	Test on complete loop or cable samples with min. 30 m active length.	loop or cable samples with min. 30 m active length.	needed for VSC technology. LI on same polarity applicable for cable–overhead line combinations or VSC technology. German TSOs can accept CIGRE TB852 approach if LI is always included.
	Attenuation measurement (after voltage test)	not specified	not specified	not specified	Harmonised. Working group recommends including attenuation measurement per IEC 60793-1-40 to identify problems early. Not a strict requirement.
	Examination	Visual examination of cable and accessories. No specification on number and length of samples.	Visual examination of cable and accessories. Cable samples of min. 1 m length from different positions.	Same as IEC 62895.	Harmonised. Working group agreed to follow (DIN) IEC 62895. More detailed examination guidelines and pass/fail criteria are still under discussion.
Re-testing and interruptions					
Re-testing and interruptions	Interruptions	Similar to TB 852.	Similar to TB 852.	Similar to TB 852.	Harmonised. Working group agreed to follow CIGRE TB852.
	Re-testing	In case of a failure in a test object, the test shall be repeated on a new object of	Similar to TB 852.	Similar to TB 852.	Harmonised. Working group agreed to follow CIGRE TB852 but with additional retesting rules depending on root cause. This needs further discussion with Europacable.

Category	Item	Cigré TB 852	IEC 62895	DIN IEC 62895	Status / Remark
		the same type as the failed one.			

Annex B Range of Approval for HVDC Cable System above 320 kV up to 525 kV and its accessories

Provided separately.