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OFFSHORE WIND ACCELERATOR (OWA)

Type testing of cable screen connections at termination

Improving reliability of metallic screen connections in offshore wind inter-array cables

Cables technical working group

March 2026

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This report is published under the Offshore Wind Accelerator (OWA) cables technical working group. It was delivered by Offshore Wind Renewables Catapult Development Services Ltd. (ODSL), a wholly owned subsidiary of Offshore Renewable Energy Catapult (OREC).

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Executive summary

This report presents the final outcomes of the project "Development of Updated Type Test Requirements for Cable Screen Connections" ("ScreenConnect"), with a focus on dissemination and standardisation of the proposed type test protocol for metallic screen (earthing) connections in offshore wind inter-array cable (IAC) terminations.

The report is structured into three key sections and an appendix section:

- Section 1: Introduction outlines the motivation and scope of the project, highlighting the need for improved reliability and standardised testing of screen connections in offshore environments.
- Section 2: Introduces a recommended type test protocol for qualifying metallic screen connections in offshore wind IAC terminations. The protocol focuses on thermal and mechanical endurance, excluding dielectric tests covered by IEC standards. It builds on CIRED WG17-1 with offshore-specific refinements, including short-circuit testing after heat cycling, a class-based short-circuit system, and a maximum declared operating temperature to ensure the widest range of approval (CIRED, 2021). Key steps include sample preparation, heat cycling (500 cycles), contact resistance measurement, IR thermography, and visual inspection. Acceptance criteria address electrical stability, thermal performance, and mechanical integrity, ensuring robust qualification under worst-case conditions and supporting future standardisation.
- Section 3: It provides strategic guidance for promoting the proposed type test protocol. It recommends engagement with standardisation bodies, actions for technical working groups, and highlights validation needs such as reduced-cycle testing and acceptance threshold refinement. It also outlines key dissemination channels and highlights the protocol's role in improving offshore cable reliability and harmonising testing practices. Calculation methods and technical requirements are provided in this section to ensure traceability and facilitate future standardisation work.
- Appendix 1: Summarises key aspects for the proposed type test protocol.

The proposed protocol addresses a critical gap in current testing practices by introducing a standalone endurance test for screen connections, focused on thermal ageing and contact resistance stability. Its adoption is expected to enhance offshore cable system reliability, reduce maintenance risks, and support harmonisation of testing practices across the industry.

This report serves as a foundation for future standardisation efforts and invites collaboration from manufacturers, certifiers, and developers to validate, refine, and implement the protocol across offshore wind projects.

Nomenclature

CIGRE	International Council on Large Electric Systems
CIRED	Congrès International des Réseaux Electriques de Distribution
IAC	Inter-Array Cable
IEC	International Electrotechnical Commission
IR	Infrared
ODSL	Offshore Renewable Energy Catapult Development Services Ltd.
OEMs	Original Equipment Manufacturers
OREC	Offshore Renewable Energy Catapult
OWA	Offshore Wind Accelerator
OWGP	Offshore Wind Growth Partnership
R&D	Research and Development
SMEs	Small and Medium-sized Enterprises
TF	Task Force
$V_{i\text{-}vi}$	Voltage Measurement of Screen Connection i to vi
V_R	Voltage Measurement of the Reference Cable Core
WG	Working Group
d	Distance between Adjacent Screen Connection Devices in test circuits
d'	Effective Joint Length, representing the spacing between screen connections across a joint
I_{NC}	Conductor current
I_{NS}	Screen current
k	Resistance factor
k_o	Resistance factor for the same connector before heat cycles
l_{RS}	Length of the Reference Cable Core
l_c	Length of Cable Core
l_r	Length between the reference cable core's voltage measurement points
Dp	Spacing between Cable Cores Positioned in Parallel
θ_{RC}	Reference Conductor Thermal Equilibrium Range
λ	Resistance Factor Ratio
δ	Initial Scatter
Y_{5-500}	Change in resistance factor over the full endurance test (dimensionless)

1. Introduction

The Offshore Wind Accelerator ("OWA") is an industry-driven collaborative research, development and demonstration programme which was initially launched by the Carbon Trust in 2008 in collaboration with five offshore wind developers. The programme has since expanded during OWA Stages I, II, III and IV to include currently nine offshore wind developers from various countries within the European Economic Area (the "OWA Partners") – SSE Renewables Developments (UK) Limited, Ørsted Wind Power A/S, RWE Offshore Wind GmbH, ScottishPower Renewables (UK) Limited, Equinor ASA, Vattenfall Vindkraft A/S, EnBW Energie Baden-Württemberg AG, Shell Global Solutions International B.V. and TotalEnergies OneTech.

OWA Stage IV, dated 27th October 2020, aims to continue the cost reduction of offshore wind to make it cost competitive with other sources of energy generation, overcome market barriers, develop industry best practice, trigger the development of new industry standards and support the international expansion of offshore wind.

Research under the OWA currently falls into five research areas: Cables, Electricals, Foundations, Logistics and O&M, and Energy Yield & Performance. Research, development and demonstration projects are carried out in each of the five research areas to address technology challenges. Each of the five research areas is managed by the Carbon Trust and governed by a Technical Working Group ("TWG") consisting of technical experts appointed by the OWA Partners

The ScreenConnect project was initiated by the OWA's Cables Technical Working group (TWG-C) to improve the reliability of power cable accessories by developing enhanced testing methodologies and promoting more standardised, rigorous type testing practices for cable screen connections.

This guideline aims to compile technical findings into a clear, actionable guideline document. It also focuses on disseminating the knowledge to industry stakeholders to promote widespread adoption of improved testing standards, thereby enhancing the reliability and performance of cable screen connections in offshore wind power systems.

This report focuses on creating, publishing, and promoting a guideline that consolidates the ScreenConnect project's findings and recommendations. Its goal is to turn technical results into practical, industry-ready guidance and ensure broad dissemination for maximum impact. This report is tasked with producing a structured, technically robust guideline document, including:

- Summarising background research and test development processes.
- Documenting proposed type test procedures, test protocols, and design criteria.
- Presenting conclusions and key recommendations to inform future testing and design standards.

2. Guideline to type test protocol for offshore wind IAC terminations

A recommended type test protocol for offshore wind IAC terminations is proposed to qualify metallic screen connections under thermo-mechanical stresses, adapting CIRED WG17-1 for broader applications. It provides a framework for industry-wide adoption and future standardisation, focusing on the contact resistance and associated failure modes that could lead to overheating, rather than on dielectric performance.

2.1. Scope and objective

The protocol qualifies metallic screen connections used in offshore wind IAC terminations, focusing on their thermal endurance and the stability of the contact interface under operational and fault conditions (short-circuit). It excludes dielectric testing, which remains covered by existing IEC standards. The protocol builds on CIRED WG17-1, refined through expanded and more detailed technical considerations to support wider applicability to metallic screen-connection qualification. This section sets the foundation for understanding the rationale and intended application of the proposed test protocol.

2.2. Key refinements to CIRED framework

This section highlights the enhancements made to the CIRED WG17-1 framework to better suit offshore wind applications and supports future standardisation:

- Short-circuit testing moved to end of heat cycling, to assess the connection in its most aged state and to avoid the contact-resistance reduction that occurs when applying short circuit current mid-test, which can mask degradation and produce false-positive results.

- Class system introduced for short-circuit duty and voltage level, to maintain a consistent qualification structure, and together with the range-of-approval criteria, enable OEMs to group their screen-connection solutions under defined classes.

- Baseline of 500 cycles established, while concepts such as reduced-cycle testing are introduced for future investigation into time- and cost-efficient qualification approaches.

- Three cable cores in a loop configuration used for termination testing, to adapt the joint-focused CIRED WG17-1 setup to termination testing by using three cable cores in parallel, with defined spacing and lengths to avoid thermal interference between cores.

- Dwell period added to heat cycle profile, to ensure thermo-mechanical forces at the contact interface have sufficient time to act at peak temperature, whereas in CIRED WG17-1 cooling starts immediately after heating with no dwell stage.

- Multifactor assessment: electrical, thermal, visual, to capture a broader range of failure mechanisms, including contact-resistance drift, local overheating, and visible degradation at the interface.

2.3. Type test logic and flow

This section describes the logical sequence of the type test for screen-connection devices, ensuring clarity in execution and decision-making. Figure 1 summarises the overall type-test procedure, showing the main test stages together with the pass/fail logic and associated retest conditions. The key steps in the type-test procedure are summarised below (with more detailed procedures provided in *Sections 2.4* to *2.11*):

- **Determine the test current** to be applied to screen connection devices during heat cycle test (adopting the screen-current class defined in *CIRED WG17-1*).
- **Complete sample preconditioning and establish the test circuit** incorporating six screen-connection devices (see ***Section 2.4***).
- **Measure the contact resistance** of all screen-connection devices and the screen-connection devices on reference cable core (see ***Section 2.5***).
- **Apply the temperature-monitoring approach** defined in ***Section 2.6***, including reference-cable thermocouples and IR thermography (where available), to control the heat-cycle profile and identify any abnormal thermal behaviour.
- **Run the heat-cycle test** and measure the contact resistance throughout the cycling period (see ***Section 2.7***).
- **Perform the short-circuit** test under the defined test procedure (see ***Section 2.8***).
- Conduct calculations and assessments, including initial scatter, stability criteria, and resistance-factor ratio, alongside visual inspections and overall evaluation of the test samples (see ***Section 2.9***).
- **Pass/Fail Logic**: the acceptance criteria governing sample performance, allowable failures, and retest conditions are defined in ***Section 2.10*** (Acceptance Criteria).
- ***Worst-case representation: Section 2.11*** sets out the general principles for selecting worst-case configurations. This is not part of the flowchart in Figure 1, but a broader test principle ensuring that the type test reflects the most onerous combination for wider range of approval.

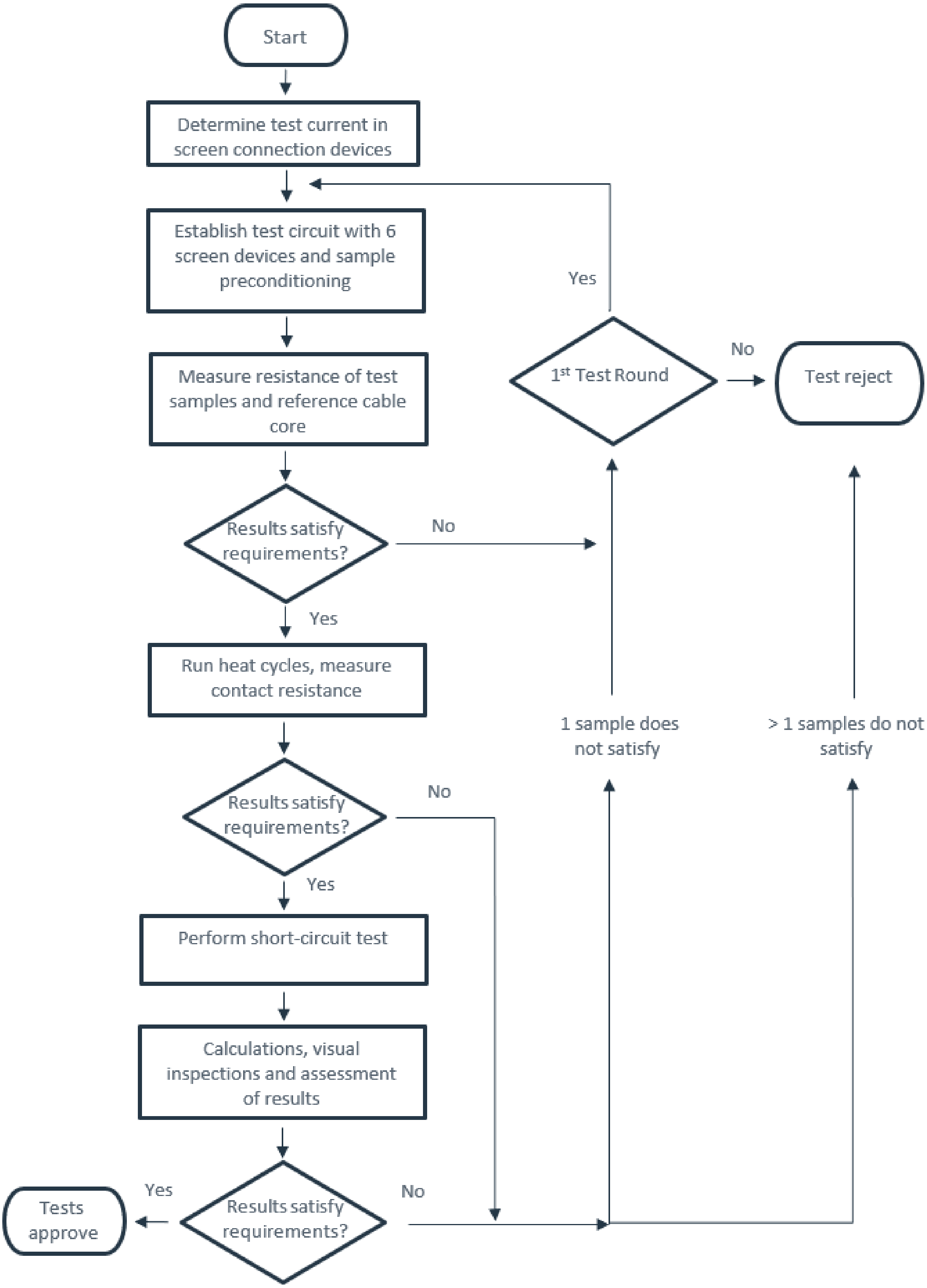


Figure 1. Recommended type test flowchart.

2.4. Test setup and sample configuration

This section describes the physical and environmental setup required for consistent and representative testing:

- Test environmental conditions: conduct tests indoors under stable laboratory conditions. Ambient temperature should be 20 ± 15 °C, and relative humidity, while not controlled, must be monitored. Avoid forced cooling or added insulation unless justified for project-specific testing.
- Cable cores preconditioning:
    - Bend three intact cable cores to the minimum allowable radius in one direction, then reverse to the opposite direction. This preconditioning must be completed prior to any stripping or preparation for the accessory. Each cable core should be prepared to the required length (minimum 3 meters long) before bending.
    - Repeat for 3 cycles.
    - Perform a visual check after preconditioning to confirm no damage has been introduced.
    - For pre-terminated cable systems, reverse-bending may be applied post-termination if this reflects expected mechanical handling and is agreed upon by stakeholders.
- Sample build:
    - Two configurations are defined:
        - Integrated configuration, the screen connection is inseparable from the termination body; approval applies only to that specific termination design.
        - Standalone configuration, the screen connection is a discrete component that may be used with different termination bodies, provided interface conditions are equivalent, enabling a wider range of approval across compatible designs.
    - For both configurations, the baseline approach is to test the screen connection as part of a complete termination assembly to capture interaction effects. The termination body shall remain intact with no modifications.
- Test circuit configuration:
    - Three single cable cores are to be connected in series and positioned in parallel, each containing 2 terminations, the test containing a total of 6 terminations.

      The conductors are serially connected via their closet neighbouring terminals, while only the metallic screens are routed in a transposed arrangement to ensure symmetrical current paths, as can be seen in Figure 2.
- Spacing:
    - Minimum 3 meters length of cable cores between terminations (l_c) on the same cable core
    - Minimum 3 meters long length of reference cable core (l_R), preferably matching the length of the cable cores on which the test samples (screen-connection devices) are installed.
    - Minimum 1 meter distance between parallel cable cores (D_p) where appropriate.
    - When a dedicated conductor coupling adaptor (e.g., T-connector, as defined for integrated configurations in the sample build) is required to maintain electrical continuity,

its integrity and low-resistance performance take priority over the 1 m spacing rule. In such cases, spacing between cable cores is determined by the termination assembly geometry, and distances below 1 m are acceptable.

- Check initial scatter (δ) following *Section 2.5*, If the calculated result does not satisfy the acceptance criterion in *Section 2.10*, the test circuit shall be re-built.
- Current sources and injection: two sources (to supply currents to core and screen conductors), matched to in-service connection (laboratory test setup must replicate the specific earthing and interconnection method used in field installation).
    - Provide two independent AC current sources: conductor current (I_{NC}) to heat the conductor, and screen current (I_{NS}) to load the screen connection.
    - If the design bonds copper wire screen and aluminium laminate together in service, inject I_{NS} so the combined path carries the current.
    - If they are bonded by separate devices, load each device to its representative service current. This ensures that even if short-sample impedances differ from long cables, each specific connection device is still tested against its actual rated service load.

Figure 2 shows the recommended cable layout and current routing for termination testing, ensuring uniform stress distribution and thermal realism.

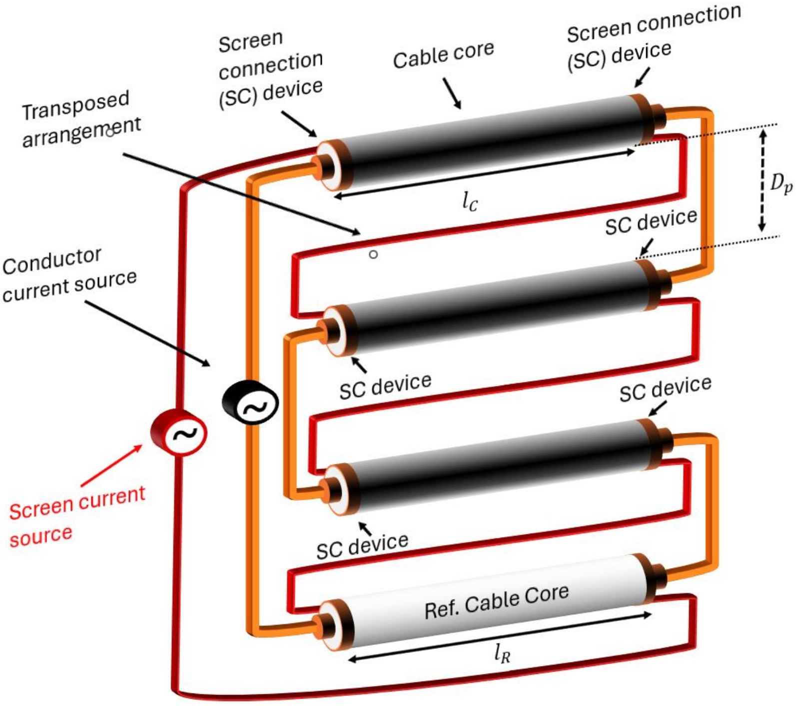
Note: The physical test set-ups illustrated in this guideline are examples only and are not prescriptive. In particular, the use of a three-cables-in-parallel arrangement is not a mandatory requirement of the proposed type test.

The recommended type test is governed by design principles, rather than fixed geometry. The primary objectives of the test set-up are to minimise thermal interference and electromagnetic field interaction between test objects, maintain a simple and well-defined layout, and ensure that the intended screen current path is stressed in a representative manner.

Different physical layouts may therefore be appropriate depending on the test objective and accessory type:

1. *A three-cables-in-parallel arrangement is particularly suited to T-connector applications, where space constraints and representative installation geometry are relevant.*
2. *A triangular layout may be preferable where the objective is to minimise thermal and electromagnetic interaction between samples.*
3. *A straight or linear layout remains appropriate for joints, which are already addressed under existing CIRED guidance.*

Allowing flexibility in the physical arrangement, while enforcing clear governing principles, is essential to maintain the wide scope of applicability of the guidance across different screen connection designs and application contexts.



D_p: Distance between cables cores in parallel.

l_c: Length of the test cable cores.

l_R: Length of reference cable core

Figure 2. Three cable cores are connected in series and arranged in parallel, forming a loop with six end-terminations.

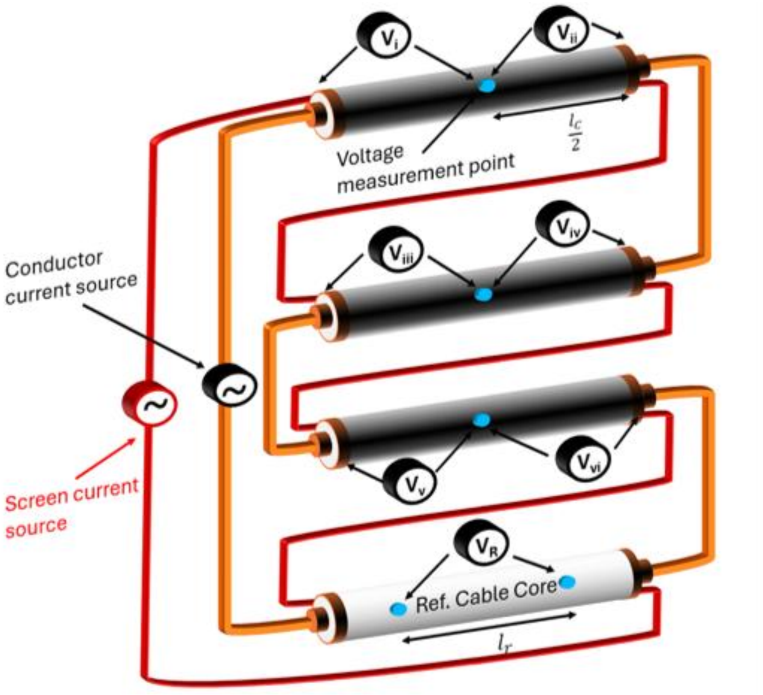
2.5. Contact resistance measurement

This section explains the procedure for measuring contact resistance, the primary performance metric for screen connections:

- Measurement method: two-wire technique where voltage measurement points are positioned directly across the screen connection interface.
- Current source: the current used for measuring the screen-connection device's contact resistance may be supplied from the entry side of the screen-current source used for heat cycling. The supplied current shall be known with sufficient accuracy to allow reliable calculation of the contact resistance, and the measurement path must exclude resistance outside the screen connection interface.
- Measurement timing: measure contact resistance between heat cycles, after cooldown, with no conductor current flowing, to eliminate induced voltages in the screen-voltage measurement. Use a DC current source to eliminate inductive effects.
- Voltages measurement points: each of the six test samples must have dedicated points for measurement (see Figure 3).
    - The midpoint measurement point requires cutting open the polymer sheath and exposing the metallic sheath and/or screen. An equaliser is needed to bond copper wire screens.
    - The contact resistance measurement method presented above is not suitable for cores with composite screen designs. For composite designs, the voltage can only be measured on the different layers at each end of the samples.

- Measurement shall be taken:
    - Before testing (initial baseline)
    - Periodically during heat cycling (To ensure data comparability, the ‘periodic measurements’ should be fixed at the end of the cooling period of each (i.e. when the system is closet to ambient temperature)
    - Before and after each short-circuit event, and at the end of the test programme.

Figure 3 shows the contact resistance measurement arrangement.



l_c: Length of cable cores in parallel

l_r: Length between the reference cable core’s voltage measurement points

$V_{i\text{-}vi}$: Voltage measurement of screen connection i to vi

V_R: Voltage measurement of the reference cable core

Figure 3. Contact resistance measurement.

2.6. Temperature monitoring

This section explains the approach for monitoring temperature during the type test:

- **General approach**: do not embed thermocouples in terminations or place sensors at presumed hot spots. Use non-contact IR thermography (if available) to measure the temperature of the screen connection. Use reference measurements (on a separate reference cable) to control the heat-cycle profile. IR is a supplementary tool only and does not form part of the primary acceptance criteria. Thermocouples may be mounted on the outside of the test samples for monitoring, control and protection.

- **If IR thermography is unavailable**: assess abnormal heating through reference-cable temperature control, visual observations during cycling, and post-test inspection.

- **IR monitoring practicalities**: continuous or out-of-hours monitoring is not required. Hand-held IR inspection during normal working periods is acceptable. Where IR is used, scans should be performed at steady-state temperature plateaus and periodically during cycling, maintaining consistent camera distance, angle and emissivity settings. IR images should be saved with timestamps. Heat-cycle scheduling should not depend on IR availability.

- **Thermocouples**:
  - Place thermocouples on the **reference cable** (surface, conductor and screen) to set and verify the heat-cycle profile.
  - For **test samples (screen connections under investigation)**, thermocouples can be placed at the cable core surface (close to the screen connection interface where the test samples are installed, to ensure that the test cable core and the reference cable core are at the same temperature).
  - Log ambient/enclosure temperature for reproducibility.
  - Record stabilised reference temperatures and corresponding current settings.

2.7. Heat cycle test protocol

This section defines the heat cycling procedure used to simulate long-term operational stress:

- Current sources:
  - It is preferred to apply both core and screen currents simultaneously.
  - Set continuous I_{NC} (conductor current) to reach and hold the target conductor temperature (maximum declared operating temperature).
  - Set continuous I_{NS} (screen current) to the level for the screen-current class claimed in CIRED WG2017-1 (CIRED, 2021).
  - Two independent AC sources for heat cycle test: I_{NC}, I_{NS}. I_{NS} corresponds to the screen-current level of the class being qualified following CIRED WG17-1. If screen and metallic water blocking layer share current through a single connection in service, load the combined path. If separate connections are used, load each device separately to share currents between them as expected in service. This may require separate, controllable sources.
- Cycle profile:
  - Heating phase (t_1): apply constant I_{NC} and I_{NS}, heating the conductor to reach target conductor temperature (rated temperature +5 °C / −0 °C).
  - Dwell (t_2): 2 hours (with constant I_{NC} and I_{NS} applied).
  - Cooling (t_3): cooling down to below 35°C or within 10K of ambient temperature, whichever is higher.
- Cycle count:
  - Default: 500 cycles.
- Resistance measurements:
  - *At least every 5 cycles up to cycle 100th.*
  - Every 50 cycles after cycle 100th.
- Check stability ($Y_{5\text{-}500}$) and resistance factor ratio (λ) following Section 2.5, the test or the system will be considered as failed if the calculated result does not satisfy the acceptance criterion in Section 2.10.

Figure 4 presents the temperature-time profile for each heat cycle, including heating, dwell, and cooling phases.

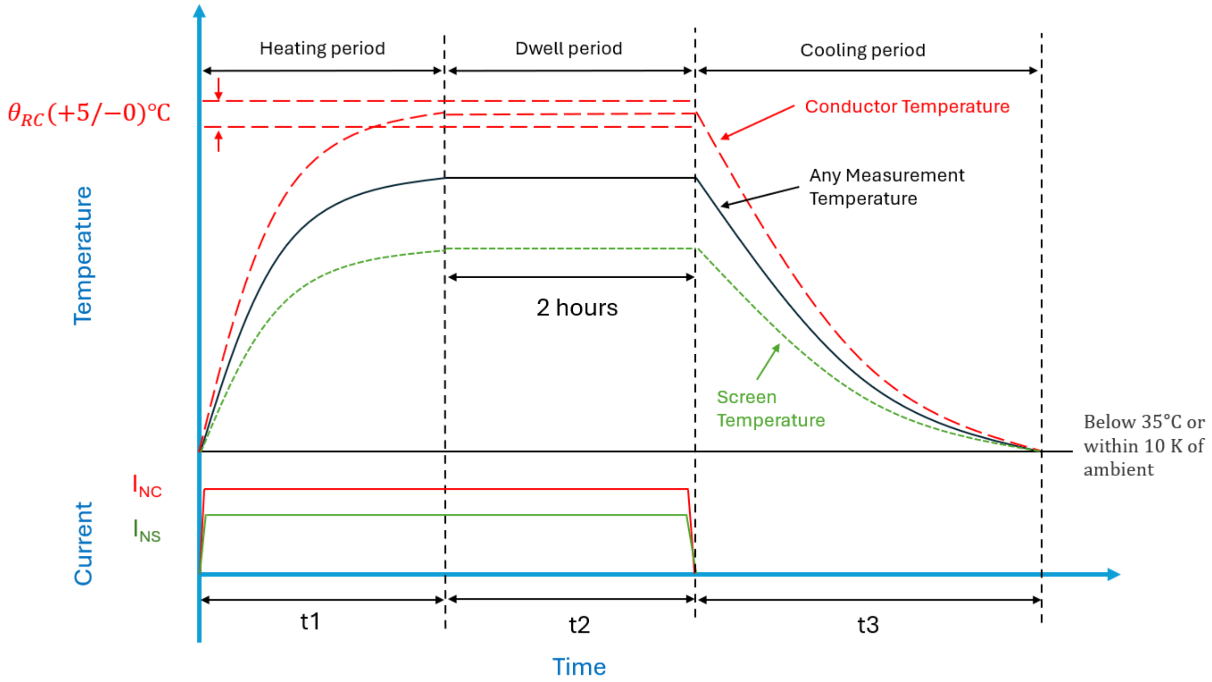


Figure 4. Heat cycle test thermal profiles.

2.8. Short-circuit test protocol

This section outlines the procedure for fault-level current testing:

- Set-up stability and relocation: relocation must follow stability checks.
- Timing: after completion of heat cycling.
- Events: apply two short-circuits.
- Select the short-circuit class (RMS value) in the test plan and apply at least that level:
    - Low: 2.5 kA for 1 s
    - Medium: 5 kA for 1 s
    - High: 15 kA for 1 s

Note: Equivalent energy/thermal duty (I^2t) over a longer duration at a lower current, up to 5 s can be applied, provided that:

- $I_b^2 t_b \geq I_a^2 t_a$
- $0.5I_a \leq I_b \leq I_a$
- $t_b \leq 5s$

$where\ I_a$ is the reference short-circuit current for 1 s class (RMS value); $t_a$is the reference duration of 1 s (per short-circuit class); I_b is the applied short-circuit current (RMS value, reduced for alternative method); t_b is the applied duration (s), not exceeding 5 s.

- Pre-Heating: Before applying the short-circuit current, heat the cable core's conductor and stabilise it at 90–95 °C for at least 2 hours, as recommended by *CIGRE 446* (CIGRE , 2011).
- Resistance measurements:
    - Before and after first short-circuit event, and after the second short-circuit event.
    - The contact resistance should be measured after the highest measured temperature cools down to below 35°C or within 10K of ambient temperature, whichever is higher.
    - Check resistance factor ratio (λ) following *Section 2.5* reject if the calculated result does not satisfy the acceptance criterion in *Section 2.10.*

2.9. Post-test inspection

This section describes the inspection procedures used to identify visible and hidden defects:

- Visual inspection:
    - After heat cycling and each short-circuit event.
    - Examine all six screen connections and adjacent areas. Record and photograph any visual signs of overheating or discolouration, corrosion, deformation or loosening of parts, insulation or sheath damage, compound migration, or other anomalies. Compare observations with the acceptance criteria in *Section 2.10*.
- Dissection:
    - At the completion of the test sequence, dissect all the screen connections to inspect contact interfaces and bonded areas for pitting, fretting, oxidation, loss of contact area, or other hidden defects.
    - Photograph findings and include them in the test report.

2.10. Acceptance criteria

Key parameters used in acceptance criteria include:

- Initial scatter, δ, of the resistance factor (k) across the six test samples.
- Resistance factor (k), a dimensionless ratio that normalises the contact resistance to the resistance of a reference length of the conductor measured at the same temperature. k_o is the resistance factor ratio for the same connector before heat cycles.
- Resistance factor ratio, λ, representing the highest resistance factor during the test relative to its initial value.
- Stability criterion (Y), a performance threshold used to determine whether test samples can be considered accept.

The following table below summarises the key performance thresholds used to determine pass/fail outcomes:

Table 1. Consolidation of electrical, thermal, and visual performance that define successful qualification of screen connections

Parameter	Definition	Threshold / Criterion	Notes
Initial scatter (δ)	Variability of resistance factor (k) across six samples before heat cycles.	Reject if $\delta > 0.3$	Confirms build consistency; avoids masking of early trends.
Stability criterion (Y_{5-500})	Change in resistance factor over the heat cycle test. Y_{5-500} is the change in resistance factor over the full endurance test.	Reject if $Y_{5-500} > 0.1$,	Applied after cycle 5th and at end of 500-cycle programme.
Resistance factor ratio (λ) during heat cycles	$\lambda = k / k_0$, overheat cycle test.	Reject if $\lambda > 2.0$	Must be combined with an absolute maximum contact resistance threshold $(m\Omega)$ to avoid acceptance of high initial values.
Resistance factor ratio (λ) during Short-circuit tests	$\lambda = k / k_0$, same k_0 should be used; λ measured before, and right after each test.	Reject if $\lambda > 2.0$	Drops in λ after short-circuit may indicate micro-welding and shall not be counted as improvement.
Visual inspection (including dissection at end of the test)	Inspection of samples after heat cycling, short-circuit tests, and final dissection to assess surface condition, mechanical integrity, and contact interfaces.	Reject if any signs of overheating, non-superficial corrosion, cracking, deformation/loosening, loss of contact area, fretting wear, or internal material damage are observed (including screen connection devices and cable cores).	Photograph and record all notable findings; confirm condition of actual contact surfaces during dissection.

Note: The thresholds are indicative only, and the calculation methods for the initial scatter, stability criterion, and resistance-factor ratio follow the procedures defined in CIRED WG17-1.

With the acceptance criteria mentioned in the above table, the conditions under which retesting is permitted and how data integrity maintained also clarified as:

- Retest: allowed only if one out of six samples fails in the first test round (as mentioned in Figure 1 the decision point – “1st Test Round”); Second test round: must use six new samples, and no further failure is allowed. A ‘test round’ is the full qualification/type test.

2.11. Worst-case representation

The guiding principle is that type testing should cover the highest combination of thermal, mechanical, and electrical stresses appropriate for the system. By testing these extreme cases, the number of tests required is minimised while remaining within the approved frame. Worst-case representation for this testing includes:

- Screen current class: maximum expected.
  - Adopt the highest screen-current level within the class being qualified, as defined by CIRED WG17-1. This ensures worst-case representation while maintaining the appropriate range of approval for that class.
- Operating temperature: Maximum declared operating temperature of the conductor.
- Restricted heat dissipation, avoid forced cooling.
- Material sensitivity: test most degradation-prone configurations.

Worst-case representation ensures that the qualified design is robust across the full range of expected offshore conditions.

3. Validation and improvement opportunities

While the protocol is technically comprehensive, several areas warrant further validation:

- Reduced-cycle protocol: Requires statistical validation to confirm early-cycle stability as a reliable predictor of long-term performance.
- Absolute resistance thresholds: Need to be calibrated against field data and thermal modelling.
- IR screening criteria: Should be refined to distinguish between benign and critical thermal anomalies.
- Short-circuit classification: May benefit from expanded classes or duration-based equivalence models.

4. Conclusions

The development of an updated type test protocol for metallic screen connections in offshore wind inter-array cable terminations represents a significant step toward improving reliability, standardisation, and industry confidence in cable accessory performance. Through a rigorous synthesis of stakeholder feedback, technical analysis, and benchmarking against existing standards, the proposed protocol addresses key gaps in current testing practices, particularly the lack of endurance-focused evaluation for screen connections.

The protocol's structure, grounded in IEC-style methodology and enhanced by offshore-specific refinements, offers a practical and scalable framework for manufacturers, developers, and certifiers. The protocol builds on CIRED WG17-1, refined through expanded and more detailed technical considerations to support wider applicability to metallic screen-connection qualification. Its emphasis on thermal ageing, contact resistance stability, and fault-level robustness ensures that screen connections are qualified under realistic service conditions.

The proposed protocol addresses a critical gap in offshore cable reliability assurance. Its adoption can:

- Enhance confidence in screen connection performance.
- Reduce maintenance risks and costs in offshore wind farms.
- Support harmonisation of testing practices across world.

Continued collaboration between developers, manufacturers, and standardisation bodies is essential to ensure the protocol evolves with industry needs and remains technically sound.

Validation efforts, such as round-robin testing, material sensitivity studies, and alignment with in-service failure data, will support evolution into a recognised industry standard.

Ultimately, this work contributes to the broader goal of enhancing offshore wind cable system reliability, reducing maintenance risks, and supporting the transition to a more resilient and cost-effective energy infrastructure.

References

CIGRE . (2011). *CIGRE TB 446:2011 Advanced design of metal laminated coverings - Recommendation for Tests, Guide to Use, Operational Feed Back.* CIGRE .

CIRED. (2021). *Test Recommendations for Ground Screen Power Cable Connections.*

Appendix 1: Summary of the key items for the proposed type test protocol

This document presents an abstracted version of a proposed type test protocol for qualifying metallic screen (earthing) connections used in offshore wind inter-array cable (IAC) terminations. Developed through an industry-supported research initiative, the protocol seeks to provide a consistent and technically robust method for assessing the performance and stability of screen-connection designs under thermo-mechanical stress under operational and fault conditions. The approach builds on the principles of CIRED WG17-1, with refinements introduced to cover broader applications, including offshore wind requirements and emerging failure mechanisms.

Only the key concepts and procedural elements are summarised here; this is not the full technical specification. The summary aims to give manufacturers, certification bodies, test laboratories, developers and standardisation groups a brief understanding of the proposed direction of work, while encouraging wider industry engagement. It provides the essential framework to support awareness, stimulate discussion and invite stakeholders to contribute feedback or request further technical detail as the methodology progresses toward broader consensus and future standardisation.

Table 2 provides a consolidated summary of the type test items, associated test conditions, and corresponding acceptance criteria (performance thresholds) and inspection requirements (visual or measurement checks to verify compliance) for the proposed type test protocol.

Figure 1 presents the type test logic and flow, considering six identical samples shall be tested under full protocol, also including pass-all rule and allowed retest condition.

Table 2. Summary of proposed type test protocol.

	Item (following Core document order)	Test Condition	Key Notes & Practical Considerations
1	**Environmental Conditions**	Indoor laboratory environment, **20 ± 15 °C**, humidity monitored. Avoid forced cooling or additional insulation unless justified.	Stable ambient conditions improve repeatability and comparability across laboratories and test campaigns.
2	**Cable Cores Preconditioning**	Reverse-bend each cable core **3 times** to the minimum allowable radius in both directions before screen connection and end termination assembly.	Help simulate handling stresses and release residual manufacturing or spooling tension before testing. For pre-terminated systems, reverse bending may be applied after assembly if that better reflects expected handling.
3	**Sample Build (Integrated vs Standalone)**	Integrated configuration: screen connection inseparable from termination body. Standalone configuration: screen connection is a discrete component compatible with multiple termination bodies.	Testing with the complete termination is preferred to capture interaction effects. Integrated designs apply only to that termination, while standalone screen-connection kits may support a wider range of approval if interface conditions are equivalent.
4	**Test Setup & Sample Configuration *(see Figure 1)***	Three cable cores are bent, prepared, and then connected in series and arranged in parallel to form six end-terminations, with a minimum 3 m cable-core length between terminations and 1 m spacing between parallel cable cores. A reference cable core of similar length is installed in parallel. The metallic screens are connected using cross-bonded return paths to establish symmetrical screen-current routing.	The three cable cores are arranged in series and placed in parallel to form six end-terminations, with defined spacing to avoid thermal interaction. The screens wires between parallel cable cores are routed using cross-bonded return paths, which balance induced electromagnetic fields.
5	**Current Sources & Injection**	Two independent AC sources for heat cycle test: I_{NC} (conductor heating), I_{NS} (screen loading). I_{NS} corresponds to the screen-current level of the **class being qualified following CIRED WG17-1**. If screen and metallic water	The conductor current is determined during the calibration cycle and must be set such that the conductor reaches its maximum

	Item (following Core document order)	Test Condition	Key Notes & Practical Considerations
		blocking layer share current in service, load combined path; if separate, load each representative component.	designed operating temperature and maintains this temperature throughout the dwell period.
6	**Contact Resistance Measurement *(see*** Figure 1*)*	Two-wire method; voltage taps directly across the screen-connection interface; exclude resistance outside the interface. Measurements: initial baseline, periodic during heat cycling, before/after each short-circuit. Measure contact resistance **between heat cycles**, with **no conductor current**, to avoid induced voltages. Use **DC current** for measurements to minimize proximity effects.	Contact resistance is the main indicator of interface performance. Measuring with zero induced voltage ensures accurate and consistent results.
7	**Temperature Monitoring**	No embedded thermocouples inside terminations. Place thermocouples on **reference cable core** surface, **conductor**, and **screen** to set and verify heat-cycle profile. Optional thermocouples on test cable core surface near the screen connection. IR thermography (if available) used for surface screening at steady-state plateaus and periodic intervals.	Reference temperature defines the heat-cycle profile. IR thermography provides supplementary evidence of heating patterns but is not an acceptance metric.
8	**Heat-Cycle Test *(see Figure 1)***	500 cycles including heating to the maximum declared operating temperature (+5/−0°C), a **2-hour dwell**, and cooling to below 35°C or within 10 K of ambient.	Heat cycling simulates long-term operational loading. The dwell period ensures adequate thermo-mechanical interaction at the screen-connection interface.
9	**Short-Circuit Test**	**Preheat** the cable cores and the assembly to 90–95 °C for at least 2 hours before each short-circuit event. Two short-circuit events applied **after heat cycling**. A **class system,** Low (2.5 kA, 1 s), Medium (5 kA, 1 s) or High (15 kA, 1 s)**,** for short circuit	Preheating reflects realistic service conditions and aligns with the worst-case principle. The proposed class system enables OEMs to qualify designs **independently of project-specific demands** and supports procurement by allowing developers to match a product class to project short-circuit requirements

	Item (following Core document order)	Test Condition	Key Notes & Practical Considerations
		current and duration is proposed by the authors as a potential framework for future standardisation and would require wider industry input.	
10	**Post-Test Visual Inspection & Dissection**	Visual inspections are carried out after heat cycling and after each short-circuit event. At the end of the full test programme, all six screen connections are dissected to expose the contact surfaces and bonded areas for detailed internal examination.	Visual inspection identifies surface degradation such as overheating, corrosion, deformation, loosening, or insulation damage that may arise during cycling or fault events. Dissection provides direct access to the contact interface, allowing detection of hidden issues such as pitting, fretting, oxidation products, or loss of intended contact area.
11	**Acceptance Criteria**	The acceptance criteria are principally defined by the contact-resistance-related parameters: δ (initial scatter), Υ (stability criterion), and λ (resistance-factor ratio). These parameters are defined and calculated following the methods in CIRED WG17-1. The acceptance criteria combine quantitative parameters (δ, Υ and λ) with qualitative checks such as visual inspection and dissection findings.	The quantitative criteria evaluate the stability and consistency of the screen-connection interface throughout the full test programme. The threshold values are proposed for discussion and have not been independently validated; further industry input is required to confirm appropriate limits and ensure broad applicability.
12	**Worst-Case Representation**	Testing performed at the **highest screen-current level within the screen-current class** being qualified, with conductor at maximum operating temperature, considering restricted-cooling conditions and degradation-prone configurations.	Worst-case representation is a **test-planning principle**, not part of the flowchart, ensuring coverage of the most onerous credible conditions.

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Published in the UK: 2026