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B1 INSULATED CABLES
PS1 Future cable systems and innovative cable applications

Development of 275kV Aluminum Conductor XLPE Cable and Connectors

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SUMMARY

This paper presents the development and evaluation of 275 kV aluminum-conductor XLPE cables and connectors for the planned replacement of Oil-Filled (OF) cables in the Tokyo metropolitan area. Due to rising copper prices, aluminum conductors are being considered as a cost-effective alternative, but they present challenges such as higher electrical resistance, greater thermal expansion, and susceptibility to creep and oxidation. To enable installation within narrow existing troughs, a wire-shielded aluminum conductor cable was developed. The prototype reduced the cable diameter by 11 mm for a 2,500 mm² conductor while maintaining transmission capacity. To achieve reliable cable connections, a compact clamp-type connector using cold spray technology was developed, offering stable contact resistance and easy installation. This connector passed various tests based on CIGRE TB 758 [1]. For aluminum-copper differential connections, good performance was observed after short-circuit testing. The need for new cable cleats suitable for securing cables within narrow troughs is also identified in this study, and their detailed design and testing will be carried out in future work. The developed cable and connector will undergo type tests based on JEC-3408[2], targeting practical application in 2030.

KEYWORDS

Aluminum conductor – connector - OF cable replacement

1 Introduction

In the Tokyo metropolitan area of Japan, there are approximately 1,220 km of Oil-Filled (OF) cable circuits, and a plan to replace them with XLPE cables by 2045 has been established. However, the recent rise in international copper prices has increased cable costs, raising concerns about construction costs. Therefore, the application of aluminum conductor cables is currently being considered to reduce the cost of cable conductors. This study focuses on the replacement plan for 275 kV OF cables installed in tunnels, and evaluates the feasibility of applying aluminum conductors, including compatibility with existing facilities and constructability. The results indicated that downsizing the cable configuration and modifying the installation design are necessary to fit the cables into narrow existing troughs. Additionally, the need for new cable cleats for securing cables within troughs and a compact, easy-to-install connector for the joint, compatible with the conventional pre-mold one-piece joint, was identified. Based on these findings, this paper reports on the design, prototyping, and performance evaluation of a 275 kV aluminum conductor XLPE cable, new cable cleats, and a novel connector.

2 Challenges in the Development of Aluminium Conductor Cables

Aluminum conductors present several technical characteristics and challenges compared to conventional copper conductors, which must be carefully considered in the design and application of XLPE cables for high-voltage underground transmission lines.

- Higher Electrical Resistance:

  Aluminum has approximately 1.6 times higher electrical resistance than copper, so a larger conductor cross-sectional area is required to ensure the same transmission capacity, resulting in larger cable sizes.

- Greater Thermal Expansion:

  The coefficient of linear expansion is higher than that of copper, making thermal expansion and contraction of the conductor more pronounced. This can impose significant thermal stress on connectors during operation.

- Susceptibility to Creep Deformation:

  Aluminum is more susceptible to creep deformation, and prolonged loading can lead to a decrease in clamping force at the connector and an increased risk of poor contact.

- Irreversible Oxidation:

  Irreversible oxidation, such as during short-circuit events, easily occurs, and the formation of an oxide film on the surface increases contact resistance between conductors, leading to heat generation and insulation degradation.

In the development of aluminum conductor XLPE cables, it is essential to address these challenges through accelerated and long-term testing.

In this study, the target is the replacement of 275 kV OF cables installed in tunnels, but there are also challenges associated with practical application. In Japan, there are many underground obstacles, making it difficult to secure new installation routes by excavation. Therefore, for replacement, new cables must be installed in the existing narrow troughs (minimum width 450 mm) that previously housed OF cables. Figure 1 shows an image of XLPE cable installation within a narrow trough. When considering the transition to aluminum conductors, the increased resistance leads to larger cable sizes, making it difficult to accommodate them within the existing troughs. Therefore, when applying aluminum conductor cables, it is necessary to consider downsizing the cable structure, modifying the installation design, and developing new cable cleats for securing cables within the troughs.

For the joint section, the same rubber block unit as the conventional pre-mold one-piece joint is planned to be used. However, desk studies have shown that conventional compression-type connectors for conductors would require longer sizes to ensure the necessary contact resistance and mechanical strength, making it difficult to fit them into the existing rubber block unit. Mechanical (screw type) connectors have become more common in recent years due to improved workability and uniform quality, but CIGRE TB 758 indicates that, for large cross-section conductors, high radial clamp force is required, which leads to increased wall thickness and a longer connector body. Therefore, compared to the compression-type connectors, it would create more difficult design and installation constraints. In fact, due to the above reasons, large-size segmental aluminium conductors have rarely been used for EHV underground transmission lines with mechanical connectors. Welding is a proven technology as a connection method, but it requires advanced skills, and due to fire risk and difficulties in safety management, its use is generally prohibited in the underground tunnel. Therefore, it is necessary to develop a new compact connector with high holding force for long-term use and suitable workability that can fit into the conventional rubber block unit. Based on the above, this paper reports on the prototyping of cables and connectors, measurement of constants, and performance evaluation results based on CIGRE TB 758 and additional mechanical tests.

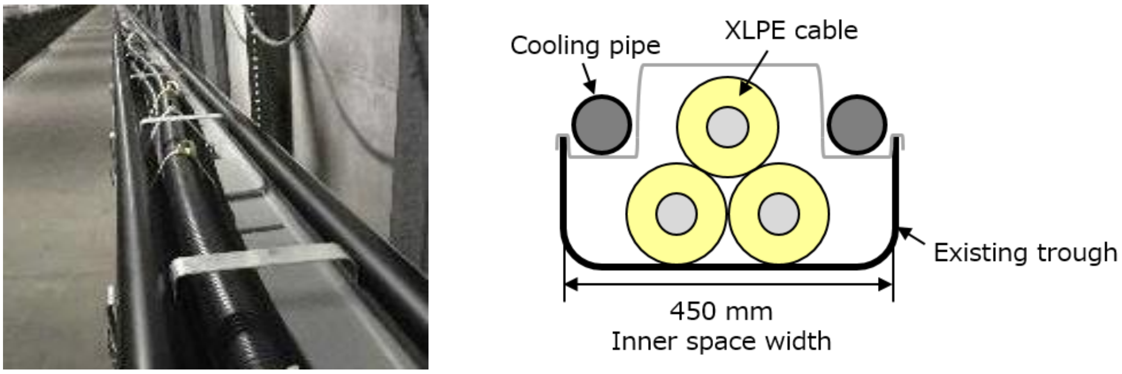


Figure 1. - Image of cable installation in a narrow trough

3 Development of 275kV aluminum conductor cable

In addition to material cost reduction, the lower mass of aluminum conductors reduces the pulling tension required during cable installation and lowers the physical workload on workers when handling and positioning the cables in tunnels and narrow troughs. These aspects are advantageous in long underground sections and confined spaces.

3.1 Design of Cable

Aluminum conductors have higher electrical resistance than copper conductors, approximately 1.6 times greater, necessitating larger conductor sizes to ensure the same transmission capacity. However, the 275 kV Oil-Filled cable replacement plan requires laying cables into existing narrow troughs, and the increased cable size due to aluminum conductors may pose challenges in accommodating them within the existing troughs. Therefore, several sheath and shield concepts were compared, namely (i) a corrugated aluminum sheath, (ii) a smooth welded aluminum sheath, and (iii) a copper wire shield with an aluminum laminate radial water barrier. The corrugated aluminum sheath has the largest metallic cross-section, resulting in relatively high sheath losses and a large overall diameter. A smooth welded aluminum sheath can reduce the outer diameter compared with a corrugated sheath, but the sheath losses remain relatively high, so an even larger aluminum conductor cross-section would be required to achieve the same ampacity as the reference copper cable. To overcome this, a design concept was adopted in which the sheath losses are reduced so that the same ampacity can be achieved with a 2,500 mm² aluminum conductor, equivalent to the cross-section of the existing 2,500 mm² copper conductor, and the sheath structure itself is made more compact. Therefore, the adoption of wire shield design instead of the aluminum sheath design was selected. A copper wire shield with a specification of 2.2 mm in diameter and 80 strands was selected based on the required earth fault capacity and manufacturability. In addition, since aluminum sheath also provided radial watertightness, an aluminum laminated tape, which has a proven track record in Japan, was adopted as an alternative structure. A cross-sectional view comparing the existing cable and the newly designed cable is shown in Figure 2. Changing the shield design can reduce the cable diameter and improve transmission capacity by reducing sheath loss especially when laid in trefoil touching formation in the confined space in the existing trough, potentially reducing conductor size. Comparing a 275 kV, 2,500 mm² corrugated aluminum-sheathed copper conductor cable with a copper wire-shielded aluminum conductor cable confirmed that changing the shield design could reduce the diameter from approximately 151 mm to 140 mm, a reduction of about 11 mm, with both cables having nearly equal transmission capacity.

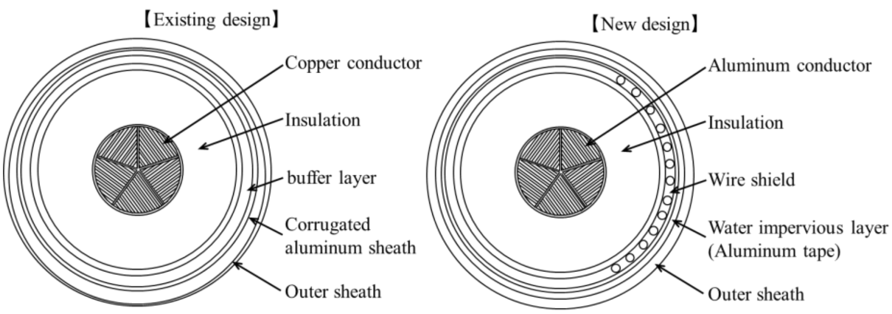


***Figure 2** - Cable cross section*

3.2 Cable constants for installation

A prototype of the 275 kV, 2,500 mm² wire-shielded aluminum conductor XLPE cable was developed, and various constants were measured. The results are shown in Table 1, followed by a detailed discussion of the measurements for each constant as described below.

- DC Conductor Resistance

  The measured values were lower than the theoretical values, which is considered to be due to higher conductivity and/or more metal weight in the prototype.

- Skin Effect Factor by AC resistance

  In domestic standards in Japan, the same factors are applied for both copper and aluminum conductors; however, the measured results for aluminum conductors were clearly lower than those for copper conductors, which shows a good agreement with Table 2-11 in CIGRE TB894 [3] among various European manufacturers. This poses important considerations regarding which values should be utilized in the design of cable transmission capacity. Additional empirical studies, including measurements for other sizes, should be conducted to further explore this issue.

- Linear Expansion Coefficient

Given that the thermal expansion coefficient of aluminum is greater than that of copper, it was anticipated that the values would be higher for aluminum conductors compared to copper conductors, and the results confirmed this expectation. In accordance with the recommendations in CIGRE TB 669 [4], horizontal snaking installation will be applied along the route. However, because the width of the existing troughs is very narrow and the amplitude of the waves cannot be made large, the effect on thermal expansion forces is limited. Therefore, additional mechanical restraint by cable cleats is also considered.

- Young's Modulus

  The measurement results for the aluminum conductor cable align with the trends observed in the measured results for the copper conductor cable, indicating that the findings are valid.

- Cable Bending Stiffness

  The measurement results exhibit a similar trend to those of the copper conductor cables and are also close to the calculated values obtained during preliminary analyses at room temperature. Therefore, these findings are considered valid.

Based on the results above, the measured values for all constants fall within the range of the theoretical or calculated values. Therefore, we plan to proceed with the detailed design of cable installations based on these measurement results. In addition, existing cable cleats cannot be installed within narrow troughs; therefore, a new structure for cable cleats is currently under development, and their performance has been evaluated in thermal behaviour tests, which confirmed that they can restrain the cable effectively under thermal expansion and contraction. Further development and detailed evaluation will be addressed in future work.

Table 1 - Wire-Shielded Aluminum Conductor XLPE Cable Constants (275kV, 2,500mm²)

No.	Measurement Item	Unit	Result	Remarks
1	DC Conductor Resistance	Ω/km@20 °C	0.01193	≤ 0.01224 *1
2	Skin Effect Factor by AC resistance	-	0.348	≤ 0.6 *1
3	Linear Expansion Coefficient	1/ °C	22.51×10^{-6}	20.0×10^{-6} *2
4	Young's Modulus	kN/mm^2	20.06 ~ 28.37	30.0 *2
5	Cable Bending Stiffness	$\times10^6$ kN/mm^2	High load: 3.6 ~ 4.9 Low load: 10.6 ~ 13.2	10.0 *1

*1 Japanese Cable Makers' Association Standard 0501 (2022)

*2 Electric Technology Research Association Report (Japanese) specified for copper conductor

4 Development of new connector

4.1 Summary of new connector

Applying the bolted connector, proven with copper conductor cables, to very large-size aluminum conductor cables showed that the increased connector length to achieve the required contact resistance would be difficult to fit into conventional one-piece rubber mold of the joint. As a compact conductor connection method, welding is an option, however, it requires technical skills and experience and welding poses a risk of damaging the cable and/or the surroundings, which is why welding is normally not allowed in the tunnel workspaces. Hence, a compact conductor connection method, that is safer and requiring less skills and experience compared to welding, is needed to ensure future construction capability. In this study, a novel connector solution using cold spray technology was developed and performance evaluations were conducted. The novel connector solution further develops on previous work presented in [5] and [6] and Figure 3 shows an overview of the main components constituting the connector design. Pull-Clamp components are mounted on the conductor to mechanically fix and compress the conductor wires, ensuring mechanical strength and integrity. The conductor end surface is coated with a silver CS Contact Layer using cold spray technology. A silver Flexible Contact Element is inserted between the conductor ends to ensure that contact points are distributed evenly, thereby reducing current crowding. The conductor ends are forced together via the half-shells including spring loaded Axial Pressure Bolts applying a pretension force above the connector tensile load requirements and ensuring sufficient contact force to be applied during thermal expansion and contraction. In addition, this connector was designed specifically for use in the existing pre-mold one-piece joint for 275 kV XLPE cables. Two-dimensional electric field calculations and comparison with the conventional copper-conductor bolted connector used in the same joint confirmed that the electric field distribution remains essentially unchanged. Therefore, no additional field grading measures are required, and the new connector can be used with the same joint design as the existing accessory.

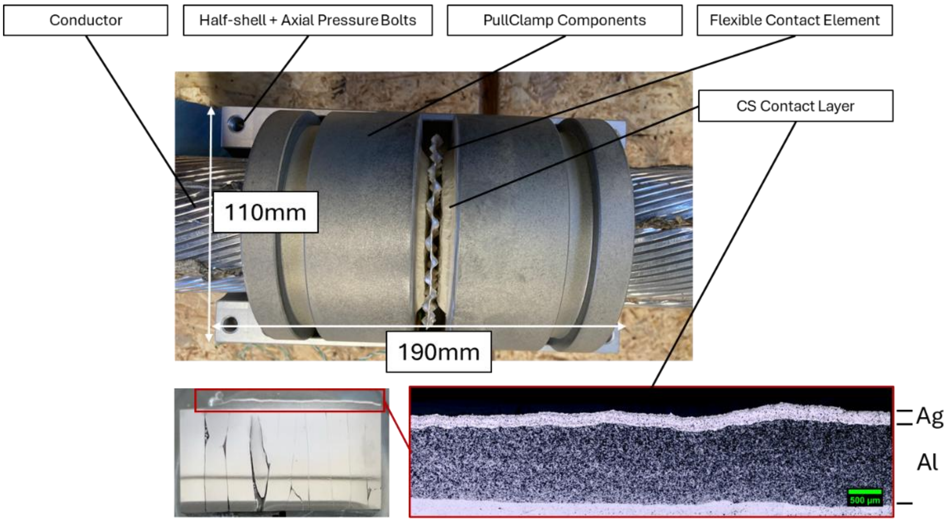


Figure 3 – Side view and cross section novel connector solution using cold spray technology

4.2 Advantages of novel connector solution compared to shear bolt connectors.

A robust design methodology is the underlying approach of the connector solution, with the aim of dividing the connector functional requirements into separate design parameters within the various mechanical components. This approach reduces sensitivity towards expected production, assembly and installation variations. As a result, this novel connector provides several advantages over bolted connectors; it features a smaller sleeve size, utilizes axial connection for minimal current path thus reducing overall connector resistance, and utilizes a silver contact surface ensuring stable and minimal contact resistance. The spring-loaded axial pretension system ensures a more robust solution towards aluminum creeping as well as the more severe thermal expansion and contraction. Finally, the CS technology makes it possible to utilize the connector solution on all types and sizes of conductors as well as transition connector from aluminium to copper, hence making the solution a truly universal approach. Further improvement related to the installation procedure can be inspected in Table 2.

Table 2 - Outlined installation advantages with the novel connector solution

No.	Description	Novel Connector	Welding techniques	Radial clamping connector (hydraulic crimping or bolted connector)
1	Risk of thermal damage of cable during installation.	No	Yes	No
2	External conductor cooling required during installation.	No	Yes	No
3	Straining wire cleaning process required.	No	Yes	Yes
4	Required technical level and expertise of installer.	Low	High	Low
5	Suitable for aluminium conductor >2500mm^2.	Yes	Yes	No
6	Automatic logging of quality parameters during installation.	Yes	No	No
7	Monitoring sensors ensuring a safe, consistent and stable operation.	Yes	No	Not relevant

4.3 Summary of performed connector test and associated results

18 Pull-Clamp components, 18 CS contact layers, 10 Pull-Clamp Power Injectors and 4 Connectors with tapered segmental conductor design have been installed, forming 4 × CCTL (Conductor Connector Test Leg) and 1 reference conductor in accordance with TB758 specifications.

The connector and corresponding components have been tested according to TB758. Further extensive connector evaluation has been included, outside TB758 scope, during tensile and short-circuit test. A more severe short-circuit test has been performed including the following elements:

- 6h thermal stability test prior short-circuit test.
- Elevated short-circuit current at 63 kA.
- Severely elevated conductor temperature during short-circuit tests up to 140 ^{o}C due to preheating and rapid sequence of short-circuit shots.
- Shipping of CCTL's from DK to JP for subsequent testing.
- Evaluation of change in thermal profile and DC resistance before and after short-circuit test.
- 10,000 cyclic tensile loads (7.5 kN) applied during the stability temperature of 50 extra thermal cycles simulating the forces on the connector over 30 years of operation.

All connectors have passed the evaluation criteria according to CIGRE TB758 requirements as shown in Table 3. All connectors show lower to equal DC resistance after tensile and short-circuit test compared to post test measurement. Connector temperature is 14-17 ^{o}C lower compared to reference conductor during thermal stability, hence well below CIGRE TB758 criteria.

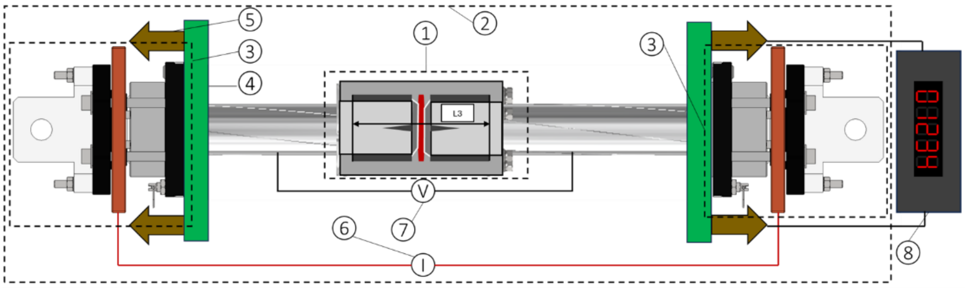
Table 3 – Test result for CIGRE TB758

Test Case	Evaluation	Result
(1) Tensile test	Change of DC resistance Sliding of connector components	DC resistance not increasing No sliding during or after test
(2) Short-circuit test	Change of DC resistance Change of temperature difference between REF & Con	DC resistance not increasing No change of temp difference
(3) 200h stability test	Temperature difference between reference conductor and connector	Stable temperature difference between 14-17degC (refer to the Figure 9)
(4) Heat cycle test	Temperature difference between reference conductor and connector	Stable temperature difference between 14-21degC (refer to the Figure 10)

4.4 Tensile test performance

50kN prestress tensile test according to CIGRE TB758 for Al conductors was performed with no visual slippage. Extensive connector evaluation outside TB758 scope is made possible due to the unique features of the connector design with open access to internal Pull-Clamp components. Continuous evaluation of movement or slippage of connector components during and after the tensile tests demonstrates 0,00mm movement/slippage during the tensile test.

Furthermore continuous 4 point DC resistance measurement over connector area during tensile test was made possible by utilizing the capability of the unique Pull-Clamp Power Injector system mounted on the conductor end. The results show no increase of the DC resistance during or after the tensile tests.



Item No.	1	2	3	4
Description	Connector	Conductor Connector Test Leg (CCTL)	PullClamp Power Injectors	Tensile Load Frame
Item No.	5	6	7	8
Description	Tensile Load Indicator	DC Power Supply	Voltage Measurement	Force Gauge

Figure 4 - Schematic diagram and picture of actual tensile test setup

4.5 Short-circuit test performance

6h thermal stability was performed prior short-circuit test, to enable subsequent connector evaluation by comparing thermal profile pre and post short-circuit test.

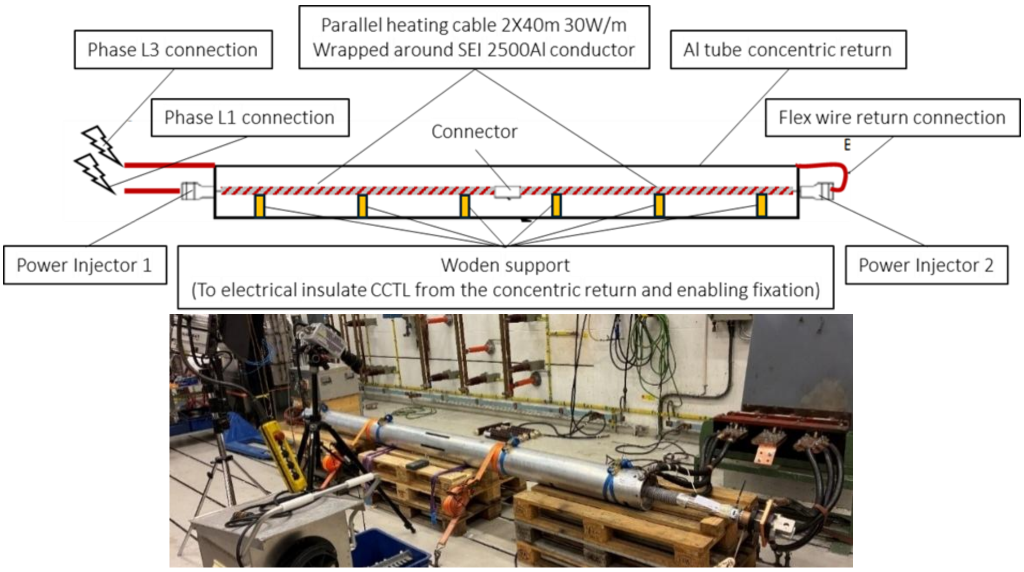


Figure 5 - Schematic diagram of a concentric return loop used for short-circuit tests on a single CCTL

6 × 63kA, 1s short-circuit test including 90 ^{o}C ± 5 ^{o}C preheating according to CIGRE TB758 was performed. Fast short-circuit sequence resulting in severely elevated conductor temperature between 130-140 ^{o}C for test leg 1, 2 and 4 according to Table 4. No signs of overheating could be detected. Resistance measurement pre and post short-circuit test shows no change in DC resistance over the connector area. Further evaluation of the connector performance after short-circuit test was carried out by comparing thermal profile post short-circuit test according to

Figure 7 with thermal profile prior short-circuit test. Results show completely stable performance of the connector solution.

***Table 4** – Conductor and connector preheating temperature as well as temperature after 3rd and 6th 63kA, 1s short-circuit. Position of temperature probe TK1, TK2 and TK3 according to Figure 6*

Test Subject	Temp Probe	Before Preheating	Pre-heating Temp	fter - 1st Pretes	After 3rd Test	After 6th test	Thermosensitive lable
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
#01 CCTL	TK1	16.6	105.4	105.0	119.2	130.7	127.0
	TK2	16.7	105.4	106.4	119.7	130.6	127.0
	TK3	16.8	98.0	99.0	110.6	122.4	116 to 121
#02 CCTL	TK1	18.6	102.0	104.0	119.3	128.3	127.0
	TK2	18.6	101.4	103.5	119.0	128.0	127.0
	TK3	18.5	92.1	93.6	105.6	115.4	110 to 116
#03 CCTL	TK1	18.8	100.8	103.7	118.1	130.1	127.0
	TK2	18.8	102.1	104.0	116.5	129.5	127.0
	TK3	18.7	92.0	95.7	108.0	120.1	121.0
#04 CCTL	TK1	18.9	104.7	108.7	125.5	139.9	127.0
	TK2	18.9	100.8	106.1	123.2	137.2	127.0
	TK3	18.8	86.3	93.7	108.1	119.6	121 to 127

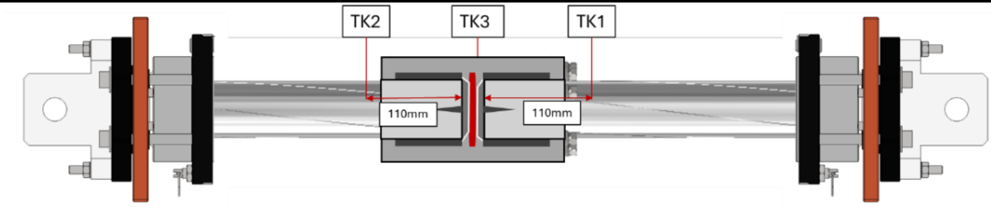


***Figure 6** -Position of temperature probe during short-circuit testing*

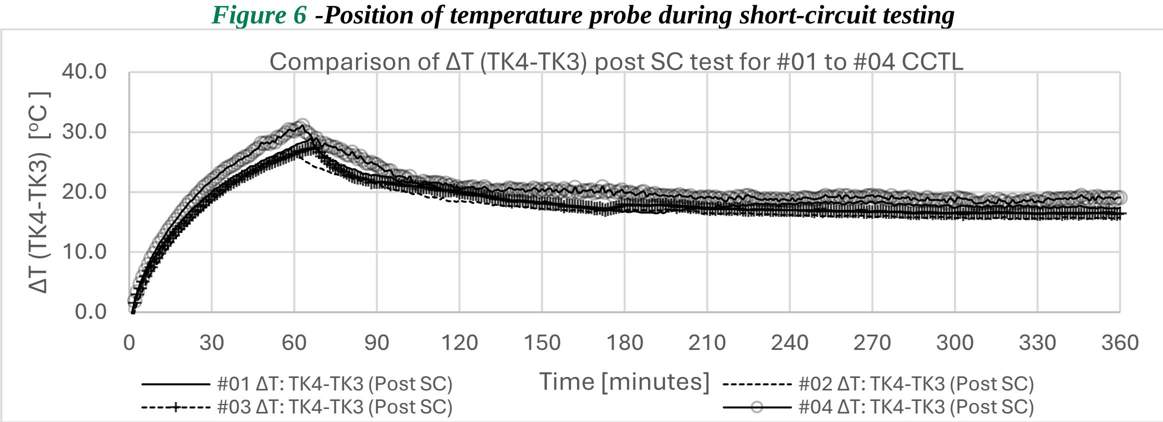


***Figure 7** -Connector temp. measurement (TK3) compared to reference conductor temp (TK4) post CCT.*

4.6 Constant high-current temperature stability test performance

200 hours high-current temperature stability test was performed according to CIGRE TB758 for four connectors after short-circuit test in the test loop as shown in Figure 8.

Reference conductor and four connectors were connected to the test loop. Temperature of reference conductor was increased to 120 °C and the temperature was maintained for 200 hours. No signs of overheating could be detected. Resistance measurement pre and post constant high-current temperature stability test shows no change in DC resistance over the connector area. Further evaluation of the connector performance during constant high-current temperature stability test was carried out by comparing thermal profile according to Figure 9. Results show completely stable performance of the connector solution.

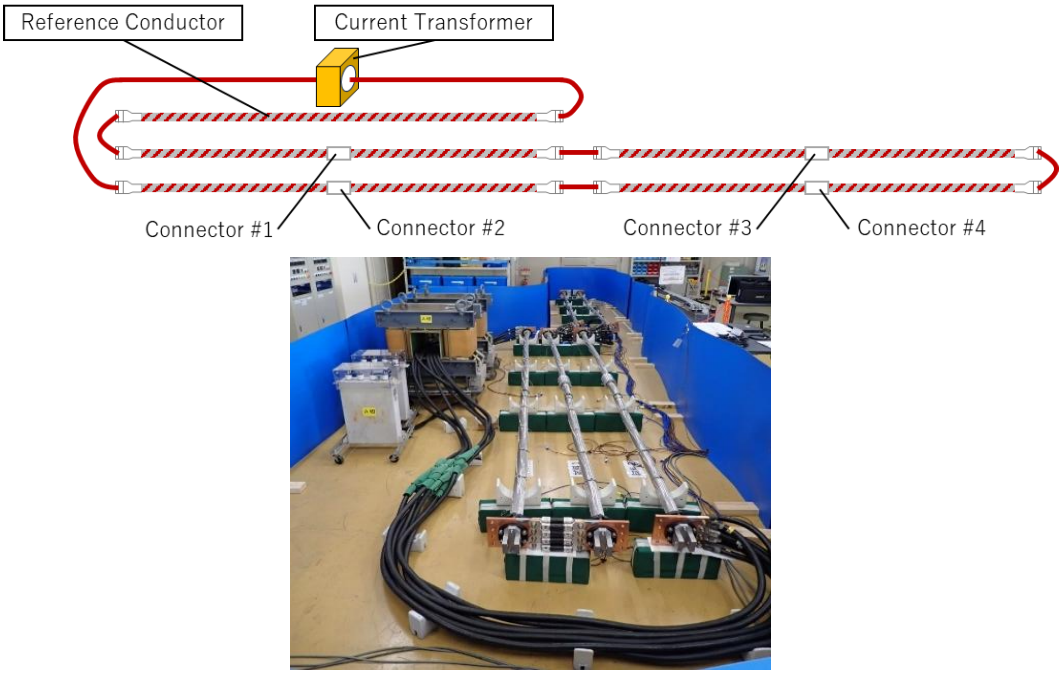


***Figure 8** -Schematic diagram of a test loop used for constant high-current temperature stability tests on a four CCTLs*

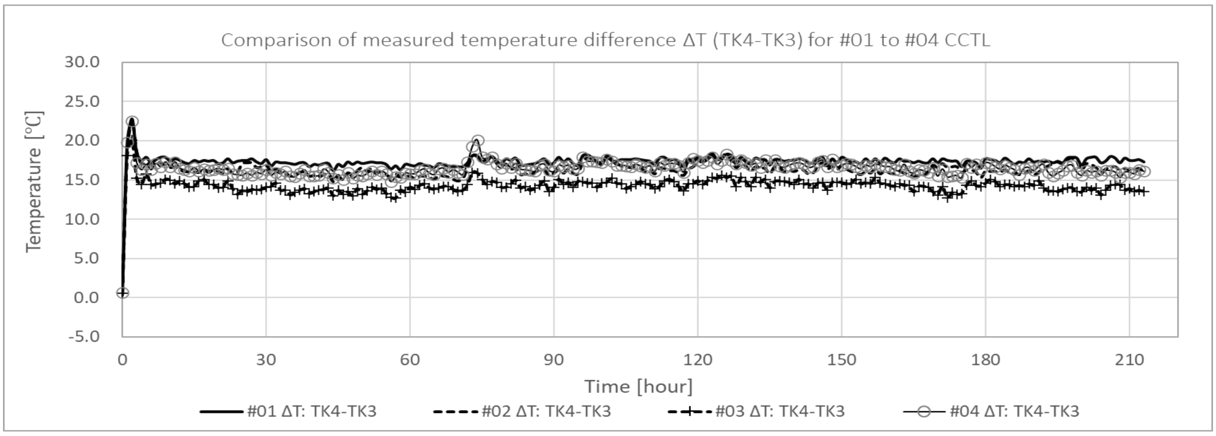


***Figure 9** -Connector temperature measurement (TK3) compared to reference conductor temperature (TK4).*

4.7 Heat cycle temperature stability test performance

200 cycles heat cycle temperature stability test was performed according to CIGRE TB758 for four connectors after constant high-current temperature stability test.

Reference conductor and four connectors were connected to the test loop same as constant high-current temperature stability test according to Figure 8. Temperature of reference conductor was increased to 120^{o}C and the temperature was maintained for 120 minutes. Then, current was turned off and temperature of all connectors and reference conductor were decreased by natural cooling. This heat cycle was repeated 200 times. No signs of overheating could be detected. Resistance measurement pre and post heat cycle temperature stability test shows no change in DC resistance over the connector area. Further evaluation of the connector performance during heat cycle temperature stability test was carried out by comparing 1st thermal profile with the

200th (last) profile, as presented in Figure 10 and 11, showing completely stable performance of the connector solution.

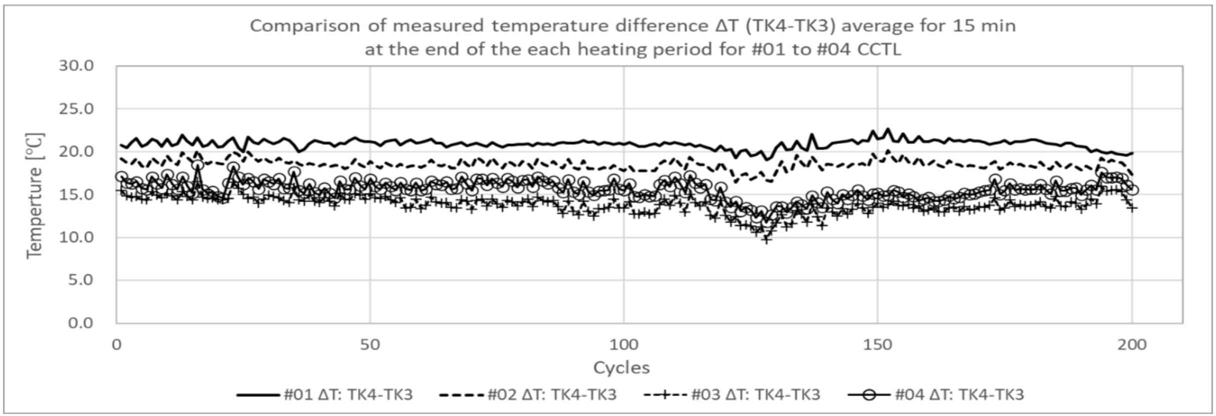


***Figure 10** -Average temperature difference for 15 min at the end of the each heating period.*

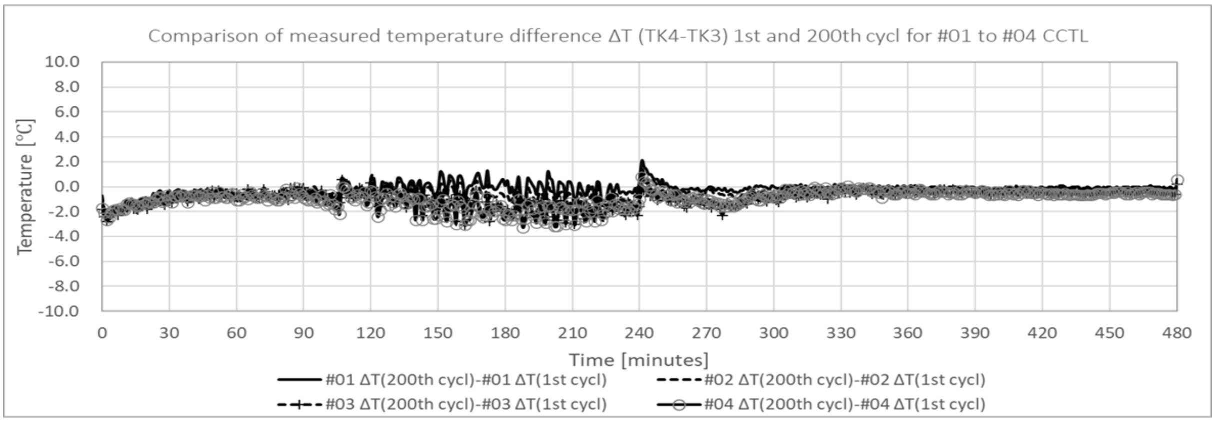


***Figure 11** -Difference in connector stability temperature 1st and 200th(last) cycle.*

4.8 Cyclic load test performance

A cyclic load of 7.5 kN was applied 10,000 times, superimposed on 50 temperature-stability cycles, according to the authors' own standard in addition to CIGRE TB758 for four connectors after Heat cycle temperature stability test. Reference conductor and four connectors were connected to the test loop including tensile force supply system as shown in

Figure 12. Temperature of reference conductor was increased to 120 °C and the temperature was maintained for 120 minutes. Then, current was turned off and temperature of all connectors and reference conductor were decreased by natural cooling. This heat cycle was repeated 50 times. In addition to the above, cyclic load at 7.5 kN was applied for 10,000 times superimposed on the 50 heat cycles. Therefore, 200 loads were applied per one heat cycle. No signs of overheating could be detected. Resistance measurement pre and post heat cycle temperature stability test shows no change in DC resistance over the connector area. Further evaluation of the connector performance during heat cycle temperature stability test was performed by comparing thermal profile with the 1st and the 50th (last) cycle as presented in Figure 12. Results show completely stable performance of the connector solution.

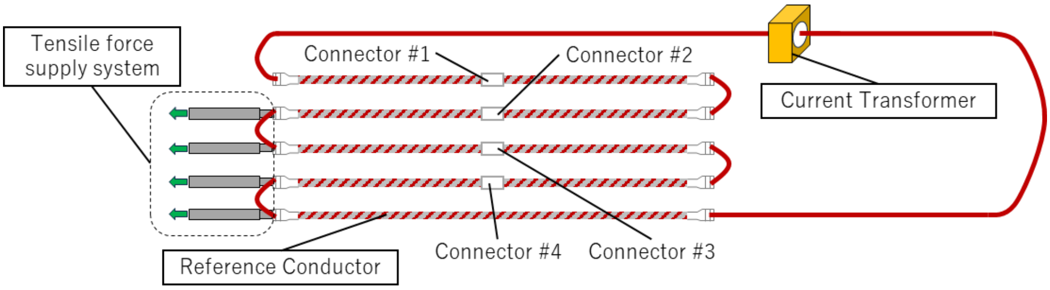


Figure 12 -Schematic diagram of a test loop used for Cyclic load tests on a four CCTLs

4.9 Residual test performance

50 kN tensile test was performed according to Japanese standard for electrical equipment after cyclic load test. Each connector was subjected to a 50 kN tensile force. No signs of visual slippage could be detected. Resistance measurement pre and post tensile test shows no change in DC resistance over the connector area. As shown in Figure 14, no change in DC resistance before and after any of the tests.

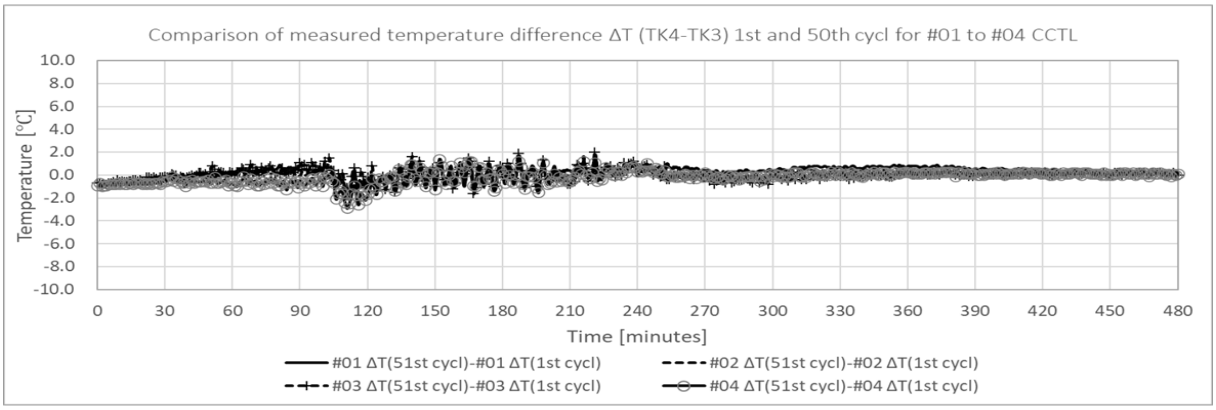


Figure 13 -Difference in connector stability temperature 1st and 50th(last) cycle.

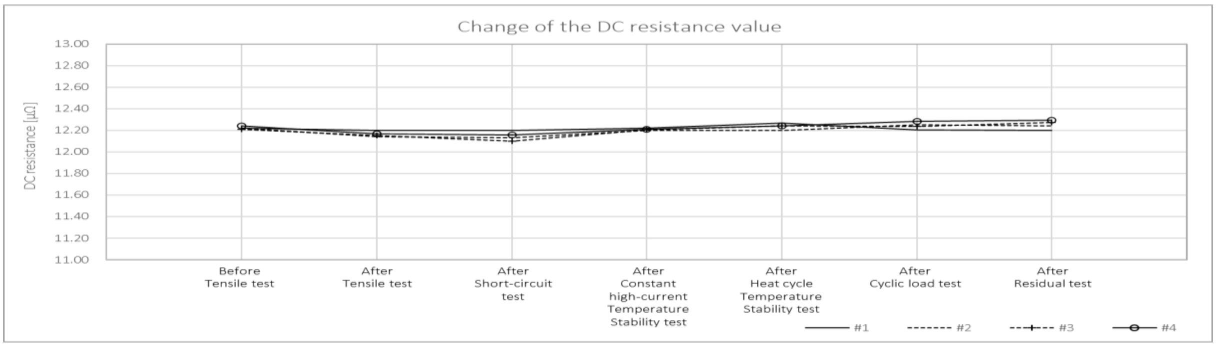


Figure 14 -Change of the DC resistance value

4.10 Differential connection between Aluminum conductor to Copper conductor

The novel connector solution utilizing CS technology allows all types and sizes of conductors to be connected and can be used for both aluminium and copper. Since a final silver layer is applied on both copper and aluminium conductors it is also possible to connect aluminium and copper conductor through the silver based flexible contact plate, hence still utilizing a silver to silver to silver contact.

A solution connecting 2500mm^2 segment aluminium conductor with a 2500mm^2 copper segmental conductor has also been developed as part of this study. The view of the differential material connector is shown in Figure 15. An initial performance test has been carried out consisting of the following sequence, similar to CIGRE TB758 except shorter thermal cycles:

- 3 × 2h Thermal Cycling Test (TCT)
- 50 kN Connector Tensile Test (CTT)
- 3 × 2h thermal stability Thermal Cycling Test (TCT)
- 6 × 63kA 1sek Short Circuit Test (SCT) including preheating up to 90 ^{o}C
- 9 × Thermal Cycling Test (TCT)

Connector performance is evaluated by DC resistance measurement as well as comparison of thermal profiles from the TCT pre CTT, post CTT and post SCT. The change of DC resistance can be inspected in Table 5 showing a reduction of DC resistance over the connector area. The change of thermal profiles are initially investigated as shown in Figure 16 showing also improved thermal performance of the connector after short circuit test. It should be noted that some part of the increased temperature difference could also be explained by the lower ambient temperature post SCT compared to the higher ambient temperature pre CTT. Further details shall be investigated but there is no meaningful deterioration in the differential connector between Copper conductor to Aluminum conductor.

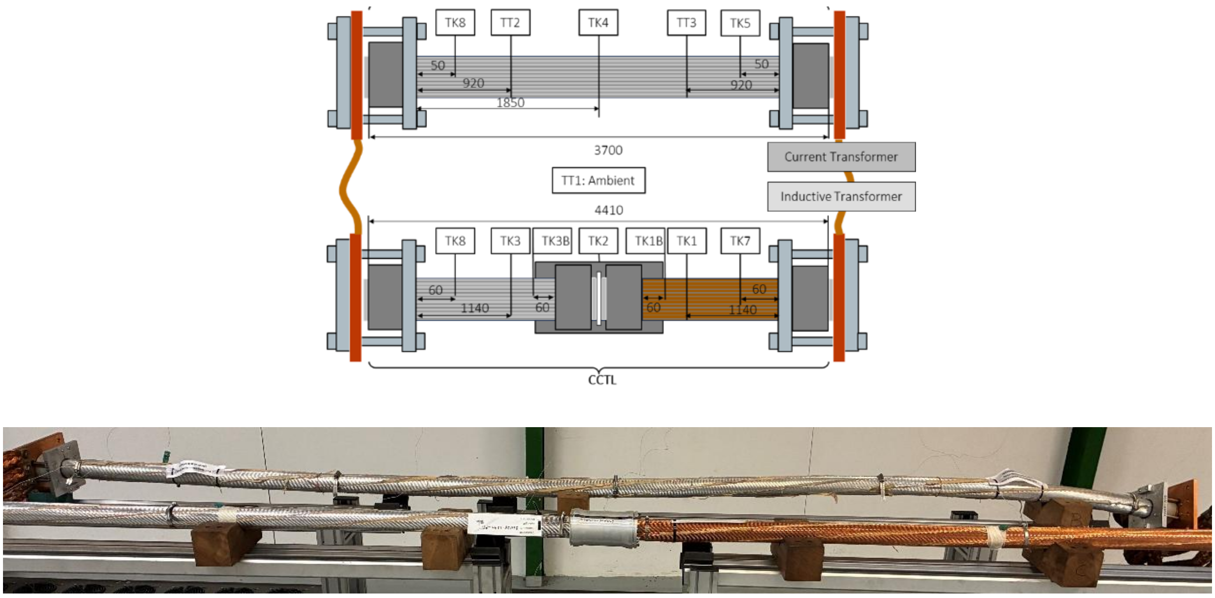


***Figure 15** – Top: Schematic diagram of Thermal Cycle Test (TCT) setup including postion of temperature sensors. Bottom: Actual TCT setup with Cu2Al connector.*

***Table 5** – DC resistance measurement at different stages of the initial performance test*

DC resistance at 20^{o}C			
Test object	**Before CTT**	**After CTT**	**After SCT**
	[μΩ/m]	[μΩ/m]	[μΩ/m]
251125-1815-CIT	9.79	9.74	9.69

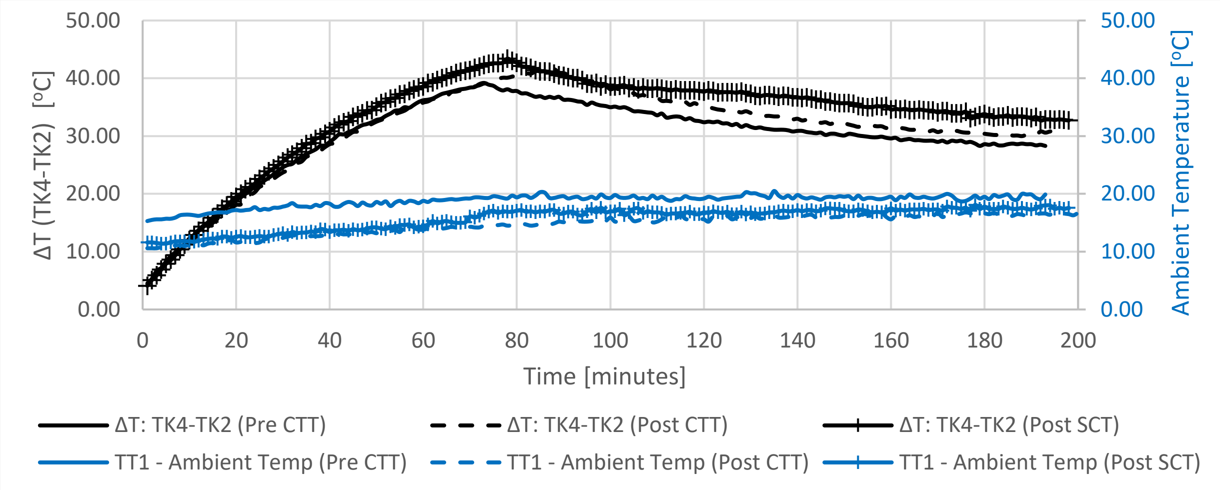


***Figure 16* - Comparison of temperature difference during TCTs at different stages of the initial performance test.**

5 Conclusion

The design, prototyping, and performance evaluation of 275 kV aluminum XLPE cables and connectors were conducted. The cable achieved downsizing by adopting a wire-shielded structure, which reduced sheath losses. A compact connector using cold spray technology was developed for the joint, and it passed tests based on CIGRE TB 758. For the aluminum-copper differential connector, good performance was confirmed after short-circuit testing. In addition, the need for new cable cleats suitable for securing cables within narrow troughs has been identified, and the detailed design and performance evaluation will be carried out in future work. Additional evaluation tests for the 275 kV cable, connector, and cleat are planned, aiming for practical application in OF cable replacement projects around 2030.

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