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FEATURED TOPIC

# Characteristics of Water Trees in Submarine Cables (Wet-Design) for Offshore Wind Power Generation

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The reduction of greenhouse gases has become an urgent issue globally, and thus the introduction of offshore wind power generation is progressing. A higher voltage requirement (at 66 kV-class) for submarine cables is due to increased power output from wind turbines and structural changes to the wet design that omits the water-impervious layer to improve manufacturability, cost, and workability. However, removing the water-impervious layer increases the risk of breakdowns due to insulation deterioration namely “water trees.” A study has been carried out on water tree retardant insulation and it has been confirmed that the new submarine cables meet the standard (CIGRE TB722) established in 2018 even with the omission of the water impervious layer. Considerations were made for a water tree retardant insulation that can be used under high voltage exceeding 66 kV-class in order to cope with long-term operation and higher power output from wind turbines in the future. This development will contribute to the promotion of offshore wind power generation.

Keywords: offshore wind power generation, submarine cables, water trees

## 1. Introduction

Recently, it has become an imperative issue for the global community to reduce greenhouse gas emissions. In 2020, the Japanese government made a declaration to attain “carbon neutrality by 2050.”

The Green Growth Strategy, which was formulated in line with this declaration, sets out a policy to introduce renewable energy as much as possible with top priority placed on decarbonization of the electricity sector. Notably, a goal has been set for the offshore wind power industry to increase its capacity to 10 GW by 2030 and to 30 to 45 GW by 2040.(1)

Thus, offshore wind power generation will become more important than before. Power cables, which are used to transmit the electricity generated, play a key role.

This paper reports the results of a study on new power cables for offshore wind power generation with future developments in offshore wind power generation in mind.

## 2. Structural Changes to Submarine Cables for Offshore Wind Power Generation

In offshore wind power generation, electricity is generated using offshore wind turbines. Power cables for harvesting electricity are laid on the sea bed to transmit electricity back to an onshore substation.

The development of wind power generation technology has been accelerating recently. As shown in Fig. 1, the size and output of wind turbines have increased. Thus, the voltage and power capacity of power cables for wind power generation have been increased accordingly.

Previously, mainly 22 kV- to 33 kV-class cables were used. Recently, there has been a shift to 66 kV-class cables. The increased size of cables to meet the higher voltage has brought about issues in terms of manufacturability, cost, and in particular, site workability.

To cope with these issues, cables with a structure without a water impervious layer (hereinafter referred to as “submarine cables without water impervious layer”), are expected to play a key role in the market in place of cables with a conventional structure, as shown in Fig. 2.

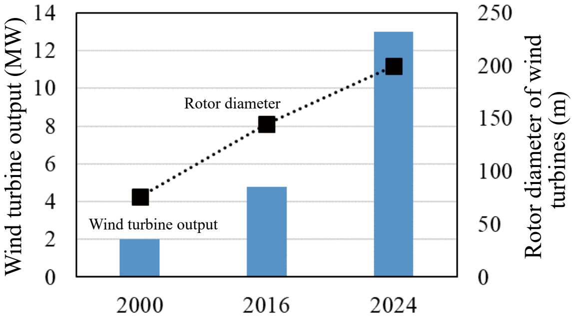

Fig. 1. Changes in size and output of wind turbines(2)

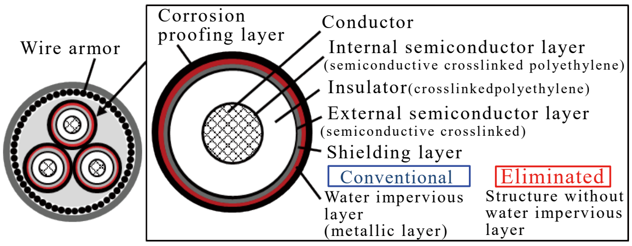

Fig. 2. Submarine cable structure

## 3. Standards for Submarine Cables

In line with market developments to eliminate the water impervious layer in cables, a standard for submarine cables without water impervious layer (CIGRE TB 722: Recommendations for Additional Testing for Submarine Cables) was established in 2018.

One of the biggest risks of eliminating the water impervious layer is a deterioration phenomenon called a water tree, which progresses in insulators during constant operation of cables in a submerged condition (to be discussed in Section 4).

CIGRE TB 722 also describes a submerged voltage endurance test for evaluating water tree characteristics.

Submarine cables without a water impervious layer for offshore wind power generation are currently required to meet the general submarine cable standard (IEC 63026) and have their water tree resistance evaluated to meet the standard of CIGRE TB 722, which was mentioned above, as shown in Fig. 3 and Table 1.

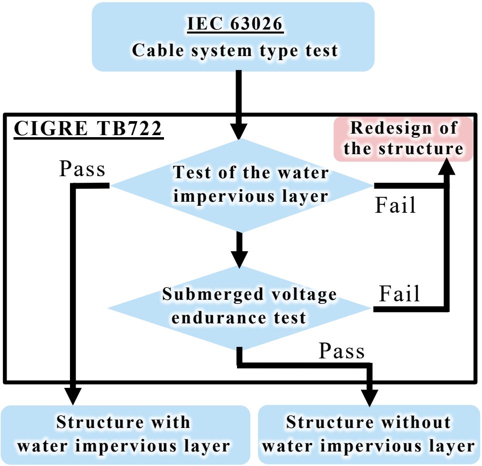

Fig. 3. Accreditation evaluation flow for structures without water impervious layer

Table 1. Test items required for submarine cables without water impervious layer

| Standard | Test | Outline of the test |
|---|---|---|
| IEC63026 | Type test<br>① Mechanical test<br>② Electrical test<br>③ Material test | ① Winding, bending/tension<br>② Partial discharge, tanδ<br>AC withstand voltage (HC: 20 times)<br>Imp withstand voltage (±10 times)<br>③ Water absorptivity, tensile strength, shrink back, hot set |
| CIGRE TB722 | Submerged voltage endurance test (Regime B) | Residual AC withstand voltage after a 3,000-h submerged voltage endurance test |

It should be noted that CIGRE TB 722 is a standard for up to 66 kV-class cables (maximum voltage: 72.5 kV). At present, the structure without a water impervious layer is only applicable up to 66 kV-class cables.

## 4. Water Tree Propagation Characteristics of Submarine Cables without Water Impervious Layer

### 4-1 Water tree deterioration of cable insulators

When moisture is present in actual operation, water trees propagate in cable insulators from tiny foreign matter, voids, and protrusions that are present in insulators based on the mechanism shown in Fig. 4, which represents one of various theories.

Propagation of water trees leads to local defects, which cause dielectric breakdown of a cable at the operating voltage. Photo 1 shows an example of the dielectric breakdown phenomenon caused by water trees.

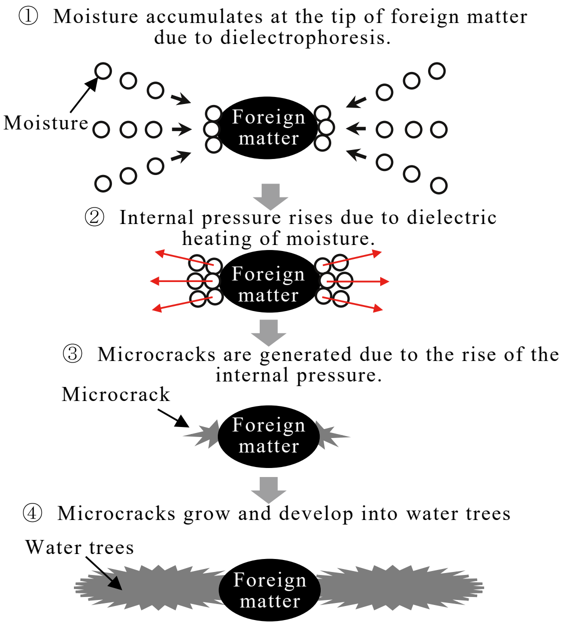

Fig. 4. Water tree propagation mechanism in an insulator

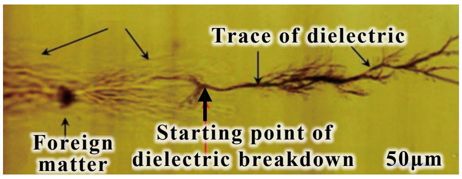

Photo 1. Example of water trees and dielectric breakdown phenomenon⁽³⁾

There is a significant number of dielectric breakdown incidents attributed to water trees. In Japan particularly, a water impervious layer (metallic layer) for preventing ingress of moisture is provided as the main countermeasure, as shown in the conventional structure in Fig. 2.

Meanwhile, there are high expectations of introducing a structure without water impervious layer in the global market. In addition, the voltage class is expected to be raised to 66 kV due to the increased output of wind turbines, as discussed above. Thus, there is a high market demand for water-tree- retardant insulators.

To meet such market needs, we conducted a study on water-tree- retardant insulators for submarine cables without water impervious layer.

### 4-2 Study of water-tree- retardant insulators

In the water tree propagation mechanism shown in Fig. 4, focus was placed on local accumulation of moisture and additives that delay accumulation of moisture in insulators as one of the measures to improve water tree resistance.

Insulator sheet samples containing special additives were fabricated and their water tree characteristics were studied in a submerged voltage endurance test.

Pressed sheets, consisting of a semiconductor layer material used for general power cables sandwiched by insulator materials, were used for a submerged voltage endurance test, as shown in Fig. 5.

For the insulator material samples, two types of insulators were used: an insulator with mixture A, which contained the additives under study, and an in-house general-purpose insulator for comparison.

With the edge of a sample submerged, high voltage was applied to the semiconductor layer material (1,000 Hz, 66 kV-class operation electric field), and the maximum length of water trees was measured every 1,000 hours of the voltage endurance test.

The investigation results are shown in Fig. 6, which indicated that mixture A had the effect of suppressing water trees compared to the in-house general-purpose insulator.

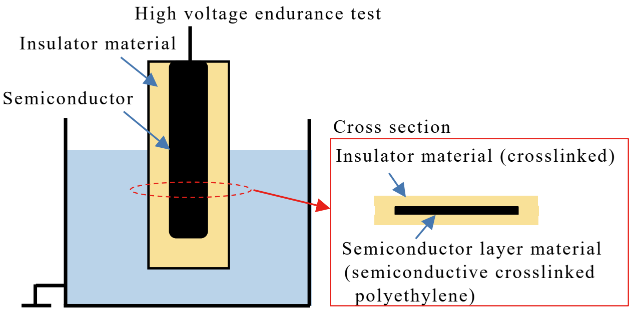

Fig. 5. Sheet sample and submerged voltage endurance test configuration

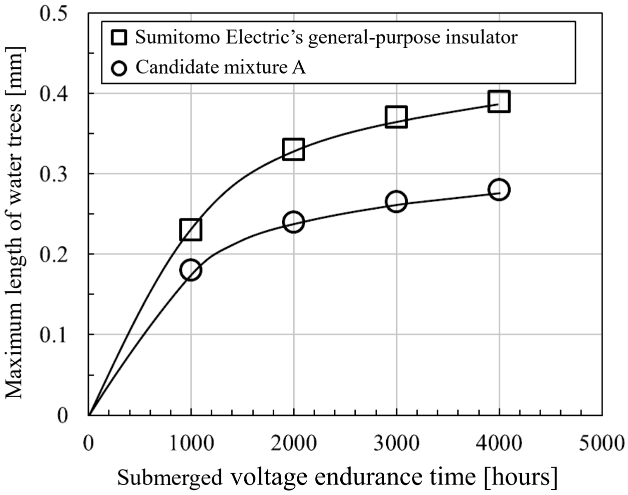

Fig. 6. Changes with time of maximum length of water trees (sheet)

Next, mixture A was used to fabricate a prototype cable and a submerged voltage endurance test was conducted in accordance with CIGRE TB 722. The test conditions are shown in Table 2.

In the test, a cable with a conductor size of 150 mm$^2$ in conformity to CIGRE TB 722 was prepared. Voltage was applied over the long term with its cable core submerged in sea water. After a 3,000-hour voltage endurance test, an AC breakdown test was conducted to evaluate the residual breakdown performance was correct.

The cable did not fail during the submerged voltage endurance test. The test results demonstrated that there is sufficient operational margin for the residual AC performance against the withstand voltage required in CIGRE TB 722.

A prototype 66 kV-class cable using mixture A was fabricated. The cable of the structure without water impervious layer passed the type test based on IEC 63026, thus confirming that the submarine cable met the standards and requirements.

Table 2. Test conditions (CIGRE TB 722)

| Electric field for testing | Submersion method | Water temperature | Voltage endurance time |
|---|---|---|---|
| 6.4 kV/mm<br>(500 Hz) | Submerge the outer semiconductive layer side | Constant at 40°C | 3,000 hours |

Figure 7 shows the results of an investigation of the maximum length of water trees which propagated during a 3,000 hour voltage endurance test. It should be noted that this is not required in CIGRE TB 722.

As shown in Fig. 7, water trees developed but hardly propagated. The results were confirmed to be good.

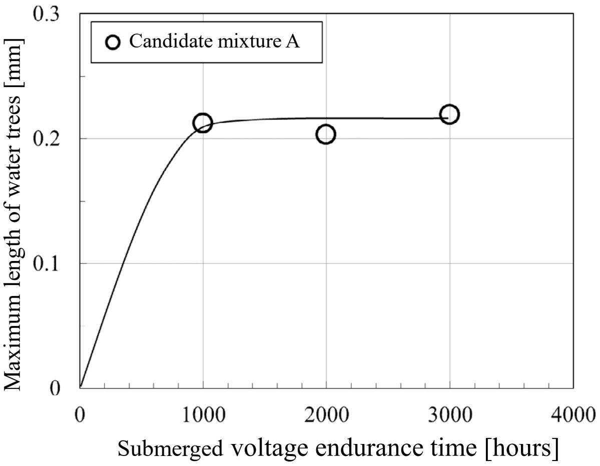

Fig. 7. Changes in maximum length of water trees over time (CIGRE TB 722)

### 4-3 Necessity to further improve water tree resistance

The water-tree-retardant insulator (mixture A), which was studied in 4-2, passed CIGRE TB 722, and the water tree resistance was confirmed to meet the standard. This insulator is expected to maintain good characteristics under normal operating conditions.

The growth of water trees is directly affected by factors such as electric field, temperature, and amount of moisture. In anticipation of future higher voltage and larger capacity requirements, a submerged voltage endurance test under severe test conditions was conducted, including an excessive supply of moisture to the insulator, to evaluate the margin of water tree resistance.

Two cable samples were prepared. One was a cable using a water-tree- retardant insulator (mixture A), and the other was a cable using an in-house general-purpose insulator.

The electric field for the test was equivalent to a 66 kV-class cable operation electric field. The maximum length of water trees was investigated after a submerged voltage endurance test. The investigation results are shown in Fig. 8.

Figure 8 shows that mixture A demonstrates the effect of suppressed water trees, as in the case of the sheet evaluation, compared to the general-purpose insulator material.

Meanwhile, it is confirmed that the propagation tendency of water trees differs from the evaluation results based on CIGRE TB 722. This result confirms that the cable using mixture A met the performance required by CIGRE TB 722 and IEC 63026 and possessed sufficient performance under normal operation. However, such an operational margin is likely to decrease under severe conditions.

Careful judgment is required in each project to determine the severe conditions to be considered in design based on the installation conditions and operation conditions. The possibility of further improvement of the mixture to meet the needs of products with safe and reliable performance that maintain cable quality under severe conditions will be studied.

At present, CIGRE TB 722 covers cables without water impervious layer up to the 66 kV class. As aforementioned, higher output of wind turbines leads to higher operating voltage and larger capacity, and the risks of insulation breakdown due to long-term propagation of water trees are likely to increase.

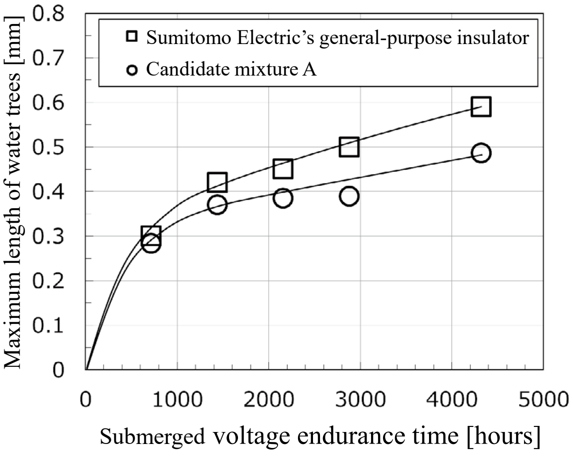

Fig. 8. Changes in time of maximum length of water trees (under severe conditions)

Based on the above, further discussions on the long-term characteristics of water trees are presented in the next section, including a study of mixture A and mixture B (improved mixture).

### 4-4 Study of long-term characteristics of submarine cables without water impervious layer

As discussed above, water tree propagation characteristics are affected by factors such as electric field, temperature, and amount of moisture. Submarine cables without water impervious layer are installed in a constantly submerged environment. Thus, when studying long-term characteristics, it is important to determine the tendencies of water tree propagation saturation characteristics.

Figure 9 shows the compiled test results of long-term characteristics. They were derived by compiling the results of the performance decrease ratio (initial dielectric breakdown strength = 1) and the test period ratio (design life = 1) based on the acquired water tree test data.

The general-purpose insulator falls below the required design level before it reaches design life, but both mixtures A and B meet the required design level during the design life period as shown in Fig. 9.

Whilst mixture A has a tight margin, mixture B has a sufficient margin against the required design level and demonstrates a saturation tendency in terms of the performance decrease rate. Thus, mixture B is considered to have stable long-term characteristics.

It is our intention to further evaluate the performance on actual equipment using mixture B.

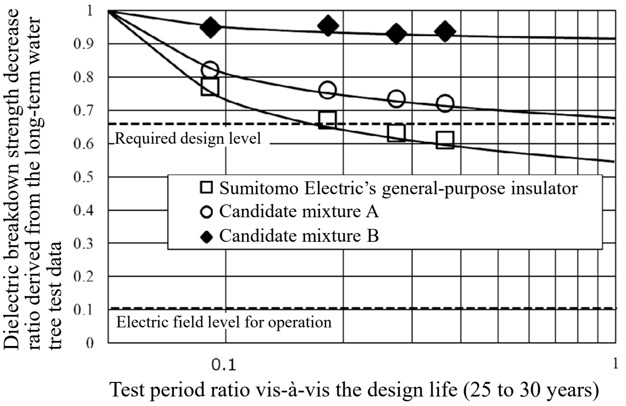

Fig. 9. Study results of long-term characteristics

## 5. Conclusion

A detailed study was conducted on submarine cables without water impervious layer with improved manufacturability, cost, and workability for offshore wind power generation, which has been introduced increasingly in and outside Japan.

The results of the study indicate that insulators with resistance to water trees are able to eliminate the largest risk of removing the water impervious layer. The evaluation also confirmed that the cable met IEC 63026 and CIGRE TB 722 for submarine cables without water impervious layer.

Efforts were made to further improve water tree resistance in order to cope with long-term operation as well as future higher voltage over the 66 kV class and larger capacity. Thus far, we have confirmed good water tree resistance characteristics.

The offshore wind market is expected to further expand as efforts to attain carbon neutrality accelerate. Recently, floating offshore wind power generation systems have attracted public attention due to restrictions such as the location to install wind turbines in addition to the need to meet requirements for highly reliable insulation performance, which can cope with higher voltage and larger capacity in response to the increasing size of wind turbines. Against this backdrop, there is growing need for mechanically robust cables.

Sumitomo Electric will continue its contribution and promotion for the use of offshore wind power generation by developing cables that meet market expectations.

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