AN INNOVATIVE POWER CABLE CONNECTION OF PROPERTY EQUIVALENCE AND NON-JOINT

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ABSTRACT

This paper proposes a new technology about cable conjunction without interfaces, which is used for power cable outage recovery or extension, and termed to be equivalent non-joint cable conjunction technology (hereinafter referred to as equivalent conjunction technology). It can be integrated with high-voltage shield, insulation and external shield into original cable without stress cone or movable interfaces; and a consecutive, equivalent conjunction combination can be created by extruded mould process, furthermore consistent specifications with original material and body structure of cables. This innovative technology is completely different from traditional technology, eliminating potential safety problems due to stress cone, movable interfaces and air gap.

INTRODUCTION

The equivalent conjunction technology is a revolutionary high-end technology of the power cable accessory field, breaking the traditional design concept of cable conjunction approach. It could realize the high-reliability technological process of the power cable with any voltage level without interfaces, and provide a more reliable technical support to the development of high-voltage and extra high-voltage cable connection technology for DC & AC and filling in the blanks in this field. This paper introduces the equivalent conjunction technology, including its design principle, technical advantage, key production process, solutions and practical projects.

1. DESIGN PRINCIPLE

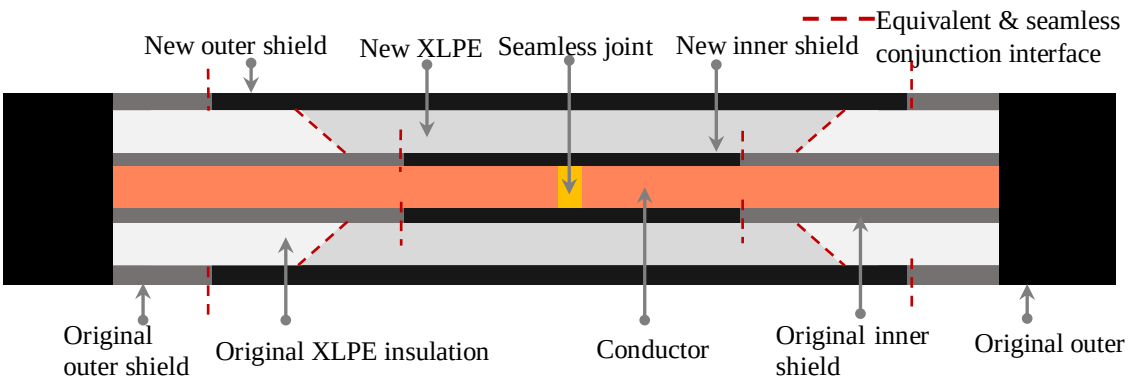
The equivalent conjunction technology is the gradual extension and restoration of the construction of each layer of the power cable using same materials and structure until the connection restores to the structure and shape of the original cable itself; the conjunction maintains consistency with the cable itself in terms of the structure and the material as exactly as the way that each layer of tree branches automatically extends and grows with non-joint, connecting the cable with fully sealed condition.

This process technology avoids some hidden dangers in design, manufacture, assembly or operation of the traditional connection method, including the change of stress cone structure, the accumulation of space charge between interface of different insulating materials, the change of interfacial stress, and the distortion of the electric field distribution easily caused by factors such as interfacial air gap or impurities. Meanwhile, the equipotential lines are smoothed and the field intensity is evenly distributed in the conjunction, the electric field concentration is not generated, and the field strength is even weakened. Thus, the equivalent conjunction can be consistent with the various characteristics of the cable itself during operation, including physical, chemical and electrical properties to achieve the requirement of equal-life operation with the cable body.

1.1 The principle structure

This principle structure of equivalent conjunction is illustrated in Figure 1. The seamless welded joint of the conductor has same diameter and resistance as the original conductor; and the regenerated XLPE insulation layer, inner and outer shield is as same as that of the original cable with regard to material composition, physical structure and characteristics.

Figure 1. The Principle Structure



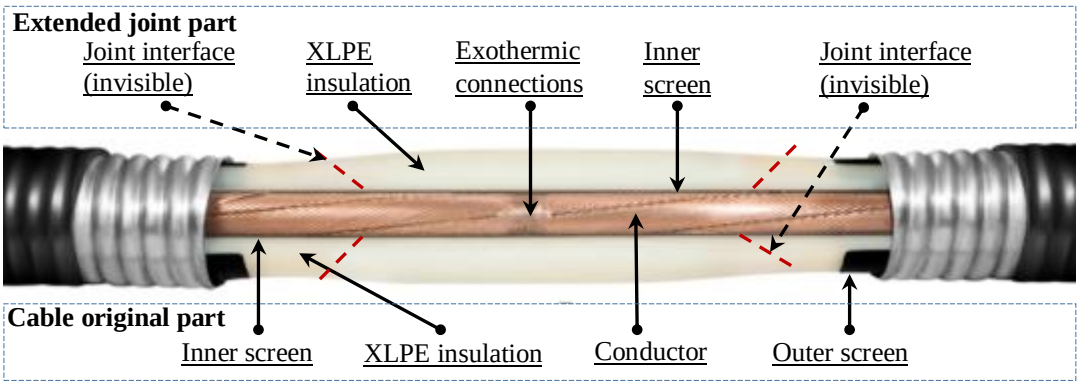
The dotted line in Figure 1 shows the welded interface between the new structures and the original parts, including the insulation layer, the inner and outer shields. The dotted line is just theoretical interfaces, in fact, the interface is invisible and there is no interface gap. Therefore, the equivalent conjunction is seamlessly integrated into the original cable.

1.2 The physical structure

Figure 2 shows a physical profile of the conjunction; the conductor, shields and XLPE insulation layer of the conjunction are components achieving equivalent recovery connection with the original cable. The movable interface does not exist at the junction between the conjunction and the original parts; and the key to connect cables is to ensure that the interface structure between the conjunction and layers of original cable is tight and not immovable.

Two conductors are connected through exothermic welding technology, which is a mature and common conductor-connect method with advantages of ampacity, conductivity and shape as same as that of an intact conductor to ensure excellent electrical performance, mechanical strength and uniform surface electric field distribution. The inner and outer shields and the XLPE insulation layer are restored by advanced moulding cross-linking process to fuse the two cable into an integral and solid whole. There are no small impurities, moisture, gas solvent and other foreign matter. The equivalent conjunction ensures the safe and stable operation of the cable, thus eliminating the risk that the conjunction part becomes a weakness in the power grid system due to the change of material and structure.

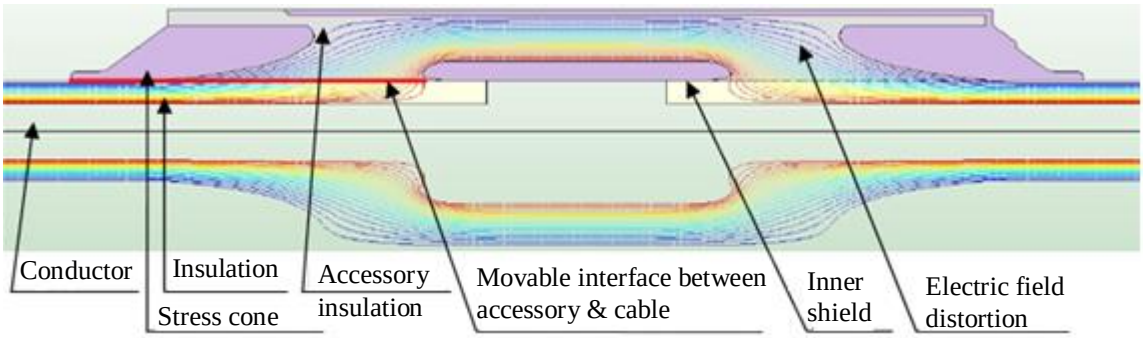
Figure 2. The Physical Structure



1.3 The electrical characteristics

Electric field equipotential line distribution can help to analysis effectiveness of equivalent conjunction. It formed by the traditional cable conjunction at the junction, and the electric field equipotential line of the original cable body are formed in distorted distribution, not similar to a natural, smooth equipotential line with the electrical properties of the cable body (Figure 3). And the equipotential lines of the equivalent conjunction body are smooth, consecutive and distributed in the same way as that of the original cable body (Figure 4). The distribution of the equipotential lines of the electric field is consistent with that of the original cable body (Note: the seamless interface in the figure is not present, but only for illustration).

Figure 3. Distribution of the equipotential lines in traditional cable conjunctions



Proper electric field intensity distribution of cable conjunction is of importance to design cable conjunctions; the principle of the traditional cable conjunction is to use the geometric structure method (i.e. stress cone, stress tube

and so on) to deal with the cable electric field distortion, and to make the electric field strength weakened, evenly distributed at the cut off of the semi-conductive layer; there is still a very big difference from the natural distribution of the electric field of the original cable, that is, the traditional cable conjunction technology can only diminish the electric field distortion, but cannot eliminate the electric field distortion (Figure 5). The equivalent conjunction body is a connection without stress cone and movable interface, restoring the connection of the cable body, without using the stress cone to control the electric field stress of the cable, so the electric field strength distribution in this connection is uniform, and the distribution of the electric field is similar to that of the original cable body (Figure 6). It is shown that the electric field strength can be weakened by appropriately enlarging the insulation outer diameter of the XLPE, thereby improving the reliability margin of the electrical stability.

Figure 4. Distribution of the equipotential lines in equivalent cable conjunctions

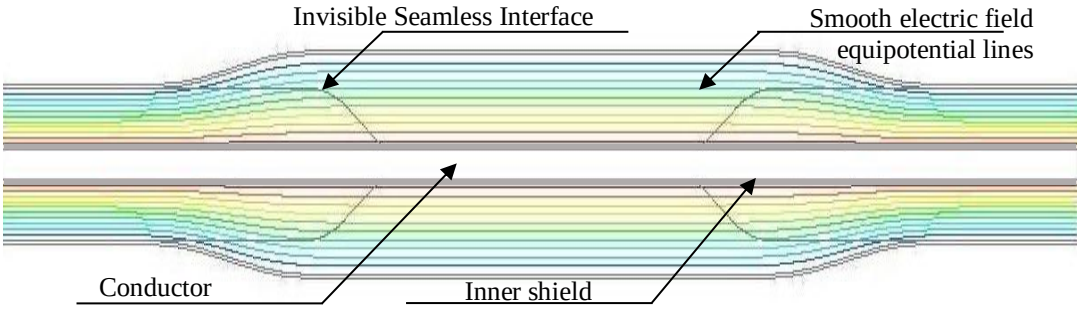


Figure 5. Distribution of electric field strength in traditional cable conjunctions

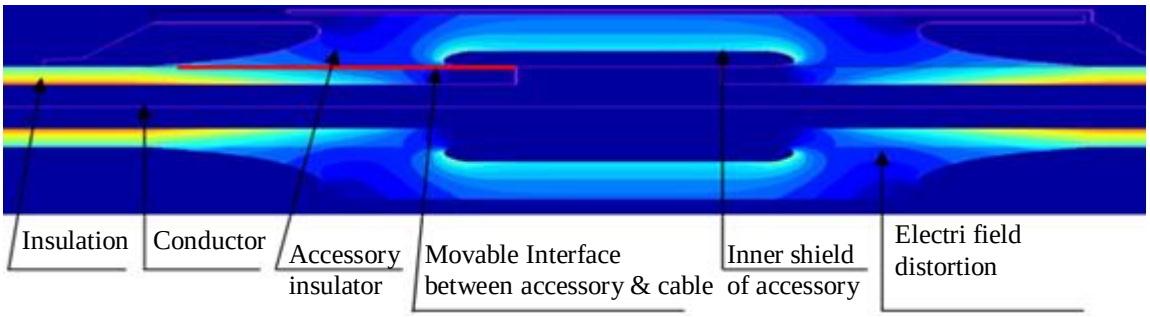
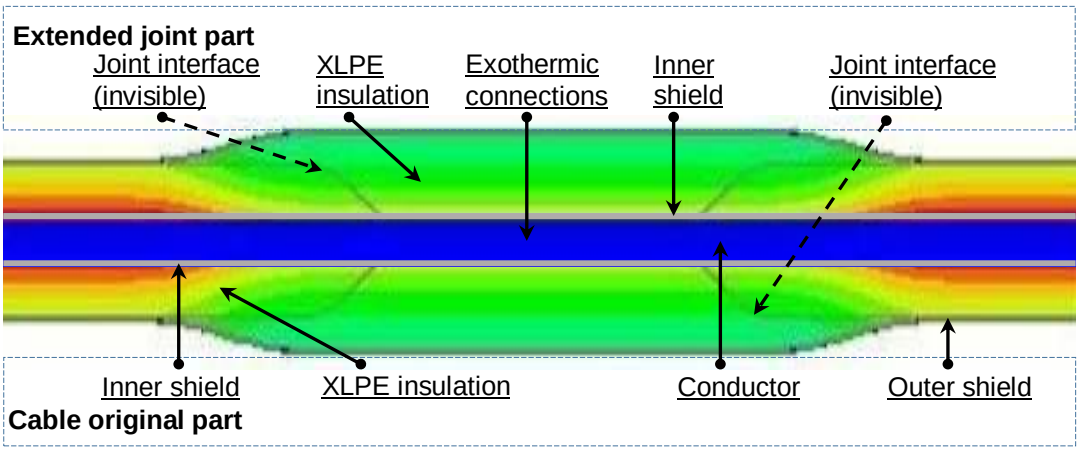


Figure 6. Distribution of electric field strength in equivalent cable conjunctions



2. ADVANTAGES AND SPECIFICATIONS

2.1 Technical advantages

Consecutive and natural electric field distribution

Following the high-voltage shield and external shield structures and specifications of the original cable, same materials are used to restore and produce conductor shield and insulation shield layers to achieve the consecutive and equivalent matched electric field shield body of the conjunction, so that the electric field distribution and the electric field strength can be well formed for its electrical

stability and operational reliability.

Excellent insulation performance
Recovering by using the XLPE material, which is equivalent to the original cable insulation, enables the fusion bonding between the insulation of the equivalent conjunction and the original cable insulation without air gap interface, and the structure is the same as that of the original cable, thus excellent electrical insulation and the durability of stable operation are fulfilled.

Flexible construction and installation
The equivalent conjunction technology and processes are precisely controlled in on-site instalment by the automation equipment. The specialized equipment can reduce the interference from the field environment on the production, and the on-site Clean Room can guarantee that the connecting work is carried out at any temperature and humidity. It features very few parts, light weight and small volume, with the production approximately equal or equal to the outside diameter of cable, as well as connected cable which is flexible and can be high-altitude suspended, with no need to worry about the impact of being dragged.

Superior water resistance
Internal and external semiconductors and insulation body make seamless fusion bonding with the original cable through on-site separate-layer injection, which has no interface and gap, with good waterproof performance.

2.2 Technical specification and application

The equivalent conjunction technology can be applied to the connection of high-voltage and extra-high voltage power cables, including AC and DC; that is, the intermediate connection between the cross-linked polyethylene (XLPE) insulated power cables of AC: 10kV, 20kV, 35kV, 48kV, 66kV, 110kV, 132kV, 220kV and 500kV as well as that of DC: ±10kV, ±20kV, ±35kV, ±110kV, ±160kV, ±200kV and ±320kV, besides submarine. The technology has been completely passed the rigorous testing on the basis of IEC standards.

3. KEY TECHNOLOGY AND PROCESSES

3.1 Conductor connection technology

As previously mentioned, the conductor connection adopts the exothermic welding technology; the advantage is that the cut-off capacity of the fusion point is the same as that of the original conductor, with excellent electrical conductivity. The rate of change of the DC resistance ratio before and after the welding is close to 0 through detection, while compared to the temperature of the original conductor of the cable, the temperature of the welding point working at the high-load current is less than or equal to 2 degrees Celsius, which cannot be achieved by the traditional cable conjunction equipment. As the exothermic welding is a molecular-level osmotic fusion, the conductor will not be broken and has no gap; the overall effectiveness of the interface of the conductor has not been changed; it is free from mechanical pressure and problems of loosening, corrosion and aging. And repetitive high-current impact can be withstood during fault, which can avoid destruction. Since high temperature of about 2000 degrees is produced during exothermic welding process, the technological means must be taken to control temperature properly during welding, Therefore, a welding cooling device with a special accustomed design shall be installed on both sides of the conductor in the vicinity of the cable insulation before welding.

3.2 Dealing with the problem of concentration of electric field stress

The recovery of the internal and external shielding layers adopts the Borealis ultra-smooth semi-conductive material specially used for the EHV cable, which is the same as the semi-conductive material for production of the cable, and has a very good fusion with XLPE of the insulation layer material. When the internal and external shielding layers are recovered, the surface of the semi-conductive material is vulcanized to form a non-strippable shielding layer. After numerous tests on the internal shielding layer of the cable of the different manufacturers, the testing fully meets the IEC standards. The technology of the equal diameter, ultra-smooth surface and seamless recovery is one of core technologies to produce the equivalent conjunction, which is also the key to determine whether electric field strength distribution in the equivalent conjunction is consistent with that in the original cable.

3.3 Recovery of insulation layer

This part of recovery adopts XLPE material for EHV cable from Borealis or the United States Dow Chemical. The specially customized computer programmed equipment automatically controls the cross-linking process between the newly increased insulation material and the XLPE insulation layer of the original cable, so as to ensure that the newly generated XLPE is consistent with the XLPE insulation layer of the original cable in terms of the material, size, physical structure and properties. After the cross-linking reaction is completed, the program controls the temperature, pressure and time until cooling, ensuring the gradual release of by-products during cross-linking of polyethylene, even the quantity and volume of particle in this new isolation are less than that produced by rapid cross-linking and nitrogen quenching during cable production.

3.4 Process of cleanness control

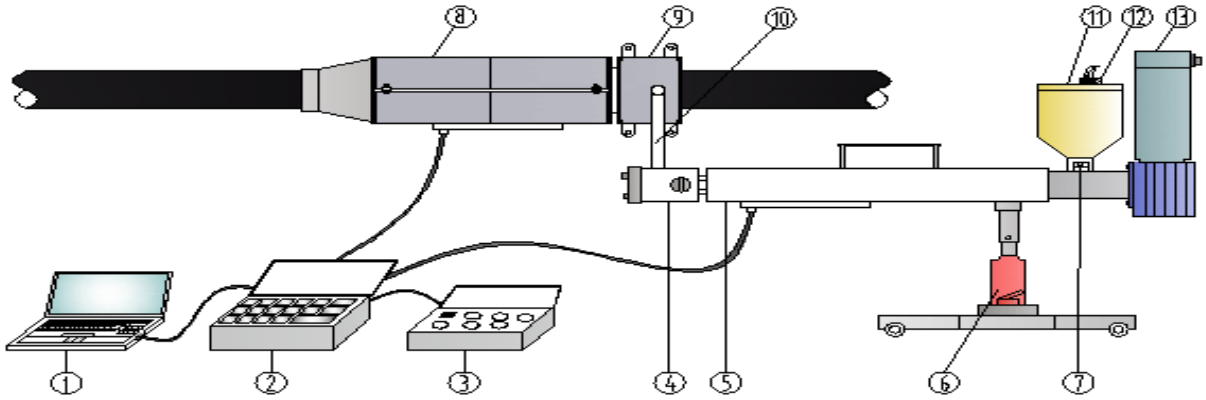
A special temporary clean room is adopted for dust-proof, waterproof, corrosion-proof and other pollution controls on site. The operator should put on clean clothes to install the mould and conduct on-site operation; the equipment should be equipped with an automatic clean treatment or clean protection device which can quickly clean the insulation surface and provide protection; the materials used in construction such as cable material must be sealed for storage and transportation.

4 TECHNICAL SOLUTION AND PRACTICAL PROJECT APPLICATION

4.1 Technical solution

The recovery processes of the semiconducting shielding layer and XLPE insulation layer for the equivalent conjunction technology are fulfilled automatically by computer program control to avoid manual operation or process variations by handwork; the device solution for accomplishing this technology is shown in Figure 7.

Figure 7. Technical solution for equivalent conjunction



1. Program controller 2. Information processor 3. Power box 4. Extrusion head 5. Extruder
6. Bracket 7. Switch 8. Mold tooling 9. Mold injection forming
10. Material feeding pipe 11. Barrel 12. Air filter 13. Servo motor

4.2 Practical project application

Project 1: Multi-Terminal VSC-HVDC Pilot Project (200kV) in Zhoushan Islands

As the first five-terminal flexible DC transmission project in the world, the converter stations were built on islands of Dinghai, Daishan, Qushan, Yangshan and Sijiao respectively, and these stations were connected by eight submarine cables and terrestrial overhead lines.

Project 2: 110kV 1600 square millimetres cable in Huizhou Boluo

The equivalent conjunction of this cable is at high altitude suspension, 23 meters from the ground height.

5 SUMMARY

A stable body is formed between the equivalent conjunction and the original cable to eliminate latent factors that make the electrical properties unstable. The insulation material and the semiconducting material for production of equivalent conjunction are exactly the same as those for production of cables. The thermal properties and mechanical properties of fusion interface fully meet the requirements of the following standards: GB/2951.1-1997, GB/T 11017.1 ~ 11017.3-2002, GB/Z 18890.1 ~ 18890.3-2002 and IEC60840: 1999 through a large number of experiments and tests.

The realization of the equivalent conjunction technology without interface eliminates expand a new area from the traditional approach of the conductor compression joint, binding insulation, expansion of package accessories and other means, since the beginning of recorded history for the cable connection technology, that has broken the traditional concept of cable connection design and achieves the highly reliable and seamless connection technology for the high-voltage and extra high-voltage cables without interface, providing a more reliable technical support for the development of the connection technology of the high-voltage and extra high-voltage cables, which is the development trend of the high-voltage and extra-high voltage cables with high reliability and without interface.

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