

## COMPARISON OF WATERPROOF RELIABILITY OF 10KV XLPE POWER CABLE JOINT IN SHANGHAI URBAN AREA

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### ABSTRACT

In Shanghai urban area, 10kV XLPE power cable is widely used in the new distribution project, and the oil-paper cable reconstruction project. One of the major challenges associated with XLPE power cable is that once water is entered into it, the water trees will eventually lead to insulation capability drop sharply. In order to prevent this situation, the best way for cable joint waterproof should be found.

Firstly, this paper defines the waterproof reliability:  $\text{Waterproof reliability} = \text{Breakdown Voltage} \times \text{operation time (in water)}$ . And this paper describes three waterproof methods of 10kV XLPE power cable joints: 1) Tape type 2) Epoxy resin type 3) Prefabricated-type, which are often used in shanghai urban area now. Meanwhile operation reliability analysis and operation data of these three methods are also given out.

Secondly, Value Engineering is used to analyze the excellent price-performance ratio type in these three types.

Lastly a new medium voltage cable option principal in Shanghai urban area is provided.

### KEYWORDS

10kV XLPE power cable, waterproof reliability, medium voltage cable selection principal

### INTRODUCTION

10kV cables insulated with extruded dielectric materials, especially crosslinked polyethylene (XLPE), are extensively used throughout the world. In Shanghai large scale commercialization of XLPE insulated cables began in the 1980s. The change of its joint did not start until the mid of 90s. Some prefabricated-type joints are used, and became widespread after 2004. At that time, in Shanghai urban area, 10kV XLPE power cable is widely used in the new distribution project, and the oil-paper cable reconstruction project. Table 1 shows that, in recently three years, many joints had been installed and the number of prefabricated-type one is rising.

sets Type	Years		
	2005	2006	2007
Tape-type	685	870	2634
Prefabricated-type	2375	2784	1777
Epoxy-type	134	145	162

Table 1 the list of installed joints in three years

But Shanghai is so close to the sea, the underground water lever is usually  $-4\text{m} \sim -5\text{m}$  altitude. All the cable is always laid in the underwater. One of the major challenges associated with XLPE power cable is that once water is entered into it, the water trees will eventually lead to insulation capability drop sharply.

### FIVE MAIN WATERPROOF MATERIALS IN SHANGHAI CABLE PROJECT

#### 1. Heat-shrinkable tube:

The basic material of heat-shrinkable tube is heat-shrinkable polyethylene, its inner layer is pasted with heat-melt boding solvent, which has the waterproof capability, when installed heated.

#### 2. Self-adhesive insulate tape:

Self-adhesive insulate tape, such as 3M ethylene-propylene rubber (EPR) tape, which thickness is 0.76mm, black, 90 degree Celsius refractory. When installed and stretched 200%, it can be adhered tightly and being waterproof.

#### 3. Epoxy resin:

In accessory of joint, epoxy resin (EP) and polyurethane resin (PUR) are commonly found. When they are mixed before the installation of joint, it can be waterproof.

#### 4. Prefabricated cone:

Interface fit between prefabricated cone and cable, which should provide adequate interface pressure, can also give the waterproof capability.

#### 5. Waterproof tape:

Waterproof tape, like 3M 2228# tape, which thickness is 1.65mm, water absorption is 0.15%.

**DEFINATION OF WATERPROOF RELIABILITY OF JOINT**

Through the experiment, we found that two factors which are breakdown voltage and time in water are main ways to measure the waterproof capability.

We define : Waterproof reliability= Breakdown Voltage × operation time (in water). (1)

**THREE DIFFERENT JOINTS**

**1. 10kV XLPE tape-type Joint**

**1. 1. Structure**

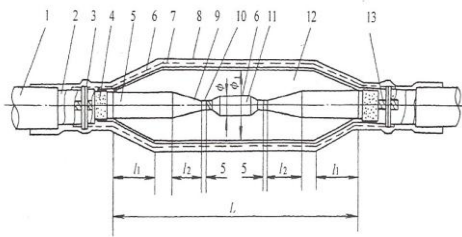


Figure 1. The structure of tape-type joint

1 - cable outer sheath;2 - cable shielding layer;3 - brass wires;4 - outer semi-conductor layer;5 - cable insulate layer;6 - self-adhesive semi-conductor tape;7 - brass shielding mesh;8 - heat-shrinkable tube;9 - inner semi-conductor layer;11 - connector;12 - self-adhesive insulate tape;13 - bridge line;

**1. 2. Waterproof method**

Figure 1 show the main waterproof capability is made by heat-shrinkable tube+ self-adhesive insulates tape. 9 coils self-adhesive insulate tapes, stretched 200%, will give it enough insulate intensity and waterproof.

**1. 3. Malfunction analysis**

In order to indentify how many tape-type joints were fault causes of the water, Table 2 is listed. It is fault associated with water. Almost two of them have been watched the WT (water tree) in the fault area.

No.	Route Name	Fault Date	Installation Date	Duration (year)
1	凯 8	07/09/21	94/12/19	12.83
2	白 35	07/12/21	01/02/22	6.5

Table 2 List of tape-type joint fault cause by water in 2007 (Average duration year =9.665)



Figure 2.白 35 fault caused by the water tree

**1. 4 Waterproof Capability**

According to the formula(1) Waterproof capability of Tape-type joint = Breakdown Voltage × operation time (in water)=10kV × 9.665=96.65.

**2. 10kV XLPE Prefabricated-type Joint**

**2. 1 Structure**

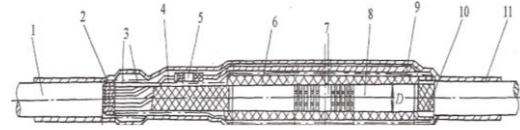


Figure 3 Structure of prefabricated-type joint

1 - cable outer sheath;2 - cable shielding layer;3 - weld spot;4 - earthing line;5 - bonding cable connector;6 - prefabricated cone;7 - conductor connector;8 - cable insulation;9 - semi-conductor layer;10 - semi-conductor shielding layer 11 - heat shrinkable tube;

**2. 2 Waterproof Method Type**

From Figure 3, the waterproof capability is mainly produced by prefabricated cone + heat-shrinkable tube. This type of waterproof is mainly depended on interface pressure between prefabricated cone and cable.

**2. 3 Malfunction analysis**

No.	Route Name	Fault Date(Y/M/D)	Installation Date(Y/M/D)	Duration( years)
1	义 10	07/04/16	06/12/11	0.4
2	半 31	07/05/28	01/08/08	5.8
3	殷 29	07/07/07	06/12/24	0.7
4	葑 26	07/08/14	06/09/25	0.9
5	葑 29	07/08/14	06/09/25	0.9
6	罗 20	07/08/23	05/08/05	2
7	桥 24	07/08/29	04/03/04	3.5
8	罗 20	07/09/22	05/08/05	2.1
9	葑 15	07/09/24	06/09/25	1
10	葑 18	07/09/24	06/09/29	1

Table 3 List of prefabricated-type joint fault cause by water in 2007

Average duration year =1.83

The waterproof capability in the normal case: Waterproof capability of Tape-type joint = Breakdown Voltage × operation time (in water)=10kV × 1.83=18.3



Figure 4. photo of fault of 罗 20

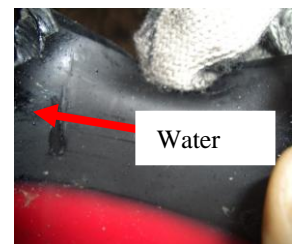


Figure 5. photo of fault of 葑 15

**2. 4 Test analysis**

Due to the rising number of fault, we have to do the test to check the key point which factor causes it.

Insulate diameter of tested cable is Φ 33.6mm,the inner diameter of joint isΦ 31mm.

**2. 5 Waterproof Capability**

From Table 4 and Table 5 below, 1#test result is best to be chosen as standard, because it is new product and passed the test. Waterproof capability of prefabricated-type joint = Breakdown Voltage × operation time (in water)=100kV × 0.55=55

Test Method	The cable is put in the water pool outdoor, depth is 2m, and it is moved in the water every one or two days. Constant voltage is 23kV, Current is 600A, Frequency is 50Hz.		
No.	1#	2#	3#
Start Day(Y/M/D)	07/12/14	07/12/14	07/12/14
Waterproof Method	PVC tape is used to cover 5mm the semi-conductor layer of the prefabricated cone. Joint outside is totally wrapped by waterproof tape.	Serration of the semi-conductor layer, inner semi-conductor layer of prefabricated cone is reduced 10mm. Joint outside is totally wrapped by waterproof tape.	Semi-conductor layer of cable is not polished, and no waterproof tape wrapped
Interference Fit	2.5mm	2.5mm	2.5mm
End Day(Y/M/D)	08/06/03	07/12/25	08/01/07
Duration	0.55	0.1	0.1
Information of test	Withstand Voltage in 50Hz is 45kV/5min, 55kV/5min, 75kV/min. 10 0kV flash over	PD overrun	Breakdown in 39kV
Fault Conclusion	Pass(standard version)	Inaccurate semi-conductor layer disposal	Inaccurate semi-conductor layer disposal and water penetrating

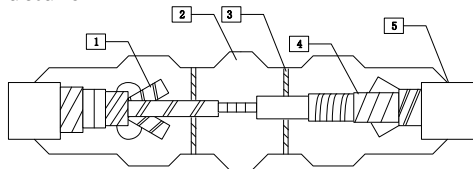
Table 4 1#, 2#, 3# test result on prefabricated-type joint

Test Method	The cable is put in the water pool outdoor, depth is 2m, and it is moved in the water every one or two days. Constant voltage is 23kV, Current is 600A, Frequency is 50Hz.		
No.	4#	5#	6#
Start Day(Y/M/D)	07/12/14	07/12/14	07/12/14
Waterproof Method	Cable Bended,, semi-conductor of cable is not polished. and waterproof tape is roughly wrapped	Cable Bended, semi-conductor of cable is not polished. Joint outside is totally wrapped by waterproof tape.	No tapes, only the prefabricated cone.
Interference Fit	2.5mm	2.5mm	2.5mm
End Day(Y/M/D)	07/12/21	08/03/06	08/03/06
Duration	0.1	0.3	0.3
Information of test	PD overrun	PD(1.1-3.1pC) 15kV background	PD(1.1-3.1pC) 15kV background
Fault Conclusion	Inaccurate waterproof tape disposal	Pass	Pass

Table5 4#, 5#, 6# test result on prefabricated-type joint

**3. 10kV Oil-paper to XLPE transition Epoxy-type joint**

**3. 1 Structure**



1.oil-paper cable 2.Epoxy resin input 3.support board 4.XLPE cable 5. Heat-shrinkable tube

Figure 6. Structure of epoxy-type joint

**3. 2 Waterproof Method Type**

For this type joint, different side has different material XLPE and Oil-paper. Epoxy resin is a good material, but it cost much time to solidify.

Method: Epoxy Resin + heat-shrinkable tube

**3. 3 Malfunction analysis**

No.	Route Name	Fault Date(Y/M/D)	Installation Date(Y/M/D)	Duration (year)
1	连 23	07/5/25	01/4/21	6.1

Table 6 List of Epoxy-type joint fault cause by water in 2007

No.	Joint Type(1 phase)	Material Description	Material Unit Cost(RMB)	Amount	Labor cost <sup>1</sup>	Total Cost(RMB)(2)
1	Tape-type	Heat-shrinkable tube	91	2	4	1431
		Self-adhesive insulate tape	41	9		
2	Prefabricated-type	Prefabricated cone	1000	1	3	1842
		Heat-shrinkable tube	91	2		
		Waterproof tape	120	4		
3	Epoxy-type	Epoxy resin	120	1.6	6	1702
		Heat-shrinkable tube	91	2		

Table 7 the total cost of three different joints

1 Unit price of Labor cost=220 Yuan

**3. 4 Waterproof Capability**

Waterproof capability of Tape-type joint = Breakdown Voltage × operation time (in water)=10kV × 6.1=61

**COST OF THREE JOINTS**

In considering the comprehensive analysis of technique and cost, we must pay more attention to the cost of joint. If the cable route has 30-phase joints, the cost difference is huge. We divide the cost into two parts: Material Cost and labor cost.

**1. Material Cost & labor Cost**

In order to calculate the total price of three different type joints, all the unit price of waterproof material should be obtained.

In Table 7, Total Cost(RMB)= Material Unit Cost × Amount + Labor cost × Unit price of labor cost . (2)

## 2. Value Engineering Analysis

Value Engineering =Function/Cost=Waterproof capability/Cost (3)

No.	Type	Waterproof capability	Cost	Result(3)	Compare
1	Tape-type	96.65	1431	0.068	Best
2	Prefabricated-type	55	1842	0.03	good
3	Epoxy-type	61	1702	0.035	Better

Table 8 the Value Engineering of three types of joint

## NEW PRINCIPLE OF JOINT SELECTION IN SHANGHAI URBAN AREA

Combined with value analysis and actual condition in Shanghai, we have a new principle in 35kV XLPE cable joint usage: we make use of tape-type joint, limitedly employ the prefabricated-cone type joint. In transition joint, we use the epoxy-resin type joint only.

Joint type \ Laying type	Ground bury	Tube	Tunnel	Cable trench	Cable bridge
Tape-type joint	✓	✓	✓	✓	✓
Prefabricated-joint		✓	✓		
Epoxy-type joint	Oil paper and XLPE transition joint only				

Table 9 the joint selection principal in Shanghai urban area

Because the tube laying and the tunnel laying, the field condition is better than other three situations. There is little water in it. Therefore only under these two situations, the prefabricated joint is given the permission. But now we are still monitoring the operating situation of it, although this type of joint is welcomed by the workers.

The foregoing information gathered over three years of field experience should help the cable owner make the right decision about the joint selection.

## SUMMARY AND CONCLUSIONS

This article has documented three different types of cable defects that were caused by water. And the comparison and value engineering are also provided. A Summary of the finding and important conclusions are provided below.

- i. In the city, like Shanghai urban area, the tape type joint is the most efficient way to avoid the water.
- ii. The cause of the high fault rate of prefabricated-type joint is not the material but the high demand on installation. From the PD test, the disposal of the semi-conductor layer mainly leads to the fault. In city like Shanghai, in which the installation condition is not very well, this type joint should be restricted.
- iii. The labor cost of solidarity of Epoxy-type is too high to be used in the daily joint, it is only used in the transition joint between oil-paper cable and XLPE cable.

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