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A DEVELOPMENT OF UNDERGROUND DISTRIBUTION CABLE FOR WATER BLOCKING AND REDUCING PROTRUSIONS

Jae-bong LEE, Korea Electric Power Research Institute(KEPRI, (KOREA), jbonglee@kepco.co.kr
Ju-yong KIM, Korea Electric Power Research Institute(KEPRI, (KOREA), juyong@kepco.co.kr
Byung-sook KIM, Korea Electric Power Corporation(KEPCO), (KOREA), kbsook@kepco.co.kr
IL-keun SONG, Korea Electric Power Research Institute(KEPRI, (KOREA), songilk@kepco.co.kr

ABSTRACT

The root causes of underground distribution medium voltage cable faults are water penetration into insulation layer(water tree) and focused stress on semi-conductive layers(protrusion). Accordingly, it is needed to improve the water blocking performance of jacket material and the structure of power cables for extending lifetime and preventing failures. We uses nonflame LLDPE compound instead of conventional PVC(polyvinyl chloride) as a outer jacket material. And the jacket structure was also changed from embedding to encapsulating structure. We also use supersmooth class semi-conductive compound as a conductive screen. The insulation screen semi-conductive compound was not changed. The newly developed cables have better AC breakdown voltage after aging tests. This cable has been installed in Korean distribution system from late 2006.

KEYWORDS

Cable, PE jacket, Waterproof, Encapsulating Structure

INTRODUCTION

The XLPE insulation of URD(underground residential distribution) cables are became common. 22.9 kV CNCV W model is the most widely used in Korea. Before 1998 CNCV cable was installed, conductor of which cable was not waterproofed. However waterproofing of conductor could not decrease cable fault rate.

The most common causes of cable fault in Korea can be divided into two categories except digging damage. The first cause ia water penetration into insulation into insulation, and the second is irregularities of interfaces between insulation and semi-conducting screens.

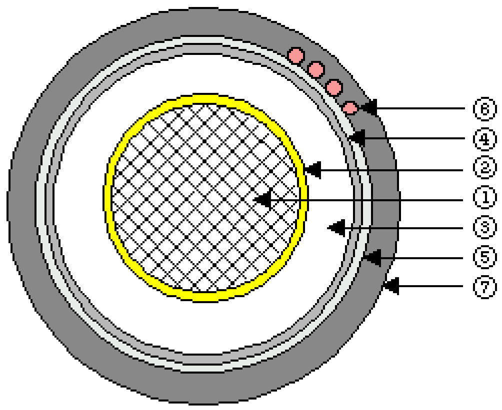
PVC outer jacket material is not preventive to water penetration. It is need to find best solution in order to enhance waterproof performance of underground cables.

The conductor screen and insulation screen are for relaxation of electrical stress from high voltages. However sometimes these semi-conducting layers have protrusions then electrical stresses are concentrated to these local defects. These protrusions were the cause of early fault of cables. These defects of semi-conducting layers cannot be completely prevented in the production process with conventional semi-conducting compounds. We have to use new semi-conducting compounds having higher smoothness.

STRATEGES FOR DESIGN OF NEW URD CABLE

We reviewed our CNCV-W model cable, laminated structure cable and encapsulating structure cables.

Laminated structure cables have the best waterproof performance but not perfect at the junction point and we have to consider the electrical behaviour of neutral conductor, long term behaviour of overlapped parts, exfoliation of bended area. So we decided to apply encapsulating structure for new design.



No	Major Components	Materials
1	Conductor	Concentric Lay Stranded Copper Conductor (with water penetration impediment sealant)
2	Conductor Shield	Super Smooth Semiconducting Compound
3	Insulation	Tree retardant Crosslinked Polyethylene Compound
4	Insulation Shield	Black Semiconducting Thermosetting Compound
5	Water Blocking Tape	Semiconducting Water Blocking Tape
6	Concentric Neutral Conductor	Round annealed Copper Wires (Encapsulated)
7	Outer Jacket	Non-flame Polyethylene

Figure 1: Structure of TR CNCV W Cable

Insulation is need to tree retardant characteristics because of containing moisture in the production process and moisture ingress through outer jacket during field operation. So we decided to apply TR XLPE compound

for insulation material.
Conductor shield shall be free from protrusions and irregularities so we decided to use super-smooth class semi-conducting compounds used in EHV cables. Figure 1 shows the design outline of our new cable design.

Table 1: Comparison of Cable Designs

Item	CNCV-W		New design	Remarks
	XLPE	TR XLPE		
Price	O	△	△	CNCV-W
Waterproof of outer jacket	X	X	△	Radial direction
Waterproof of neutral wire	△	△	O	
Water tree retardant	X	O	O	
Installation work.	O	O	O	Using special tool
Flame resistance	O	O	O	Flame retardant PE

DEVELOPMENT OF OUTER JACKET COMPOUND

PVC(Polyvinyl chloride) used to as a outer jacket material because of its low price and flame resistance, but it has poor performance in moisture ingress, mechanical properties, producing toxic gas when fire and cannot operate in high temperature above 130 ℃.
To find a alternative material for PVC as a outer jacket, we choose 6 polyolefins as a base resin. Physical properties of 2 kinds of LDPE, 2 kinds of LLDPE, MDPE and HDPE were tested. LLDPE have the best properties in mechanical properties, WVT(water vapour transmission). MDPE and HDPE also have good properties but hardness is not suitable. LLDPE have higher melt index than LDPE so that can get more extrusion in the same production conditions, and have better properties in mechanical and thermal aging.
We tested again for the same 6 kinds of compounds from base resins. The results are similar to that of base resins. LLDPE and MDPE compounds are best in the physical properties, mechanical characteristics and WVT. Especially they are 10 ~ 20 times excellent in the WVT property than PVC (See Figure 2 and 3).

Table 2: Properties of Base Resins for Outer Jacket

Physical Properties	LLDPE		LDPE		MDPE	HDPE
	1	2	1	2		
Melt Index [g/10min]	1.1	2.3	0.3	0.33	0.23	0.21
Tensile Strength [Mpa]	20	20.7	18.9	18.4	34.5	34.8
Tensile Elongation [%]	836	872	593	684	860	865
Retension of Tensile St. [%]	102	100	52	46	85.6	96.2
Retension of Elongation [%]	90	96	69	70	86	89
Shore D Hardness	49	48	48	49	56	60

It is difficult to apply ASTM E96 with real cable sample to test water penetration characteristics. We used the Tokyo Electric Power Company's method for transmission cables. Cable length is 30 cm and cores are removed and the silica gel is inserted into there and sealed. Samples are set in the bath of 60 ℃ and we measured the weight of samples every 10 days until 30 days. The water permeability was calculated by following equation;

$$(P) = \frac{\frac{Q}{L} \times \log(\frac{R_2}{R_1})}{2\pi t d} \qquad [1]$$

Where, Q is penetrated water weight (g), L is length of sample (cm), R_1 is inner diameter of jacket, R_2 is outer diameter of jacket, d is saturated vapour pressure at test temperature (mmHg, 149.5 mmHg at 60 ℃), and t is test time (day).

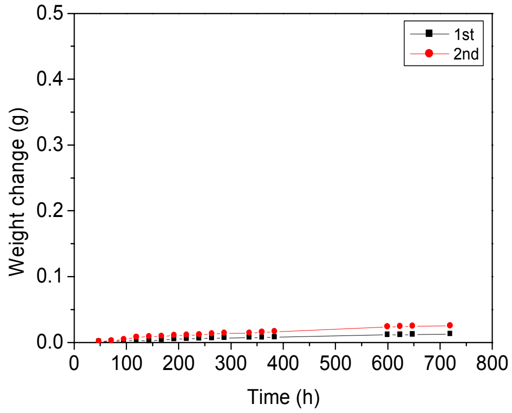


Figure 2: WVT of LLDPE Compound

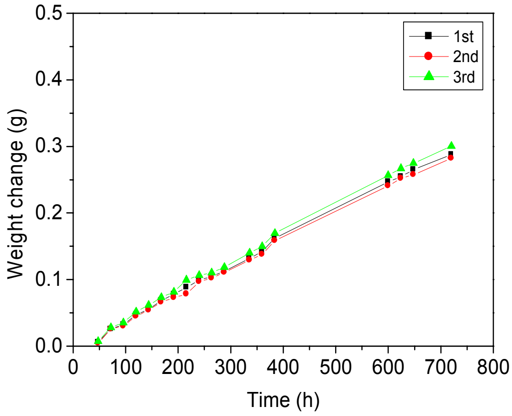


Figure 3: WVT of PVC Compound

We tested following 4 samples;
- CNCV-W cable (PVC jacket)
- Laminated cable (LLDPE or MDPE jacket)
- Encapsulating cable (LLDPE or MDPE jacket)
- FR CNCO-W cable (flame-retardant PE jacket)

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Figure 4: Water Penetration Test (TEPCO Method)

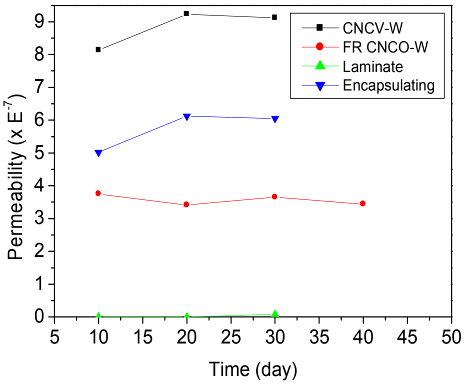

Figure 5: Results of Water Penetration Test

CNCV-W cable is chosen to test PVC jacket and FR CNCO-W cable is chosen to water penetration property of flame retardant PE.

Water permeability of CNCV-W cable was increased until 20 days and then slightly decreased. This is considered due to saturation of moisture. Water permeability of CNCV-W cable didn't meet the criterion of TEPCO's method. It is considered this result came from that PVC has polarity.

FR CNCO-W cable didn't have saturation of water permeability until 30 days, so test was done more 10 days. The permeability didn't meet the criterion of TEPCO, this result came from that FR CNCO-W doesn't have metallic shield different from Transmission cable.

Laminated cable met the criterion regardless of jacket material. It is considered that metallic shield is the perfect barrier of water transfer.

Encapsulating cable also didn't meet the criterion and had higher value than that of FR CNCO-W cable. After all, encapsulating structure, in which water permeability is depends only jacket material, is not perfect barrier of water penetration in radial direction.

DEVELOPMENT OF SEMICONDUCTING COMPOUND

Upgrading of semi-conducting material is to improve smoothness between insulation and shield layers so that enhance the insulation property of cables. Conductor shield is more important because it affects more insulation layer. It is considered that water penetration will be prevented by outer jacket material and structure change, but we also decided to upgrade insulation shield in electrical and water penetration properties.

Insulation shield material of CNCV-W cable is EVA(ethylene vinyl acetate). We choose 4 type of new base resin for conductor shield material, 2 types of EVA, EEA(ethylene ethyl acrylate), and EBA(ethylene butyl acrylate). We tested basic physical properties, WVT and electrical properties.

EEA is better than EVA in thermal stability and mechanical property. EBA is cheaper than EEA. EEA is also better than EVA in WVT and a.c. breakdown voltages.

Table 3: Properties of Base Resins for Conductor Shield

Physical Property	EVA1	EVA2	EEA	EBA
Melt Index [g/10min]	5.79	12.35	7.03	3.80
Tensile Strength [Mpa]	20	24.5	16.8	14
Tensile Elongation [%]	747	688	746	700
DSC Melting Point [℃]	90	63	100	93

Compounds were made from 4 types of base resins with antioxidants, lubricants for processing property modification, carbon black for electrical conductivity and cross-linking agents for mechanical properties.

Resin variation tests and carbon black content variation tests for base resins are carried out for conductor shield material, but for insulation shield material carbon black types and content variation tests for only one base resin.

Compounds with EVA and EEA as a base resin and AB and FB-2 as carbon black were suitable for conductor shield materials. Compounds using EEA as a base resin shows low WVT. In the carbon black content variation test, 60 phr of carbon black in EVA or EEA were optimal for the electrical and mechanical properties.

Proper mechanical strength and electrical conductivity and strippability are important for the insulation shield materials. For strippability, we use only one type of EVA and the carbon black variation test result shows that AB and FB-2 were suitable for the extruded surface shape. In the carbon black content variation test for the AB and FE-2, showing good properties in carbon black variation test, all compounds showed good property, but if carbon black content were decrease, electrical conductivity also decrease, so 60 ~ 65 phr of carbon black was the optimal content.

In the WVT test, new compounds for the insulation shield material showed better results. It is considered this result came from EVA having more VA.

EVALUATION OF NEW MODEL CABLE

Main features of new cable are super-smooth semi-conducting material for the conductor shield, TR XLPE for the insulation material and encapsulating structure of flame retardant outer jacket.

Super-smooth semi-conducting material uses EEA as a base resin which has good thermal stability, and acetylene black to give electrical conductivity. This compound is expected to get rid of protrusions and irregularity of interface between insulation and conductor shield.
TR XLPE is applied to the insulation material because of water penetration form joint. We expect more reduction of water tree by TR XLPE insulation. The thicknesses of core layers are same to those of CNCV-W cable.
Flame retardant PE for the outer jacket material were applied by LLDPE with flame retardant agents, considering flame retardant features, physical properties, and prices. Thickness of outer jacket is decided by referencing RS standard of KEPCO and IEC 60502-2.
Structure of new model cable is showed in Table 4.

Table 4: Structure of New Cable Model (draft)

Components	Material	Size
Conductor	Concentric Lay Stranded Copper Conductor(with water penetration impediment sealant)	325 ㎟.
Conductor Shield	Super Smooth Semi-conducting Compound	0.6 mm
Insulation	Tree retardant Crosslinked Polyethylene Compound	6.8 mm
Insulation Shield	Black Semi-conducting Thermosetting Compound	1.2 mm
Water Blocking Tape	Semi-conducting Water Blocking Tape	
Concentric Neutral Conductor	Round annealed Copper Wires (Encapsulated)	
Outer Jacket	Flame Retardant Polyethylene	2.4mm

We made following 2 types of model cables to study what influence come from the conductor shield.

- Conventional Smooth
- Super Smooth

Conductor size of model cable is 60 ㎟, and water retardant sealant is not applied to accelerate the aging effect. The thickness of conductor shield is same to that of CNCV-W as 0.6 ㎜. Insulation thickness is 1.8 ㎜ to accelerate the aging.

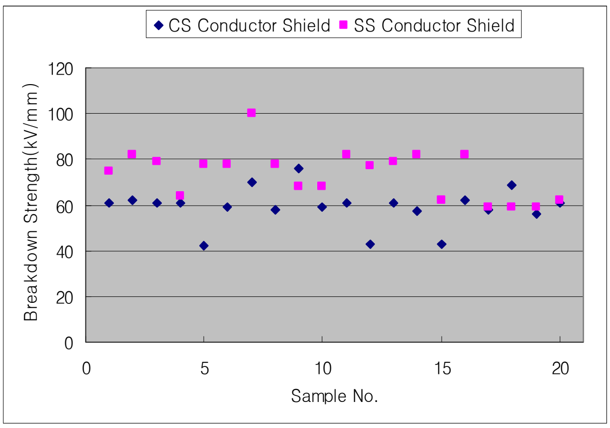

Figure 6: AC Breakdown Strength of Model Cables

Model cables were laid under the water bath in 75% of its length, and aged on 85℃ of conductor temperature during 100 hours.
After the aging a.c. breakdown voltage tests were carried on the model cables. Figure 6 shows the results. The model cables having super-smooth conductor shield shows higher breakdown strengths. So we could consider the new model cable has the better insulation performance.
We also made real size cable and carry out AWTT(Accelerated Water Treeing Test) of AEIC for the new design cable and old design cable. New design cable has better results but we won't mention it in detail in this paper for the lack of space.

CONCLUSIONS

We developed new URD cable having enhanced insulation performances with water proofing into the cable and no-protrusion in shield layers. Supersmooth semiconducting compound was applied to upgrade the flatness of conductor shield. TR XLPE compound was used in the insulation in order to prevent water tree growth by penetrated water from joints. Outer jacket material and structure also changed to flame retardant and waterproofing PE and encapsulating structure respectively.
New cable is going to be used in fields from 2006 after the design tests. We are expecting through model cable tests that new TR CNCE-W cable has better water-proofing performance and long life in Korean URD environments.

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