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HVDC 500kV PPLP MI 케이블시스템 개발

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Development of HVDC 500kV PPLP MI cable systems in Korea

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Abstract - This paper describes the development of HVDC ±500kV polypropylene laminated paper (PPLP) mass-impregnated (MI) type cable system for HVDC transmission lines. As you know, mass-impregnated type cable generally has only insulating layer with the Kraft paper impregnated with a high-viscosity insulating compound. But polypropylene laminated paper is made of a layer of extruded polypropylene (PP) film sandwiched between two layers of Kraft paper. Thanks to PP film and its combination with Kraft paper, PPLP has higher AC, Impulse (Imp.) and DC breakdown (BD) strengths as well as lower dielectric loss than conventional Kraft paper insulation. In addition, Kraft MI cable has a limitation for the maximum conductor temperature as 55℃. But this PPLP MI cable has higher maximum conductor temperature than that of Kraft MI cable due to advantage of oil drainage characteristics. It is the most economic type of cable for HVDC transmission. Also HVDC ±500kV PPLP MI cable system was developed including land joints and outdoor-terminations. In order to prove the mechanical and electrical performances, the type test was carried out according to CIGRE recommendations. A full scale cable system has been tested successfully. And additional load cycle and polarity reversal tests on the cable system showed a higher performance compared with a similar mass impregnated paper cable.

1. Introduction

Recently, HVDC seems more suitable than AC for long length high voltage power transmission. Indeed, multiple losses such as capacitive loss encountered in AC can be drastically reduced by working in HVDC. Therefore, a HVDC cable with large power transmission capacity, environmental-friendly features and economic benefits has been required in the world. This paper describes the development of HVDC ±500kV polypropylene laminated paper (PPLP) mass-impregnated type submarine cable system for HVDC transmission lines. As you know, mass-impregnated type cable uses the Kraft paper impregnated with a high-viscosity insulating compound as the insulation layer. And PPLP is the only artificial insulating material having high dielectric strength and low loss that can substitute for conventional cellulosic Kraft paper. Recently, PPLP insulated oil-filled cables have already been installed in DC transmission lines for up to 600kV.

For almost of the long distance HVDC links mass-impregnated type cables have been employed. Since Oil-filled (OF) cables require fluid-pressurizing, it is fundamentally unsuited to long-distance transmission more than about 50km. In case of PPLP MI cable, there is no requirement to maintain pressure in the cable therefore there is no limit on the length of cable that can be used. Also, MI cable has a limitation for the maximum conductor temperature as 55℃. But this PPLP MI cable has not 55℃ but 80℃. In addition, it is the most economic type of submarine cable for HVDC transmission.

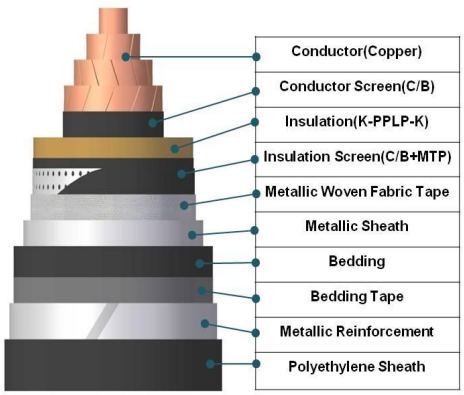
At the initiatory stage, we developed ±250kV mass-impregnated type cable with cross-section of 900㎟ conductor, flexible joints and terminations. This submarine cable system was established between Jindo and Jeju special self-governing province in Korea.

And we recently developed HVDC ±500kV PPLP MI submarine cable, land joints and outdoor-terminations. In order to prove the mechanical and electrical performances, we carried out the type test according to CIGRE recommendations (Electra No. 171[1] & 189[2]). We determined the insulation thickness of cable as 22 mm to ensure that the working stress at high temperature is lower than E_{dc}=40 kV/mm and E_{imp}= 100 kV/mm, and validated by calculating electrical stress. The specimen was consisted of about 50m long cable with land joint and terminations. These specimens have passed the type test successfully, including load cycle test, polarity reversal test and superimposed impulse test.

2. Development of HVDC ±500kV PPLP MI cable

2.1 Designs of cable and joint

Polypropylene laminated paper(PPLP) is a laminated paper consisting of Polypropylene(PP) film and conventional Kraft paper. PPLP has excellent electrical characteristics, which are higher electrical breakdown strengths and lower dielectric loss than those of conventional Kraft paper. The electrical breakdown strengths of PPLP is significantly improved in proportional to PP ratio in PPLP since most of electrical stress in PPLP is distributed in the part of PP film due to lower permittivity and higher resistivity than those of Kraft paper. We recently developed HVDC ±500kV 2500㎟ PPLP MI submarine cable, land joints and outdoor terminations. Figure 1 shows the construction of ±500 kV PPLP MI submarine cable. Insulation material used polypropylene laminated paper(PPLP) mass-impregnated (MI) with a high-viscosity insulating compound.

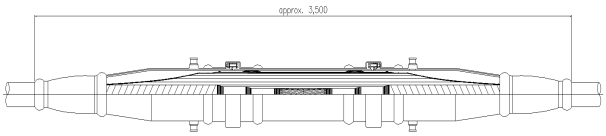


<Figure 1> Construction of ±500kV PPLP MI cable

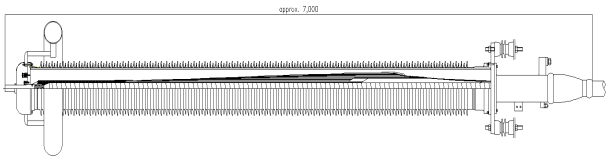
We determined the insulation thickness of cable as 22 mm to ensure that the working stress at high temperature is lower than E_{dc}=40 kV/mm and E_{imp}=100 kV/mm, and validated by calculating electrical stress.

The land joint is schematically as shown in Figure 2 a). Since with DC the electric field is controlled by conductivity, the operating conditions of the joint are completely different from AC. Particular attention has been paid to the relative distribution of stresses between the impregnated paper rolls with similar to the cable insulation structure in the joint. Numerical calculations of the field distribution have been performed, taking into account the dependence of the two electric conductivities upon both temperature and electric stress. Figure 2 b) shows the structures of d outdoor termination. It is a condenser cone type that is an advantage of controlling the electric field distribution, similar to apply for ac cable system. The

length of the outdoor termination is determined by the creepage distance of the polymer insulator required for withstanding the DC operating voltage in contaminated condition referred by IEC 60185.



a) Land joint



b) Outdoor termination

〈Figure 2〉 Structures of land joint and outdoor termination

2.2 Type test

In order to prove the mechanical and electrical performances, we carried out the type test according to CIGRE recommendations (Electra No. 171[1] & 189[2]). The type test was performed with load cycle and also with polarity reversal test and superimposed impulse voltage tests. During all of the electrical, the temperature of the conductor was controlled to be 328K(55℃) ±5K by applying AC current to the conductor. In case of the superimposed switching and lightning impulse tests, a blocking capacitor of 35nF and a protection resistor of 30MΩ were used for the protection of testing facilities. The specimen was consisted of about 50m long cable with land joint and terminations. The test circuit for HVDC ±500kV PPLP MI cable system is shown in Figure 3.

〈Figure 3〉 Test circuit for HVDC ±500kV PPLP MI cable system

The electrical type tests were performed in the following manner:
Load cycle and test and polarity reversal test for HVDC ±500kV PPLP MI cable system
- 10 cycles at (-)900kV, "24hours" load cycle (8hrs heating/16hrs cooling)
- 10 cycles at (+)900kV, "24hours" load cycle (8hrs heating/ 16hrs cooling)
- 10 cycles with polarity reversal at 700kV, "24hours" load cycle (8hrs heating/16hrs cooling, Polarity reversals every 4hrs within 2min.)

The superimposed impulse voltage test was performed on test objects that have successfully passed the load cycle test, in the following manner:
Superimposed switching impulse test for HVDC ±500kV PPLP MI cable system
- Udc=(+)500kV,USI=(-)1090kV,10times
- Udc=(-)500kV,USI=(+)1090kV,10times

Superimposed lightning impulse test for 500kV PPLP MI cable system
- Udc=(+)500kV,ULI=(-)1360kV,10times
- Udc=(-)500kV,ULI=(+)1360kV,10times

Table 1 shows the type test conditions. These specimens have passed the type test successfully, including load cycle test, polarity reversal test and superimposed impulse test.

〈Table 1〉 Test items, conditions and the results

Test item		Test condition	Result
Mechanical Test		Bending test	Good
Electrical Test	24hrs Loading Cycle test	+900kV : 10 Cycles -900kV : 10 Cycles 1 Cycle : Heating 8 hrs/ Cooling 16 hrs Conductor Temp. : 328K(55℃)±5K	No B.D
	Polarity reversal test	±700kV : 10 Cycles Polarity reversal : every 4 hr (Within 2 min.) 1 Cycle : Heating 8 hrs/ Cooling 16 hrs Conductor Temp. : 328K(55℃)±5K	No B.D
	Super-imposed impulse test	Conductor Temp. : 328K(55℃)±5K Lightning impulse DC (-/+) 500kV +L.I(+/-)1,360kV : 10 times for each polarity Switching impulse DC (-/+) 500kV +S.I(+/-)1090kV : 10 times for each polarity	No B.D

3. Conclusion

At the initiatory stage, we developed ±250kV mass-impregnated type cable with cross-section of 900㎟ conductor, flexible joints and terminations. This submarine cable system was established between Jindo and Jeju special self-governing province in Korea. This transmission line has been operated since 2014.
HVDC ±500kV 2500㎟ PPLP MI cable system was developed including land joints and outdoor-terminations. In order to prove the mechanical and electrical performances, the type test was carried out according to CIGRE recommendations. The cable system specimen has passed the type test successfully, no breakdown occurred during load cycle test, polarity reversal test and superimposed impulse test.

[REFERENCES]

[1] "Recommendations for Mechanical Tests on Submarine cables", Electra 171, 1997
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