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How to prove long term performance for EHV cable system

1.Introduction

Long term performance of transmission cable system is a great interest of asset owners. Especially for EHV cable system, it takes longer time for recovery and also availability of the compatible system component would be a potential concern in future, therefore, it is essential to store the spare parts in their warehouse. Nevertheless, it is desirable to determine the long term performance criteria for EHV cable system and in 2001 IEC62067 has introduced the concept of Prequalification test as a long term test based on CIGRE SC 21 recommendation and it could be interpreted that the long term performance criteria of EHV AC XLPE cable system based on PQ test has been demonstrated in service experiences. According to the latest service experience reported in CIGRE TB815(2021), however, it seems it is not proved yet by the operational statistics of EHV AC XLPE cable system. As can be seen in Table 11 of CIGRE TB815, the failure rate of cable accessories of EHV AC XLPE cable (220kV-500kV) based on PQ test is much greater than those of SCOF cable system (2-10 times), and also HVAC XLPE (60kV-219kV) cable system without PQ test shows lower failure rate than EHV cable system. This would lead us to a hypodermis that there is more necessity to assess the long term performance of EHV cable system criteria in advance, such as development stage or type test.

Table 11 Failure rates on the different types of AC land cable accessories (Unit: Faults/100units-year)

AC ACCESSORIES		VOLTAGE RANGE kV					
CABLE TYPE	COMPONENT TYPE	all voltages	60-109kV	110-219kV	220-314kV	315-499kV	500kV and above
Extruded cables (EPR, PE or XLPE)	Joint	0.0047 145905pcs/62faults	0.0021 123230pcs/23faults	0.0160 16624pcs/24faults	0.0266 5449pcs/11faults	0.113 353pcs/4faults	0 249pcs/0faults
	AIS Termination Fluid filled Porcelain	0.0107 29530pcs/28faults	0.0018 25081pcs/4faults	0.0111 4011pcs/4faults	0.570 420pcs/20faults	0 18pcs/0faults	
	AIS Termination Fluid filled Composite	0.132 2741pcs/23faults	0.0362 597pcs/1faults	0.0307 1347pcs/3faults	0.344 773pcs/17faults	0.833 24pcs/2faults	
	AIS Termination Dry Porcelain	0.0036 3086pcs/1faults	0.0040 2788pcs/1faults	0 286pcs/0faults	0 12pcs/0faults	0pcs/0faults	
	AIS Termination Dry Composite	0.0880 2636pcs/13faults	0.111 2149pcs/13faults	0 448pcs/0faults	0 36pcs/0faults	0 3pcs/0faults	
	GIS or Transformer Termination Fluid filled	0.0127 9412pcs/11faults	0 6332pcs/0faults	0.0265 1332pcs/3faults	0.0347 1706pcs/5faults	1.00 30pcs/3faults	0 12pcs/0faults
	GIS or Transformer Termination Dry	0.0068 34244pcs/20faults	0.0039 29284pcs/10faults	0.0114 4344pcs/4faults	0.155 559pcs/6faults	0 27pcs/0faults	0 30pcs/0faults
	Other Components	0pcs/11faults		0pcs/5faults	0pcs/6faults		

AC ACCESSORIES		VOLTAGE RANGE kV					
CABLE TYPE	COMPONENT TYPE	all voltages	60-109kV	110-219kV	220-314kV	315-499kV	500kV and above
SCOF Cables	Joint	0.0115 40525pcs/46faults	0.0031 19636pcs/6faults	0.0267 14739pcs/39faults	0.0020 4971pcs/1faults	0 888pcs/0faults	0 291pcs/0faults
	AIS Termination Porcelain	0.0382 4712pcs/18faults	0 2522pcs/0faults	0.0538 1863pcs/10faults	0.2656 300pcs/8faults	0 24pcs/0faults	0 3pcs/0faults
	GIS or Transformer Termination	0.0091 3387pcs/3faults	0 1310pcs/0faults	0.0147 1438pcs/2faults	0.0189 546pcs/1faults	0 66pcs/0faults	0 27pcs/0faults
	Other Components	0pcs/15faults	0pcs/0faults	0pcs/4faults	0pcs/7faults	0pcs/4faults	0pcs/0faults

2. Failure mode after long time use

In order to prove the cable system after installation, it is recommended to conduct AC high voltage test and/or Partial Discharge measurement as a commissioning test. Miss workmanship could be already checked by AC high voltage test at commissioning test, however, deterioration after long time use is difficult to be predicted, or not successfully recognized at early stage.

In Japan, EHV XLPE cable system has been introduced since the early 1990's and some failure modes of AC-XLPE cable accessories have already been recognized and the following is an example of the known failure mode of "extraction mechanism" at the stress cone interface which is a combination of chemical and electrical deterioration as published in IEEJ [1]. In Japan, all failures in transmission system shall be reported to government authority with details and therefore, there is a common platform to exchange the knowledge among TSOs.

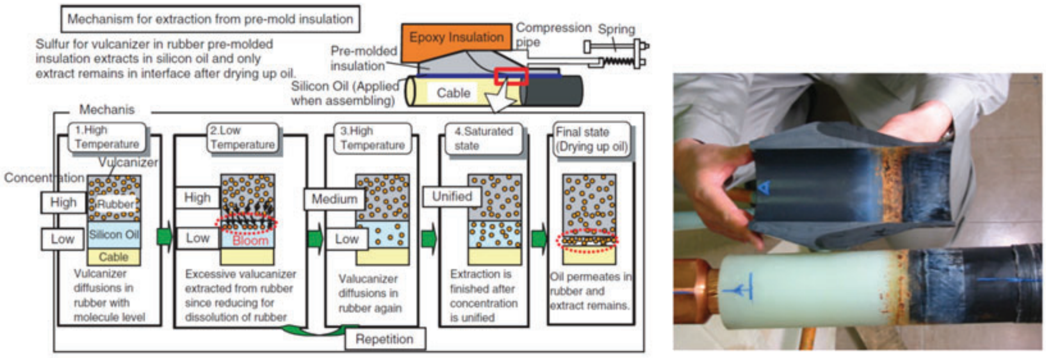
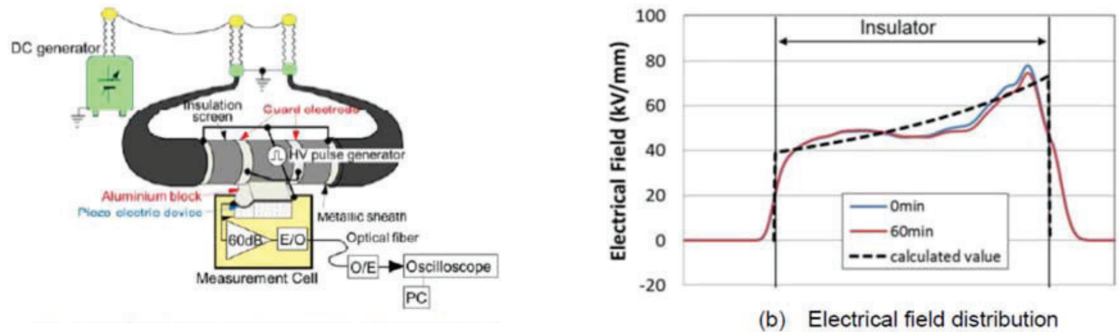


Figure 1. Example of Failure Mode of EHV cable accessory reported in Japanese

3. **Extensive performance tests after Type/PQ test for EHV DC cable system**

For DC-XLPE cable system, PQ test has also been introduced in CIGRE TB 219 (2001) and we have been developing and qualifying DC XLPE cable system based on the latest CIGRE recommendation. In addition, based on the lesson learned from EHV AC XLPE cable system, EHV DC XLPE cable system has been also verified by more extensive performance test after Type/PQ test for EHV DC cable system as summarized below:

- Case 1: Space charge measurement after 400kV PQ test [2]
  ⇒ No obvious distortion of electrical stresses even at 1000kV. (Fig (b) below)
- Case 2: Additional 100 heating cycle after 400kV type test [3]
  ⇒ More than 120 cycles and total of 120 Impulse shots were completed
- Case 3:Successful DC 525kV type test after 525kV PQ test complete (CIGRE 2022)
  ⇒ After successful completion of DC525kV type test, breakdown test was conducted at the DC superimpose LI (+/-640kVdc -/+ 1344kVp) to prove some design margin, but without no clear indication of deterioration after dissection.



(a) Space charge measurement in cable after PQ

Figure 2. Space charge measurement after 400kV PQ test and electrical field distortion of cable

In conclusion, EHV DC cable system (≥20kV/mm) has shown no electrical deterioration so far.
More insight in chemical deterioration are necessary as we experienced in HVAC XLPE cable system.

Bibliography:

(1) A. Toya et al.:2007 "Recent Technologies of Joints for HV and EHV XLPE Cables in Japan" TRANSACTIONS ON ELECTRICAL AND ELECTRONIC ENGINEERING IEEJ Trans 2007; 2: 523–530
(2) T. Katayama et al.:2015 "Space Charge Characteristics in DC-XLPE Cable after 400 kV PQ test." A7.2, Jicable 2015
(3) T. Igi et al.:2019 "Qualification, installation and commissioning of world's first DC 400kV XLPE cable system" A6.1 Jicable 2019

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