

HVDC extruded cable space charge measurement under operating condition with temperature difference

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ABSTRACT

HVDC extruded cable has become one of the key technologies in the development of Energy Internet, where the operation and construction lines are over 4000km and the highest voltage is up to ± 400 kV. The paper presents XLPE insulated HVDC extruded cable operation condition assessment as well as full-size cable space charge measurement techniques under controlled temperature gradient. The performance evaluation test and space charge measurement of an ± 160 kV HVDC cable under different operating conditions are carried out and the results are briefly discussed. The hetero-charge accumulation near outer semi-conductive layer having lower temperature is obvious under controlled temperature gradient, and interfacial electric field is unacceptably distorted due to this space charge accumulation.

KEYWORDS

HVDC cable; space charge; temperature gradient; operation condition assessment testing system;

INTRODUCTION

In the past five years, China have achieved rapid progress in development, construction and operation of HVDC cable system, and realized the triple jump of HVDC cable voltage level [1]. In December 2013, the ± 160 kV/200MW three-terminal VSC-HVDC system had put into operation in Nanao Island, Shantou. The project is connected by overhead lines and cable. The total length of the line is about 28.3km, including 10.7 km for submarine cable, 9.5 km for land cable, and 8.1km for overhead line [2]. In July 2014, Zhoushan ± 200 kV/1000MW five-terminal VSC-HVDC system was successfully put into operation, which spans five islands with the total length of 140.4km [3]. The highest voltage level and the largest transmission capacity project of Xiamen ± 320 kV/1000MW VSC-HVDC project was officially put into operation in December 2015 in China. The length of XLPE insulated HVDC cable(land cable) line is 10.7km [4-5]. As a new grid asset, the long-term evaluation method of XLPE extruded HVDC cable have become a major concern for utilities and manufacture companies.

After development test and type test, the pre-qualification test for up to 12 months (8760h) is carried out before commercial operation so as to assess HVDC cable long-term performance [6-7]. However, the pre-qualification test method of XLPE HVDC cable is similar to AC cable at present, which includes heating the cable core to 70°C by induced current during the load cycle test while the cable sheath is maintained at ambient temperature. However, this evaluation method could hardly truly reflect the change of the temperature gradient in the insulation layer due to load or ambient temperature changes under operating conditions.

In addition, the pulse electroacoustic method (PEA) has become the main technical means for space charge measurement of thin film and coaxial model cable samples in the stage of HVDC cable research and development as well as insulation material selection and evaluation. Furthermore, the effect of the interface between insulation and semiconductive layer on the space charge is much greater than material volume effect due to the testing sample thickness. Therefore, the measurement results cannot objectively evaluate space charge generation, migration and accumulation characteristic of HVDC cable insulation material. The different temperature gradient changes are formed at different positions of HVDC extruded cable insulation layer as the load changes under actual operating conditions. Since electrical conductivity of HVDC insulation material is the function of the electric field and temperature, the DC electric field distribution changes accordingly. The electric field distribution in HVDC extruded cable is extremely complicated due to the multi-physics coupling relationship of the electrical conductivity, electric field, temperature and space charge in the XLPE insulated material. Therefore, the result of space charge measurement under film or plate samples could not truly reflect the space charge characteristics in the XLPE HVDC cable insulation under operating conditions.

HVDC EXTRUDED CABLE OPERATION CONDITION ASSESSMENT TEST METHOD

The mechanism of defect generation and development until insulation failure in DC insulation system is different from AC insulation system. Accordingly, XLPE insulation is required to be tested and evaluated under controlled temperature gradient to accurately acquire the relationship between electric field distribution, deterioration, space charge and operating environment during researching the insulation reliability of HVDC cable.

The HVDC cable long-term evaluation method proposed in this paper is different from AC cable pre-qualification test. The temperature of cable core and outer sheath are controlled independently during long-term load cycle test. Simultaneously, the space charge measurement is carried out under operating conditions, and the influence of load, voltage, polarity reversal and voltage application time to field strength distortion are analyzed.

HVDC extruded cable operation condition assessment system design principle

HVDC extruded cable operation condition assessment system is a test evaluation platform established for carrying out HVDC cable R&D, long-term reliability evaluation, ampacity check and pre-qualification test. The key function of this system is to do load cycle and long-term insulation performance test by controlling conductor temperature and insulation layer temperature difference precisely and flexibly. Considering for the feature of