QUALIFICATION OF A 525 KV 80 DEGREES HVDC CABLE SYSTEM AND VERIFICATION OF INSULATION PERFORMANCE THROUGH ELECTRIC CABLE PEELING CHARACTERIZATIONS

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ABSTRACT

New insights on the long term reliability of extruded HVDC cable systems are essential, as today a large onshore and offshore transmission system buildout is well underway with limited extruded HVDC in-service experience, especially at the highest voltage levels. This work presents the results of a successfully qualified 525 kV HVDC cable system with rated conductor temperature at 80 °C, as well as different characterizations performed on it. Three diagnostic methods comprising of loss angle measurements, leakage current measurements and space charge measurements, the latter one on extracted cable peelings, were employed to verify the insulation performance. Successful system qualification was indeed achieved and the electrical characterizations revealed stable thermo-electric properties, inspiring confidence in the long term operational performance of such systems.

KEYWORDS

HVDC cable; qualification; losses; leakage current; cable peelings; space charge measurement, PEA.

INTRODUCTION

Reliable HVDC cable systems are a necessity to facilitate implementing significant quantities of intermittent renewable energy generation into the power grid, allowing to level out arising supply-demand imbalances over vast geographical areas. Constructing highly reliable HVDC cable links, requires intricate knowledge of long term cable performance, to ensure that the cable remains healthy even when approaching the end of its 40 year design life. In a lab environment, 40 years of cable operation can be compressed into a one year pre-qualification (PQ) test according to Cigré TB 852 [1]. This work presents the successful outcome of a 525 kV PQ test performed at 80 °C rated conductor temperature, as well as a study on the insulation's electro-thermal behaviour prior to, during and after this test. Earlier work [2], established that DC grade crosslinked polyethylene's (XLPE) conductivity may exhibit a time dependent evolution during the qualification test, in addition also different radial XLPE peroxide decomposition product (PDP) distributions were found prior and post PQ test. Such biproduct distortion may strongly contribute to observed leakage current evolutions and can conceal any contribution from thermo-electric ageing processes that change the polymer nature. Therefore, this work employs space charge measurements in addition to monitoring of the insulation leakage current evolution. The space charge measurements using the Pulsed-Electro-Acoustic (PEA) method on cable peelings extracted post and prior to the PQ test was used to verify the insulation performance.

Underlying cable physics

An HVDC cable insulation system experiences ohmic losses that yields leakage currents proportional to applied field strength as:

$$\mathbf{J} = \sigma\, \mathbf{E} \qquad [1]$$

Where **J** is the current density in A/m^2, σ is the conductivity in S/m and **E** is the electric field strength in V/m. Direct proportionality between leakage current density and field strength is lost as conductivity may exhibit field strength dependency, formulated by Klein's conductivity expression as:

$$\sigma(E,T) = \sigma_0\, e^{\alpha T}\, e^{\beta|E|} \qquad [2]$$

where σ_0 is the base level conductivity in S/m, α is the temperature parameter in 1/K, T is the temperature in K and β is the field parameter in m/V (or mm/kV).

While it is feasible to quantify ohmic insulation losses directly on the HVDC cable system's ground connection by means of leakage current measurements, also other loss measurements exsist. The electric loss tangent/factor, typically measured at 50 Hz, can give insight into material losses segmented into polarization, conduction and other loss contributers. The loss tangent's proportion related to conduction losses can be estimated as:

$$\tan\delta_c = \sigma(E,T)/(\omega\varepsilon_0\varepsilon_r') \qquad [3]$$

where ω is the angular frequency in radians and ε_0 and ε_r' are respectively the vacuum permittivity in F/m and the real permittivity. Loss tangent measurements can thus assess conduction losses, although the other loss types contributing to it (e.g., polarization loss and possible PD activity (tip-up)) can skew the results.

For charge transport in the insulation bulk, conductivity can be split into its individual charge transport components as:

$$\sigma(E,T) = e\sum n_k\mu_k \qquad [4]$$

where e is the elementary charge in C, while n_k and μ_k are individual densities and mobilities of electronic and ionic charge carriers of both polarities in m^{-3} and in m^2/(Vs). The field and temperature dependency in the conductivity can originate both from charge injection and generation processes as well as the individual carrier mobilities. In simplified terms, the local balance between charge injection/generation, transport and recombination rates governs to which degree certain carrier types can accumulate. The total carrier amounts create a net charge density ρ_{net} in Cm^{-3} as:

$$\rho_{net} = e\sum \pm n_k \qquad [5]$$

where again n_k represents electronic and ionic charge carrier densities and "±" indicates the inverse contribution between positive and negative carriers. The net charge density scales the local electrostatic potential through Poisson's equation as: