Thermal Cycle Simulation And Current Requirement Estimation For Power Cable PQ Testing

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Abstract

High-voltage (HV) power cables are vital components of modern electrical infrastructure, enabling power transmission over long distances with lower environmental footprint compared to overhead lines, i.e., improved visual impact, better biodiversity aspects and minimal wildfire risk. According to IEC 62067 [1], extruded HV cable systems rated above 150 kV are subject to pre-qualification (PQ) tests, which include thermal cycling and electrical stress tests. The test is performed on a cable loop, where the cable is connected end-to-end to form a closed path. During the test, the cable is subjected to 170% of its rated voltage and undergoes at least 180 thermal cycles for one year. Each cycle consists of three phases: six hours of heating until the conductor reaches a temperature 0 K to 5 K above its maximum value in normal operation, two hours of temperature stabilization in the aforementioned temperature, and at least sixteen hours of natural cooling. A successful PQ test qualifies the manufacturer to supply cable systems of the same or lower voltage ratings.
To carry out the test, an initial current is injected in the PQ loop in order to achieve and maintain the maximum temperature, while an automatic control system feeds back and adjusts the initial injection depending on the current temperature. Therefore, the current excitation may vary strongly in a range of values per cycle in order to keep the conductor temperature at the desired levels. A common industry practice is to determine the necessary conductor current through pre-test trials, following a trial-and-error process. This approach consumes valuable time and resources and exposes the cable to potential overheating risks. A more systematic approach involves modeling and, particularly, finite element method (FEM) simulations. The work in [2] presents an elegant FEM-based method for ampacity calculation, which can calculate the conductor current given its desired temperature. However, this approach assumes steady-state and, thus, cannot be applied to PQ heating cycles which are essentially a time-dependent problem. One alternative is to mimic the trial-and-error process, by manually guessing and adjusting current values until the temperature profile aligns with the target. This process, however, becomes extremely time-consuming, especially in transient simulations.
In this work, an efficient method to calculate the required current values using COMSOL Optimization Module is proposed. The methodology is demonstrated for a 225 kV underground cable, focusing on the early cycles of the PQ test and, thus, treating the challenge of determining the initial current injection. A two-steps current excitation is assumed for simplicity. A fully coupled, heat transfer with magnetic fields model is initially developed to represent precisely the loss generated in the cable and its heat dissipation. To make the procedure computationally more efficient, the cable losses are then calculated as per the IEC 60287-1-1 Standard method [3] and compared with the fully coupled model. Heating and stabilization currents are determined by minimizing the deviation between the simulated and target conductor temperature over time. Laboratory measurements confirm that the estimated current values closely match those required in practice.

Reference

[1] IEC 62067: Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) – Test methods and requirements, IEC, 2022, Edition 3.0.
[2] K. Bitsi et al., Direct FEM Ampacity Calculations for Submarine and Underground Power Cables, COMSOL Conference Proceedings, pp. 1–6 (2023).
[3] IEC 60287-1-1: Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100% load factor) and calculation of losses - General, IEC, 2023, edition 3.0.

Figures used in the abstract

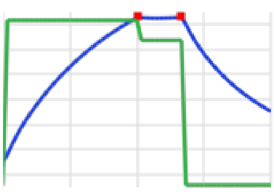

Figure 1 : Model Temperature, compared to Target Temperature, for the calculated current profile

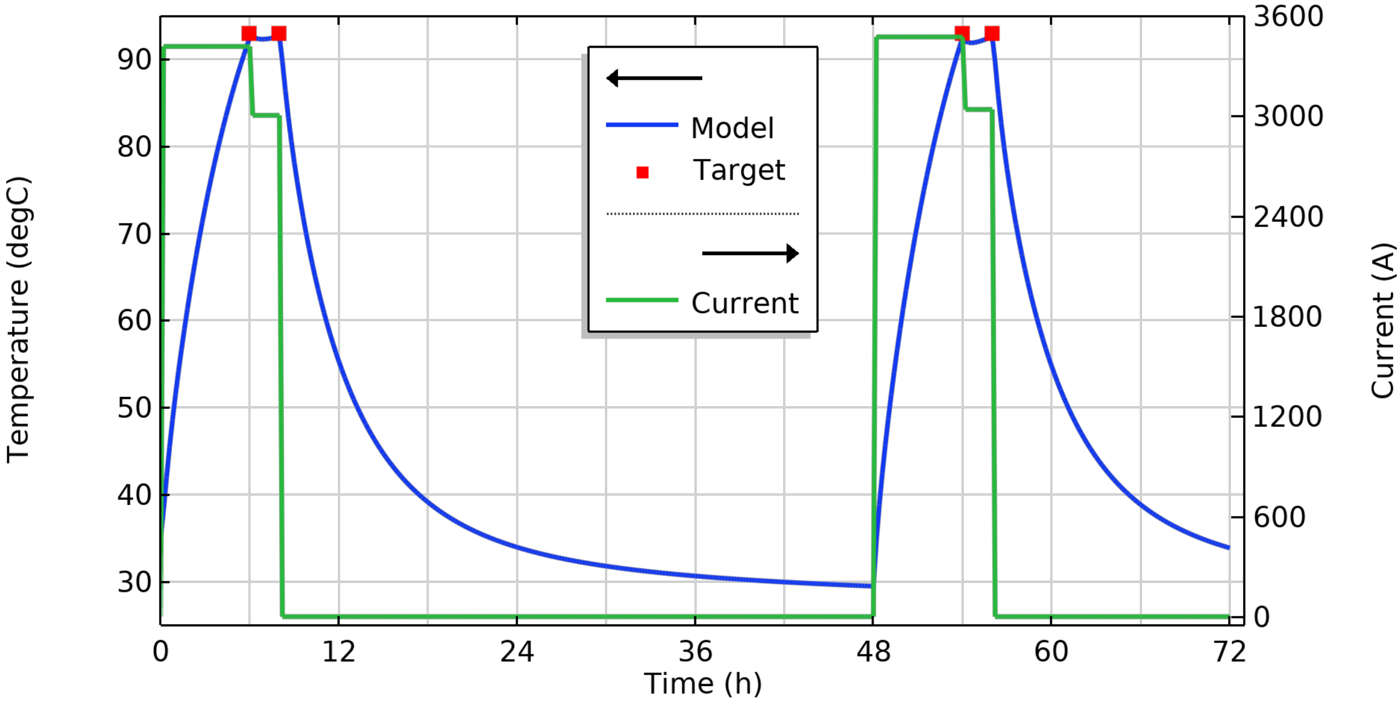

Figure 2 : Model Temperature, compared to Target Temperature, for the calculated current profile