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Underground MV power cable joints: A nonlinear thermal circuit model and its experimental validation

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ABSTRACT

The analysis of the thermal stress of underground MV power cable joints under different environmental conditions, both in normal operation and during faults, is crucial to assess any correlation between the occurrence of overheatings and the anomalous increase of failures (two to three times compared to previous years) which have been observed in the Italian distribution network during summer 2015 (the hottest year ever since 1880). In order to perform this analysis, we have developed a nonlinear circuit model that is able to estimate, both in stationary conditions and in transient ones, temperature profiles inside MV joints, referring to different environmental conditions and with current flowing both in the core conductor and in the metallic shield. The model has been implemented in the Simulink environment and then it has been validated with a set of experimental tests, specifically set up in order to check its performance in steady state and during transients. The numerical results were always in good agreement with the measurements. Subsequently, the circuit model has been employed to perform a predictive analysis of the joint internal temperatures, which may be achieved in operation and during faults by varying the ambient temperature. In all cases, the temperature limits tolerated by insulations have never been exceeded.

1. Introduction

In Italy, MV/LV public distribution networks include HV/MV primary substations, PSs, MV feeders (almost entirely cable lines operated at 15 kV and 20 kV), MV/LV secondary substations, SSs, LV feeders (practically all cable lines operated at 400 V) and electronic electricity metering equipment (i.e., electronic energy meters). The whole Italian MV/LV public distribution network (whose total extension amounts to 388,174 km at MV level and 857,658 km at LV level [1]) is operated by many Distribution System Operators, DSOs, (137 DSOs fall under AEEGSI, i.e. the Italian Regulatory Authority for Electricity Gas and Water, [1]); among them, the most important is ENEL Distribuzione S.p.A., which operates throughout Italy and is responsible for the 85% of the overall electric energy distributed at MV and LV level. ENEL owns and operates more or less 2000 PSs, 349,386 km MV feeders, 450,000 SSs and 782,624 km LV feeders. Besides ENEL, other DSOs operate in Italy (e.g., the most important in terms of energy provided are A2A Reti Elettriche in Milan, ACEA Distribuzione in Rome, AEM Torino Distribuzione in Turin, HERA in Bologna) at regional, provincial or municipal level.

Considering that the MV distribution network overall extension is about 400,000 km, and taking into account that a single MV cable stretch may be 500 m long at most, at least 3,800,000 cable joints are currently installed in Italy. It is well known that joints are weak points of MV distribution networks: more than 50% of overall cable faults consists of cable joint failures due to insulation breakdown, caused either by an imperfect installation or by the joint aging (the most important aging effect is related to overtemperatures). In 2015, particularly during the month of July, DSOs in Italy recorded an abnormal increase of MV cable failures (from two to three times compared to previous years) and ascribed such failures to the excessive heat registered that summer, when for a significant number of days temperatures were higher than the seasonal averages. Cable and joint thermal analysis is thus required in order to verify if some correlation between the increase of the ambient temperature and the increase of cable failures exists. In the last few years, many numerical methods were developed based on the finite element method [2], on the finite volume method [3], on the boundary element method [4], on a coupled finite/boundary element approach [5] and on the filament method [6]. Such models, however, mostly focus on the calculation of the cable ampacity and do not take

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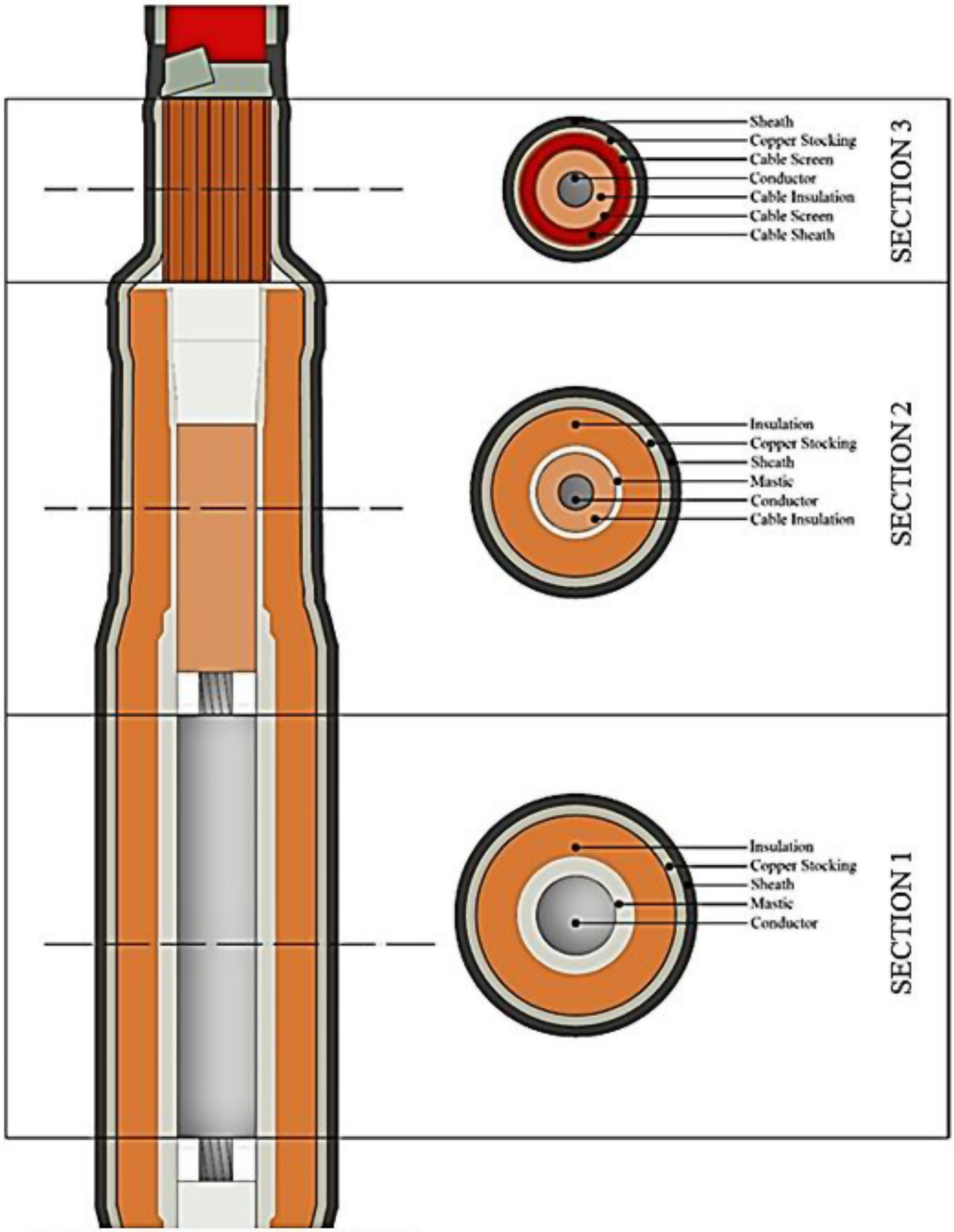

Fig. 1. Sections subdividing the simulated cold-shrinkable joint (see text for details).

into account the cable joint. Only few papers in literature focus on the cable joint: in Ref. [7] analysis to detect cable joint failures are reported; in Ref. [8] joint failure experience in Australian wind farms is reported, whereas in Refs. [9,10] diagnostics of cable joints are proposed. In some papers, experimental tests are carried out in order to evaluate probable causes of joint failures, such as the ambient temperature [11,12] or the thermal cycling [13]. Regarding cable joint modeling, in Ref. [14] an analytical method for thermal analysis of joints in an oil-filled high-voltage cable is presented; in Ref. [15] an analogous resistance network for the steady-state thermal analysis of a 400 kV cable through joint is developed, whereas in Ref. [16] a numerical method based on the finite element method is described. Since the aim of Ref. [16] is to evaluate the influence of contact resistance of power cable joints on the thermal behavior of the joint, simplifying assumptions are made: only steady-state is considered and, most important, the connection tube and con-