LOW-LOSS CONDUCTORS FOR (EXTRA) HIGH-VOLTAGE APPLICATIONS

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ABSTRACT

An important factor in the design of low loss conductors for high-voltage and extra-high-voltage cable applications is the resulting AC resistance relative to the DC resistance and the weight and cost of the materials involved. This paper will discuss the following important parameters from a modelling- and measurement standpoint: a) Effect of number of segments; b) Effect of wire size and the selection of 4 vs. 5 layers in the segment design; c) Effect of center wire/rod; d) Effect of wire pitch lengths and directions. In addition, some practical aspects will be discussed.

KEYWORDS

Large AC conductors, low-loss segmental Milliken conductors, electro-magnetic FEM modelling, Comsol Multiphysics, AC losses, AC-resistance measurement.

INTRODUCTION

Underground AC power cables are one of the main pillars of electric energy transmission. Larger cross-sections are needed to transport the increasing amount of electrical energy [1,2]. A main challenge is to transmit the high amount of renewable energy generated far away from consumers of electrical energy. It is important to transmit electrical energy with as little loss as possible and with efficient use of materials and capital. The conductor losses occur due to the finite electrical conductivity of the conductor materials used. In addition, frequency-dependent self-field losses and proximity losses occur due to AC operation and neighboring phase conductors. The current displacement (skin effect) can be important in the large conductors often used with EHV cables. To prevent these negative effects, constructive measures are taken in the cable conductor design. The segmental Milliken conductors are mainly used to optimize the current distribution in the conductor cross-section. The electrical AC resistance can be drastically reduced compared to a round compacted conductor. To design and to manufacture this kind of low-loss conductor one needs to understand the theoretical and practical dependencies between the different variables that are important for the overall conductor performance. This solid knowledge background about low-loss conductors enables development and manufacturing of ever larger conductor cross-sections.

METHODOLOGY

Large-size Milliken conductors were developed through a cycle of FEM modelling using Comsol Multiphysics software, manufacturing trials using standard segmental stranding and compaction machines, and measurements of the resulting AC resistance. The so-called K_s (self-field) and K_p (proximity) factors are taken as basis for the quality evaluation after production steps. The K_s and K_p performance parameters were calculated according to the formulae given in [3]. Enamelled copper wires were used.

FEM Modelling approach

The FEM modelling was carried out using the frequency domain solver of the Comsol Multiphysics software. The modelled and measured arrangements were the same, i.e. flat and close trefoil configurations. The “2.5D” approach also used in [4] was applied. A 2D model with the cross sections of three complete conductors, Fig. 1, was coupled to electrical circuit models that represent the effects of axial fields, Fig 2. The exact formulae for the driving voltages, V_{ij}, the self-inductances related to the axial fields in the segments, L_{jj}, and the mutual inductances between layers in a segment, M_{jk}, are given under the respective topics below. In general terms, the main effect of the transposition of the wires to all positions in the layer of a segment is simulated in Comsol by defining all wires in each layer in all segments as one coil and connecting the wires in series [4]. The driving voltage for each coil therefore needs to be multiplied by a factor N_s (number of segments) x N_{wj} (number of wires in layer j).

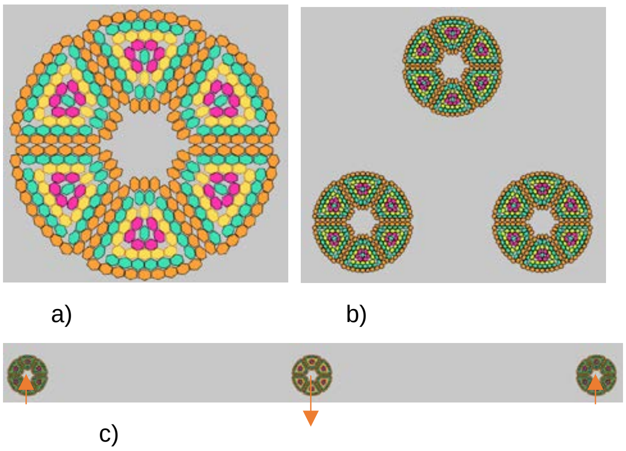

Fig. 1: a) 2D FEM Comsol model representing a six-segment conductor with individual hexagonal wires organized in layers; b) three-phase system in close tri-foil configuration for calculating proximity effects; c) flat formation simulating the self-field measurement configuration with two symmetric return leads, each carrying half of the return current.

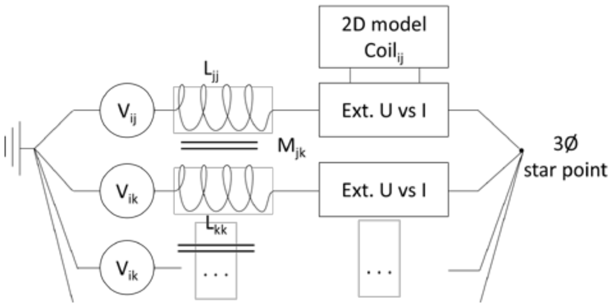

Fig. 2: Electrical circuit physics coupling the axial inductions of the wire layers within one segment.