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Calculation method of power cables AC resistance with individually insulated strands

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Résumé

Les formules usuelles pour calculer la résistance des conducteurs en courant alternatif, proposées notamment par la Publication CEI 60287, ne sont applicables qu'à des conducteurs de sections limitées, ou avec des géométries particulières (conducteur non-segmenté ou à 4 secteurs généralement). Cette article propose une extension de la Publication CEI 60287, qui permet de prendre en compte des conducteurs de section quelconque ou possédant plus de 4 secteurs. Deux modèles sont ensuite proposés, qui permettent une description très précise des conducteurs. Ces modèles permettent de démontrer le grand intérêt de conducteurs à fils isolés ou à comportant une isolation entre couches de fil. Des exemples d'optimisation de conducteurs sont donnés.

Abstract

Commonly used formulas for calculating the resistance of conductors carrying alternating currents, proposed particularly by IEC Publication 60287, are only applicable to conductors with limited cross-sections, or with special geometries (usually non-segmented conductor or conductor with 4 sectors). This article proposes an extension to IEC Publication 60287, which also considers conductors with an arbitrary cross-section or with more than 4 sectors. Two models are then proposed, which enable a very precise description of the conductors. These models are used to demonstrate the significant advantages of using conductors with insulated strands, or with insulation between strand layers. Conductor optimization examples are given

Introduction

The calculation of additional Joule losses that arise in a conductor carrying an alternating current is an old problem. Lord Kelvin was the first to make precise calculations for the skin effect in the case of a solid conductor, in 1873 [1]. Later, a number of persons put forward precise or empirical formulas to evaluate additional losses due to skin and proximity effects, but always in the case of a solid conductor [2], [3] and [4].

The gradual increase in the size of conductor cross-sections imposed by the continuously increasing demand and increasingly severe size requirements, obliged cable manufacturers to develop empirical solutions (segmentation, stranding, insulation of strand layers, individual insulation of strands, magnetic shielding of sectors, etc.) to reduce Joule losses in conductors [5], [6], [7]. But the use of these techniques very much complicates the geometry and makes the calculation of exact analytic formulas much more difficult. Different empirical formulas were then proposed [8], [9], particularly by the IEC (see IEC 60287-1-1). Although these formulas can be used to predict Joule losses for the case of a «conventional» cable, they quickly become unsuitable in frequently found cases, particularly for cables with a very large cross-section (greater than 1600 mm²) for which it is impossible to optimize the geometry. This is why new theoretical formulas are necessary.

A large amount of analytic calculation work has been done by different cable manufacturers [10], [11] and [12]. These studies formed a basis for making suggestions about the main choices for models taking account of the exact structure of segmented conductors to calculate skin effect losses, regardless of the cable cross-section. This article uses two of these models which appear to be the most efficient, and suggests an extension to the formula given in IEC Publication 60287, to take account of strands with cross-sections larger than 1600 mm² and comprising more than four sectors. The first model is based on a calculation of magnetic fields through circuits consisting of different conductor strands. The second model evaluates losses starting from real magnetic fields in the sectors. These two models use a number of assumptions that were presented and commented upon.

Based on these two models and the extension to IEC Publication 60287, two guidelines have been proposed to optimize the structure of conductors with very large cross-sections. The special case of a conductor with a cross-section of 2500 mm² is extensively illustrated and demonstrates the advantage of the various techniques: increase the number of sectors, insulation of strands, increase in the number of strand layers in a sector, etc.