Transient analysis of 3-core SL-type submarine cables with jacket around each core

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ABSTRACT

This paper addresses several issues related to the calculation of transient rating of 3-core submarine cables with a metallic screen around each core. It shows that the equations given in the IEC standards for the reduction of a multi-loop thermal network of an SL-type cable to its two-loop equivalent need to be modified as they are in error in some parts. The second task is to introduce a new model for the most common construction of the 3-core submarine cables with polyethylene layer over each lead sheath and common armour. The IEC Standard does not deal with such cables at all.

KEYWORDS

power cables, rating calculations, submarine cables, SL-type cables.

INTRODUCTION

Analytical solutions to the heat transfer equations are available only for simple cable constructions and simple laying conditions. In trying to solve the cable heat dissipation problem, electrical engineers noticed a fundamental similarity between the heat flow due to the temperature difference between the conductor and its surrounding medium and the flow of electrical current caused by a difference of potential [1]. Using their familiarity with the lumped parameter method to solve differential equations representing current flow in a material subjected to potential difference, they adopted the same method to tackle the heat conduction problem. The method begins by dividing the physical object into a number of volumes, each of which is represented by a thermal resistance and a capacitance. The thermal resistance is defined as the material's ability to impede heat flow. Similarly, the thermal capacitance is defined as the material's ability to store heat. The thermal circuit is then modelled by an analogous electrical circuit in which voltages are equivalent to temperatures and currents to heat flows. If the thermal characteristics do not change with temperature, the equivalent circuit is linear and the superposition principle is applicable for solving any form of heat flow problem.

In a thermal circuit, charge corresponds to heat; thus, Ohm's law is analogous to Fourier's law. The thermal analogy uses the same formulation for thermal resistances and capacitances as in electrical networks for electrical resistances and capacitances. Note that there is no thermal analogy to inductance and in steady-state analysis; only resistance will appear in the network.

Since the lumped parameter representation of the thermal network offers a simple means for analyzing even complex cable constructions, it has been widely used in thermal analysis of cable systems. A full thermal network of a cable for transient analysis may consist of several loops. Before the advent of digital computers, the solution of the network equations was a formidable numerical task. Therefore, simplified cable representations were adopted and methods to reduce a multi-loop network to a two-loop circuit were developed. A two-loop representation of a cable circuit turned out to be quite accurate for most practical applications and, consequently, was adopted in international standards.

In this paper, we will examine a thermal circuit of one particular cable type, namely 3-core, SL-type cable construction.

TRANSIENT TEMPERATURE RISE OF A CABLE CIRCUIT

Response to a step function

The transient temperature response of a cable to a step-function of current in its conductor depends on the combination of thermal capacitances and resistances of the cable circuit. In the first part of the transient, the response of the cable components is important whereas the contribution of the surrounding soil is negligible. On the other hand, when the response for long times is required, the most important factor is the thermal transient in the surrounding soil.

The method for the calculating the temperature response of a cable to suddenly applied constant value of conductor current is to consider that the whole thermal circuit is divisible into two independent parts. One part is made up of the cable components out to the outer surface of the cable; the second part is the environment of the cable. The individual responses of these two parts are partial transients, with which the total transient of the complete system can be built up.

In this paper, we will focus on the cable representation in the thermal network.

Reduction of a multi-loop circuit to a 2-loop model

CIGRE [2, 3] and later IEC [4,5] introduced computational