Cyclic Loading of Underground Cables Including the Variations of Backfill Soil Thermal Resistivity and Specific Heat With Temperature Variation

Ossama El-Sayied Gouda, Gomaa Fahmey A. Osman, Waleed A. A. Salem, and Shawky H. Arafa

***Abstract*—The aim of this paper is to calculate the temperature distribution of a cable conductor and the soil surrounding the cable under cyclic loading conditions, taking into account the formation of a drying zone in the backfill material. The thermal model of an underground cable is considered by using the IEC 60853-2 method, including the effects of the variations in temperature on the thermal resistivity and specific heat of the soil. The results are compared with IEC 60853-2 and thermoelectric equivalent method calculations. This study is done on eight sandy soil types as backfill materials, and calculations are carried out by using a 33-kVx cable. The results indicate that the modifications done on the IEC 60853-2 method are required to improve its capability to simulate the field conditions during load cycling of power cables.**

***Index Terms*—Power cables, thermal analysis, thermal resistivity, moisture content, specific heat, dry band.**

I. Introduction

THE thermal analysis of buried power cables plays major role when designing underground electrical grid. Cables should transfer power at maximum current carrying capacity without exceeding permissible limits [1]. This current is affected by cable design parameters and the properties of the surrounding backfill materials as given in IEC 60287-1-3 [1]. Many studies have discussed the important factors that influence the current carrying capacity of cables under steady state conditions [2]–[5]. Under load cycling conditions, buried cables generate varying amounts of radiated heat depending on the amount of load that is being served. This heat can reduce the moisture level in the backfill material surrounding the cable. This phenomenon can cause dry band formations in the soil surrounding the cable, leading to thermal instability of the soil and potential breakdown failure of the polymeric insulation of the cable due to over-heating [6]–[8]. Cyclic ratings and thermal analysis of underground power cables are studied in [9], [10]. Experimental study and numerical simulation of heat dissipation in underground power cables are explained in [11], [12]. Power cable thermal analysis, soil model for dynamic thermal rating and soil characteristics in designing underground cables are investigated in [13]–[15]. References [16], [17] report on moisture movement in the soil surrounding a cable and the current capacity of the cable as related to the use of artificial background materials. IEC 60853-2 [9] included the effect of temperature on conductor resistance, but ignored the changes in soil resistivity and specific heat caused by variations in temperature of the conductor due to load cycling. References [8] and [13] present numerical models to measure heat and moisture transfer in the soil surrounding a power cable during transient conditions using the equations of Reference [16]. This paper presents a modified thermal model for improving IEC 60853-2 [9] calculations. Variations of soil thermal resistivity and volumetric specific heat with moisture content are investigated and included in IEC 60853-2 calculations. Experimental work is carried out in this paper on eight different soil types to consider the relations between moisture content and specific heat with soil temperature, and determination of the temperature where the formation of the dry zone occurs for each soil type. The calculations are done on a single core 33 kV cable and the results obtained are compared with those obtained by using IEC 60853-2 [9] and the TEE model.

Manuscript received February 22, 2018; revised April 12, 2018 and May 23, 2018; accepted June 16, 2018. Date of publication June 19, 2018; date of current version November 20, 2018. Paper no. TPWRD-00186-2018. *(Corresponding author: Ossama El-Sayied Gouda.)*

The first author is with the Department of Electrical Engineering, Cairo University, Egypt (e-mail: prof_ossama11@yahoo.com) and the last three authors are with the Department of Electrical Engineering, Benha University, Egypt (e-mail: gom3a_osman@yahoo.com; walid.attia@bhit.bu.edu.eg; shawky.ibrahim@bhit.bu.edu.eg).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TPWRD.2018.2849017

II. Experimental Work

A. Experiment Setup

Eight natural backfill materials are tested to determine the thermal behavior and drying band formation of each soil type. Fig. 1 shows the testing arrangement used in the soil thermal analysis. Each soil sample is placed in a plastic cylinder with a diameter of 100 mm and a height of 120 mm. The heater that simulates the heat flux generated during thermal loading of the underground cable is placed at the top of the isolated cylinder. The heat flow is in the downward direction of the testing device and measured using a heat flux meter. The cylinder containing the samples was closed and thermally insulated from the surrounding environment by O-ring. By this configuration, moisture tension and water content can be regulated. Moisture sensor is placed in the isolated cylinder to measure the level of the soil moisture that changes with temperature. A number of junction-K thermo-couples are placed at different distances from the heat source to measure the temperature variation along the length of the sample of soil. The characteristics of the samples of soil are shown in Table I. Grain size analysis was done for the clay and sand mixtures using a sieve. The sand and clay soil