IET Generation, Transmission & Distribution

Research Article

Load cycling of underground distribution cables including thermal soil resistivity variation with soil temperature and moisture content

ISSN 1751-8687
Received on 29th December 2017
Revised 19th May 2018
Accepted on 23rd July 2018
E-First on 4th September 2018
doi: 10.1049/iet-gtd.2018.5589
www.ietdl.org

Ossama E. Gouda[1] ✉, Gomaa F.A. Osman[2], Waleed A.A. Salem[2], Shawky H. Arafa[2]

[1]*Faculty of Engineering, Electrical Power Department, Cairo University, Cairo, Egypt*

[2]*Benha Faculty of Engineering, Benha University, Benha, Egypt*

✉ *E-mail: prof_ossama11@yahoo.com*

Abstract: As it is known the load of distribution cables is not constant with respect to the daytime, increasing the current in some hours may lead to an increase of soil surrounding the cable resistivity due to the migration of soil moisture content. Formation of dry zones may cause failure of cable insulation. Also because the soil thermal properties change with time according to the weather conditions of different seasons, the current capacity changes significantly from time to time. This paper studies the effect of dry zone formation during load cycling of underground cables on their temperature rise and the temperature distribution in the surrounding which is not considered by IEC 60853-2. The thermal model of the cables using the thermoelectric equivalent method is modified by including the thermal soil resistivity variation with soil temperature and moisture content. The finite element method is used also in this study to obtain heat map of the cable and surrounding soil. Additionally, experimental work of three soil types was investigated to study the effect of temperature and moisture content variation on the soil thermal resistivity and the dry zone formation of each soil type. Field measurements of temperature distribution surrounding the cables are done.

1 Introduction

Underground distribution power cables are used to lade electric power in cities and densely populated areas. According to IEC 60287-1-3 [1], the current carrying capacity of underground cables under steady state affected by the properties of the cable material, laying method, and properties of the surrounding soil such as thermal resistivity, moisture content, and ambient temperature. However, any cable carrying a current generates heat and this heat is dissipated to the surrounding soil. The rate of dissipation of this heat depends on the soil thermal resistivity. The temperature of the cable is limited according to the type of insulation material used in the cable and soil thermal resistivity [2, 3]. On the other hand, loads are varying with time. In the case of variable loads, the losses of the cable produce heat; this heat leads to migration of the moisture content in the soil around the cable. Also, in turn, dry areas may be formed around the cable, raising the thermal resistance of the soil and interruption the heat dissipation of the cable to the surrounding soil [4, 5].

Thermal analysis of underground cables is an important theme in these days to the power cable engineers, to avoid cable damage. Many studies discuss the thermal analysis of underground cables using analytical and numerical methods, and experimental investigation was performed [6–18]. Thermal analysis of underground power cables using two-dimensional finite element method is reported by the authors in [19–21]. IEC 60853-2 [13] presented a method for calculation of the cyclic and emergency current rating of cables. In this standard, the variation of soil thermal resistivity with load, losses, and temperature variations is ignored. Olsen *et al.* [18] studied the dynamic temperature estimation and emergency rating of cyclic cable loading but with constant thermal soil resistivity. In an attempt to investigate the effect of moisture content and the soil thermal resistivity on the cable temperature loaded by cyclic loading, Koopmans and Gouda [14] solved the equations of Philip and De Vries [15] to study the transport of heat and soil moisture content with hysteretic moisture potential during cyclic cable loading. In this paper, the thermal soil resistivity variation with the soil temperature and moisture content during load cycling are considered. Experimental work is done in this paper on three different soils to investigate the relation between the soil resistivity and the temperature and moisture content and also to determine the critical temperature of dry zone formation. The thermal model of the underground cables using the modified thermoelectric equivalent method (MTEE) and the finite element method (FEM) is used in this study.

2 Distribution cables simulation

2.1 Lumped parameter method

According to IEC 60853-2 [13], the cable elements are represented by lumped parameters thermoelectric equivalent method (TEE). The analogy between thermal and electrical circuits can be used to calculate the temperature distribution in the cable elements and surrounding soil respecting time variation [16–25]. A TEE thermal model of underground cable is shown in Fig. 1*a*. In this figure, the thermal resistances of the metallic parts of the cable are ignored. In this paper, the TEE model is modified by including the effect of the soil temperature and moisture content on the soil thermal resistivity. The MTEE model includes the effect of dry zone formation around the cable during load cycling in which no one has ever studied it before. The differential equations representing the system of Fig. 1*a* are

$$\theta_j' = \frac{1}{C_4}\cdot\left(\frac{\theta_s-\theta_j}{T_3}-\frac{\theta_j-\theta_a}{T_4}\right)$$

$$\theta_s' = \frac{1}{C_3}\cdot\left(W_s+W_{d2}+\frac{\theta_c-\theta_s}{T_1}-\frac{\theta_s-\theta_j}{T_3}\right) \quad (1)$$

$$\theta_c' = \frac{1}{C_1}\cdot\left(W_c+W_{d1}-\frac{\theta_c-\theta_s}{T_1}\right)$$

where, θ_j, θ_s, and θ_c are the surface (jacket), screen, and conductor temperature above ambient temperature (θ_a), respectively, and T_1, T_3, and T_4 are the insulation, jacket, and surrounding soil thermal resistances, respectively. The loss of the conductor is also denoted