D.2.1. Forces de tirage de câbles de distribution 25 kV posés en conduits

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Résumé

Une nouvelle méthode est proposée pour l'estimation par calcul des forces de tirage appliquées aux câbles de distribution 25 kV au cours de leur installation en conduit souterrain. Cette méthode est basée sur des modèles analytiques simplifiés, qui tiennent compte des effets de flexion du câble aux coudes, et sur des essais de caractérisation mécanique réalisés en laboratoire. Le logiciel correspondant PULLFLEX a été validé avec les mesures de forces de tirage prises au cours de plusieurs tirages réels, en réseau et sur un site expérimental.

D.2.1. Pulling forces of 25 kV distribution cables layed in conduits

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Abstract

The paper describes a new method of estimating the pulling forces applied to 25-kV distribution cables installed in underground duct. This calculation method is based on simplified analytical models that take into account the cable bending effects at bends and, also, on mechanical characterization tests in laboratory. The corresponding software PULLFLEX was validated with the values of the pulling forces recorded in the field, on real underground line sections and at a test site.

Introduction

For all underground distribution lines, there is an economic need to increase the length of the pulling sections [1-3] in order to reduce the number of manholes and gain flexibility in routing the line. The pulling lengths are limited by the allowable mechanical limits of each cable in terms of the maximum tensile force and maximum sidewall pressure at bends, applied to the cable during its installation. For long and/or convoluted sections, the pulling forces should be estimated at the line design stage in order to avoid possible deterioration of the electrical insulation.

All available software for calculating the pulling forces [2, 4] is based on the analytical model proposed in 1953 by R.C. Rifenburg [5] and generalized in 1981 by D.G. Smith [6]. This classical model describes the behavior of a very flexible cable (rope without bending stiffness), considering the longitudinal friction created by the cable weight and by the lateral pressures against the intrados of bends, related to the change in direction of the cable tension. As proven by the many measurements Hydro-Québec has performed both in the field and at its Vanier test site, the pulling forces calculated by the computer codes based on the Rifenburg-Smith model could grossly underestimate the measured values for some of the more convoluted sections of underground lines. Tests on a 25-kV three-phase cable with bare concentric neutral, typical at Hydro-Québec, which was pulled into a PVC or fiberglass duct without using any lubricant, have shown that 10 to 15% of the measured maximum tensions exceed the values predicted by the model by as much as 100% and an extreme case of 300% was once recorded!

This paper describes a comprehensive study comprising the development and validation of a new, more realistic, method for calculating pulling forces. The main additional effects considered are listed below [7].

1. The bending stiffness of three-phase distribution cables is high enough to affect the position of a cable pulled into a tight duct with a sinuous route. In opposition to a very flexible cable, the main differences appear at the bends: as the cable enters and leaves each curve, the bending stiffness forces it away from the intrados toward the extrados of the curved segments. Often, this results in additional points of lateral contact between the cable and the extrados of the duct. Furthermore, the shear force present in the cross section of stiff cables increases the lateral pressure applied on the bend intrados. All these additional contact forces lead to higher longitudinal friction than predicted by the classical model.
2. During the successive bending of a cable pulled through the curved and rectilinear segments of the line section, the internal friction between cable components consumes mechanical energy, as reflected by a non-linear diagram of the cable curvature vs. bending moment, with hysteresis and relaxation effects. The internal loss of energy is offset by a greater pulling