Thermo-mechanical behavior of HV and EHV large conductor XLPE cables in duct-manhole systems

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ABSTRACT

Since 2002 EPRI has used advanced FEA techniques to model the behavior of large conductor EHV cables in duct/manhole systems and has designed and constructed a 55m long test rig to simulate the mechanical effects found in service. The rig was commissioned with a 345 kV, 2000 mm^2 copper conductor, XLPE insulated, corrugated aluminum sheathed cable and the first set of experimental heating runs was completed in 2013.

The key findings are that i) the magnitude of axial force is lower than extrapolated from smaller conductor cables and ii) thermo-mechanical patterns form, but are less pronounced in the magnitude of lateral deflection.

KEYWORDS

Finite Element Analysis, Thermo-mechanical forces, XLPE, Duct-manhole.

INTRODUCTION

Transmission cable systems are being installed in duct-manhole systems in North America. Since 2001 the maximum conductor size has risen from about 1267mm^2 (2500 kcmil) to systems with 2500mm^2 (~5000kcmil) conductors. Similarly transmission system voltages have risen from 345kV to 500kV. With the rise in conductor cross section and system voltage comes a rise in the cable dimensions and forces associated with the thermal expansion due to the temperature rise caused by the load current. Initially lack of full understanding of the forces involved, especially in the manholes, led to some installations where insufficient restraint was provided [1].

It has been known for cables and joints to fall from severely distorted, insufficiently robust steel structures in manholes due to poor clamping arrangements and for expansion of cable into manholes to cause severe snaking and bending of the cable adjacent to the joints. This risks the electrical integrity of the installation. The calculation of the differential forces exerted by the cables and the uneven cable linear expansion into manholes needed properly to design the manhole restraints has been, up until recently, too complicated for analytical techniques.

Nevertheless there are distinct benefits arising from the use of duct-manhole installations. The benefits include:

- Reduced force at the joints in the manholes
- Less disruption to road users during installation as the pipes are installed in short lengths.
- The possibility of re-use of the pipe asset.
- The cables are in a controlled environment.

Disadvantages of the technique include:

- The possibility of unbalanced forces across the joints due to asymmetry in the route geometry and the formation of cable distortion patterns in the adjacent pipe.
- The risk of longitudinal movement in premoulded joints and associated distortion of adjacent cable in support systems which are not designed to withstand unbalanced forces.
- The necessity to design a constraint system capable of coping with the forces developed by the cable.
- The possibility of the pipe and manhole filling with water – especially at the bottom of slopes.

In 2002 Electric Power Research Institute (EPRI) began investigations into the thermo-mechanical behavior of cross-linked polyethylene (XLPE) insulated transmission class cables. The initial project was centered on the calculation, using Finite Element Analysis (FEA), of the mechanical behavior of a single XLPE cable in a duct-manhole system and of three XLPE cables in a pipe-manhole system.

INITIAL CONCEPTS AND MODELLING

The project consisted primarily of two efforts: experimental measurement of cable parameters and the development of a mathematical FEA simulation of the thermal and mechanical behavior of transmission class XLPE cables. The cable parameters measured would be used in the simulations. The measurements were performed at an EPRI laboratory following a detailed protocol specified as part of the project. In parallel an FEA simulation method was developed using an 'explicit' modeling technique and the method was applied to examples from real service routes. The simulation was based on the representation of the complex cable behavior with 'linear-elastic' parameters, and utilized the results of the experimental work carried out by the EPRI laboratory so far as was possible. The modelling was fairly comprehensive and also included design techniques for cables inside manholes restrained using cleats and the effects of short circuit forces and traffic vibrations. The results of this work were published in 2004 [2] [3].

As part of the work 12 parameters were identified as collectively controlling the mechanical behavior of the cables in normal operation. A sensitivity study on these parameters was carried out which provided the output data upon which a simplified Personal Computer based calculation method was developed without the complication of FEA. This software employs user-provided data such as route and cable details to calculate the cable axial, bending and torsional stiffnesses for any