Spatially-resolved measurement and diagnostic method for power cables using interference characteristics of travelling waves

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ABSTRACT

In this paper, a new approach of a spatially-resolved diagnostic method for power cables will be briefly introduced. This method uses travelling waves and their interference characteristics to generate specific electrical energy losses inside the test object. The method has been tested in several simulations, which are based on discretized cable models. This is followed by setting up a laboratory test to verify the simulation results. From this set of experiments, the most significant results will be presented in this article. In the described experiments, the proposed approach of a diagnostic method shows local degradations of power cables and coaxial signal cables both in simulation and laboratory measurements, which cannot be detected by established reflectometry methods.

KEYWORDS

Power cables; diagnostic method; measurement method; spatial resolution; condition monitoring; local degradation; reflectometry; time domain; TDR.

INTRODUCTION

In modern power networks, condition monitoring and remaining lifetime estimation of cable grids and related equipment are necessary to maintain supply reliability, to improve investment planning and for maintenance strategy.
Currently, the key parameters of well-established diagnostic methods for power cables are based on the partial discharge (PD) levels (inception voltage and intensity) and tanδ values. In the field of cables and especially in case of PILC cables or water tree-degraded XLPE cables, the requirements on these measurements are rather complex. However, the reliability of these methods is also dependent on the experience of the test engineers and the interpretation of all measured parameters. Many parameters, besides electrical ones, must be taken into account, like the test temperature, equipment dimensions, cable length and noise. Furthermore, the measured PD activity of a cable does not determine the condition itself but shows local defects and tanδ measurements can evaluate the cable condition only integrally. For diagnostic improvements, additional methods must be analyzed, optimized or further developed.

Especially methods with spatial resolution are of greatest interest due to the advantage to detect local degradations before a cable failure occurs. Therefore, a specific replacement of segments of power cables with the prognosis of a short remaining lifetime will be possible. As a consequence, unnecessary expenses for replacement of complete cable routes and related civil engineering can be saved. Fig. 1 shows an exemplary measurement of a power cable condition to illustrate what spatial resolution means. On the one hand the abscissa (cable length) divides the test object (power cable) into cable segments of a defined length, on the other hand the ordinate (cable condition) categorizes the test cable between healthy and critically-aged. The z-axis is split up to all physical line parameters: Capacitance (C), conductance (G), inductance (L) and resistance (R). The main goal will be the determination of all these line parameters of every cable segment with the aid of combining different methods.

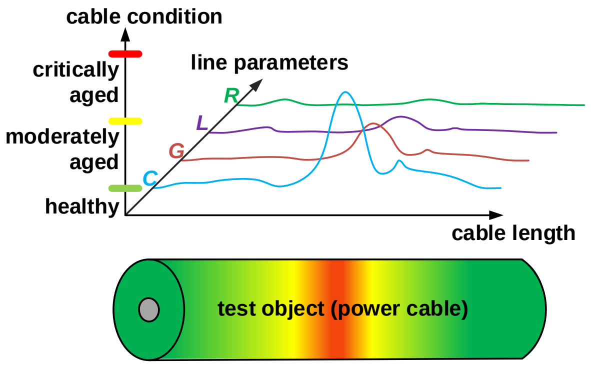

Fig. 1: Exemplary measurement of a cable condition with spatial resolution

In the following, an approach of a new spatially-resolved measurement and diagnostic method will be briefly introduced. The method has been tested in simulations and laboratory measurements, which will be presented afterwards.

NEW METHOD WITH SPATIAL RESOLUTION

This new method uses travelling waves and their interference characteristics to generate detectable electrical energy losses inside the test object. These losses can be measured and give a qualitative indication about the local physical condition of cable insulation.

Theory and transmission line model

To achieve this, several travelling waves are generated by injecting defined pulse patterns into the test object. These waves propagate with a characteristic velocity and are attenuated and distorted caused by losses inside the transmission line. Attenuation and distortion are defined by the propagation constant γ, which consists of a real part, the attenuation constant α, and an imaginary part, the phase constant β [1]:

$$\gamma = \alpha + j\beta = \sqrt{(R' + j\omega L') \cdot (G' + j\omega C')} \qquad [1]$$

According to Fig. 2, a transmission line can be divided into a number of increments N of a defined length. One segment k can be modeled by the equivalent circuit shown in Fig. 2 [2]. On the basis of this transmission line model and an extended form of it considering the skin-effect, a selected range of simulation and measurement results will be presented subsequently.