HIGH FREQUENCY SIGNAL PROPAGATION IN SOLID DIELECTRIC TAPE SHIELEDED POWER CABLES ---- THEORY AND ITS APPLICATIONS

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ABSTRACT

This paper studies the characteristics of the high frequency signal propagation in tape shielded solid dielectric cable. As the cable ages, corrosion along the tape shield can reduce the conduction between the tape laps, forcing a percentage of the shield current to spiral down the tape, which increases the cable inductance and therefore affects all the signal propagation characteristics. The cable inductance as well as the signal propagation velocity and the characteristic impedance in a custom-manufactured cable sample were computed as a function of the fraction of the helical shield current, which are in reasonable agreements with measurements. Some practical consequences of the helical shield current determined propagation characteristics in a tape shielded cable on cable diagnostic techniques are also presented.

KEYWORDS

Tape shielded power cables; High frequency signal propagation; Propagation velocity; Characteristic impedance; Attenuation; Time domain reflectometry; Partial discharges.

INTRODUCTION

Many diagnostic techniques for power cables such as time domain reflectometry (TDR), partial discharge (PD) location, etc., strongly depend on the understanding of the high frequency signal propagation in the cable under test. For example, the accuracy of TDR location depends on the knowledge of the electromagnetic propagation velocity in the cable and the pulse reflection amplitude which is determined by the high frequency attenuation of the cable. The optimum PD detection bandwidth and maximum cable length over which PD is detectable are also determined by frequency dependent attenuation of the cable. A detailed knowledge of high frequency propagation characteristics of shielded power cable is important.

High frequency signal propagation in shielded power cables has been studied since the 1980s [1], and the signal propagation characteristics of power cable with concentric neutral wires or a solid metallic shield are fairly well understood [1-5]. However, signal propagation in tape shielded cable is more complicated. In new copper tape shielded cable, high frequency pulse propagation is similar to that in a solid shield cable [3]. As a copper tape shielded cable ages, corrosion of the copper tape impedes conduction at the laps. The worst case occurs when the tape laps are nonconducting, in which case nearly all the shield current spirals down the tape to form a solenoid. The helical shield current induces an axial magnetic field which increases cable inductance and thereby reduces the propagation velocity, increases the characteristic impedance and high frequency attenuation.

The propagation characteristics for a cable with no copper tape lap conductivity were computed and measured on a custom manufactured 15 kV, 133% EPR insulation copper tape shielded cable with 1/0 copper conductor and PET tape intercalated with the copper tape shield to eliminate conduction at the tape laps. The tape width (w_{tape}) is 25.4 mm (1 inch), and the overlap between two adjacent tape laps ($w_{overlap}$) is 3.2 mm (⅛ inch). The effective tape width (w_{eff}), i.e., the width less the lap in the axial direction, is 23.6 mm (0.928 inch). The number of copper tape laps per unit length of the cable is the reciprocal of this effective tape width. The helical shield current follows the direction of the tape with an angle (θ) to the cable axis, which has two components in circumferential and in axial directions, separately. Assuming the fraction of the helical shield current to the total shield current is S, the fraction of the circumferential shield current, s, is given by

$$s = S \cdot \sin(\theta) = S \cdot \left(\frac{w_{tape} - w_{overlap}}{w_{eff}} \right) \tag{1}$$

The θ is about 71° in the cable sample described above. The fraction of the circumferential current s is about 94% if all the shield current spirals down (S=1).

Based on the knowledge of the helical shield current determined high frequency signal propagation characteristics in a tape shielded cable, some practical consequences on cable diagnostic techniques are discussed.

CABLE INDUCTANCE

The shield current in a tape shielded cable can be separated into axial and circumferential components. The latter increases during aging as a result of reduced lap conduction and induces an axial magnetic field within the cable. Cable inductance (L), which is a function of both frequency and fraction of circumferential shield current, can be calculated from the magnetic field energy as

$$W(f,s) = \frac{1}{2} L(f,s) \cdot I^2 = \frac{\mu}{2} \int_V H(f,s)^2 \, dV \tag{2}$$

where I is the RMS total shield current, which, at high frequencies, is the same as the current in the conductor. V is the volume element, and H is the magnetic field in the cable induced by both the conductor current and the circumferential shield current.

The conductor current induces a circumferential magnetic field in the cable insulation and the semicon layers which, from Ampere's Law, is given by

$$H_{cir\_ins}(r) = \frac{I}{2\pi r}, \quad r_{con} < r < r_{gsemi} \tag{3}$$

where r_{con} and r_{gsemi} are the outer radii of the cable conductor and the ground shield semicon. The magnetic field within the conductor decreases with the distance inward from the surface as a result of skin effect. When the skin depth is much less than the conductor radius, the