CONSTRUCTION OF PHYSICALLY REALIZABLE DRIVING-POINT FUNCTION FROM IMPEDANCE SPECTROSCOPY OF THE CABLE USING SWEEP FREQUENCY RESPONSE ANALYSIS.

Aritra **DAS**, C. C. **REDDY,** Indian Institute of Technology Ropar (India), aritra.20eez0014@iitrpr.ac.in, reddy@iitrpr.ac.in.

ABSTRACT

In this paper, the driving point impedance function (DPIF) of a power cable is constructed, as a first step toward the application of sweep frequency response analysis (SFRA) technique for condition monitoring in power cables. The construction of DPIF is proposed to be done using SFRA data or from the knowledge of material properties and dimensions of the cable. Experimentally, the DPIF is obtained from poles and zeroes of the impedance graph for a test cable. Frequency-dependent model is considered in ANSYS Maxwell to simulate and compare the impedance graph with the proposed analytical functions and test cable.

KEYWORDS

Driving-point impedance function, testing circuit, ladder network of a cable, ANSYS Maxwell, Hurwitz polynomial, poles, and zeroes.

INTRODUCTION

The SFRA test is very common in the diagnosis and condition monitoring of power apparatus [1]-[3]. In the SFRA test, a sinusoidal voltage signal is swept over a band of frequencies at any two terminals of the testing equipment (one of the two terminals can be ground or main core), and the corresponding amplitude and phase angle of current and voltage are obtained. This test is quite capable of condition monitoring in different power apparatuses, however, a scarce amount of research is performed in cable regarding the use of SFRA, and its application is only limited to finding the location of the short-circuited fault in the cable [4].

SFRA of an unhealthy cable does not match with that of a healthy one, because of changes in its equivalent circuit, which in turn cause changes in resonant frequencies. The changes that might have happened due to mechanical or electrical damage, can also be found using this technique Therefore, the test appears to be appealing for power cables, where, condition monitoring i.e. identifying weaker sections of underground or submarine cables assumes paramount importance in power system reliability.
However, apparently, the SFRA test has only been reported to locate short-circuited faults only for power cables, however, formulation of DPIF (driving point impedance function) and how these parameters will affect a DPIF graph which is needed for ascertaining the feasibility of SFRA for power cable condition monitoring applications were not reported.

In view of this, the paper investigates the feasibility of performing SFRA in a single-core power cable by estimating DPIF from the measured SFRA data, with certain changes in the circuit compared to that of transformers. Next, the synthesis of a ladder network has been done from the data. This data must be represented as a polynomial in the form of "s", to construct a rational function. This rational function has to satisfy some properties so that the proposed ladder network can be synthesized. The conditions that must be satisfied are [5]: the measured data corresponds to DPIFs i.e. impedance and admittance functions; the rational function generated should be real and positive. Of these, the first one can be checked by performing experiments. Carefully planned experiments are performed for this purpose. To check physical reliability every function has been verified by writing as a Hurwitz polynomial [6].

Apart from the experimental measurements, construction of the ladder network, and formulation of DPIFs, certain simulations were also carried out using circuit simulation software for verifying the results as an additional check. The results indicate reasonable accuracy of the analytical DPIFs and try to establish the feasibility of the SFRA test for power cables.

PREDICTED DPIF OF THE CABLE

Similar to a transmission line, the ladder network of a cable consists of four basic parameters: *R, L, G,* and *C*. The conductor carrying the current offers series resistance and series self-inductance. The insulation between the conductor and the ground will offer shunt capacitance and shunt conductance. Referring to Fig. 1, for a single core power cable with effective conductor radius "*r*" and the radius of the outer surface of insulation as "r_2", Under operating at a high frequency (>100 KHz), there will be a predominant skin and proximity effect for the conductor and these make the series resistance and shunt conductance to vary with frequency. With the detailed references [7], the analytically calculated four parameters of the cables that are used in this paper are:

$$R = \rho \frac{1}{\pi\left[r^2 - \left(r - \frac{1}{\sqrt{\pi\mu\sigma f}}\right)^2\right]} \qquad [1]$$

$$L = \frac{\mu_0}{2\pi}\ln\left(\frac{{r_2}^2}{r^2}\right) \qquad [2]$$

$$C = \frac{\frac{\mu_0}{2\pi}\ln\left(\frac{{r_2}^2}{r^2}\right)}{\left(\frac{1}{\mu\varepsilon}\right)\left(\left(\frac{\mu_0}{2\pi}\ln\left(\frac{{r_2}^2}{r^2}\right)\right)^2 - \left(\frac{\mu_0}{2\pi}\ln\left(\frac{r_2}{r}\right)\right)^2\right)} \qquad [3]$$

$$G = 2\pi f \times \; tan\,\delta \times C \qquad [4]$$

Here, ρ = Resistivity of the conductor, μ_0 = Permeability at free space, μ_r = Relative permeability of the conducting material, $= \mu_0 \times \mu_r$, $\sigma =$ Conductivity of the conducting material. The actual ladder network of the cable at power frequency is shown in Figure 2.

It should be noted that, according to the existing literature [8], high-frequency resistance increases with frequency as