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# Influence of frequency characteristics of soil parameters on ground-return transmission line parameters

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ABSTRACT

Electromagnetic transient processes are strongly related to the parameters of transmission lines. With the ground return parameters considered, the frequency dependent parameters of transmission lines are highly dependent on the soil parameters, which include resistivity and dielectric permittivity. In this paper, with the measurement results of frequency variation of soil parameters, the influence of the frequency dependent soil parameters on the frequency dependent characteristics of the transmission line parameters were studied using the complex return plane method. According to the calculation results, the frequency characteristics of soil parameters have obvious influences on the parameters of overhead transmission lines. The influences of the humidity, temperature and particle size of the soil on the ground-return parameters were also evaluated.



## 1. Introduction

Ground return parameters have been considered to be very important in the evaluation of transient behavior of overhead transmission lines. In most literatures about evaluations of electromagnetic transient behavior on transmission lines, the parameters of the soil are considered to be constant. However, the parameters of the soil, including resistivity and dielectric permittivity, are significantly frequency dependent. With the frequency dependence of soil parameters considered, the ground return parameters can be quite different. Hence, the study on the frequency variation of soil parameters is very important to the electromagnetic transient analysis of power system.

The frequency dependent characteristics of the soil parameters have attracted much interest of many researchers. Many scholars had carried out researches on the frequency dependence of soil parameters [1–10]. Among these studies, Visacro et al. [5–8] used a buried electrode to get the frequency variation of the parameters of low and high resistivity soils, and the variation of soil parameters was determined in the respective frequency range of lightning currents, from the measured voltage and current waves and corresponding impedances. Based on the measurements, Visacro and Alipio [9] developed an empirical model to express the frequency dependent soil parameters. Portela carried out a series of soil parameter measurements and evaluated the influence on the transmission line transient performance [10,11]. Moura et al. also made some researches on the impact of the frequency dependence of soil parameters on transient behavior of transmission lines [12,13].

On the other hand, a number of fundamental papers have developed expressions for line parameters with ground return [14–23]. Early researchers used a single logarithmic approximation of the integral term to express the ground return parameters [11–17]. For graphically interpreting this algorithm, Deri et al. [17] developed the concept of an ideal current return plane placed below the ground surface at a complex distance equal to the complex penetration depth for plane waves, which was first proposed by Wait in 1969 [18]. The parameter of the soil has great effect on the ground return parameters. In [19], Semlyen studied the sensitivity of the resistivity of the soil to the overhead line parameters. Actually, the dielectric permittivity also has great effect on the overhead line parameters [20]. Pizarro and Eriksson proposed a double logarithmic approximation in 1991, which can provide more accurate results of ground return parameters [21]. Similar to Deri's single complex ground-return plane, Noda proposed a double complex ground-return plane to interpret the double logarithmic approximation [22].

In previous work [23,24], an experimental method for the measurement of the material characteristics was proposed to measure the frequency variation of the soil parameters directly. Different from Visacro and Alipio's method, a broad band dielectric

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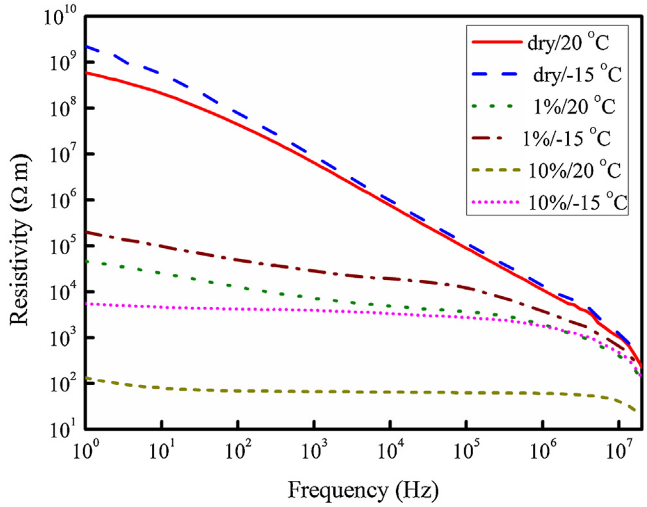


**Fig. 1.** Frequency dependent characteristics of the resistivity of the soil sample.

spectrometer was used in the measurements. With the obtained frequency dependent soil parameters obtained in the previous work, this paper took the ground return into account and studied the effect of the soil parameters on the frequency dependent behavior of the overhead transmission line parameters. Furthermore, the temperature, moisture and density of soil were changed to investigate the influence of the soil parameters on the transmission line parameters.

## 2. Frequency characteristics of soil parameters

Soil is a very complicated system which usually has solid, liquid and gas compositions. The soil parameters will change with the frequency and also with the soil characteristics, such as the temperature, humidity and soil particle size.

In previous work, using a broad band dielectric spectrometer, the soil parameters in a certain frequency range were measured and the frequency variation curves of soil parameters were obtained [23,24]. The frequency variation of resistivity and relative permittivity are shown in Figs. 1.

According to Fig. 1, the soil resistivity decreases with the increase of the frequency, especially for the dry soil. The frequency dependent behavior of the soil with low humidity is more obvious.

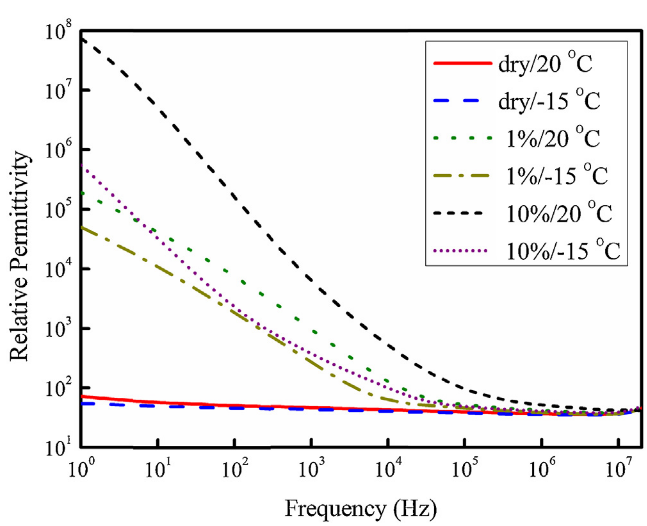


**Fig. 2.** Frequency dependent characteristics of soil relative permittivity.

The temperature has little influence on the resistivity of soil with low humidity. However, with the humidity increases, this influence gets stronger. From Fig. 2, the permittivity of the soil decreases with the increase of the frequency. Along with the increase of the soil moisture content, the influence of the frequency on the soil permittivity increases. The permittivity of the soil with higher temperature is smaller. The influence of the temperature on the permittivity of wet soil is more obvious than the dry soil. The permittivity of dry soil is smaller than the soil with high humidity.

## 3. Frequency-dependent parameters of overhead transmission lines

The longitudinal impedance of the overhead transmission lines consists of internal impedance of the conductor and ground return impedance. The ground return impedance is high related to the soil parameters.

A quasi mode approach was presented by Semlyen [19] to analyze the influence of frequency-dependent soil parameters. This method is very similar to Deri's method [17], but the value of the complex penetration depth $p$ is different. In this paper, the value of $p$ is calculated with (1)

$$p = \frac{1}{\sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}} \quad (1)$$

where $\omega$ is the angular frequency of the wave; $\mu$ is the permeability of the soil; $\sigma$ is the conductivity of the soil and $\varepsilon$ is the permittivity of the soil. Expression (1) is the full type which is derivate from Maxwell equations. In [17], Deri neglect the permittivity and simplified the value of $p$ as $1/\sqrt{j\omega\mu\sigma}$. However, with the frequency dependent soil parameter considered, the permittivity is unnegligible in high frequency range.

In the experiments of the previous work [23,24], the measurement results consist of real part and imaginary part:

$$\varepsilon_P = \varepsilon_1 - j\varepsilon_2 \quad (2)$$

The real part of $\varepsilon_P$ is the relative permittivity that we concerned, while from the imaginary part the resistivity can be calculated [19].

$$\rho = \frac{1}{2\pi f \varepsilon_0 \varepsilon_2} \quad (3)$$

Take the frequency characteristics of the conductivity $\sigma$ and the permittivity $\varepsilon$ of the soil into account, subscribe (2) and (3) into expression (1), the complex penetration depth can be described as

$$p = \frac{1}{\sqrt{j\omega\mu(\omega\varepsilon_0\varepsilon_2 + j\omega\varepsilon_0\varepsilon_1)}} = \frac{1}{(j\omega\sqrt{\mu\varepsilon_0\varepsilon_P})} \quad (4)$$

By assuming the overhead transmission lines are perfectly parallel to the ground, the ground return impedance of the lines can be evaluated with the complex penetration depth $p$.

$$Z_{ii} = j\omega\frac{\mu_0}{2\pi}\ln\frac{2(h_i + p)}{r} \quad (5)$$

$$Z_{ij} = j\omega\frac{\mu_0}{2\pi}\ln\frac{\sqrt{(h_i + h_j + 2p)^2 + d_{ij}^2}}{\sqrt{(h_i - h_j)^2 + d_{ij}^2}} \quad (6)$$

where $h_i$, $h_j$ are the conductor height above ground; $r$ is the conductor radius; $d_{ij}$ is the horizontal distance between conductors $i$ and $j$. For most soils, the magnetic permeability $\mu$ is equal to that of vacuum, hence the relative permeability value was set as 1.

Both self impedance $Z_{ii}$ and mutual impedance $Z_{ij}$ consist of real part and imaginary part:

$$Z_{ii} = R_{ii} + j\omega L_{ii} \quad (7)$$