Some Patterns of Formation of Interference on Wire Lines from Short Electromagnetic Pulses

Limits of Applicability of the Telegrapher's Equations when Calculating Interference Characteristics

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Abstract—The exact solution is obtained for the problem of wire lines formed by two thin infinitely long ideally conducting cylinders under the influence of a short EMP. The limits of applicability of the telegrapher's equations are found by comparison with the exact solution. The errors that arise in the case of the use of telegrapher's equations for finding disturbances on two-wire lines from HEMP and UWB pulses are estimated.

Keywords−electromagnetic pulse (EMP), pulse electric disturbance, wire line, telegrapher's equations.

I. INTRODUCTION

Any calculation method has its own limits and going beyond those limits leads to unacceptable errors. These problems were repeatedly analyzed in the literature, as an example, in several books [1, 2]. Nevertheless, sometimes erroneous results of calculations are encountered, which, apparently, are caused by insufficiently deep understanding of the patterns of formation of disturbances on wire lines and the incorrect application of well-known calculational methods. In connection with this, the method proposed by the authors of this article for investigating the patterns of disturbance formation on wire lines, as well as an analysis of the limits of telegrapher's equations applicability, which are often used to calculate the characteristics of these disturbances, may prove useful for specialists engaged in solving similar problems.

II. CURRENT FORMATION IN A WIRE LINE OF TWO THIN INFINITELY LONG IDEALLY CONDUCTING CYLINDERS

The problem of current formation in wire lines was solved in two stages. At the first stage, the exact solution of the problem of current formation in one infinitely long ideally conducting cylinder was found. Then, using the results of the first stage, an exact solution was found for the current arising in two parallel thin cylinders:

$$I_1 = E_0 \frac{\alpha - \beta e^{-ikh}}{\alpha^2 - \beta^2}, \qquad I_2 = E_0 \frac{\alpha e^{-ikh} - \beta}{\alpha^2 - \beta^2}. \tag{1}$$

Here I_1, I_2 are currents in the wires; α and β are geometry depending constants; k is the wave number; h is the distance between the cylinders. It follows from equations (1) that the currents in the cylinders forming the two-wire line are different. This circumstance can be interpreted as follows: two types (modes) of induced current are formed in the line, namely, in-phase (I) and antiphase (ΔI). Using equations (1), it is not difficult to find the exact solutions for I and ΔI, as well as expressions for calculating these parameters under the condition of transverse quasi-stationarity, where $kh = 1$.

III. ANALYSIS OF THE TELEGRAPHER'S EQUATIONS APPLICABILITY LIMITS

The basic assumption used in deriving the telegrapher's equations is the condition of transverse quasi-stationarity. In practice, this condition is often violated. Thereby, the question arises of the applicability limits of telegrapher's equations and the possible consequences of going beyond these limits. To answer these questions the antiphase current ΔI was calculated using the exact and approximate equations. Then the results obtained are compared with one another. This comparison shows that to calculate the current induced in a two-wire line under the influence of a bipolar pulse, the telegrapher's equations can be used only if $T \geq 10(h/c)$, where: T is the pulse duration; h is the distance between the line wires; and c is the speed of light. At the same time, when assessing the HEMP interference from the unipolar waveform recommended by the standard [3], limits of the use of telegrapher's equations are much weaker. However, it should be noted that the form of the complete HEMP waveform is not unipolar. In this regard, it is possible that the use of the telegrapher's equations for disturbance calculations on wire lines from real HEMPs requires additional analysis.

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