Solve the passive interference of UHF transmission lines based on LE-PO method

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Abstract: On the research about the ultra-high frequency (UHF) re-radiation interference (RRI) from the power lines, traditional high-frequency algorithms need excessive computing resources or have a bad calculation precision. Based on the surface model of RRI, the calculation idea using large element-physical optics (LE-PO) is proposed to calculate the level of RRI. According to the assumption of LE-PO, the electric field integral equation is simplified. When the excitation source is plane wave, Linearly Phased-Rao Wilton Glisson (LP-RWG) basis functions are used to disperse the surface-induced current and the expression of scattering field from the tower of power lines was deduced. Related analysis example is used to analyse the calculation precision and the computing resource of LE-PO. As a result, the computing resources of LE-PO are much less than PO, while the calculation precision of LE-PO is the same as PO.

1 Introduction

With the rapid development of current science and technology, a variety of UHF radio stations (such as those used for analogue TV and digital TV broadcasting stations and military aviation radars) that have strict requirements on the surrounding electromagnetic environment have emerged in large numbers [1]. Structure of the UHV transmission line of these stations to solve the problem of passive interference has become a research hot spot [1, 2].

In the mid-wave frequency band, IEEE explicitly proposed using the method of moment to solve the passive interference of transmission lines numerically [3]. However, with the increase of the calculation frequency, the domestic and foreign studies find that when the moment method is used to discrete the induced current on the surface of transmission towers, the matrix operations also increase, which makes the current computer hardware resources unable to solve the UHF (0.3–3 GHz) conditions of passive interference [4, 5]. Therefore, Tang et al. [6] proposed a method of solving high-frequency passive interference in transmission lines based on uniform theory of diffraction (UTD). However, UTD is a theory to study the propagation of light rays and is suitable for the calculation of the electromagnetic wave with a wavelength of \(\lambda \approx 0\) [7]. Therefore, using this method to solve the problem in the ultra-high frequency range will cause a large error in the result. Although there are no other effective algorithms for solving the problem of passive interference in UHV transmission lines at present, the large-size electromagnetic scattering algorithm similar to transmission lines is available for reference [8]. Aiming at the electromagnetic scattering characteristics of large electric objects, the paper proposes to use triangular optics to discrete targets so that physics optics (PO) can solve arbitrary shape targets. As the PO algorithm is still based on the target surface current analysis, the accuracy of the PO algorithm in UHF electromagnetic scattering research is higher than that of the UTD method. However, in order to ensure the accuracy of the PO algorithm, the segmentation of the large size target model must be finer with increasing frequency. This kind of algorithm also caused the problem that computing resource needs too big to be solved. In the follow-up study, Nazo [9] introduced a modified LP-RWG (linearly-phased RWG) basis function of the traditional Rao-Wilton-Glisson basis function, thus proposed a large-Large element-physical optics, LE-PO), and achieved good results in solving the electromagnetic scattering of large electric size targets.

Therefore, in order to solve the problem of passive interference in UHV transmission line effectively, this paper introduces the LE-PO method to solve the passive interference of UHV transmission line based on the passive interference model of transmission line. The research on the mathematical model of passive interference in UHV transmission lines and the electromagnetic scattering characteristics laid the foundation.

2 Algorithm selection of passive interference in UHF transmission lines

2.1 Various types of algorithms for passive interference in UHF transmission lines

At present, the UHF algorithms used for the electromagnetic scattering of electric large size targets can be classified into two types according to the principle: a ray-based method and a current-based method.

Based on ray optics, the problem of electromagnetic scattering is transformed into pure geometric problems of ray tracing, such as geometrical optics method, geometrical diffraction theory, and consistent geometrical diffraction theory. Among them, the conformable diffraction theory is to calculate the frequency of passive the fastest way to interfere [6].

UTD algorithm based on the local principle of high-frequency field, the transmission line as a combination of plate, column, cone of these three typical models, using the typical solution to find the local field after the stack together to get the total field. In fact, the transmission line cannot be completely formed by the combination of plates, columns, and cones. Therefore, when solving the diffractive field of transmission line, there is an inevitable partial solution in the absence of an accurate diffraction coefficient. In addition, UTD is a theory that studies the propagation of light rays and is suitable for calculating the case where the wavelength of an electromagnetic wave is \(\lambda \approx 0\), that is, the more accurate the frequency is.

Based on the current method, the approximate induced current of the target surface is obtained first, and then the scattering field is obtained by the induced current, such as the PO method and the physical diffraction theory (PTD).

Since the final integral of the PTD method is generally difficult to solve, so commonly used PO method to solve. However, the traditional PO method usually uses RWG basis function to divide the large size or even super large size targets of transmission lines into large ones, which requires huge computing resources and is limited by the current computer hardware. In order to solve this problem, the LE-PO method appears. This method introduces a
correction term based on the RWG function to characterise the change of the current phase. Therefore, the large-area segmentation of the transmission line model can be greatly reduced. The number of unknowns overcomes the problem that the traditional PO method has a large demand for computing resources. Obviously, the problem of passive interference in transmission lines can be considered by the LE-PO method.

2.2 Application of LE-PO method conditions

LE-PO method and PO method of solving the process is similar, but divided by the basis of the different functions can be used to dissect large elements. Therefore, when applying the LE-PO method, it is also necessary to satisfy three assumptions when applying the PO method [8]: (i) The radius of curvature of the surface of the object is much larger than the wavelength of the electromagnetic wave; (ii) the induced current on the irradiated surface of the object has the same characteristics of induced current on an infinity plane tangent to the incident surface; (iii) There is only induced current on the surface of the object directly irradiated by the incident wave, and the induced current in other areas is zero.

In the case of UHF, the transmission line model is rough and cannot be applied. In this case, we must use a very close to the actual transmission line passive interference surface model, which can theoretically be used for short-wave and above any frequency band of passive interference horizontal solution [4]. In this model, the transmission line tower consists of ‘∟’ angle steel with only one metal part such as the transmission line tower is obtained, the induced current on the surface of the object directly irradiated is determined, the induced current on the surface of the tower can be expressed by the basis function [12]:

\[ E_{SP} = \frac{j\omega \mu_0}{2\pi R} \int_{S_i} \left[ n \times H' - k \times (n \times H') \right] e^{-jk \cdot r} dS' \] (1)

In the formula, \( \omega \) is incident wave frequency, \( \mu_0 \) is Vacuum permeability, \( n \) is the outer normal direction of the \( S_i \) surface, \( H' \) is incident wave magnetic field, \( r \) represents the vector of the observation point \( P \) to the origin of the reference coordinate system, \( R \) represents the radius of the origin of \( dS' \) surface to the reference coordinate system, \( R = |r - r'| \), \( k \) represents wave number, \( k \) represents the electromagnetic wave propagation vector.

According to the literature [11], the curl vector in (1) can be expressed by the induced current density vector:

\[ j^{LE-PO}(r') = 2\delta \times n \times H' \] (2)

In the formula, coefficient \( \delta \) is to consider the effect of occlusion. If the observation point \( r \) is in the shadow area, then \( \delta = 0 \). If in the lighting area, \( \delta = \pm 1 \), then its sign is determined by the relationship between the incident angle and the surface normal vector.

Equation (2) into (1) shows, LE-PO method is essentially the transmission line tower scattering field expressed as a function of induction current on the surface of the transmission line tower integral, and the tower surface induced current density equation unknown. Therefore, as long as the induced current distribution of the metal part such as the transmission line tower is obtained, the scattered field of the transmission line can be solved by the simplified integral equation of the electric field.

3.2 Solution of induced current on tower surface of transmission line

According to the principle of LE-PO method, it is necessary to divide the tower surface into many small triangular regions when solving the induced current on the tower surface. Therefore, in the triangular facet pairs \( T_n \) and \( T_m \) shown in Fig. 2, the LP-RWG basis functions [12] associated with the \( n \)th edge \( i_n \) are, respectively, established:

\[ A_{in}(r) = \begin{cases} \frac{l_n}{2A_{in}} \rho_{in} \times e^{-jk_s \cdot \rho_{in}}, & r \in T_n^m \\ \frac{l_n}{2A_{in}} \rho_{in} \times e^{-jk_s \cdot \rho_{in}}, & r \in T_n^m \\ 0, & \text{other} \end{cases} \] (3)

In the formula, \( l_n \) represents the edge length of the \( n \)th edge, \( A_{in} \) and \( A_{in} \) represent the area of triangular facets \( T_n^m \) and \( T_n^m \), respectively, \( \rho_{in} \) is the position vector pointed by \( O \) in \( T_n^m \), \( \rho_{in} \) is the position vector pointing to \( O \) in \( T_n^m \), \( \rho_{in} \) and \( \rho_{in} \) are the vectors of the triangular facets \( T_n^m \) and \( T_n^m \) non-common vertices to the common midpoint, respectively. \( k_s = 0, (3) \) is converted to RWG basis function, denoted as \( f_{in}(r) \).

Similar to the moment method, after the current basis function is determined, the induced current on the surface of the tower can be expressed by the basis function \( A_{in}(r) \) [13]:

\[ J_s = \sum_{n=1}^{N} y_n \times A_{in}(r) \] (4)

where \( y_n \) is the unknown coefficient, \( N \) is the total number of edges of the triangular facets to the common edge after the entire facet model is partitioned, the boundary edges that cannot form the triangular face pair and the edges at the junction of the shadow region and the lighting region are not included.
In the formula, \( k = 1, 2, \ldots, N \). Multiply both ends of (4) simultaneously and bring (2) into:

\[
\gamma_n = (r_n^+ + r_n^-) \times 2\pi \times n \times H[f(e^{-j(k_n \cdot r_n^+)} - e^{j(k_n \cdot r_n^-)} + e^{-j(k_n \cdot r_n^+) - e^{j(k_n \cdot r_n^-)}}] \quad (6)
\]

The formula (6) into (4) can be obtained as tower induction current, and then according to (1), the induction current function is integrated to obtain tower scattering field.

In solving the induced current, the triangular facet size of the LP-RWG basis function can be much larger than the triangular facet size of the RWG basis function. The angle of the tower model can be seen as two planes, even if the two planes were used to delimit a large triangle, but also to reflect the local details of the angle, so as to ensure the accuracy of the calculation. At the same time, the use of larger triangular facets can also reduce the number of unknowns and save computing resources. Therefore, compared with the traditional PO method, the LE-PO method can achieve a faster solution of the scattering field on the basis of ensuring the calculation accuracy. Reference [4] in the tower size, the effect of triangular facets divided as shown in Fig. 3.

### 4 Case study

#### 4.1 Accuracy analysis of algorithm-based on angle steel model

After solving the scattering field of transmission line, the level of passive interference of transmission line can be solved by the following formula [2]:

\[
S = 20\log_{10} \frac{E_{\text{there are transmission lines}}}{E_{\text{no transmission line}}} \quad (7)
\]

where, \( E_{\text{there are transmission lines}} \) is the electric field strength of the observation point when there is a transmission line; \( E_{\text{no transmission line}} \) is the electric field strength of the observation point when there is no transmission line. This equation can be used as a criterion to evaluate the level of passive interference.

Due to the fact that it is very difficult to experimentally verify the passive interference of UHF transmission lines at present [6], and the calculation accuracy of moment method is high [15], the result of moment method can be used to analyse the accuracy of LE-PO method. However, due to the limitation of computational resources, the method of moment method can only calculate the passive disturbance level of some angle steels. Therefore, the equilateral angle model can be established to analyse the accuracy of the algorithm.

Select the actual transmission line tower part of the equilateral angle of the calculation, the simulation model shown in Fig. 4a below. As the skin effect of the angle steel is obvious at UHF, its thickness can be neglected. The simplified model is consistent with the angle steel in the tower model, as shown in Fig. 4b.

For the model in Fig. 4b, the incident wave is a vertically polarised plane wave with a field strength of 1 V/m. Angle steel width of 20 cm, height of 1 m, >10 times the wavelength of the incident wave, so to meet the requirements of large size, high-frequency algorithm can be used to solve. Based on the case study [4], we study the level of passive interference at a distance of 2000 m from the transmission line. This distance is about 20 times higher than that of the example tower. Therefore, the observation point in this paper selects 20 times the angle of the steel angle (0,20,0). MoM method, PO method, LE-PO method and UTD method are, respectively, used to calculate the passive interference level of the section steel. The calculation results are shown in Fig. 5. Due to the difference between the UTD method and the other three methods, the data comparison is shown in Fig. 5b separately.

As can be seen from Fig. 5, if the moment method is used as the evaluation criterion, the LE-PO method and the PO method calculate the passive interference level curve basically coincide, and the trend with the MoM curve is basically the same, while the UTD law is the opposite; if taking 0.1 dB/m as the allowable range of deviation, the calculation precision of LE-PO method and...
PO method is higher, UTD law is far beyond the allowable range of deviation, but with the increase of frequency, the deviation of UTD method and moment method getting smaller and smaller, accuracy has improved.

Although the basic functions used by the LE-PO method and the PO method are different, they are essentially approximations of physical optics, differing in the size of the split bins, so when solving the passive interference level of a simple target like angle steel, the phenomena of creeping wave and so on, which inevitably will produce certain deviation, but the calculated deviation is within the allowable range. Due to the higher accuracy of the UTD method at higher frequencies, the UTD method and the MoM method get closer to each other with the increase of the frequency, but there is still a large deviation. Therefore, the UTD method does not suit for solving the passive interference of UHF transmission lines.

4.2 Algorithm precision and resource analysis based on complete line model

The interference of ±800 kV UHVDC transmission line to a special type of radar was studied using the example in [6]. The example model and parameters are shown in Fig. 6.

Although the elevation of the radar will have an impact on the level of passive interference in transmission lines, this paper only considers the same situation as the shortwave radio stations [2, 3, 5, 16], that is, the pitch angle of the radar is set to 0°.

According to the model shown in Fig. 6, the vertical polarised plane wave at infinity is used for excitation. The excitation electric field intensity is 1 V/m and the excitation frequency interval is 27 MHz. The PO and LE-2) at the level of UHF passive interference sweep calculation, the calculation results shown in Fig. 7.

As can be seen from Fig. 7, the passive interference level fluctuates irregularly with the increase of radar operating frequency, which includes multiple resonance points. The deviation of LE-PO method and PO method is 0.002 dB/m.

Due to the irregular oscillation tendency of the scattering field at the observation point with increasing frequency, the corresponding passive interference level also shows the trend, which is similar to the trend of passive interference in transmission lines under medium and short wave conditions [2, 3, 5, 16]. Due to the different basis functions used by the LE-PO method and the PO method, certain deviations must exist, but these deviations are very small. For the angle model in Section 4.1, the deviation is almost zero. However, for a transmission line pavement model consisting of a large number of angles, the deviations are somewhat cumulative, but still too small to be neglected.

It is noteworthy that this article uses the angle steel model to analyse the LE-PO method to calculate the accuracy. For the case of 4.2, the result is accurate. However, from the principle of LE-PO solution, it can only give a more accurate result in the range of ±40° from the axis of the ray [10]. However, the relative position of the actual UHV transmission lines and the adjacent radio stations is rather complicated, so there is bound to be a range that cannot be solved by the LE-PO method. Therefore, in subsequent studies, attention should be paid to algorithms deviating ±40° from the axis of the ray.

Table 1 shows the computational resources required for LE-PO and PO methods. It can be seen that the LE-PO method has a significant reduction in the computational resources needed to solve the passive interference in transmission lines compared with the traditional PO method.

From the point of view of the mechanism of splitting, the LE-PO theory ignores the surface currents in the transmission line tower, it is impossible to obtain a strict numerical solution. However, under the present conditions, this method is the most effective way to calculate the passive interference of UHV transmission lines good algorithm.

5 Conclusion

5.1 Accuracy analysis of algorithm based on angle steel model

i. Compared with the UTD method and the PO method, the LE-PO method not only has higher accuracy but also requires less computational resources and is suitable for solving the passive interference of UHF transmission lines.

ii. Although the LE-PO theory ignores the surface currents in the diffractive and discontinuous sections of the angles of the transmission line tower, it is impossible to obtain a strict numerical solution. However, under the present conditions, this method is the most effective way to calculate the passive interference of transmission lines good algorithm.

6 References

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