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Application of adaptive sampling algorithm in solving the scattering field of UHVAC/DC transmission lines

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Abstract: Using MBPE technology can quickly predict the approximation of the frequency response of transmission lines' scattering field. However, equal interval sampling method is usually used in the calculation of transmission lines' scattering field, it results a possibility that the sampled data may be with lack of important points, which makes the fitting results difficult to control, or samples duplicated information to increase the amount of calculation. In order to calculate more accurately, the adaptive sampling algorithm is introduced here. In the fast solution of frequency response of transmission lines' scattering field, it greatly improved the accuracy of results. Finally, compared with those of the traditional interval sampling methods, the results of using adaptive sampling algorithm were in line with the actual situation.

1 Introduction

Model-based Parameter Estimation (MBPE technology can be a good electromagnetic characteristics of the scattering field transmission line analysis [1]. However, in actual situation, MBPE technology has strict requirements on the sampling points. Sampling appropriate points can quickly calculate the approximation of the frequency response of the scattering field. However, if the sampling points are not selected properly, the calculated frequency response data will not be in good agreement with the actual data [2]. Therefore, to select appropriate sampling points is an important issue to be solved by MBPE technology.

On the selection of sampling points in MBPE technology, R. Lehmensiek proposed an Adaptive Sampling Algorithm (ASA) that searches for suitable sampling points automatically without any experience. This algorithm can reduce the number of sampling points as much as possible while satisfying a certain accuracy. Some scholars applied it in the fast solution of single-station RCS and got satisfied fitting results [3]. However, this sampling method has the problem of fuzzy selection of sampling points, and sometimes it is not possible to obtain sampling points with the largest amount of information. Therefore, it is necessary to improve this sampling method.

In order to use the adaptive sampling algorithm to obtain suitable sampling points, the frequency characteristics of the scattering field of transmission lines can be analysed more accurately. Here, the adaptive sampling algorithm is extended to the field of fast analysis of electromagnetic scattering characteristics of transmission lines with large size. A more accurate analysis of the frequency characteristics of the scattered field of the electromagnetic open system consisting of the determination of the excitation source and the transmission line was carried out. The results showed that using adaptive sampling method in solution of transmission lines' passive interference can analyse the frequency characteristics of the transmission line scattering field more accurately than equal sampling method.

2 Existing problems in fitting algorithm

2.1 Transmission line MBPE fitting algorithm

When using MBPE technology to solve the scattering field of transmission lines, the first step is to select several frequency points as the sampling points within the range of the research frequency band, then the vector representation of the scattered field can be obtained by experimental measurement or numerical calculation, finally, to use moment method to calculate the sampling points' amplitude and phase of the scattering field.

According to the complex vector theory, the scattered field is represented by a time-independent complex number, and then Euler's formula is used to deform the scattering field formula. Then, MoM method is used to obtain several sampling points in the frequency range. Get the specific expression of the Padé interpolation function and get the matrix equation expression.

Finally, the equations are calculated. After obtaining Padé rational coefficients, the frequency response of the scattering field in the frequency range can be obtained [1].

2.2 MBPE algorithm to solve the problem of transmission line scattering field

When using MBPE technology to obtain the frequency response of the scattering field in the frequency range, the positions of the sampling points are different, which directly affect the accuracy of the fitting result. Obviously, the expansion radius of the sampling point located at the place where the frequency response changes drastically should be smaller than the expansion radius of the sampling point which changes gently. Therefore, the sampling points near the extreme field strength should theoretically be denser than the flat areas.

However, sampling points are sampled at equal intervals when using MBPE to solve the scattering field. This sampling method does not take into account that the number of sampling points is different in places where the field intensity changes drastically and gently. Field near the extreme value should require more sampling points, and field changes in the gentle place can be a corresponding reduction in sampling points. Equal-interval sampling does not adapt to this rule, which makes it necessary to omit some of the key sampling points while adding some unnecessary sampling points, making the fitting result unstable by the sampling interval.

3 Adaptive sampling algorithm

3.1 Adaptive sampling algorithm principle

In the field of natural science and technology science, the authors are often not satisfied with knowing the data of a limited number of points in an interval, but want to obtain the information of the entire interval or have already known a group of data, and the authors hope to estimate the value of some important points around based on the information of these acquired data. At this time, the

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authors need to use the interpolation function to perform the function approximation to get the value of any points.

In theory, any arbitrary rational function model of infinite order can be used to approximate arbitrary curves with arbitrary precision. The curves obtained by modelling a finite number of sampling points with two rational function models are different. However, as the number of sampling points increases, the difference between the two curves will also become smaller and eventually converge to the same true curve. Adaptive interpolation technology is based on this principle, using more than two rational function models to model and compare the differences between the models for a limited number of sampling points, and then increase the sampling point at the point of maximum difference according to the size of the difference, until the difference less than a certain value. At this point, it can be assumed that the constructed rational functions have converged to the true curve. The adaptive sampling algorithm is based on this idea. The sampling points of the adaptive sampling algorithm is the set of sampling points at the maximum point.

Adaptive sampling algorithm is as follows, the sampling algorithm first need to define a relative residual [2]:

$$E_k(x) = \frac{|Y_k(x) - Y_{k-1}(x)|^2}{(|1 + Y_k(x)|^2)} \quad (1)$$

(1) is a comparison of the estimated error between the interval obtained after k samples and the previous sample estimate. Find the point with the largest error and compare with it. If so, record the position of the largest sampling point of this error as the new sample point. Assuming the user needs the accuracy of *tol*, the workflow is as the follows:

The first step is to choose a third sampling point x_2 (the midpoint of the default interval) arbitrarily within the interval $[x_0, x_1]$, sample the points $[x_0, y_0]$ and $[x_2, y_2]$,solve for $Y_1(x)$, and then get the points $[x_0, y_0]$, $[x_1, y_1]$, and $[x_2, y_2]$ from $Y_2(x)$. The second step, using the residual formula (1), $E_2(x)$ is solved at equal intervals in the interval $[x_0, y_0]$, while the new sampling point x_3 is chosen at the maximum $E_2(x)$.

The third step, repeat the second step until $E_k(x)$ met the $E_k(x) <$ tol at the entire region $[x_0, x_2]$

3.2 transmission line passive interference fitting calculation of adaptive sampling algorithm

In order to solve the problem that the traditional adaptive sampling method is inaccurate for the sampling point information, the Fisher information matrix method is used to solve this problem. Fisher information matrix theory is proposed based on the probability theory. It uses the parameter model to construct the information matrix and passes the frequency. The point information matrix performs information volume analysis to classify frequency points so that people can perform optimal processing.

First, the authors assume that the parameter model is $f(w, 0)$. O is the parameter group in the parametric model. The actual sampling value at the frequency point w is (w), and the calculation error at the frequency point w is defined as:

$$e = e(w, \Theta) = O(w) - f(w, \Theta) = e_r(w, \Theta) + je_I(w, \Theta) \quad (2)$$

Probability density function:

$$\begin{aligned} P(e, w, \Theta) &= P(e_R, w, \Theta)P(e_1, w, \Theta) \\ &= \sqrt{\frac{\beta}{2\pi}}\exp\left(-\frac{1}{2}\beta e_R^2\right)\exp\left(-\frac{1}{2}\beta e_I^2\right) \end{aligned} \quad (3)$$

Among them, β is the reciprocal of the noise variance (a non-zero positive number), its size has little effect on the information matrix, generally can be taken as 0.02.

The correlation between the information matrix K and the parameters in the parametric model is related. The representation of the (i, j) elements $K_{\rm ij}$ at the frequency point $(0, 2000, 2)$ is as follows:

$$K_n(i, j) = \int p(e, w_n, \Theta)\frac{\partial \ln p(e, w_n, \Theta)}{\partial \Theta_i}\frac{\partial \ln p(e, w_n, \Theta)}{\partial \Theta_j}de_R de_I \quad (4)$$

Substitute for:

$$K_n = \beta \mathrm{Re}\left\{[\nabla_\theta f(w_n, \Theta)][\nabla_\theta f(w_n, \Theta)]^H\right\} \quad (5)$$

Among them, H denotes the conjugate transposition, and Re denotes the complex real part. The total Fisher information matrix K_T^N made up of the first N sample points can be simply expressed as the sum of the K_n of the sample point information matrixes.

$$K_T^N = \sum_{n=1}^{N} K_n \quad (6)$$

The total amount of information q^N for the first N sampling points can be simply defined as:

$$q^N = \left|K_T^N\right| = \left|\sum_{n=1}^{N} K_n\right| \quad (7)$$

The adaptive frequency selection target is to find a set of sampling frequency points containing the largest amount of information, and the parameters of the parametric model are calculated through these frequency points so that the corresponding parametric model complies with the real scattering field broadband response. This problem can be solved by converting the first N sampling frequency points to obtain the $N+1$th frequency point containing the maximum amount of information.

Let:

$$F = [F_R, F_I] = [Re\{\nabla_\Theta f(w_{N+1}, \Theta)\}, Im\{\nabla_\Theta f(w_{N+1}, \Theta)\}] \quad (8)$$

We can get the total amount of information of the first $N+1$ frequency sampling points q^{N+1}

$$q^{N+1} = \left|K_T^{N+1}\right| = \left|K_T^N + K_{N+1}\right| = \left|K_T^N\right|\left|I + \beta F^T (K_T^N)^{-1} F\right| \quad (9)$$

Among them, I is a 2×2 identity matrix,

The information increment of the $N+1$th frequency point δq^{N+1} is defined as:

$$\delta q^{N+1} = \ln q^{N+1} - \ln q^N = \ln\left|I + \beta F^T (K_T^N)^{-1} F\right| \quad (10)$$

Therefore, the adaptive frequency selection is to select the frequency point w_{N+1} that maximises δq^{N+1} That is:

$$w_{N+1} = \arg_w \max \delta q^{N+1}(w) \quad (11)$$

The improved adaptive sampling method is as follows:

In the first step, the frequency points of the endpoints are selected at equal intervals in the interval $[x_0, x_1]$, and these two sampling points are added to the sampling point group. The second step is to use the existing sampling points to calculate its model parameters. Then calculate the value of each interest frequency point according to the model parameters. In the third step, the Fisher information matrix is calculated based on the previously calculated model parameters. The fourth step is to calculate the information increment of each interest frequency point according to the information matrix and find the frequency point with the largest increment of information. In the fifth step, the true value at the maximum point of information increment is obtained and added to the sampling point group. In the sixth step, repeat the second step until it meets the accuracy requirement and stop the iteration.

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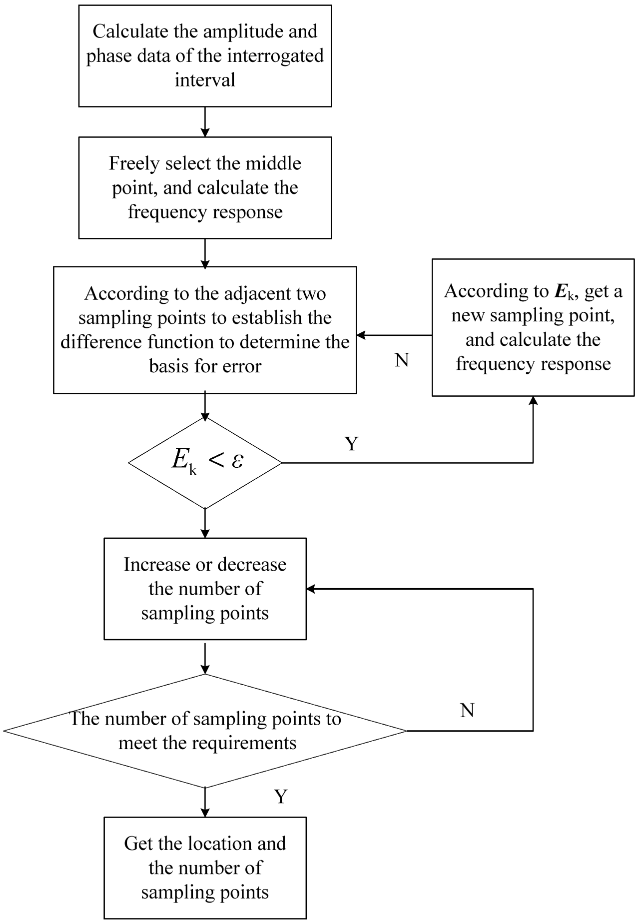

Fig. 1 *Calculation flow chart*

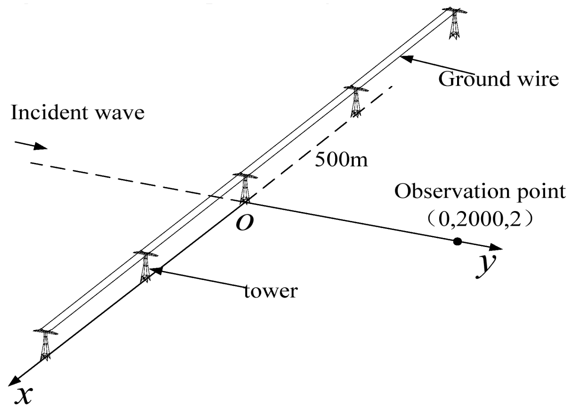

Fig. 2 *Calculation model of scattering field of UHV transmission lines*

It should be pointed out that as the number of loops increases, the solution matrix will become more complex, and it is easy to calculate overflows or singularities of the matrix. As a result, if the set precision is not reached, subsequent sampling points will be stopped and the algorithm will fail. At the same time, the number of initial sampling points is too small, and each sampling point except the endpoint contains the required sampling point information. Therefore, the use of adaptive sampling at the beginning will increase the computational resources and increase the calculation time. Further optimisation of adaptive algorithms for these problems:

To solve the problem of high accuracy, you can set the number of cycles and specify the maximum number of cycles in advance to limit the number of sampling points. If the number of sampling points does not meet the accuracy requirement, the accuracy cannot be achieved within the number of sampling points. Stop sampling and output sample points. The problem of resource consumption due to the selection of the sampling points at the beginning can be solved by the combination of equal intervals and adaptation, that is, the basic sampling points are selected at equal intervals, and the remaining sampling points are calculated based on these sampling points.

Conducting transmission lines passive interference calculation, the first is to determine the calculation interval. The amplitude $|\boldsymbol{E}(\boldsymbol{r})|$ and phase φ° of the scattered field at the end of the interval are calculated by the moment method. Fig. 1.

The third point to take the sample interval midpoint, end points of an interpolation function obtained, to give another end coupled with a mid-point interval interpolation function. Taking the two interpolation functions into (1), the authors get an equation with independent variable as the frequency. Solving this equation, whichever is the maximum value of the point for the next sampling point, record the sampling point at this time. The residual error is compared with the set error at the time. If the accuracy is not satisfied, the solution is continued until all the sampling points meet the accuracy requirements.

4 Numerical examples

4.1 Calculation example:

Fig. 2 shows the ±800 kV UHV DC transmission line model

It is assumed that all types of wireless stations in the infinite infiltration of plane electromagnetic waves on the transmission line are model incentives. Vertical polarised plane wave as the excitation source. Taking the high-frequency band of 3–30 MHz as an example, the vertical polarised plane wave is used for excitation, the electric field strength of excitation is 1 V/m, Select the observation point of the scattering field as an interpolation object.

For the model shown in Fig. 2, the frequency interval of exciting electromagnetic wave is 0.1 MHz, and the moment field is used to calculate the frequency of the scattering field of each frequency point in the research frequency band. The sampling points are obtained at equal intervals of 0.6 MHz within the range of the moment method sweep (3.1–16.3 MHz), and the precision of the adaptive sampling method is taken as $\mathrm{tol} = 1 \times 10^{-5}$. The sampling points obtained by the two sampling methods are fitted to obtain the frequency response of the scattering field of the transmission line in the frequency band.

Fig. 3 shows the comparison of the frequency response of the scattering field under the excitation of the vertical plane wave in a wider band obtained by MBPE under different sampling methods.

It can be seen that the results obtained by the MBPE fitting of the sampling points obtained by the adaptive sampling method are in good agreement with the results of the moment method. However, the sampling at equal intervals is blind to sampling intervals, and the sampling points at different intervals have different fitting results. The result of the extreme-region fitting is still not very satisfactory, because equally spaced sampling will lose some points with important information, especially near the extreme value, this is because the sampling points need to be increased correspondingly where the field intensity changes drastically, while equal interval sampling did not take this factor into account. The adaptive sampling algorithm will select more sampling points where the field intensity changes drastically, which makes the fitting result more accurate.

Fig. 4 is the adaptive sampling algorithm under the sweep interval (16.3–30 MHz) sampling point position image. It can be seen that the sampling points selected by the adaptive sampling method select the amplitude of the field strength more often because these places contain a lot of information and the sampling points can be selected to make the fitting result better.

4.2 Calculation results analysis

The global average absolute error is used to analyse the error of fitting results between adaptive sampling points and equally spaced sampling points.

The global average absolute error is calculated as:

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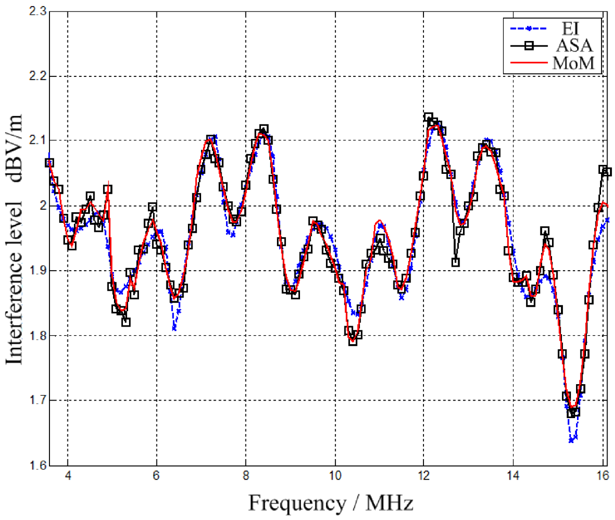

Fig. 3 *Comparison of the method of fitting map*

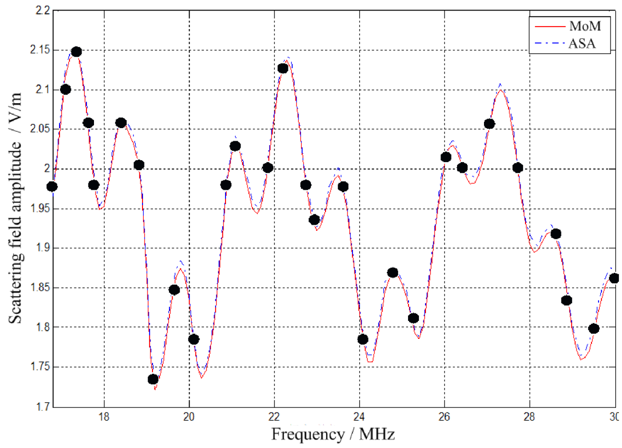

Fig. 4 *Adaptive sampling point diagram*

$$\mathrm{mad} = \frac{\sum_{i=1}^{N} |E_i - E_i^*|}{N} \tag{12}$$

Table 1 Comparison of global maximum absolute error and maximum global maximum relative error

Sampling method	Mad, V/m	Δmax, V/m
adaptive	0.152×10^{-8}	0.014×10^{-8}
equal spacing	0.272×10^{-6}	0.017×10^{-6}

where E_i represents the MBPE interpolation result of the scattering field corresponding to the i frequency, and E_i^* represents the result of the moment method of the scattering field corresponding to the i frequency.

Table 1 shows the global average absolute error and the global maximum relative error of the results of the equally spaced sampling and the adaptive sampling. It can be found that the fitting result obtained by adaptive sampling method is more accurate than the equally spaced sampling method.

5 Conclusion

Aiming at the blindness of the mid-interval sampling method to calculate the existing transmission line fitting, this paper introduces an adaptive sampling algorithm and applies it to such large-sized transmission lines. The numerical results show that compared with the traditional equally spaced sampling points, the proposed method improves the computational accuracy and reduces the blindness of the sampling point selection.

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