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High Frequency Modeling Method of Series Diode Array Based on Differential Evolution Algorithm

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Abstract: *This paper adopts the method of combining impedance test and simulation to model the high frequency characteristics of series diode array. Firstly, the high frequency equivalent circuit model of series diode array is established and its impedance calculation method is explained; then use the vector network analyzer (VNA) to complete the impedance test of series diode array, and use the differential evolution algorithm (DE Algorithm) to fit and optimize the high frequency model parameters; finally The characteristics of the ideal diode and this high frequency model are compared under different frequency, and the PFC circuit simulation verification is carried out in ANSYS software. The results show that this high frequency model not only matches the characteristics of ideal diodes at low frequencies, but also reflects the high frequency characteristics of series diode arrays that are different from ideal diodes at high frequencies. The modeling effect is excellent.*

Keywords: *series diode array, DE algorithm, high frequency model, parasitic parameters*

1. Introduction

A rectifier diode is a semiconductor device, which is usually composed of two pairs of diodes in series and has the function of converting alternating current into direct current. Rectifier diodes are widely used in switching power supplies, high frequency inverters and other devices. With the gradual development of switching power supplies and other devices towards high frequency, the application of a large number of semiconductor components has become an inevitable choice. Semiconductor components have parasitic parameters due to non-ideal factors such as component structure and material properties. The parasitic parameters attached to the rectifier diodes used at high frequencies have brought great challenges to various existing design schemes. For example, the parasitic parameters attached to the inductance and capacitive devices in the LLC resonant converter will greatly interfere with the working efficiency and stability of the LLC resonant converter.

Many scholars' research on diode high frequency modeling is mostly limited to single diodes or specific applications. Researches on high frequency modeling of diode arrays with more complex structures are still lacking, which hinders subsequent electromagnetic interference simulations. Therefore, the research on the high frequency modeling method and characteristic analysis of the series diode array has become a significant work.

2. High Frequency Equivalent Model of Series Diode Array

2.1. Series Diode Array High Frequency Circuit Topology

In various circuit simulations, diodes are generally regarded as ideal devices, but in practical applications, parasitic parameters will have a greater impact on the results of diode simulations at high frequencies. The high frequency equivalent circuit model of the series diode array proposed in this paper is shown in Figure 1. D_1 and D_2 are two ideal diodes connected in series. R_1, L_1, and C_1 respectively correspond to the parasitic resistance, parasitic inductance and parasitic capacitance of D_1. R_2, L_2 and C_2 respectively correspond to the parasitic resistance, parasitic inductance and parasitic capacitance of D_2.

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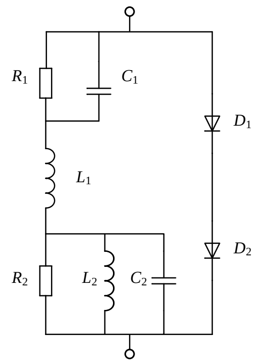

Figure 1: High frequency equivalent circuit model of series diode array.

According to the circuit topology, the impedance of the series diode array can be expressed as

$$Z_{D1D2}=\frac{R_1}{j\omega R_1C_1+1}+j\omega L_1+\frac{j\omega L_2R_2}{-\omega^2R_2C_2L_2+j\omega L_2+R_2} \tag{1}$$

$$S=j\omega \tag{2}$$

$$\omega=2\pi f \tag{3}$$

Where f is the frequency.

2.2. Impedance Test Based on VNA

The impedance test method adopted in this article is to weld the 15VD60 series diode array to the PCB board, and then use the vector network analyzer (VNA) to conduct impedance test.

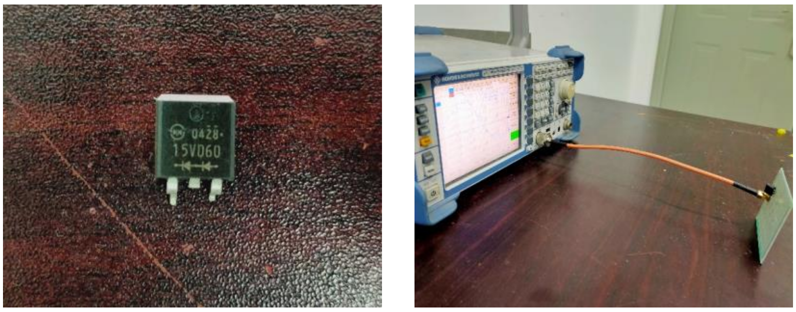

Figure 2: Impedance test diagram.

For the series diode array, the number of sampling points of the VNA is set to 2000, and the test frequency range is 9*KHz* to 300*MHz*, and the impedance test curve obtained is shown in Figure 3.

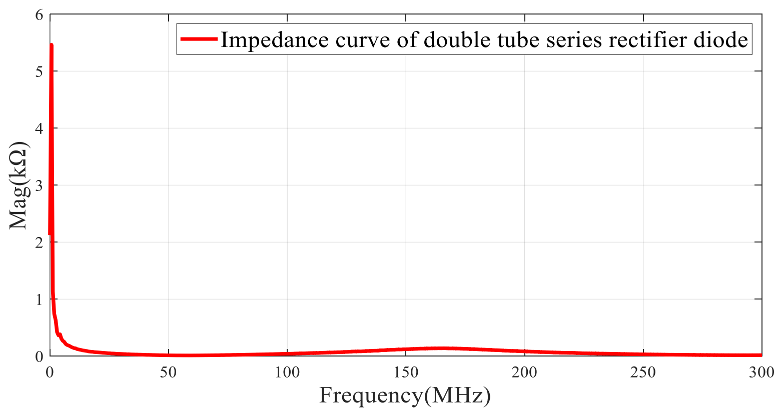

Figure 3: Impedance test curve of series diode array.

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2.3. DE Algorithm Fitting Optimization

In this paper, the differential evolution algorithm (DE Algorithm) is used to fit and optimize the parasitic parameters of the series diode array. The flow chart of DE algorithm is shown as in Figure 4.

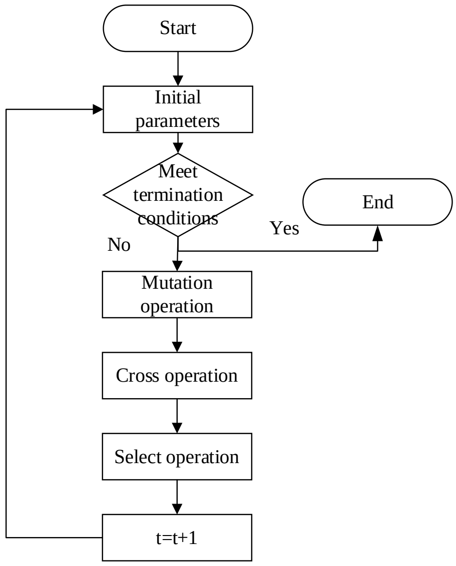

Figure 4: DE algorithm flow chart.

The comparison between the high frequency parameter fitting using DE algorithm and the actual measurement is shown in Figure 5.

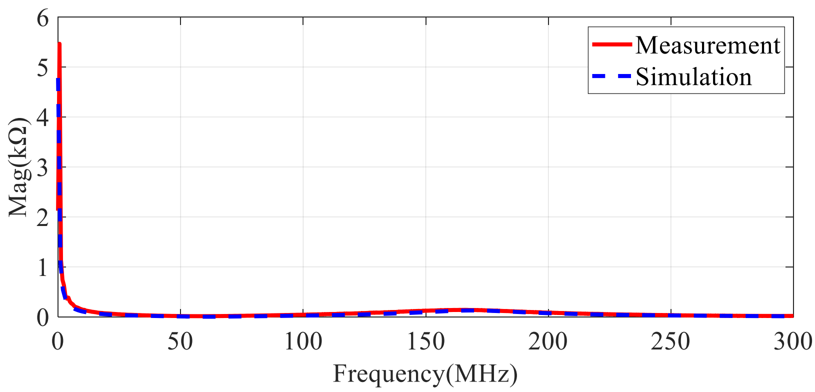

Figure 5: Comparison of impedance simulation and actual measurement.

It can be seen that the high frequency model proposed in this paper matches well with the measured values in the frequency range of 9*kHz* to 300*MHz*, and there is only a small error in the comparison between the parasitic parameters and the measured values. The high frequency *RLC* parameters after fitting and optimization are given in Table 1.

Table 1 Parameters of high frequency equivalent circuit model

Parameter	DE algorithm results
R_1	4.78 kΩ
L_1	0.011 uH
C_1	145.89 pF
R_2	127.53 kΩ
L_2	30.58 nH
C_2	28.72 pF

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3. Analysis of High Frequency Characteristics of Series Diode Array

3.1. Diode Characteristic Analysis

In order to verify that the series diode array can reflect the characteristics of the diode, the circuit as shown in Figure 6 is constructed in the circuit simulation software, and a 50*V* power frequency (50*Hz*) sinusoidal AC source is applied. The value of each *RLC* component is set as given in Table 1. High frequency parameters, and a load R_3 with a resistance of 50*Ω* in series on the power supply side.

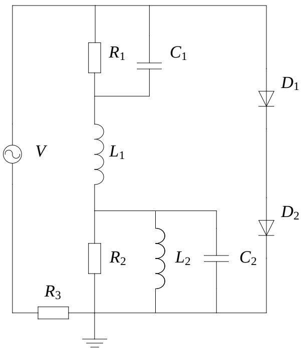

Figure 6: Characteristic simulation circuit of series diode array.

The simulation results of the diode characteristics are shown in Figure 7. When the diode is forward-conducting, its voltage is about 0, which is the on state; when the diode is reversely cut off, its maximum voltage is about 220*V*, which is the off state. The current flowing through the diode reaches the maximum value of about 4.4*V* when it is on, and the minimum value of about 0 when it is off, which proves that the model can basically reflect the characteristics of the diode.

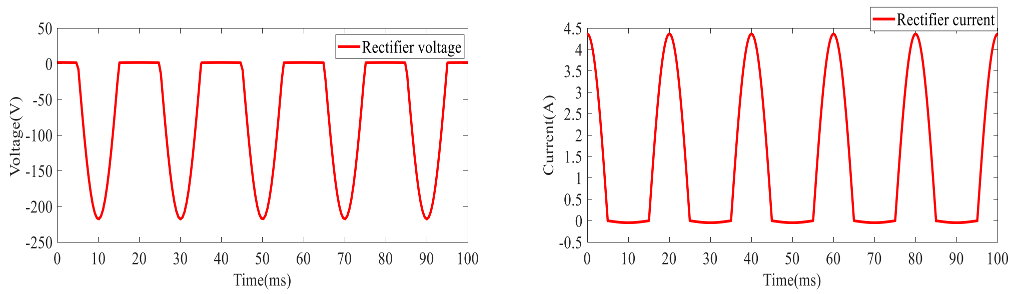

Figure 7: Characteristic simulation results of series diode array.

3.2. Characteristic Analysis of High Frequency Model of Series Diode Array

To verify the effectiveness of modeling, a simulation circuit as shown in Figure 8 is built. The value of each *RLC* component is set to the highfrequency parameters in Table 1, and a load with a resistance of 1000*Ω* is connected to the back end of the circuit. The low frequency excitation is 220*V*/50*Hz* sinusoidal AC source, and the high frequency excitation is set to 220*V*/300*MHz* sinusoidal AC source.

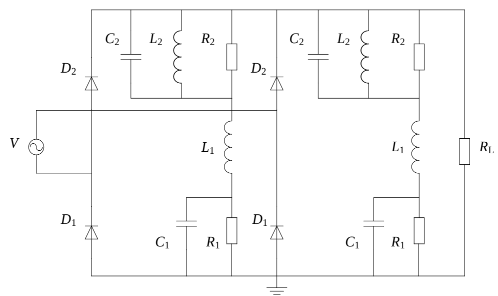

Figure 8: Simulation results of rectifier bridge.

The simulated current waveform is shown in Figure 9. The left image uses low frequency excitation, and the right image uses high frequency excitation.

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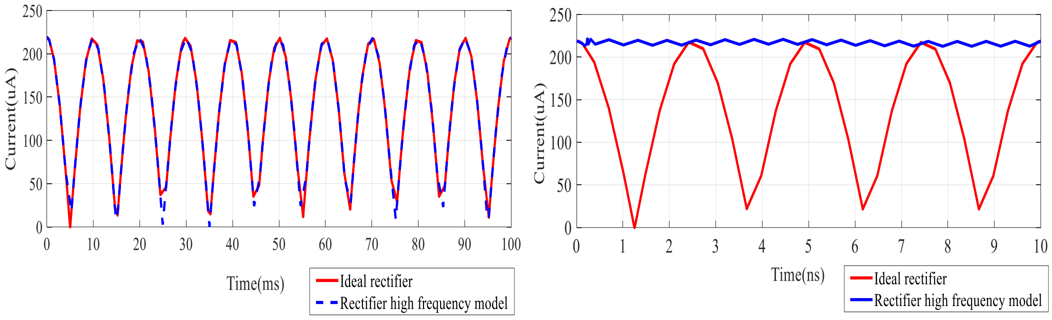

Figure 9: Comparison of simulation results under different frequency excitation.

It can be seen from the above figure that the characteristics of the ideal diode and the high frequency model of the series diode array are basically the same when the low frequency excitation works. When the high frequency excitation works, the high frequency model of the series diode array reflects the unique high frequency that is different from the ideal diode characteristic.

4. Characteristic Analysis of Series Diode Array in PFC Circuit

In order to further the practicality of the model proposed in this paper to accurately analyze EMI noise, a simple PFC circuit as shown in Figure 10 is built.

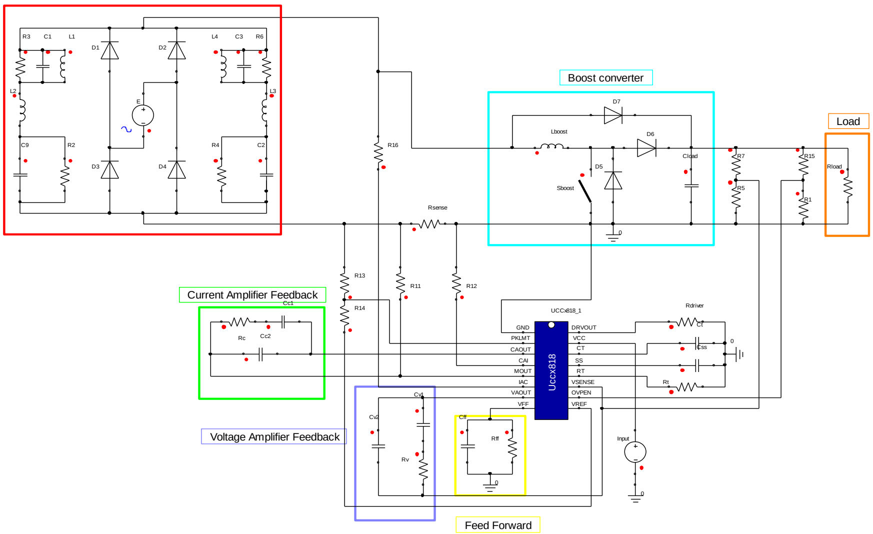

Figure 10: PFC simulation circuit.

Then extract the current simulation results of the input terminal, analyze the influence of the ideal model and the high frequency model of the series diode array on the input current of the circuit, as shown in Figure 11.

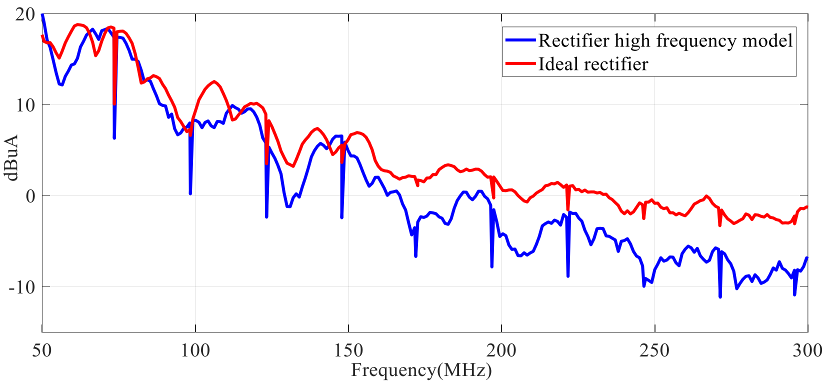

Figure 11: Frequency domain analysis of excitation current in simulation circuit.

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It can be seen from Figure 11 that compared to the ideal diode rectifier bridge, the series diode array rectifier bridge can reflect more abundant electromagnetic noise components in the frequency domain, which provides strong support for the subsequent conduction noise analysis and radiation noise analysis.

5. Conclusion

This paper proposes a modeling method for the high frequency model of a series diode array. First, the high frequency model topology is proposed, and the DE algorithm is used to optimize the high frequency parameters. Then through the comparison of the simulation results, the results show that the high frequency model is better than ideal at low frequencies. The model has the same characteristics and can also reflect unique characteristics at high frequencies. Finally, this article explores the practicability of this model, and provides an accurate and effective high frequency model for conducting noise simulation of devices using this model.

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